OPERATION AND DIAGNOSTICS OF WASTEWATER TREATMENT FACILITIES USING AN EXPERT SYSTEM

By

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Abstract

This research examines the use of microcomputer-based expert systems as a diagnostic tool and an operational aid of conventional secondary wastewater treatment facilities. The research has shown that rule-based systems are well suited for the domain of wastewater treatment facilities operations using observational information. Advances in expert systems software combined with increased microcomputer processing power have made this development work possible with personal computers. These systems possess the capability to provide fully automated diagnostics and process control as well as acting as a teaching and development tool for operators in full-scale treatment facilities. The thesis describes the technical aspects of wastewater treatment as applied to the development of a finished knowledge base system called WASTES (WAStewater Treatment Expert System). The thesis also discusses the development of the knowledge bases from their sources to implementation in the system. Recommendations and conclusions are also presented along with potential areas for further research.

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Finally, this work is dedicated to my grandfather, Michael Chilibeck, who supported me through all my years at the University of British Columbia.

Chapter 1.0 Introduction

This research represents the applications of expert systems in the field of wastewater treatment operations, with respect to diagnosis, problem solution and control of the treatment operations. The objectives of the research were as follows. One, to prove that an expert system can be designed and built to the demonstration level. Two, that the domain of knowledge regarding wastewater treatment is viable for knowledge-based systems. Three, that a functioning expert system is useful as a diagnostic system. Four, that these systems could be used for training and for further system development.

The research examines current expert system applications, the requirements and capabilities of wastewater treatment technology, the treatment model used in the research and a review of present treatment plant control techniques. The thesis will deal specifically with how the expert system operates and how the knowledge bases were developed, and will present the results and conclusions of the research as well as recommendations for future research in the field.

Although expert systems are a relatively new analytical tool, their applications involve both older traditional engineering applications and research involving more current technology. Expert systems continue to grow as existing problems and new ideas are developed into applications that continue to forward research in many diverse fields.

Expert systems (ES) development can be broken down into two distinct areas: the development of expert system shells and programs, and the development of expert system applications. Development of ES shells and programs is well advanced and there are a large number of commercially available shell programs for mini and micro systems like KEE, VP Expert, M.1 and Insight 2+. Applications development is also well established at the university research level and commercial systems are appearing and being used in such diverse fields as financial planning, database development, medical diagnosis and training systems. Civil engineering has also experienced a flurry of applications development as shown by the most current technical journals. At the Department of Civil Engineering, University of British Columbia, expert systems applications are developed or under research in the following areas:

Construction Management .... Project Scheduling
Water Resources .... Drainage and Lift Station Design
Structural Engineering .... Program Output Interpreter
Transportation Engineering .... Highway Location System
Environmental Engineering ..... Waste Treatment Diagnostics.

Environmental engineering has been relatively slow, in relation to other fields of civil engineering, in developing applications. There are several areas in the field, including activated sludge process control and plant diagnostics, that are ideal for expert systems. More recently, research in environmental engineering and expert systems has increased dramatically.

There has been a great deal of research regarding the development of control and modeling of the activated sludge treatment process.[1] However, most of the modeling and control was based on quantitative numerical results utilizing biological models and various control strategies. To date there are none of the accurate dynamic process models developed in the same sense as electrical, mechanical and chemical engineering due mainly to the variability of the complex biological systems examined. Other problems have hampered application of control research to practical activated sludge process control. Generally, treatment plant control concepts are not taught to civil and environmental engineering students who conduct graduate level research, those people who are expected to design controllable flexible treatment plants and often oversee operation of such facilities. There are several practical problems as well. There is a lack of reliable on-line instrumentation to monitor process parameters. Also in many plants there is a lack of proper process control features such as return piping, valving and pumps. Until recent times, the costs of investment for process control instrumentation, personal computers and plant equipment flexibility have been overlooked as a necessary piece of the treatment process. However, several factors are pushing for increased investment, in plant capital investment and research, and technological innovation in the wastewater treatment industry. Across the North American continent there has been an increase in the level of treatment required and in many areas sophisticated treatment systems are becoming essential. Downstream tertiary processes are dependent on the effective operation and control of the biological activated sludge process, thus reaffirming its importance as a treatment operation. Increased use of biological removal of nitrogen and phosphorus to protect receiving waters has emphasized activated sludge as an important part of the full advanced treatment process. Increasing energy and capital costs have forced plants to reduce annual operational costs. Reductions in staffing and plant budgets have led to the use of more efficient and automated operations. Technology and cost-effectiveness have forced innovation in a field that has been often viewed as mundane and basic. This technological drive has supported past development and continues to fuel research and development in the field.

Research in the control and modeling of activated sludge has led to investigation of this field with expert systems technology. Much of the driving force is due to the need to fill the large gap between research theory and practical treatment plant application. Investigations using experience as a basis for control began as a novel approach to control logic systems. Beck first suggested the use of qualitative rule-based or heuristic results as a logical method for process control of the activated sludge process.[2]

He has also stated:

> An operator has a mental image, or model, of the process dynamic behavior based on empirical experience of that process. At the present time this kind of experience is probably a more valuable asset ... than the currently available mathematical programs.

Tong et al. published further in the field based upon the use of fuzzy logic.[3] In his paper, he set up his input and output variables and related them through linguistic rules in the form:

WHEN "ESS is small and NH_3-N is large"
DO "make a small positive change in the RRSP".

This translates into "when the effluent suspended solids (ESS) are low and the effluent ammonia is high, make a small increase in the return sludge rate (RRSP)". The "fuzziness" arises in terms of how the values of "small", "large" and "small positive change" are interpreted under different situations. Twenty such rules were developed to consider effluent solids, BOD and NH_3, and included process operational parameters like aeration rates, wastage and return rates. Jenkins modified Beck's linguistic rules and used his activated sludge numerical simulation program to control a lab-scale activated sludge process.[4] He held discussions with various plant operators to establish a series of discrete operational conditions with known cause or causes. This was the first attempt to use actual operator experience to control an activated sludge process by a heuristic program. Maeda proposed a knowledge-based system for the wastewater treatment process.[5] He theorized that his production rule-based system could replace existing rules with new rules as information became available to the expert system, thus become a forward chaining system. Johnson set up a rule-based diagnostics system based on operator judgement.[6] Ortolano and Steinemann have summarized 24 unpublished systems under development, the table below shows the knowledge domains investigated.[7]

KNOWLEDGE DOMAIN	NUMBER
Hazardous Waste Treatment	13
Water Treatment Systems	4
Wastewater Treatment Systems	3
Model Calibration and Usage	4

Table I - Summary of Environmental Expert Systems under Development

In the wastewater treatment domain, two of the systems deal specifically with diagnostics and control. One is to assist operators at facilities with trickling filters to diagnose failures and suggest remedies and the other. Another expert system is to assist operators of activated sludge facilities in diagnosing problems and improving plant performance. Ortolano and Steinemann also reported two researchers in the United Kingdom working on activated sludge plants and expert systems development. The field of expert system applications in environmental engineering is growing. New systems are being constantly developed and as research continues increasing numbers of these systems will become available for evaluation and eventually commercial use.

Chapter 2.0 Fundamentals of Wastewater Treatment

Raw sewage is approximately 99 percent water. The balance consists of solids, both organic and inorganic, dissolved and suspended. The goal of municipal wastewater treatment is to modify, remove and dispose of a portion of that small percentage of impurities to improve, protect and maintain the various aspects of the environment. Such treatment is accomplished by utilizing mechanical, physico-chemical and biological processes. Before the effluent is discharged, constituents that could negatively affect the quality of the receiving waters are removed. Federal and provincial regulations set out effluent permits and solids disposal regulations that determine what may be discharged in the effluent and what must be removed and disposed of by other means. The amount of treatment required is usually determined by the need to maintain receiving water quality. Present technology in advanced wastewater treatment can consistently achieve high levels of effluent quality, removing all impurities to extremely low levels of concentration. The question is often asked why all our sewage is not treated to such high standards. The answer is that wastewater treatment is engineered and built to fulfill the local treatment objectives using the best available technology in a cost-effective manner. This often includes utilizing the full potential of the treatment process plus the natural assimilative capacity of the receiving waters.

2.1 Wastewater

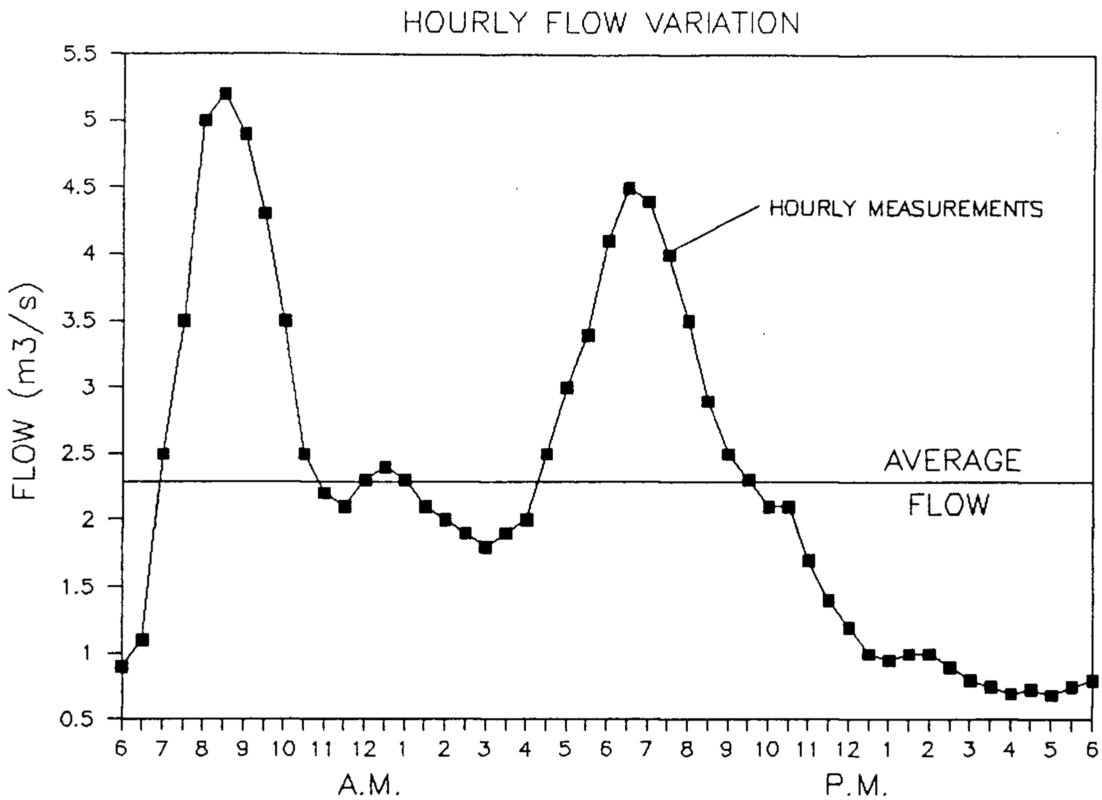
In the design and operation of a wastewater treatment plant it is important to understand the characteristics of the influent wastewater. For the design engineer, this provides information for the selection and sizing of the process and the proper equipment for the facility. In the operation of a plant, the information on the geographical area of generation and the flows and levels of constituents before, during, and after the processes provide the basis for process control. Detailed monitoring and analysis of common parameters provide information for controlling the physical and biological processes in the treatment plant.

Wastewater can be characterized in two ways: by origin and by its chemical, physical and biological characteristics. Classification by origin generally describes the type of area from which the wastewater was produced. Generally, municipal sewage comprises both domestic and industrial based wastes. The domestic component of a waste stream refers to sewage generated from residential and commercial areas. It includes kitchen, bathroom and laundry flows. The industrial component of wastewater is usually generated by manufacturing processes and possesses the characteristics that reflect the raw materials, processing products and by-products of the particular manufacturing or production process. Industrial flows can be the major point source contributors of toxic materials and regulations may require pretreatment of these wastes before disposal into sewer systems to prevent overloading and upset of biological treatment processes. Stormwater flows result from the interception of run-off from precipitation in combined and sanitary sewage systems. Stormwater increases the hydraulic flow into the plant and carries with it increased grit and debris as well as other contaminants. Combined sewerage systems carry wastewater and collected stormwater. As a result, the stormwater can have a major impact on the hydraulic loading of the treatment plant. Sanitary sewerage systems, by definition, carry only wastewater, so the effect of precipitation is felt only by infiltration into the sewer system though the joints and cracks of the network of piping. The increase in flow due to stormwater infiltration is small when compared to that which occurs in a combined sewerage system.

Considerably more insight into the quality of a wastewater is achieved when the physical, chemical and biological characteristics are provided. These characteristics will vary over time and in comparison to wastewaters collected from other geographical areas. Common physical characteristics used to describe wastewater include: temperature, odour, color, flow rate and solids concentration and type. Temperature affects most processes within the treatment plant. Characteristics such as raw water , water utilization processes, and the amount of infiltration are factors that determine raw sewage temperatures. Reduced temperatures decrease the reaction rates in biological and chemical processes and can negatively impact on physical processes like flocculation and settling. The microbial growth and use of substrates in activated sludge treatment are reduced with colder wastewater temperatures which may require changes in the process to maintain adequate treatment. Reduced temperatures may also require changes in chemical feed rates and may cause decreased floc settleability in secondary clarifiers.

Odour and color are two subjective parameters that are used for checking the operation of several of the treatment processes. Typically a musty, earthy, but disagreeable odour is associated with oxygenated raw wastewater while a stale, rotten egg-type odour indicates anaerobic or septic conditions. Fresh wastewater will usually be a pale grey color while septic wastewater is a dark grey or black. Other colors could indicate industrial discharges into the sewer system and should be investigated.

Flow into a plant will naturally exhibit hourly, daily and seasonal variations. The size of the variation in flows is of importance to the design engineer and plant operator because flow rates impact on the mass loading rates of impurities and detention times in key treatment processes that in turn effect the effluent quality. Municipal sewage flows generally follow a diurnal pattern with peaks in the morning and evening hours (Figure 1). There can also daily changes through the week as there is a flux of population in or out of the serviced area. Seasonal changes are also apparent in areas with large tourist populations and where raw water use patterns change.



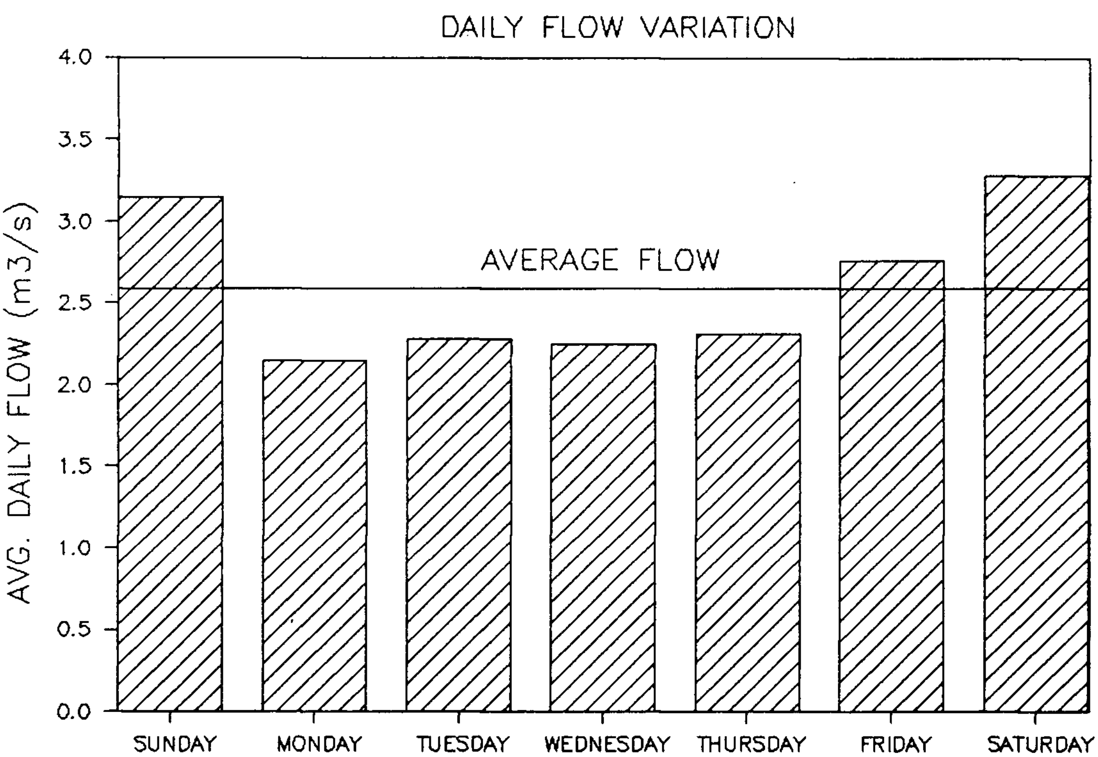


Figure 1 - Typical Flow into a STP

The operator can make changes in the plant operation to reduce the effects of some variations in flow. However, if continuous high treatment efficiency is required, the effects of variations in flow can be mitigated with flow equalization using dedicated storage basins, spare clarifiers and sewer valving systems.

One of the more important sewage quality parameters is the amount and type of solids loading. Solids are usually classified as floating, settleable, suspended, colloidal and dissolved. Floating solids typically represent the paper, grease and debris that float to the surface of the wastewater. Settleable solids represent the suspended solids that can be removed by simple quiescent settling. Finer suspended and colloidal solids are much smaller is size and are removed by physico-chemical coagulation and settling or by biological means in conventional treatment plants. Dissolved solids are generally ionic in nature, and usually require advanced treatment for highly efficient removal. Suspended solids are commonly used as a measure of the amount of material in effluent discharged from conventional treatment plants. Different forms of solids are removed by different processes within the treatment plant and are discussed in more detail with the specific unit operation.

Solids can be composed of both inert matter and organic matter, with the terms fixed and volatile solids being used by operators and design engineers. Fixed solids are the materials remaining after firing the sample at 550°C for 1 hour. Volatile solids is the difference between the total solids (fired at 105°C) and the fixed solids. The amount of volatile solids generally represents the amount of organic material present in the sample. The volatile solids test is used to estimate the amount of organic matter in raw sewage, and the amount of live organisms in a biological sewage treatment process.

The chemical characteristics of wastewater are determined by the chemical properties of the organic and inorganic solids and their relative concentrations. These solids possess the physical properties described previously. Organic compounds contain carbon in combination with one or more other elements. The organics associated with wastewater are usually dead animal and plant matter, by-products and waste material. Many by-products result from biological decomposition of the organic materials before the wastewater enters the treatment plant due to the presence of living organisms in the waste materials discharged. Complex organic materials like phenols found in sewage are often the result of industrial discharges.

Bacteria will naturally degrade most organic chemical constituents thereby consuming oxygen and releasing CO_2, H_2O and other end products. In the environment, this process removes dissolved oxygen from the receiving waters which, if not replaced by re-oxygenation, reduces the net dissolved oxygen content. Dissolved oxygen or DO depletion reduces stream and marine productivity for fish and other valuable species. Removal of organic compounds and the DO demand on receiving waters is a primary wastewater treatment priority. The common measure of this organic oxygen demand is done through a analysis which indicates the biochemical oxygen demand over a specific amount of time (usually 5 days), hence the term BOD_5. Testing for chemical oxygen demand (COD) measures the chemically oxidizable fraction of a sample. This measurement includes the BOD or biologically degradable substances as well as the other compounds not readily assimilated by biological processes. COD measurements may be 20 to 500 percent larger that BOD values from the same sewage due to the organic complexity and strength.[8] One benefit of COD tests is that they can be completed in less than one hour, while the standard BOD test takes 5 days. In the operation of treatment plants, this information is required as soon as possible; hence COD tests are usually run and correlated to BOD results as a control test. Complex organic compounds require a long period of time to be biologically decomposed and degraded as the bacteria must produce specialized enzymes to reduce them. Hence the type and amounts of organic compounds can affect the operation of any biological process which is being used to stabilize and degrade fine colloidal and dissolved organic compounds.

Inorganic compounds in wastewater consist primarily of grit, sand, sediment and other relatively inert substances. Dissolved inorganic compounds include nutrients like phosphorus and nitrogen essential for the microorganisms metabolism, as well as complexed metals and elemental metal ions, and chemical compounds, such as calcium carbonate that make up the waters hardness. Metal ions, which can act as micronutrients in low concentrations, are often toxic or inhibitory to most biological organisms at higher levels. Many of the heavy metals and complex inorganic compounds are usually a result of industrial discharges as well as surface run-off in combined sewage systems. Table II illustrates the forgiving nature of the activated sludge process and the ability of the bacteria to accept metal loadings on a continuous and slug-loading basis.

MATERIAL	CONTINUOUS LOADING (mg/l)	SLUG LOADING (mg/l)
Cd	1	10
Cr	2	2
Cu	1	1.5
Fe	35	100
Pb	1	-
Mn	1	-
Hg	0.002	0.5
Ni	1	5
Ag	0.03	0.25
Zn	1 - 5	25
Co	> 1	-
C=N	1	1 -10
As	0.7	1

Table II - Toxic Loading for Various Metals on the Activated Sludge Process[9]

The source of grit and sediment is primarily from washed grit from cleaning operations like car washes and residential laundry, urban storm run-off, and erosion within the sewerage system.

Sewage contains living organisms because it carries the waste products of animals whose guts contain living organisms. The most common organisms are bacteria, although protozoa, worms and their eggs and larvae, and viruses are also present. Receiving waters are often used as recreational areas where there is human contact with diluted effluent material, and as raw water sources for human consumption and use. Removal of these organisms from wastewater is essential to protect the health of people and animals using the receiving water. In North America, most treated wastewater is disinfected using chlorination, which involves the addition, mixing and prolonged contact of chlorine compounds with the wastewater. This operation kills a high percentage of living organisms and produces a residual in the wastewater with the potential of further disinfection.

Some species of the bacterial population present in the raw sewage is cultured and used to remove organic impurities from the sewage in a biological waste treatment process. This is the basis for biological wastewater treatment. Differences in geography, climate and culture insure that no two municipal wastewaters are exactly the same. Even in a single facility, influent sewage will exhibit variation in flow and composition with time. The influent parameters will change as the sewered area grows and develops. This influent variation challenges the engineer to design a facility useful for a 20 to 25 year design life, and the operator who must treat a continually changing influent to provide a much less variable, treated effluent.

2.2 Wastewater Treatment Facilities

The nomenclature "primary facility" or "a secondary plant" is often used to describe treatment facilities. The terms preliminary, primary, secondary and tertiary or advanced treatment describe the general level of treatment provided and are generally cumulative. A treatment plant is in fact an interconnected string of individual unit operations and unit processes. These units are physical, chemical or biological in nature, and each removes a portion of the contaminants from the sewage. The combined effect of these units is to produce a satisfactory effluent. Figure 2 illustrates where influent solids of various forms and BOD are removed with respect to the unit operations.

Preliminary treatment usually combines the unit operations of raking and screening, shredding and grit removal. Primary treatment includes the unit operations of primary sedimentation or microscreening. Secondary treatment involves biological or physico-chemical processes. Physico-chemical treatment uses chemical addition, mixing, clarification and filtering to remove suspended material and organic contaminants. In this thesis, only biological secondary processes will be investigated. Advanced treatment can be used to further reduce the concentrations of constituents removed in lower levels of treatment or to remove special inorganic or organic materials whose removal is impossible with normal secondary level treatment. Due to the wide variety and level of technical

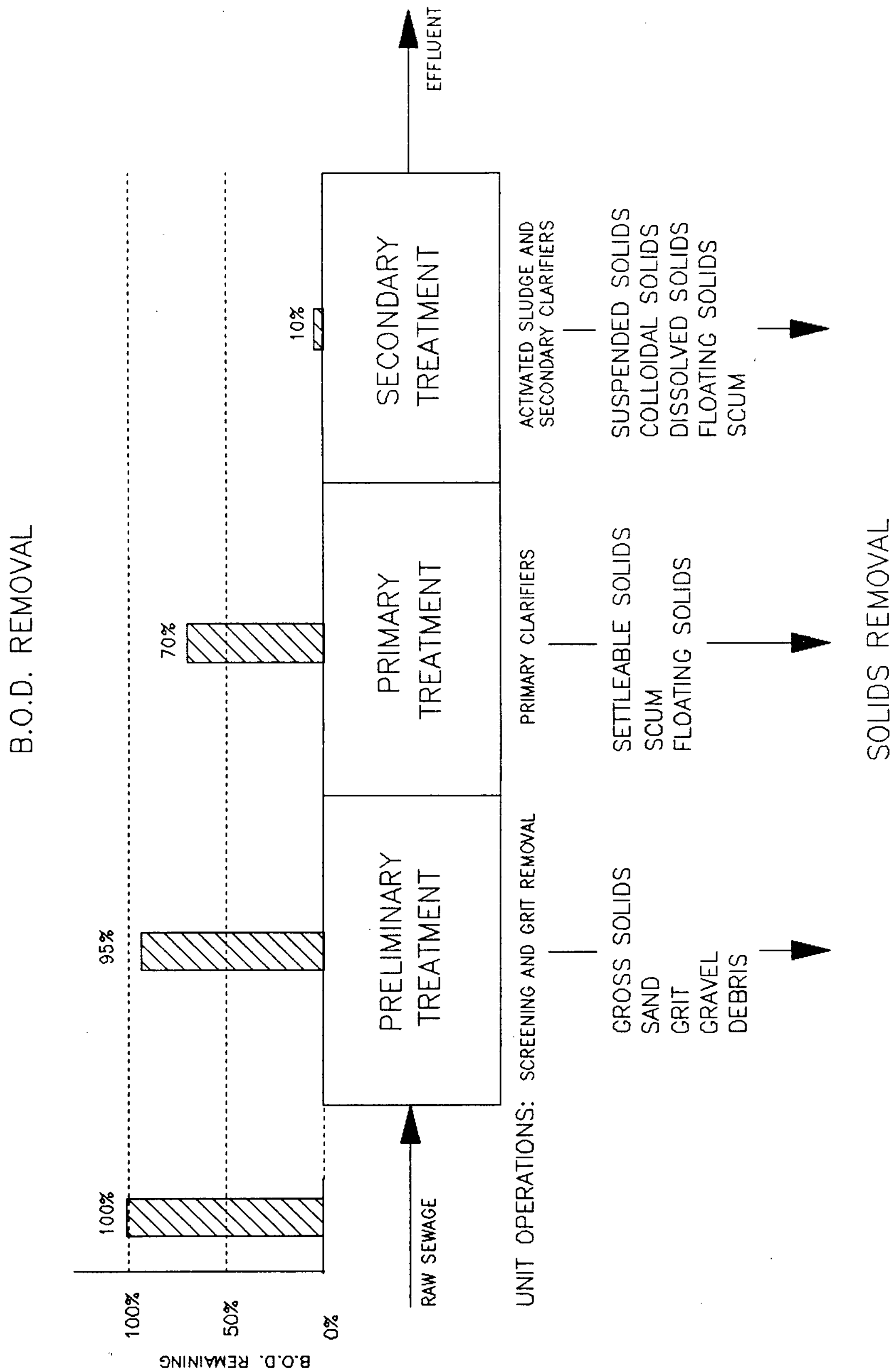


Figure 2 - Typical Solids and BOD Removal in a Secondary STP

complexity involved with most tertiary systems, they are not included in this thesis; however most are outlined in common design texts. The only advanced treatment process examined will be that of biological nitrogen removal. Examples of advanced unit operations include activated carbon filtration, ion exchange, reverse osmosis and gas stripping.

2.3 Unit Operations

Following is a short description of the unit operations used in the development of the thesis.

2.3.1 Raw Sewage Pumping

The channel roughness, weirs and constrictions of the various unit operations create a loss of energy in the open channels and piping of the waste treatment plant. The sum of all these head losses under the worst conditions is the maximum head or lift required for the sewage to flow through the plant. Raw sewage is usually pumped above ground in order that the plant can be built without major excavation and with enough head for all foreseeable flow conditions. The pumps are design to provide required flow and lift, and be rugged and reliable. Two of the more common types of raw sewage lift pumps used are screw pumps and centrifugal pumps.

2.3.2 Racks and Screening

Racks and screens are the simplest form of wastewater treatment. This in-stream unit operation has a dual purpose. Raking and screening removes the large inorganic or organic debris such as rags, paper, wood and plastics found in municipal sewage. Generally there are coarse racks, designed to remove pieces of wood and other large items, and fine screens to remove smaller pieces of plastic, rags and paper. The water flows through the openings and impinges the debris where it can be removed manually or by automatic rakes, triggered by head loss through the rack or by timers. The WASTES system is designed to diagnose two types of racks: fixed racks and moving racks. Fixed racks remain stationary with manual or automatic raking. Moving screens revolve continually to remove debris from the flow and are often cleaned using high pressure water jets.

2.3.3 Shredding

Shredding is associated with screening because shredders are often attached to the screens to shred the accumulated material allowing it to flow through the plant and be removed in the clarifiers. Shredding usually occurs in treatment facilities where accumulation and disposal of such debris is problematic. It is normally preceded by at least coarse racks.

2.3.4 Grit Removal

Grit removal rids the sewage of grit, sand, rocks and other dense materials. There are conventional and aerated grit tanks which provide classical discrete particle settling conditions or utilize a cyclonic action to remove the denser materials. The settled material is generally collected by augers or conveyors for disposal by burial.

2.3.5 Primary Clarification

Primary clarification removes floating solids, grease, scum and settleable solids. Primary clarifiers are an important part of the treatment process because they are capable of removing 25 to 45 percent of the total BOD entering the plant, while at the same time providing 50 to 70 percent suspended solids removal.[10] Removal rates decrease as flow rates through the clarifiers and the overflow rates over the tanks weirs increase. Settled solids are pumped from the bottom of the clarifier as a sludge while floatables are skimmed from the surface. As a preliminary step to biological treatment, primary clarifiers reduce the solids and BOD loading allowing for smaller design tank volumes and air requirements in the subsequent secondary treatment operation.

2.3.6 Microscreening

Microscreening is a primary unit operation that utilizes a rotating screen that impinges solids from the wastewater flow and is then scraped or sprayed to remove the solids from the screen. Microscreens occupy much less area than primary clarifiers, providing approximately one half of the capacity to remove suspended solids and BOD.[11]

2.3.7 Biological Treatment

Biological treatment removes colloidal and dissolved organic impurities from wastewater. The three most common forms of biological treatment used in North America are the activated sludge process, rotating biological contactors, or trickling filters. Each of these is provided with a following clarifier to remove the accumulated biological solids. The operation of the biological systems and the secondary clarifiers are very closely related and thus are treated as a single treatment unit.

2.3.7.1 Activated Sludge

The activated sludge system uses recycled heterotrophic bacteria from the secondary clarifier to be mixed with the wastewater in the aeration tanks. The combination is called mixed liquor. The aeration tanks are aptly named because air or oxygen must be supplied to provide the aerobic bacteria with O_2. The bacterial flocs first sorb the substrate in the first 15 to 30 minutes of contact with the wastewater then they use enzymes to break down the substrate and transport it inside the cell to metabolize it.[12] The organic contaminants are effectively removed from the wastewater by sorption to the floc. After the mixed liquor flows out of the aeration tanks, it enters the secondary clarifiers where the flocs settle to the bottom and thicken. The clarified effluent is discharged through the weirs on the clarifier surface. The thickened sludge, called return sludge, is pumped to the beginning of the aeration tank where the activated sludge flocs are mixed with the influent sewage. This process occurs continuously as bacterial cells feed, grow, multiply and die. Figure 3 illustrates a simple activated sludge system.

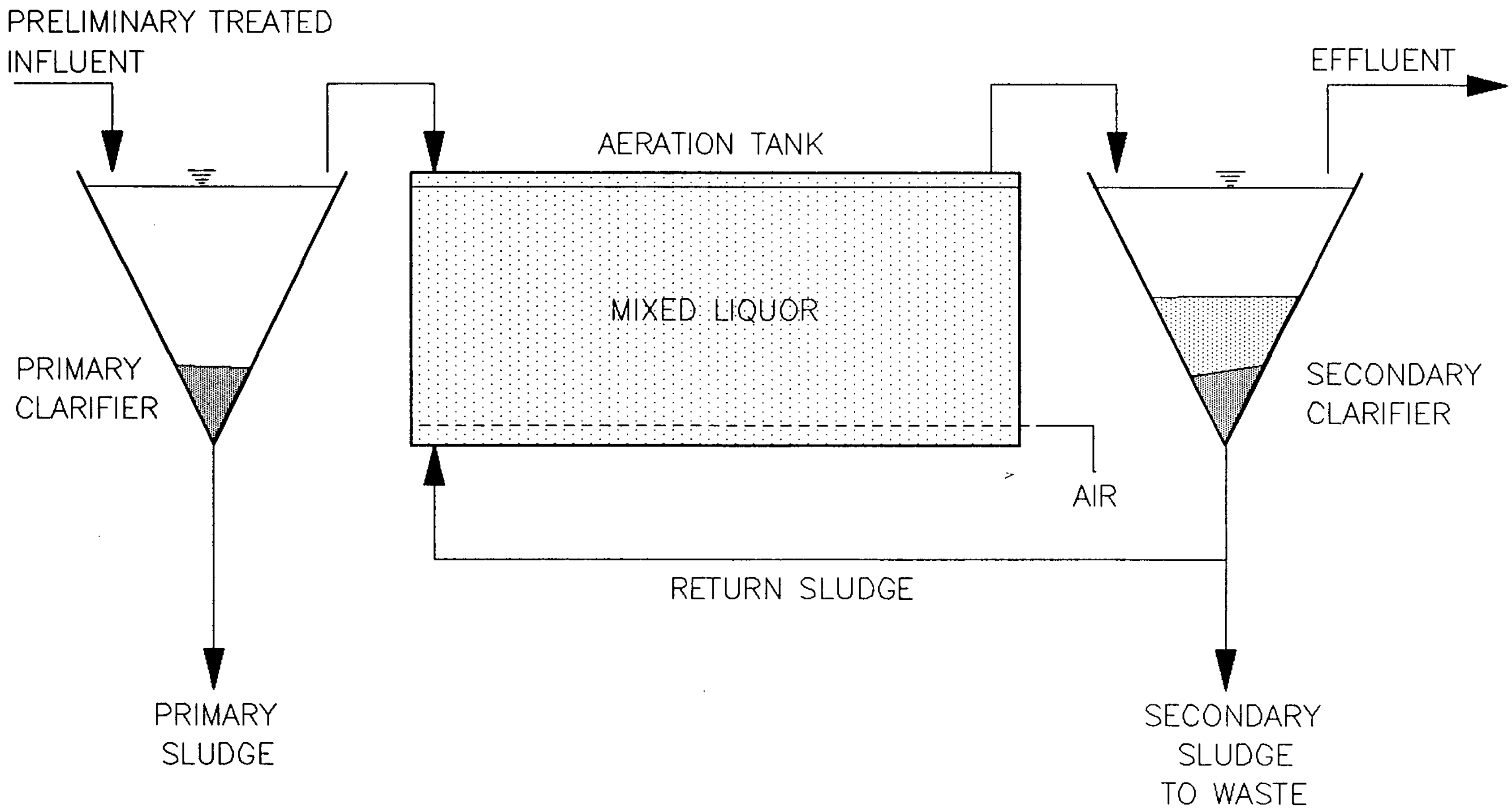


Figure 3 - Schematic of the Activated Sludge Process

The aeration system is designed and operated to provide oxygen to the microorganisms, and to adequately mix and suspend the flocs and substrate. There are two common aeration systems - compressed air and mechanical. A compressed air system consists of air filters, compressors, piping and valving, and submerged diffusers. The pressurized air is fed into diffusers placed near the bottom of the aeration tanks. Coarse bubble diffusers produce large bubbles. Large bubbles rise quickly through the mixed liquor and provide less surface area which results in slower oxygen transfer with the surrounding bulk liquid. Fine bubble diffusers produce clouds of very small bubbles with very high transfer efficiencies. However, there are several drawbacks of fine bubble diffusers. One is the high pressure compressed air system necessary to overcome the head losses of the diffusers, while another is the cleaning required to keep the diffuser heads from constantly clogging with grit and debris. Both systems provide mixing by reducing the bulk density of the liquid with the bubbles of air compared with that surrounding it.

The second common aeration system uses mechanical aerators. Updraft aerators use a blade or pump system to lift the mixed liquor out of the tank, thus producing turbulence that increases oxygen transfer into the formed liquid droplets. Downdraft mechanical aerators entrain air bubbles producing surface and sub-surface turbulence that aids oxygen transfer.

Activated sludge systems can be designed and operated to provide nitrogen and phosphorus removal as well as organic carbon removal and this technology is regarded as advanced wastewater treatment. The complexity and importance of activated sludge units requires a trained staff, rigorous lab analysis and data collection for proper operation and a good quality effluent.

2.3.7.2 RBCs and Trickling Filters

RBCs and trickling filters are both aerobic fixed biological film system that utilize bacteria, similar to those in activated sludge, to remove organic substrates from the influent sewage as food for growth and reproduction. Primary end products are CO_2 and H_2O. RBCs are large partially-submerged disks that revolve in the wastewater, sequentially providing both substrate and oxygen to the attached biomass. As the bacteria reproduce, the film on the disks grows thicker and excess material sloughs off due to the hydrodynamic drag forces provided by the rotation. These solids are captured in the secondary clarifier and need not be recirculated to the front of the RBCs, as is done in activated sludge systems. This constant sloughing provides a self-regulating loading control that responds naturally to the influent organic loading. As a result, there is very little process control required for RBC units. Wastewater flows through a series of these large units for a desired level of treatment. In trickling filters, the rock or plastic media is stationary and situated in large cylindrical tanks. The wastewater is distributed via a rotating sprayer at the top and flows downward through the media and attached biomass. Large vents around the circumference provide air circulation upward through the filter and oxygen for the biomass. The same growth and sloughing occurs in trickling filter systems however the shearing action is provided by the flowing wastewater.

2.3.7.3 Secondary Clarification

Secondary clarifiers remove the biological solids and scum from the treated wastewater before it is disinfected and discharged. The collected sludge is pumped from the bottom of the clarifier to the head of the treatment works or to sludge treatment facilities.

In the activated sludge process, after the mixed liquor has been aerated, it passes into the secondary or final clarifiers. These tanks are designed to provide conditions suitable for the settling of the activated sludge floc. In the quiescent conditions of the clarifier, the floc settles downward to form a sludge blanket on the bottom of the clarifier. The density of the activated sludge floc is only slightly greater than water so secondary clarifiers are susceptible to adverse flows and currents that carry the floc solids over the effluent weirs. As the sludge collects on the clarifier bottom, it compacts under its own weight, thickening the mass of biological solids and water. Typically a plow-type scraper is employed to move the sludge towards the center of the tank where it is pumped to the head of aeration tank and mixed with the sewage.

The operation of the aeration tank and final clarifier is intrinsic with the treated effluent entering the clarifier and the settled sludge pumped back to the aeration tank to mix with the incoming sewage. A portion of this sludge is removed from the system or wasted to control the process. This link is why effective treatment and operation of the activated sludge system depends on both the aeration and clarification processes and their operation.

With RBCs and trickling filters, the solids are usually collected and pumped out of the clarifiers for disposal.

Proper operation of secondary clarifiers is key for producing quality effluents with low BOD and suspended solids. Major operational problems include changes in sludge quality and flow conditions due to changes in influent characteristics or a combination of pumping and mechanical problems.

Chapter 3.0 The Model Wastewater Treatment Plant

3.1 Introduction

A conventional activated sludge treatment facility was chosen as the model facility for the expert system. There were several reasons for choosing this type of treatment facility. Firstly, secondary treatment plants make up the largest proportion of plants in use in North America. Secondly, developing a system for use in secondary plants would involve preliminary, primary and secondary treatment operations and processes, and would therefore find a wide range of applicability. Thirdly, the biological process of activated sludge was chosen because it is used most frequently as the secondary treatment process of choice in North America.

The activated sludge process requires substantial operator knowledge and input for process control as compared to other secondary process like RBCs and trickling filters. The treatment process itself is also adaptive to many operator-controlled process variations that result in different operational modes.

3.2 Layout

The layout of the model treatment plant is shown in Figure 4. In the model plant, influent passes through a lift pump to the racks, shredders and grit chambers. The sewage then enters the primary clarifiers and then the aeration tanks. The treated sewage finally enters the secondary clarifiers and the clarified

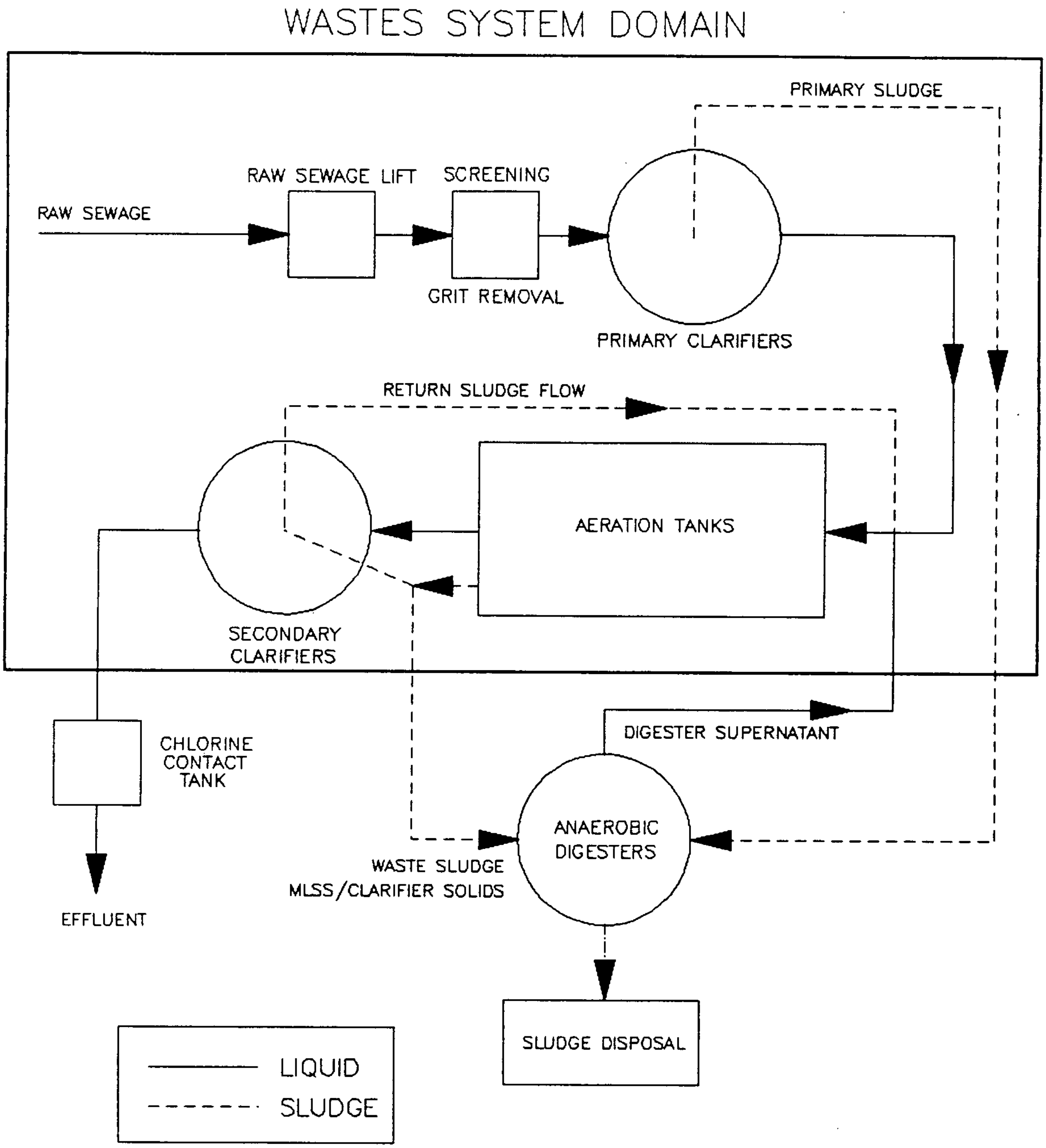


Figure 4 - WASTES STP model for Expert System

effluent can be chlorinated and discharged. The primary clarifier sludge and part of the secondary clarifier sludge is pumped to the sludge treatment and disposal works. The sludge may undergo a series of separate unit operations before final disposal. Sludge treatment works were not included in the development of the expert system because their operation, although important, has little bearing on the operation of the main liquid treatment process. The chlorination system was also omitted because most plants already utilize automated chlorine dosage regulation and measurement systems.

3.3 Operation

To understand what is involved in the operations of a secondary wastewater treatment plant we should examine the context and conditions in which it functions. Most facilities are operated by municipalities or regional districts who employ trained staff directly responsible for daily operations and maintenance. In British Columbia, wastewater treatment plants are operated to provide the effluent quality set out in the individual facility's waste discharge permit provided by the Waste Management Branch of the provincial Ministry of the Environment. These regulations generally set out effluent concentrations for BOD_5 and suspended solids and other contaminants. These guidelines are based on the daily volume of sewage treated, daily flow variation, effluent dilution, receiving water type and volume. Monitoring of these effluent concentrations to check compliance is a responsibility of the permit holder. If these permitted levels are exceeded regularly, the offender is asked to correct the problem, offered assistance and can face potential prosecution.

The plant staff monitor the operation variables, effluent parameters, and maintain and repair the various unit operations. To insure the facility is running efficiently and effectively, sampling and lab analysis must be undertaken to provide information to control the process. Staff must integrate all plant objectives including effluent quality, sludge disposal, plant operations, costs, and budgeting. Often the original plant design may limit the design life or process flexibility of the facility. This forces the operator to run his plant in an overloaded condition and face permit violations. Budget restrictions may limit staffing and operational funds, thus leading to reduced effectiveness of unit operations due to mechanical break downs and lack of maintenance.

3.4 Operational Objectives

Generally the activated sludge process (the aeration tanks and final clarifiers) is operated to provide the following basic goals:

- o required BOD removal
- o minimal loss of suspended solids into the effluent
- o nitrification where required
- o denitrification where required.

The required removal of BOD will occur if there is a sufficient mass of active biomass in the mixed liquor to remove and oxidize the organic compounds in the influent, and if sufficient oxygen is provided to the biomass. Most influent sewage characteristics including flows, BOD loading, and temperature are beyond the control of the operator. Operation of the process can simply be stated as an attempt to satisfy the treatment goals subject to the variability of the inputs and limitations of the controlling variables.

3.5 Process Operation and Control

A basic, well designed treatment plant has four basic process control operational variables which the operator manipulates to meet the treatment objectives:

- o air (oxygen) input
- o return sludge rate
- o sludge wastage rate
- o mixing energy.

The following sections will describe how and why the model treatment plant responds to these process controls and what parameters are manipulated and changed in the system.

3.5.1 Aeration Rates

The amount of aeration applied to the aeration tanks is generally determined by the following:

- o dissolved oxygen requirements
- o mixing energy to suspend mixed liquor suspended solids (MLSS)

Most activated sludge plants are operated with a dissolved oxygen content (DO) in the bioreactor ranging from 1 to 2 mg/L.[13] If there is sufficient biomass in the aeration tanks, i.e. high enough MLSS, oxygen demand is proportional to the organic loading. The MLSS, or mixed liquor suspended solids, is the liquid mixture of wastewater and activated sludge that flows through the plant. The mass organic loading into the plant generally follows a similar pattern to that of flow (see Fig. 1). Hence, the oxygen demand will not be uniform but will decrease during the night and increase during the diurnal peaks of the day. It is essential that the process remain aerobic at all times so a minimum DO should be present at all points in the aeration tanks. The presence of a significant DO in the effluent of the aeration tanks helps to keep the settled sludge in the clarifiers aerobic, which in turn precludes the onset of anaerobic conditions. If the conditions in the bottom of the clarifiers were to become anaerobic, the facultative bacteria would use the nitrate present in the wastewater and produce N_2 gas, and rising sludge. Conservative operational practice suggests a minimum DO level at the effluent end of the aeration basin of 2.0 mg/L.[14] This level of DO at the effluent end of the aeration tanks will maintain aerobic conditions in the clarifiers. Without a functioning control strategy, aeration demands for minimum DO requirements at peak organic loading will lead to elevated DO concentrations and possible overaeration at lower loadings. Overaeration of the biomass wastes power and increases operating costs. The biological floc is actually broken apart by the mixing energy. This allows oxygen into the floc's center, and can aid in the development of robust, healthy activated sludge flocs.

There are two basic methods for measuring and controlling the DO level in the aeration tanks: one if the plant aeration is manually controlled and the other if the plant has automatic DO control. Manually controlling the DO requires the use of a DO probe, measuring the DO at critical locations, and adjusting the aeration valving or operation of the mechanical aerators to match the oxygen requirements. Automatic control uses permanently installed probes throughout the aeration tank that automatically adjust the air valving along the length of the tank to match the oxygen demand or adjusts mechanical aerators. Automatic controllers can eliminate excessive aeration and reduce power costs. Monitoring the DO profile along the tank also identifies shock loads on the biomass and aeration system failures.

3.5.2 Return Sludge Flow (RSF)

As illustrated earlier, the purpose of the return sludge flow is to pump the produced mass of activated sludge flocs back to the head of the aeration tanks in order to provide rapid assimilation of the organic wastes in the influent. Maintaining the correct return sludge flow:

- o maintains an adequate aeration tank MLSS
- o optimizes the sludge blanket in the clarifier.

Optimizing the sludge blanket in the clarifiers accomplishes several things. First, it maximizes the amount of activated sludge in the aeration tanks available for increases BOD loading. Second, it keeps the return sludge flow as low as possible while at the same time keeping the storage of solids in the clarifier low enough to minimize the risk of loss of solids into the plant effluent due to plant hydraulic overloading or other plant upset condition.

Methods that are commonly used to determine the correct return sludge flow include:

- o calculation of a mass balances on the system
- o measurement of the sludge blanket thickness in the secondary clarifiers.

The correct RSF can be calculated using a mass balance approach. This requires the operator to monitor the solids concentration and flow rate in the return sludge underflow, in the clarifier and aeration tanks. This method is can be used but it has several drawbacks. One, it requires a lot of calculation and monitoring of solids concentrations and flows. Second, the concentration in the various parts of the system can change rapidly and unless the monitoring intervals are short, large errors can accumulate.

Controlling RSF is one of the most complex operations in the activated sludge treatment plant because continuous control is affected by almost all aspects of the treatment plant process; influent flows and BOD loading, clarifier design and solids loading rate, and activated sludge characteristics are just three of the major parameters affecting RSF.

Increased BOD loading, whether through increased flow or increased influent BOD concentration, into the plant will increase the solids loading on the clarifiers through the conversion of BOD to cell matter or activated sludge flocs. The flow through the system will carry the solids from the aeration tanks into the clarifiers. As long as the proper design solids loading rate on the clarifiers and the hydraulic loading on the effluent weirs are not exceeded, the extra activated sludge will simply collect into a sludge blanket in the bottom of the clarifiers. The actual hydraulic retention time (AHRT) is the retention time of in the aeration tanks including the RSF. The nominal hydraulic retention time (NHRT) is the retention time that uses only the influent flowrate and does not include the RSF. Subsequently, increasing the RSF will decrease the AHRT (while the NHRT in the aeration tanks and overflow rate of the clarifiers remain the same) and it will reduce the sludge blanket thickness; however, it will, at least in the short term, increase the solids loading on the clarifiers. This could possibly cause a loading rate above the solids loading capacity and cause a loss of solids or wash-out into the effluent. Experiments by the USEPA confirm that the MLSS concentration levels in the aeration tanks respond poorly to changes in RSF flows.[15] Large increases in the RSF produce only minor changes in the MLSS levels in the bioreactor during steady hydraulic conditions.

While the effects of RSF may be minor in affecting the MLSS in the aeration tanks, decreasing the RSF will increase the AHRT in the aeration tanks tending to offset the reduction caused by increased sewage flows. This in turn will decrease the solids loading rate on the clarifiers. As long as the clarifiers have the capacity to store the solids over the hydraulic "event" and the overflow rate on the weirs is not exceeded, no solids should be lost into the effluent. After the period of reduced AHRT due to high inflows, the RSF could be increased to remove the sludge blanket and return the solids to the aeration tanks. This transfer of solids from the bioreactor to the clarifiers, then back to the bioreactor. The effect of changing the RSF is limited by the solids loading capacity of the clarifiers.
The clarifiers should be operated with a low stored volume of sludge, which can be monitored by measuring the blanket thickness (BLT). Minimizing the BLT is a method of operation that reduces chances of solids losses. It also ensures that most of the activated sludge solids are kept in the aeration tanks where they can actively metabolize substrate. However, RSF and solids loading rate are not the only factor that effect BLT. The

blanket thickness is also function of the sludge settleability and the amount of solids in the combined aeration tank and clarifier. The sludge blanket in the clarifier will rise as the sludge settleability decreases. Conversely, the blanket level will drop if the settleability increases. Disregarding the quality of sludge in terms of its settleability can lead to wrong operating decisions. If the settleability is poor or slow, increasing the RSF will only make matters worse as the solids loading on the clarifiers is increased. As referenced earlier, aeration tank MLSS levels are poorly affected by return sludge rates, but they do respond strongly to wasting rates. Wasting sludge from the system is the key to controlling the entire activated sludge process.

Higher solids production in the aeration tanks requires more sludge to be pumped from the secondary clarifiers to the head of the aeration tanks. It also produces greater solids loadings on the clarifiers. Wholly inadequate RSF rates will cause an increase in the BLT over a very short time if the solids loading capacity is not exceeded. Hobson[16] also suggests the following operational point concerning RSF control:

- adjust RSF 10 to 25 percent per adjustment
- large RSF adjustments should be made in 2 or 3 smaller adjustments, 2 or 3 hours apart.
- there is a minimum RSF below which the sludge may plug return sludge piping.

Increases in BOD loading will also create increased solids loading, but they will occur over a longer time frame resulting in a gradual increase in the BLT variation over a varying inflow and constant RSF. Waste sludge flow (WSF) happens to be one way the whole activate sludge process is controlled, so observations concerning blanket changes or solids loadings on the clarifiers could reveal even more important process control information.

3.5.3 Waste Sludge Flow and Process Control

The discussion in this section deals with the general behavior of the activated sludge process to external forces. The effects of different loadings and plant design and operational factors may produce different sludge characteristics and plant conditions.

Under conditions of constant inflow and BOD loading and no WSF, the mass of biological solids in the system will increase due to the conversion of the influent organics into more bacteria through growth and reproduction. The MLSS concentration would increase in the system, and the biological solids would eventually fill the clarifiers and wash out the effluent weirs. At the same time, the sludge might not settle well in the clarifier and the effluent quality would deteriorate. From an operational point of view, the solution is to remove or waste some of the biological solids or sludge from the system. How much and why is the basis of activated sludge process control.

In general, the activated sludge process responds to and is regulated by two basic variables: food (organics) and microorganisms (bacteria). The F/M or food-to-microorganism ratio plays an important role in process control because it affects:

- o effluent quality
- o dissolved oxygen consumption
- o sludge quality and quantity.

Bacterial growth rates are generally proportional to the relative amount of substrate; more food creates a high growth rate in the organisms, provided that DO, nutrients, or other environmental conditions are not limiting. A high F/M produces high relative growth rates and under such conditions, a larger percentage of the BOD removed is synthesized into new cellular material than is used for energy in the cells. A low F/M results in lower growth rates and accordingly more BOD is used for energy requirements than reproduction. From an operational point of view this is important because by controlling the F/M we can control growth rates and the settling characteristics of the activated sludge. A high biological solids growth rate may result in:

- o incomplete BOD removal.
- o excess sludge production
- o cloudy effluent
- o poor settling sludge.

The rates of BOD removal per unit mass of biological solids is higher, but the high F/M and high growth rate can also result in the formation of large, lacy, low density activated sludge flocs. These flocs settle and compact poorly to create a bulking sludge that can build up and escape out the clarifier effluent weirs. Pin flocs can develop from the poor adsorptive, or floc forming characteristics in the fast-growing bacteria due to a lack of external enzymes which assist flocculation. These pin flocs can also develop from shearing of already formed lacy flocs which can cloud the effluent and do not settle out in the clarifier, and resulting in high effluent suspended solids. Overall, the high F/M system has high organic loading on the sludge flocs, resulting in a higher growth rate and increased sludge production as the BOD is converted into more cell matter. Savings are realized in the smaller bioreactor volumes or shorter HRT required for removal of the substrate, but the settling characteristics of the sludge could result in having to design the clarifiers for a "younger", poorly settling sludge. The amount of sludge produced can be excessive for the sludge handling and disposal unit operations if they are not designed initially for this treatment mode.

A low F/M means a relative lack of food per unit mass of microorganisms. With the lower growth rate of the organisms, they begin endogenous respiration where they begin to use their own cell contents as food. Operating the activated sludge process at a low F/M may result in:

- o high BOD removal
- o low net sludge production
- o cloudy effluent
- o large aeration requirements.

The higher MLSS concentration levels, along with lower growth and substrate removal rate, require higher tankage volumes for adequate BOD removal (lower BOD removal rate per unit mass). The poorly settling sludge and cloudy effluent can be attributed to the nature of the bacterial floc under low F/M conditions. The lack of food will cause the floc to decrease in size as the cells endogenously respire. The problem with the small flocs is the lack of agglomeration of the smaller discrete particles that would normally be trapped by larger activated sludge flocs. These can cloud the clarifier effluent and create suspended solids problems even if the flocs settle easily. Very old sludge will also become less dense as the floc decreases in mass as the bacteria undergo endogenous respiration. The result is small light flocs that can rise over the effluent weirs. Even with the poor effluent solids conditions, low F/M operation is often used. One example is called extended aeration. It provides low effluent soluble BOD with some loss of relatively inert suspended solids combined with low sludge wastage volumes to handle and dispose. Drawbacks of this operating mode are the relatively large tank volumes and aeration requirements that must be provided to allow operation at a low F/M ratio.

Besides operating at different F/M ratios, the aeration and mixing rates, bioreactor design and return sludge flow can be varied in order to operate the process in different modes. Two of the most common process configurations for the activated sludge process are complete mix and plug flow. Complete mix activated sludge (CMAS) uses square or rectangular tanks whose entire contents are aerated and mixed so the MLSS has essentially a uniform F/M profile from inlet to outlet. Plug flow tanks are long (L:W generally > 5:1) and have a tapered F/M, high at the inlet and low at the outlet. Whereas the completely mixed tank has a uniform MLSS quality, the plug flow system has a varied MLSS that lags the F/M curve. This tapered F/M and MLSS lead to the need for tapered aeration which will provide DO to match the loading and MLSS demand. Another form of the plug flow tank is the step feed system. In this mode, influent sewage and return sludge are introduced into different parts along the plug flow tank. This mode is particularly resistant to shock loadings. Another configuration, often called contact stabilization, has a first tank where the substrate is sorbed rapidly by the activated sludge floc. The mixed liquor flows into a second tank by re-aerating the activated sludge, overall higher plant loadings can be achieved.[17]

Controlling the activated sludge process for organic carbon removal involves maintaining the biological F/M ratio in a range of values that provides adequate BOD removal concomitantly with the development of sludge characteristics that provide good settling in the clarifier. The F/M is managed because the increased mass of solids due to growth and reproduction would build up and decrease the F/M ratio from its optimum. Wasting sludge is the method of removing those solids resulting from growth and maintaining the desired process F/M.

Strict F/M control would require keeping the biological process at a fixed F/M. As the organic loading increased, a suitable amount of biomass would be introduced to the reactor to keep a constant F/M ratio. The extra accumulated solids would subsequently be wasted as the BOD loading dropped. Although this control scheme makes sense, in practical applications in is very difficult to achieve. This operation would require fairly sophisticated sampling equipment or a rigorous hand sampling program by the operator. Variability in the hydraulic and organic loading would make it very difficult to maintain one F/M over the course of a day or week as influent conditions change. Problems result from attempting to maintain and store viable sludge to release into the aeration tank as loadings increase. The plant F/M is useful as an occasional check of plant operation but not as a regular control strategy.

Controlling the MLSS maintains the mixed liquor in the aeration tanks at a constant solids concentration. This technique is used by operators of small plants because it is easy to understand and requires a minimum amount of laboratory work. Large fluctuations in hydraulic and organic loading make it difficult to maintain a steady MLSS and attempts at this control regime often result in poor quality effluent. The operator maintains a wasting regime that keeps the MLSS at a level that appears to provide the best effluent and sludge qualities for the current BOD loading into the plant. If the MLSS increases, the operator wastes a bit more sludge from the system. If the MLSS decreases, wasting is reduced to bring up the mixed liquor levels. The major drawback of this process control method is the inability to adjust to changing conditions in the treatment plant. If problems occur there is a lack of data with which to make rational process adjustments. For example, seasonal variations bring colder influent temperatures that necessitate increasing MLSS concentrations to overcome the reduction in biological activity and thereby to maintain BOD removal. Unless the operator had a seasonal schedule of MLSS levels, this strategy provides no basis from which to determine a solution to this problem.

Mean cell retention time (MCRT) or solids retention time (SRT) control is considered one of the best methods of control. MCRT or SRT refers to the time in days an average bacterium or solids particle resides in the system before being wasted or lost in the effluent. Most process design manuals can theoretically show that MCRT and F/M and MLSS are related through the following equation:

$$\frac{1}{\theta_c} = Y * F/M - k_d \quad \ldots \; 18$$

where:

θ_c = mean cell retention time, days
F/M = process loading factor, kg BOD/kg MLVSS-day
Y = yield coefficient, kg VSS/kg BOD removed
k_d = bacterial decay coefficient, day^{-1}

This equation shows that our three control options are in fact related to each other. By setting the MCRT, the F/M is fixed because k_d and Y are relatively constant. A long MCRT equates to a low F/M operation and a short MCRT relates to a high F/M. By fixing the F/M, the biomass growth rate and MLSS responds to the organic loading of the process which is a function of the flow and influent BOD concentration.

Maintaining a given MCRT involves wasting a set percentage of the systems solids every day. If the clarifiers are operated with minimum sludge blankets most of the solids will be in the aeration tanks and wasting 10% of the aeration tank volume per day will give a 10 day MCRT. The operator can waste sludge by either wasting MLSS from the aeration tanks or wasting some of the return solids underflow to account for that set percentage of solids in total. Wasting from the underflow can often lead to problems. The return solids concentration must be known to calculate the amount of return solids to waste. As the return sludge flow increases the solids concentration will drop as the sludge thins out and the amount of solids actually wasted can vary. In smaller plants, the RSF is often intermittent; so the RSF concentration will vary with time of operation. Plant flow variations will affect the solids blanket levels and sludge concentrations as increased flows shift solids into the clarifiers. If solids are wasted from a fairly constant RSF and steady blanket height, the solids content should be steady. One benefit to wasting from the clarifier underflow is that the solids content of the waste stream is higher than the mixed liquor concentration so that the volume of sludge wasted would be less than wasting MLSS from the aeration tanks. This point can be very important if the sludge processing and treatment facilities have a limited capacity.

Hobson's advice for wasting includes[19]:

- o adjust MCRT by no more than 10% allowing at least 2 MCRTs before adjusting again
- o MCRT must be increased 20 to 50 percent to allow for adequate removal where mixed liquor temperatures fall drastically during winter months
- o try to account for all solids including those lost in effluent and stored in the clarifiers when calculating wastage.

Setting the MCRT will determine the quality of sludge in the activated sludge process in the plant. Hobson, in relating operational experiences, noted that, in general, a fairly fast rising clarifier sludge blanket (minutes or hours) is usually a result of improper RSF rates while slow increases in blanket height (days or weeks) is usually a function of solids build-up due to insufficient wasting.[20]

3.5.4 Biological Nitrogen Removal

Biological nutrient removal is an advance wastewater treatment that uses variations in the activated sludge process to remove nitrogen and/or phosphorus from wastewaters. Biological nitrogen removal uses a combination of nitrification and denitrification. Nitrifying bacteria utilize the ammonia to produce nitrites then nitrates. Denitrifying bacteria then use the nitrates and produce nitrogen gas which escapes to the atmosphere. Nitrification requires aerobic conditions and sufficient MCRT. Denitrification requires anaerobic or anoxic conditions and a carbon substrate for the heterotrophic bacteria, the BOD in the raw sewage provides this in the pre-denitrification process. Advances in process control and design have led to single sludge systems that utilize predenitrification or postdenitrification or both. In the single sludge system some carbonaceous BOD removal also occurs in the anoxic reactor, due to the metabolic requirements of the heterotrophic denitrifiers. The lack of BOD may be a limiting condition in the operation of post-denitrification reactors and this requires a large tankage volume in order to give sufficient HRT for endogenous denitrification. The use of movable bulkheads and partitions in plugflow aeration tanks allows variable tankage volumes to suit influent conditions and process function. With any type of biological nutrient control, no sludge blanket should be developed in the secondary clarifiers. Figure 5 illustrates both the pre and post denitrification layouts for activated sludge systems.

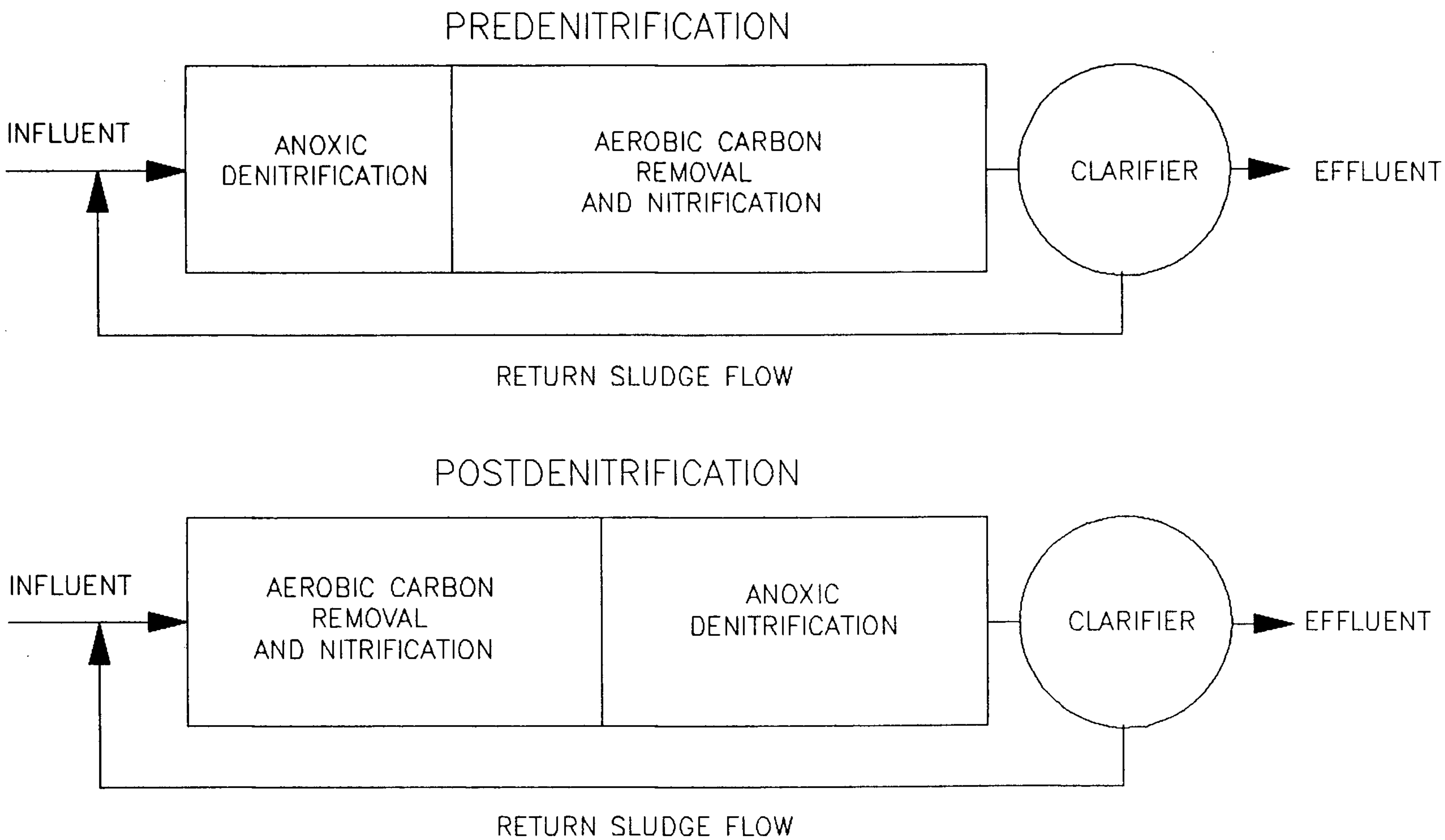


Figure 5 - Pre and Post Denitrification Process Layouts

3.5.5 Microscopic Observations

Controlled operation of the activated sludge process requires knowledge of microbial organisms and their roles in the treatment process. Some of the important types and forms of microorganisms include:

- o heterotrophic bacteria
- o autotrophic bacteria
- o protozoa
- o filamentous organisms.

Oxygen is required to support the aerobic heterotrophic bacteria that utilize organic carbon compounds, oxidizing them for energy and cell synthesis, releasing CO_2 and H_2O.[21]

Oxidation:

$$COHNS + O_2 \xrightarrow{\text{bacteria}} ENERGY + CO_2 + NH_3 + H_2O + \text{others}$$

Cell Synthesis:

$$COHNS + O_2 + ENERGY \longrightarrow C_5H_7NO_2 \text{ (cell material)}$$

Endogenous respiration:

$$C_5H_7NO_2 + 5O_2 \longrightarrow ENERGY + 5CO_2 + NH_3 + 2H_2O$$

These bacteria are the most common in the mixed liquor and are responsible for removing the colloidal and dissolved BOD materials. When there is a lack of food, the bacteria can utilize their own cell mass for endogenous respiration.

In addition, there may be some autotrophic nitrifying bacteria present, which use CO_2 to synthesize cell material. They also use ammonia for energy production, with the formation of nitrites and nitrates in a process called nitrification.

$$NH_4^+ + 3/2O_2 \xrightarrow{\text{nitrosomonas}} NO_2^- + 2H^+ + H_2O$$

$$NO_2^- + 1/3O_2 \xrightarrow{\text{nitrobacter}} NO_3^-$$

$$NH_4^+ + 2O_2 \longrightarrow NO_3^- + 2H^+ + H_2O$$

Anoxic conditions in the mixed liquor trigger some heterotrophic organisms to use compounds other than O_2 as their final electron acceptors; such organisms are called facultative aerobes. Some facultative aerobic organisms can use nitrates to produce free N_2 gas in a process called denitrification, as indicated in the following.

$$NO_3^- + \text{organic carbon} \longrightarrow NO_2^- + CO_2 + H_2O$$

$$NO_2^- + \text{organic carbon} \longrightarrow N_{2\,g} + CO_2 + H_2O + OH^-$$

$$6NO_3^- + 5CH_3OH \longrightarrow 3N_{2\,g} + 5CO_2 + 7H_2O + 5CO_2 + 6OH^-$$

The organic carbon source required by the heterotrophic bacteria in the denitrifying process will most often be a variety of organics naturally present in the sewage.

Bacterial flocs are small masses of bacteria. Floc-forming bacteria such as Zoogloea ramigera produce extracellular capsules of slime that enmesh other bacteria, organic and inorganic particles and form the typical activated sludge flocs. Under certain process conditions, the presence of small, non-settleable bacterial flocs cause a cloudy effluent from the clarifiers. Their numbers are reduced and a clearer effluent results, by agglomeration with other bacteria and by removal through predation. Microscopic animals such as Ciliates and Rotifers are found in the activated sludge. They graze over the sludge flocs, consuming organic matter and free bacterium. Using rotifers or other advance protozoa as an indicator organisms, the operator can often identify when the plant has experienced a toxic loading. Under normal conditions, rotifers and ciliates are actively moving about and feeding. If a slug of toxic material has recently entered the plant, the protozoa will be inactive, or worse, apparently absent.

Filamentous organisms such as Sphaerrotilus natans form long fibrous strands visible under the microscope. In small numbers, they can aid in forming and enmeshing bacterial flocs in the activated sludge process.[22] However, in excess these filaments create a spongy, poor settling sludge also known as bulking sludge. High powered microbial examination of bulking sludge is necessary to determine the exact type of filamentous organisms. Their presence does not necessarily cause bulking, nor does it cause high effluent solids. However, it is generally true that if their numbers reach a high enough level relative to other bacterial species in the mixed liquor, bulking sludge conditions will be experienced. The relationship between sludge volume and mass is measure by the sludge volume index (SVI), which is the volume occupied by 1 g of activated sludge solids after 30 minutes settling in a 1000 ml graduated cylinder. It is useful for relating the settling characteristics within a given plant. Correlating Sludge Volume Index (SVI) to an observed percentage filaments in a microscopic field of view at a certain magnification can provide a means for predicting a deterioration of settling quality of the sludge and operational sludge bulking for a particular plant. Eikelboom notes that just a small increase in the number of filaments can change a good settling sludge into a bulking sludge.[23]

There is a whole ecology of bacteria and microscopic animals and organisms within the process regulated by the presence of two variables: oxygen, substrate (food), and population (microorganisms). The F/M or food-to-microorganism ratio plays an important role in determining the microbial diversity of the plant. Different activated sludge systems operate at different F/M ratios or MCRTs. Figure 6 below shows the relative predominance of the type of organisms at various F/Ms or MCRTs as well as the succession of organisms that can generally be expected in an activated sludge process.[24] The longer MCRTs allow higher level organisms to prevail while the shorter MCRTs show a predominance of simple faster reproducing flagellates and

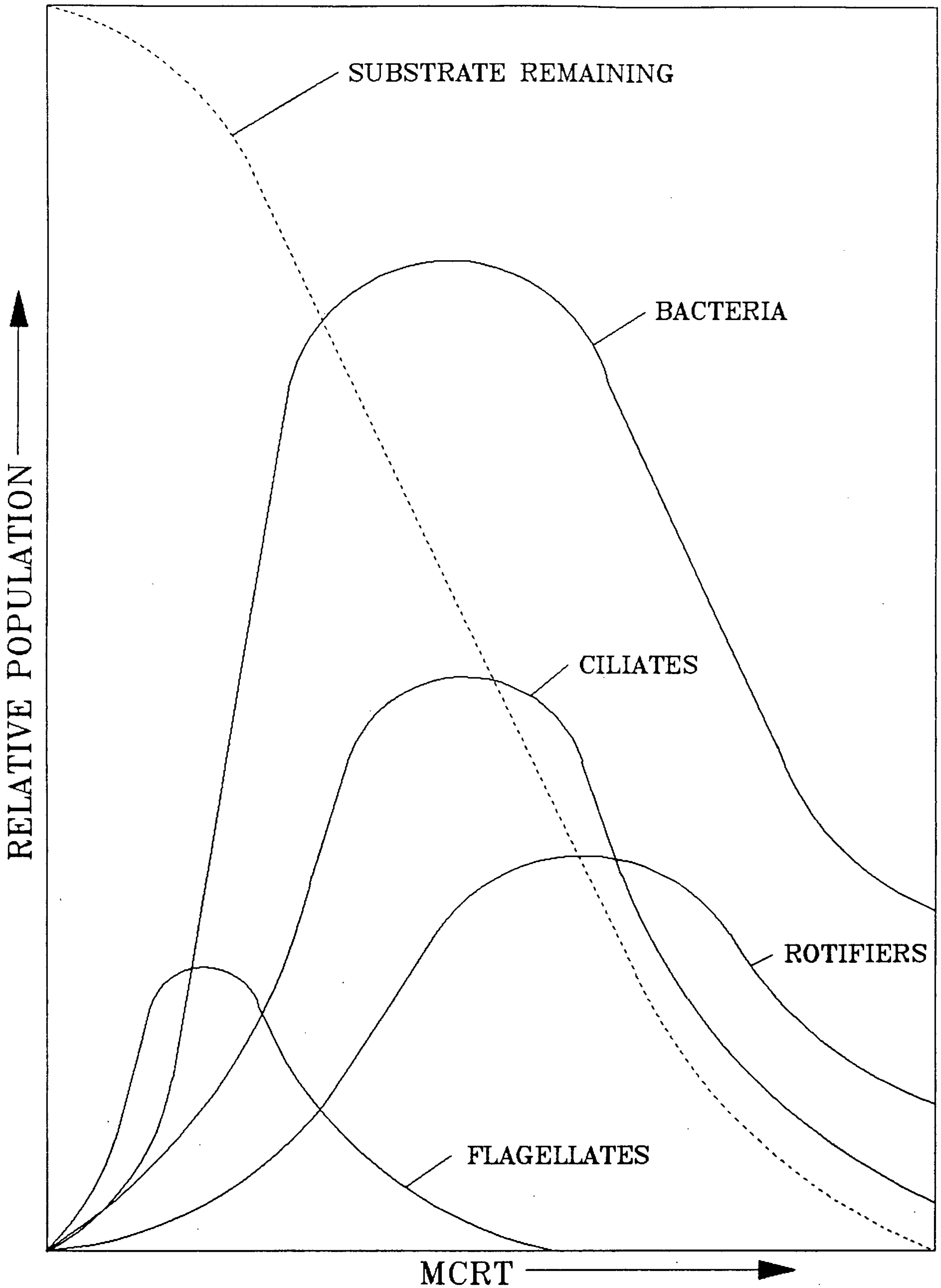


Figure 6 - Microbial Diversity with respect to F/M

bacterium. High F/M loadings could be seen microbial by a predominance of large, lacy, dark colored activated sludge flocs resulting from rapid growth caused by excess substrate. There would be very few of the slower growing rotifers or stalked ciliates while flagellates and other dispersed organisms would appear. Midrange F/M loadings, as found in conventional activated sludge plants, would show a fairly diverse range of organisms in the mixed liquor including bacterial flocs, stalked and free swimming ciliates. Figure 7 illustrates some of the common types of microscopic organisms found in activated sludge. The bacterial flocs could be described as full and well developed indicating balanced floc growth. The unchlorinated effluent from the secondary clarifier might reveal a few rotifers and other higher protozoa indicating a low BOD and good quality treatment. Low F/M loadings found in extended aeration activated sludge systems show small, compact, lighter bacterial flocs. The long MCRTs allow the higher order protozoa to predominate with little else. In different treatment plants there will be a completely different ecology, which is always changing in response to the plant organic loading. The operator must learn what each organism means in terms of the plant operations. The succession of free ciliates, stalked ciliates and rotifers can be identified with periods of good operation (low effluent BOD, good settling sludge) and changes and shifts in those populations as indicators to operational problems. Only during start-up or plant recovery conditions are amoebic organisms present in the microscopic examination of mixed liquor.[25] Dispersed bacteria could also be

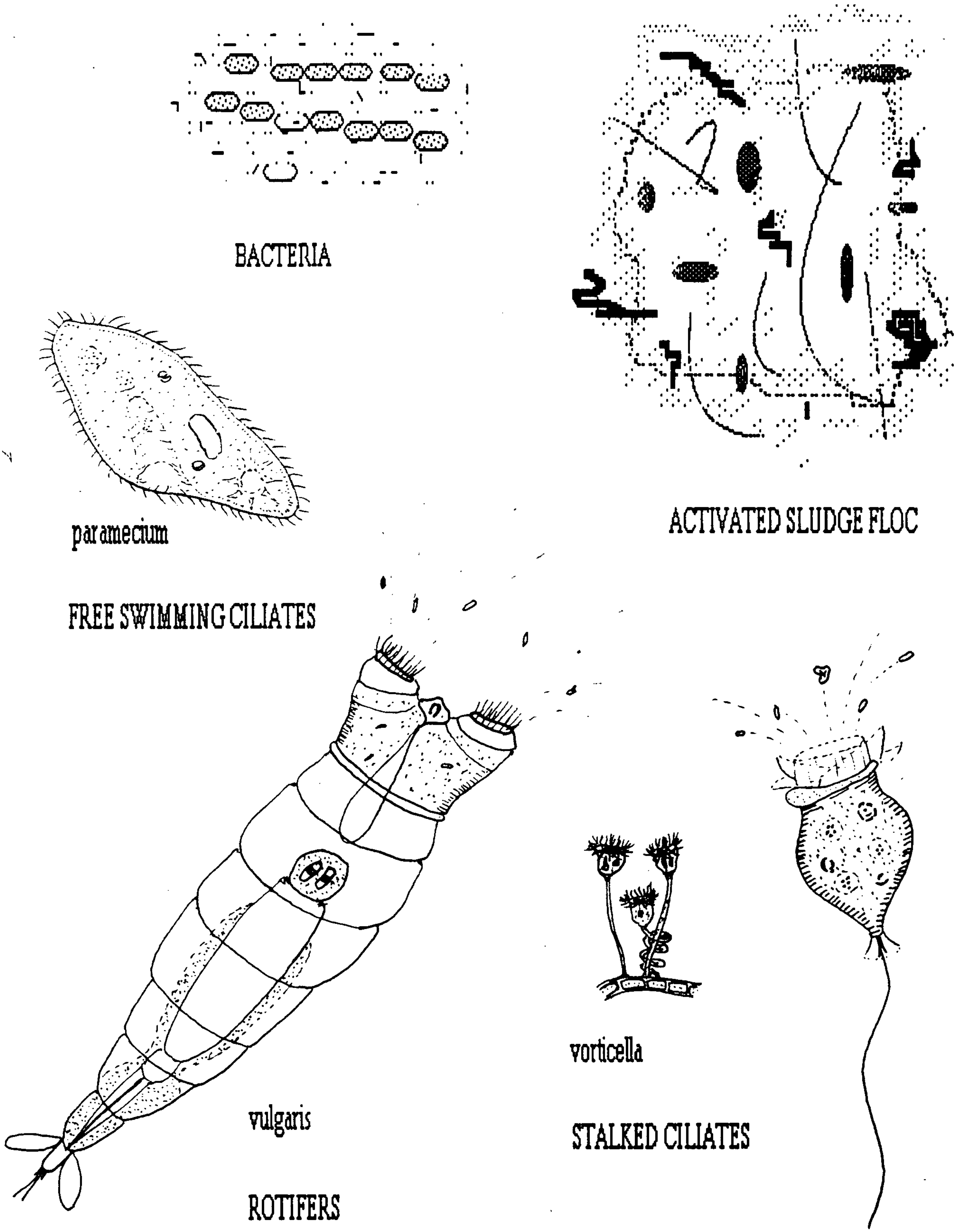


Figure 7 - Common Activated Sludge Organisms

an indication of very young sludge present as the plant begins operation. Dispersed bacteria are a natural occurring phenomena in stable systems as the sludge flocs are broken apart and endogenously respire during aeration and differences in the relative numbers, younger sludge being higher, would distinguish the two different MCRTs.

In conjunction with hard process control numbers (MLSS, flows and BOD loadings), the process control of the expert system uses the observational results of the color and condition of the mixed liquor and aeration tanks, and its microscopic inhabitants. The operational goals of the model secondary treatment plant have been incorporated and developed for use in the expert system. The expert system attempts to maintain the objectives of BOD removal, minimal effluent suspended solids losses, and biological nitrification and denitrification utilizing the process control parameters available to the operator. Chapter 6 further explains the exact information that was cataloged, assembled and used in the system and it also details the process control logic as it pertains to the expert system developed.

Chapter 4.0 The FRO Expert System

The WASTES system utilizes an expert system shell developed by Thomas Froese, a research engineer at U.B.C. who worked under Drs. A.D. Russell and W.F. Caselton. The system shell is called FRO and in part is a chaining, rule-based, goal-driven system that provides the expert system reasoning. An expert system created using FRO is made up of two basic parts: the inference engine and the knowledge base. The inference engine is the compiled FRO program and it provides the reasoning system and user interface. The WASTES system is the structured knowledge base file that is compiled by the inference engine and executed.

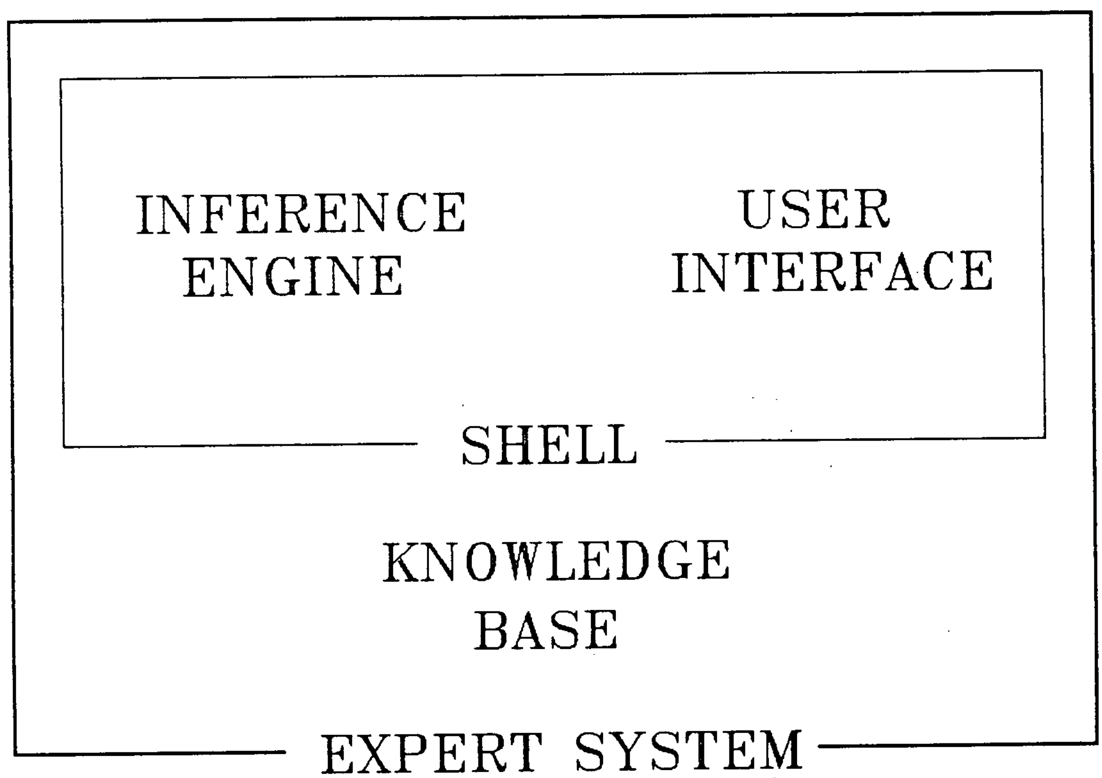


Figure 8 - Expert System Shell Structure

The WASTES system consists of not one, but several problem files. The core of the system is the "TREAT.KB" file which contains the basic menu structure, the activated sludge system knowledge and the basic treatment system questions. The other related files are smaller knowledge bases that are loaded according to the needs of the main knowledge base. This separation of knowledge bases minimizes file loading and boot-up times and facilitates easier logic development and editing. Figure 9 represents how the system is loaded and maintained with respect to the various knowledge bases.

Fro's basic task is to solve primary goal statements as defined in the knowledge base. In order to solve the primary goal, the expert system may need to solve other sub-goals and so on. The primary goal is written in the TREAT.KB knowledge base as:

```
goal run.
rule run if setup
        and solve.
```

The goal run is completed if both setup and solve are solved or proven. Knowledge is represented in the form of propositions that are in the forms of facts, rules and questions for the purpose of solving the primary goal. These propositions have the form:

CONCEPT is VALUE

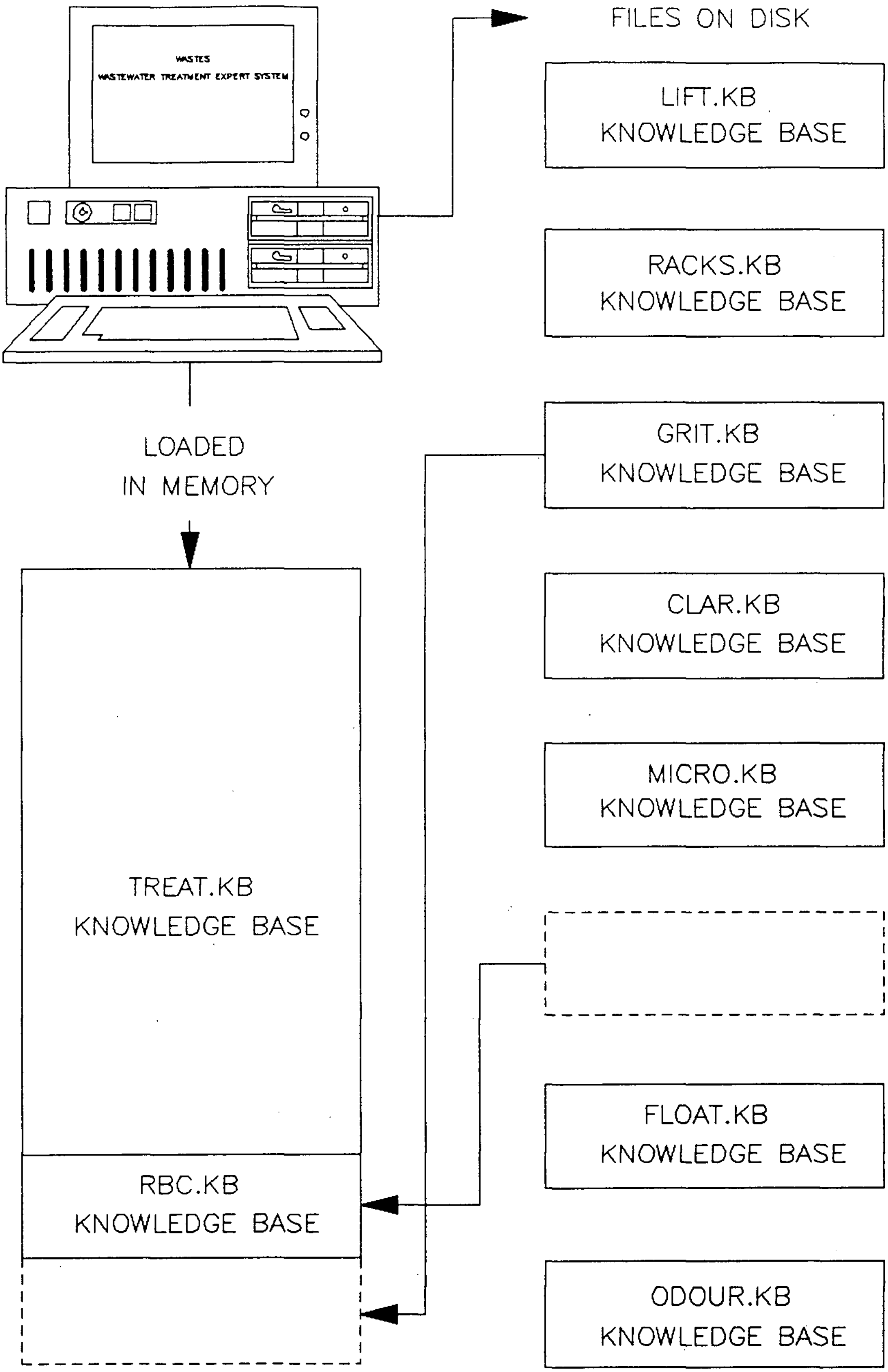


Figure 9 - WASTES System File Structure

Where CONCEPT is some variable or symbol of interest and VALUE is a value we assign to that concept. Examples of propositions include:

```
Jack is boy.
'average plant flow' is 4.25.
```

Both the CONCEPT and the VALUE can be a string or an atom. A string must be enclosed inside a pair of dollar signs:

```
$What is the condition of the primary solids?$
$Aeration Tanks$.
```

Strings take up more memory but can be larger than atoms and are used only for print statements in WASTES. An atom can contain only lowercase letters and consist of a single string of characters or be enclosed in apostrophes. Atoms are used in all forms of the propositions in the knowledge base:

```
boy
the_white_foam
'screen solids'.
```

Atoms using uppercase characters are identified as VARIABLES. They are special VALUES in that their value is determined through further inference with rules or question statements. The words and names used in the propositions have no value but are arbitrary symbols used by the expert system shell to infer logic to further rules. Assigning variables to atoms allows further flexibility in the inference structure by increasing the possibility of different outcomes based on the user input. It is important that these propositions be worded accurately and precisely. They must convey the understanding of the knowledge and reasoning clearly. They must also be singular and independent so that one concept does not represent more than one value. The knowledge logic will be accurate and comprehensible if it is assembled this way. In many occasions the knowledge has more than one attribute per CONCEPT. For example, the color of the dog is brown relates ATTRIBUTE of the CONCEPT (dog) is VALUE (brown). The dog can also have a size, shape and name (all with different values) but it is still the same dog or CONCEPT. Propositions can not have multiple values but by assigning ATTRIBUTES to CONCEPTS we effectively get multiple VALUES. The statement form is:

```
CONCEPT(ATTR 1, ATTR 2, ...) is VALUE.
```

Multiple attributes provide increased inference resolution by better defining the knowledge in the system.

In the knowledge base, propositions are written in the form of facts, rules and question statements. Facts are the most basic form of knowledge storage used by the FRO system consisting of a proposition followed by a period. For example:

```
'average plant flow' is '4.25'.
'wastewater temp' is '10.4'.
```

These facts are stored in the system database and used to solve rules. Generally they represent knowledge that relates to all problems, hence are called domain knowledge. The above fact statements are good examples of domain knowledge in the WASTES system.

Rules allow the system to perform reasoning by storing the inference relationship knowledge. Rules are made up from a proposition and a premise, which itself consists of one or more propositions, in the form:

rule CONCEPT is VALUE if PREMISE

If the PREMISE is satisfied, the proposition is stored as a fact in the system and used to solve higher level statements. In effect the PREMISE becomes the new goal of the system as it attempts to solve that particular rule. If the PREMISE can not be satisfied, the rule neither succeeds or fails and the system looks for other means to solve the higher level query.

The propositions in the premise may be separated by "and", "or", and the use of parenthesis. The "and" separates the propositions in the PREMISE into separate goals, each of which must succeed in order for the rule to succeed. The "or" allows the entire PREMISE to succeed if any one of the separated propositions are proven. The FRO system places logical precedence on "and" over "or". The use of line returns, short rule statements and parenthesis aids debugging and logic viewing when the PREMISE becomes quite complex. For example:

```
rule 'check DO'
    if ('type aer' is 'diffused air'
```

```
        and 'solve DO diffused'
        and succeed)
    or ('type aer' is 'mechanical'
        and 'solve DO mechanical'
        and succeed).
```

Note that the value for the concept 'check DO' is not present. In these cases, FRO assumes the value 'is true' and continues attempting to prove that concept. The 'succeed' proposition acknowledges that the premise is completed and the rule is proven.

Question statements enable the system to interact with the user in order to gain information on the VALUE of a CONCEPT in a proposition. A question statement is can be written in the basic form:

```
CONCEPT ask QUESTION alt (ALT 1, ALT 2, ...).
```

The concept is the valueless entity that can be assigned one of the selected alternatives listed in the statement (ALT 1, ALT 2, ...). The QUESTION is a string that is printed to the screen to which the user responds. Therefore the question statement that looks like:

```
'ask rotate' ask
$What is the circular sludge collection scraper arm doing?$
       alt ('rotating',
            'not rotating',
            'rotating but erratically').
```

would appear on the screen as:

What is the circular sludge collection scraper arm doing?

1. rotating

```
2. not rotating
3. rotating but erratically
>>>>
```

The user could then select the best alternative that answers the system query and it would continue by assigning that alternative value to the CONCEPT. A second list of alternatives can be placed in the question statement that are assigned as the values to the concept instead of the listed alternatives. This feature allows for more explicit alternative description with shorter value statements in accompanying rules. If no alternatives are placed after the question statement, the system waits for a data entry from the user. This is used with variables in the rule statements.

An "explain" feature can also provide additional information by printing a user-supplied string to the screen. It can expand on the question posed by the system by supplying a more detailed description. It can explain how the question statement relates to the logic of the knowledge base and the development of the rules to support a specific goal. It can also explain what information it hopes to gain from each of the alternatives. Simple yes/no questions can be given the form:

```
CONCEPT ask QUESTION alt yn.
```

in which a yes/no corresponds to true/false value assigned to the CONCEPT.

Complex expert systems can be developed using the fact, rule and question statements provided in the FRO system shell. Fact statements can provide basic domain knowledge available to the entire system. Rule statements develop the logic structure and main body of the system. The structuring of question statements and their alternatives form the basis of the user interface and input. Combined with effective interaction through printing strings to the screen, WASTES uses these statements to represent the knowledge domain of wastewater treatment plant operations.

Chapter 5.0 Development of WASTES Model

Developing the knowledge bases for the WASTES system requires:

- o knowledge acquisition and development
- o logic assembly
- o testing the knowledge bases.

5.1 Knowledge Sources

Developing the WASTES knowledge base requires extensive research and acquisition of operational and process control information from both written and human sources. The written sources of information consist of texts specifically written for plant operations and process control, articles from magazines, and research publications from journals. The USEPA has published troubleshooting guides and process control manuals for municipal treatment works.[26,27] Additional troubleshooting information was gained from the Water Pollution Control Federation publications on design and operation of treatment facilities as well as their monthly series, Operations Forum. Much of his work can be referenced to previous work by Al West of the Environmental Protection Agency in the early 1970's.[28] Other reference materials are cited as they appear. Although much of the raw information used was based on written material, most of the key process control points were gained from personal conversation with Dr. Bill Oldham, Department of Civil Engineering U.B.C., and Mr. Gil Bradshaw of the Environmental Protection Service.

5.2 Knowledge Development

After the raw information was obtained, the expert system, which is a model of the operational aspects of a treatment plant, was assembled. Before the actual knowledge bases were written, an outline was formed which was developed into the overall framework for the system.

The first phase of the outline involved identifying the unit operations and processes in the treatment plant and treatment plant problems. The treatment plant problems divided into two fields: one that dealt with unit operations and processes, and another with common operational and effluent problems. The unit operations were sub-divided and the purposes of each outlined. They were examined individually and problems were identified. The key information that would distinguish what problem or problems were present was identified. Parameters examined included those within the unit operation and external to it. The values of the parameters are the information that would have to be obtained interactively through the expert system. Finally, the corrective actions were correlated to the problems identified using the parameters. Linking the correct actions to the problem is the basic role of the expert system.

The final result was a diagnostic or logic flowsheet for each unit operation or process that outlined all the possible problems, the information required to determine what problems were present, and possible solutions to the identified problems.

A similar process was developed for common operational problems and common effluent violations.

Each logic structure or tree represents a small independent expert system. The next step was to write the rules that would transform the logic structure into a logic system in the expert system. Starting with the smallest trees, the rules were coded and knowledge base files written. Once the coding was keyed into the files, it was debugged for logic and syntax errors. Then the logic was tested using the tracing feature in the FRO shell. The tracing feature puts a small window in the bottom of the computer screen that relays the inference path and goals. This allows the user to see exactly what the expert system is trying to determine and to locate errors in the rule logic.

The completed small expert system knowledge bases were now ready to be linked together using a menu structure and linking rules in the main knowledge base file, treat.kb. The look and feel of the system is a function of designing a menu structure for an intended user group. One of the goals of the system was to make it simple enough that a person unfamiliar with wastewater treatment facilities could operate the expert system, understand what the system is doing, and learn about the treatment process. At the same time, the system should be designed to be useful to someone familiar with wastewater treatment and that person should be able to quickly find an area that he or she is interested in and examine it thoroughly with the system. In order to provide both concepts, the expert system was divided into two different fields with the initial system query of whether the user wants to examine a general or a specific area of interest.

Menus according to each field are provided. The specific menu lists the unit operations. If the operator knew the problem was in the secondary clarifiers, he or she would select that area from the menu and the diagnostics on that unit operation would begin. The general problem menu choice invokes a secondary menu that deals with total plant problems. Most of these general problems deal with the activated sludge process and effluent violations.

The size and scope of a perceived problem often requires the expert system to examine more than one area of the treatment plant in order to fully diagnose the problem. This may require examining different logic structures and loading more than one knowledge base file. This process is called linking. It is accomplished by providing rules that make the expert system examine unit operations and processes related to the current problem. These rules load other knowledge base files and assign new system goals.

This system is not an analytical model but instead is based on a heuristic or rule-based system that uses observational data. The expert system is a representation of the model treatment plant and its operation developed in Section 3.0. Hill[29], Hobson[30] and

West[31] have published articles on the correlation of visual observations to activated sludge process operation. Similar visual observations are used in the expert system to provide additional information. Common observational data used to identify problems includes:

o activated sludge floc type and settleability
o aeration tank foaming and foam type
o secondary clarifier observations
o microbiological examination.

These observations are used in conjunction with monitoring effluent BOD and TSS levels, and BOD and F/M loading rates to determine the condition of the activated sludge process. These same characteristics have been used in the WASTES system to develop a controller/diagnostics routine. The knowledge base interactively records observations and by consulting the domain knowledge and inferring through the rule structure suggests probable causes and remedies for common activated sludge problems. The basis for the process control system in WASTES is illustrated in Table III.

5.3 Completing the Knowledge Bases

With basic system structure and knowledge bases completed, attention was focused on fully developing the system. The content of each knowledge base was reviewed and most files were simplified and reduced in size. Reducing the overall size of the combined knowledge bases allows all the program and knowledge

Table III - Process Control Logic used by WASTES

CLARIFIER SOLIDS CONDITION	SLUDGE SETTLE	RELATIVE F/M LOADING	CLARIFIER SLUDGE BLANKET	OTHER CONDITIONS	IDENTIFIED PROBLEM	RECOMMENDED ACTION
BILLOWING	SLOW	HIGH		FOAMING	F/M TOO HIGH	DECREASE WASTAGE
THROUGHOUT	SLOW	LOW	INCREASED SLOWLY		F/M TOO LOW	INCREASE WASTAGE
CLARIFIER AREA	SLOW			FILAMENT. ORGANISMS	BULKING SLUDGE	INVESTIGATE CAUSES
						CHECK B
BILLOWING IN			INCREASED RAPIDLY	PUMPS NOT WORKING	BROKEN RSF PUMPS	REPAIR OR BACK-UP PUMPS
PARTS OF			INCREASED RAPIDLY	PIPES CLOGGED	RSF TOO LOW	INCREASE RSF
CLARIFIER AREA			INCREASED SLOWLY		RSF TOO LOW	INCREASE RSF
			TOO HIGH		RSF TOO LOW	INCREASE RSF
				WIND/NO COVER		ADD COVER OR WIND BREAK
				CHECK EFFLUENT WEIRS	WEIRS NOT LEVEL	LEVEL EFFLUENT WEIRS
						CHECK C
CLUMPS AND MATS		LOW		BLACK SOLIDS	SEPTIC OR LOW DO	INCREASE RSF
OF RISING SOLIDS	FAST	LOW		BROWN OR TAN SOLIDS	DENITRIFICATION	DECREASE WASTAGE
ASH-LIKE SOLIDS ON				GREASE IN INFLUENT		CHECK PRIMARY CLARIFIERS
CLARIFIER SURFACE	FAST				BEGINNING DENITR.	CHECK C
DISPERSED SOLIDS	SLOW/NORM.		INACTIVE ROTIFERS		TOXIC LOADING	DECREASE WASTAGE
OR	FAST	HIGH		FOAMING	F/M TOO HIGH	DECREASE WASTAGE
CLOUDY EFFLUENT	FAST	LOW			F/M TOO LOW	INCREASE WASTAGE
			PLANT START-UP	FOAMING	F/M TOO HIGH	NO WASTAGE FOR 10 DAYS

base files to fit on one 5.25" floppy disk, and reduced the response time for file loading and disk read/write operations. This kept the system portable, convenient and compatible with a wide variety of computers. Continued use and testing revealed that further streamlining was necessary in order that the knowledge presented was accurate and easy to understand. The initial system was several smaller expert systems tied together. Integrating the domains together by adding more links would fill out the system. Several knowledge bases were added like float.kb and odour.kb to deal with a common problem over the entire plant process. The float.kb knowledge base deals with floating material and the odour.kb knowledge base deals with odour in all unit operations. Large rules had been written in an effort to get most accurate representation of the tree-like logic structure. Unfortunately these large rules were very difficult to debug, edit and re-program. Most of the rules were broken down into numerous smaller rules making the logic structure clearer and more readable without changing the size of the program. While the WASTES system was being developed, the FRO shell was also constantly updated. Changes in the print string structure in the FRO shell permitted enhanced formatting but necessitated changes in all knowledge bases. New user features were added including explain and show functions. These features enhanced the WASTES system considerably by displaying more information on what the expert system is doing. While the expert system has remained dedicated as a diagnostic and solution-oriented program, further effort has been made to round out the knowledge bases by providing relevant information to the user at all levels in the system. Statements have been added at most logical points to provide detailed solution choices. In cases where a solution is not developed the system suggests alternatives or other areas to examine before the expert system is consulted again.

5.4 Knowledge Logic Structures

This section is a breakdown of the individual knowledge bases in terms of the function and logic used. Each section is designed to the following format:

Knowledge Base: Name of the knowledge base file used by WASTES

Purpose: A Description of the goals of the knowledge base file.

Problems: A list the major problems addressed by the knowledge base.

Parameters: The information WASTES uses to determine the solution to the problems.

Solutions: A list of the possible actions available to solve or remedy the problems.

Logic Structure: A flowchart illustrating the rule structure of the knowledge base.

The logic structure for each process or operation being investigated, proceeds from start to finish in the order that it is represented by the expert system (see Figure 10). The diamond shapes are questions or rules that denote nodes in the system. The rectangles represent rules that produce general information. The "STORE" command indicates information that is stored by the system and used later. The PRINT "information" are samples of the information relayed to the user by the system. The "LINK" statement beside some of the shapes show where that knowledge base links to other knowledge bases in the WASTES system.

The preceding subsections introduce each knowledge base and give a general description as to what the knowledge base performs. The problems, described in point form, list the various problems that the knowledge base can solve. The parameters are a list of the information that WASTES will use to determine one or more of the solutions listed below. These lists are in point form and appendix 1 contains the actual file listing which complements each subsections. The flowcharts describe the logic process that the expert system uses for each knowledge base, where links occur between knowledge bases, and the structure of queries that WASTES uses to extract information from the user of the system. More detailed results and print strings are given in the corresponding knowledge base listing in appendix 1.

5.4.1 Knowledge Base: LIFT.KB

Purpose:

Diagnose and troubleshoot raw sewage lift facilities at wastewater treatment plants.

Problems:

- o not operational
- o excessive noise
- o reduced discharge

Parameters:

- o type of lift pump
- o number of installed and on-line lift pumps
- o condition of pump

Solutions:

Correct condition
- o discharge - put more pumps on-line;use back-up pump(s)
- o operation - repair or shut down
- o noise - servicing

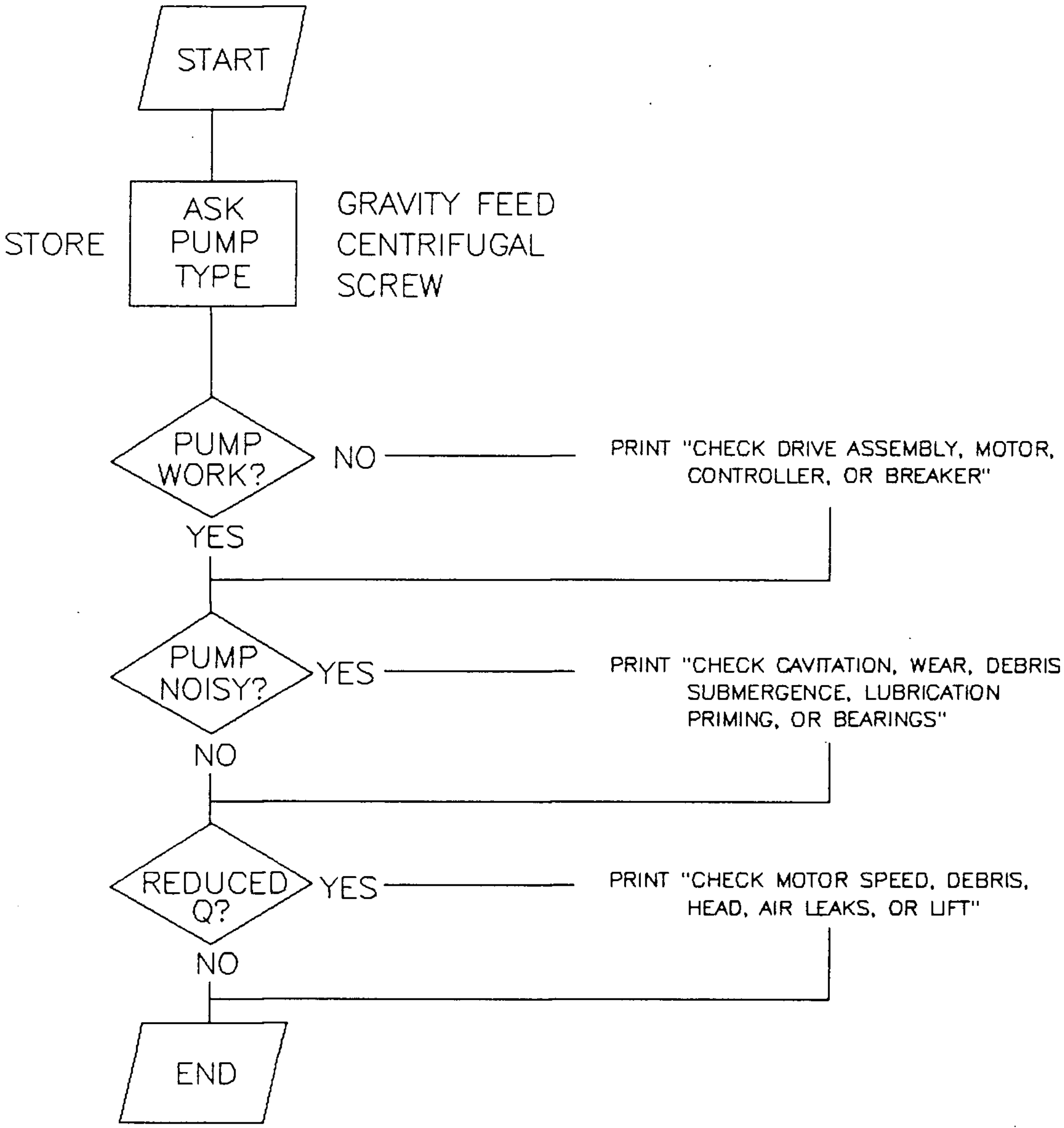


Figure 10 - LIFT.KB Logic Structure

5.4.2 Knowledge Base: RACKS.KB

Purpose:

Preliminary treatment diagnostics of the unit operations of bar screens and shredding devices.[32]

Problems:

Inadequate debris removal from racks
- o Build-up on racks creates backwater and head loss

Debris disposal
- o debris attracts flies and creates odours
- o excessive debris a disposal problem

Shredder operation
- o poor operation might hamper downstream operations like scum removal and clogged aerators

Parameters:

- o number of influent channels
- o cleaning frequency of bar racks
- o type of bar racks
- o condition of shredder and shredded solids

Solutions:

- o increase cleaning frequency
- o bypass channel
- o change bar rack design
- o install shredding device
- o repair shredder blades
- o repair mechanical problems

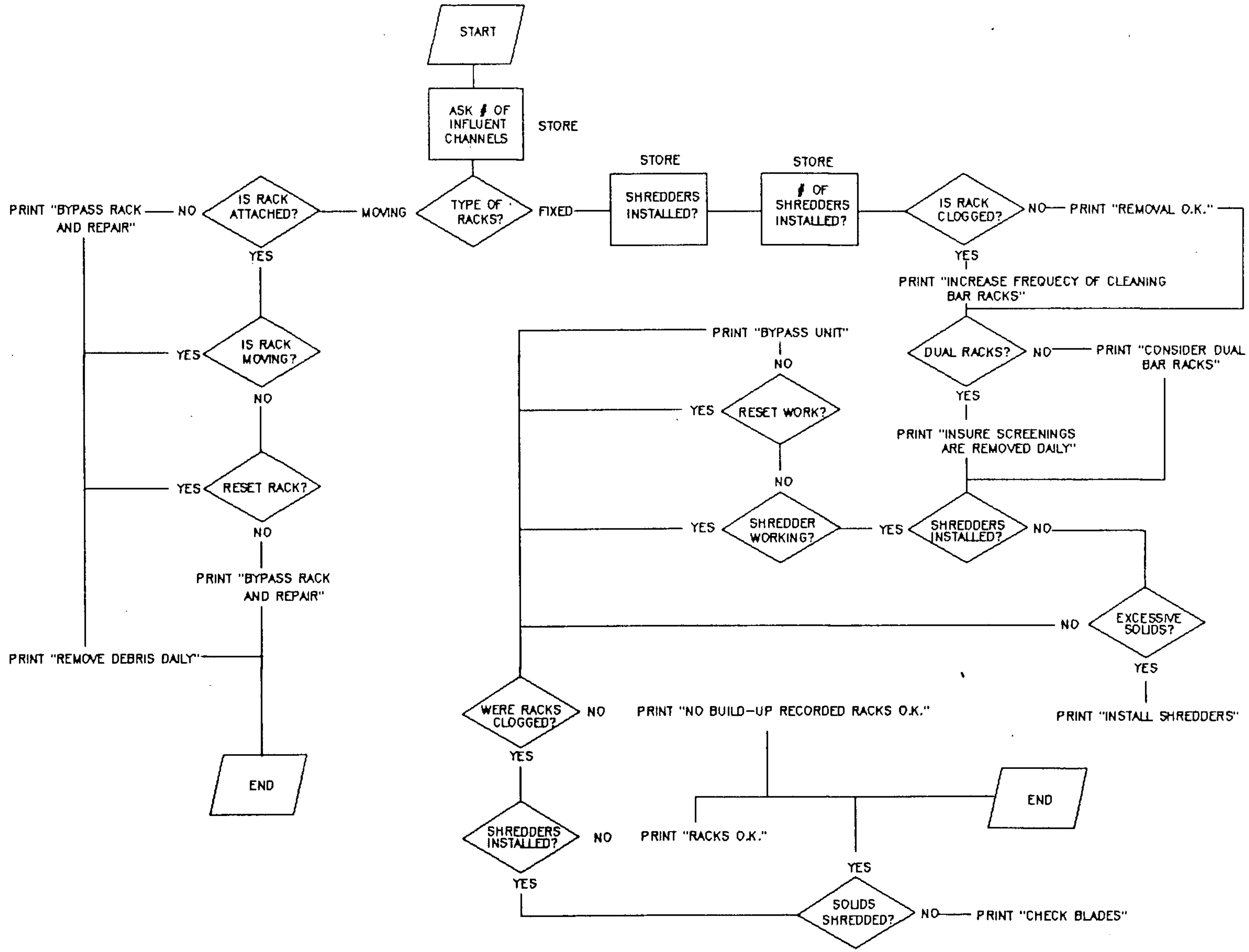


Figure 11 - RACKS.KB Logic Structure

5.4.3 Knowledge Base: GRIT.KB

Purpose:

Diagnostics of sedimentation and aerated grit tanks used to remove sand, grit and gravel from the treated sewage.[33,34]

Problems:

Inadequate grit removal
- o clog sludge removal pipes
- o ruin pump impellers
- o cementing effect in primary sludge
- o wear and abrasion on bearings
- o loss of available volume in primary clarifiers and sludge digesters

Clogged/broken grit removal mechanism
- o build-up of grit in chamber reduces grit removal

Parameters:

- o type of grit tank
- o number of installed and on-line grit tanks
- o condition of removal mechanism
- o sufficient grit removal

Solutions:

- o bypass faulty tank
- o raise effluent weir
- o adjust grit removal mechanism
- o repair grit removal mechanism
- o reset circuit breaker

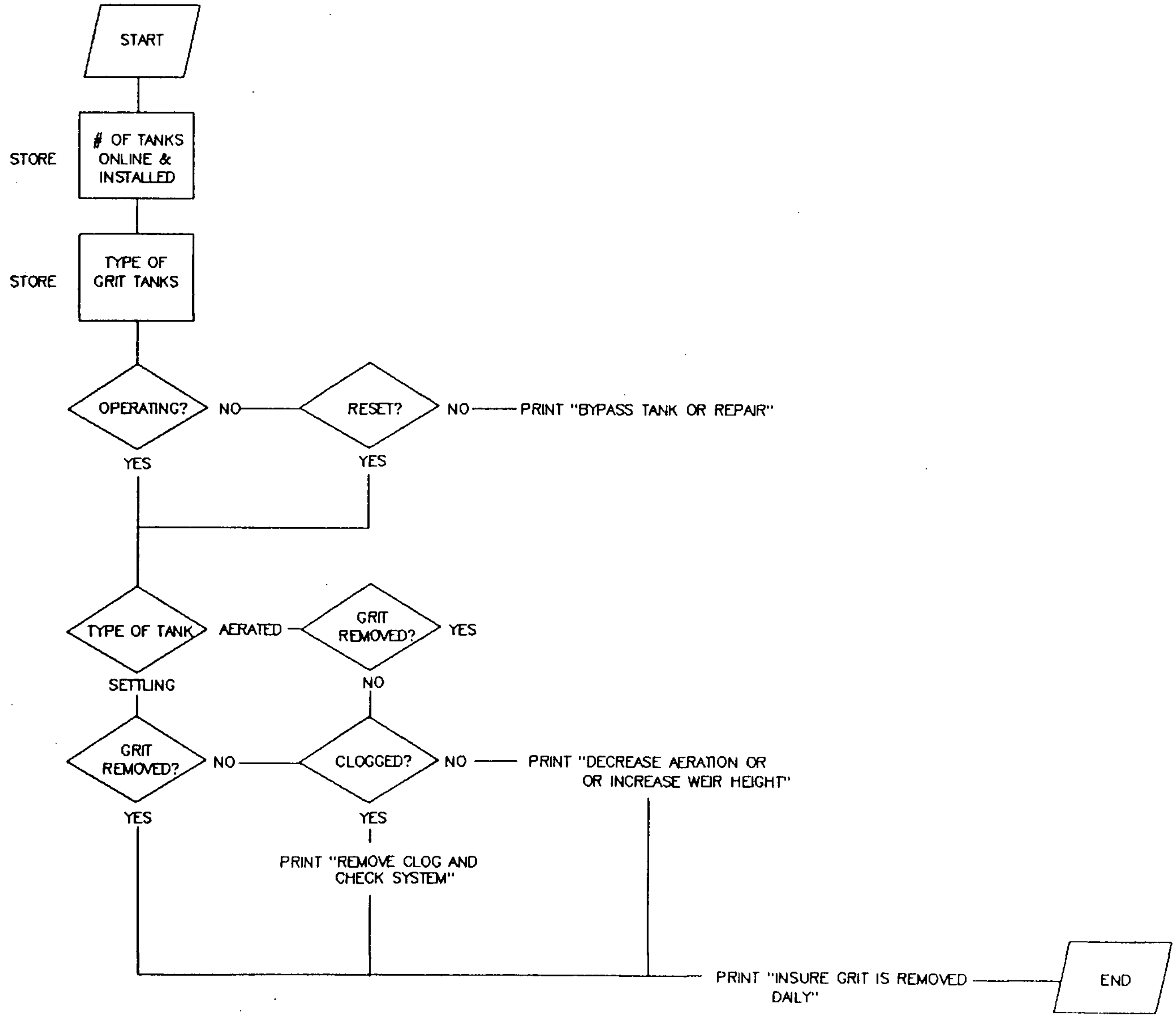


Figure 12 - GRIT.KB Logic Structure

5.4.4 Knowledge Base: MICRO.KB

Purpose:

To diagnose the common operational problems that occur with microscreens.[35]

Problems:

- o accumulation of solids in influent chamber
- o loss of solids through screen
- o slime build-up
- o erratic rotation

Parameters:

- o drum rotation speed and condition
- o condition of solids at microscreen
- o drive system and circuit breaker
- o number of installed and on-line microscreens

Solutions:

- o increase drum speed
- o repair drum screen
- o repair drive unit and/or motor
- o bypass faulty microscreen
- o install spray washers

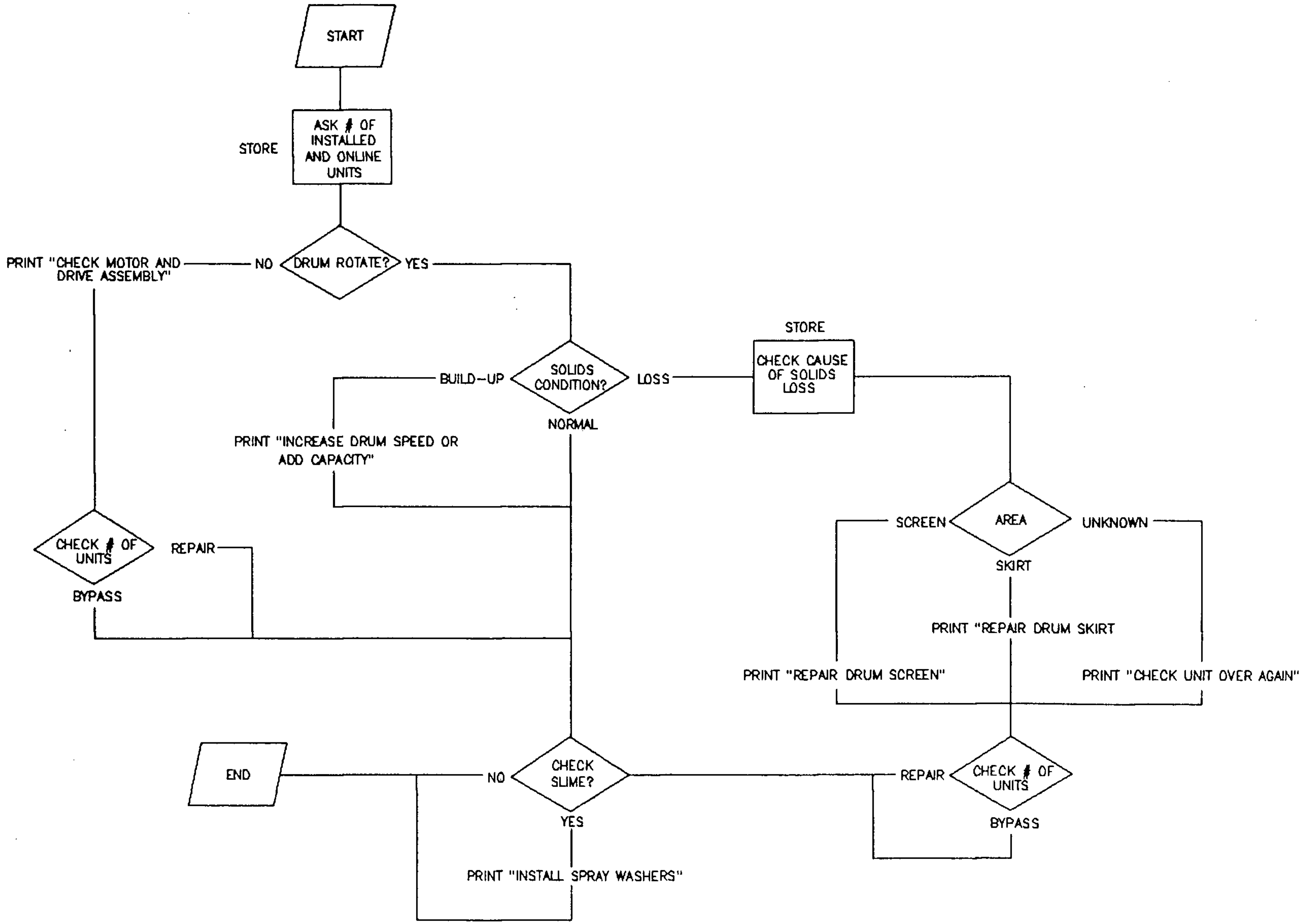


Figure 13 - MICRO.KB Logic Structure

5.4.5 Knowledge Base: CLAR.KB

Purpose:

To diagnose the operation of the primary and secondary clarifiers including sludge and scum removal.[36,37,38]

Problems:

Loss of solids
- o hydraulic or solids overloading
- o inadequate sludge removal
- o weir placement
- o secondary currents due to flow, wind and temperature

Mechanical problems
- o sludge pumping
- o scraper mechanism operation

Scum removal
- o inadequate removal
- o clogged weirs
- o excess floating solids

Parameters:

- o type of clarifiers
- o number of installed and on-line clarifiers
- o sludge scraper operation
- o sludge pumping operation
- o flow into clarifiers
- o condition of scum removal
- o type of solids loss (if any)
- o air and wastewater temperature (secondary only)

Solutions:

- o bypass clarifier(s)
- o repair motor/drive assemblies
- o increase sludge pumping
- o level effluent weirs
- o provide more clarification capacity
- o check inlet diffusers
- o increase aeration in activated sludge tanks (secondary only)
- o provide cover over clarifiers
- o use back-up sludge pumps

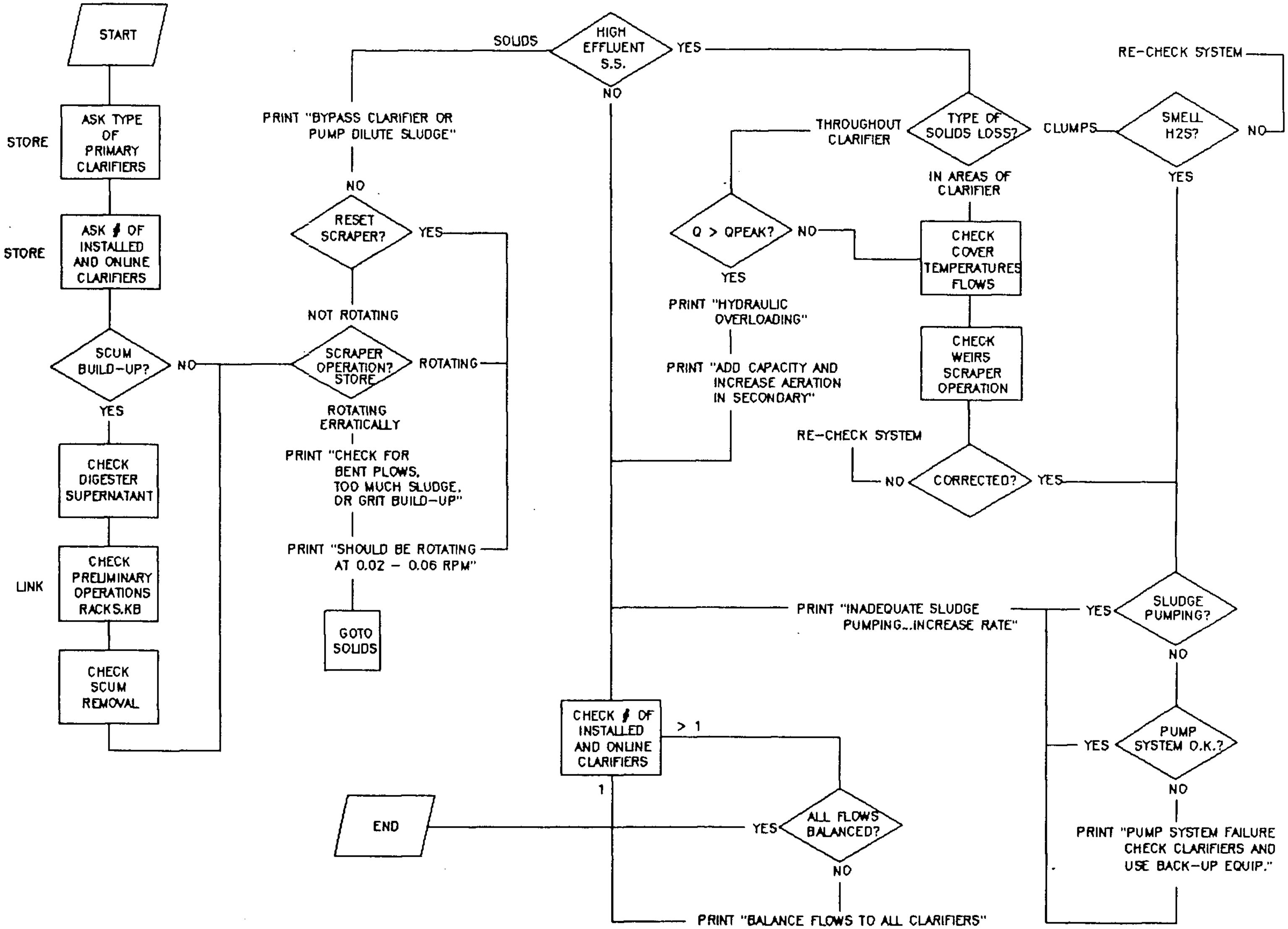


Figure 14 - CLAR.KB Logic Structure

5.4.6 Knowledge Base: RBC.KB

Purpose:

Diagnose and troubleshoot the rotating biological contactor (RBC) treatment system that provides BOD removal from municipal wastewater.[39]

Problems:

- o organic overloading
- o excessive sloughing
- o broken shaft/media
- o mechanical drive/motor problems
- o toxic loadings

Parameters:

- o condition and color of RBC biomass
- o visual inspection
- o speed of rotation (RPM)

Solutions:

- o bypass part of flow around 1st stage
- o increase/decrease RPM
- o add aeration
- o repair or replace broken shaft/media
- o check solids in clarifiers

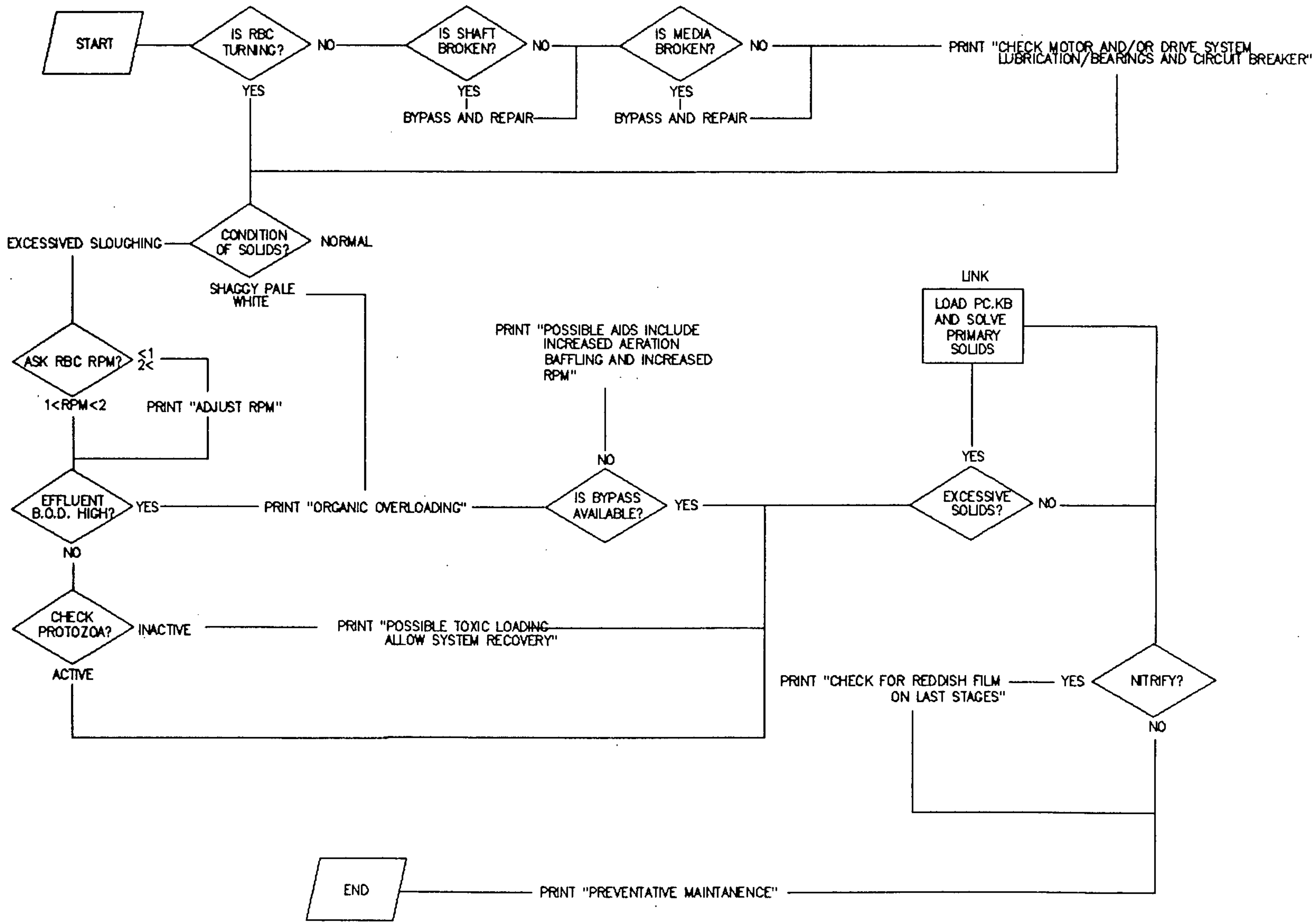


Figure 15 - RBC.KB Logic Structure

5.4.7 Knowledge Base: FLOAT.KB

Purpose:

Determines the cause or source of floating solids or scum on the primary clarifiers, aeration tanks and secondary clarifiers.[40]

Problems:

- o scum or solids on the primary clarifiers
- o foam on the aeration tanks
- o scum, foam or solids on the secondary clarifiers

Parameters:

- o unit operation with problem
- o type of solids or scum
- o source of foam or scum
- o loss of solids from unit operation

Solutions:

- o check loading on aeration tanks
- o check sludge wastage from primary clarifiers
- o check sludge wastage from secondary clarifiers
- o install baffles at aeration outlet
- o check preliminary unit operations
- o check primary clarifier scum removal

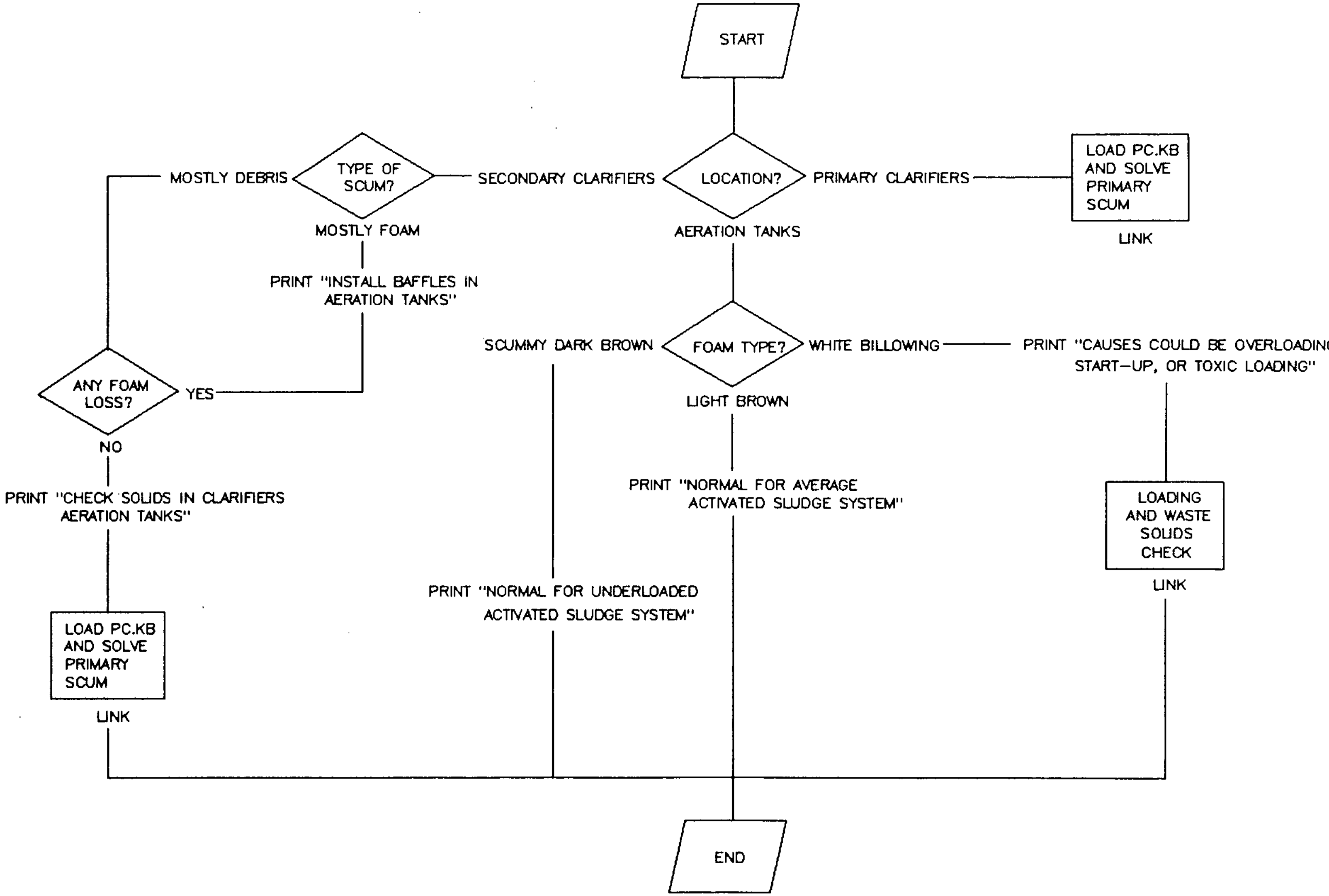


Figure 16 - FLOAT.KB Logic Structure

5.4.8 Knowledge Base: ODOUR.KB

Purpose:

Diagnoses source of disagreeable odours from treatment plant and directs action to source of problems.

Problems:

Disagreeable odour from:
- o aeration tanks
- o anoxic reactor
- o primary clarifiers
- o secondary clarifiers

Parameters:

- o location of odour
- o subjective type of odour

Solutions:

- o increase aeration in aeration tanks
- o check primary sludge wastage
- o check secondary sludge wastage
- o add pre-aeration

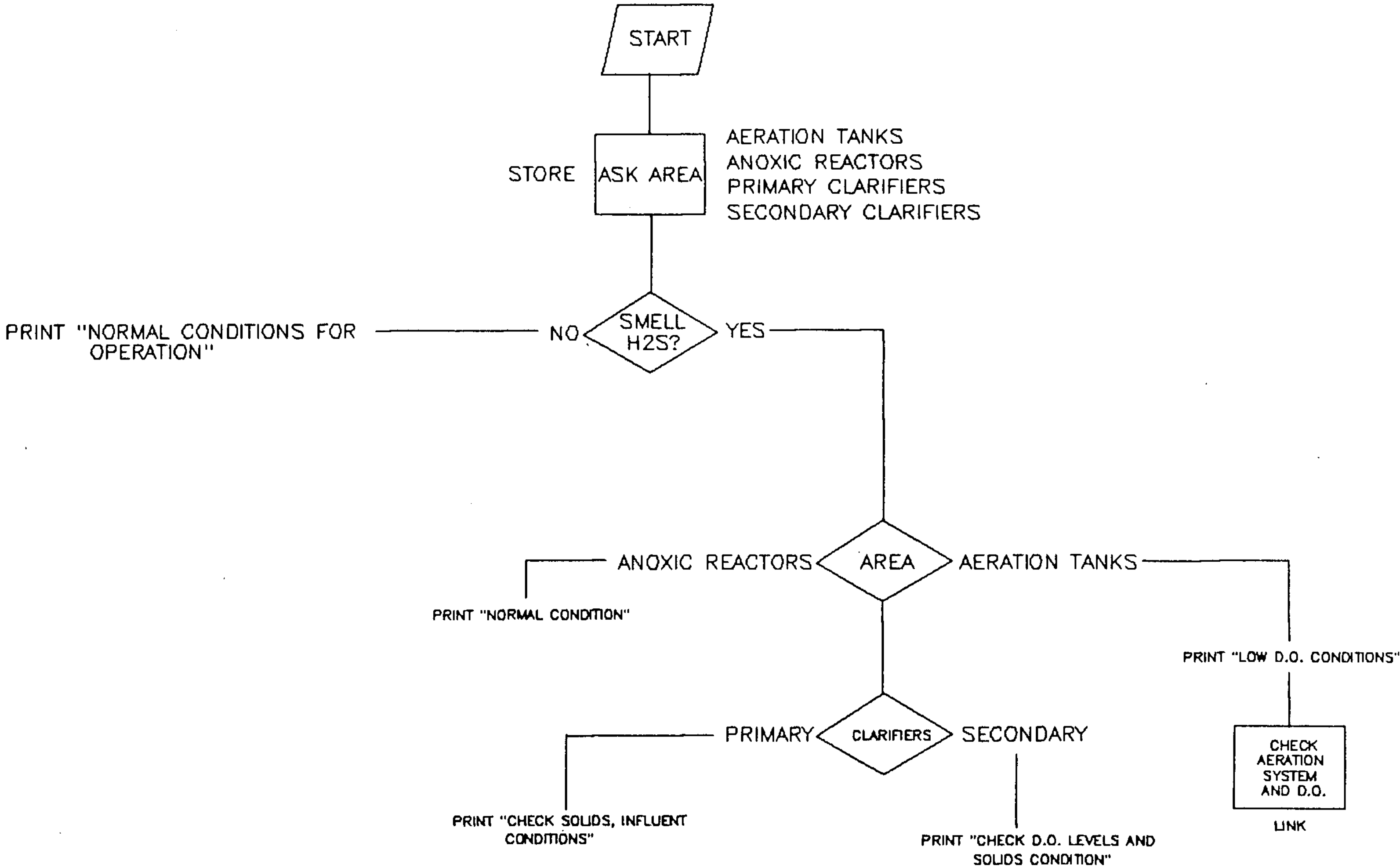


Figure 17 - ODOUR.KB Logic Structure

5.4.9 Knowledge Base: TREAT.KB

The TREAT.KB knowledge base contains the menu system, basic plant lay-out questions, and the diagnostics for the activated sludge system and the aeration system[41,42,43] ,and the secondary clarifiers.[44]

Part 1: Aeration System

Problems:

- o unbalanced aeration
- o clogged aerators
- o broken air piping/compressors
- o low DO
- o high DO
- o faulty mechanical aerators
- o overmixing

Parameters:

- o visual inspection
- o DO meter inspection
- o type of aerators

Solutions:

- o repair of piping/compressors
- o balance valving
- o clean/replace/adjust aerators
- o increase/decrease aeration (DO)
- o check motors/drives/circuit breaker/power

PART 2: Activated Sludge Process Control

Problems:

- o excess effluent BOD
- o excess effluent suspended solids
- o excess effluent NH_4
- o excess effluent NO_3
- o improper organic loading (F/M)
- o improper wastage
- o improper return solids flow
- o secondary sludge pumping
- o scraper mechanism operation

- o inadequate scum removal
- o clogged weirs

Parameters:

- o color of activated sludge floc
- o relative MLSS concentration
- o type and color of aeration tank foam
- o relative F/M loading
- o BOD test results
- o type of solids loss (if any)
- o sludge settling characteristics
- o microbiological observations
- o process type
- o nitrification/denitrification expected [45]
- o number of installed and on-line secondary clarifiers
- o sludge scraper operation and type
- o sludge pumping operation
- o sludge blanket thickness
- o plant flow
- o condition of scum removal
- o air and wastewater temperature
- o sludge disposal method

Solutions:

- o increase/decrease wasting
- o change wastage (F/M) control method
- o increase/decrease return solids flow
- o bypass secondary clarifier(s)
- o repair motor/drive assemblies
- o level effluent weirs
- o provide more clarification capacity
- o check inlet diffusers/balance flows
- o check DO requirements
- o provide cover over clarifiers
- o use back-up sludge pumps
- o process modifications and additions

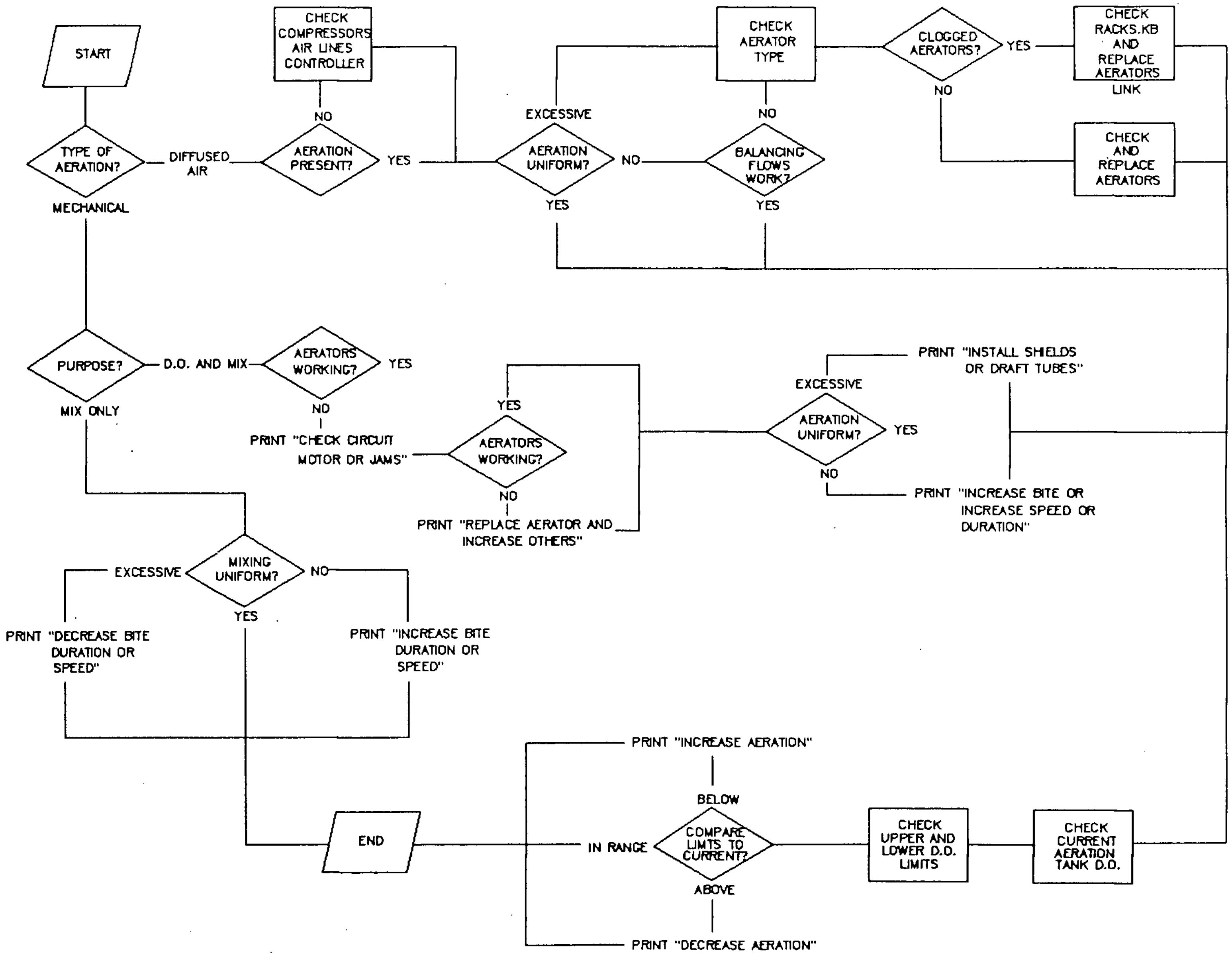


Figure 18 - Aeration System Logic Structure (TREAT.KB)

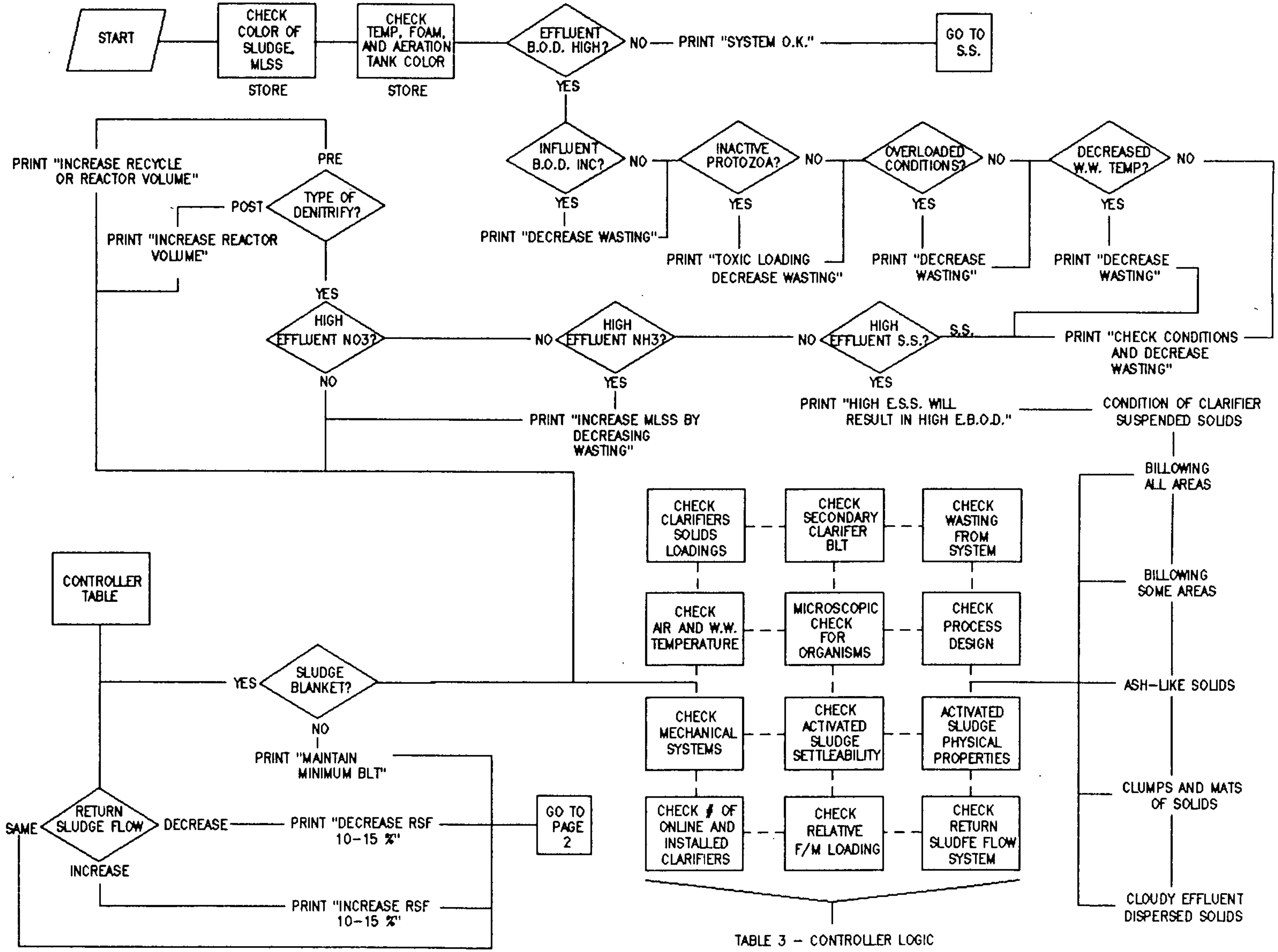


Figure 19 - Activated Sludge Process Control (TREAT.KB)

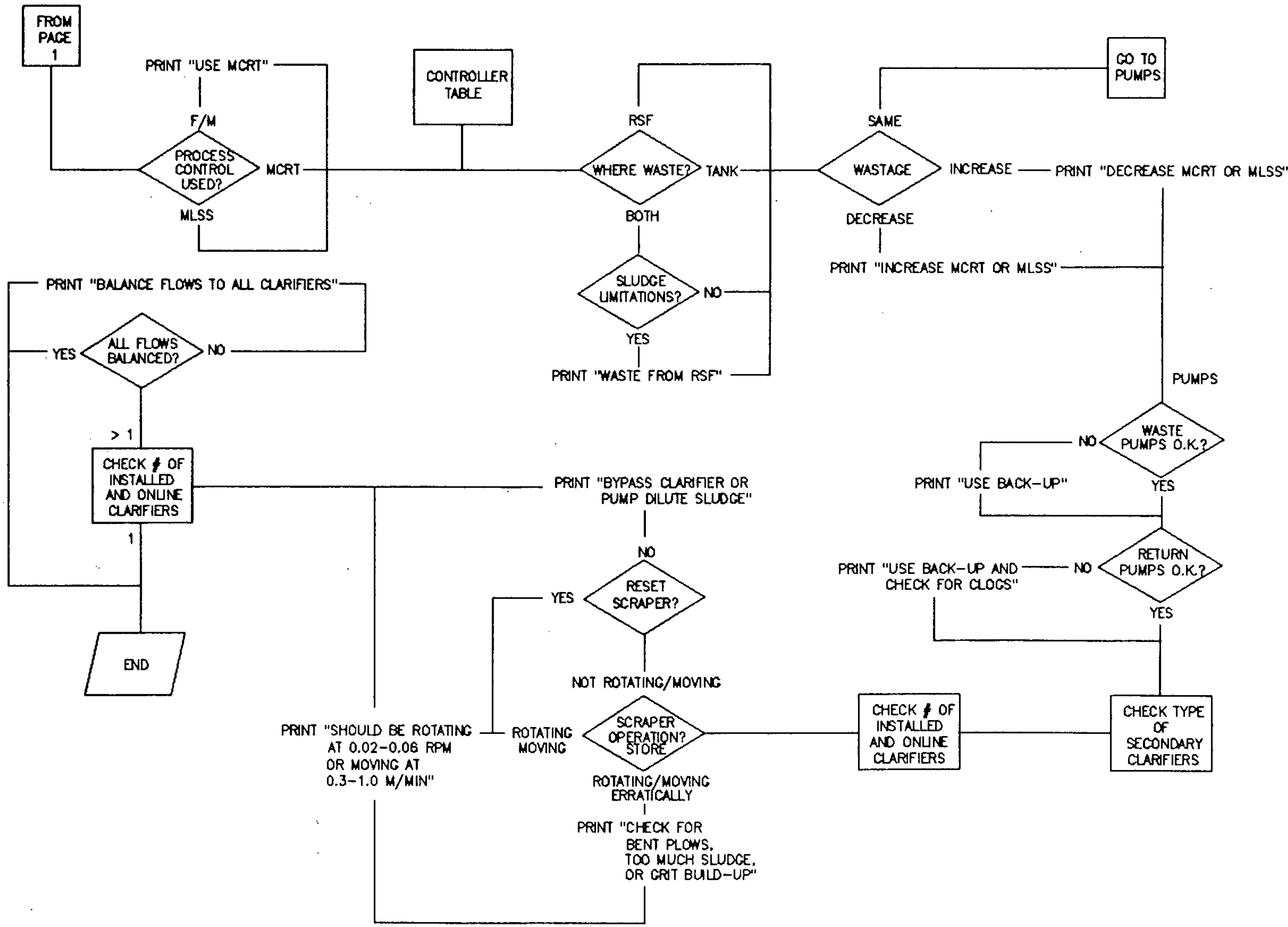


Figure 20 - Activated Sludge Process Control (TREAT.KB)

Chapter 6.0 Results

The result of the research is a completed functional expert system capable of demonstrating the potential of combining a knowledge-rich domain, wastewater treatment plant operations and process control, and a powerful flexible expert system shell. The diskette in Appendix 4 contains the functioning WASTES system, the result of the work undertaken.

Initially, research determined whether process control and troubleshooting procedures could be used in conjunction with heuristic or rule-based programs in comparison to the bulk of systems modeling research which took more numerical approaches. It was found that although the heuristic field is relatively new, there is currently extensive research underway and increasing volumes of available information. This research represented a new direction for the analysis of wastewater treatment plant operations.

In general, most of the initial research time was spent on gathering the domain knowledge to put into the system. The development time to produce the WASTES expert system was reduced by selecting a capable, full-featured expert system shell. The shell was not overly complicated, difficult to use or edit, and it had a user interface that suited this research.

The research has progressed through several milestones. After the initial investigations and decision to go ahead with the direction of the research, the first was reached when the framework for the system was completed and the raw information was gathered and edited, and getting the system operational and logical. This required extensive debugging though each part of the system and checking the output of the shell against the logical structure intended in its design.

Once the information was placed in the knowledge bases and used, the certain limitations of the expert system and the knowledge bases system became apparent. From the hardware perspective, the size of the WASTES knowledge bases were too large for the computer's 640 Kb memory and caused the FRO system to fail. The WASTES system also had too many hard disk read-write operations, which slowed the program down until it was inoperable. To solve this problem the large single knowledge base was broken down into smaller associated domains. The single Treat.kb is loaded and executed by the shell, but only loads the other related files as required by the system in response to the user's input. The process of breaking down the larger domain into small applications that could be readily inputted, debugged and then linked together had other benefits. The smaller domains, in the form of separate ".kb" files, could be easily checked for errors in syntax and logic. Since debugging was the most time consuming task, breaking the system up, as well as the tracing feature of the shell, led to faster development of the system.

The separation of the larger domain into smaller domains also benefited the system development because the process stream in the model treatment plant was composed of unit operations with specific purposes and individual operations. These unit operations were developed as complete knowledge bases before the entire system was assembled. Each smaller domain could be run as a separate knowledge base and individual errors in the logic and print statements could be corrected. The tracing feature of the FRO shell was invaluable and facilitated the development of the large WASTES system by finding errors relatively easily. Finally, the system was put together and linked using a feature of the shell that loaded the files and would involve the new information with the existing knowledge base in the computer memory.

The user interface depends on the rule structure, the amount of knowledge contained in the system, and the querying structure of the shell. What information the user of the system receives from the expert system also depends on this interface, as well as his own capabilities of understanding the information presented.

The rule structure determined the order in which information was imparted from the user to the system. By the nature of the knowledge base and the shell, the system moves from general to specific, from problem to solution. It solves problems by asking increasingly specific questions that narrow the possible solutions to a single individual solution. The system does not give the most probable solution, but the solution determined by the answers the user has returned. This method requires that every branch of the logic structure have a conclusion that fits the logic that reaches that point. The logic for the activated sludge process controller best represents this as all conditions lead to a solution. If the logic determines that no real solution can be determined then the system must return that information. This is the major drawback of using a deterministic rather than a probablistic system. It was compensated by the fact that the FRO shell would ask questions in the order they were read from the knowledge base. Using that fact, I could bias the shell by invoking the most probable situation first, decreasing to the least probable. This bias was based on my own development of the knowledge base structure and not on any mathematical probabilities developed in the shell. If probability was used in the shell, I doubt that there would be as large a scope of information in the knowledge bases.

The computer hardware limitations would have reduced the scope of my research and fundamentally altered the goals of the research if I had not broken the system into smaller related knowledge bases. One of the goals was to produce a system that embraced a fairly wide domain of knowledge about a specific field, wastewater treatment plant operations. However, there is a minimum amount of information and depth within the expert system that must be developed so that it assumes the interactive characteristic that makes it unique. A narrow scope or field entitles a domain to possess a lot of knowledge within the subject area without a large size. A wider scope requires an increased size to maintain the sense and feel of the interactive expert system, and present the technical information and knowledge. The WASTES system is large because the scope of the domain is wide and there was attention to providing the interactiveness and correct information in all areas of the knowledge bases.

The interactiveness of the expert system is a function of its querying capabilities. The FRO system provides menus and accepts user input which increases the range and flexibility of user responses. An effort was made to use question statements rather than fact statements in the WASTES knowledge bases. By utilizing question statements, the knowledge base is larger but provides a more flexible and interesting system.

One of the original goals was to in effect replace the operator with this intelligent expert system to run the treatment plant. It quickly became apparent that there are several obstacles to face, besides the domain being so large and diverse for this one system.

One problem is that treatment operations are site-specific and unique to each location; accurate systems would have to be designed for each plant. Without adequate size, these expert systems would not possess the depth of knowledge necessary to deal with all types of plants and their problems. Without detail and accuracy, the practicality and usefulness of these systems are reduced considerably.

The availability and consistency of the domain knowledge proved to be another limitation. The source of raw information was generally written data from other people who had investigated wastewater treatment plant operations and visual aspects of activated sludge process control. Other sources, such as interviewing operators and other experts, often provided information that was contrary to other previous information. The knowledge engineer determines what was correct and relevant in the face of conflicting information. This requires the knowledge engineer to have access to an expert with the field he or she is attempting to reduce into a workable expert system.

Another problem encountered is that in many cases in the WASTES system there are no hard solutions to the problems. The problem faced is in fact unanswerable given the available information. This requires the knowledge developer to engineer a system that provides answers for these difficult questions that satisfy the user and direct him to further areas to investigate for more information. It also leads the researcher to investigate the use of probability and uncertainty, for which the FRO shell is fully capable of representing using Dempster-Shafer theory.

The use of a system like WASTES as a teaching tool became apparent considering the lack of coherent process control information and the poor medium that exists in transferring this knowledge or skill to new operators. A new operator generally learns his trade by experience, reading and course work. An expert system could be used to interactively illustrate the basics of plant operations and activated sludge process control to students operators. An expert system combined with real-time graphics could illustrate process changes as flow and loadings changed and the function of the various unit operations based on the actual facility's operational data and operator knowledge. Interactive changes in operation in the treatment plant operation would be simulated by the program and visually displayed. The system could describe the sampling and monitoring required to provide process control data in conjunction with other visual information.

The software and processing power required to develop these sophisticated programs is available. Education and training systems is the one application using expert systems that has the highest potential for practical commercial application and could provide the greatest benefits.

Chapter 7.0 Conclusions

This research involved the development of an expert system from raw information to a demonstration level in a new application domain: wastewater treatment.

Researching and assembling the raw information, identifying the vital pieces of knowledge, and developing the logic structure were the initial accomplishment in this research. Coding the information into the knowledge bases and testing, both the whole system and each of its parts, was the most time consuming task. The final accomplishment is presenting a functioning system, enclosed on a diskette in Appendix 4, that demonstrates the applications of expert systems in the field of wastewater treatment operations, with respect to diagnosis, problem solution and control of the treatment operations. The amount of knowledge involved in the field of wastewater treatment, both design and operations, and the type of knowledge, that much of it is experience-based, proves it ideal for development of expert systems applications. The ability of the system to begin at a general level and work down to specific problems or circumstances by way of the inference of the expert system illustrates ideally the diagnostics of problem-solving wastewater treatment problems. The system contains a great deal of information that can be presented to the user in a way that promotes understanding of the reasoning and logic behind a decision. This feature of the expert system broadly supports the idea of utilizing systems like WASTES as training and development tools to support the transfer of human knowledge and understanding of a field like wastewater treatment operations and diagnostics.

Chapter 8.0 Recommendations

There are several recommendations with regards to future research in the field of expert systems applications for wastewater treatment plant operation.

The first recommendation is to incorporate some aspects of uncertainty into the wastes system using the shell-based uncertainty system in the FRO shell.[46] The key areas would be in activated sludge process control and problem determination. The system could return the most likely problem, the user could choose to accept this or ask for the next likely problem based on statistical results. The use of probability would also reduce the rigid tree structure of the present WASTES system, allowing for a wider range of possible problems and solution.

The second recommendation would be to field test the system at an operating wastewater treatment plant, customizing the system to the problems identified at the facility. In this case, just a small part of the whole process could be investigated in conjunction with developing the probablistic shell. The addition of further information in the areas of actual numerical data would be advantageous in developing a fuller process control program.

The existing shell could also be applied to other research in the Environmental Engineering Group at U.B.C. such as:

- o municipal waste landfill siting requirements
- o toxic waste treatment option determination
- o lab-scale process controllers using personal computers
- o biological phosphorus removal process control
- o biological phosphorus removal process design.

In the area of teaching (specifically with regards to treatment plant operations), these intelligent systems could educate potential plant operators and environmental engineers in the fundamentals of treatment plant operation and process control by demonstration and interactive displays. The base of knowledge involving biological phosphorus removal could also be developed using expert systems. It would be an ideal area to develop both controllers and design systems utilizing pilot plant facilities. Other research, such as landfill siting, impact assessment and monitoring, could easily be adapted and used in expert systems.

Chapter 9.0 Endnotes

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Chapter 10.0 Appendix 1 - WASTES Knowledge Base File Listing

10.1.1 LIFT.KB

```
%   LIFT PUMPS

rule 'lift pumps'
    if print
$^15 ^r5|
Raw sewage lift pump interactive unit operation diagnosis.$
   and (    ('ask lift' is 'gravity feed from sewers'
             and print
$^15 ^r5|
Gravity feed into treatment facility - no lift pumps.$
             and succeed)
         or ('ask lift' is 'centrifugal pumps'
             and 'ask units' is A
             and 'ask pump flow' is B
             and 'lift 2'
             and succeed)
         or ('ask lift' is 'screw pumps'
             and 'ask units' is A
             and 'ask pump flow' is B
             and 'lift 3'
             and succeed)).

rule 'lift 2'
    if (    ('work pump' is true
             and print
$^15 ^r5|
Lift pump may not be operating due to:|
a) Blown breaker, therefore reset.|
b) Defective controller in wet well.|
c) Defective motor or drive assembly.|
If pump is still inoperative, use back-up unit(s).|^p$)
         or succeed)
   and (    ('noisy pump' is true
             and print
$^15 ^r5|
A noisy centrifugal pump may be due to:|
a) Cavitation.················e) Poor lubrication.|
b) Incomplete priming.·······f) Worn bearings or impellers.|
c) Clogged intake bell.······g) Poor foundation and vibration|
d) Incomplete submergence.|^p$)
         or succeed)
   and (    ('reduced pump' is true
             and print
$^15 ^r5|
Reduced discharge from a centrifugal pump may be due to:|
a) Air cavitation.···········f) Too high suction lift.|
b) Clogged impeller.·········g) Clogged piping.|
c) Too low motor speed.······h) Air leaks in suction line.|
```

```
d) Too high discharge head.••i) Partially closed valving.|
e) Worn or improper impellers.|^p$)
          or succeed)
   and print
$^15 ^r5|
Maintain pumps and drive units and rotate on-line and back-up
units for
uniform wear.||
Centrifugal raw sewage lift pumps functioning properly.$.

rule 'lift 3'
    if (    ('work pump' is true
             and print
$^15 ^r5|
Lift pump may not be operating due to:|
a) Blown breaker, therefore reset.|
b) Defective controller in wet well.|
c) Defective motor or drive assembly.|
If pump is still inoperative, use back-up unit(s).|^p$)
          or succeed)
   and (    ('reduced pump' is true
             and print
$^15 ^r5|
Reduced discharge from a screw pump may be due to:|
a) Poor seal between screw and casing due to wear or improper|
•••installation.|
b) Use of a non-covered casing with more splashing and less
volume|
•••per revolution than an enclosed screw pump.|^p$)
          or succeed)
   and (    ('noisy pump' is true
             and print
$^15 ^r5|
Noisy screw pumps may be due to:|
a) Grit and rocks caught between the screw and the casing.|
b) Worn or poorly lubricated bearings.^p$)
          or succeed)
   and print
$^15 ^r5|
Screw lift pumps can pass most solids found in raw wastewater
before screening
and grit removal but wet well should have a grit trap and clean-
out for large solids.||
Raw sewage screw lift pumps functioning properly.^p$.

'ask lift' ask
$^15 ^r5|
How is the wastewater lifted to the head of the facility?$
         alt ('gravity feed from sewers',
              'screw pumps',
              'centrifugal pumps')
         expl ($Selecting gravity feed assumes there are no lift
               pumps installed in the facility.$).
```

```
'ask units' ask
$^15 ^r5|
How many pumps are installed? (on-line and back-up)$.

'ask pump flow' ask
$^15 ^r5|.
What percent of the design peak flow is serviced by one pump?|
i.e. 4 pumps @ 30% = 120% peak design flow.$.

'noisy pump' ask
$^15 ^r5|
Are any of the pumps making an unknown noise or sound?$
         alt yn.

'reduced pump' ask
$^15 ^r5|
Are any of the pumps operating with a reduced discharge?$
         alt yn.

'work pump' ask
$^15 ^r5|
Are any of the pumps not working?$
         alt yn.
```

10.1.2 RACKS.KB

```
%   INFLUENT CHANNELS, RACKS, AND SHREDDERS

rule 'solve racks and shredders'
    if print
$^15 ^r5|
Preliminary treatment interactive unit operation diagnosis|$
  and ('# of ic' is A
       and A >= 1
       and (    ('type rack' is 'fixed bar'
                 and (    ('shredder' is true
                           and '# of shred' is B)
                       or succeed)
                 and 'fixed rack 1'
                 and 'fixed rack 2'
                 and 'shredder 1'
                 and succeed)
            or ('type rack' is 'moving or chain'
                 and 'moving rack 1'
                 and succeed))
       and succeed)
    or (print
$^15 ^r5|
There is no preliminary treatment installed in the current
plant.|$
        and succeed).

rule 'fixed rack 1'
    if ('ask racks' is false
        and print
$^15 ^r5|
Debris removal from racks and screens is O.K.|$)
    or (print
$^15 ^r5|
Increase the frequency of cleaning the bar racks by:|
a) If cleaned manually, get staff to clean and check the racks|
···more frequently.|
b) If cleaned mechanically, reduce the timer duration on the|
···raking mechanism.|^p$).

rule 'fixed rack 2'
    if ('dual racks' is false
        and print
$^15 ^r5|
Insure that screening are removed daily to prevent the build-up
of
obnoxious odours, flies, and insects.|
If debris suddenly accumulates, check upstream sources and storm
sewer connections, if plant receives combined flows.|^p$)
    or (print
$^15 ^r5|
Consider installing an in-line dual rack and screen system|
- initial coarse bar rack: 20 to 100 mm clear spacing.|
```

```
- finer screen downstream: 2 to 6 mm clear spacing.|
Both angled 30 to 40 degrees into the flow.|
This system will perform better and prevent clogging of
pumps and other equipment than a single rack system.||
Insure that screening are removed daily to prevent the build-up
of obnoxious odours, flies, and insects.|
If debris suddenly accumulates, check upstream sources and storm
sewer connections, if plant receives combined flows.|^p$).

rule 'shredder 1'
    if ('shredder' is false
        and (    ('check solids' is true
                  and print
$^l ^r|
Install shredder(s) for disposal of excessive solids collected by
the screen installed in the plant.|
Insure that the coarse bar rack is installed upstream of the
shredder(s) to prevent damage by logs and heavy debris.|^p$)
              or ('shredder 4')))
    or 'shredder 2'.

rule 'shredder 2'
    if ('ask shredder' is false
        and 'shredder 3')
    or ('ask shredder' is true
        and 'shredder 4').

rule 'shredder 3'
    if ('reset rack 1' is false
        and print
$^15 ^r5|
a) Bypass non-functioning shredder to other channel rack.|
b) Remove non-functioning shredder for full servicing.|
c) Manually rake the screens or racks to remove the solids
accumulated.|^p$
        and 'shredder 4')
    or (print
$^15 ^r5|
The shredder is operating, checking solids.|$
        and 'shredder 4').

rule 'shredder 4'
    if ('ask racks' is false
        and print
$^15 ^r5|
No solids build-up on racks recorded.||
The preliminary unit operations in the influent channel(s) are
functioning
properly.|^p$)
    or (    ('shredder' is true
             and (    ('coarse' is false
                       and print
$^15 ^r5|
Check the shredder blades and replace worn and/or broken teeth to
```

```
insure solids are shredded and do not collect on rack(s).|^p$)
                   or succeed))
          or print
$^15 ^r5|
Solids build-up on racks recorded.||
The preliminary unit operations in the influent channel(s) are
functioning
properly.|^p$).


rule 'moving rack 1'
    if ('ask attached' is false
        and '# of ic' is A
        and print
$·····There are $,A,$ influent channels with moving racks
installed.|
^tBypass rack and repair worn or broken link on screen
chain.|^p$)
    or 'moving rack 2'.

rule 'moving rack 2'
    if ('ask roll' is true
        and print
$^15 ^r5|
Insure that screening are removed daily to prevent the build-up
of obnoxious odours, flies, and insects.|
If debris suddenly accumulates, check upstream sources and storm
sewer connections, if plant receives combined flows.||
The preliminary unit operations in the influent channel(s) are
functioning
properly.|^p$)
    or ('ask roll' is false
        and (    ('reset rack 2' is false
                  and print
$^15 ^r5|
If the unit was jammed and did not reset you might have damaged
the motor
and/or drive gear assembly.|
Remove it for repair and bypass to other rack(s).|^p$)
              or ('reset rack 2'is true
                  and print
$^15 ^r5|
Insure that screening are removed daily to prevent the build-up
of obnoxious odours, flies, and insects.|
If debris suddenly accumulates, check upstream sources and storm
sewer connections, if plant receives combined flows.||
The preliminary unit operations in the influent channel(s) are
functioning
properly.|^p$))).

'shredder' ask
$^15 ^r5|
Are there shredding devices like a comminutors or barmunitors
installed in
```

```
the influent channels?$
          alt yn.

'ask shredder' ask
$^15 ^r5|
Are the installed shredding device(s) operating?$
          alt yn.

'type rack' ask
$^15 ^r5|
What type of racks or screens are installed in the plant?$
          alt ('fixed bar',
               'moving or chain').

'ask attached' ask
$^15 ^r5|
Is the chain rack attached to the drive sprocket at the top of
the rack?$
          alt yn.

'ask roll' ask
$^15 ^r5|
Is the chain rack revolving and removing debris?$
          alt yn.

'ask racks' ask
$^15 ^r5|
Are the racks or screens clogged with debris?$
          alt yn.

'dual racks' ask
$^15 ^r5|
Do you have a single bar rack or screen installed in the plant?$
          alt yn.

'check solids' ask
$^15 ^r5|
Are excessive solids being collected by the racks and screens
without a comminutor?$
          alt yn.

'reset rack 1' ask
$^15 ^r5|
Check: a) Debris jams in the shredder blades|
·······b) Failure of the motor or reducer gears|
·······c) Reset of the power breaker|
Does the unit work now?$
          alt yn.

'reset rack 2' ask
$^15 ^r5|
Check: a) Debris jams in the chain|
·······b) Failure of the motor or reducer gears|
·······c) Reset of the power breaker|
```

```
Does the unit work now?$
         alt yn.

'coarse' ask
$^l5 ^r5|
Are the solids collected on the rack being ground up and not
collecting?$
         alt yn.
```

10.1.3 GRIT.KB

```
%   GRIT TANKS

rule 'solve grit tanks'
    if ('grit a' is A
        and 'grit b' is B
        and A >= 1
        and B >= 1
        and print
$^15 ^r5|
Grit removal interactive unit operation diagnosis.$
        and 'solve grit 1a'
        and 'solve grit 1b')
    or print
$^15 ^r5|
There are no grit tanks installed in the current plant
configuration.$.

rule 'solve grit 1a'
    if ('grit removal' is false
        and (    ('reset grit' is false
                  and print
$^15 ^r5|
If the grit collection unit was jammed and did not reset you
might have
damaged the motor and /or drive gear assembly.$
                  and (    ('grit a' is A
                             and 'grit b' is B
                             and A > B
                             and print
$^15 ^r5|
Bypass to other grit tank(s) while present tank repaired.$)
                             or succeed))
              or ('reset grit' is true
                  and print
$^15 ^r5|
Now that the grit tank is working.$
                  and succeed))
              or succeed).

rule 'solve grit 1b'
    if 'solve grit 2'
    or 'solve grit 3'.

rule 'solve grit 2'
    if 'ask grit type' is 'velocity settling trough'
   and (    ('stone' is false
             and (    ('sandy pipes' is true
                       and print
$^15 ^r5|
a) Raise outlet weir to provide longer retention.|
b) Increase scraper speed and grit washer auger speed|
···or decrease timer interval on mechanical collector to remove|
```

```
•••amounts of collected grit in chambers.|
c) Provide baffles to increase detention time in tank.||
Sedimentation grit tank operation functioning properly.|^p$)
                   or ('sandy pipes' is false
                       and print
$^l5 ^r5|
a) Remove clog from pipe or auger.|
b) Fix scraper for better collection of grit.|
Then:|
a) Raise outlet weir to provide longer retention.|
b) Increase scraper speed and grit washer auger speed|
•••or decrease timer interval on mechanical collector to remove|
•••excessive amounts of collected grit in chambers.|
c) Provide baffles to increase detention time in tank.||
Sedimentation grit tank operation functioning properly.|^p$))
         or ('stone' is true
             and print
$^l5 ^r5|
a) Insure that collected grit is removed daily to prevent the
•••build-up of obnoxious odours, flies, and insects.|
b) If grit suddenly accumulates, check upstream sources and storm
•••sewer connections, if plant receives combined flows.||
Sedimentation grit tank operation functioning properly.^p$))).

rule 'solve grit 3'
    if 'ask grit type' is 'aerated chamber'
   and (    ('stone' is false
             and (    ('sandy pipes' is false
                       and print
$^l5 ^r5|
a) Reduce air supply to aerated chamber to increase detention
•••time and increase removal of grit.|
b) Increase scraper speed and grit washer auger speed or
•••decrease timer interval on mechanical collector to remove
•••excessive amounts of collected grit in chambers.|
c) Provide baffles to increase detention time in tank.||
Aerated grit tank operation functioning properly.^p$)
                   or ('sandy pipes' is true
                       and print
$^l5 ^r5|
a) Remove clog from pipe or collection auger.|
b) Fix clogged aerators.|
Then:|
a) Reduce air supply to aerated chamber to increase detention
•••time and increase removal of grit.|
b) Increase scraper speed and grit washer auger speed or
•••decrease timer interval on mechanical collector to remove
•••excessive amounts of collected grit in chambers.|
c) Provide baffles to increase detention time in tank.||
Aerated grit tank operation functioning properly.^p$))
         or ('stone' is true
             and print
$^l5 ^r5|
a) Insure that collected grit is removed daily to prevent the
```

```
•••build-up of obnoxious odours, flies, and insects.|
b) If grit suddenly accumulates, check upstream sources and storm
•••sewer connections, if plant receives combined flows.||
Aerated grit tank operation functioning properly.^p$))).

'reset grit' ask
$^l5 ^r5|
Check:|
a) Debris jams in the unit|
b) Failure of the motor or reducer gears|
c) Reset of the power breaker|
Does the unit work now?$
         alt yn.

'grit removal' ask
$^l5 ^r5|
Is the grit tank operating.|
Is aeration occurring or is the mechanical scraper operating?$
         alt yn.

'stone' ask
$^l5 ^r5|
Is the grit being sufficiently removed from the raw sewage flow?$
         alt yn.

'sandy pipes' ask
$^l5 ^r5|
Is the removal auger clogged or is the mechanical scraper
functioning?$
         alt yn.
```

10.1.4 MICRO.KB

```
%   MICROSCREENS

rule 'solve microscreens'
    if ('micro a' is A
        and 'micro b' is B
        and A >= 1
        and B >= 1
        and print
$^15 ^r5|
Microscreen interactive unit operation diagnosis.$
        and 'microscreen 1'
        and 'microscreen 4')
    or print
$^15 ^r5|
There are no microscreens installed in the current facility
configuration.$.

rule 'microscreen 1'
    if ('ask microscreen' is true
        and (    ('type rotate' is true
                  and print
$^15 ^r5|
Check belt drive on microscreen for slippage.$)
              or ('type rotate' is false
                  and (    ('screen solids' is 'build-up of
                            solids' and print
$^15 ^r5|
To remove build-up of solids:|
a) Increase drum speed slightly, note that large increases in|
•••drum speed drastically reduce solids removal efficiency.|
b) Add another unit if capacity of unit is overloaded.|^p$
                            and succeed)
                        or ('screen solids' is 'normal removal of
                            solids' and succeed)
                        or ('screen solids' is 'loss of solids'
                            and 'microscreen 2')))))
    or ('microscreen 3'
        and succeed).

rule 'microscreen 2'
    if 'microscreen 2a'
    or 'microscreen 2b'
    or 'microscreen 2c'
    or (print
$^15 ^r5|
Unknown solids, check for leakage.$
         and succeed).


rule 'solve microscreen 2a'
    if 'check screen' is true
   and 'check seals' is false
```

```
   and print
$^l5 ^r5|
Repair screen and fix skirt seals to prevent loss of solids
through|
and around or under microscreen.|^p$
   and (    ('micro a' is A
             and 'micro b' is B
             and B > A
             and print
$^l5 ^r5|
a) Bypass microscreen to remove and repair screen and seals.|
b) Use other on-line unit(s).|^p$)
          or succeed).

rule 'microscreen 2b'
    if 'check screen' is false
   and 'check seals' is false
   and print
$^l5 ^r5|
Repair skirt seals on unit.|
Bypassing of microscreen is probably unnecessary.|^p$.

rule 'microscreen 2c'
    if 'check screen' is true
   and 'check seals' is true
   and print
$^l5 ^r5|
Repair screen to prevent loss of solids through microscreen
unit.|^p$
   and (    ('micro a' is A
             and 'micro b' is B
             and B > A
             and print
$^l5 ^r5|
a) Bypass microscreen to remove and repair screen.|
b) Use other on-line unit(s).|^p$)
          or succeed).

rule 'microscreen 3'
    if print
$^l5 ^r5|
Check the microscreen for:|
a) broken drive belt or chain|
b) burned out motor or reducing gear box|
c) bearing failure in unit.|^p$
   and (    ('micro a' is A
             and 'micro b' is B
             and B > A
             and print
$^l5 ^r5|
Bypass non-functioning microscreen and use other on-line
unit(s).|^p$)
          or succeed)
   and succeed.
```

```
rule 'microscreen 4'
    if ('slime' is true
        and print
$^l5 ^r5|
Install spray washers or scrapers to remove slime accumulating on
screen surface.|Slime could clog microscreen and lead to a build-
up of solids and prevent proper flow through the screen.|^p$)
    or print
$^l5 ^r5|
Microscreen(s) unit operation functioning properly.$.

'ask microscreen' ask
$^l5 ^r5|
Is the microscreen drum rotating?$
     alt yn.

'type rotate' ask
$^l5 ^r5|
Is the drum rotating erratically?$
     alt yn.

'screen solids' ask
$^l5 ^r5|
What is the condition of the solids at the unit?$
     alt ('loss of solids',
          'build-up of solids',
          'normal removal of solids').

'check screen' ask
$^l5 ^r5|
Are there any splits or holes in the drum screen?$
     alt yn.

'check seals' ask
$^l5 ^r5|
Do the seals appear intact with no leakage of solids around or
under the microscreen drum?$
     alt yn.

'slime' ask
$^l5 ^r5|
Is there a build up of slime on the screen?$
     alt yn.
```

10.1.5 CLAR.KB

```
%   PRIMARY CLARIFIERS

rule 'solve primary clarifiers'
    if ('pc a' is A
   and A >= 1
   and 'pc b' is B
   and (    ('type of pc' is 'circular'
             and print
$^15 ^r5|
Circular primary clarifier interactive unit operation diagnosis.$
             and 'primary scum'
             and 'scraper c'
             and 'primary solids'
             and 'balance primary'
             and print
$^15 ^r5|
Circular primary clarifier(s) functioning properly.$)
         or ('type of pc' is 'rectangular'
             and print
$^15 ^r5|
Rectangular primary clarifier interactive unit operation
diagnosis.$
             and 'primary scum'
             and 'scraper r'
             and 'primary solids'
             and 'balance primary'
             and print
$^15 ^r5|
Rectangular primary clarifier(s) functioning properly.$)))
         or print
$^15 ^r5|
There are no primary clarifiers installed in the plant.$.

rule 'primary scum'
    if  ('ask scum' is true
         and (     (    ('super' is true
                         and print
$^15 ^r5|
Check digester supernatant levels for possible withdrawal of
floating scum
layer.$)
                    or succeed)
               and (    ('float' is true
                         and print
$^15 ^r5|
Check the preliminary unit operations to ensure that debris is
collected
and/or is being shredded effectively.$
                         and load $racks.kb$
                         and 'solve racks and shredders')
                    or succeed)
               and (    ('weeds' is true
```

```
                          and print
$^15 ^r5|
Pull weeds and clean weirs out, especially in summer.$)
                     or succeed)
               and (    ('weir' is true
                          and print
$^15 ^r5|
Repair:|
a) Scum draw-off weirs and skimmer.|
b) Scum collection box and scrapers.|
To collect and remove the floating scum and grease on the primary
clarifier(s).|^p$)
                     or succeed)
               and print
$^15 ^r5|
The scum may also be floating sludge indicating septic conditions
in the
clarifier.$))
    or print
$^15 ^r5|
No loss of scum from primary clarifier(s).$
       and succeed.

rule 'scraper c'
    if  ('ask rotate' is 'rotating'
         and print
$^15 ^r5|
Scraper should be rotating at 0.02 to 0.06 RPM for proper
operation.|^p$
         and succeed)
     or ('ask rotate' is 'not rotating'
         and (    ('reset scraper 1' is true
                   and succeed)
               or ('reset scraper 1' is false
                   and print
$^15 ^r5|
Possible solutions are:|
a) Bypass primary clarifier to other unit(s) and repair scraper
arm.
b) Continue using clarifier, but pump dilute primary sludge to|
•••sludge handling facilities until scraper arm is repaired and|
•••prepare for some solids loss into aeration tank(s).|^p$
                    and succeed)))
    or ('ask rotate' is 'rotating but erratically'
        and print
$^15 ^r5|
Scraper should be rotating at 0.02 to 0.06 RPM for proper
operation.
Check for:|
a) Bent or broken sludge plow on scraper arm.|
b) Build-up of grit and sediment due to insufficient grit
•••removal. Check the grit tank(s) operation.|
c) Slippage of drive belts on collection arm.|
d) Build-up of collected sludge.|^p$
```

```
        and succeed).

rule 'scraper r'
    if  ('ask travel' is 'moving'
         and print
$^15 ^r5|
Chain scraper or travelling bridge should be moving at 0.3 - 1.0
meters per
minute for proper operation.|^p$
         and succeed)
     or ('ask travel' is 'not moving'
         and (    ('reset scraper 2' is true
                   and succeed)
               or ('reset scraper 2' is false
                   and print
$^15 ^r5|
Possible solutions are:|
a) Bypass primary clarifier to other unit(s) and repair scraper
arm.|
b) Continue using clarifier, but pump dilute primary sludge to|
···sludge handling facilities until scraper arm is repaired.|
···and prepare for some loss of solids into aeration tank(s).|^p$
                   and succeed)))
    or ('ask travel' is 'moving but erratically'
        and print
$^15 ^r5|
Chain scraper or travelling bridge should be moving at 0.3 - 1.0
meters per
minute for proper operation.|
Check for:|
a) Broken flight or worn sprockets.|
b) Build-up of grit and sediment due to insufficient grit
···removal.Check the grit tank(s) operation.|
c) Slippage of drive belts on drive sprockets.|
d) Build-up of collected sludge slowing scraper boards.|^p$
        and succeed).

rule 'primary solids'
    if (    ('ESS type 1' is A
             and A is 'no solids in effluent'
             and print
$^15 ^r5|
No loss of solids from primary clarifier(s).$
             and succeed)
         or A is true
         or print
$^15 ^r5|
Cannot determine type of solids loss from primary clarifier.|
Check conditions and query system again to try to find a
cause.|^p$).

rule 'loss of solids throughout the area'
    if ('peak pflow' is A
        and 'current pflow' is B
```

```
        and A < B
        and print
$^15 ^r5|
Hydraulic overloading of clarifier(s).|
Plant design flow = $,A,$ m3/second.|
Present plant flow = $,B,$ m3/second.|
Possible solutions:|
a) Bring back-up clarifier(s) on-line to increase _hrt and
decrease|
···weir loading rates allowing solids to settle.|
b) Increase aeration to assimilate heavier organic loading on|
···the activated sludge biomass.|^p$
        and succeed)
    or ('primary wastage'
        and succeed).

rule 'loss of solids in some areas'
    if ('cover' is false
        and print
$^15 ^r5|
Wind-induced currents over uncovered clarifier(s) could be
creating currents
carrying solids to surface.|
Possible solutions:|
a) Provide wind breaks around clarifier(s).|
b) Cover clarifier(s).|
c) Increase aeration to assimilate heavier organic loading on|
···the activated sludge biomass.|^p$
        and succeed)
    or ('ask air temp' is X
        and 'ask ww temp' is Y
        and X < Y
        and print
$^15 ^r5|
Differences between air and wastewater temperatures could cause
wastewater to
rise causing loss of solids.|
Wastewater temperature = $,B,$ °C.|
Present air temperature = $,X,$ °C.|
Possible solutions:|
a) Check inlet diffusers to insure influent is distributed
evenly|
···in clarifier(s).|
b) Provide sufficient baffling to distribute flow.|
c) Increase aeration to assimilate heavier organic loading on|
···the activated sludge biomass.|^p$
        and succeed)
    or ('balance primary'
        and succeed)
    or ((    ('ask rotate' is 'rotating')
          or ('ask travel' is 'moving'))
        and print
$^15 ^r5|
Solids loss due to probable effluent weir imbalance which causes
```

```
solids to
surge and billow in areas of increased flow.|
Solutions:|
a) Use surveyor's level to sight and level effluent weirs.|
b) Increase aeration to assimilate heavier organic loading on|
•••the activated sludge biomass.|^p$
        and succeed)
    or ((    ('ask rotate' is 'rotating but erratically')
          or ('ask travel' is 'moving but erratically'))
        and print
$^15 ^r5|
Solids overloading of clarifier(s) that is jamming sludge removal
scrapers.|
Sludge removal scrapers are moving erratically.|^p$
        and 'primary wastage'
        and succeed)
    or ('loss of solids throughout the area'
        and succeed).

rule 'rising clumps and mats of solids'
    if 'describe smell' is true
   and print
$^15 ^r5|
Clarifier solids condition indicates that solids losses are due
to rising sludge caused by anaerobic or septic conditions.|
Solids are rising in clumps and mats and odour indicates septic
conditions.|^p$
   and 'primary wastage'
   and succeed.

rule 'primary wastage'
    if (    ('wspumps' is true
             and print
$^15 ^r5|
Wastage operating but insufficient removal rates.|
Possible solutions:|
a) Increase wastage from the clarifier.|
b) Increase aeration in activated sludge unit to assimilate
•••higher organic loading.|^p$
             and succeed)
         or (    ('check pump' is true
                  and print
$^15 ^r5|
Wastage operating but insufficient removal rates.|
Possible solutions:|
a) Increase wastage from the clarifier.|
b) Increase aeration in activated sludge unit to assimilate
•••higher organic loading.|^p$
                  and succeed)
              or ('check pump' is false
                  and print
$^15 ^r5|
Sludge wastage system failure.|
Failed sludge wastage pumps, clogged wastage piping or failed
```

```
sludge plows
or scrapers.|
Possible solutions:|
a) Bypass clarifier with clogged sludge withdrawal pipes or
pumps|
b) Use back-up pumps if only sludge pump failure.|
c) Repair pumps or unplug wastage pipes.|
d) Increase aeration to assimilate heavier organic loading on|
•••the activated sludge biomass.|^p$
                  and succeed))).

rule 'balance primary'
    if (    ('pc b' is A
             and (    (A >= 2
                       and succeed)
                   or (print
$^15 ^r5|
Only one clarifier on-line or installed.|$
                       and fail))
             and 'ask balance' is false
             and print
$^15 ^r5|
Unbalanced flows to on-line clarifiers can cause surges of
solids|
Try to balance flows to the operational clarifiers by:|
a) Checking wastage rates and durations for the different wastage
•••pumps.|
b) Balancing inflows between the on-line clarifiers by
•••throttling flows at splitter box and increasing head losses to
•••reduce the effects of surges in the influent channels.|^p$
             and succeed)
         or (print
$^15 ^r5|
Flows to on-line clarifiers equal.|
No possible solids losses due to surging.|^p$)).

'ask scum' ask
$^15 ^r5|
Is there a build-up of collected scum on the clarifier and/or is
it overloading into the secondary system?$
         alt yn.

'ask windy' ask
$^15 ^r5|
Are there winds in excess of 15 km/h at the plant site?$
         alt yn
         expl ($Wind could create currents in the clarifier(s)
               strong enough to carry solids up and over the
               weirs.$).

'ask air temp' ask
$^15 ^r5|
What is the current air temperature outside the facility? (°C)$
         expl ($I would like to compare the wastewater
```

```
               temperature with the air temperature so see if
               temperature currents could be causing a loss
               of solids.$).

'ask ww temp' ask
$^15 ^r5|
What is the current wastewater temperature entering the
clarifier(s)? (°C)$
         expl ($I would like to compare the wastewater
               temperature with the air temperature so see if
               temperature currents could be causing a loss
               of solids.$).

'ask balance' ask
$^15 ^r5|
Are the wastewater flows to the on-line clarifiers approximately
equal?$
         alt yn.

'wspumps' ask
$^15 ^r5|
Is sludge wastage occurring from the primary clarifier(s)?$
         alt yn.

'check pump' ask
$^15 ^r5|
Check the sludge wastage pumps.|
Make sure all pumps are operational.|
Check the pumps for debris jams.|
Check and reset pump breakers.|
Check sludge wastage pipes for clogs or restrictions caused by
debris or accumulated grit.|
Is the wastage system O.K.?$
         alt yn.

'ESS type 1' ask
$^15 ^r5|
What is the condition of the solids at the clarifier overflow
weir(s)?$
         alt ('loss of solids throughout the area',
              'loss of solids in some areas',
              'rising clumps and mats of solids',
              'no solids in effluent')
         expl ($The condition of the solids in the primary
               clarifier(s) helps the system determine corrective
               actions.$).


'cover' ask
$^15 ^r5|
Is there a cover over the clarifier or some sort of wind buffer
protecting the clarifier?$
         alt yn.
```

```
'ask travel' ask
$^l5 ^r5|
What is the chain scraper or travelling bridge scraper doing?$
         alt ('moving',
              'not moving',
              'moving but erratically')
         expl ($The action of the scraper helps the system
               determine what is wrong in the clarifier(s) and
               the proper corrective actions.$).

'ask rotate' ask
$^l5 ^r5|
What is the circular sludge collection scraper arm doing?$
         alt ('rotating',
              'not rotating',
              'rotating but erratically')
         expl ($The action of the scraper helps the system
               determine what is wrong in the clarifier(s) and
               the proper corrective actions.$).

'super' ask
$^l5 ^r5|
Is there anaerobic digester supernatant pumped to the head of the
plant above the primary clarifier?$
         alt yn.

'float' ask
$^l5 ^r5|
Does the scum have a lot of paper, rags, and other debris?$
         alt yn.

'weeds' ask
[nl,$   Are there weeds or algal build-ups in the scum collection
weirs?$]
        alt yn.

'weir' ask
$^l5 ^r5|
Is there a blockage or problem with the scum removal mechanism
caused by collected grease or debris?$
         alt yn.

'reset scraper 1' ask
$^l5 ^r5|
Check:|
a) Debris jams in the bottom of the clarifier.|
b) Bent or broken plow.|
c) Failure of the motor or reducer gears.|
d) Reset of the power breaker.|
Does the unit work now?$
         alt yn.

'reset scraper 2' ask
$^l5 ^r5|
```

```
Check:|
a) Debris jams in the bottom of the clarifier.|
b) Broken flight.|
c) Failure of the motor or reducer gears|
d) Reset of the power breaker|
Does the unit work now?$
         alt yn.

'describe smell' ask
$^15 ^r5|
Is the odour over the surface like rotten eggs or sulfides?$
         alt yn
         expl ($The presence of sulfide-like odours is usually an
               indication of anaerobic or septic conditions in
               the clarifier(s).).
```

10.1.6 RBC.KB

```
rule 'solve rbc'
    if print
$^15 ^r5|
RBC units require little operator control and provide excellent
treatment, however RBCs can operate poorly if they are not
maintained properly and adjustments are not made for process
control. The following is a concise diagnosis of an RBC
system.|^p$
                and 'rbc 1'
                and 'rbc 2'.

rule 'rbc 1'
    if ('ask turn' is true
        and succeed)
    or (    (    ('broken shaft' is true
                  and print
$^15 ^r5|
Bypass broken RBC unit and repair or replace broken shaft.$)
               or succeed)
        and (    ('media' is true
                  and print
$^15 ^r5|
Bypass broken RBC unit and repair or replace media/disc
connection.$)
               or succeed)
        and print
$^15 ^r5|
Check for failures in the following:|
a) Drive and motor system.|
b) Check and lubricate all bearings.|
c) Check the power breaker and reset if thrown.|^p$
        and succeed).

rule 'rbc 2'
    if (    ('ask condition' is 'shaggy grey white'
             and (    ('high EBOD' is true
                        and print
$^15 ^r5|
Biofilm condition and effluent BOD indicate that RBC stage is
organically overloaded.|^p$
                        and 'rbc 3')
                  or (print
$^15 ^r5|
Condition could indicate overloading.|Check influent BOD and
effluent BOD over composited samples.|^p$
                        and 'rbc 4'))
         or ('ask condition' is 'grey brown slime'
             and print
$^15 ^r5|
Biofilm condition is normal for domestic wastewaters.|^p$
             and 'rbc 4')
         or ('ask condition' is 'excessive amount of sloughed
```

```
                                   solids'
             and (     ('ask rpm' is true
                        and print
$^15 ^r5|
Proper operation indicates: 1 < RPM < 2 , therefore adjust motor
and drive reducers for proper rotational speed.|^p$)
                    or succeed)
             and (     ('high EBOD' is true
                        and print
$^15 ^r5|
Biofilm sloughing condition and high effluent BODindicates that
RBC stage is organically overloaded.|^p$
                        and 'rbc 3')
                    or (print
$^15 ^r5|
Excessive sloughed solids could be indicating a toxic loading has
entered the plant.|Examine clarifier solids under microscope for
protozoa.|^p$
             and (     ('rotifer' is true
                        and print
$^15 ^r5|
Toxic loading most likely cause of solids loss and still present
in the plant wastewater.|Maintain operation and find upstream
source of contaminant.|^p$
                        and 'rbc 4')
                    or (print
$^15 ^r5|
Toxic loading most likely cause of solids loss and has probably
left the
system.|Maintain operation and find upstream source of
contaminant.|^p$)
                        and 'rbc 4'))))))).

rule 'rbc 3'
    if (     ('bypass' is true
              and print
$^15 ^r5|
Bypassing flow around overloaded stage will reduce organic
loading rate and allow stage to recover.|
a) Monitor composited influent and effluent BOD levels.|
b) Expect some amount of sloughed solids as stage recovers.|^p$
              and 'rbc 4')
          or print
$^15 ^r5|
Bypass flow is not available, therefore the following could also
be used to reduce the organic loading:|
a) Install supplemental aeration to raise DO in bulk liquid and |
•••increase organic removal rates.|
b) Install baffling to reduce the hydraulic loading, hence the|
•••organic loading on the biofilm.|
c) Increase the rotational speed of the RBC.|
d) Increase capacity of the plant by installing more RBC units|
•••or higher density media.|^p$
            and 'rbc 4').
```

```
rule 'rbc 4'
    if (    ('ask condition' is 'excessive amount of sloughed
solids'
             and print
$^15 ^r5|
Sloughing solids from RBC unit, checking condition of solids in
final clarifier.$
             and load $CLAR.KB$
             and 'primary solids')
         or succeed)
   and (    ('ask nitrify film' is true
             and print
$^15 ^r5|
Nitrifying conditions in RBC plant are typified by the presence
of thin reddish biofilm on the fourth and last stage.|High
density media should be used in third and fourth stages to insure
full nitrification of influent.|^p$)
         or succeed)
   and print
$^15 ^r5|
As part of regular maintenance:|
a) Check the drive and motor system.|
b) Check and lubricate all bearings.|
c) Inspect all RBC shafts and shaft/media connections.|
•••(Area of highest failure in all RBC plants.)|
d) Check or install adequate venting to prevent corrosion.^P$
   and succeed.

'ask nitrify film' ask
$^15 ^r5|
Is the RBC plant designed to nitrify?$
         alt yn.

'bypass' ask
$^15 ^r5|
Can you bypass part of the flow to another stage to reduce the
organic loading
on the overloaded RBC stage?$
         alt yn.

'ask rpm' ask
$^15 ^r5|
Is the rotational speed of the RBC shaft > 2 rpm or < 1 rpm?$
         alt yn.

'broken shaft' ask
$^15 ^r5|
Does the non-rotating RBC have a broken shaft?$
         alt yn.

'media' ask
$^15 ^r5|
Has the media broken away from the RBC shaft?$
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```
         alt yn.

'ask turn' ask
$^l5 ^r5|
Are the all RBC media and shafts turning?$
         alt yn.

'ask condition' ask
$^l5 ^r5|
What best describes the physical condition of the RBC biofilm?$
         alt ('shaggy grey white',
              'grey brown slime',
              'excessive amount of sloughed solids')
         expl ($WASTE uses the visual condition of the biofilm as
               an indicator of the organic loading and of
               possible toxic loading into the RBC unit.$).
```

10.1.7 FLOAT.KB

```
%   FLOATABLES

rule 'solve foam or scum'
    if 'ask what' is A
   and A is true.

rule 'scum on the primary clarifier(s)'
    if load $CLAR.KB$
   and 'primary scum'.

rule 'foam on the aeration tank(s)'
    if (    ('type of foam' is 'white billowing foam'
             and print
$^15 ^r5|
White billowing foam can be present:|
a) During plant start-up (first two weeks)|
b) If there has been a toxic loading to plant|
c) If the process is organically overloaded|^p$
             and 'loading 1'
             and 'waste solids'
             and succeed)
         or ('type of foam' is 'light tan or brown foam'
             and print
$^15 ^r5|
This foam is typical of normally loaded activated sludge aeration
tank(s).| If foam builds up readily, install effluent sprayers to
reduce volume.|^p$
         or ('type of foam' is 'dark brown foam'
             and print
$^15 ^r5|
This type of foam is typical of underloaded or extended aeration-
type activated sludge aeration tanks.|If you are not operating in
extended aeration mode, check your wastage requirements and
increase wasting.|^p$)).

rule 'foam or scum on the secondary clarifier(s)'
    if 'second foam or scum'.

rule 'second foam or scum'
    if ('what foam' is 'scum, solids and other floating debris'
        and print
$^15 ^r5|
Checking possible sources of scum on the secondary clarifier(s).$
        and (    ('foam loss' is true
                  and print
$^15 ^r5|
One possible source of scum is from aeration basin foam.|
Install baffles of a weir to keep foam out of effluent channels
in the aeration tank(s).|^p$)
              or succeed)
        and (    (print
$^15 ^r5|
```

```
One possible source of scum is from the primary clarifier(s) or
the preliminary operations of screening and shredding.|^p$
                   and load $CLAR.KB$
                   and 'primary scum')
               or succeed)
         and (     ('clumps' is true
                   and print
$^15 ^r5|
One possible source of scum is from rising solids in the
secondary clarifier(s).|^p$)
               or succeed)
         and succeed)
     or ('what foam' is 'foam with no debris and little solids'
         and print
$^15 ^r5|
Possible source of scum is from aeration basin foam.|
Install baffles of a weir to keep foam out of effluent channels
in the aeration tank(s).|^p$
         and succeed).

'foam loss' ask
$^15 ^r5|Is foam coming through clarifier inlet weirs from the
aeration tank(s)?$
          alt yn.

'what foam' ask
$^15 ^r5|
What appears to be on the surface of the clarifier(s)?$
          alt ('scum, solids and other floating debris',
               'foam with no debris and little solids')
          expl ($Scum and other solids are usually paper, plastic
                products, grease and organics discharged in
                sewage.|Foam is usually the result of the build-up
                of foam from the aeration tank(s).$).

'ask what' ask
$^15 ^r5|
What appears to be the problem?$
          alt ('scum on the primary clarifier(s)',
               'foam on the aeration tank(s)',
               'foam or scum on the secondary clarifier(s)')
          expl ($WASTE would like to know where the problem is so
                it can suggest the proper corrective action.$).
```

10.1.8 ODOUR.KB

```
%   ODOURS

rule 'solve smell'
     if ('gas 1'
         or 'gas 2')
    and succeed.

rule 'gas 1'
    if (    ('area' is 'aeration tank(s)'
             and 'smell' is true
             and print
$^l5 ^r5|
That odour is an indication of low dissolved oxygen or DO in the
reactor and anaerobic conditions could exist.|^p$
             and 'check DO')
         or ('area' is 'anoxic reactor'
             and 'smell' is true
             and print
$^l5 ^r5|
Due to the anaerobic nature of anoxic reactors used to denitrify
the wastewater that is a common odour.|^p$)
         or ('area' is 'primary clarifier(s)'
             and 'smell' is true
             and print
$^l5 ^r5|
That odour indicates septic conditions.|
a) Check condition of primary clarifier solids.|
b) Check for septic wastewater from sewerage system.|
c) Check anaerobic digester supernatant if pumped to plant
•••headworks above primary clarifier(s).|
d) If odours persist, add pre-aeration to wet sump or influent|
•••channels to sweeten wastewater.|^p$)
         or ('area' is 'secondary clarifier(s)'
             and 'smell' is true
             and print
$^l5 ^5r|
That odour indicates septic conditions.|
a) Check condition of secondary clarifier solids.|
b) Check for septic conditions in reactor.|
c) If odours persist, add pre-aeration to wet sump or influent|
•••channels to sweeten wastewater.|^p$)).

rule 'gas 2'
    if ('area' is 'aeration tank(s)'
        and print
$^l5 ^r5|
That odour is typical of a properly operating activated sludge
basin with an adequate DO level.|^p$)
    or ('area' is 'primary clarifier(s)'
        and print
$^l5 ^r5|
That odour is normal and if the odour becomes acrid or like
```

```
sulfides there are septic conditions in the wastewater or
clarifier.|^p$)
    or ('area' is 'secondary clarifier(s)'
        and print
$^15 ^r5|
That odour is normal and if the odour becomes acrid or like
sulfides there are septic conditions in the wastewater or
clarifier.|^p$)
    or ('area' is 'anoxic reactor'
        and print
$^15 ^r5|
A well mixed reactor should have no odours associated with it as
long as the influent is not anaerobic or septic.|^p$).

'smell' ask
$^15 ^r5|
What does it smell like rotten eggs or sulfides?$
         alt yn
         expl ($The presence of that smell means that anaerobic
               or septic conditions exist in the area and
               operational corrections have to be made.$).

'area' ask
$^15 ^r5|
What area of the plant are the odours from?$
         alt ('aeration tank(s)',
              'anoxic reactor',
              'primary clarifier(s)',
              'secondary clarifier(s)')
         expl ($WASTES would like to know what area in the plant
               the odours are coming from so it can suggest
               corrective action if any.$).
```

10.1.9 TREAT.KB

```
%************ WASTE TREATMENT EXPERT SYSTEM ********************%
%                                                    %
%************************* GOAL *********************************%
%                                                    %
goal run.                                            %
%                                                    %
%************************* RULES ********************************%

rule 'run'
    if 'setup'
   and 'solve'.

rule 'solve'
    if ('ask user' is 'part'
     and 'unit' is A
     and A is true)
    or ('ask user' is 'system'
     and 'whole' is true).

'ask user' ask
$^15 ^r5|
Do you want to select a treatment problem or pick a selected unit
operation, or do you want to try the whole system ?$
      alt ('process or unit operation',
           'secondary activated sludge system')
      ralt ('part','system')
      expl ($WASTES is trying to determine whether you want to
             look at. Specific problem or unit operation, or|
             the activated sludge treatment system.$).

rule 'section'
     if 'unit' is 'A'
    and 'A' is true.

'unit' ask
$^15 ^r5|
Select a system or unit operation from the list and WASTES will
diagnose the problem and attempt to find a solution.$
      alt ('rack(s) and shredder(s)',
           'lift pump(s)',
           'grit tank(s)',
           'microscreen(s)',
           'primary clarifier(s)',
           'aeration tank(s)',
           'RBC(s)',
           'secondary clarifier(s)',
           'all unit operations')
      expl ($WASTES wants to know what operation or system you
            would like to diagnose or troubleshoot.|If you want
            to check all the unit operations installed in WASTES,
             choose #9.$).
```

```
rule 'rack(s) and shredder(s)'
    if load $racks.kb$
    and 'solve racks and shredders'.

rule 'lift pump(s)'
    if load $lift.kb$
   and 'lift pumps'.

rule 'grit tank(s)'
    if load $grit.kb$
   and 'solve grit tanks'.

rule 'microscreen(s)'
    if load $micro.kb$
   and 'solve microscreens'.

rule 'primary clarifier(s)'
    if load $clar.kb$
   and 'solve primary clarifiers'.

rule 'aeration tank(s)'
    if 'ask aeration' is A
   and A is true.

'ask aeration' ask
$^l5 ^r5|
What function of the aeration tank(s) would you like to look at
?$
      alt ('aeration and mixing system',
           'foaming problems',
           'DO levels in aeration tank(s)',
           'aeration odour',
           'activated sludge process control',
           'all aeration tank systems')
      expl ($WASTES would like to know what area of the aeration
             system you would like to look at.|If you want to
             look at the whole system, choose #6, all aeration
             tank systems.$).

rule 'aeration and mixing system'
    if 'solve aeration/mixing'.

rule 'foaming problems'
    if 'loading'.

rule 'DO levels in aeration tank(s)'
    if 'check DO'.

rule 'aeration odour'
    if load $odour.kb$
   and 'solve smell'.

rule 'activated sludge process control'
    if 'activated sludge'.
```

```
rule 'all aeration tank systems'
    if 'foaming problems'
   and 'aeration and mixing system'
   and 'activated sludge process control'.

rule 'RBC(s)'
    if load $RBC.kb$
   and 'solve rbc'.

rule 'secondary clarifier(s)'
    if 'secondary floc clarifiers'.

rule 'all unit operations'
    if 'rack(s) and shredder(s)'
   and 'lift pump(s)'
   and 'grit tank(s)'
   and 'microscreen(s)'
   and 'primary clarifier(s)'
   and 'aeration tank(s)'
   and 'RBC(s)'.

rule 'whole'
    if 'excess primary solids'
   and 'aeration and mixing system'
   and 'foam or scum problems'
   and 'odour'
   and 'activated sludge process control'.

rule 'excess primary solids'
     if load $clar.kb$
    and 'primary solids'
    and 'balance primary'.

rule 'foam or scum problems'
    if load $float.kb$
   and 'solve foam or scum'.

rule 'odour'
    if load $odour.kb$
   and 'solve smell'.

fail is false.
succeed is true.

'# of shred' ask
$^15 ^r5|
In how many influent channels are there shredding devices
installed ?$.

'# of ic' ask
$^tHow many influent channels enter the plant from the sewer
system ?$.
```

```
'average pflow' ask
$^l5 ^r5|
What is the average design flow of the treatment plant in m3/s
?$.

'peak pflow' ask
$^l5 ^r5|
What is the peak design flow of the treatment plant in m3/s ?$.

'current pflow' ask
$^l5 ^r5|
What is the current treatment plant flow in m3/s ?$.

'grit a' ask
$^l5 ^r5|
How many grit tank(s) are installed in the plant ?$.

'grit b' ask
$^l5 ^r5|
How many grit tank(s) are operating ?$.

'ask grit type' ask
$^l5 ^r5|
What type of grit tank(s) are installed in the plant ?$
      alt ('velocity settling trough',
           'aerated chamber')
      expl ($Different grit tanks have different problems.
             |Select the type of grit tanks installed in your
              facility.$).

'micro a' ask
$^l5 ^r5|
How many microscreen(s) are installed in the plant ?$.

'micro b' ask
$^l5 ^r5|
How many microscreen(s) are operating ?$.

'pc a' ask
$^l5 ^r5|
How many primary clarifier(s) are installed at the plant ?$.

'pc b' ask
$^l5 ^r5|
How many primary clarifier(s) are operating ?$.

'type of pc' ask
$^l5 ^r5|
What type of primary clarifier(s) are installed in the plant ?$
      alt ('circular',
           'rectangular')
      expl ($I think you know the difference between the two
             shapes !|Enter  the type you have installed at your
n            facility.$).
```

```
'sc a' ask
$^l5 ^r5|
How many secondary clarifiers are installed ?$.

'sc b' ask
$^l5 ^r5|
How many secondary clarifiers are operating ?$.

'average flow' ask
$^l5 ^r5|
What is the average design flow of the aeration tank(s) in m3/s
?$.

'peak flow' ask
$^l5 ^r5|
What is the peak design flow of the aeration tank(s) in m3/s ?$.

'current flow' ask
$^l5 ^r5|
What is the current plant flow in m3/s ?$.

%************************* SCREEN SET-UP *************************%

rule setup if print
$^l18|
                          Welcome to|
              ╔═════════════════════════════════════════╗
              ║                 WASTES                  ║
              ║   WAStewater Treatment Expert System    ║
              ║   (C) Barry Chilibeck   Version 3.0     ║
              ╚═════════════════════════════════════════╝
|
^l5 ^r5|
This program is intended to assist in the diagnosis and
correction of common problems encountered in the operation of
wastewater treatment facilities.  It should be used only as a
reference and guide.  The purpose of WASTES is to illustrate the
application of expert systems to the field of wastewater
treatment.||Completed as partial requirement for the degree of
Masters of Applied Science, Environmental Engineering, Department
of Civil Engineering, University of British Columbia, 1990, by
Barry Chilibeck.|
^p||||||||||||||||||||||||$.

%   ACTIVATED SLUDGE SYSTEM

rule 'activated sludge'
    if print
$^l5 ^r5|
In order to change the condition of the activated sludge process,
the operator usually has 3 basic variables which he can vary:||
^c20 1) Aeration rates in the aeration tank(s)|
^c20 2) Return solids flow|
^c20 3) Wastage of solids.||
```

```
Regardless of the method of process control used, these variable
are manipulated to correct effluent and plant problems.  The
suggested solutions to user-selected system problems will be
offered in terms of adjustments or corrections to one or more of
the operator-controlled variables.|^p$
  and 'loading'
  and 'excess secondary effluent suspended solids'
  and print
$^l5 ^r5|
Process control operations completed.||Checking mechanical
systems in secondary
clarifier(s) and pumping systems.$
  and 'pumps'
  and 'secondary floc clarifiers'.

rule 'loading'
   if ('loading 1' or 'loading 2').

rule 'inc mlss'
   if succeed.

rule 'dec mlss'
   if succeed.

rule 'inc return'
   if succeed.

rule 'dec return'
   if succeed.

rule 'loading 1'
   if 'ebod' is true
  and (    ('ibod' is false
         and (    ('rotifer' is true
                and print
$^l5 ^r5|
Inactive protozoa could be an indication that a toxic slug
loading has entered the plant and disrupted the biological
system.|Retain biomass to speed plant
recovery.|^p$)
           or (      ('type of foam' is 'white billowing foam')
                or ('floc' is 'darker')
                or ('MLSS' is 'lower')
                and print
$^l5 ^r5|
Conditions indicate that the process is organically overloaded.|
Increase MLSS by decreasing wastage from the process.|
If there is excessive foaming insure grease or other industrial
surfactants are not entering the aeration tank(s) and install
sprays to reduce foam build-up.|^p$)
           or ('temp' is true
                and print
$^l5 ^r5|
Reduced wastewater temperatures decrease the biomass ability to
```

```
digest organics.|Reduce wasting to increase MLSS.|^p$)
            or (print
$^15 ^r5|
Check influent COD and BOD and reduce wasting to build-up
MLSS.|Also check metal concentrations in influent.|^p$))
         and succeed)
     or print
$^15 ^r5|
Insufficient MLSS for present loading, probably excessive
wasting.| Increase MLSS by decreasing wastage from the process.|
If there is excessive foaming insure grease or other industrial
surfactants are not entering the aeration tank(s) and install
sprays to reduce foam
build-up.|^p$)
   and 'inc mlss'
   and 'wastage'
   and succeed.

rule 'loading 2'
    if print
$^15 ^r5|
Sufficient biomass available in aeration tank(s) for increased
loading.|
Maintain MLSS, wasting rates and aeration.|^p$
   and succeed.

rule 'excess secondary effluent BOD'
    if (    ('ebod' is true
          and (    ('ess' is true
                 and 'excess secondary effluent suspended solids'
is true
                 and succeed)
             or ('loading' is true
                 and succeed))
          and succeed)
      or succeed).

rule 'excess secondary effluent suspended solids'
    if (    ('ess' is true
          and print
$^15 ^r5|
High effluent suspended solids will probably result in high
effluent BOD values.|Diagnose effluent suspended solids.$
          and 'ESS type 2' is A
          and A is true
          and succeed)
      or succeed).

rule 'normal - exiting along entire length of weir'
    if ('sludge settle' is 'slow settling'
     and 'fmload' is 'high'
     and 'bltspeed' is 'slowly'
     and print
$^15 ^r5|
```

```
Conditions indicate that the process is organically overloaded.|
Increase MLSS by decreasing wastage from the process.|
Check that grease or other industrial surfactants are not
entering the aeration tank(s) and install sprays to reduce foam
build-up.|^p$
     and 'inc mlss'
     and 'wastage'
     and succeed)
    or ('sludge settle' is 'slow settling'
     and 'fmload' is 'low'
     and 'bltspeed' is 'slowly'
     and print
$^15 ^r5|
F/M loading: low.|
Condition of aeration tank(s) suggest that MLSS concentrations
are high relative to the organic loading and endogenous
respiration is occurring.| Increase wastage to decrease biomass
in aeration tank(s).|^p$
     and 'dec mlss'
     and 'wastage'
     and succeed)
    or ('sludge settle' is 'slow settling'
     and 'filament' is true
     and 'solve filament'
     and succeed)
    or ('return pump' is true
     and succeed)
    or ('normal - exiting only in discrete areas of weir'
     and succeed).

rule 'return pump'
    if ('ask return pump' is true
     and (      ('slr' is 'above'
            and print
$^15 ^r5|
Insufficient secondary clarifier capacity.|Solids loading rates
are too high at design flows.|Increase loading capacity by
increasing capacity or reducing loading|^p$
            and succeed)
           or ('ofr' is true
            and print
$^15 ^r5|
Hydraulic overloading of secondary clarifier(s).|
Solutions:|
a) Bring back-up clarifier(s) on-line to increase overall
   hydraulic| retention time and reduce overflow rates.|
b) Bypass part of plant flow to reduce flow through the plant.|
c) Install baffling in secondary clarifier(s) to improve
   hydraulic capacity.|
d) Equalize sewage inflows and inplant flow streams.|^p$)
     and succeed))
    or ('ask return pump' is false
        and 'bltspeed' is 'quickly'
        and print
```

```
$^l5 ^r5|
Solids overloading of secondary clarifier(s) due to return solids
system failure.|
a) Use back-up or supplemental pumps to remove solids from
   secondary clarifier(s).|
b) Check for clogged return pumps or return sludge lines.|
c) Bring back-up clarifier(s) on-line.|^p$
     and succeed).

rule 'normal - exiting only in discrete areas of weir'
    if ('cover' is false
        and 'blt' is 'high'
        and print
$^l5 ^r5|
Wind-induced currents over uncovered secondary clarifier(s) could
be creating currents carrying solids to surface and over weirs.|
Possible solutions:|
a) Provide wind breaks around clarifier(s).|
b) Cover clarifier(s).|^p$
     and succeed)
    or ('ask air temp' is X
     and 'ask ww temp' is Y
     and X < Y
     and print
$^l5 ^r5|
Differences between air and wastewater temperatures could cause
wastewater to rise causing loss of solids in secondary
clarifier(s).|
Possible solutions:|
a) Check inlet diffusers to insure influent is distributed
   evenly in secondary clarifier(s).|
b) Provide sufficient baffling to distribute flow.|^p$
       and succeed)
   or ('balance secondary'
       and succeed)
   or (    (    ('ask rotate c' is 'rotating')
          or ('ask travel r' is 'moving'))
       and 'blt' is 'high'
       and print
$^l5 ^r5|
Solids loss due to probable effluent weir imbalance which causes
solids to surge and billow in areas of increased flow.|
Use surveyor's level to sight and level effluent weirs.|^p$
       and succeed)
  or (      (    ('ask rotate c' is 'rotating but irratically')
         or ('ask travel r' is 'moving but irratically'))
      and print
$^l5 ^r5|
Solids overloading of clarifier(s) that is jamming sludge removal
scrapers.|
Sludge removal scrapers are moving irratically.|^p$
      and 'inc return'
      and 'return solids'
      and succeed)
```

```
  or ('normal - exiting along entire length of weir' is true
      and succeed).

rule 'ash-like solids on the surface'
    if print
$^15 ^R5|
Ash on surface could be caused by excessive grease entering
aeration tanks from primary operations or the beginning of
denitrification in the clarifier(s).|^p$
  and 'rising clumps and mats of solids'
  and succeed.

rule 'rising clumps and mats of solids'
    if (    ('ask nitrify' is true
          and print
$^15 ^r5|
Excessive solids retention times in the secondary clarifier(s) is
causing denitrification of nitrified biomass.|
Increase return solids rates to eliminate solids blanket|^p$
          and 'inc return'
          and (    ('ask denit' is true
                 and print
$^15 ^r5|
Denitrification in the secondary clarifier(s) due to insufficient
denitrification in anoxic reactor.|Increase clarifier recycle to
remove solids blanket.|Adjust return solids rate so no solids
blanket forms.|^p$
                 and 'excess secondary effluent NO3'
                 and succeed)
             or print
$^15 ^r5|
Denitrification in the secondary clarifier(s) due to excessive
solids retention time.|Adjust return solids rate so no solids
blanket forms.|Check for insufficient sludge removal or plugged
recycle.|^p$
                and succeed)
           and 'return solids'
           and succeed)
      or print
$^15 ^r5|
Solids could be due to insufficient removal by scrapers or sludge
collecting on side walls of clarifier(s).|
Inspect sludge collectors and clean side walls.|^p$
         and (    ('color of solids' is 'tan or brown'
                and print
$^15 ^r5|
Partial denitrification in the secondary clarifier(s) due to
increased temperature and/or sufficient MCRT.|
Increase wastage to decrease MLSS and MCRT.|^p$
                and 'dec mlss'
                and 'wastage')
            or ('color of solids' is 'black'
                and print
$^15 ^r5|
```

```
Solids color and condition indicate probable septic condition in
the secondary clarifier(s).|
Increase return rate and DO levels in aeration tank(s).|^p$
                and 'inc return'
                and 'return solids'))
         and succeed).

rule 'cloudy effluent - dispersed solids'
    if (    ('sludge settle' is 'slow settling')
      or ('sludge settle' is 'normal')
     and (       ('rotifer' is true
            and print
$^15 ^r5|
Inactive protozoa could be an indication that a toxic slug
loading has entered the plant and disrupted the biological
system.|Retain biomass to speed plant recovery.|^p$
            and 'inc mlss'
            and 'wastage'
            and succeed)
           or succeed)
     and (       ('fmload' is 'high'
            and print
$^15 ^r5|
Conditions indicate that the process is organically overloaded.|
Increase MLSS by decreasing wastage from the process.|
Check that grease or other industrial surfactants are not
entering the aerationtank(s) and install sprays to reduce foam
build-up.|^p$
            and 'inc mlss'
            and 'wastage'
            and succeed)
           or succeed))
    or ('sludge settle' is 'fast settling'
     and (       ('fmload' is 'high'
            and print
$^15 ^r5|
Conditions indicate that the process is organically overloaded.|
Increase MLSS by decreasing wastage from the process.|
Check that grease or other industrial surfactants are not
entering the aeration tank(s) and install sprays to reduce foam
build-up.|^p$
            and 'inc mlss'
            and 'wastage'
            and succeed)
           or succeed)
     and (       ('fmload' is 'low'
            and print
$^15 ^r5|
Condition of aeration tank(s) suggest that MLSS concentrations
are high relative to the organic loading and endogenous
respiration within the biomass is occurring.|Probable cause of
cloudy effluent is underloaded process.|Increase wastage to
decrease biomass in aeration tank(s).|^p$
            and 'dec mlss'
```

```
              and 'wastage'
              and succeed)
             or succeed))
     or (print
$^15 ^r5|
Check influent conditions or preliminary treatment
operations.|^p$
      and succeed).

rule 'excess secondary effluent NH3'
     if print
$^15 ^r5|
Conditions of loading and/or temperature have changed in the
aeration tank(s)to reduce the biological ability to nitrify
influent ammonia.|Increase MLSS and sludge age by reducing
wasting.|^p$
    and 'inc mlss'
    and 'wastage'
    and succeed.

rule 'excess secondary effluent NO3'
     if ('type denit' is 'predenitrification'
      and print
$^15 ^r5|
Loss of nitrates could be due to:||
a) Insufficient nitrate recycle to anoxic zone.|
b) Insufficient anoxic reactor volume.|
c) Increased nitrate levels (nitrification rate).|
d) High DO levels in recycle.||$
      and print
$^15 ^r5|
Possible solutions:|
Increase nitrate recycle.|
Check influent ammonia loadings and necessary anoxic zone
volume.|Increase anoxic reactor volume.|Decrease DO in aerobic
recycle.|Check clarifier for continued denitrification.|^p$
      and succeed)
     or ('type denit' is 'postdenitrification'
      and print
$^15 ^r5|
Loss of nitrates could be due to:||
a) Insufficient anoxic reactor volume.|
b) Increased nitrate levels (nitrification rate).|
c) Insufficient carbon for denitrifying heterotrophs.|
d) High DO levels in aerobic reactor passing through to anoxic|
   reactor.||$
        and print
$^15 ^r5|
Possible solutions:|
Check influent ammonia loadings and necessary anoxic zone
volume.|
Supply supplemental carbon or raw sewage bypass to anoxic zone.|
Increase anoxic reactor volume.|
Check clarifier for continued denitrification.|^p$
```

```
       and succeed).

rule 'balance secondary'
    if (     ('sc b' is A
          and A >= 2
          and 'ask balance 2' is false
          and print
$^15 ^r5|
Unbalanced flows to on-line clarifiers can cause surges of
solids.|
Try to balance flows to the operational clarifiers by:|
a) Checking return pumping rates and durations.|
b) Balancing inflows between the on-line clarifiers by
   throttling|úúúflows at splitter box and increasing head losses
   to reduce the effects of surges in the influent channels.|^p$
          and succeed)
      or succeed).

rule 'return solids'
    if (     ('blt' is 'high' or 'low'
          and (     ('inc return' is true
                 and print
$^15 ^r5|
Increase return rates by 10 to 15 % over present flow.$)
             or ('dec return' is true
                 and print
$^15 ^r5|
Decrease return rates by 10 to 15 % over present flow.|
Insure that solids blanket does not exceed 1/3 of the
clarifier(s) depth.|$))
          and print
$^15 ^r5|
Adjust return solids rate so that a minimum blanket is maintained
in the secondary clarifier(s) over the varying flow conditions.|
Thick sludge blankets in the clarifier(s) will:|
a) plug return solids pipes|
b) jam sludge scrapers on clarifier bottom(s)|
c) tend to become septic or denitrify and cause rising
   solids.|^p$
          and (     ('ask nitrify' is true
                 and print
$^15 ^r5|
When the process is controlled for nitrification no sludge
blanket should develop in the secondary clarifier(s).|The sludge
would quickly deplete the available DO and begin to denitrify the
available nitrates, causing rising solids.|^p$)
             or succeed)
          and (     ('ask denit' is true
                 and print
$^15 ^r5|
When the process is controlled for denitrification no sludge
blanket should develop in the secondary clarifier(s).|In single
sludge systems, nitrates that are not recycled or are not
denitrified could denitrify in the secondary clarifier(s) causing
```

```
rising solids.|^p$)
             or succeed)
          and succeed)
      or (print
$^15 ^r5|
Return solids rate so sludge blankets are not built up in the
secondary clarifier(s).$)).

rule 'wastage'
    if 'wastage 1'
    or 'wastage 2'
    or print
$^15 ^r5|
Maintain wasting at current rates.|$.

rule 'wastage 1'
    if 'inc mlss' is true
   and (    ('where wastage' is 'tank'
          and print
$^15 ^r5|
Increase MCRT by decreasing the volume of mixed liquor wasted
from the aeration tank(s).|This will increase MLSS levels in the
aeration tank(s).$)
      or ('where wastage' is 'rflow'
          and print
$^15 ^r|
Increase MCRT by decreasing wastage to increase MLSS levels.|I
suggest wasting from the aeration tank(s) due to their uniform
MLSS as compared to the uneven solids levels experienced in the
return solids flow.$)
      or ('where wastage' is 'both'
          and print
$^15 ^r5|
I suggest wasting from the aeration tank(s) due to their uniform
MLSS.|Increase MCRT by decreasing the volume of mixed liquor
wasted from the aeration tank(s).|This will increase MLSS levels
in the aeration tank(s).$)
      and succeed)
   and succeed.

rule 'wastage 2'
    if 'dec mlss' is true
   and (    ('where wastage' is 'tank'
          and print
$^15 ^r5
Decrease MCRT by increasing the volume of mixed liquor wasted
from the aeration tank(s).|This will decrease MLSS levels in the
aeration tank(s).$)
      or ('where wastage' is 'rflow'
          and print
$^15 ^r5|
Decrease MCRT by increasing wastage to decrease MLSS levels.|I
suggest wasting from the aeration tank(s) due to their uniform
MLSS as compared to the uneven solids levels experienced in the
```

```
return solids flow.$)
      or ('where wastage' is 'both'
          and print
$^15 ^r5|
I suggest wasting from the aeration tank(s) due to their uniform
MLSS.|
Decrease MCRT by increasing the volume of mixed liquor wasted
from the aerationtank(s).|This will decrease MLSS levels in the
aeration tank(s).$))
   and print
$^15 ^r5|
Decrease MCRT by 10% per MCRT, that is allow sufficient time for
biomass to adjust to new conditions before re-adjusting wastage
rates.$
   and (    (    ('where waste' is 'tank')
           or ('where waste' is 'both')
     and 'sludge' is true
     and print
$^15 ^r5|
Large volumes of waste solids are possible when wasting occurs
from the aeration tank(s).|Stagger wasting over shifts to
continuously process sludge.|Possibleneed for increased sludge
handling capacity.$
           and succeed)
     or succeed)
   and print
$^15 ^r5|
Generally, an increase in organic or NH3 loadings are accompanied
by an increasein MLSS levels and an increased DO demand. The
inverse is also true.|At all times, maintain minimum DO
requirements and check aeration and compressor systems.$.

rule 'pumps'
    if (    ('waste pump' is true
          and succeed)
      or ('waste pump' is false
          and print
$^15 ^r5|
MLSS pumping system failure.|
a) Use back-up or supplemental pump(s) to recirculate MLSS for |
   denitrification or wastage.|
b) Return solids underflow can be wasted as control option.|
c) Check for general pump failures and power breakers.|^p$
          and succeed))
   and (    ('ask return pump' is true
          and succeed)
      or ('ask return pump' is false
          and print
$^15 ^r5|
Return solids pumping system failure.|
a) Use back-up or supplemental pumps to remove solids from |
   secondary clarifier(s).|
b) Check for clogged return pumps or return sludge lines.|
c) Bring back-up clarifier(s) on-line.|^p$
```

```
        and succeed)).

rule 'solve filaments'
    if print
$^l5 ^r5|
Bulking sludge due to filamentous organisms can cause serious
problems inwastewater treatment plants.  Older technology uses
the following:||
a) chlorination - 2 to 3 kg per 1000 kg MLSS per day|
b) nutrient addition to follow the ratio 100:5:1:0.5
  (BOD:N:P:Fe)|
c) change in DO - either low to high or high to low|
d) change in pH - either increase or decrease||$
  and print
$^l5 ^r5|
These control practices are intended to kill or change the
conditions thought to be specific to the filamentous organisms.
They can and should be used to control bulking in the short-term.
However, bulking has been found to occur over a wide range of
conditions in wastewater treatment plants and more permanent
control practices can be applied.|^p|$
  and print
$^l5 ^r5|
Five major biological control practices are suggested to reduce
the possibility of producing conditions favorable to filamentous
bulking sludges:||
1) The use of very long (L:W ò 20:1) plug flow reactors to
   minimize back-mixing.|
2) Compartmentalization of a biological reactor to reduce |
   back-mixing and produce a high-to-low F/M gradient throughout
   the reactor.|
3) The operation of the first zone of reactor in a fully aerobic
   conditions : DO ò 2.0 mg/L  OUR:DO ó 25:1 while under a |
   high F/M loading (ò 3 kg BOD/kg MLSS/day).|$
                 and print
$^l5 ^r5|
4) The operation of the first zone of reactor in a near-anaerobic
   conditions : DO ó 0.2 mg/L  OUR:DO ò 500:1 while under a |
   high F/M loading (ò 3 kg BOD/kg MLSS/day).|
   while under a high F/M loading (ò 3 kg BOD/kg MLSS/day).|
5) Anaerobic treatment of the return solids before re-entering
the reactor and mixing with the raw wastewater.||^p$
   and (    ('type tank' is 'completely mixed reactor'
          and print
$^l5 ^r5|
CMAS reactors tend to promote a bulking sludge due to the concept
of their design.  The overall low substrate concentration and
reaction rate favors filamentous organisms.|Suggested action:|$
                 and print
$^l5 ^r5|
a) Separate and compartmentalize the CMAS reactors to produce a
plugflow type reactor with a high-to-low F/M gradient.|
b) Aeration - should use automatic DO control with |^p$)
      or ('type tank' is 'plug flow reactor'
```

```
          and print
$^15 ^r5|
PFAS reactors can be retrofitted quite easily to compartmentalize
the reactor
basin and prevent back-mixing.|Suggested action:|
a) Compartmentalize - baffles should cover ÷ 90% of the|
   cross-section and can float on the surface or span the tank
   for support.|
b) Aeration - should use automatic DO control with coarse bubble|
   diffusers and capacity of 200% required air.|
c) Mixing - minimum air in first compartment for mixing or use of
   mechanical mixers to suspend MLSS.|
d) Loading - Influent into first compartment should give F/M
   loading 3 kg BOD/kg MLSS per day.|^p$)).

rule 'secondary floc clarifiers'
    if (print
$^15 ^r5|
Secondary Clarifier Interactive Unit Operation Diagnosis||This
session checks
the secondary clarifiers and clarifier-dependant systems.^p$
     and 'sc a' is A
     and A >= 1
     and 'sc b' is B
     and B >= 1
     and A >= B
     and (      ('type sc' is 'circular'
            and 'rotating plow')
           or ('type sc' is 'rectangular'
            and 'chain and flight'))
     and 'excess secondary effluent suspended solids'
     and 'balance secondary'
     and succeed)
    or (print
$^15 ^r5|
There are no secondary clarifier(s) installed in the plant.$
     and succeed).

rule 'rotating plow'
    if    ('ask rotate c' is 'rotating'
      and print
$^15 ^r5|
Scraper should be rotating at 0.02 to 0.06 RPM for proper
operation.$
      and succeed)
     or ('ask rotate c' is 'not rotating'
      and (      ('reset scraper 1' is true
             and succeed)
            or ('reset scraper 1' is false
             and print
$^15 ^r5|
Possible solutions are:|
a) Bypass secondary clarifier to other unit(s) and repair|
   scraper arm.|
```

```
b) Continue using clarifier, but pump dilute activated sludge to|
   sludge handling facilities until scraper arm is repaired.|^p$
              and succeed)))
     or ('ask rotate c' is 'rotating but irratically'
      and print
$^15 ^r5|
Scraper should be rotating at 0.02 to 0.06 RPM for proper
operation.|
Check for:|
a) Bent or broken sludge plow on scraper arm.|
b) Slippage of drive belts or worn gear drives on collection
   arm.|
c) Build-up of collected sludge.|^p$
      and succeed).

rule 'chain and flight'
    if    ('ask travel r' is 'moving'
       and print
$^15 ^r5|
Chain scraper or travelling bridge should be moving at 0.3 - 1.0
meters per minute for proper operation.$
       and succeed)
      or ('ask travel r' is 'not moving'
       and (      ('reset scraper 2' is true
              and succeed)
             or ('reset scraper 2' is false
              and print
$^15 ^r5|
Possible solutions are:|
a) Bypass secondary clarifier to other unit(s) and repair|
   scraper arm.|
b) Continue using clarifier, but pump dilute activated sludge to|
   sludge handling facilities until scraper arm is repaired.|^p$
              and succeed)))
     or ('ask moving r' is 'moving but irratically'
      and print
$^15 ^r5|
Chain scraper or travelling bridge should be moving at 0.3 - 1.0|
meters per minute for proper operation.|
Check for:|
a) Broken flight or worn sprockets.|
b) Slippage of drive belts on drive sprockets.|
c) Build-up of collected sludge slowing scraper boards.|^p$
      and succeed).

'temp' ask
$^15 ^r5|
Has the influent wastewater temperature decreased and remained
lower
than normal?$
       alt yn.

'fmload' ask
$^15 ^r5|
```

```
What is the current F/M loading on the aeration tank(s)?$
      alt ('< 0.5','0.5 - 0.2','> 0.2')
      ralt ('high','normal','low')
      expl ($The process loading on the aeration tanks helps
             WASTES determine whether the process is under or
             overloaded.|
             Changing the limits in the question 'fmload'
             customizes the limits to a specific process or
             facility.$).

'ofr' ask
$^15^r5|
Is the clarifier(s) overflow rate above design flow(s)?$
     alt yn.

'waste pump' ask
$^15 ^r5|
Are the pump(s) for wastage of MLSS from the aeration tank(s)
operating?$
      alt yn.

'ask return pump' ask
$^15 ^r5|
Are the return solids pump(s) operating and is there flow back to
the aeration tank(s)?$
      alt yn.

'floc' ask
$^15 ^r5|
Under microscopic observation, what is the color of the
biological
floc relative to normal conditions?$
      alt ('lighter',
           'same',
           'darker').

'sludge' ask
$^15 ^r5|
Do the sludge handling or treatment methods used at the plant
have a limited capacity to the amount of waste sludge that can be
processed?$
      alt yn.

'ask blanket' ask
$^15 ^r5|
Are the secondary clarifier(s) and return solids flow controlled
so that a sludge blanket develops on the bottom(s).$
     alt yn.

'type of scraper' ask
$^15 ^r5|
What type of sludge collector is installed in the secondary
clarifier(s)?$
     alt ('rotating plow-type',
```

```
          'chain and flight').

'type sc' ask
$^15 ^r5|
What type of secondary clarifier(s) are installed in the plant?$
     alt ('circular',
          'rectangular').

'MLSS' ask
$^15 ^r5|
What do you think the present MLSS concentration is compared to
normal loading conditions in the aeration tank(s)?$
     alt ('higher',
          'same',
          'lower').

'ask nitrify' ask
$^15 ^r5|
Is the plant purposely nitrifying influent ammonia for effluent
requirements?$
     alt yn.

'ask denit' ask
$^15 ^r5|
Is the plant purposely denitrifying to remove nitrogen from the
effluent for effluent requirements?$
     alt yn.

'type tank' ask
$^15 ^r5|
What type of mixing regime or tank design is used at the plant?$
     alt ('completely mixed reactor',
          'plug flow reactor').

'color of MLSS' ask
$^15 ^r5|
What describes the color of the mixed liquor in the aeration
tank(s) as compared to normal conditions?$
      alt ('lighter',
           'same',
           'darker').

'type of foam' ask
$^15 ^r5|
What best describes the color and type of foam present on the
surface of the
aeration tank(s) at the present time?$
      alt ('white billowing foam',
           'light tan or brown foam',
           'dark brown foam').

'where wastage' ask
$^15 ^r5|
Where can biological solids wasted or removed from the system?$
```

```
      alt ('aeration tank(s)','secondary clarifier
           underflow','both')
      ralt ('tank','rflow','both')
      expl ($WASTES would like to know where you waste solids
            from youractivated sludge process so I can estimate
            the changes needed to correct your system.$).

'sludge settle' ask
$^15 ^r5|
What best describes the settling ability of the activated sludge
mixed liquor
entering the secondary clarifier(s)? $
      alt ('slow settling',
           'normal settling',
           'fast settling').

'blt' ask
$^15^r5|
Where is the position of the sludge blanket in the clarifier(s)?$
     alt ('high',
          'low',
          'none').

'bltspeed' ask
$^15^r5|
How did the level of the sludge blanket change?$
     alt ('quickly (minute/hours)',
          'slowly (days)')
     ralt ('quickly',
           'slowly').

'slr' ask
$^15^r5|
What is the current solids loading rate on the clarifier(s)
relative
to the design solids loading rate?$
     alt ('above',
          'at or below').

'filament' ask
$^15 ^r5|
Does a microscopic examination of the activated sludge show
masses of
filamentous organisms present?$
      alt yn.

'ess' ask
$^15 ^r5|
Does the effluent from secondary clarifier(s) contain excess
suspended solids?$
      alt yn.

'ESS type 2' ask
$^15 ^r5|
```

```
What do the solids appear like at the clarifier overflow
weir(s)?$
      alt ('normal - exiting along entire length of weir',
           'normal - exiting only in discrete areas of weir',
           'ash-like solids on the surface',
           'rising clumps and mats of solids',
           'cloudy effluent - dispersed solids').

'ebod' ask
$^15 ^r5|
Is the BOD of the plant effluent above normal levels?$
      alt yn.

'ibod' ask
$^15 ^r5|
Has the organic loading or F/M of the process increased?$
      alt yn.

'rotifer' ask
$^15 ^r5|
Does a microscopic examination show inactive rotifer protozoa?$
      alt yn.

'cover' ask
$^15 ^r5|
Is there a cover over the clarifier or some sort of wind buffer
protecting the
clarifier?$
     alt yn.

'ask travel r' ask
$^15 ^r5|
What is the chain scraper or travelling bridge scraper doing?$
          alt ('moving',
             'not moving',
             'moving but irratically').

'ask rotate c' ask
$^15 ^r5|
What is the circular sludge collection scraper arm doing?$
          alt ('rotating',
             'not rotating',
             'rotating but irratically').

'reset scraper c' ask
$^15 ^r5|
Check: a) Debris jams in the bottom of the clarifier|
       b) Bent or broken plow.|
       c) Failure of the motor or reducer gears|
       d) Reset of the power breaker|
Does the unit work now?$
     alt yn.

'reset scraper r' ask
```

```
$^l5 ^r5|
Check: a) Debris jams in the bottom of the clarifier|
       b) Broken flight.|
       c) Failure of the motor or reducer gears|
       d) Reset of the power breaker|
Does the unit work now?$
     alt yn.

'color solids' ask
$^l5 ^r5|
What do the rising solids look like?$
      alt ('tan or brown',
           'black').

'ask balance 2' ask
$^l5 ^r5|
Are the wastewater flows to the on-line secondary clarifiers
approximately
equal?$
      alt yn.

'type denit' ask
$^l5 ^r5|
What type of denitrification system employing an anoxic zone is
being used?$
      alt ('predenitrification',
           'postdenitrification').

% AERATION AND MIXING SYSTEMS

rule 'solve aeration/mixing'
    if ('type aer' is 'diffused air'
     and print
$^l5 ^r5|
Diffused aeration of activated sludge tanks.$
     and 'aeration present'
     and 'aeration uniform'
     and 'check DO')
    or ('type aer' is 'mechanical'
     and (      ('ask bubbles' is 'to provide DO and mix the
MLSS'
            and print
$^l5 ^r5|
Mechanical aeration of activated sludge tanks.$
            and 'aeration mechanical'
            and 'solve DO mechanical')
           or ('ask bubbles' is 'only to mix the MLSS'
            and print
$^l5 ^r5|
Mechanical aeration of activated sludge tanks.$
            and 'mix mechanical'))).

rule 'aeration present'
    if ('ask present' is false
```

```
     and print
$^15 ^r5|
a) Check your compressor(s) to see if they are operating.|
b) Examine the piping and valve system to see if there are any
   split casings, blown gaskets, or frozen valves.|
c) If using DO controller, check readings.|^p$
     and (      ('ask air loss' is 'piping system failure'
            and print
$^15 ^r5|
If the failure is on a main air supply conduit to a tank:|
a) Reduce compressor output to minimum.|
b) Close valves leading to aeration tank(s).|
   (Closing valves under pressure could cause more damage)|
c) Use aeration piping bypass to supply the tank.|
d) If no bypass is available, provide aeration through mechanical
means:|
mechanical aerators, pumping and spraying the MLSS.|
Provide DO to the biomass and prevent reactor upset or
failure.|^p$)
           or ('ask air loss' is 'compressor failure'
            and print
$^15 ^r5|
a) Close valving to prevent backflow into compressor and use
   other installed compressors or back-up units to meet DO demand
   of aeration tank(s).|
b) Immediately get compressor or motor and drive unit
   serviced.|^p$)
           or ('ask air loss' is 'controller failure'
            and print
$^15 ^r5|
a) Check installed DO probes operation.|
b) Install DO probe self-checking in controller software.|^p$)))
     or succeed.

rule 'aeration uniform'
    if ('ask uniform' is 'excessive agitation and splashing'
     and (      ('ask head' is 'coarse bubble diffuser'
            and print
$^15 ^r5|
Reduce agitation and splashing by:|
a) Installing fine diffuser heads on some or all of the aeration
   units.|
b) Install spargers to break up the coarse air bubbles.|^p$)
           or ('ask head' is 'fine bubble diffuser'
            and print
$^15 ^r5|
Check the positioning of the aeration heads relative to the
aeration
tank walls to ensure they are not too close.|^p$))
            and print
$^15 ^r5|
Reduced aeration rates could solve excessive agitation and
splashing.|
Check the mixing condition after the aeration tank(s) have had a
```

```
period of time
to settle down.|
Check and monitor:|
a) DO levels throughout aeration tank.|
b) MLSS mixing conditions.|^p$
            and succeed)
    or ('ask uniform' is 'uniform and thoroughly mixed'
     and succeed)
    or ('ask uniform' is 'non-uniform with dead spots of settling
MLSS'
     and print
$^15 ^r5|
Non-uniform aeration leads to dead spots in the tank and reduced
efficiency of removal.|
Balance the air supply to aeration heads by adjusting the air
flow valves at
the aeration tank(s).|^p$
     and    ('ask air balance' is true
          and print
$^15 ^r5|
Insure that all aeration tanks are balanced and check air flow
meters to insurethat all aeration tanks are receiving equal
flow.|^p$
          and succeed)
         or ('ask air balance' is false
          and print
$^15 ^r5|
Lift aerators out that are experiencing continued poor air flow
and inspect for:|
a) aerators clogged with rags or debris.|
b) dark, dirty aerators.|^p$
          and (      ('ask clog' is true
                 and print
$^15 ^r5|
Aerators clogged with debris, check the preliminary unit
operation racks and shredders.$
                 and load $racks.kb$
                 and 'racks and shredders')
                or ('ask clog' is false
                 and print
$^15 ^r5|
Remove the aeration head and replace with new one.$
                 and (    ('ask head' is 'fine bubble diffuser'
                        and print
$^15 ^r5|
Probable cause of failure is dirty air therefore replace or
install air filters on compressors.|
Fine bubble diffusers are prone to clogging and could be replaced
with medium or coarse bubble diffusers but with increased air
flow necessary and at reduced transfer efficiencies.|^p$)
                      or succeed))))
     and succeed).

rule 'aeration mechanical'
```

```
    if ('ask present' is false
     and print
$^15 ^r5|
Check the following on the mechanical aerators:|
a) Power supply main breakers.|
b) Power connections to aerators.|
c) Motor breaker and reducer drive for jams.|^p$
     and    ('ask stir' is true
          and print
$^15 ^r5|
Now that the aerator is functioning.$
          and succeed)
         or ('ask stir' is false
          and print
$^15 ^r5|
Remove the aerator from the tank for servicing.|
a) Replace with back-up aerator.|
b) If there is no back-up aerator available, increase aeration|
   with other units installed in the tank by:|
   - lowering them into the MLSS and increasing the bite of the|
     impellers|
   - increasing the duration of operation of the other aerators|
   - increasing the speed of the units|
c) Monitor DO levels and level of mixing in tank.|^p$))
    or     (    ('ask uniform' is 'excessive agitation and
splashing'
            and print
$^15 ^r5|
Decrease the agitation and splashing by:|
a) Installing shields or covers around impellers to reduce spray|
   and wash.
b) Reduce bite of impellers and install draft tubes to retain|
   mixing and aeration|
Wait an hour before testing bulk DO levels in MLSS.|^p$)
        or ('ask uniform' is 'uniform and thoroughly mixed'
            and succeed)
        or ('ask uniform' is 'non-uniform with dead spots of
settling MLSS'
            and print
$^15 ^r5|
Increase the aeration and mixing of the mechanical aerators by:|
a) Lowering them into the MLSS and increasing the bite of the|
úúimpellers.|
b) Increasing the duration of operation of the other aerators.|
c) Increasing the speed of the units.|
d) Install draft tubes to improve circulation of MLSS.|
e) Bring additional aerators on-line in the tank.|
Wait an hour before testing bulk DO levels in MLSS.|^p$))
     and succeed.

rule 'mix mechanical'
    if ('ask mix' is true
     and    ('ask uniform' is 'uniform and thoroughly mixed'
          and print
```

```
$^15 ^r5|
Good mixing is essential for suspended MLSS.$)
         or ('ask uniform' is 'excessive agitation and splashing'
          and print
$^15 ^r5|
Excessive agitation will:|
a) Entrain air into the MLSS and reduce the ability to enitrify.|
b) Cause excessive shearing of the biofloc creating clarification
   problems.|
Therefore:|
a) Reduce the mixing power input or motor speed.|
b) Decrease the on duration time on some of the mixers.|^p$)
         or ('ask uniform' is 'non-uniform with dead spots of
settling MLSS'
          and print
$^15 ^r5|
Insufficient mixing will allow the MLSS to settle and reduce
removal efficiency.|
a) Increase the mixing power input or motor speed.|
b) Increase the on duration time on some of the mixers.|^p$))
    or ('ask mix' is false
     and    ('ask uniform' is 'uniform and thoroughly mixed'
          and print
$^15 ^r5|
Good mixing is essential for suspended MLSS.$)
         or ('ask uniform' is 'excessive agitation and splashing'
          and print
$^15 ^r5|
Excessive agitation can shear the sludge flocs causing ash on the
surface of
the clarifier(s).|
Therefore:|
a) Reduce the mixing power input or motor speed.|
b) Decrease the on duration time on some of the mixers.|^p$)
         or ('ask uniform' is 'non-uniform with dead spots of
settling MLSS'
          and print
$^15 ^r5|
Insufficient mixing will allow the MLSS to settle and reduce
removal efficiency.|
a) Increase the mixing power input or motor speed.|
b) Increase the on duration time on some of the mixers.|^p$)).

rule 'check DO'
    if ('type aer' is 'diffused air'
     and 'solve DO diffused'
     and succeed)
    or ('type aer' is 'mechanical'
     and 'solve DO mechanical'
     and succeed).

'ask DO high' is 1.8.
'ask DO low' is 1.4.
```

```
rule 'solve DO diffused'
    if 'ask DO' is A
   and (    ('ask DO low' is X
         and A < X
         and print
$^15 ^r5|
DO levels are too low for stable aerobic conditions in dispersed|
growth biomass:|
a) Increase aeration by increasing the air flow to the aeration |
   tank(s).|
b) If automated DO control is used, decrease the DO setpoint|
   on the controller.|^p$)
      or ('ask DO high' is Y
         and 'ask DO low' is X
         and A >= X
         and A =< Y
         and print
$^15 ^r5|
DO levels are good for stable aerobic conditions in dispersed
growth biomass
and economical air use for facility operation.|^p$)
      or ('ask DO high' is Y
         and A > Y
         and print
$^15 ^r5|
DO levels are too high for economical air use for facility
operation:|
a) Decrease aeration by decreasing the air flow to the aeration|
   tank(s).|
b) If automated DO control is used, increase the DO setpoint|
   on the controller.|^p$)).

rule 'solve DO mechanical'
    if 'ask DO' is A
   and (    ('ask DO low' is X
         and A < X
         and print
$^15 ^r5|
DO levels are too low for stable aerobic conditions in dispersed
growth
biomass considering mechanical aeration is used.|
Increase the aeration and mixing of the mechanical aerators by:|
a) Lowering them into the MLSS and increasing the bite of the|
   impellers.|
b) Increasing the duration of operation of the other aerators.|
c) Increasing the speed of the units.|
or you can bring additional aerators on-line in the tank.|^p$)
      or ('ask DO high' is Y
         and 'ask DO low' is X
         and A >= X
         and A =< Y
         and print
$^15 ^r5|
DO levels are good for stable aerobic conditions in dispersed
```

```
growth biomass
and economical power use for facility operation.|^p$)
      or ('ask DO high' is Y
          and A > Y
          and print
$^l5 ^r5|
DO levels are too high for economical power use for facility
operation.|
Decrease the aeration and mixing of the mechanical aerators by:|
a) Raising them out of the MLSS and decreasing the bite of the|
   impellers.|
b) Decreasing the duration of operation of the other aerators.|
c) Decreasing the speed of the units.|
or you can take additional aerators off-line in the tank.|^p$)).

'ask DO' ask
$^l5 ^r5|
What is the current mean bulk dissolved oxygen content in the
aeration tank(s)
expressed in mg/L ? -> enter a one decimal place number $
      expl ($WASTES would like to know the current DO so it can
compare it
            to the low and high values and suggest corrective
action if
            necessary.$).

'ask stir' ask
$^l5 ^r5|
Did the aerator restart and is now functioning?$
      alt yn.

'ask clog' ask
$^l5 ^r5|
Is the aeration head functioning properly now after cleaning?$
      alt yn.

'ask head' ask
$^l5 ^r5|
What type of diffused air head is installed in the aeration
tanks?$
      alt ('fine bubble diffuser',
           'coarse bubble diffuser').

'type aer' ask
$^l5 ^r5|
What type of equipment is installed in the activated sludge
tank(s)?$
      alt ('diffused air',
           'mechanical').

'ask air balance' ask
$^l5 ^r5|
Did the air flow adjustment work or is the aeration still
variable perhaps
```

```
with air escaping out the blow-off legs on the aerators?$
      alt yn.

'ask bubbles' ask
$^l5 ^r5|
The the purpose of the mechanical mixing installed in the tank
is?$
      alt ('to provide DO and mix the MLSS',
           'only to mix the MLSS').

'ask present' ask
$^l5 ^r5|
Are all the units installed in the tank(s) functioning?$
      alt yn.

'ask air loss' ask
$^l5 ^r5|
What appears to be the cause of the apparent lack of air to
supply the aerators
in the tank(s)?$
      alt ('failed compressed air piping system',
           'compressor failure',
           'controller failure').

'ask uniform' ask
$^l5 ^r5|
What best describes the condition of the aeration tank(s)?$
      alt ('non-uniform with dead spots of settling MLSS',
           'uniform and thoroughly mixed',
           'excessive agitation and splashing')
      expl ($WASTES uses this description as a indication of the
mixing
            provided by the aeration system and bases corrective
action on
            the result.$).

'ask DO high' ask
$^l5 ^r5|
What is the upper limit for the DO range on the aeration tank(s)
expressed
in mg/L ? -> enter a one decimal place number $.

'ask DO low' ask
$^l5 ^r5|
What is the lower limit for the DO range on the aeration tank(s)
expressed
in mg/L ? -> enter a one decimal place number $.

'ask mix ' ask
$^l5 ^r5|
Is the mixing in an anoxic denitrification reactor?$
      alt yn.
```

Chapter 11.0 Appendix 2

Microscopic Examination of Activated Sludge

1.0 Introduction

The daily examination of the activated sludge mixed liquor and the secondary clarifier effluent is a powerful diagnostic tool available to the treatment plant operator.
The presence, predominance, and condition of certain types of microorganisms can help determine:

- Filamentous bulking sludge
- Organic overloading
- Organic underloading
- Toxic loading
- Overall treatment efficiency.

The following tutorial is a general guide to help you distinguish the various types of microorganisms present in the activated sludge system.

2.0 Visual Examination

Microscopic examination of the activated sludge mixed liquor and final clarifier effluent can be done on a standard phasecontrast light microscope with an available magnification of 500 X. The mixed liquor sample should be fresh and always taken from the same areas of the tanks. Assuming that the set-up and operation of the microscope and samples is known, the time for a daily visual analysis and recording of the characteristics should only take 15 minutes. A sample observation sheet is attached as a reference.

2.1 Initial Observations

The mixed liquor should be placed in a 1.0 liter beaker and suspended by stirring. The observations should be done by eye or hand lens to record the following:

- o colour of the sludge
- o odour of the sludge
- o any trapped gases or unknown solids
- o sludge settling test

2.2 Low Power Observations

The next observation should be done under low magnification (100-200 X) for:

- o shape, size, and structure of the sludge floc
- o presence of filamentous organisms
- o type of inorganic inclusions in the floc
- o identification and observation of protozoa in the mixed liquor.

2.3 High Power Observations

The final observations should be made under high power (400 - 500 X) to detail:

- o composition of flocs
- o nature of dispersed bacteria
- o identification of flagellates and filamentous bacteria (diameter > 1 μm)

3.0 Results

All observations are subjective and what I would say is dark brown, you could say is light black thus the key to rendering good observational results is consistency and objectivity. Try to be consistent in when you sample, where you sample, and who samples. One person should do the microscopic analysis and interpret the results, in a way become the resident expert of that plant's microbial population. The form at the end of the guide serves as a sample of examination guide.

3.1 Macroscopic Observations

The observations of mixed liquor colour and odour, combined with the operational observations of the aeration tanks and secondary clarifier and results of the simple settling test help determine the observational data for the WASTES system. The information gathered is used to determine the type, condition, and loading of the treatment process.

4.0 Sample Observations Sheet

DATE: ____________________ MIXED LIQUOR ☐

TIME: ____________________ SETTLED SLUDGE ☐

LOCATION: ____________________ OTHER: ____________________

TANK #: ____________________

A. VISUAL OBSERVATIONS (1.0 l SETTLEOMETER)

COLOR: ____________________ TRAPPED GASES ☐

ODOR: ____________________ OTHER: ____________________

B. ACTIVATED SLUDGE FLOC OBSERVATIONS

LARGE LACY FLOCS	☐	DARK	☐
PIN FLOCS	☐	LIGHT	☐
NORMAL FLOCS	☐	IRREGULAR	☐
FILAMENTS	☐	DISPERSED	☐

PROTOZOA ACTIVE ☐ INACTIVE ☐

C. DETAILED OBSERVATIONS (400–500X)

APPROX. FLOC SIZE: ____________________ (μm)

PROTOZOA:	TYPE	NUMBER
	____________________	__________
	____________________	__________
	____________________	__________
	____________________	__________

Chapter 12.0 Appendix 3 - WASTES User Manual

This is a guide of how to use WASTES, wastewater treatment expert system, and FRO, the accompanying system shell.

1. System Requirements

An IBM or compatible personal computer with at least 256 Kb of RAM memory. An installed hard disk drive is preferred due to the amount of reading and writing to disk while the system operates, but a single floppy disk will work and the system will be slower.

2. Loading the system

Turn the computer on and making sure that any memory-resident are not loaded to maximize the available memory for the expert system and minimize the amount of reading and writing to disk.

a. Install WASTES on a hard disk drive.

Copy all the files from either the high density or the standard floppy disk to a subdirectory on the hard disk, i.e. C:\waste. The files copied should be:

FRO.EXE	RACKS.KB	CLAR.KB	FLOAT.KB
FRO.IDB	GRIT.KB	MICRO.KB	ODOUR.KB
FRO.P00	LIFT.KB	RBC.KB	TREAT.KB

b. On floppy disk systems insert the system disk into the disk drive with the correct dos prompt.

c. To begin WASTES type "fro" and enter at the dos prompt in the correct subdirectory and disk drive:

C>fro <enter> or A>fro <enter>

If you are not using a mouse, use:

C>fro /n <enter> or A>fro /n <enter>

d. A frame should appear on your monitor with key definitions along the top border.

3. FUNCTION KEY DEFINITIONS

a. Before you begin..

Before you press a key to continue, notice the along the top of the frame are definitions for the function keys on the keyboard: These are the function keys for the Fro system. You will also notice that some of the definitions have been blanked out by a row of dots. This means that the function is not active. Here are explanations of the function keys:

F1: HELP This key provides a help function for the knowledge base. Pressing the key provides information on what area of the knowledge base you are presently in.

F2: FILES or EXPLAIN The context of this key changes between FILES and EXPLAIN, depending on the status of the system. The FILES function prompts the user to enter the name of a knowledge base to be loaded into the FRO system. The EXPLAIN function is active when the system is asking a question. It provides a window of information concerning the question.

F3: EXECUTE Used after the FILES command, this key executes the top level goal in the loaded knowledge base and begins the WASTES system.

F4: SAVE This function is also used after the FILES command. It saves the loaded knowledge base in two binary files, FRO_SAVE.IDB and FRO_SAVE.P00. When FRO is re-started, these files are automatically loaded and the top level goal is executed.

F5: TRACE The TRACE function invokes a logic tracing window along the bottom of the screen. Inside the screen, the individual statements and goals are stepped through as the FRO system works through the knowledge base. The space bar steps through the individual operations in the shell allowing the user an idea of the logic developed in the knowledge base. The F5 key toggles the trace function on and off.

F6: Quit The QUIT function ends the interpretive session and returns you to the DOS prompt. To end the session at any point, press this key. To re-start WASTES, type fro <enter>.

4. Using WASTES

Press F2 and type treat.kb <enter>. Once the system returns the statement:

loaded

You have two options before you press F3 and execute the program. One, you can press F4 and save the knowledge base in binary and re-start the program. This is the option allows the system to load much faster, cutting disk read operations and shortening response times. Second, you can press any key to continue and use the system as it is. Whatever options you choose, execution of the program will begin with:

Welcome to

WASTES
WAStewater Treatment Expert System
(C) Barry Chilibeck..Version 3.0

followed by a short program description and the first system question. The explain function should be present at the first question. In WASTES, the explain function can provide three different pieces of information. First, it can expand on the question posed by the system by suppling a more detailed description. Second, it can explain how this question relates to the logic of the knowledge base and development of the rules to support a goal. Last, it can explain what pieces of information it hopes to gain from each of the different possible responses.

Operating the system is very simple, just answer the questions and choose what you would like to query or troubleshoot. You can answer questions by entering the number of your selection. With the mouse you simply move the pointer to your selection, it becomes highlighted, and you press the mouse button to select it.

The easiest way to understand how the expert system shell and the knowledge base operates is to use them. Try different responses to the questions and experiment with all of the options available to you. If the system chains through all the possible rules and solves the top level goal it prints:

*** Session Completed ***

and the knowledge base is finished. The system is not fool-proof and there may be some errors, especially on different PCs. If it hangs simply re-start and try again. Attached with this manual is a review sheet. Your comments and criticisms will help me improve WASTES and give me new ideas on what to include or develop with the system. I hope you can take some time to use the system and complete the review sheet.

REVIEW SHEET

a. Did you think that there were any conclusions that you did not agree with? Any errors or omissions?

b. What did you think about using the system? Was it easy to understand? Were all the questions worded clearly?

c. Did you learn something about what might be involved in operating a full wastewater treatment facility? In general, do you think that systems similar to this would make good teaching tools?

d. Are there any other comments you would like to add?

Chapter 13.0 Appendix 4 - WASTES System Diskette