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AN OPTIMIZATION MODEL - PRELIMINARY SELECTION OF
APPROPRIATE TECHNOLOGY IN WASTEWATER TREATMENT
ALTERNATIVES

by

S L TANG

A Doctoral Thesis
submitted in partial fulfilment of the requirements
for the award of PhD of the
Loughborough University of Technology

March 1989

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PART 1

PRELIMINARY WORK AND REVIEW OF LITERATURE
CHAPTER 1 --- SYNOPSIS AND INTRODUCTION

1.1 Synopsis

This research is concerned with the use of techniques of system analysis / operations research in the selection of the optimal - or most appropriate - wastewater treatment techniques in any given situation. An extensive investigation of existing treatment system optimization models, applying techniques of linear programming, dynamic programming and non-linear mathematical programming, has been carried out. None of these existing models deals with the socio-cultural and environmental conditions but merely with the economy of treatment. In this work the more subjective or intangible factors are included in the proposed optimization model in which twenty parameters are identified. These parameters are considered to be most important in the selection of appropriate alternatives for treating municipal wastewater. They include technical, economic, environmental and socio-cultural factors. The model was developed to rank a definite number (n) of wastewater treatment alternatives (decision variables) by the evaluation of the twenty parameters.

The model applies a recently developed system analysis technique called eigenvector prioritization (or analytic hierarchy process) and requires the use of a computer program to integrate a 20 x 20 parameter matrix with twenty
n x n decision variable matrices for obtaining the final ranking of the treatment alternatives. The computer program is written in IBM-pc BASIC and can be run on any IBM personal computer (or any XT or AT). The model was tested using data collected from actual treatment plants in Malaysia, Thailand, Taiwan and Hong Kong. A sensitivity analysis was then carried out. As a result the model was extended to be able to forecast a change of appropriate technology as social and environmental conditions altered with time.

1.2 Introduction

Chapter 1 of this thesis, as can be seen from its title, gives a bird's eye view of the contents contained in the thesis. Chapter 2 is a brief but comprehensive description of existing wastewater treatment techniques which are commonly in use. Chapter 3 is an extensive survey on the development of treatment system optimization models since 1962. Models based on operations research techniques including linear programming, dynamic programming and non-linear mathematical programming proposed by various researchers are described in this chapter.

Chapter 4 begins to discuss the model proposed in this research. In the chapter, the complete sets of the parameters and the decision variables (or treatment
alternatives) are described. Chapter 5 then gives a detailed discussion on the mathematical tool (eigenvector prioritization) applied in the model. It also explains the reasons for using this particular mathematical technique and discusses the advantages of it over the others. After a theoretical background is given in Chapter 5, Chapter 6 continues to describe the development of the model in detail, including the discussion of the computer program.

There are two distinctive methods in research --- deductive and inductive methods.\(^1\) The deductive method uses logic that moves from the general to the specific. In such a method, a theory or an idea is obtained after a general consideration of all occurrences. The inductive method, however, uses logic that is launched from a specific occurrence and moves to inferences concerning the general. In other words, if a number of special cases occurs according to a general theory or idea then the latter is supported. The inductive method is applied in this research. The model is formulated firstly as a hypothesis, as described in Chapters 4, 5, and 6. It is then tested by using four different situations. Chapter 7 and Chapter 8 describe the tests using data collected from four different places, namely, Malaysia, Thailand, Taiwan and Hong Kong. The test results obtained are the four optimal (or most appropriate) treatment alternatives for the four given situations.
Chapter 9 is a description of the sensitivity analysis of the model, the technique of which is applied to forecasting change of appropriate technology as a result of change of situation. Chapter 10, the last chapter, gives an account on the merits and demerits of the model, which is then followed by a suggestion of further work to be done for improving the effectiveness of the model.
CHAPTER 2 --- CURRENT AVAILABLE WASTEWATER TREATMENT ALTERNATIVES

The wastewater treatment methods currently available are numerous. For the purpose of making a survey of them, they are categorized into eight groups so that the discussion can be made more systematically:

1. Clarification
2. Stabilization ponds
3. Aerated lagoons
4. Biofiltration
5. Activated sludge process
6. Small treatment plants
7. Land application
8. Tertiary treatment

Each group of the treatment methods will be discussed in the following sections.

2.1 Clarification

This is a physical form of treatment. A percentage of the insoluble pollutants will settle to the bottom under the influence of gravity when the wastewater is allowed to stand in a tank for a certain time (usually 2 to 6 hours). This method will remove only insoluble pollutants in wastewater. There are primary clarifiers and secondary clarifiers, the former allow settlement of pollutants to
occur prior to secondary / biological treatment, and the latter do so following secondary treatment. Usually, secondary clarification is classified as a part of secondary treatment. There are basically three types of clarifiers --- horizontal flow, radial flow and vertical flow. The radial flow clarifiers are most commonly used, particular for secondary clarification.

Primary clarification can remove about 60% to 70% of s.s. and 35% to 40% of BOD$_5$ of a preliminarily treated municipal wastewater$^{(23)}$. If the standard of effluent required is not high, this method of treatment is simple and cheap. It does not require very high technical skills of its operation and needs only small site area. However, attention has to be paid to the treatment and disposal of the settled solids (or primary sludge) in using primary clarification.

Pathogens in the wastewater settle partly to the sludge layer (in both primary or secondary clarifiers) either by direct sedimentation or by being adsorbed onto solids that are in the process of settling. In primary clarification, very little or no removal of virus (causing diseases such as diarrhoea, infectious hepatitis, yellow fever, etc.) is achieved$^{(9)}$. About 50% of removal of bacteria (causing diseases such as diarrhoea, cholera, typhoid, etc.) may be achieved in about 4 hours retention time$^{(9)}$. Protozoal cysts (causing diseases such as
diarrhoea, amoebic disentery, malaria, etc.) in the crude sewage can be reduced by 30% to 50%\(^{(3)}\). Helminth eggs (causing diseases such as human round worm and hook worm, fish-borne parasites (Clonorchiasis), bilharzia, filariasis, etc.) can also be removed by 50% to 70\(^{(9)}\).

2.2 Stabilization Ponds

Stabilization ponds are shallow, large area flat bottomed ponds surrounded by an earth dike. Natural physical and biological treatment processes occur in the ponds. Stabilization ponds may be classified as anaerobic ponds, facultative ponds and maturation ponds.

An anaerobic pond functions similarly to an open septic tank. It is deeper (up to 5 m) than the other two types of ponds, with retention time of about a day, and is usually used together with other forms of treatment as a pre-treatment process. Odours are a problem with anaerobic ponds, and efficiencies of treatment are generally low. The major \(\text{BOD}_5\) removal by an anaerobic pond, like primary clarification, is achieved through the removal of the suspended solids, as it is unreasonable to expect a crude anaerobic digestor such as a pond to further reduce the \(\text{BOD}_5\) of a relatively weak municipal wastewater\(^{(7)}\). Therefore, an anaerobic pond is usually designed as a primary settlement unit, but instead of desluding the settled solids (as in the case of clarifiers), they are
allowed to accumulate at the bottom of the pond and encouraged to stabilize anaerobically and so continual handling of sludge can be avoided.

Facultative ponds are typically 1 to 1.5 m deep and in them anaerobic breakdown occurs at the bottom layer while aerobic stabilization takes place at the top layer. They can be used alone but can also be used together with other types of ponds in series. If a facultative pond is used in series with other ponds, it must be put after an anaerobic pond and/or before a maturation pond. The oxygen necessary for biochemical oxidation at the upper layer of the pond is supplied by the photosynthetic activity of algae grown in the pond naturally and also by the direct adsorption of atmospheric oxygen through the air/water interface. Retention times range from 10 to 40 days, achieving up to 95% removal of BOD₅.

Maturation ponds are shallow fully aerobic ponds normally used to receive effluent from facultative ponds so that the effluent may be improved. They have a depth of about 1.5 m and retention times of 5 to 10 days. Maturation ponds are used principally to achieve the removal of excreted pathogens, especially faecal bacteria and viruses. The presence of predators (e.g. rotifers and various protozoa), algal competition, nutrient deficiencies, high D.O. concentration, high pH, and good sunlight penetration (ultraviolet radiation) are suggested.
to be the reasons for pathogen removal in maturation ponds(7). Besides pathogen removal, the ponds can be employed to further lower the concentration of $BOD_5$ and the s.s. in the wastewater. They also oxidize any remaining ammonia to nitrate (ie. nitrification), and lower the concentration of the soluble nutrients, nitrates and phosphates(7). These two nutrients are removed by anabolic uptake during the growth of algae and of other microorganisms. Phosphates are also removed by precipitation as hydroxyapatite \( [Ca_5(PO_4)_3OH] \) at high pH values (8.2 or above) developed as the result of photosynthesis(7).

Anaerobic ponds, facultative ponds and maturation ponds may be designed, as mentioned previously, in series so as to accomplish the more complete treatment of wastewaters. Anaerobic and facultative ponds are mainly designed for $BOD_5$ and s.s. removal, whereas maturation ponds mainly for pathogen destruction and effluent polishing. If large site area is readily available and land cost is low, stabilization ponds can be the most economic method of wastewater treatment. The degree of purification by ponds, both in terms of $BOD_5$ and pathogen, is high and they can withstand both organic and hydraulic shock loads due to large pond volume, long retention period and hence high buffer capacity. At the same time, they require only low capital and maintenance costs and need minimal technical skill and attention in their operation.
Another advantage of ponds over other forms of treatment is that they do not require continual sludge removal. Desludging is only required once in a considerable long period of time. An anaerobic pond needs desludging perhaps every 3 to 5 years, whereas a facultative pond may only need that every 10 to 15 years if it is preceded by an anaerobic pond\(^{(14)}\). However, climatic conditions are an important consideration, as ponds are much less efficient in cold weather when bacterial metabolism is slow; also the possibility of an ice cover exists. Another major disadvantage is that the effluent from a series of stabilization ponds will be heavily laden with algae. This can increase considerably the BOD of the effluent, sometimes by a factor of two to three\(^{(8)}\). Various techniques (e.g. sand filtration, dissolved-air flotation, rock filters, etc.) have been employed to remove algae from the effluent, but more attention is required in operating these techniques and a higher cost will be involved. If the reason for selecting stabilization ponds in treating wastewater is because of their simplicity and low cost in both construction and operation, the algal burden in the effluent is generally accepted as an unavoidable fact as a result of employing this treatment alternative.

A well designed pond system having a total retention time of 20 days will produce an effluent with complete elimination of protozoal cysts and helminth eggs, retaining only a very small fraction of excreted bacteria and
viruses. Bacteria and viruses can also be completely eliminated if a retention time of 40 days or more is allowed. Stabilization ponds, however, can be favourable sites for mosquito breeding, particularly in reeds and weeds near to the banks. Mosquitoes serve as vectors for diseases such as malaria, filariasis and yellow fever. Consideration must be given as to whether or not ponds may be employed as treatment alternatives if these diseases are endemic.

2.3 Aerated Lagoons

Aerated lagoons resemble small stabilization ponds (about 1/10 the size) but usually with surface mechanical aerators supplying oxygen for the biochemical mechanism taking place in the lagoons. They are more correctly considered as a simple modification of the activated sludge process (about 8 times the size of a conventional activated sludge plant) and without sludge return system. Primary settlement, as with stabilization ponds, is not necessary for aerated lagoon treatment system. Retention time for lagoons is 2 to 6 days and lagoon depths are 2 to 4 m. There are two types of aerated lagoons --- fully-suspended aerated lagoons and partially-suspended aerated lagoons.

In a fully-suspended aerated lagoon, all solids are kept in suspension by the surface aerators and therefore
secondary settlement is required. Settlement tanks (minimum retention of 2 hours) or maturation ponds (retention of about 2 days) are usually used as secondary settlement alternatives for such purpose. A pond should be preferred whenever land is available because it saves the necessity of continual sludge removal/handling and is easy to operate and maintain.

In a partially-suspended aerated lagoon, a lower rate of oxygen is added mechanically and a lower concentration of volatile solids is continually held in suspension. The mass of suspended solids again represents an embryonic mixed-liquor. Surface aerators can be put in a "tapered" fashion so that the section near the outlet of the lagoon will be most undisturbed, thus allowing it to require no secondary settlement in the design. Suspended solids concentrations of 50 to 100 mg/l are normally anticipated in the final effluent(8).

The two types of aerated lagoons can be put in series, normally with a fully-suspended one followed by a partially-suspended one(13,21). Retention times of the two lagoons can be expressed as dependent variables in equations with BOD₅ concentration of the intermediate effluent as the independent variable. The minimum total retention time of the two lagoons can be found by differentiating the total retention time with respect to the independent variable.
BOD$_5$ removal by aerated lagoons can be 90% or higher, depending on the length of retention time. For pathogen removal, the efficiency is somewhere in between that of stabilization ponds and conventional activated sludge treatment plants, aerated lagoons have a better pathogen removal capacity than activated sludge processes but a lower one than ponds$^{(9)}$. The pathogen removal efficiency of activated sludge will be discussed in Section 2.5.

2.4 Biofiltration

Biofiltration is a secondary treatment process and must be preceded by primary settlement. The biological (or percolating or trickling) filter is a circular or rectangular bed of graded medium, usually 40 to 60 mm coarse aggregate and about 1.8 m deep (or specially manufactured plastics with greater depth), contained in a brick or concrete structure. Settled sewage is periodically dosed onto the surface of the filter and trickles down over the surface of the medium. On these surfaces, a biological film is formed which oxidizes and hence purifies the settled sewage as it flows through. The loading of the filter is normally measured by either the "hydraulic loading" or the "BOD$_5$ loading". The hydraulic loading measures the volume, in m$^3$, of settled sewage that is applied to each cubic meter of the filter media per day. The BOD$_5$ loading measures the kilograms of BOD$_5$ applied per cubic meter of media per day. The BOD$_5$ loading is more
commonly used nowadays. For a conventional simple biofilter, a BOD$_5$ loading of between about 0.07 and 0.10 kg/m$^3$/day is applied$^{(20)}$. Thus, a simple biofilter plant needs quite a large volume of media and hence requires about 5 times the site area a conventional activated sludge plant does for treating sewage from the same population$^{(12)}$. It is, however, about 15 times smaller than a stabilization pond. Biofilters require sludge handling facilities which increase both the capital and the running costs of biofiltration plants.

Modifications to the above-described simple biofilters have tended to lower the volume of the filter media required (ie. to increase the BOD$_5$ loading). The modifications include the recirculation of effluent and the alternating double filtration techniques. In such cases, settled sewage can be dosed to the filters at a higher rate than simple biofiltration, up to about 0.24 kg BOD$_5$/m$^3$/day$^{(20)}$. In applying recirculation, a portion of the purified and settled effluent is returned to be mixed with the settled sewage and this mixed and diluted sewage is then dosed to the filter surfaces. In applying alternating double filtration, two filters are operated in series. The intermediate effluent from the first filter, after settlement, is applied to the second filter. At the end of a selected period (possibly a week) the order of the first and second filters is reversed. This system of alternating the two filters is continued indefinitely. In
using the modified forms of biofiltration, the land area requirement of the plant can be reduced to about 3 times the size of a conventional activated sludge plant\(^{(12)}\) due to the higher loading rate and the smaller volume of media required.

Percolating filters are quite efficient at removing \(\text{BOD}_5\) and s.s. (85% to 95%) from municipal wastewaters, but they do not appear to be efficient at removing viruses (only about 30% to 40%)\(^{(9)}\). Removal efficiency of about 85% for bacteria and protozoal cysts can be achieved by biofilters, but much lower removal rates for helminth eggs are reported\(^{(9)}\). In general, effluent from biofiltration satisfying "Royal Commission Recommendations" will be of poor microbiological quality and still be highly pathogenic. Tertiary treatment (see Section 2.8) may be the only way to help produce a good final effluent from a public health viewpoint.

If the requirement of the quality of the final effluent is not high, then the high-rate filtration can be applied. This is simply an increase in dosage rate (e.g. 1.11 kg \(\text{BOD}_5/\text{m}^3/\text{day}\)\(^{(8)}\) at the Dunstable Plant) to the filter. The sizes of the filter media used in this case will be larger so as to provide larger voids and hence reduce the chance of blocking and ponding. The high-rate filtration can also be facilitated by using plastic media (90% voids) in tall towers rather than the usual stone
media (40% voids) so that the loading rate can be as high as 2.0, 4.0 and even 6.0 kg BOD₅/m³/day (8,20). To obtain a better effluent in using high-rate filters, low-rate (simple) biofilters are sometimes put in series after them as secondary filters to further treat the intermediate effluent. Recirculation can be incorporated in such so-called double filtration systems (8).

2.5 **Activated Sludge Process**

Activated sludge process is a secondary treatment and therefore, similar to biofiltration, must be preceded by primary treatment. The settled sewage flowing into an aeration basin (also termed reactor or mixed-liquor tank) contains organic polluting material (BOD) which acts as a food supply to the micro-organisms in the sewage. In the presence of abundant air (or more correctly oxygen) supply, the micro-organisms metabolize the BOD, producing new microbial cells and at the same time reducing the organic pollutants. The mixed-liquor in the reactor is in the form of biological floc and is continuously transferred to a clarifier (secondary settlement) for gravity separation of the floc and discharge of the clarified effluent. A high percentage of the settled floc (termed secondary sludge) is returned continuously to the aeration basin for mixing with fresh settled sewage while a small percentage of it is surplus and is led to the sludge treatment and disposal facilities.
In the conventional activated sludge process, atmospheric oxygen is supplied by either surface-aeration (ie. mechanical agitation) or diffused-aeration to the settled sewage. This is carried out in the reactor which normally has a hydraulic retention time of approximately 6 to 10 hours. The biological floc (or activated sludge floc) which is kept suspended by agitation in the reactor consists mainly of a high concentration of micro-organisms which is responsible for the carbonaceous oxidation and the nitrification of the organic polluting material. An equilibrium is reached in the system such that the rate of organism growth is equal to the rate of organism decay and the rate of discharging surplus secondary sludge (6,15).

The suspension in the reactor, as previously mentioned, is then led to a secondary clarifier in which the secondary sludge (mainly living and dead micro-organisms) is allowed to settle. The supernatant from the secondary clarifier (or final effluent) is thus highly purified, usually attaining 95% or higher BOD₅ and s.s. removal with respect to the raw sewage incoming to the plant. The purpose of continually recycling a major part of the secondary sludge from the secondary clarifier back to the reactor is to ensure that a high concentration of micro-organisms (usually referred to as MLVSS or mixed-liquor volatile suspended solids) in the reactor is maintained. The surplus secondary sludge and the primary sludge are handled together in the sludge treatment and disposal facilities which must be provided with in an activated sludge plant.
The activated sludge process is therefore expensive due to two reasons: (1) power needed for continual supply of atmospheric oxygen to the reactors, and (2) provision of sludge handling facilities. In addition, a high technical skill is required in the operation of an activated sludge plant as D.O. concentration, MLVSS level in the reactor, discharge of surplus activated sludge and so on have to be carefully and effectively monitored so as to allow the process to run smoothly.

There are a number of modifications to the conventional activated sludge plants. They include high-purity oxygen plants, deep-shaft plants, oxidation ditches and packaged activated sludge plants (extended aeration or contact stabilization). The first two modifications will be discussed here. The last two fall into the category of small treatment plants and will therefore be discussed in the next section (ie. Section 2.6).

High-purity oxygen plants are activated sludge plants in which pure oxygen is supplied to reactors instead of air (ie. atmospheric oxygen). The reactors in these plants allow for much higher oxygen transfer efficiencies than in conventional air-based plants so that the rate of biological oxidation is accelerated and therefore power costs are substantially reduced (but at the expense of additional oxygen cost). They have a better adaptability to variation of sewage strengths, and possibly produce less
sludge than air-based plants\(^{(12)}\). The size of a pure oxygen plant is smaller so the resultant savings in capital cost may somehow offset the cost of the oxygen supply. High-purity oxygen plants are useful particularly to deal with relatively high strength wastes because of the increased rate of oxygen transfer. The disadvantages are that they require even a higher operation skill, besides a higher operation cost, than the conventional air-based plants. Also, with the enclosed UNOX-type plant, nitrification is rarely achieved in the process due to the effect of low pH value as a result of the presence of CO\(_2\) in the mixed-liquor\(^{(22)}\).

A deep-shaft plant consists of two vertical shafts (one called downcomer and one called riser) which are sunk 40 to 150 meters underground. Air is injected into the downcomer at a sufficient depth to cause the mixed-liquor to circulate at a velocity of 1 to 2 m per second\(^{(11)}\). The non-aerated section above the downcomer air injection position has a lower voidage and therefore a higher density than the corresponding section of the riser. The difference in density between downcomer liquid and riser liquid above the point of air injection produces a net driving force and hence the liquid motion in the shaft is maintained. High oxygen transfer efficiency can be achieved in deep shafts because of three reasons: (1) the high pressure (10 to 15 atmospheres) existed at the low part of the shafts, giving a 5 to 10 fold increase in
solubility of oxygen, (2) the high bubble contact time of the order of 3 to 5 minutes (compared to 15 seconds in conventional air-based reactors), and (3) the high level of turbulence in the process. Deepshafts are capable of treating sewage of high BOD strength and are more resistant to shock loads than conventional activated sludge plants. Because of the reduction of reactor volume due to their high treatment rate and of the saving in land area (shafts are usually less than 3 m in diameter although there is a tendency currently to build bigger ones), the disadvantage of their high construction cost may be offset if the land cost is high. The capital saving increases with the increase in plant size. Power consumption by deepshafts compares favourably with conventional air-based plants. Lower sludge production rate is achieved. Also, no primary treatment is required for deep-shaft plants. It is, however, more difficult in separating sludge during secondary settlement (3), and it requires a very high standard of technical ability from the operators in order that the process be successfully monitored and controlled.

Activated sludge systems are more effective in removing viruses than trickling filters and up to 90% removal efficiency can be achieved (9). Similar efficiency is also reported for removing bacteria. In respect of the removal of helminth eggs and protozoal cysts the activated sludge process is, however, inferior to biofiltration, but a considerable proportions of the eggs may be removed in

20
the secondary clarifiers. On the whole, effluents from activated sludge plants are of marginally better quality than those produced by biofilters, but still contain significant numbers of any pathogen found in the raw sewage (9).

2.6 Small Treatment Plant

Small treatment plants are usually specially designed plants tailored to treat wastewaters from small communities of perhaps 5000 population equivalent or less. There are rotating biological contactors (or RBC), oxidation ditches and package activated sludge plants. The RBC is actually another form of fixed-film biological process, similar to biofiltration, while the other two are in fact modifications of the activated sludge process. They will be discussed in turn below.

Instead of dosing settled sewage onto stationary media (i.e. conventional biofiltration), rotating biological contactors use a moving media (rotating discs) to contact the "stationary" sewage contained in tanks. It is a form of secondary treatment process. Vertical discs (1 to 4 m in diameter) mounted on horizontal shafts are partially submerged in the sewage so that organisms may adhere to the discs surfaces where they multiply. Due to the rotation (0.5 to 3 revolutions per minute) of the discs, the biological slimes adhering to them are alternatively
exposed to the atmosphere and then to the wastewater, thus are provided with both fresh nutrient and an oxygen supply. Usually, several discs units (3 to 5) are put in series and plug-flow characteristics enhance the efficiency of the system. Secondary settlement is required after the process. RBCs are simple to operate and require little maintenance or supervision and hence require low operating and power costs. Capital costs can also be low in some parts of the world (e.g. Taiwan, Hong Kong and Thailand). With the increasing popularity of RBC plants, the discs are being manufactured through mass production (e.g. in China and Taiwan) so that the capital costs tend to go down substantially. Yet, they are capable of producing very good quality effluents. This treatment process is increasingly employed these days and the use of it is sometimes not limited to populations of less than 5000 persons. Pathogen removal by RBCs has not been studied but it is believed that it is about the same as for biofilters.

The Oxidation ditch is a modification of the activated sludge process. Aeration time for oxidation ditches is usually extended so that only a small quantity of surplus sludge is produced which requires handling. The ditches are race-course shaped tanks usually of about 1.5 m depth and between 2.5 to 4 m wide in which preliminarily treated crude sewage is aerated and circulated around. Hydraulic retention times are between 1 to 2 days. Conventional oxidation ditches (or Pasveer ditches) operate with
horizontally rotating aerators and were originally operated on periodic aeration, settlement and effluent withdrawal basis. Modifications such as "twin-spur", "split-channel" and "alternating double" Pasveer ditches\(^{(4,8,19)}\) were brought into use later to allow continual effluent withdrawal from the ditches without having any secondary settlement units. If secondary settlement is used, an oxidation ditch becomes an aeration unit of conventional activated sludge process and nearly all \((>95\%\)) the secondary sludge will be returned to the ditch. Carrousel ditches run with vertical rotors instead of horizontal ones, and have greater depths (usually 2 to 3 m) than Pasveer ditches\(^{(16)}\). They are usually constructed together with secondary clarifiers. In general, the advantages of oxidation ditches are that primary settlement is eliminated and that sludge production is low. Secondary settlement can also be avoided in the cases of twin-spur, split-channel and alternating double Pasveer ditches. The capital cost for an oxidation ditch plant is relatively low due to the facts that the ditch is a simple construction and that the machinery required is relatively simple. However, the process needs a little higher technical skill and attention to operate than RBC plants. The land area required is about 20 times less than that required by a stabilization pond\(^{(17)}\) or about 4 times more as that required by the conventional activated sludge process. The effluent usually has a pathogen content similar to that of the effluent produced by a conventional plant, although as
a result of the increased retention time slightly lower survivals may be achieved\(^9\). Oxidation ditches, like RBCs, are now sometimes used for populations larger than 5000.

Package plants are activated sludge based and therefore are also called package activated sludge plants. Pure oxygen system (see Section 2.5) can also be incorporated in a package plant (e.g. Vitox system of British Oxygen Company). The more usual types of package plants widely used nowadays are extended-aeration system and contact-stabilization system. The former requires long aeration time (24 to 48 hours) and the latter only half an hour in the first stage (for unsettled sewage) and then 4 hours in the second stage (for reaeration of settled activated sludge). These factory-built plants can achieve a high treatment efficiency and the performances are designed to be less sensitive to regular maintenance than conventional activated sludge plants\(^{17}\). Yet, the technical ability required to run these plants is still fairly high --- higher than both the RBC plants and the oxidation ditches. Saving in capital cost (but not operating cost), however, is possible because the components are standardized and produced in mass. Such plants are perhaps appropriate for small incoming sewage flows where conventional activated sludge treatment plant construction is not suitable. The pathogen removal efficiency for these plants has not been reported but it is
believed to be similar to that of conventional activated sludge process.

2.7 Land Application

Land application is any treatment technique which utilizes the interactions between natural soil and vegetation and wastewaters to upgrade the quality of the wastewater. It can be classified into three main techniques: irrigation, overland flow and infiltration / percolation (15).

For irrigation, wastewater is applied to the land; being either evaporated, transpired, incorporated into plants, or percolated into the subsoil. Primary sedimentation is the minimum preapplication treatment which is usually provided (15). Therefore, the wastewater applied to the land for irrigation usually passes through either a primary clarifier, septic tank or anaerobic pond before application. If the soil is suitable, salable crops may be grown and harvested, the income from which will partially offset the cost of treatment. The wastewater (or irrigation water) can be applied by spraying from fixed or moving sprinklers, by ridge-and-furrow spreading, or by border-strip flooding (8). The groundwater level must be at least 0.75 m from land surface (15).

For overland flow, wastewater is fed onto and allowed
to flow across gently sloping areas covered with natural vegetation but below which the subsoil is impervious. Primary treatment for the wastewater is optional in overland flow application\(^{(15)}\). Biological treatment occurs as the wastewater contacts with the vegetation and the soil. The treated wastewater is then collected in ditches at the lower end of the ground for either discharge or reuse. The vegetation produced is not usually harvested\(^{(18)}\), and grasses or pasture are usually preferred to cash crops as they are more deeply rooted and are more permanent in covering the land\(^{(8)}\). Groundwater level is not a critical factor when this technique is used\(^{(15)}\).

With the infiltration / percolation technique, wastewater is applied to permeable soils. Primary treatment, like irrigation, is usually necessary in applying this technique\(^{(15)}\). The treatment occurs as it percolates through the soil. Wells may be installed to intercept the treated wastewater which is then extracted for reuse. A high level of wastewater purification can be achieved by the method. Vegetation growth is usually not encouraged in this technique\(^{(18)}\). Groundwater level must be at least 3 m below the surface; lesser depths may be acceptable if underdrainage systems are provided\(^{(15)}\).

Loamy soils are best for irrigation; clays or clay-loams are best for overland flow; and well drained sandy soils are best for infiltration/percolation. Usually, a
very large land area is required in applying land treatment techniques. About 11 to 21 Ha per 1000 m$^3$/day is required for irrigation, 3 to 12 Ha for overland flow and 2 to 6 Ha for infiltration/percolation\(^8\). Therefore, the techniques require even a much larger area than stabilization ponds, which, for the same treatment capacity (ie. 1000 m$^3$/day), require about 1.5 Ha to 3 Ha of land. It should be noted that the constituents retained in the soil may accumulate to certain levels so that rest periods (about 2 to 3 weeks) are essential to allow the accumulated biodegradable organic matter to be broken down. It is possible that after a long period of time, when the toxic constituents retained in the soil have accumulated to intolerable levels, the land is no longer suitable for further wastewater application. This is another drawback of land application technique, besides the potential of creating polluted environment, ground water contamination and health hazards by improper management. Isolation from the public, therefore, is desirable when the techniques are used.

The land application techniques (all the three) are very efficient in BOD$_5$ and s.s. removals, and are efficient in removing nitrogen and phosphorus. Bacteria and viruses will also be removed\(^{18}\). Protozoa and helminths are not reported but it is believed that they will also be removed by passing through soils. On the whole, high pathogen removal efficiency can be achieved by the techniques. It is necessary to be aware, however, that land application
(especially irrigation) may lead to the creation of a foul and unsanitary bog if poorly managed, resulting fly/mosquito nuisance. A high level of technical control is therefore essential.

2.8 Tertiary Treatment

Tertiary treatment is a collective name given to the process used to improve the quality of secondary effluents from conventional treatment plants. BOD₅ and s.s levels of the secondary effluents can be substantially reduced following tertiary treatment. Rapid sand filtration is one of the tertiary treatment techniques and is usually applied in large treatment works. It has been conventionally operated at hydraulic loadings of between 120 to 140 m³/m²/day(14) but higher rates are now commonly employed. The filter consists of a bed of sand (1 mm to 2.5 mm grading) of about 1.5 m depth supported on an underdrainage system provided with facilities for back-washing. Reduction in s.s. ranges from 65% to 85% with an associated BOD₅ removal of about 50% from a secondary effluent(14). Because of the short retention time, little biological activity occurs and thus the technique is not expected to achieve much nitrification or pathogen removal.

Slow sand filtration, another tertiary treatment technique, which has been employed in small works, is operated at a hydraulic loading of only 3.5 to 7
m³/m²/day (24). The filters are usually about 0.5 m deep, consisting of a layer of sand resting on a layer of coarse aggregates which in turn rests on a system of drainage pipes. Construction is simple and hence cheaper than that of the rapid sand filter because no back-washing facilities are required. The land area needed, however, is very much larger than that needed by the rapid sand filter. Slow sand filters also require lower operation and maintenance costs and lesser attention than that for rapid filters. They can be expected to remove 65% to 90% of s.s. and 65% to 75% of BOD₅ from a secondary effluent (24). Significant biological activity occurs in these filters and therefore high pathogen removal efficiency (usually above 90%) can be achieved (24).

Microstraining, a tertiary treatment technique too, is good for removing s.s. but less good for BOD. Reported removals range from 35% to 75% s.s. and 12% to 50% BOD₅ (20). Little pathogen removal can be expected from microstraining. It is, therefore, not a very efficient "polisher" of secondary effluents from this point of view. The advantage of using microstrainers is that they need only very small installation space and can be easily placed under cover, thus rendering them suitable for large works.

Other tertiary treatment techniques include upward-flow clarification (pebble bed clarifiers), land treatment (overland flow on grass plots or infiltration for
collection in underdrains\(^{(9)}\) and maturation lagooning. Tertiary treatment processes were not originally designed for pathogen removal but for "polishing" secondary effluents, particularly for the removal of residual suspended solids. However, some of them (slow sand filtration, land treatment and maturation lagooning) do have very good pathogens removal characteristics.

Another advance in effluent polishing is the use of nitrifying filters. In certain treatment processes (e.g. high-purity oxygen system or deep-shaft) only carbonaceous oxidation is achieved but not nitrification. In order to upgrade the secondary effluent and to nitrify it completely, nitrifying filters may be employed. They are similar to conventional biofilters but are deeper (or taller), being about 3.5 to 4 m in depth. The increased depth is acceptable because of the low content of the carbonaceous biodegradable material in the effluent applied to the filters which limits the demand for oxygen in the process compared with that of orthodox biofiltration. For the same reason, finer grades of media can be used in the filters. Nitrifying bacteria (different from those for carbonaceous oxidation) will grow on the media, but unlike conventional biofilters, blockage of filters as a result of excessive built-up of biological slime will rarely occur. It is supposed that the pathogen removal efficiency for nitrifying filters is low.
Other advanced tertiary treatment techniques include chemical clarification, recarbonation, activated carbon adsorption and regeneration, demineralization (reverse osmosis, electrodialysis and ion exchange) and so on\(^5,20\). Since these latter techniques are rarely necessary and generally not cost-effective for large scale use in treating municipal wastewater (at least in the context of this research), they will not be discussed and will not be considered in the proposed model contained in this thesis.

The above is a brief survey of existing wastewater treatment techniques which are commonly used. The formation of decision variables/treatment alternatives (see chapter 4) for the proposed optimization model will be based on these various techniques. In the next chapter (ie. Chapter 3), a survey of the existing treatment system optimization models will be made.
3.1 Linear Programming Optimization

There are quite a number of optimization approaches in wastewater treatment alternatives selection which have been developed over the past twenty-six years. Lynn, et al. (17) were the first, in 1962, who attempted to use the method of operations research or system analysis techniques to optimally select treatment processes for a wastewater treatment plant. In this first attempt, a linear programming model was used to optimize treatment alternatives at minimum total costs. From the result of the analysis, one may be able to select the most cost-effective treatment alternative or alternatives. The example given in this paper is most famous and historic and is therefore worthwhile to be reproduced in Fig. 3.1 below:

(Node 1: influent, Node 1: primary sedimentation with 850 gpd/ft², Node 2: primary sedimentation with 1700 gpd/ft², Node 3: activated sludge, Node 4: percolating filter, Node E: effluent)

Fig. 3.1: Linear Programming Model on Treatment Process optimization by Lynn, et. al.
The linear programming model for such a system is:

Minimize $T_C = \sum_{j=1}^{4} C_{jj'} (X_{jj'} \cdot \xi_j)$

subject to:

$\sum_{j} X_{ij} = X_I \quad ; \quad j = 1, 2$

$\sum_{i} X_{iE} \leq X_E \quad ; \quad i = 3, 4$

$\sum_{i} X_{ij} - X_{jj'} = 0 \quad ; \quad j = 1, 2, 3, 4$

$(1 - \xi_j) X_{jj'} - \sum_{k \neq j} X_{jk} = 0 \quad ; \quad j = 1, 2, 3, 4$

and $X_{ij} \geq 0$

where

$T_C = \text{total costs}$

$C_{jj'} = \text{cost to treat 1 kg of BOD applied to the jth process.}$

$X_{jj'} = \text{the quantity of BOD (in kg) applied to the unit process \(j\).}$

$X_{ij} = \text{the quantity of BOD (in kg) flowing from process \(i\) to process \(j\).}$

$\xi_j = \text{the fraction of BOD removal in process \(j\).}$

$X_I$ (influent BOD) and $X_E$ (effluent BOD standard) are given quantities.

The model can, of course, be solved by any one of the many computer packages available on the market for analyzing linear programming problems. The solution for the example was that only primary sedimentation with 850 gpd/ft$^2$ (Node 1) should be used for meeting the required standard with which the processing cost could be reduced to a minimum.
Lynn, after two years, in 1964, developed a further linear programming model\(^{(18)}\) for capital budgeting of sewage treatment plant construction. The objective of this model was to minimize treatment cost throughout the history of the project. The solution of the model indicated for each increment of time (a) the type and increment of treatment to be constructed, (b) the amount of funds available, (c) the amount of funds needed to be borrowed, (d) a per capita service charge, and (e) the schedule for investment of funds. It is more of a financial model than a process selection one and is therefore not to be further discussed.

3.2 Dynamic Programming Optimization

Linear programming techniques were soon found to be not a good tool for treatment processes optimization due to the fact that wastewater treatment formula, either rational or empirical, are usually non-linear. Dynamic programming, instead, began to gain popularity in this emerged field of interest.

In contrast to linear programming, there is no standard formulation of a specific dynamic programming problem\(^{(14)}\). It is a strategy of optimization that simplifies the decision-making process for a serial system (or system in stages). The procedures in dynamic programming suitable for analyzing wastewater treatment
serial systems can, however, be generalized as shown in Fig. 3.2(12):

\[ S(n-1)_{ij} - N \]
\[ X(n-1)_{ij} \]
\[ Y_{nij} \]
\[ S_{ni} \]
\[ N \]
\[ S(n-1)i \]
\[ S(n-2)i \]
\[ \ldots \]
\[ S2i \]
\[ S1i \]
\[ S0i \]
\[ X1j \]
\[ X2j \]
\[ \ldots \]
\[ Xnj \]

\( S = \) input state, \( X = \) decision variable, \( Y = \) return

Fig. 3.2: Diagrammatic Presentation of A Dynamic Programming Problem

Each step at which a decision is made is called a stage and there are \( N \) stages in the diagram. For each stage a return, \( Y_{nij} \) \( (n = 1, 2, \ldots N) \), serves as the objective function in the optimization. In wastewater treatment alternatives optimization, the objective is usually to minimize the treatment cost. According to the Bellman's principle of optimality (1), a serial system is optimized when its downstream components are suboptimized with respect to the feed they received from upstream.

Starting from Stage 1 (see Fig. 3.2), an input state \( S_{11} \) is assumed and held constant while the decision variable \( X_{1j} \) is varied. For each value of \( X_{1j} \), there will
be an associated return $Y_{1j}$. The minimum cost $m_{1j}$ is the minimum of the values of $Y_{1j}$ for different $X_{1j}$, and $m_{1j}$ is associated with decision $X_{1j}$. If the above procedure is repeated for a number of different input states $S_{1i}$, the result will be information that gives the minimum costs $m_{1j}$ as a function of the input state, and each value of $m_{1j}$ will have associated with it a decision $X_{1j}$.

After the suboptimization of Stage 1, Stage 2 must be suboptimized with respect to, firstly, the input state $S_{21}$. From the information, giving $m_{1i}$ as a function of $S_{1i}$, the value of $m_{1i}$ associated with each decision $X_{2j}$ made in Stage 2 can be found. The total return associated with each decision $X_{2j}$ is the return of Stage 2, $Y_{21j}$, plus the minimum return of Stage 1, $m_{1i}$. Having obtained $Y_{21j} + m_{1i}$ for a number of values of $X_{2j}$, the minimum value $m_{2i}$ (ie. minimum of $Y_{21j} + m_{1i}$) can be selected. If the procedure is repeated for a number of input states $S_{2i}$, the result will be information that gives the minimum costs of stages 1 and 2 together, $m_{2i}$, as a function of $S_{2i}$, with each value of $m_{2i}$ associated with it a decision $X_{2j}$.

The above will be repeated until all stages have been considered. When stage $N$ is reached, the result will give the minimum cost of the entire system as a function of the input state $S_{Ni}$. If $S_{Ni}$ is fixed (ie. a given quantity), the minimum overall process cost is also fixed and the optimal decision for stage $N$ and all the others are known.
Grady (12) gave an example, in his paper of 1977, of the application of dynamic programming to optimize an activated sludge process as shown in Fig. 3.3 below:

![Process Diagram](image)

Fig. 3.3: Process Optimization Using Dynamic Programming

The method of solution, as already described, can be expressed mathematically as follows (3, 4):

\[ Y_{nij} = Y_n(X_{nj}, S_{ni}) \]

where

\[ Y_n = \text{the cost function of nth treatment process} \]

\[ T_n = \text{the performance function of nth treatment process} \]

If \( Y \) = total system costs, then

\[ Y = \sum_{n=1}^{N} Y_{nij} \]

\[ = \sum_{n=1}^{N} Y_n(X_{nj}, S_{ni}) \]
If $B_m$ is defined as the total subsystem costs up to stage $m$ such that

$$B_m = \sum_{n=1}^{m} Y_n(X_{nj}, S_{ni}) ; \quad m=1,2,\ldots,N$$

then

$$B_m = B_m(X_{1j}, X_{2j}, \ldots, X_{mj}, S_{mi})$$

and

$$B_m = Y_m(X_{mj}, S_{mi}) + B_{m-1}(X_{1j}, X_{2j}, \ldots, X_{(m-1)j}, S_{(m-1)i})$$

Let $G_m(S_{mi}) \leq B_m(X_{1j}, X_{2j}, \ldots, X_{mj}, S_{mi})$ in which $G_m(S_{mi})$ is the optimal total $m$-stage subsystem costs with input $S_{mi}$ and

$$G_{m-1}(S_{(m-1)i}) \leq B_{m-1}(X_{1j}, X_{2j}, \ldots, X_{(m-1)j}, S_{(m-1)i})$$

Now, $G_m(S_{mi})$ can be expressed mathematically as:

Min

$$G_m(S_{mi}) = X_{mj}\{Y_m(X_{mj}, S_{mi}) + G_{m-1}(S_{(m-1)i})\}$$

or

$$G_m(S_{mi}) = X_{mj}\{Y_m(X_{mj}, S_{mi}) + G_{m-1}(T_m(X_{mj}, S_{mi}))\}$$

and for the entire system, the optimal treatment costs, $Y_{\text{min}}$, will be:

Min

$$Y_{\text{min}} = X_{Nj}\{(Y_N(X_{Nj}, C) + G_{N-1}(T_N(X_{Nj}, C)))\}$$

where $S_{Ni} = C = a \text{ given quantity (usually the quality of incoming sewage to plant)}$

In using dynamic programming, one trend has been to optimize the design of a single and prefixed system of treatment processes, such as Grady's work\(^{(12)}\). The other trend has been to optimize treatment systems by selection from among many alternative processes, such as the works by Chia & Krishnan\(^{(4)}\) (1969), Evenson, et. al.\(^{(11)}\) (1969), and Chia & DeFilippi\(^{(3)}\) (1970).
In Chia & DeFilippi's dynamic programming, percentage of BOD removal was used to be the input state $S_{2i}$ at stage 2 at which treatment alternatives were to be selected. Alternative treatment processes with a range of treatment efficiency for each process were used as the decision variables $X_{2j}$. The results obtained from the dynamic programming model would indicate the type of treatment alternative that would give the minimum total costs.

In Evenson's model, 11 alternative treatment processes were tested. They were: (a) sedimentation, (b) chemical precipitation, (c) chemical oxidation, (d) trickling filtration, (e) activated sludge, (f) aerated lagoon, (g) aerobic ponds, (h) facultative ponds, (i) anaerobic ponds, (j) spray irrigation, and (k) evaporation ponds. The model was applied a number of times to different flow conditions: plant sizes from 0.5 mgd to 8.0 mgd. In contrast to Chia & DeFilippi's model, percentage of BOD removal was used as decision variable $X_{nj}$ and s.s. as input state $S_{ni}$. The objective was, of course, to minimize total treatment costs.

3.3 Non-linear Programming Optimization

Another approach, besides linear programming and dynamic programming, for treatment processes optimization is non-linear programming (or called mathematical programming in general). Mathematical programming models
for optimizing problems involving treatment costs can be
generalized in the following format \((19)\):

\[
\text{Minimize } Z = f(X_1, X_2, \ldots, X_n) \quad \text{-------------------(0)}
\]

subject to

\[
g_1(X_1, X_2, \ldots, X_n) \leq L_1 \quad \text{-------------------(1)}
\]

\[
g_2(X_1, X_2, \ldots, X_n) \geq L_2 \quad \text{-------------------(2)}
\]

\[
\vdots \quad \vdots \quad \vdots \quad \vdots \quad \vdots
\]

\[
g_m(X_1, X_2, \ldots, X_n) = L_m \quad \text{-------------------(m)}
\]

Equation \((0)\), the objective function (or the cost function) is equal to the total costs of the wastewater treatment system. The total costs is the sum of the capital costs and the present worth \((21, 25)\) of the annual operation and maintenance costs for a given discount rate and time horizon \((24)\). The decision variables \(X_1, X_2, \ldots, X_n\) are quantities describing the system such as tank volumes, solids concentrations, detention times, and so on.

Equations \((1)\), \((2)\), \ldots, \((m)\) are constraint equations which set limits for the performance functions of the decision variables. They are derived from limitations on equipment, space and other scarce resources, effluent quality standard, and from mathematical descriptions (either rational or empirical) on various unit process performances.
Different researchers, such as Middleton & Lawrence (19) (1976), CIRIA (2,5,6,7) (1976), Lauria, et.al. (15) (1977), Craig, et.al. (8) (1978), Rossman (22) (1980), Narbaitz & Adams (20) (1980) and Dick (9) (1984), used different cost functions in formulating the objective function as well as different performance functions in formulating constraints. However, all models have a common feature that there is an objective function which minimizes total treatment costs followed by constraints which are mathematical expressions describing treatment performances and so on. These cost functions and performance functions can be found in the works by Smith (23) (1969), Lawrence & McCarty (16) (1970), U.S.E.P.A. (26) (1975), WRC (27) (1977), Craig, et.al. (8) (1978), and Hasit & Vesilind (13) (1981).

With the exception of Lauria's model which simply used the calculus of Lagrangian analysis for solutioning, all the models required the use of computer oriented optimization techniques such as Box-Complex algorithm (Craig, et.al.), RSSRSSR* (Narbaitz & Adams), and Powell's hill-climbing algorithm (CIRIA and Dick).

It is worthwhile to note that all non-linear programming models developed before Rossman (1980) were for optimizing the design of a single pre-structured stream of

* Random Search with Systematic Reduction of the Size of Search Region
treatment system. They were not used to optimize systems by selecting alternative treatment process streams. Only until Rossman and later researchers, the models developed were capable of selecting optimal treatment alternatives. This was accomplished by the introduction of zero-one decision variables in the constraints so the problems become one of non-linear integer programming. Assuming that there are $N$ stages in the treatment system with $J$ alternative treatment processes at any stage $i$ available for selection, and $z_{ij}$ be a decision variable whose value is 1 if alternative $j$ is chosen at stage $i$ and is 0 otherwise, then the mathematical formulation can be generalized in the following form:

\[
\text{Minimize } T_C = \sum_{i=1}^{N} \sum_{j=1}^{J} z_{ij} C_{ij}
\]

subject to

\[
X_{i+1} = \sum_{j=1}^{J} z_{ij} f_{ij}(X_i) \quad ; \quad i = 1,2,\ldots,N
\]

\[
S_i = \sum_{j=1}^{J} z_{ij} g_{ij}(X_i) \quad ; \quad i = 1,2,\ldots,N
\]

\[
X_{L+1} = \sum_{i=1}^{L} S_i
\]

\[
X_1 = X_0 + \sum_{i=L+1}^{N} S_i
\]

\[
\sum_{j=1}^{J} z_{ij} = 1 \quad ; \quad i = 1,2,\ldots,N
\]

\[
z_{ij} = 1 \text{ or } 0 \quad ; \quad i = 1,2,\ldots,N \quad \& \quad j = 1,2,\ldots,J
\]
where

\[ T_c = \text{total costs} \]

\[ L = \text{number of stages which belong to the liquid treatment (there is a stream of } L \text{ stages for liquid treatment and another of } (N-L) \text{ stages for sludge treatment while the sidestreams from sludge treatment are returned to head of the plant)} \]

\[ X_i = \text{influent quality to stage } i \]

\[ X_{i+1} = \text{effluent quality from stage } i \text{ (or influent quality to stage } i+1) \]

\[ S_i = \text{quality of sidestream from stage } i \text{ (to sludge treatment stream)} \]

\[ f_{ij} = \text{performance function describing how } X_i \text{ is changed to } X_{i+1} \text{ at stage } i \text{ if alternative } j \text{ is chosen} \]

\[ g_{ij} = \text{performance function describing how } X_i \text{ is changed to } S_i \text{ at stage } i \text{ if alternative } j \text{ is chosen} \]

\[ C_{ij} = \text{cost incurred by choosing alternative } j \text{ at stage } i \text{ (} C_{ij} \text{ is a function of } X_i \text{ and } X_{i+1} \text{)} \]

\[ X_0 = \text{incoming wastewater quality to the plant (given)} \]

The first two constraints express the stage-wise transformation of influent waste flows and the generation of sidestreams. The third constraint expresses the influent to the sludge treatment stream as the sum of the sludge sidestreams generated in the liquid treatment stream. The fourth constraint closes the loop by adding the sludge treatment sidestreams to the plant influent. The last two constraints model that only one alternative is chosen at each stage. Constraints on effluent discharges are not shown in the above but should be included in an
actual model so that the effluent standard is regarded as a fixed design parameter rather than a variable. A computer package called "EXECUTIVE" developed by U.S.E.P.A.\(^{(10)}\) was used by Rossman to solve the non-linear integer programming model and the optimal stream of treatment alternatives was found. Such an approach overcomes the limitation that the system structure (i.e., choice of treatment processes) be prefixed as it operates on a discrete set of candidate treatment alternatives.

3.4 The Proposed Model

An extensive survey on the development of treatment system optimization models has been made. A summary of it is shown on Fig. 3.4 (see next page). It can be seen that the accuracy and the degree of sophistication of the models increases with time as the theory of treatment and the mathematical tools for system analysis progress in the past twenty-six years. It is the opinion of the author that researchers who attempt to improve significantly the latest existing models based on the same techniques will most likely only waste their efforts in view of the already well developed state of the art. A break-through can be made only if a different mathematical technique (system analysis other than linear programming, dynamic programming or non-linear programming) or a different approach, if more basically, were applied.
<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>Technique</th>
<th>With treatment alternatives selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lynn, et.al.</td>
<td>1962</td>
<td>Linear programming</td>
<td>Yes</td>
</tr>
<tr>
<td>Chia &amp; Krishnan</td>
<td>1969</td>
<td>Dynamic programming</td>
<td>Yes</td>
</tr>
<tr>
<td>Evenson, et.al.</td>
<td>1969</td>
<td>Dynamic programming</td>
<td>Yes</td>
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<tr>
<td>Chia &amp; DeFilippi</td>
<td>1970</td>
<td>Dynamic programming</td>
<td>Yes</td>
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<td>1976</td>
<td>Non-linear programming</td>
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<tr>
<td>CIRIA</td>
<td>1976</td>
<td>Non-linear programming</td>
<td>No</td>
</tr>
<tr>
<td>Lauria</td>
<td>1977</td>
<td>Lagrangian analysis</td>
<td>No</td>
</tr>
<tr>
<td>Grady Jr.</td>
<td>1977</td>
<td>Dynamic programming</td>
<td>No</td>
</tr>
<tr>
<td>Craig, et.al.</td>
<td>1978</td>
<td>Non-linear programming</td>
<td>No</td>
</tr>
<tr>
<td>Rossman</td>
<td>1980</td>
<td>Non-linear programming</td>
<td>Yes</td>
</tr>
<tr>
<td>Narbaitz &amp; Adams</td>
<td>1980</td>
<td>Non-linear programming</td>
<td>Yes</td>
</tr>
<tr>
<td>Dick</td>
<td>1984</td>
<td>Non-linear programming</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Fig. 3.4: Summary of Treatment System Optimization Models
A common drawback of the existing models is that none of them considers other objectives besides minimizing cost. They are excellent models, of course, if cost minimization is to be achieved under perfect performance conditions for which can they be represented by a full set of mathematical relations. However, reality is more than a set of mathematical expressions. The questions now are: would it be possible to develop a model, though it may be one from a completely different approach, which considers other very basic factors affecting the optimal selection of treatment alternatives? Would it be possible to produce a model which includes some investigation into environmental, social, cultural etc. factors which are most important contributing factors towards successful plant performance? Could there be a model for preliminary selection of optimal treatment alternatives by considering, besides cost, the motives, drives, abilities and discipline of the people who construct, operate and use the treatment plant? The following chapters will describe a model of this kind and it is the hope of the author that it represents a breakthrough in both the approach and the application of treatment system optimization models.
PART 2

DEVELOPMENT OF MODEL
CHAPTER 4 --- PARAMETERS & DECISION VARIABLES

4.1 Problem Definition

In a similar manner to that employed in existing models, there are one set of parameters and one set of decision variables in the proposed model. The parameters are no longer merely flow rates, BOD or MLSS etc. but are more general or basic descriptions of technical, economic, social, environmental and cultural factors affecting the appropriate choice of treatment processes. The decision variables, likewise, are no longer just retention time or percentage of BOD removal etc. but are definite candidate treatment alternatives from which the optimum one is to be selected.

In the proposed model, the quantity and quality of influent and the effluent standard required will be given; the size and location of the site on which the plant is to be built will also be given. The problem is to select an optimal wastewater treatment alternative.

In the following sections, full sets of parameters and decision variables for the model will be discussed.
4.2 Parameters

4.2.1 Identifying and Describing The Parameters

There are 20 parameters in the model. They are:

1. Flow
2. Influent / Effluent
3. Size of site
4. Nature of site
5. Land cost
6. Local money for construction
7. Foreign money for construction
8. Local skill for construction
9. Community support
10. Power source
11. Availability of local material
12. Cost of operation and maintenance
13. Professional skill available for operation and maintenance
14. Local technical skill available for operation and maintenance
15. Administration set-up
16. Training
17. Professional ethics
18. Climate
19. Local water-borne diseases
20. Endemic vector-borne (water-related) diseases
Each of the parameter above is associated with a set of indicators which give detailed explanations on the relevance of the parameter. The indicators corresponding to each parameters are listed below:

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Flow</td>
<td>a. Maximum design flow</td>
</tr>
<tr>
<td></td>
<td>b. Variation in flow on daily basis</td>
</tr>
<tr>
<td></td>
<td>c. Variation in flow on long term basis (present and future)</td>
</tr>
<tr>
<td>2. Influent/Effluent</td>
<td>a. Strength of influent</td>
</tr>
<tr>
<td></td>
<td>b. Variation of influent strength on daily basis</td>
</tr>
<tr>
<td></td>
<td>c. Variation of influent strength on long term basis</td>
</tr>
<tr>
<td></td>
<td>d. Effluent standard required</td>
</tr>
<tr>
<td>3. Size of site</td>
<td>a. Size of land available</td>
</tr>
<tr>
<td></td>
<td>b. Possibility of future extension</td>
</tr>
<tr>
<td>4. Nature of site</td>
<td>a. Topography</td>
</tr>
<tr>
<td></td>
<td>b. Possibility of flooding</td>
</tr>
<tr>
<td></td>
<td>c. Proximity to sludge disposal facilities</td>
</tr>
<tr>
<td></td>
<td>d. Ground water level</td>
</tr>
<tr>
<td></td>
<td>e. Proximity to municipality</td>
</tr>
<tr>
<td>5. Land cost</td>
<td>a. Cost of land for plant construction</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>------------------------------------------</td>
</tr>
<tr>
<td>6.</td>
<td>Local money for construction</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Foreign money for construction</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Local skill for construction</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>Community support</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>Power source</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>Availability of local material</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>12.</td>
<td>Cost of operation and maintenance</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>13. Professional skill available for operation and maintenance</td>
<td>a.</td>
</tr>
<tr>
<td></td>
<td>b.</td>
</tr>
<tr>
<td>14. Local technical skill available for operation and maintenance</td>
<td>a.</td>
</tr>
<tr>
<td></td>
<td>b.</td>
</tr>
<tr>
<td>15. Administration set-up</td>
<td>a.</td>
</tr>
<tr>
<td>16. Training</td>
<td>a.</td>
</tr>
<tr>
<td></td>
<td>b.</td>
</tr>
<tr>
<td></td>
<td>c.</td>
</tr>
<tr>
<td></td>
<td>d.</td>
</tr>
<tr>
<td>17. Professional ethics</td>
<td>a.</td>
</tr>
<tr>
<td></td>
<td>b.</td>
</tr>
<tr>
<td>18. Climate</td>
<td>a.</td>
</tr>
<tr>
<td></td>
<td>b.</td>
</tr>
<tr>
<td>19. Local water-borne diseases</td>
<td>20. Endemic vector-borne (water-related) diseases</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>a. Infectious hepatitis</td>
<td>a. Yellow fever</td>
</tr>
<tr>
<td>b. Diarrhoeal diseases</td>
<td>b. Malaria</td>
</tr>
<tr>
<td>c. Cholera, typhoid</td>
<td>c. Filariasis</td>
</tr>
<tr>
<td>d. Amoebic dysentery</td>
<td></td>
</tr>
<tr>
<td>e. Human round worm and hook worm, fish-borne parasites (Clonorchiasis), Schistosomiasis (Bilharzia)</td>
<td></td>
</tr>
</tbody>
</table>

c. Length of dry season

d. Intensity and duration of sunshine

The above 20 parameters will be the basis for the selection of the most appropriate treatment alternative. The selection process will utilize a recently developed operations research technique named eigenvector prioritization which will be explained in the next chapter (Chapter 5). The most appropriate alternative is to be selected from a set of decision variables which are definite candidate treatment processes and will be described in Section 4.3.

4.2.2 Significance of The 20 Parameters

The parameters were selected based on (1) the experience of the author, (2) the ideas gained from reading
Parameters 1 to 4 are technical factors. The design flow (Parameter 1) affects significantly the choice of treatment methods. For example, a large flow (e.g. 100,000 m³/day) may not be suitable for treatment by small/package plants or stabilization ponds. On the contrary, a small flow (e.g. 100 m³/day) is not suitable to be treated by activated sludge deep shaft process. Variation in flow or shock flows can be accepted by certain treatment methods but vulnerable to others; the monsoon climate in some tropical situations can lead to shock flows if the combined sewerage system is used or if the separate sewerage system is poorly constructed (leakage). Treatment efficiency (Parameter 2) is an importance consideration too. Primary treatment, for instance, will not be able to satisfy the requirement if a high standard of treatment is required. Variation in strength of influent or shock loads can be more adaptable by some treatment methods but less by the others. This is particularly significant when the influent is a mixture of industrial and municipal wastewaters. Size of site (Parameter 3) is, without question, another very basic and essential technical consideration, as some treatment alternatives (e.g. stabilization ponds and land applications) cannot be applied in small sites. Nature of the site (Parameter 4) where the treatment plant is to be
built is also a technical factor. For example, a site with high ground water table is not suitable for constructing ponds or applying infiltration (land treatment), nor these alternatives are suitable to be adopted to build on sites which are not isolate enough. Whether the site is near to sludge disposal sites also affects the choice, for certain treatment alternatives (e.g. ponds) do not require regular sludge disposal and hence are more advantageous than other methods in that respect.

Parameters 5 to 7 are economic factors concerned with capital cost. Land cost (Parameter 5) is considered separately from construction costs (Parameters 6 and 7) because it may represent a significant part of the capital cost and so merits an individual consideration. If the land cost is high, those treatment methods requiring large land area (e.g. ponds and land treatment) are less suitable. High purity oxygen activated sludge or deep shaft plants which require much less land area are probably more appropriate in situations where land cost is extremely high. Local money for construction (Parameter 6) in general refers to the cost of civil engineering works incurred in local currency and that of equipment supplied locally to build the plant. Foreign money (Parameter 7) for purchasing imported equipment may form an important component of the construction costs for certain more sophisticated treatment alternatives. It is considered separately from the construction cost incurred in local
money because this parameter may be crucial for situations in which there is a lack of foreign currency or stringent control of foreign exchange.

Local skill for construction (Parameter 8) is a subjective factor because skill is something difficult to quantify. The complexity of the construction techniques required for building a wastewater treatment plant must be compatible with the level of the local skill available for the construction. This factor is important in order to avoid later troubles arising from bad construction (e.g. leakage etc.) when the plant is in operation.

Community support (Parameter 9) is a social factor. It is concerned with the attitude of the users of the treatment facilities, which, in some cases, is decisive for their successful operation. Whether or not the politicians are enthusiastic enough to improve such "less visible" infrastructure in the country? Whether or not the general public are willing to accept the facilities and to pay the price for living in a better environment in order that the recurrent expenditure for the latter can be covered? Are there any religious inhibitions and/or traditions which do not favour the choice of certain technology? These are factors which, though indirectly related to the problem, should be considered.

Parameters 10 to 14 are factors related to operation
and maintenance. The availability and reliability of power supply (Parameter 10) to the treatment plant are most basic to certain more advanced treatment techniques and are therefore of paramount importance as the selection criteria. The availability of local material and components (Parameter 11) is essential for plants to be built in remote sites, particularly in developing countries. The availability of construction materials (e.g. pipes, cement etc.) for plant maintenance and the ability to make locally the mechanical parts of the machinery used in the plant, or if not, the ease and speed of reordering them from places of origin or otherwise, can be significant in the smooth operation of a treatment plant. Operation and maintenance costs (Parameter 12) differ for different treatment alternatives. The more sophisticated treatment alternatives (e.g. high-purity oxygen plant) require much higher operation / maintenance costs than that of the less advanced ones (e.g. stabilization ponds), and therefore the former should be avoided when the funds are limited. It is not unusual that adequate funds are available for plant construction but not sufficiently for operation and maintenance (a one-time commitment is always easier than a long-term one). It is not uncommon that treatment plants do not work as planned, or do not function at all, largely due to the lack of continuing availability of operation and maintenance funds. There is a serious danger of placing too much emphasis on construction but neglecting maintenance of the
works already built. This parameter, therefore, should be one of the most important considerations in the appropriate technology selection. Professional and technical skill available for operation and maintenance (Parameters 13 and 14) are again subjective factors. These parameters must be considered because the level of the treatment technology chosen must be, similar to Parameter 8, compatible with the level of the skill of the professionals and the technicians who will look after the treatment plant. The two (ie. professional and technical) are considered separately because experience reveals that there are cases where good professionals do not always have good local technical supports and vice versa.

The ability of the local administration set-up (Parameter 15) which looks after the planning and the implementation (ie. design, construction and running) of the treatment plant is another factor that should not be ignored. Whether or not there is a good liaison between those responsible for planning and for implementation for situations where these two functions are not discharged by the same body is a question of some importance. For the administration set-up which implements, whether or not those who design and construct are sufficiently aware of the problems usually faced by those who support the operation and maintenance is again a vital question. (The effectiveness of the operation and maintenance arrangements is usually a more significant test of administrative
capability and poor maintenance performance is often the first signal that the administration set-up is inadequate. There are a number of additional questions that need to be considered too. Whether or not there are too many independent organizational set-ups with confused division of responsibility and authority over the implementation of the works? Whether or not those who are responsible for the supply of potable water and those for the treatment of wastewaters (the whole water cycle) are grouped under one administration? Whether or not there is a practicable legislation on water quality control with adequate enforcement of the legislation so that the design influent quality to the treatment plant will not be hampered by illegal industrial wastewater discharges? The answers to these questions will reflect whether or not the ability of the administration set-up will adequately support the work's operation. Obviously, the more sophisticated the technology of treatment is, the more effective the administration set-up will need to be.

Parameters 16 and 17 are socio-cultural factors. They are, of course, at present largely subjective factors. Training (Parameter 16) has only an indirect effect on successful plant operation but it has great long-term significance. Good plant operation must be supported by well trained staff. The education / training provided in the situation under consideration must be able to maintain / upgrade the professional / technical skill.
The fact that good training will ensure a continuing supply of good professionals and technicians for continual successful plant operation and also technology upgrading/improvement in the future is something which should not be neglected, particularly in a situation where the quality of training is declining. Professional ethics (Parameter 17) is a very sensitive parameter but is, indeed, very important in selecting appropriate treatment technology. Are the operating staff committed to their job? Do they incline to avoid responsibilities? Is it usual to find them taking unnecessarily long breaks for drinking coffee or doing irrelevant things during their working hours? On the other hand, is corruption a serious problem in the situation under consideration? Will the cost for purchasing foreign equipment, for instance, become unreasonably high or will the supply of materials be unnecessarily delayed as a result of corrupted administration? This parameter is therefore again a factor of paramount importance in the selection of appropriate treatment alternatives. It has been said that a less knowledgeable person with good ethics is no worse than a more knowledgeable one but without. The author completely agrees with this view.

Parameters 18 to 20 are environmental factors. Climate (Parameter 18) is an important consideration as certain treatment alternatives are only suitable in hot or dry climates. The prevalence of certain water-borne
diseases (Parameter 19) and/or vector-borne (water-related) diseases (Parameter 20) describes the general sanitary / health conditions of a given situation and so by considering these two parameters some treatment alternatives should be avoided and some be encouraged. For example, if cholera or typhoid (diseases due to bacteria) are causing health hazard in a particular situation, then perhaps percolating filtration should be preferred rather than activated sludge process (see page 15) in order that a higher percentage of bacteria can be removed. But if infectious hepatitis or diarrhoea (diseases due to viruses) are the hazard causers, then activated sludge process would be preferred to percolating filtration (see page 20) in order to remove viruses more effectively. However, treatment by stabilization ponds will be more effective for both bacteria and viruses removal than either percolating filtration or activated sludge process. In general, diseases described in Parameter 19 are transmitted mainly by contacting with waters, whereas those described in Parameter 20 are transmitted mainly by vectors. The former is significant if the effluent from the selected treatment process is likely to be in contact with people either directly or indirectly; the latter is significant if the treatment process is located near to where people live so the diseases will be easily transmitted to people by vectors. This may be a vital factor in deciding for or against the use of stabilization ponds.
The above is an initial discussion of the significance of the twenty parameters to the selection of appropriate wastewater treatment technology for a given situation. Further discussions on these parameters will be found in Section 6.3 of Chapter 6.

4.3 Decision Variables

The decision variables, as mentioned before, are sets of treatment alternatives. Altogether, 46 decision variables have been formulated. Where not otherwise stated, all of them are assumed to have included prior preliminary treatment and they are:

A. Stabilization Ponds

1. Facultative pond
2. Anaerobic pond + Facultative pond
3. Facultative pond + Maturation pond
4. Anaerobic pond + Facultative pond + Maturation pond

B. Aerated Lagoons

5. Fully-suspended aerated lagoon + Secondary settlement
6. Septic tank + Fully-suspended aerated lagoon + Secondary settlement
7. Anaerobic pond + Fully-suspended aerated lagoon + Secondary settlement
8. Fully-suspended aerated lagoon + Partially-suspended aerated lagoon
9. Septic tank + Fully-suspended aerated lagoon + Partially-suspended aerated lagoon

10. Anaerobic pond + Fully-suspended aerated lagoon + Partially-suspended aerated lagoon

11. Partially-suspended aerated lagoon

12. Septic tank + Partially suspended aerated lagoon

13. Anaerobic pond + Partially-suspended aerated lagoon

C. Biofiltration (humus tanks/final clarifier included)

14. Primary clarifier + Simple percolating filtration

15. Septic tank + Simple percolating filtration

16. Primary clarifier + Simple percolating filtration + Tertiary treatment

17. Primary clarifier + Percolating filtration with recirculation

18. Septic tank + Percolating filtration with recirculation

19. Primary clarifier + Percolating filtration with recirculation + Tertiary treatment

20. Primary clarifier + Alternating double filtration

21. Primary clarifier + Alternating double filtration + Tertiary treatment

22. Primary clarifier + High-rate filtration + Low-rate filtration

D. Activated Sludge Processes (final clarifier included)

23. Primary clarifier + Conventional activated sludge process

24. Septic tank + Conventional activated sludge process

25. Primary clarifier + Conventional activated sludge process + Tertiary treatment

26. Deep shaft
27. Deep shaft + Nitrifying filter
28. Primary clarifier + High-purity oxygen activated sludge process
29. Primary clarifier + High-purity oxygen activated sludge process + Tertiary treatment

E. Primary Settlement

30. Primary clarification
31. Anaerobic pond
32. Septic tank

F. Land Application

33. Primary clarifier + Land application
34. Septic tank + Land application
35. Anaerobic pond + Land application
36. Land Application

G. Small Plants (final clarifier included unless otherwise stated)

37. Primary clarifier + Rotating biological contactor
38. Septic tank + Rotating biological contactor
39. Primary clarifier + Rotating biological contactor + Tertiary treatment
40. Oxidation ditch without final clarifier
41. Oxidation ditch
42. Oxidation ditch + Tertiary treatment

H. Package Activated Sludge Plants

43. Package activated sludge plant
44. Package activated sludge plant + Tertiary treatment
4.4 Hierarchical Structure of Decision Variables

The hierarchy of the decision variables has, in fact, already been partly reflected in the above listings. A diagram (Fig. 4.1) is drawn to show the hierarchical structure:

![Hierarchical Structure of Decision Variables]

Fig. 4.1: Hierarchical Structure of Decision Variables

The category of A to H has been classified as shown in Section 4.3. The category of a to l is a further subdivision of the previous category. They are:
a. Stabilization ponds  
b. Fully-aerated lagoons + Secondary settlement  
c. Fully/Partially aerated lagoons  
d. Simple percolating filtration  
e. Modified percolating filtration  
f. Conventional activated sludge process  
g. Deep-shaft/High-purity oxygen processes  
h. Primary settlement  
i. Land application  
j. Rotating biological contactors  
k. Oxidation ditches  
l. Package activated sludge plants  

The last category, 1 to 46, consists of all the individual treatment alternatives which have been shown in Section 4.3.

In the optimization process, one can either select the most appropriate treatment alternative from the category of A, B, ...., H, or from the category of a, b, ...., l, or from the category of 1, 2, ...., 46. Examples will be given in Part III of this thesis.

Further discussions on the decision variables (or treatment alternatives) will be found in Section 6.5 of Chapter 6.
CHAPTER 5 --- MATHEMATICAL TOOL FOR THE MODEL

5.1 Theoretical Background

The operations research technique used in the proposed model is called, as already mentioned in Chapter 4, eigenvector prioritization (or analytic hierarchy process). This technique was invented by T.L. Saaty\(^4,8\) about ten years ago and the theory was then further developed by his student L.G. Vargas\(^11\) in some later years. As the technique is only recently developed and is applied here for the first time in civil/environmental engineering, it is worthwhile to give a very brief description of what the technique is before going on with discussing the application of it in the model.

5.1.1 Similarity Transformation

In matrix similarity transformation\(^{10,13}\), any \(n \times n\) square matrix \(A\) can be transformed, by applying \(Q^{-1}AQ\) (where \(Q\) is an appropriate matrix\(^{12,14}\) related to \(A\)), to either:

a) a \(n \times n\) diagonal matrix \(\Lambda\) if matrix \(A\) has \(n\) linear independent eigenvectors where:

\[
\Lambda = \begin{bmatrix}
\lambda_1 & 0 & \cdots & 0 \\
0 & \lambda_2 & \cdots & 0 \\
\vdots & \vdots & \ddots & \vdots \\
0 & 0 & \cdots & \lambda_n
\end{bmatrix}
\]

\((\lambda_1, \lambda_2, \ldots, \lambda_n\) are the eigenvalues of matrix \(A\))
or

b) a $n \times n$ Jordan matrix $J$ (a nearly diagonal one) if matrix $A$ is defective\(^{(13)}\) and has less than $n$ linear independent eigenvectors where:

$$J = \begin{bmatrix}
\lambda_1 & 1 & 0 & \cdots & 0 \\
0 & \lambda_2 & 1 & \cdots & 0 \\
\vdots & \vdots & \ddots & \ddots & \vdots \\
0 & 0 & \cdots & \cdots & \lambda_n
\end{bmatrix}$$

Since similarity transformation does not alter the rank\(^{(1)}\), $R(A)$, of the matrix $A$, therefore, the rank of $A$ is equal to that of $\Lambda$ and $J$, ie. $R(A) = R(\Lambda)$ or $R(A) = R(J)$.

By applying the rule\(^{(1)}\) in finding the rank of matrices $\Lambda$ or $J$, and hence $R(A)$, the following theorem can be deduced: if $A$ is any $n \times n$ square matrix and $R(A) = r$ for $r \leq n$, then $A$ has $r$ non-zero eigenvalues.

5.1.2. Pairwise Comparison Matrix

In assessing the relative weighting of $n$ alternatives, pairwise comparisons are used which mean that any particular alternative is not compared to all others simultaneously but rather one at a time. If the results of each and every pairwise comparisons on the relative weighting of the alternatives are known, the priority of the alternatives can be found by evaluating the priority vector of a matrix whose elements are the pairwise comparisons of the weightings. Suppose a set of $n$ alternatives are to be compared in pairs and the alternatives are denoted by $\text{Alt}_1$, $\text{Alt}_2$, $\ldots$, $\text{Alt}_n$ and
their individual weighting (assumed known) by $x_1$, $x_2$, $x_n$ respectively, then the pairwise comparisons may be represented by a $n \times n$ square matrix $A$ as follows:

$$
A = \begin{pmatrix}
1 & \frac{x_1}{x_2} & \ldots & \frac{x_1}{x_n} \\
\frac{x_2}{x_1} & 1 & \ldots & \frac{x_2}{x_n} \\
\vdots & \vdots & \ddots & \vdots \\
\frac{x_n}{x_1} & \frac{x_n}{x_2} & \ldots & 1
\end{pmatrix}
$$

The above is a positive reciprocal matrix, satisfying the conditions that all the elements are positive and that $a_{ij} = 1/a_{ji}$ where $a_{ij}$ and $a_{ji}$ are the elements of matrix $A$. If a column vector $X$ such that the elements of $X$ are $x_1$, $x_2$, $\ldots$, $x_n$ (ie. the individual weightings of $\text{Alt}_1$, $\text{Alt}_2$, $\ldots$, $\text{Alt}_n$) is introduced, then

$$AX = nX$$

and therefore $n$ is, by definition, an eigenvalue of matrix $A$ and the column vector $X$ an eigenvector corresponding to the eigenvalue $n$. The rank of matrix $A$, $\text{r}(A)$, is equal to 1 as the matrix has all rows equal to each other after applying elementary operations(1) to it. By the theorem mentioned at the end of Section 5.1.1, it can be deduced that matrix $A$ has only one non-zero eigenvalue, and this eigenvalue is equal to $n$. This point is confirmed by the fact that the trace of matrix $A$ is equal to $n$, that is, $\text{Tr}(A) = n$. As matrix $A$ is a positive matrix and by the
Perron-Frobenius Theorem\(^{(2,9)}\), it is also known that \( n \) is the maximum eigenvalue of \( A \) and that there exists an eigenvector, \( X \) (the same \( X \)), which has positive components and is the solution eigenvector of \( AX = \lambda X \) for taking \( \lambda = n \).

5.1.3 Inconsistency in Reality

The theories contained in Section 5.1.2 are based on the assumption that all entries of the positive reciprocal matrix \( A \) are consistent which means that \( (a_{ij})(a_{jk}) = a_{ik} \), or \( (x_i/x_j)(x_j/x_k) = x_i/x_k \). Such perfect consistency is possible only if we can construct matrix \( A \) based on the weightings of individual alternatives (ie. \( x_1, x_2, \ldots, x_n \)). However, in the application of the technique, this will not be the case, that is, one can only construct matrix \( A \) first and then find out the values of \( x_1, x_2, \ldots, x_n \). This will create inconsistency in the reciprocal matrix. The following will explain why it is so.

Just take a simple example of comparing three alternatives. If the relative weighting of \( \text{Alt}_1 \) and \( \text{Alt}_2 \) is estimated to be 3 and that of \( \text{Alt}_2 \) and \( \text{Alt}_3 \) to be 2, it is not necessarily true that, in reality, the relative weighting of \( \text{Alt}_1 \) and \( \text{Alt}_3 \) will be \( 6 \) (ie. consistent case). Take an analogy of three football teams: if team 1 beats team 2 by 3:1 and team 2 beats team 3 by 2:1, it is not necessarily the case that team 1 will beat team 3 by 6:1,
and if not, inconsistency occurs.

When inconsistency occurs, the problem $AX = nX$ becomes one of $A'X' = \lambda_{\text{max}}X'$. For the positive reciprocal matrix $A'$, $\lambda_{\text{max}}$ will not be exactly equal to $n$ and all other eigenvalues will not be equal to zero. But from the Perron-Frobenius theorem, it is known that matrix $A'$ has a real positive eigenvalue with multiplicity of one which is equal to $\lambda_{\text{max}}$, whose corresponding eigenvector (or called priority vector) has positive components. This priority vector is not unique and its solutions differ by a multiplicative constant \(^{(14)}\). It is therefore desirable to have it normalized so that its components sum up to unity and when it is normalized it is unique.

It has been proved by Saaty \(^{(8)}\) that $\lambda_{\text{max}}$ is closer to $n$ when matrix $A'$ is closer to consistency (ie. $A'$ is consistent if and only if $\lambda_{\text{max}} = n$) and $\lambda_{\text{max}} > n$ always if $A'$ is inconsistent. The larger the $\lambda_{\text{max}}$ is, the more inconsistent the matrix $A'$ will be.

5.2 An Illustrative Example

An example given by Saaty \(^{(8)}\) is reproduced below to illustrate how this mathematical technique is applied.

Selecting a plan for vacation out of Philadelphia:

With a view to spending a week on vacation, four
places were evaluated in terms of the following criteria:

- **F₁**: Cost of the trip from Philadelphia
- **F₂**: Sight-seeing opportunities
- **F₃**: Entertainment
- **F₄**: Mode of travel
- **F₅**: Eating places

The places considered were:

- **S**: Short trips (i.e. New York, Washington D.C. etc.)
- **Q**: Quebec
- **D**: Denver
- **C**: California

The comparison matrix of the criteria with respect to overall satisfaction with a vacation plan is given by:

<table>
<thead>
<tr>
<th></th>
<th>F₁</th>
<th>F₂</th>
<th>F₃</th>
<th>F₄</th>
<th>F₅</th>
</tr>
</thead>
<tbody>
<tr>
<td>F₁</td>
<td>1</td>
<td>1/5</td>
<td>1/5</td>
<td>1</td>
<td>1/3</td>
</tr>
<tr>
<td>F₂</td>
<td>5</td>
<td>1</td>
<td>1/5</td>
<td>1/5</td>
<td>1</td>
</tr>
<tr>
<td>F₃</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>1/5</td>
<td>1</td>
</tr>
<tr>
<td>F₄</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>F₅</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1/5</td>
<td>1</td>
</tr>
</tbody>
</table>

The priority vector of the above positive reciprocal matrix, \( X_b \), after normalized, is given by:

\[
X_b = \begin{bmatrix}
0.09 \\
0.13 \\
0.23 \\
0.43 \\
0.13
\end{bmatrix}
\]

The comparison matrices of vacation sites with respect to the criteria are:
For $F_1$: Cost

<table>
<thead>
<tr>
<th>S</th>
<th>Q</th>
<th>D</th>
<th>C</th>
<th>(\lambda_{\text{max}} = 4.21 &gt; n = 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>1</td>
<td>3</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Q</td>
<td>1/3</td>
<td>1</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>D</td>
<td>1/7</td>
<td>1/6</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>C</td>
<td>1/9</td>
<td>1/7</td>
<td>1/3</td>
<td>1</td>
</tr>
</tbody>
</table>

Normalized priority \(X_1 = \begin{pmatrix} 0.08 \\ 0.30 \\ 0.58 \end{pmatrix}\)

For $F_2$: Sight-seeing

<table>
<thead>
<tr>
<th>S</th>
<th>Q</th>
<th>D</th>
<th>C</th>
<th>(\lambda_{\text{max}} = 4.34 &gt; n = 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>1</td>
<td>1/5</td>
<td>1/6</td>
<td>1/4</td>
</tr>
<tr>
<td>Q</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>D</td>
<td>6</td>
<td>1/2</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>C</td>
<td>4</td>
<td>1/4</td>
<td>1/6</td>
<td>1</td>
</tr>
</tbody>
</table>

Normalized priority \(X_2 = \begin{pmatrix} 0.12 \\ 0.38 \\ 0.45 \end{pmatrix}\)

For $F_3$: Entertainment

<table>
<thead>
<tr>
<th>S</th>
<th>Q</th>
<th>D</th>
<th>C</th>
<th>(\lambda_{\text{max}} = 4.06 &gt; n = 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>1</td>
<td>7</td>
<td>7</td>
<td>1/2</td>
</tr>
<tr>
<td>Q</td>
<td>1/7</td>
<td>1</td>
<td>1</td>
<td>1/7</td>
</tr>
<tr>
<td>D</td>
<td>1/7</td>
<td>1</td>
<td>1</td>
<td>1/7</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>7</td>
<td>7</td>
<td>1</td>
</tr>
</tbody>
</table>

Normalized priority \(X_3 = \begin{pmatrix} 0.52 \\ 0.06 \\ 0.36 \end{pmatrix}\)

For $F_4$: Node of travel

<table>
<thead>
<tr>
<th>S</th>
<th>Q</th>
<th>D</th>
<th>C</th>
<th>(\lambda_{\text{max}} = 5.38 &gt; n = 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>1</td>
<td>4</td>
<td>1/4</td>
<td>1/3</td>
</tr>
<tr>
<td>Q</td>
<td>1/4</td>
<td>1</td>
<td>1/2</td>
<td>3</td>
</tr>
<tr>
<td>D</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>1/3</td>
<td>1/3</td>
<td>1</td>
</tr>
</tbody>
</table>

Normalized priority \(X_4 = \begin{pmatrix} 0.19 \\ 0.41 \\ 0.21 \end{pmatrix}\)
For F₅: Eating

<table>
<thead>
<tr>
<th></th>
<th>S</th>
<th>Q</th>
<th>D</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Q</td>
<td>1</td>
<td>1</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>D</td>
<td>1/7</td>
<td>1/6</td>
<td>1</td>
<td>1/4</td>
</tr>
<tr>
<td>C</td>
<td>1/4</td>
<td>1/3</td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>

\[ \lambda_{\text{max}} = 4.08 > n = 4 \]

If a 4x5 composite matrix, C, is constructed by using the normalized priority vectors of X₁, X₂, X₃, X₄ and X₅ as columns given by:

\[
C = \begin{bmatrix}
0.58 & 0.06 & 0.36 & 0.21 & 0.43 \\
0.30 & 0.45 & 0.06 & 0.19 & 0.38 \\
0.08 & 0.38 & 0.06 & 0.41 & 0.05 \\
0.04 & 0.12 & 0.52 & 0.19 & 0.14
\end{bmatrix}
\]

then, the resultant (overall) priority vector for the vacation sites will be the result of C x X₅ and is equal to:

\[
\begin{bmatrix}
0.29 \\
0.23 \\
0.25 \\
0.24
\end{bmatrix}
\]

Therefore, the ranking of the four places obtained is:

S = 0.29  
Q = 0.23  
D = 0.25  
C = 0.24

and this shows that the four are almost equally preferred, with short-trips (ie. S) having a slight edge over the others.

In the proposed model of this research work, the parameters (see Chapter 4) are equivalent to the criteria in the example (ie. F₁, F₂, F₃, F₄ and F₅) and the decision
variables are equivalent to the vacation sites (i.e. S, Q, D and C). In the model, the decision variables will be ranked through the evaluation of the 20 parameters so that a resultant priority vector (or final ranking) for the decision variables will be obtained. This will be further discussed in detail in Chapter 6.

5.3 Suitability of The Mathematical Tool for The Model

5.3.1 Size of Problem

The objective of the proposed model is to prioritize a set of decision variables (or treatment alternatives) so that the best one can be selected by obtaining the ranking from the resultant priority vector. Since there are many parameters and treatment alternatives to be considered, it is extremely difficult, if not impossible, for a human brain to compare the treatment alternatives simultaneously and prioritize them through the consideration of all the 20 parameters without using techniques of system analysis. The mathematical technique just described provides one with a systematic procedure that facilitates comparisons and that not only is in harmony with but also supplements the insufficiency of intuition and human feelings over large problems.
5.3.2 Intangible Factors

Unlike the mathematical techniques used by existing models as described in Chapter 3, the proposed model, while applying this particular technique, enables one to consider intangible parameters (such as parameters 8, 9, 13, 14, 15, 16 and 17 identified in Chapter 4) which are believed to be most important in optimal treatment alternatives selection. This represents a break-through in the approach of the current techniques as all the existing treatment selection optimization models, using other mathematical tools, do not easily enable one to include such intangible factors in the selection process.

5.3.3 Inconsistency in Real Application

As seen in the example and the analogy given in Section 5.1.3, one must prepare to accept the fact that inconsistency will occur in the parameter matrix and the decision variables matrices if they are to be constructed in a way so as to be closer to reality. (Parameter matrix and decision variable matrices are to be discussed in detail in Chapter 6). For example, if parameter 4, say, is three times more important than parameter 6 and parameter 6 is twice as important as parameter 11, it is not necessary that parameter 4 be six times more important than parameter 11. The importance of parameter 4 over parameter 11 is only four instead of six (see Fig. 6.3 of Chapter 6). As a
matter of fact, improving consistency does not always mean getting an answer closer to reality\(^{(5,8)}\), and on the contrary, the reverse is true in some cases. In the application of the proposed model, inconsistency in the reciprocal matrices constructed should be allowed for if a more realistic result is desired.

One extraordinary feature of the proposed model is that, while applying the priority vector approach, it does not reject inconsistent input data but allows them to be taken in. However, one cannot allow the input matrices to be too inconsistent if the theory discussed in Section 5.1 is to be applicable. Hence, some form of mathematical technique must be used to test for consistency. L.G. Vargas, following T.L. Saaty, published a paper in 1982\(^{(11)}\) in which he illustrated that if the inconsistency of a positive reciprocal matrix is 10\% or less, it can be accepted that the result of the priority vector is reliable. The inconsistency of the reciprocal matrix can be measured by a consistency index, \(\mu\), which is defined as \((\lambda_{\text{max}} - n) / (n - 1)\). Such consistency testing will be further discussed and illustrated in Section 6.3 of Chapter 6.

In 1979, after Saaty but prior to Vargas, Johnson, Beine and Wang jointly published an article\(^{(7)}\) questioning the reliability of the eigenvector prioritization technique. They observed that disagreed results between a right eigenvector (i.e. \(AX = \lambda_{\text{max}}X\)) and a left eigenvector
(ie. $X^T A = \lambda_{\text{max}} X^T$) could sometimes be obtained by using the technique and they believed that there was no reason for a right eigenvector to yield a better solution than the left. This observation was interesting and such disagreement between the left and right eigenvectors is still not fully understood and is yet to be explained. However, the Johnson-Beine-Wang observation was based on random positive reciprocal matrices of a relatively high inconsistency. Vargas, three years later in 1982, as mentioned in the previous paragraph, proved that the result of the right priority vector be reliable if the inconsistency of the reciprocal matrix is 10% or less. Therefore, the data matrices for entering into the proposed model must be consistent enough to yield a reliable result. The model will automatically test every pairwise comparison matrix entered and will instruct the user to adjust it if a consistency higher than 10% is detected.

5.3.4 Measure of Differences in Priorities

The eigenvector prioritization technique can provide one with the knowledge from the resultant priority vector of how much one alternative is better than the others in exact scores. This has already been illustrated by the resultant priority vector in the example given in Section 5.2. Intuition and human feeling can never give such exact value of differences unless they are helped by systematic procedures, as what are being used in the proposed model.
5.4 Evaluation of Priority Vector

In the above discussions, it has been seen that $\lambda_{\text{max}}$ is the most important root of the characteristic polynomial equation \((3,13)\) of a pairwise comparison reciprocal matrix. It is the only eigenvalue that is required in the computation of the priority vector. The Power Method \((3,6)\), a method for finding the largest eigenvalue of a matrix, is used in the proposed model for evaluating $\lambda_{\text{max}}$, and hence the priority vector. As this method requires performing iterations, a computer sub-routine (see sub-routine 1.1 of Appendices B.1.2 and B.1.3) is written for finding $\lambda_{\text{max}}$ such that the loop will stop when the eigenvalues computed in the last two iterations differ by less than 0.1%. The computer program will store in a separate memory the result of the priority vector corresponding to the $\lambda_{\text{max}}$ calculated by the above sub-routine.

Now, the theoretical background for developing the proposed model has been discussed. In the next chapter, the details of the model will be described.
CHAPTER 6 --- THE MODEL

6.1 Hierarchy of Objectives and Alternatives

Consider a hierarchy of three levels\(^{(5)}\) shown in Fig. 6.1:

![Hierarchy Diagram]

- **Level 1**: Principal Objective (Optimal Treatment Alternative)
- **Level 2**: Subordinate Objectives (Parameters)
- **Level 3**: Alternatives (Decision Variables)

**Fig. 6.1: Hierarchy of Principal Objective, Immediate Objective and Alternatives**

As shown in Fig. 6.1, the first level has a single principal objective. The second level has \(m\) subordinate objectives (i.e. the parameters in this model) and their priorities are derived from reciprocal matrix of pairwise comparisons with reference to the principal objective of the first level. The third level has \(n\) alternatives (i.e. decision variables) which are to be prioritized. One has to determine how can the decision variables in Level 3 be ranked to meet the principal objective in Level 1 through the consideration of the \(m\) parameters given in Level 2 (\(m = 20\) in this case). The priority vector for the decision variables with respect to each parameter can be obtained...
from a pairwise comparisons matrix with reference to that single parameter as objective. Thus, \( m \) resultant priority vectors of Level 3 are obtained after considering all the parameters and then they are weighed by the priority vector of the second level to obtain a resultant priority vector (ie. overall ranking) of the decision variables. The procedures are described as follows:

**Step 1:** Construct a parameter matrix (called matrix \( B \)) of dimension \( m \times m \) with pairwise comparisons of the parameters with respect to the principal objective as the elements of \( B \). Then find the priority vector of matrix \( B \) and denote it by \( x_B \).

**Step 2:** If there are \( n \) decision variables (ie. treatment alternatives) to be ranked, a total of \( m \) reciprocal matrices \( A_i \) (\( i = 1,2,...,m \)) of size \( n \times n \) are to be formed, each of which consists of elements of pairwise comparisons of the \( n \) decision variables with respect to a single parameter as objective, that is:

\[
A_1 = \begin{bmatrix}
1 & 2 & \ldots & n \\
1 & & & \\
2 & & & \\
\vdots & & & \\
n & & & \\
\end{bmatrix}
\]

using parameter 1 as objective
Step 3: If $X_i$ ($i = 1, 2, \ldots, m$) is the priority vector of the corresponding $A_i$, then a $n \times m$ composite matrix $C$ is formed by taking $X_i$ as columns in $C$ in sequence such that:

$$C = [X_1, X_2, \ldots, X_m]$$

The resultant priority vector, $X_C$, is the result of the multiplication of matrices $C$ and $X_b$, that is:

$$X_C = C \times X_b$$

From the result of $X_C$, the ranking of the decision variables can be obtained. The optimal treatment alternative can be selected from the top of the ranking list.
<table>
<thead>
<tr>
<th>Intensity of Importance</th>
<th>Definition</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal importance</td>
<td>Two activities contribute equally to the objective</td>
</tr>
<tr>
<td>3</td>
<td>Weak importance of one over another</td>
<td>Experience and judgement slightly favour one activity over another</td>
</tr>
<tr>
<td>5</td>
<td>Essential or strong importance</td>
<td>Experience and judgement strongly favour one activity over another</td>
</tr>
<tr>
<td>7</td>
<td>Demonstrated importance</td>
<td>An activity is strongly favoured and its dominance is demonstrated in practice</td>
</tr>
<tr>
<td>9</td>
<td>Absolute importance</td>
<td>The evidence of favouring one activity over another is of the highest possible order of affirmation</td>
</tr>
<tr>
<td>2, 4, 6, 8</td>
<td>Intermediate values between the two adjacent judgements</td>
<td>When compromise is needed</td>
</tr>
</tbody>
</table>

Fig. 6.2: Scales of 1 to 9 for pairwise comparisons (a reproduction of figure from Chapter 3 of Saaty's book)

6.2 Scale of Pairwise Comparison

T.L. Saaty\(^{(5)}\) proposed a scale of values from 1 to 9 as shown in Fig. 6.2. With the use of such scale values, L.G. Vargas\(^{(7)}\) later further proved that the technique of eigenvector prioritization remains valid provided the inconsistency of the reciprocal matrix is 10% or less. The warnings given by Johnson C.R. et.al. (see Section 5.3.3 of Chapter 5) about the use of the technique can be neglected as the examples illustrating difficulties or disagreed
results quoted in their paper were in general of reciprocal matrices with inconsistency much higher than Vargas' recommendation.

It was recommended by Saaty that the number of alternatives to be ranked (n) should not be larger than 9 to maintain a reasonable consistency if the coefficients of the matrix were randomly entered\(^{(5)}\). Such a recommendation was made after he had carried out an experiment on randomly filled reciprocal matrices. In the experiment, he used 50 random reciprocal matrices for each n (order of matrix) tested and the n he used was ranging from 2 to 16. In other words, he tested 750 (ie. 50x15) random matrices. It was found that the consistency of nearly all the random matrices became poor when n exceeds 9.

In a random matrix, comparisons of alternatives are not made logically. For example, if Alternative 1 is 3 times more important than Alternative 2 for a certain objective, and Alternative 2 is 3 times more important than Alternative 3, then Alternative 1 should be, logically, 9 times more important than Alternative 3. But in the random matrix, it can happen that the coefficient of element 1-3 be 1/9 (ie. Alternative 1 be 9 times less important than Alternative 3) while the coefficients of elements 1-2 and 2-3 remain unchanged. This, however, can never happen, at least within the context of this research, if the comparisons of the alternatives are made in a realistic
Therefore, it is the author's suggestion that a reasonably good consistency can still be expected even if \( n \) is larger than 9 provided the coefficients are not entered randomly but are entered with realistic and logical comparisons, although limited inconsistency will still be expected even though comparisons are realistically and logically made. Such a suggestion can be proved by evaluating the consistency of a matrix whose \( n \) is larger than 9 and the result can then be compared with the Vargas' recommendation.

In the model, the parameter matrix is one of \( n = 20 \) — much greater than 9! The coefficients, however, are carefully, realistically and logically entered, and so its consistency is found to be good (see Section 6.3). The author's suggestion is hence supported. This parameter matrix will be discussed in detail in the next section below.

6.3 The Parameter Matrix

The parameter matrix is a 20x20 square matrix. Each and every one of the 20 parameters has been described in detail in Chapter 4. For easy reference, they are reproduced below (indicators are neglected to avoid complexity):
<table>
<thead>
<tr>
<th>Parameters</th>
<th>Description</th>
<th>No of Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Flow</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>Influent / Effluent</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>Size of site</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Nature of site</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>Land cost</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Local money for construction</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>Foreign money for construction</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>Local skill for construction</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>Community support</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>Power source</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>Availability of local material</td>
<td>2</td>
</tr>
<tr>
<td>12</td>
<td>Cost of operation and maintenance</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>Professional skill for operation and maintenance</td>
<td>3</td>
</tr>
<tr>
<td>14</td>
<td>Local technical skill for operation and maintenance</td>
<td>2</td>
</tr>
<tr>
<td>15</td>
<td>Administration set-up</td>
<td>1</td>
</tr>
<tr>
<td>16</td>
<td>Training</td>
<td>4</td>
</tr>
<tr>
<td>17</td>
<td>Professional ethics</td>
<td>2</td>
</tr>
<tr>
<td>18</td>
<td>Climate</td>
<td>4</td>
</tr>
<tr>
<td>19</td>
<td>Local water-borne diseases</td>
<td>5</td>
</tr>
<tr>
<td>20</td>
<td>Endemic local water-related diseases</td>
<td>3</td>
</tr>
</tbody>
</table>

Fig. 6.3 shows the coefficients of the parameter matrix which are pairwise comparisons on the relative importance of the parameters. $\lambda_{\text{max}}$ of the matrix is found to be 20.56. The consistency index $\mu$ (see Section 5.3.3)
<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<th>13</th>
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<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
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<td>⅔</td>
<td>⅔</td>
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</tr>
</tbody>
</table>

All lower triangular entries = $b_{ij}$

Fig. 6.3: The Parameter Matrix (i.e. Matrix B)
is obtained as follows:

\[
\mu = \frac{\lambda_{\text{max}} - n}{n-1} = \frac{20.56 - 20}{20 - 1} = 0.030 \quad \text{(ie. 3%)}
\]

As is within the acceptable limit recommended by Vargas\(^{(7)}\), it is assumed that the parameter matrix is good enough to give a reliable result after integrating with the other twenty decision variable matrices. The integrating exercise requires the use of a computer program due to the size and the complexity of the problem. A detailed description of the computer program will be given later in Section 6.4.

The pairwise comparisons of the parameter matrix given in Fig. 6.3 are made based on the author's knowledge and experience, and will be a built-in feature of the model (see Section 6.4 for details). This matrix is a subjective and original product of the author. The validity of his judgements will be revealed or confirmed from the the final results given by the model.

In the pairwise comparisons of the parameter matrix, the author has given a very high weighting to parameter 3 (ie. size of site). In Fig. 6.3, it can be seen that elements 3-10 and 3-11, say, are 3 and 9 respectively,
which means that parameter 3 has weak importance over parameter 10 (see Fig. 6.2) and that it has absolute importance over parameter 11. This parameter is regarded as being of very high importance because the size of the site is an absolute determinant of the appropriate alternative which one can select. The reason is simple: if a small and confined site in a densely populated area is given for building a STP it will be impossible for stabilization ponds or land application to be used as appropriate alternatives. With the exception of parameter 2, all the other eighteen parameters are not as absolute a determinant as parameter 3, although they are as well very important parameters (with, naturally, various degrees of importance). Parameter 2 (ie. influent / effluent) is also an absolute determinant. Since the effluent standard has to be met in a given situation, the treatment efficiency of the alternative selected must be able to satisfy the requirement. For example, it will be impossible for primary treatment alone to achieve a high percentage of pollutants removal, nor will it be possible to obtain a very high quality effluent if tertiary treatment is not used. Parameters 2 and 3, therefore, are regarded as the most important parameters among all and this has been reflected in the parameter matrix in Fig 6.3.

Parameter 10 (ie. power source) is the next most important parameter, just second to parameters 2 and 3. Elements 3-10 and 1-10, for instance, are 3 and $\frac{1}{3}$.
respectively, which means that parameter 3 is slightly more important than (ie. weak importance over) parameter 10 but parameter 1, on the other hand, is slightly less important than parameter 10. Power source is close to an absolute determinant because all treatment alternatives cannot be successfully operated without it. In essence, this parameter is as important as parameters 2 and 3, but since it is a changeable factor (the other two are not), it has been assigned a slightly lower weightage than the latter two.

The next most important parameters, then, are 1, 4 and 18 (ie. flow, nature of site and climate). The importance of these three parameters has already been discussed in Section 4.4.2 of Chapter 4. They are given high weightages because they are all unchangeable factors. Their level of significance, on the other hand, is lower than that of parameters 2, 3 and 10. This is because that parameters 1, 4 and 18 are not as absolute as parameters 2, 3 and 10. The following example will explain this statement: it is impossible for a stabilization pond to be built on a small site but is possible for it to be constructed in any climatic conditions, although it may not be an appropriate form of treatment in a certain type of climate (e.g. cold weather). Hence, parameter 3 (ie. size of site) is absolute and parameter 18 (ie. climate) is not so absolute.

The next most important parameters are 12, 17, 19 and
20 (ie. cost of operation and maintenance, professional ethics, water-borne and vector-borne diseases). Their importance has been explained in detail in Section 4.4.2 as well. As discussed in the Section, plant maintenance is always more difficult than plant construction and the most basic problem in plant maintenance is the availability of funds for such a purpose. Poor professional ethics stifle the successful operation of any plant and it is the feeling of the author that this parameter should be given a high weightage (the parameter matrix is a subjective product anyway). The spreading of diseases, either water-borne or vector-borne, should not be taken lightly because it can cause chain public health effects which may lead to unexpected big national losses. However, these four parameters, like parameters 1, 4 and 18, are not absolute ones, but on the other hand, unlike 1, 4 and 18, are changeable factors. Because of this reason, they (ie. parameters 12, 17, 19 and 20) are considered as less important than parameters 1, 4 and 18 (and parameters 2, 3 and 10 of course) but more important than the rest ten parameters.

The remaining ten parameters are 5, 6, 7, 8, 9, 11, 13, 14, 15 and 16. Out of the ten, parameters 5, 6 and 7 (ie. land cost, costs of construction in local and foreign currency), are given slightly higher weightage than the other seven. This is because that the availability of construction funds is nevertheless important. Without it,
<table>
<thead>
<tr>
<th>Parameters</th>
<th>Description</th>
<th>( x_b )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Flow</td>
<td>0.0812</td>
</tr>
<tr>
<td>2</td>
<td>Influent / Effluent</td>
<td>0.1828</td>
</tr>
<tr>
<td>3</td>
<td>Size of site</td>
<td>0.1828</td>
</tr>
<tr>
<td>4</td>
<td>Nature of site</td>
<td>0.0585</td>
</tr>
<tr>
<td>5</td>
<td>Land cost</td>
<td>0.0240</td>
</tr>
<tr>
<td>6</td>
<td>Local money for construction</td>
<td>0.0187</td>
</tr>
<tr>
<td>7</td>
<td>Foreign money for construction</td>
<td>0.0216</td>
</tr>
<tr>
<td>8</td>
<td>Local skill for construction</td>
<td>0.0144</td>
</tr>
<tr>
<td>9</td>
<td>Community support</td>
<td>0.0144</td>
</tr>
<tr>
<td>10</td>
<td>Power source</td>
<td>0.1192</td>
</tr>
<tr>
<td>11</td>
<td>Availability of local material</td>
<td>0.0140</td>
</tr>
<tr>
<td>12</td>
<td>Cost of operation and maintenance</td>
<td>0.0386</td>
</tr>
<tr>
<td>13</td>
<td>Professional skill for operation and maintenance</td>
<td>0.0194</td>
</tr>
<tr>
<td>14</td>
<td>Local technical skill for operation and maintenance</td>
<td>0.0160</td>
</tr>
<tr>
<td>15</td>
<td>Administration set-up</td>
<td>0.0165</td>
</tr>
<tr>
<td>16</td>
<td>Training</td>
<td>0.0165</td>
</tr>
<tr>
<td>17</td>
<td>Professional ethics</td>
<td>0.0353</td>
</tr>
<tr>
<td>18</td>
<td>Climate</td>
<td>0.0556</td>
</tr>
<tr>
<td>19</td>
<td>Local water-borne diseases</td>
<td>0.0353</td>
</tr>
<tr>
<td>20</td>
<td>Endemic local water-related diseases</td>
<td>0.0353</td>
</tr>
</tbody>
</table>

Fig. 6.3(a) : Normalized Priority Vector of Parameter Matrix
there will be no need of any selection. The remaining seven parameters (i.e. local skill for construction, community support, local material, professional and technical skill for operation and maintenance, administration set-up, training) are all playing a supporting role to the successful plant construction and operation. They are changeable and are not absolute determinants. Therefore they are given the lowest weighting. Nevertheless, their importance assigned in the parameter matrix is significant enough to affect the choice of appropriate technology in the ranking process.

6.4 The Computer Program

The computer program is written based on the mathematical theories described in Chapter 5 and the procedures already described in this chapter. The parameter matrix, as described in Section 6.3, is a built-in feature of the model and is stored in a separate file named "PARAMAT". Users do not have to know what the values are inside the parameter matrix when they use the model. They only have to input matrices $A_1, A_2, \ldots, A_{20}$ (see Section 6.1) into the computer. Users may choose the number of decision variables, $n$, to be ranked, that is, if decision variables in category A, B, C, \ldots (see Fig. 4.1 of Chapter 4) are to be ranked, then $n$ is put equal to 8 (see Section 7.3 of Chapter 7); if decision variables in category a, b, c, \ldots are to be ranked, then $n$ is put
equal to 12 (see Section 7.4 of Chapter 7); and so on. Due to the limitation on the sizes of the input matrices, it is recommended that the number of decision variables taken should not be greater than fifteen (ie. \( n \leq 15 \)), although the model will still work, probably with lesser accuracy, if \( n > 15 \). The 46 decision variables at the lowest category (Fig. 4.1) can be easily cut down to 15 or less using a simple screening process which will be illustrated in Section 7.5 of Chapter 7. The computer program is written\(^1\) in BASIC language\(^3,4\) on an IBM personal computer\(^6\). As the program requires a considerable amount of memory space, it can be run on a PC (or XT or AT) only after it is compiled by an IBM BASIC compiler\(^2\). The IBM personal computer was chosen because it is believed to be most convenient and easily accessible by all prospective users and this should be so for a number of years to come.

A flow chart of the program and a listing of it are given in Appendices B.1.2 and B.1.3 respectively. A users' manual of the program is given in Appendix B.1.1.

It should be noted that elements of the decision variable matrices should be entered in six decimal places, but they will be shown afterwards on the screen in three decimal places (see users' manual in Appendix B1). This however, will not affect the accuracy of the calculation in which data of six decimal places will be used throughout.
After the program is run once, twenty new data files (i.e. decision variable matrices) named PARA1.LIQ, PARA2.LIQ, ..., PARA20.LIQ will be formed if they were originally not existing. In addition, two files named "COMPOMAT.LIQ" and "REPORT.LIQ" will also be formed --- the former stores the data of the composite matrix C (see Section 6.1) and the latter stores a record of all interactions between the user and the computer when the model was in use. Once can view at the contents of these files by using the 'TYPE' command.

6.5 Decision Variable Matrices

6.5.1 Matrix Construction

The construction of the decision variable matrices is done according to the same principle which is used in constructing the parameter matrix. The scales as shown in Fig. 6.2 are adhered to as well. As already mentioned in Section 6.1, a total of 20 reciprocal decision variable matrices will be formed for each situation under test as the number of parameters considered in the model is 20. Each decision variable matrix consists of elements of pairwise comparisons of the n decision variables with respect to a single parameter as objective where n is the number of decision variables to be ranked. For the situation of Malaysia under test, n is equal to 8 (see Section 7.3 of chapter 7 and Section 8.1 of Chapter 8).
Therefore, there are twenty 8x8 decision variables matrices constructed in this test. As an illustrative example, let us take a look at the 8x8 decision variable matrix for parameter 12 shown in Section 8.1. For easy reference, this matrix is reproduced hereunder in Fig. 6.4.

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<th>Bio-</th>
<th>A.S.</th>
<th>Primary</th>
<th>Land</th>
<th>Small Package</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pond</td>
<td>Lagoon</td>
<td>filter</td>
<td>Process</td>
<td>Treatment</td>
</tr>
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<td>Pond</td>
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<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Lagoon</td>
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<td>4</td>
<td>1</td>
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<tr>
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<tr>
<td>Treatment</td>
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</tr>
<tr>
<td>All lower triangular elements = a_{ij}</td>
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<td></td>
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</tr>
<tr>
<td>Land</td>
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<tr>
<td>Plant</td>
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</tr>
</tbody>
</table>

Fig. 6.4: Decision Variable Matrix for Parameter 12 (Malaysia)

Parameter 12 is the cost of operation and maintenance. Therefore, as far as the cost of O & M is concerned, a stabilization pond is slightly cheaper (and hence better) than an aerated lagoon. Element 1-2 entered is therefore equal to 3. If a pond is compared to an activated sludge plant, the former is significantly cheaper to operate and maintain than the latter, and hence element 1-4 is entered.
as 5. This principle is used for entering all the elements in the matrix, and the author calls this the first principle, which is simple but basic in the theory of eigenvector prioritization.

However, elements 1-2 and 1-4 entered as 3 and 5 must be done with a knowledge of the economic situation of Malaysia in question. If the alternatives are to be considered in another situation (ie. a place other than Puchong of Malaysia), the entries for the matrix will not be the same. For instance, the decision variable matrix for the same parameter (ie. parameter 12) for Hong Kong situation will be quite different. For easy reference, this parameter (shown in Section 8.4.1 of Chapter 8) is reproduced hereunder in Fig. 6.5. It can be seen that in this case the pond is only very slightly better than the activated sludge process. Element 1-4 is 2 only for Hong Kong whilst the same element for Malaysia is 5. This is because that funds for operation and maintenance of a wastewater treatment plant are readily available in Hong Kong and that funds for such a purpose are less stringent in Hong Kong than in Malaysia. The author calls the principle described in this paragraph the second principle in constructing decision variable matrices. Matrices of parameter 5 (ie. land cost) for Malaysia and Hong Kong situations reveal another example of this principle. In other words, the degree of influence to the selection of the appropriate treatment alternative due to a particular
parameter is reflected by the values entered. If the parameter is a pressure point in a given situation, the values in the decision variable matrix will be high and vice versa.

<table>
<thead>
<tr>
<th></th>
<th>Bio-</th>
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<th>Land</th>
<th>Small Package</th>
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<td>1</td>
<td>2</td>
<td>1</td>
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<td>Lagoon</td>
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<td>1</td>
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</tr>
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</tbody>
</table>

Fig. 6.5: Decision Variable Matrix for Parameter 12 (Hong Kong)

There is a third principle also. If the decision variable matrices of Parameters 13 and 14 of Thailand are compared (see Section 8.2), it can be observed that the relative importance of the decision variables are basically the same for the two parameters but the scores entered in parameter 14 is slightly higher than those in parameter 13. This is because of the fact that the technical skill
available in that situation is inferior to the professional skill available (see Appendix C.3.2).

Therefore, the first principle is intra-matrix oriented; the second principle is inter-situations oriented; the third principle is inter-matrices and intra-situation oriented. In constructing the decision variable matrices, these three principles are used throughout.

6.5.2 Comparison of Decision Variables Using Each Parameter as Objective

Various kinds of treatment alternatives have been described in Chapter 2. Their merits and demerits with respect to certain parameters have been mentioned in that chapter. Section 4.2.2 of Chapter 4 has also included some discussions on the same topic. Since the subject has been partly covered in the above two places, the author is not going to enter into it too deeply in this section. A summary only will be given in the following pages.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Stabilization Ponds</th>
<th>Aerated Lagoons</th>
<th>Bio-Filtration Process</th>
<th>A.S. Process</th>
<th>Primary Treatment</th>
<th>Land Treatment</th>
<th>Small Plants</th>
<th>Package A.S. Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Flow</td>
<td>not suitable</td>
<td>not suitable</td>
<td>suitable</td>
<td>suitable</td>
<td>not</td>
<td>suitable</td>
<td>suitable</td>
<td>suitable</td>
</tr>
<tr>
<td></td>
<td>for large flow</td>
<td>for very large</td>
<td>for small and medium</td>
<td>for medium</td>
<td>for any</td>
<td>for small</td>
<td>for small</td>
<td>for small</td>
</tr>
<tr>
<td></td>
<td>resistant</td>
<td>flow; not</td>
<td>flow; resistant</td>
<td>flow; not</td>
<td>resistant</td>
<td>flow; not</td>
<td>resistant</td>
<td>flow; not</td>
</tr>
<tr>
<td></td>
<td>to shock flow</td>
<td>quite resistant</td>
<td>to shock flow</td>
<td>quite resistant</td>
<td>resistant</td>
<td>to shock flow</td>
<td>resistant</td>
<td>to shock flow</td>
</tr>
<tr>
<td></td>
<td></td>
<td>to shock flow</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Influent/Effluent</td>
<td>treatment efficiency is quite high; resistant to shock load</td>
<td>treatment efficiency is quite high; resistant to shock load</td>
<td>treatment efficiency is low; resistant to shock load</td>
<td>treatment efficiency is high; resistant to shock load</td>
<td>treatment efficiency is high; not quite resistant to shock load</td>
<td>treatment efficiency is high; resistant to shock load</td>
<td>treatment efficiency is high; not quite resistant to shock load</td>
<td>treatment efficiency is high; not quite resistant to shock load</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Size of site</td>
<td>very large</td>
<td>large</td>
<td>moderately large</td>
<td>small</td>
<td>very small</td>
<td>extremely large</td>
<td>moderately</td>
<td>moderately small</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Nature of site</td>
<td>low water; must be isolate; no sludge disposal; no flooding</td>
<td>low water; must be isolate; is sludge disposal essential</td>
<td>low water; must be isolate; is sludge disposal essential</td>
<td>low water; must be isolate; is sludge disposal essential</td>
<td>low water; must be isolate; is sludge disposal essential</td>
<td>low water; must be isolate; is sludge disposal essential</td>
<td>low water; must be isolate; is sludge disposal essential</td>
<td>low water; must be isolate; is sludge disposal essential</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Land cost</td>
<td>Very high</td>
<td>high</td>
<td>quite</td>
<td>low</td>
<td>very low</td>
<td>extremely high</td>
<td>moderately</td>
<td>moderately high</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Local money for construction</td>
<td>low</td>
<td>moderately low</td>
<td>moderately high</td>
<td>high</td>
<td>low</td>
<td>moderately low</td>
<td>moderately high</td>
<td>high</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Foreign money for construction</td>
<td>very low</td>
<td>low</td>
<td>moderately can be</td>
<td>low</td>
<td>low</td>
<td>moderately can be</td>
<td>low</td>
<td>moderately high</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>low high</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Local skill for construction</td>
<td>low</td>
<td>moderately low</td>
<td>moderately very high</td>
<td>low high</td>
<td>low</td>
<td>moderately high</td>
<td>low</td>
<td>high</td>
</tr>
</tbody>
</table>

98
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Stabilization Ponds</th>
<th>Aerated Lagoons</th>
<th>Bio-Filtration</th>
<th>A.S. Process</th>
<th>Primary Treatment</th>
<th>Land Treatment</th>
<th>Small Plants</th>
<th>Package A.S. Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>9. Community support</td>
<td>can easily obtain support; may be disliked due to religious reasons</td>
<td>not difficult to obtain support</td>
<td>moderately difficult to obtain support</td>
<td>difficult to obtain support</td>
<td>not too difficult to obtain support</td>
<td>not difficult to obtain support</td>
<td>moderately difficult to obtain support</td>
<td>difficult to obtain support</td>
</tr>
<tr>
<td>10. Power source</td>
<td>least important</td>
<td>quite important</td>
<td>important</td>
<td>most important</td>
<td>quite important</td>
<td>quite important</td>
<td>important</td>
<td>important</td>
</tr>
<tr>
<td>11. Availability of local material</td>
<td>available</td>
<td>available</td>
<td>may not be too easily available</td>
<td>available</td>
<td>available</td>
<td>available</td>
<td>may not be too easily available</td>
<td>available</td>
</tr>
<tr>
<td>12. Cost of O &amp; M</td>
<td>low</td>
<td>quite low</td>
<td>average high</td>
<td>low</td>
<td>low</td>
<td>average high</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13. Professional skill for O &amp; M</td>
<td>very low</td>
<td>low</td>
<td>average high</td>
<td>low</td>
<td>quite high</td>
<td>low</td>
<td>average</td>
<td></td>
</tr>
<tr>
<td>14. Local technical skill for O &amp; M</td>
<td>very low</td>
<td>low</td>
<td>average high</td>
<td>low</td>
<td>quite high</td>
<td>low</td>
<td>average</td>
<td></td>
</tr>
<tr>
<td>15. Administration set-up</td>
<td>least important</td>
<td>moderately important</td>
<td>moderately important</td>
<td>important</td>
<td>not too important</td>
<td>moderately important</td>
<td>moderately important</td>
<td>moderately important</td>
</tr>
<tr>
<td>16. Training</td>
<td>least important</td>
<td>not too important</td>
<td>moderately important</td>
<td>very important</td>
<td>not too important</td>
<td>important</td>
<td>moderately important</td>
<td>important</td>
</tr>
<tr>
<td>17. Professional ethics</td>
<td>least important</td>
<td>moderately important</td>
<td>very important</td>
<td>moderately important</td>
<td>very important</td>
<td>moderately important</td>
<td>important</td>
<td>important</td>
</tr>
<tr>
<td>18. Climate</td>
<td>not suitable for cold climate; sunshine is essential</td>
<td>not</td>
<td>not</td>
<td>not</td>
<td>try</td>
<td>not</td>
<td>not</td>
<td>not</td>
</tr>
<tr>
<td>19. Local water-borne diseases</td>
<td>very good in pathogen removal</td>
<td>moderately good in pathogen removal</td>
<td>moderately bad in pathogen removal</td>
<td>extremely bad in pathogen removal</td>
<td>very good in pathogen removal</td>
<td>moderately bad in pathogen removal</td>
<td>bad in pathogen removal</td>
<td>bad in pathogen removal</td>
</tr>
</tbody>
</table>
St.~ilization

Pit neter

Ponds

20. t.duic
'e<tor-borne
'waterrelated)

,ery euy
to spread
the diseases

.i seases

Aerated
lagoons

BioA.S.
filtlltion ~

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to spread
di seases
spread the the
di seases
di seases

lOO

Priury
Treatlfn!

Land
Treahent

Stall
Plants

Package
A. S. PI ant s

least easy
to sprud
the
di seases

fltrelely
easy to
spread the
di seases

less easy
to sprud
the
diseases

less easy
to spread
the
diseases


PART 3

TESTING OF MODEL
7.1 Selection of Plants for Testing

The model can be tested by feeding into it data collected from actual wastewater treatment plants. By using data collected from an actual plant, the result that the model indicates (i.e., the most appropriate treatment alternative) can be compared with the real situation. Assuming that the model works satisfactorily, the result it gives should be more or less in agreement with the treatment process used by the plant if the latter works successfully, or it will indicate some other more appropriate treatment alternative if the plant works unsatisfactorily (if at all it works).

The next question then is which plants are to be chosen for the test? Without doubt they must be municipal wastewater treatment plants as the model is designed for ranking treatment alternatives for treating municipal wastewaters. They must also represent a wide spectrum of environmental and socio-cultural differences in which they were built. However, the number of plants and their locations used for testing must be within a practicable limit, although a wide spectrum of differences is desirable. Having considered all these factors, four existing sewage treatment plants were selected. They are:
1. Puchong Sewage Treatment Plant in Malaysia
2. Pattaya South Sewage Treatment Plant in Thailand
3. Min Shen Sewage Treatment Plant in Taiwan
4. Shatin Sewage Treatment Plant in Hong Kong

7.2 Collection of Data

The data were collected using questionnaires supported by site visits. There were three different questionnaires. The first one was of a general type, acquiring general information about sewerage systems and sewage treatment of a particular country (see Appendix C.1). This same questionnaire was given to university lecturers and practicing sanitation engineers of various countries in the south-east Asia with whom the author had had previous connections. The completed questionnaires were carefully studied so that a general picture of wastewater engineering in each country was known. In addition, each returned questionnaire provided the names and addresses of several sewage treatment plants in each of the countries so that further contact with individual treatment plants was made possible. Then, a second questionnaire, asking for much more detailed information about an individual plant (see Appendix C.2), was sent to all those treatment plants whose addresses were obtained from the first questionnaire. Less than 50% of the questionnaires sent were completed and returned. From the results of the second questionnaire, four plants (as
mentioned in Section 7.1) were selected as candidate plants for testing the model. They were selected for three reasons: (1) they are in different environmental and socio-cultural contexts, (2) they are of different sizes (i.e. capacities) and (3) the returned questionnaires from these plants (except the plant in Thailand) were completed in greater detail and with greater care (not all returned questionnaires were so) and it was therefore assumed that the data of these plants would be more reliable and that further contact with these plants would be more profitable. The plant in Thailand was selected because of reasons (1) and (2) but not (3). However, there was another reason for choosing this particular plant and the reason will be discussed in Section 7.4.

Then, a third questionnaire was designed to acquire further information concerning the candidate plants (see Appendix C.3). This questionnaire was not sent but was taken along with the author during his visit to these plants. The questions contained in it were put by the author when he met with the plant managers and the staff during the visits. The site visits also helped him acquire a greater understanding of the environmental and social situations of the candidate countries so that the data for the intangible parameters could be entered with greater accuracy into the model.

In the following sections, descriptions of the test
procedures for the plants in Malaysia, Thailand, Taiwan and Hong Kong respectively will be given.

7.3 **Puchong Sewage Treatment Plant (Malaysia)**

The Puchong STP, built in 1984-85, is located at the south-west of Kualu Lumpur, the capital of Malaysia. The plant is situated outside the city boundary but not far away from Kuala Lumpur, and is therefore situated in a semi-rural area (see Fig. 7.1)(3). The plant was designed to treat an average daily dry weather flow of 1800 m$^3$/day (ie. 8000 P.E.) and the designed influent BOD$_5$ was 220 mg/l(3). However, due to ground water infiltration into the sewerage system, the actual mean BOD$_5$ figure was found to be only 108 mg/l when the plant was commissioned (see Appendix C.2.1). The treatment plant consists of two ponds, one facultative pond (3 Ha) and then one maturation pond (0.9 Ha). Land is available in Puchong area. The capacity of the plant can be increased in the future by the construction of additional stabilization ponds as land for extension has already been reserved. The effluent is discharged to a river named Sungai Kelang and has BOD$_5$ and s.s. standards of 29 mg/l and 2 mg/l respectively (result of weekly grab samples). The plant can be considered, in general, as working successfully.

Other details concerning Malaysia in broad terms -- as well as the Puchong STP itself -- can be seen in Appendices.
AREAS SERVED AND PHASE 1 - FACILITIES

KEY PLAN

Fig. 7.1: LOCATION OF PUCHONG STW

ENGINEERING - SCIENCE, INC. & MALAYSIA INTERNATIONAL CONSULTANTS, SDN. BHD.
C.1.1, C.2.1 and C.3.1. Although not all questions were answered in the completed questionnaires, the information obtained was adequate for making up the twenty decision variable reciprocal matrices for entry into the model. Each decision variable matrices is of order 8x8. As mentioned on Page 65 (Chapter 4) and Sections 6.4 and 6.5.1 (Chapter 6), the 8 decision variables used were those in the first category (ie. A, B, ...., H) shown in the hierarchical structure in Fig. 4.1 of Chapter 4. They are reproduced hereunder for easy reference:

<table>
<thead>
<tr>
<th>Decision Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Stabilization ponds</td>
</tr>
<tr>
<td>2</td>
<td>Aerated lagoons</td>
</tr>
<tr>
<td>3</td>
<td>Biofiltration</td>
</tr>
<tr>
<td>4</td>
<td>Activated sludge processes</td>
</tr>
<tr>
<td>5</td>
<td>Primary Settlement</td>
</tr>
<tr>
<td>6</td>
<td>Land application</td>
</tr>
<tr>
<td>7</td>
<td>Small plants</td>
</tr>
<tr>
<td>8</td>
<td>Package activated sludge plants</td>
</tr>
</tbody>
</table>

The decision variable matrices for the 20 parameters are shown in Section 8.1 of Chapter 8 and their construction was based on the discussions contained in Section 6.5 of Chapter 6. These data were entered into the model according to the procedures given in the computer program users' manual (Appendix B.1.1). The result (ie. output of the model) is also shown at the end of Section 8.1.
The optimum treatment alternative given on Page 132 as selected by the model, which scores 100\%, is stabilization pond (ie. Decision Variable 1). The second best alternative, which scores 87\%, is aerated lagoon (ie. Decision Variable 2). The third, which scores 75\%, is small plant (ie. Decision Variable 7). This is the result that had been anticipated from a less rigorous, general appreciation of the situation. It should be noted that, however, stabilization pond is the optimal alternative only for this very particular situation. If the site is relocated somewhere else in Malaysia with a different environment, or if the requirement on the standard of effluent is different, or if there are any changes that have taken place in terms of the social conditions, the result may well be a treatment alternative other than stabilization ponds.

7.4 Pattaya South Sewage Treatment Plant (Thailand)

Pattaya is one of Thailand's main local and international tourist attractions and is second only to Bangkok in foreign exchange earnings from tourism. The total town area of Pattaya is about 200 km\(^2\) and the resident population is about 50,000. Most of the population is concentrated in the relatively small beach zone (see Fig. 7.2). Due to the continual growth of the town and the continual deterioration of the beach environment, it is a great concern on the part of the
Fig. 7.2: MAP OF PATTAYA CITY AND SEWERAGE SERVICE AREA
Fig. 7.3: OLD SERVICE AREA AND SEWERAGE SYSTEM
Pattaya government that the degradation of the beaches may cause a loss of tourist income. So, in 1982, a simple sewerage system and a wastewater treatment plant were built for servicing a densely populated but relatively small zone at south Pattaya as shown in Figs. 7.2 and 7.3\(^{(4)}\).

As the treatment plant is located at a very densely populated zone, the site area available for the plant is very limited (about 0.2 Ha). The plant was designed to treat a daily average DWF of 1000 m\(^3\)/day (ie. 5000 P.E.) of municipal sewage and the effluent standard for BOD\(_5\) was set to be not more than 15 mg/l\(^{(4)}\). Effluent would be discharged to a canal (Khlong Pattaya) and then to the beach. The treatment process employed is extended aeration activated sludge. Surface aerators are used in the aeration tank. Details of the treatment plant can be found in Appendix C.2.2 and other details concerning Thailand/Pattaya can be found in Appendices C.1.2 and C.3.2.

This plant is now not in operation. The author was informed during the visit that the plant had previously been working unsatisfactorily. This fact identifies the additional reason, which was not mentioned in Section 7.2, for selecting this plant for testing the model. The model should, if it works well, give an optimal treatment alternative which is not that of the activated sludge process. So, for this particular test, the result should
be a negative one rather than a positive one, unlike the Puchong STP of Malaysia.

The decision variables used, as mentioned on Page 65, were those in the second category (ie. a, b, ......, 1) shown in the hierarchical structure in Fig. 4.1 of Chapter 4. They are:

<table>
<thead>
<tr>
<th>Decision Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Stabilization ponds</td>
</tr>
<tr>
<td>2</td>
<td>Fully-aerated lagoons + Secondary settlement</td>
</tr>
<tr>
<td>3</td>
<td>Fully/Partially aerated lagoons</td>
</tr>
<tr>
<td>4</td>
<td>Simple percolating filtration</td>
</tr>
<tr>
<td>5</td>
<td>Modified percolating filtration</td>
</tr>
<tr>
<td>6</td>
<td>Conventional activated sludge process</td>
</tr>
<tr>
<td>7</td>
<td>Deep-shaft/High-purity oxygen process</td>
</tr>
<tr>
<td>8</td>
<td>Primary settlement</td>
</tr>
<tr>
<td>9</td>
<td>Land application</td>
</tr>
<tr>
<td>10</td>
<td>Rotating Biological contactors</td>
</tr>
<tr>
<td>11</td>
<td>Oxidation ditches</td>
</tr>
<tr>
<td>12</td>
<td>Package activated sludge plants</td>
</tr>
</tbody>
</table>

The twenty 12x12 decision variable matrices entered into the model are given in Section 8.2 of Chapter 8. They were again constructed based on Section 6.5. On Page 143, the optimal treatment alternative obtained, which scores
100%, is that of rotating biological contactors (ie. Decision Variable 10) and not the installed activated sludge process. The second best alternative, which scores 86%, is package activated sludge plants (ie. Decision Variable 12). The third, which scores 84%, is conventional activated sludge process (ie. Decision Variable 6). It is worthwhile to mention that there is a RBC plant built recently (in 1985) in Pattaya to serve the new service area (Fig. 7.2) and it was found to work very successfully when the author visited this plant in early 1987.

7.5 Min Shen Sewage Treatment Plant (Taiwan)

Min Shen Sewage Treatment Plant is at the north-east of Taipei city, the capital of Taiwan which has a population of two millions. The plant is not too far away from the city centre (see Fig. 7.4), and is responsible for treating the wastewater from the Min Shen Housing Estate (the Minshen Community). It was built on quite a small site (about 0.8 Ha) which was assigned by the government of Taipei city for constructing sewage treatment facilities. The plant was designed to treat 15,500 m³/day (daily average) of municipal wastewater (ie. 60,000 P.E.) and the designed influent BOD₅ and s.s. were both 200 mg/l. Two different treatment processes are used in the plant --- RBC and activated sludge. The settled sewage flows to a distribution chamber which leads about 20% of the flow to the RBC basin and 80% to the activated sludge aeration
Fig. 7.4: LOCATION OF MINSHEN STW
tank. The effluent after secondary treatment goes through tertiary treatment (rapid sand filtration) before it is discharged to the Keelung River which is adjacent to the plant. The effluent is required by the authority to be of a very high standard (BOD$_5$: 5-10 and s.s.: 5-10) for two reasons: (1) the Keelung River is already fairly polluted as a result of the rapid industrialization (the environmental protection programmes launched there recently have not been able to cope with the rapid industrial development), (2) the effluent is partly used in a scenic fountain in the San Min Park of the Min Shen Housing Estate, which is a pioneering project of wastewater reuse in Taiwan. The effluent from the RBC usually has a BOD$_5$ of 10 to 15 mg/l and that from the activated sludge process 20 to 30 mg/l. These figures reduce to about 8 mg/l and 18 mg/l respectively following tertiary treatment. Therefore, for most of the time, only the tertiary treated effluent from the RBC process is used in the wastewater reuse project. However, it is the desire of the authority to have more reusable effluent from the plant. Further details of this plant can be found in Appendix C.2.3 and that of Taiwan/Taipei in general can be found in Appendices C.1.3 and C.3.3.

The decision variables used on this occasion were those in the third category (ie. 1, 2, ......, 46) shown in the hierarchical structure in Fig. 4.1. Since there were too many decision variables in this category, they had to
be reduced to a smaller number --- preferably not exceeding 15 (see Section 6.4 of Chapter 6) --- by the use of a screening exercise. In this test, the number of decision variables that remained after screening was 10. The screening exercise is simple and is described in the next paragraph.

Decision variables numbered 1 to 13 were not to be considered as the site area available could in no way permit their selection. Now, only 33 (ie. 45 - 13) decision variables remained for selection. Out of these 33 decision variables, only those with tertiary treatment were to be considered because the required effluent standard could only consistently be met with the use of tertiary treatment. Now there were only 10 decision variables remaining all of which include tertiary treatment and hence they were taken as the decision variables for the test.

<table>
<thead>
<tr>
<th>Decision Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Primary clarifier + Simple percolating filtration + Tertiary treatment</td>
</tr>
<tr>
<td>2</td>
<td>Primary clarifier + Percolating filtration with recirculation + Tertiary treatment</td>
</tr>
<tr>
<td>3</td>
<td>Primary clarifier + Alternating double filtration + Tertiary treatment</td>
</tr>
<tr>
<td>4</td>
<td>Primary clarifier + Conventional activated sludge process + Tertiary treatment</td>
</tr>
<tr>
<td>5</td>
<td>Primary clarifier + High-purity oxygen activated sludge process + Tertiary Treatment</td>
</tr>
</tbody>
</table>
The tertiary treatment in the above decision variables is assumed, except for Deep Shaft, to be rapid sand filtration, the existing tertiary treatment method used by the plant. Other tertiary treatment techniques (e.g. microstraining) of course could have been used in this plant, but whether or not they are more appropriate than the existing rapid sand filtration is an irrelevant question in this selection exercise, as the objective here is to select the best alternative to be employed before the tertiary treatment. The twenty 10x10 decision variable matrices entered into the model are given in Section 8.3 of Chapter 8. The result of the computer run on Page 154 shows that the optimal treatment alternative, which scores 100%, is primary clarifier + RBC + tertiary treatment (i.e. Decision Variable 7), which is, again, in agreement with the existing situation. The second best alternative, which scores 95%, is primary clarifier + high-purity oxygen activated sludge process + tertiary treatment (i.e. Decision Variable 5). The third, which scores 91%, is primary
clarifier + conventional activated sludge process +
tertiary treatment (ie. Decision Variable 4).

7.6 **Shatin Sewage Treatment Plant (Hong Kong)**

Shatin STP is situated at the south-west end of Tolo
Harbour (see Fig. 7.5)\(^6\). The effluent from the plant is
discharged to the Harbour. Since Tolo Harbour is nearly an
enclosed bay, there is a lack of natural currents in the
sea water to dilute and disperse the discharged effluent.
Hence, the standard of the effluent required is high in
order to control the water quality in the harbour which has
experienced a decline in environmental conditions as a
result of rapid residential and industrial development in
Shatin. The plant was built on a piece of reclaimed land
created by filling a huge volume of earth onto the Tolo
Harbour. The site is quite isolated. Land is always a
problem in Hong Kong and the cost of land is extremely
expensive. In this particular case, land for building the
plant was not available unless it was reclaimed from the
sea, thus making the land cost exceptionally costly.

The construction of Shatin STP began in late 1970's
and the first phase of the plant started operation in 1981,
treating an average daily dry weather flow of 100,000
m\(^3\)/day (about 240,000 P.E.). The second phase of the
plant, treating also the same amount of flow, started
operation in 1986, resulting in a total treatment capacity
Fig. 7.5 Map of Hong Kong and Location of Sewage Treatment Plants: 1 - Shek Wu Hui STP, 2 - Tai Po STP, 3 - Shatin STP and 4 - Yuen Long STP.
of 200,000 m$^3$/day for the plant. The treatment method employed is the activated sludge process. 60% of the influent is from the municipality of Shatin New Town and 40% from the industrial establishments in the vicinity. The mixed influent has an average BOD$_5$ of 250 mg/l and s.s. of 220 mg/l. No tertiary treatment (e.g. microstrainers or rapid sand filters) is provided in the plant. The effluent standard is of 10 to 15 mg/l BOD$_5$ and 15 to 25 mg/l s.s. in average. The plant is considered to be working quite satisfactorily. Other details concerning Hong Kong in broad terms and the Shatin STP itself can be found in Appendices C.1.4, C.2.4 and C.3.4.

The decision variables used in the test were those in the first category (i.e. A, B, ...., H) shown in the hierarchical structure in Fig. 4.1 of Chapter 4. They are:

<table>
<thead>
<tr>
<th>Decision Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Stabilization ponds</td>
</tr>
<tr>
<td>2</td>
<td>Aerated lagoons</td>
</tr>
<tr>
<td>3</td>
<td>Biofiltration</td>
</tr>
<tr>
<td>4</td>
<td>Activated sludge process</td>
</tr>
<tr>
<td>5</td>
<td>Primary settlement</td>
</tr>
<tr>
<td>6</td>
<td>Land application</td>
</tr>
<tr>
<td>7</td>
<td>Small plants</td>
</tr>
<tr>
<td>8</td>
<td>Package activated sludge plants</td>
</tr>
</tbody>
</table>

The 8x8 decision variable matrices for the 20
parameters are shown in Section 8.4.1 of Chapter 8. The computer run shows that activated sludge process (i.e. Decision Variable 4) is the optimal treatment alternative (see Page 165).

Then, the seven decision variables (numbered 23, 24, 25, 26, 27, 28 and 29) under Activated Sludge Process in the hierarchical structure shown in Fig. 4.1 were further ranked. These seven decision variables are:

<table>
<thead>
<tr>
<th>Decision Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Primary clarifier + Conventional activated sludge process</td>
</tr>
<tr>
<td>2</td>
<td>Septic tank + Conventional activated sludge process</td>
</tr>
<tr>
<td>3</td>
<td>Primary clarifier + Conventional activated sludge process + Tertiary treatment</td>
</tr>
<tr>
<td>4</td>
<td>Deep shaft</td>
</tr>
<tr>
<td>5</td>
<td>Deep shaft + Nitrifying filter</td>
</tr>
<tr>
<td>6</td>
<td>Primary clarifier + High-purity oxygen activated sludge process</td>
</tr>
<tr>
<td>7</td>
<td>Primary clarifier + High-purity oxygen activated sludge process + Tertiary treatment</td>
</tr>
</tbody>
</table>

The term tertiary treatment that appears in the decision variables should refer to either microstrainers or rapid sand filters as Shatin STP is a huge plant. The twenty 7x7 decision variable matrices are shown in Section 8.4.2 of Chapter 8. The model gives a result on Page 176 that primary clarifier + conventional activated sludge
process + tertiary treatment (ie. Decision Variable 3) is the most appropriate treatment alternative. Although the existing Shatin plant is working quite successfully without the use of tertiary treatment, it is the opinion of the author that the latter (perhaps microstrainers) should be added to the plant in order that a even more satisfactory treatment result will be achieved.
CHAPTER 8 --- MODEL TESTING (II)

This chapter must be read in conjunction with Appendix B.1.1, the user's manual of the model. The user should also refer to the DOS manual of an IBM-PC\(^{(1)}\) if he uses the PC at the first time. The following sections show a complete record of the dialogue between the user and the computer for ranking wastewater treatment alternatives in Malaysia, Thailand, Taiwan and Hong Kong respectively.

8.1 Computer Run for Puchong STP (Malaysia)

This section must be read in conjunction with Section 7.3 of Chapter 7. The following is a record of running the model.

RANKING OF LIQUID TREATMENT ALTERNATIVES

Order of decision variable matrix is \(n \times n\) where \(n = 8\)

PARAMETER 1 : Flow

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA1.LIQ

The decision variable matrix is:

\[
\begin{array}{cccccccc}
1.000 & 1.000 & 1.000 & 3.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 3.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 3.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
0.333 & 0.333 & 0.333 & 1.000 & 0.333 & 0.333 & 0.333 & 0.333 \\
1.000 & 1.000 & 1.000 & 3.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 3.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 3.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 3.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
\end{array}
\]

Do you want to change data in the above matrix? Y or N? N
PARAMETER 2 : Influent / Effluent
Do you want to use data from an existing file? Y or N? Y
Name of the existing file is? PARA2.LIQ
The decision variable matrix is:

1.000 1.000 1.000 1.000 5.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 5.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 5.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 5.000 1.000 1.000 1.000
0.200 0.200 0.200 0.200 1.000 0.200 0.200 0.200
1.000 1.000 1.000 1.000 5.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 5.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 5.000 1.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N
The matrix just entered is stored in a file named PARA2.LIQ
Press the RETURN key to continue

PARAMETER 3 : Size of site
Do you want to use data from an existing file? Y or N? Y
Name of the existing file is? PARA3.LIQ
The decision variable matrix is:

1.000 1.000 1.000 1.000 1.000 3.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 4.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 5.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 5.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 6.000 1.000 1.000
0.333 0.250 0.200 0.200 0.167 1.000 0.200 0.200
1.000 1.000 1.000 1.000 1.000 5.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 5.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N
Please wait .....
The matrix just entered is stored in a file named PARA3.LIQ
Press the RETURN key to continue

PARAMETER 4 : Nature of site
Do you want to use data from an existing file? Y or N? Y
Name of the existing file is? PARA4.LIQ
The decision variable matrix is:

1.000 1.000 3.000 3.000 3.000 3.000 3.000
1.000 1.000 3.000 3.000 3.000 3.000 3.000
0.333 0.333 1.000 1.000 1.000 1.000 1.000
0.333 0.333 1.000 1.000 1.000 1.000 1.000
0.333 0.333 1.000 1.000 1.000 1.000 1.000
0.333 0.333 1.000 1.000 1.000 1.000 1.000
0.333 0.333 1.000 1.000 1.000 1.000 1.000
0.333 0.333 1.000 1.000 1.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N
Please wait......
The matrix just entered is stored in a file named PARA4.LIQ
Press the RETURN key to continue

PARAMETER 5 : Land cost
Do you want to use data from an existing file? Y or N? Y
Name of the existing file is? PARA5.LIQ
The decision variable matrix is:

1.000 0.500 0.333 0.333 0.333 3.000 0.333 0.333
2.000 1.000 0.500 0.500 0.500 4.000 0.500 0.500
3.000 2.000 1.000 1.000 1.000 5.000 1.000 1.000
3.000 2.000 1.000 1.000 1.000 5.000 1.000 1.000
3.000 2.000 1.000 1.000 1.000 5.000 1.000 1.000
0.333 0.250 0.200 0.200 0.200 1.000 0.200 0.200
3.000 2.000 1.000 1.000 1.000 5.000 1.000 1.000
3.000 2.000 1.000 1.000 1.000 5.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N
Please wait......
The matrix just entered is stored in a file named PARA5.LIQ
Press the RETURN key to continue

PARAMETER 6 : Local money for construction
Do you want to use data from an existing file?  Y or N? Y
Name of the existing file is? PARA6.LIQ
The decision variable matrix is:

1.000 2.000 4.000 5.000 2.000 2.000 3.000 5.000
0.500 1.000 3.000 4.000 1.000 1.000 2.000 4.000
0.250 0.333 1.000 2.000 0.333 0.333 0.500 2.000
0.200 0.250 0.500 1.000 0.250 0.250 0.333 1.000
0.500 1.000 3.000 4.000 1.000 1.000 2.000 4.000
0.500 1.000 3.000 4.000 1.000 1.000 2.000 4.000
0.333 0.500 2.000 3.000 0.500 0.500 1.000 3.000
0.200 0.250 0.500 1.000 0.250 0.250 0.333 1.000

Do you want to change data in the above matrix?  Y or N? N
Please wait......
The matrix just entered is stored in a file named PARA6.LIQ
Press the RETURN key to continue

PARAMETER 7 : Foreign money for construction
Do you want to use data from an existing file?  Y or N? Y
Name of the existing file is? PARA7.LIQ
The decision variable matrix is:

1.000 1.000 3.000 5.000 1.000 1.000 3.000 4.000
1.000 1.000 2.000 4.000 1.000 1.000 2.000 4.000
0.333 0.500 1.000 3.000 0.333 0.333 1.000 2.000
0.200 0.250 0.333 1.000 0.200 0.200 0.333 0.500
1.000 1.000 3.000 5.000 1.000 1.000 2.000 4.000
1.000 1.000 3.000 5.000 1.000 1.000 2.000 4.000
0.333 0.500 1.000 3.000 0.500 0.500 1.000 2.000
0.250 0.250 0.500 2.000 0.250 0.250 0.500 1.000

Do you want to change data in the above matrix?  Y or N? N
Please wait......
The matrix just entered is stored in a file named PARA7.LIQ
Press the RETURN key to continue
PARAMETER 8 : Local skill for construction

Do you want to use data from an existing file? Y or N? Y
Name of the existing file is? PARA8.LIQ

The decision variable matrix is:

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>1.000</td>
<td>1.000</td>
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<td>0.333</td>
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<td>1.000</td>
<td>0.333</td>
<td>0.200</td>
<td>0.500</td>
</tr>
</tbody>
</table>

Do you want to change data in the above matrix? Y or N? N

Please wait.....

The matrix just entered is stored in a file named PARA8.LIQ

Press the RETURN key to continue

PARAMETER 9 : Community support

Do you want to use data from an existing file? Y or N? Y
Name of the existing file is? PARA9.LIQ

The decision variable matrix is:

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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<td>0.500</td>
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</tr>
<tr>
<td>0.333</td>
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<td>0.500</td>
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<td>1.000</td>
<td>0.333</td>
<td>0.200</td>
<td>0.500</td>
</tr>
</tbody>
</table>

Do you want to change data in the above matrix? Y or N? N

Please wait.....

The matrix just entered is stored in a file named PARA9.LIQ

Press the RETURN key to continue

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PARAMETER 10 : Power source

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA10.LIQ

The decision variable matrix is:

1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait ......

The matrix just entered is stored in a file named PARA10.LIQ

Press the RETURN key to continue

PARAMETER 11 : Availability of local material

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA11.LIQ

The decision variable matrix is:

1.000 1.000 2.000 4.000 2.000 1.000 2.000 3.000
1.000 1.000 1.000 4.000 1.000 1.000 1.000 3.000
0.500 1.000 1.000 3.000 1.000 1.000 1.000 2.000
0.250 0.250 0.333 1.000 0.333 0.333 0.500 1.000
0.500 1.000 1.000 3.000 1.000 1.000 2.000 3.000
1.000 1.000 1.000 3.000 1.000 1.000 2.000 3.000
0.500 1.000 1.000 2.000 0.500 0.500 1.000 2.000
0.333 0.333 0.500 1.000 0.333 0.333 0.500 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait ......

The matrix just entered is stored in a file named PARA11.LIQ

Press the RETURN key to continue
PARAMETER 12 : Cost of operation & maintenance

Do you want to use data from an existing file ? Y or N ? Y

Name of the existing file is ? PARA12.LIQ

The decision variable matrix is:

1.000 3.000 4.000 5.000 3.000 3.000 3.000 5.000
0.333 1.000 2.000 4.000 1.000 1.000 1.000 4.000
0.250 0.500 1.000 3.000 0.500 0.500 0.500 3.000
0.200 0.250 0.333 1.000 0.333 0.333 0.333 1.000
0.333 1.000 2.000 3.000 1.000 1.000 1.000 3.000
0.333 1.000 2.000 3.000 1.000 1.000 1.000 3.000
0.333 1.000 2.000 3.000 1.000 1.000 1.000 3.000
0.200 0.250 0.333 1.000 0.333 0.333 0.333 1.000

Do you want to change data in the above matrix ? Y or N ? N

Please wait ..... 

The matrix just entered is stored in a file named PARA12.LIQ

Press the RETURN key to continue

PARAMETER 13 : Professional skill available for operation & maintenance

Do you want to use data from an existing file ? Y or N ? Y

Name of the existing file is ? PARA13.LIQ

The decision variable matrix is:

1.000 1.000 2.000 5.000 1.000 3.000 2.000 3.000
1.000 1.000 2.000 4.000 1.000 2.000 2.000 2.000
0.500 0.500 1.000 3.000 0.333 1.000 0.500 1.000
0.200 0.250 0.333 1.000 0.200 0.333 0.250 0.333
1.000 1.000 3.000 5.000 1.000 3.000 2.000 3.000
0.333 0.500 1.000 3.000 0.333 1.000 0.500 1.000
0.500 0.500 2.000 4.000 0.500 2.000 1.000 2.000
0.333 0.500 1.000 3.000 0.333 1.000 0.500 1.000

Do you want to change data in the above matrix ? Y or N ? N

Please wait ..... 

The matrix just entered is stored in a file named PARA13.LIQ

Press the RETURN key to continue
PARAMETER 14 : Local technical skill available for operation & maintenance

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is ? PARA14.LIQ

The decision variable matrix is:

<table>
<thead>
<tr>
<th></th>
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<th>2.000</th>
<th>3.000</th>
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<td></td>
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<td>1.000</td>
<td>0.500</td>
<td>1.000</td>
<td></td>
</tr>
</tbody>
</table>

Do you want to change data in the above matrix? Y or N? N

Please wait ......

The matrix just entered is stored in a file named PARA14.LIQ

Press the RETURN key to continue

PARAMETER 15 : Administration set-up

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is ? PARA15.LIQ

The decision variable matrix is:

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<th></th>
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</tr>
</thead>
<tbody>
<tr>
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<td>1.000</td>
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</tr>
</tbody>
</table>

Do you want to change data in the above matrix? Y or N? N

Please wait ......

The matrix just entered is stored in a file named PARA15.LIQ

Press the RETURN key to continue
PARAMETER 16 : Training

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA16.LIQ

The decision variable matrix is:

\[
\begin{array}{ccccccc}
1.000 & 3.000 & 5.000 & 9.000 & 3.000 & 5.000 & 3.000 \\
0.333 & 1.000 & 3.000 & 7.000 & 1.000 & 3.000 & 1.000 \\
0.200 & 0.333 & 1.000 & 5.000 & 0.333 & 1.000 & 0.500 \\
0.111 & 0.143 & 0.200 & 1.000 & 0.143 & 0.200 & 0.143 \\
0.333 & 1.000 & 3.000 & 7.000 & 1.000 & 3.000 & 1.000 \\
0.200 & 0.333 & 1.000 & 5.000 & 0.333 & 1.000 & 0.333 \\
0.333 & 1.000 & 2.000 & 7.000 & 1.000 & 3.000 & 1.000 \\
0.143 & 0.200 & 0.333 & 3.000 & 0.200 & 0.333 & 0.200 \\
\end{array}
\]

Do you want to change data in the above matrix? Y or N? N

Please wait......

The matrix just entered is stored in a file named PARA16.LIQ

Press the RETURN key to continue

PARAMETER 17 : Professional ethics

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is PARA17.LIQ

The decision variable matrix is:

\[
\begin{array}{ccccccc}
1.000 & 2.000 & 4.000 & 7.000 & 2.000 & 4.000 & 2.000 \\
0.500 & 1.000 & 3.000 & 6.000 & 1.000 & 3.000 & 1.000 \\
0.250 & 0.333 & 1.000 & 4.000 & 0.500 & 1.000 & 0.500 \\
0.143 & 0.167 & 0.250 & 1.000 & 0.200 & 0.333 & 0.200 \\
0.500 & 1.000 & 2.000 & 5.000 & 1.000 & 3.000 & 1.000 \\
0.250 & 0.333 & 1.000 & 3.000 & 0.333 & 1.000 & 0.500 \\
0.500 & 1.000 & 2.000 & 2.000 & 1.000 & 3.000 & 1.000 \\
0.200 & 0.250 & 0.500 & 2.000 & 0.250 & 1.000 & 0.333 \\
\end{array}
\]

Do you want to change data in the above matrix? Y or N? N

Please wait......

The matrix just entered is stored in a file named PARA17.LIQ

Press the RETURN key to continue
PARAMETER 18 : Climate

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA18.LIQ

The decision variable matrix is:

\[
\begin{array}{ccccccc}
1.000 & 1.000 & 2.000 & 2.000 & 2.000 & 5.000 & 2.000 \\
1.000 & 1.000 & 2.000 & 2.000 & 2.000 & 5.000 & 2.000 \\
0.500 & 0.500 & 1.000 & 1.000 & 1.000 & 3.000 & 1.000 \\
0.500 & 0.500 & 1.000 & 1.000 & 1.000 & 3.000 & 1.000 \\
0.500 & 0.500 & 1.000 & 1.000 & 1.000 & 3.000 & 1.000 \\
0.200 & 0.200 & 0.333 & 0.333 & 0.333 & 1.000 & 0.333 \\
0.500 & 0.500 & 1.000 & 1.000 & 1.000 & 3.000 & 1.000 \\
0.500 & 0.500 & 1.000 & 1.000 & 1.000 & 3.000 & 1.000 \\
\end{array}
\]

Do you want to change data in the above matrix? Y or N? N

Please wait.....

The matrix just entered is stored in a file named PARA18.LIQ

Press the RETURN key to continue.

PARAMETER 19 : Local water-borne diseases

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA19.LIQ

The decision variable matrix is:

\[
\begin{array}{cccccccc}
1.000 & 2.000 & 3.000 & 3.000 & 5.000 & 1.000 & 3.000 & 3.000 \\
0.500 & 1.000 & 2.000 & 2.000 & 4.000 & 0.500 & 2.000 & 2.000 \\
0.333 & 0.500 & 1.000 & 1.000 & 3.000 & 0.333 & 1.000 & 1.000 \\
0.333 & 0.500 & 1.000 & 1.000 & 3.000 & 0.333 & 1.000 & 1.000 \\
0.200 & 0.250 & 0.333 & 0.333 & 1.000 & 0.200 & 0.333 & 0.333 \\
1.000 & 2.000 & 3.000 & 3.000 & 5.000 & 1.000 & 3.000 & 2.000 \\
0.333 & 0.500 & 1.000 & 1.000 & 3.000 & 0.333 & 1.000 & 1.000 \\
0.333 & 0.500 & 1.000 & 1.000 & 3.000 & 0.333 & 1.000 & 1.000 \\
\end{array}
\]

Do you want to change data in the above matrix? Y or N? N

Please wait.....

The matrix just entered is stored in a file named PARA19.LIQ

Press the RETURN key to continue.
PARAMETER 20: Endemic vector-borne (water-related) diseases

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA20.LIQ

The decision variable matrix is:

\[
\begin{array}{ccccccccc}
1.000 & 1.000 & 0.333 & 0.333 & 0.333 & 2.000 & 0.333 & 0.333 \\
1.000 & 1.000 & 0.333 & 0.333 & 0.333 & 2.000 & 0.333 & 0.333 \\
3.000 & 3.000 & 1.000 & 1.000 & 1.000 & 3.000 & 1.000 & 1.000 \\
3.000 & 3.000 & 1.000 & 1.000 & 1.000 & 3.000 & 1.000 & 1.000 \\
3.000 & 3.000 & 1.000 & 1.000 & 1.000 & 3.000 & 1.000 & 1.000 \\
0.500 & 0.500 & 0.333 & 0.333 & 0.333 & 1.000 & 0.333 & 0.333 \\
3.000 & 3.000 & 1.000 & 1.000 & 1.000 & 3.000 & 1.000 & 1.000 \\
3.000 & 3.000 & 1.000 & 1.000 & 1.000 & 3.000 & 1.000 & 1.000 \\
\end{array}
\]

Do you want to change data in the above matrix? Y or N? N

Please wait ......

The matrix just entered is stored in a file named PARA20.LIQ

You have already entered all the necessary data

Press the RETURN key to continue

Please wait. Calculation of the ranking of the alternatives is in process.

The ranking is:

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Ranking in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative 1</td>
<td>100</td>
</tr>
<tr>
<td>Alternative 2</td>
<td>87.95443</td>
</tr>
<tr>
<td>Alternative 3</td>
<td>70.46707</td>
</tr>
<tr>
<td>Alternative 4</td>
<td>60.0522</td>
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<tr>
<td>Alternative 5</td>
<td>67.94486</td>
</tr>
<tr>
<td>Alternative 6</td>
<td>60.55442</td>
</tr>
<tr>
<td>Alternative 7</td>
<td>75.00223</td>
</tr>
<tr>
<td>Alternative 8</td>
<td>66.6338</td>
</tr>
</tbody>
</table>
8.2 **Computer Run for Pattaya South STP (Thailand)**

This section must be read in conjunction with Section 7.4 of Chapter 7. The following is a record of running the model.

**RANKING OF LIQUID TREATMENT ALTERNATIVES**

Order of decision variable matrix is $n \times n$ where $n = 12$

**PARAMETER 1 : Flow**

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA1.LIQ

The decision variable matrix is:

| 1.000 1.000 1.000 2.000 2.000 2.000 3.000 2.000 1.000 2.000 2.000 2.000 |
| 1.000 1.000 1.000 2.000 2.000 2.000 3.000 2.000 1.000 2.000 2.000 2.000 |
| 1.000 1.000 1.000 2.000 2.000 2.000 3.000 2.000 1.000 2.000 2.000 2.000 |
| 0.500 0.500 0.500 1.000 1.000 1.000 2.000 1.000 0.500 1.000 1.000 1.000 |
| 0.500 0.500 0.500 1.000 1.000 1.000 2.000 1.000 0.500 1.000 1.000 1.000 |
| 0.500 0.500 0.500 1.000 1.000 1.000 2.000 1.000 0.500 1.000 1.000 1.000 |
| 0.333 0.333 0.333 0.500 0.500 0.500 1.000 0.500 0.333 0.500 0.500 0.500 |
| 0.500 0.500 0.500 1.000 1.000 1.000 2.000 1.000 0.500 1.000 1.000 1.000 |
| 1.000 1.000 1.000 2.000 2.000 2.000 3.000 2.000 1.000 2.000 2.000 2.000 |
| 0.500 0.500 0.500 1.000 1.000 1.000 2.000 1.000 0.500 1.000 1.000 1.000 |
| 0.500 0.500 0.500 1.000 1.000 1.000 2.000 1.000 0.500 1.000 1.000 1.000 |
| 0.500 0.500 0.500 1.000 1.000 1.000 2.000 1.000 0.500 1.000 1.000 1.000 |

Do you want to change data in the above matrix? Y or N? N

Please wait......

The matrix just entered is stored in a file named 'PARA1.LIQ'

Press the RETURN key to continue
PARAMETER 2 : Influent / Effluent

Do you want to use data from an existing file?  Y or N?  Y

Name of the existing file is PARA2.LIQ

The decision variable matrix is:

1.000 0.500 1.000 0.500 0.500 0.333 0.333 9.000 0.333 0.333 0.500 0.333
2.000 1.000 2.000 1.000 1.000 0.500 0.500 9.000 0.500 0.500 1.000 0.500
1.000 0.500 1.000 0.500 0.500 0.333 0.333 9.000 0.333 0.333 0.500 0.333
2.000 1.000 2.000 1.000 1.000 0.500 0.500 9.000 0.500 0.500 1.000 0.500
2.000 1.000 2.000 1.000 1.000 0.500 0.500 9.000 0.500 0.500 1.000 0.500
3.000 2.000 3.000 2.000 2.000 1.000 1.000 9.000 1.000 1.000 2.000 1.000
3.000 2.000 3.000 2.000 2.000 1.000 1.000 9.000 1.000 1.000 2.000 1.000
3.000 2.000 3.000 2.000 2.000 1.000 1.000 9.000 1.000 1.000 2.000 1.000
0.111 0.111 0.111 0.111 0.111 0.111 0.111 1.000 0.111 0.111 0.111 0.111
3.000 2.000 3.000 2.000 2.000 1.000 1.000 9.000 1.000 1.000 2.000 1.000
1.000 2.000 3.000 2.000 2.000 1.000 1.000 9.000 1.000 1.000 2.000 1.000
2.000 1.000 2.000 1.000 1.000 0.500 0.500 9.000 0.500 0.500 1.000 0.500
3.000 2.000 3.000 2.000 2.000 1.000 1.000 9.000 1.000 1.000 2.000 1.000

Do you want to change data in the above matrix?  Y or N?  N

Please wait .......
The matrix just entered is stored in a file named PARA2.LIQ

Press the RETURN key to continue

PARAMETER 3 : Size of site

Do you want to use data from an existing file?  Y or N?  Y

Name of the existing file is PARA3.LIQ

The decision variable matrix is:

1.000 1.000 1.000 1.000 0.200 0.111 0.111 0.111 1.000 0.111 0.200 0.111
1.000 1.000 1.000 1.000 0.200 0.111 0.111 0.111 1.000 0.111 0.200 0.111
1.000 1.000 1.000 1.000 0.200 0.111 0.111 0.111 1.000 0.111 0.200 0.111
1.000 1.000 1.000 1.000 0.200 0.111 0.111 0.111 1.000 0.111 0.200 0.111
5.000 5.000 5.000 5.000 1.000 0.200 0.200 0.200 7.000 0.200 1.000 0.200
9.000 9.000 9.000 9.000 5.000 1.000 1.000 1.000 9.000 1.000 5.000 1.000
9.000 9.000 9.000 9.000 5.000 1.000 1.000 1.000 9.000 1.000 5.000 1.000
9.000 9.000 9.000 9.000 5.000 1.000 1.000 1.000 9.000 1.000 5.000 1.000
9.000 9.000 9.000 9.000 5.000 1.000 1.000 1.000 9.000 1.000 5.000 1.000
1.000 1.000 1.000 1.000 0.143 0.111 0.111 0.111 1.000 0.111 0.111 0.111
9.000 9.000 9.000 9.000 5.000 1.000 1.000 1.000 9.000 1.000 5.000 1.000
5.000 5.000 5.000 5.000 1.000 0.200 0.200 0.200 9.000 0.200 1.000 0.200
9.000 9.000 9.000 9.000 5.000 1.000 1.000 1.000 9.000 1.000 5.000 1.000

Do you want to change data in the above matrix?  Y or N?  N

Please wait .......
The matrix just entered is stored in a file named PARA3.LIQ

Press the RETURN key to continue
PARAMETER 4 : Nature of site

Do you want to use data from an existing file?  Y or N?  Y

Name of the existing file is ? PARA4.LIQ

The decision variable matrix is:

<p>| | | | | | | | | | | | | |</p>
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<td>5.000</td>
<td>1.000</td>
<td>9.000</td>
</tr>
</tbody>
</table>

Do you want to change data in the above matrix?  Y or N?  N

Please wait ..... 
The matrix just entered is stored in a file named PARA4.LIQ

Press the RETURN key to continue

PARAMETER 5 : Land cost

Do you want to use data from an existing file?  Y or N?  Y

Name of the existing file is ? PARA5.LIQ

The decision variable matrix is:

<p>| | | | | | | | | | | | | |</p>
<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.000</td>
<td>0.333</td>
<td>0.500</td>
<td>0.250</td>
<td>0.200</td>
<td>0.167</td>
<td>0.143</td>
<td>0.125</td>
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<td>0.250</td>
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<td>3.000</td>
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Do you want to change data in the above matrix?  Y or N?  N

Please wait ..... 
The matrix just entered is stored in a file named PARA5.LIQ

Press the RETURN key to continue
PARAMETER 6 : Local money for construction

Do you want to use data from an existing file?  Y or N?  Y

Name of the existing file is ? PARA6.LIQ

The decision variable matrix is:

1.000 2.000 2.000 4.000 4.000 5.000 7.000 2.000 2.000 3.000 2.000 5.000
0.500 1.000 1.000 3.000 3.000 4.000 6.000 1.000 1.000 2.000 1.000 4.000
0.500 1.000 1.000 3.000 3.000 4.000 6.000 1.000 1.000 2.000 1.000 4.000
0.250 0.333 0.333 1.000 1.000 2.000 4.000 0.333 0.333 0.500 0.333 2.000
0.250 0.333 0.333 1.000 1.000 2.000 4.000 0.333 0.333 0.500 0.333 2.000
0.200 0.250 0.250 0.500 0.500 1.000 3.000 0.250 0.250 0.333 0.250 1.000
0.143 0.167 0.167 0.250 0.250 0.333 1.000 0.167 0.167 0.200 0.167 0.333
0.500 1.000 1.000 3.000 3.000 4.000 6.000 1.000 1.000 2.000 1.000 4.000
0.500 1.000 1.000 3.000 3.000 4.000 6.000 1.000 1.000 2.000 1.000 4.000
0.333 0.500 0.500 2.000 2.000 3.000 5.000 0.500 0.500 1.000 0.500 3.000
0.500 1.000 1.000 3.000 3.000 4.000 6.000 1.000 1.000 2.000 1.000 4.000
0.200 0.250 0.250 0.500 0.500 1.000 3.000 0.250 0.250 0.333 0.250 1.000

Do you want to change data in the above matrix?  Y or N? N

Please wait ..... The matrix just entered is stored in a file named PARA6.LIQ

Press the RETURN key to continue

PARAMETER 7 : Foreign money for construction

Do you want to use data from an existing file?  Y or N?  Y

Name of the existing file is ? PARA7.LIQ

The decision variable matrix is:

1.000 3.000 3.000 5.000 5.000 7.000 9.000 3.000 3.000 5.000 4.000 7.000
0.333 1.000 1.000 3.000 3.000 5.000 7.000 1.000 1.000 3.000 2.000 5.000
0.333 1.000 1.000 3.000 3.000 5.000 7.000 1.000 1.000 3.000 2.000 5.000
0.200 0.333 0.333 1.000 1.000 3.000 5.000 0.333 0.333 1.000 0.500 3.000
0.200 0.333 0.333 1.000 1.000 3.000 5.000 0.333 0.333 1.000 0.500 3.000
0.143 0.200 0.200 0.333 0.333 1.000 3.000 0.200 0.200 0.333 0.250 1.000
0.111 0.143 0.143 0.200 0.200 0.333 1.000 0.143 0.143 0.200 0.167 0.333
0.333 1.000 1.000 3.000 3.000 5.000 7.000 1.000 1.000 3.000 2.000 5.000
0.333 1.000 1.000 3.000 3.000 5.000 7.000 1.000 1.000 3.000 2.000 5.000
0.200 0.333 0.333 1.000 1.000 3.000 5.000 0.333 0.333 1.000 0.500 3.000
0.250 0.500 0.500 2.000 2.000 4.000 6.000 0.500 0.500 2.000 1.000 4.000
0.143 0.200 0.200 0.333 0.333 1.000 3.000 0.200 0.200 0.333 0.250 1.000

Do you want to change data in the above matrix?  Y or N? N

Please wait ..... The matrix just entered is stored in a file named PARA7.LIQ

Press the RETURN key to continue
PARAMETER 8: Local skill for construction

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is ? PARA8.LIQ

The decision variable matrix is:

```
1.000 1.000 1.000 1.000 1.000 3.000 5.000 1.000 1.000 1.000 1.000 1.000 3.000
1.000 1.000 1.000 1.000 1.000 3.000 5.000 1.000 1.000 1.000 1.000 1.000 3.000
1.000 1.000 1.000 1.000 1.000 3.000 5.000 1.000 1.000 1.000 1.000 1.000 3.000
1.000 1.000 1.000 1.000 1.000 3.000 5.000 1.000 1.000 1.000 1.000 1.000 3.000
1.000 1.000 1.000 1.000 1.000 3.000 5.000 1.000 1.000 1.000 1.000 1.000 3.000
0.333 0.333 0.333 0.333 0.333 1.000 3.000 0.333 0.333 0.333 0.333 0.333 0.333 1.000
0.200 0.200 0.200 0.200 0.200 0.333 1.000 0.200 0.200 0.200 0.200 0.200 0.200 0.333
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1.000 1.000 1.000 1.000 1.000 3.000 5.000 1.000 1.000 1.000 1.000 1.000 3.000
0.333 0.333 0.333 0.333 0.333 1.000 3.000 0.333 0.333 0.333 0.333 0.333 0.333 1.000
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Do you want to change data in the above matrix? Y or N? N

Please wait ......

The matrix just entered is stored in a file named PARA8.LIQ

Press the RETURN key to continue

PARAMETER 9: Community support

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is ? PARA9.LIQ

The decision variable matrix is:

```
1.000 1.000 1.000 1.000 1.000 3.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 3.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 3.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 3.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
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1.000 1.000 1.000 1.000 1.000 3.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
0.333 0.333 0.333 0.333 0.333 0.333 0.333 0.333 0.333 0.333 0.333 0.333 0.333 0.333
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Do you want to change data in the above matrix? Y or N? N

Please wait ..... The matrix just entered is stored in a file named PARA9.LIQ

Press the RETURN key to continue
PARAMETER 10 : Power source

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA10.LIQ

The decision variable matrix is:

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Do you want to change data in the above matrix? Y or N? N

Please wait.....
The matrix just entered is stored in a file named PARA10.LIQ

Press the RETURN key to continue

PARAMETER 11 : Availability of local material

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA11.LIQ

The decision variable matrix is:

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Do you want to change data in the above matrix? Y or N? N

Please wait.....
The matrix just entered is stored in a file named PARA11.LIQ

Press the RETURN key to continue
PARAMETER 12: Cost of operation & maintenance

Do you want to use data from an existing file?  Y or N?  Y

Name of the existing file is? PARA12.LIQ

The decision variable matrix is:

1.000 3.000 2.000 3.000 3.000 6.000 8.000 2.000 2.000 3.000 3.000 5.000
0.333 1.000 0.500 1.000 1.000 4.000 6.000 0.500 0.500 1.000 1.000 4.000
0.500 2.000 1.000 2.000 2.000 5.000 7.000 1.000 1.000 2.000 2.000 5.000
0.333 1.000 0.500 1.000 1.000 4.000 6.000 0.500 0.500 1.000 1.000 4.000
0.333 1.000 0.500 1.000 1.000 4.000 6.000 0.500 0.500 1.000 1.000 4.000
0.167 0.250 0.200 0.250 0.250 1.000 3.000 0.200 0.200 0.250 0.250 1.000
0.125 0.167 0.143 0.167 0.167 0.333 1.000 0.143 0.143 0.167 0.167 0.333
0.500 2.000 1.000 2.000 2.000 5.000 7.000 1.000 1.000 2.000 2.000 5.000
0.500 2.000 1.000 2.000 2.000 5.000 7.000 1.000 1.000 2.000 2.000 5.000
0.333 1.000 0.500 1.000 1.000 4.000 6.000 0.500 0.500 1.000 1.000 4.000
0.333 1.000 0.500 1.000 1.000 4.000 6.000 0.500 0.500 1.000 1.000 4.000
0.167 0.250 0.200 0.250 0.250 1.000 3.000 0.200 0.200 0.250 0.250 1.000

Do you want to change data in the above matrix?  Y or N?  N

Please wait......
The matrix just entered is stored in a file named PARA12.LIQ

Press the RETURN key to continue

PARAMETER 13: Professional skill available for operation & maintenance

Do you want to use data from an existing file?  Y or N?  Y

Name of the existing file is? PARA13.LIQ

The decision variable matrix is:

1.000 1.000 1.000 2.000 3.000 5.000 7.000 2.000 2.000 3.000 3.000 3.000
1.000 1.000 1.000 2.000 3.000 5.000 7.000 2.000 2.000 3.000 2.000 3.000
1.000 1.000 1.000 2.000 3.000 5.000 7.000 2.000 3.000 2.000 3.000 2.000
0.500 0.500 0.500 1.000 2.000 4.000 6.000 1.000 2.000 1.000 1.000 2.000
0.333 0.333 0.333 0.500 1.000 3.000 5.000 0.500 1.000 0.500 0.500 1.000
0.200 0.200 0.200 0.250 0.333 1.000 3.000 0.250 0.333 0.250 0.250 0.333
0.143 0.143 0.143 0.167 0.200 0.333 1.000 0.167 0.200 0.167 0.167 0.200
0.500 0.500 0.500 1.000 2.000 4.000 6.000 1.000 2.000 1.000 1.000 2.000
0.333 0.333 0.333 0.500 1.000 3.000 5.000 0.500 1.000 0.500 0.500 1.000
0.500 0.500 0.500 1.000 2.000 4.000 6.000 1.000 2.000 1.000 1.000 2.000
0.500 0.500 0.500 1.000 2.000 4.000 6.000 1.000 2.000 1.000 1.000 2.000
0.333 0.333 0.333 0.500 1.000 3.000 5.000 0.500 1.000 0.500 0.500 1.000

Do you want to change data in the above matrix?  Y or N?  N

Please wait......
The matrix just entered is stored in a file named PARA13.LIQ

Press the RETURN key to continue
PARAMETER 14 : Local technical skill available for operation & maintenance

Do you want to use data from an existing file?  Y or N ? Y

Name of the existing file is ? PARA14.LIQ

The decision variable matrix is:

<p>| | | | | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>1.000</td>
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<td>4.000</td>
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<tr>
<td>0.250</td>
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</tr>
<tr>
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<td>0.143</td>
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<td>0.200</td>
<td>0.333</td>
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<td>0.250</td>
<td>0.333</td>
<td>0.333</td>
<td>0.500</td>
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<td>3.000</td>
<td>5.000</td>
<td>0.500</td>
<td>1.000</td>
<td>0.500</td>
<td>0.500</td>
</tr>
</tbody>
</table>

Do you want to change data in the above matrix?  Y or N ? N

Please wait ....
The matrix just entered is stored in a file named PARA14.LIQ

Press the RETURN key to continue

PARAMETER 15 : Administration set-up

Do you want to use data from an existing file?  Y or N ? Y

Name of the existing file is ? PARA15.LIQ

The decision variable matrix is:

<p>| | | | | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<td>0.143</td>
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<td>0.143</td>
<td>0.167</td>
<td>0.167</td>
<td>0.333</td>
<td>1.000</td>
<td>0.167</td>
<td>0.250</td>
<td>0.167</td>
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<td>0.500</td>
<td>2.000</td>
<td>0.500</td>
<td>0.500</td>
</tr>
</tbody>
</table>

Do you want to change data in the above matrix?  Y or N ? N

Please wait ....
The matrix just entered is stored in a file named PARA15.LIQ

Press the RETURN key to continue
PARAMETER 16: Training

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is PARA16.LIQ

The decision variable matrix is:

```
 1.000 2.000 2.000 2.000 2.000 4.000 6.000 2.000 2.000 2.000 2.000 3.000
 0.500 1.000 1.000 1.000 1.000 3.000 5.000 1.000 2.000 1.000 1.000 2.000
 0.500 1.000 1.000 1.000 1.000 3.000 5.000 1.000 2.000 1.000 1.000 2.000
 0.500 1.000 1.000 1.000 1.000 3.000 5.000 1.000 2.000 1.000 1.000 2.000
 0.333 0.500 0.500 0.500 0.500 2.000 4.000 0.333 1.000 0.500 0.500 1.000
 0.500 1.000 1.000 1.000 1.000 3.000 5.000 1.000 2.000 1.000 1.000 2.000
 0.500 1.000 1.000 1.000 1.000 3.000 5.000 1.000 2.000 1.000 1.000 2.000
 0.500 1.000 1.000 1.000 1.000 3.000 5.000 1.000 2.000 1.000 1.000 2.000
 0.500 1.000 1.000 1.000 1.000 3.000 5.000 1.000 2.000 1.000 1.000 2.000
 0.500 1.000 1.000 1.000 1.000 3.000 5.000 1.000 2.000 1.000 1.000 2.000
 0.500 1.000 1.000 1.000 1.000 3.000 5.000 1.000 2.000 1.000 1.000 2.000
```

Do you want to change data in the above matrix? Y or N? N

Please wait.....
The matrix just entered is stored in a file named PARA16.LIQ

Press the RETURN key to continue

PARAMETER 17: Professional ethics

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is PARA17.LIQ

The decision variable matrix is:

```
 1.000 2.000 2.000 4.000 4.000 7.000 9.000 2.000 4.000 2.000 2.000 5.000
 0.500 1.000 1.000 3.000 3.000 6.000 8.000 1.000 3.000 1.000 1.000 4.000
 0.500 1.000 1.000 3.000 3.000 6.000 8.000 1.000 3.000 1.000 1.000 4.000
 0.250 0.333 0.333 1.000 1.000 4.000 6.000 0.500 1.000 0.500 0.500 2.000
 0.250 0.333 0.333 1.000 1.000 4.000 6.000 0.333 1.000 0.333 0.333 3.000
 0.143 0.167 0.167 0.250 0.250 1.000 3.000 0.167 0.250 0.167 0.167 0.333
 0.111 0.125 0.125 0.167 0.167 0.333 1.000 0.125 0.167 0.125 0.125 0.200
 0.500 1.000 1.000 2.000 3.000 6.000 8.000 1.000 3.000 1.000 1.000 4.000
 0.250 0.333 0.333 1.000 1.000 4.000 6.000 0.333 1.000 0.333 0.333 1.000
 0.250 0.333 0.333 1.000 1.000 4.000 6.000 0.333 1.000 0.333 0.333 1.000
 0.250 0.333 0.333 1.000 1.000 4.000 6.000 0.333 1.000 0.333 0.333 1.000
 0.500 1.000 1.000 2.000 3.000 6.000 8.000 1.000 3.000 1.000 1.000 4.000
 0.200 0.250 0.250 0.500 0.333 3.000 5.000 0.250 1.000 0.250 0.250 1.000
```

Do you want to change data in the above matrix? Y or N? N

Please wait.....
The matrix just entered is stored in a file named PARA17.LIQ

Press the RETURN key to continue
PARAMETER 18 : Climate

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA18.LIQ

The decision variable matrix is:

1.000 1.000 1.000 3.000 3.000 2.000 2.000 2.000 5.000 2.000 2.000 2.000
1.000 1.000 1.000 3.000 3.000 2.000 2.000 2.000 5.000 2.000 2.000 2.000
1.000 1.000 1.000 3.000 3.000 2.000 2.000 2.000 5.000 2.000 2.000 2.000
0.333 0.333 0.333 1.000 1.000 0.500 0.500 0.500 3.000 0.500 0.500 0.500
0.333 0.333 0.333 1.000 1.000 0.500 0.500 0.500 3.000 0.500 0.500 0.500
0.500 0.500 0.500 2.000 2.000 1.000 1.000 1.000 4.000 1.000 1.000 1.000
0.500 0.500 0.500 2.000 2.000 1.000 1.000 1.000 4.000 1.000 1.000 1.000
0.500 0.500 0.500 2.000 2.000 1.000 1.000 1.000 4.000 1.000 1.000 1.000
0.200 0.200 0.200 0.333 0.333 0.250 0.250 0.250 1.000 0.250 0.250 0.250
0.500 0.500 0.500 2.000 2.000 1.000 1.000 1.000 4.000 1.000 1.000 1.000
0.500 0.500 0.500 2.000 2.000 1.000 1.000 1.000 4.000 1.000 1.000 1.000
0.500 0.500 0.500 2.000 2.000 1.000 1.000 1.000 4.000 1.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait ......
The matrix just entered is stored in a file named PARA18.LIQ

Press the RETURN key to continue

PARAMETER 19 : Local water-borne diseases

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA19.LIQ

The decision variable matrix is:

1.000 2.000 1.000 4.000 5.000 3.000 4.000 7.000 2.000 5.000 3.000 3.000
0.500 1.000 0.500 3.000 4.000 2.000 3.000 6.000 1.000 4.000 2.000 2.000
1.000 2.000 1.000 4.000 5.000 3.000 4.000 7.000 2.000 5.000 3.000 3.000
0.250 0.333 0.250 1.000 2.000 1.000 1.000 5.000 0.333 2.000 0.500 0.500
0.200 0.250 0.200 0.500 1.000 0.500 0.500 4.000 0.250 1.000 0.333 0.333
0.333 0.500 0.333 1.000 2.000 1.000 2.000 5.000 0.333 3.000 0.500 0.500
0.250 0.333 0.250 1.000 2.000 0.500 1.000 5.000 0.333 2.000 0.500 0.500
0.143 0.167 0.143 0.200 0.250 0.200 0.200 1.000 0.167 0.250 0.200 0.200
0.500 1.000 0.500 3.000 4.000 3.000 3.000 6.000 1.000 4.000 3.000 3.000
0.200 0.250 0.200 0.500 1.000 0.333 0.500 4.000 0.250 1.000 0.500 0.500
0.333 0.500 0.333 2.000 3.000 2.000 2.000 5.000 0.333 2.000 1.000 1.000
0.333 0.500 0.333 2.000 3.000 2.000 2.000 5.000 0.333 2.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait ......
The matrix just entered is stored in a file named PARA19.LIQ

Press the RETURN key to continue
PARAMETER 20: Endemic vector-borne (water-related) diseases

Do you want to use data from an existing file?  Y or N?  Y

Name of the existing file is ? PARA20.LIQ

The decision variable matrix is:

```
1.000 1.000 1.000 0.500 0.500 0.333 0.200 0.333 3.000 0.200 0.500 0.333
1.000 1.000 1.000 0.500 0.500 0.333 0.200 0.333 3.000 0.200 0.500 0.333
1.000 1.000 1.000 0.500 0.500 0.333 0.200 0.333 3.000 0.200 0.500 0.333
2.000 2.000 2.000 1.000 1.000 0.500 0.250 0.500 4.000 0.250 1.000 0.500
2.000 2.000 2.000 1.000 1.000 0.500 0.250 0.500 4.000 0.250 1.000 0.500
3.000 3.000 3.000 2.000 2.000 1.000 0.333 1.000 5.000 0.333 2.000 1.000
5.000 5.000 5.000 4.000 4.000 3.000 1.000 3.000 7.000 1.000 4.000 3.000
3.000 3.000 3.000 2.000 2.000 1.000 0.333 1.000 5.000 0.333 2.000 1.000
0.333 0.333 0.333 0.250 0.250 0.200 0.143 0.200 1.000 0.143 0.250 0.200
5.000 5.000 5.000 4.000 4.000 3.000 1.000 3.000 7.000 1.000 4.000 3.000
2.000 2.000 2.000 1.000 1.000 0.500 0.250 0.500 4.000 0.250 1.000 0.500
3.000 3.000 3.000 2.000 2.000 1.000 0.333 1.000 5.000 0.333 2.000 1.000
```

Do you want to change data in the above matrix?  Y or N?  N

The matrix just entered is stored in a file named 'PARA20.LIQ'

You have already entered all the necessary data

Press the RETURN key to continue

Please wait. Calculation of the ranking of the alternatives is in process.

The ranking is:

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Ranking in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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</tr>
<tr>
<td>2</td>
<td>66.4855</td>
</tr>
<tr>
<td>3</td>
<td>65.83235</td>
</tr>
<tr>
<td>4</td>
<td>50.38338</td>
</tr>
<tr>
<td>5</td>
<td>55.20052</td>
</tr>
<tr>
<td>6</td>
<td>84.51299</td>
</tr>
<tr>
<td>7</td>
<td>84.36512</td>
</tr>
<tr>
<td>8</td>
<td>82.55039</td>
</tr>
<tr>
<td>9</td>
<td>63.00436</td>
</tr>
<tr>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>11</td>
<td>63.26463</td>
</tr>
<tr>
<td>12</td>
<td>86.33479</td>
</tr>
</tbody>
</table>

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8.3 Computer Run for Min Shen STP (Taiwan)

This section must be read in conjunction with Section 7.5 of Chapter 7. The following is a record of running the model.

RANKING OF LIQUID TREATMENT ALTERNATIVES

Order of decision variable matrix is \( n \times n \) where \( n = 10 \)

PARAMETER 1 : Flow

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is ? PARA1.LIQ

The decision variable matrix is:

\[
\begin{array}{cccccccccc}
1.000 & 0.500 & 0.500 & 0.500 & 0.500 & 3.000 & 0.500 & 0.500 & 3.000 & 3.000 \\
2.000 & 1.000 & 1.000 & 1.000 & 1.000 & 4.000 & 1.000 & 1.000 & 4.000 & 4.000 \\
2.000 & 1.000 & 1.000 & 1.000 & 1.000 & 4.000 & 1.000 & 1.000 & 4.000 & 4.000 \\
2.000 & 1.000 & 1.000 & 1.000 & 1.000 & 4.000 & 1.000 & 1.000 & 4.000 & 4.000 \\
2.000 & 1.000 & 1.000 & 1.000 & 1.000 & 4.000 & 1.000 & 1.000 & 4.000 & 4.000 \\
2.000 & 1.000 & 1.000 & 1.000 & 1.000 & 4.000 & 1.000 & 1.000 & 4.000 & 4.000 \\
0.333 & 0.250 & 0.250 & 0.250 & 0.250 & 1.000 & 0.250 & 0.250 & 1.000 & 1.000 \\
2.000 & 1.000 & 1.000 & 1.000 & 1.000 & 4.000 & 1.000 & 2.000 & 4.000 & 4.000 \\
2.000 & 1.000 & 1.000 & 1.000 & 1.000 & 4.000 & 0.500 & 1.000 & 3.000 & 3.000 \\
0.333 & 0.250 & 0.250 & 0.250 & 0.250 & 1.000 & 0.250 & 0.333 & 1.000 & 1.000 \\
0.333 & 0.250 & 0.250 & 0.250 & 0.250 & 1.000 & 0.250 & 0.333 & 1.000 & 1.000 \\
\end{array}
\]

Do you want to change data in the above matrix? Y or N? N

Please wait ......

The matrix just entered is stored in a file named 'PARA1.LIQ'

Press the RETURN key to continue

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PARAMETER 2 : Influent / Effluent

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is ? PARA2.LIQ

The decision variable matrix is:

1.000 1.000 1.000 0.500 0.500 0.500 0.500 1.000 0.500 0.500
1.000 1.000 1.000 0.500 0.500 0.500 0.500 1.000 0.500 0.500
1.000 1.000 1.000 0.500 0.500 0.500 0.500 1.000 0.500 0.500
2.000 2.000 2.000 1.000 1.000 1.000 2.000 1.000 1.000
2.000 2.000 2.000 1.000 1.000 1.000 2.000 1.000 1.000
2.000 2.000 2.000 1.000 1.000 1.000 2.000 1.000 1.000
2.000 2.000 2.000 1.000 1.000 1.000 2.000 1.000 1.000
2.000 2.000 2.000 1.000 1.000 1.000 2.000 1.000 1.000
2.000 2.000 2.000 1.000 1.000 1.000 2.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait ......

The matrix just entered is stored in a file named PARA2.LIQ

Press the RETURN key to continue

PARAMETER 3 : Size of site

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is ? PARA3.LIQ

The decision variable matrix is:

1.000 0.200 0.200 0.111 0.111 0.111 0.111 0.333 0.111 0.111
5.000 1.000 1.000 0.200 0.200 0.200 0.200 3.000 0.200 0.200
5.000 1.000 1.000 0.200 0.200 0.200 0.200 3.000 0.200 0.200
9.000 5.000 5.000 1.000 1.000 1.000 1.000 7.000 1.000 1.000
9.000 5.000 5.000 1.000 1.000 1.000 1.000 7.000 1.000 1.000
9.000 5.000 5.000 1.000 1.000 1.000 1.000 7.000 1.000 1.000
9.000 5.000 5.000 1.000 1.000 1.000 1.000 7.000 1.000 1.000
3.000 0.333 0.333 0.143 0.143 0.143 0.143 0.143 0.143 0.143
9.000 5.000 5.000 1.000 1.000 1.000 1.000 5.000 1.000 1.000
9.000 5.000 5.000 1.000 1.000 1.000 1.000 6.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait ......

The matrix just entered is stored in a file named PARA3.LIQ

Press the RETURN key to continue
PARAMETER 4 : Nature of site

Do you want to use data from an existing file?  Y or N ?  Y

Name of the existing file is ? PARA4.LIQ

The decision variable matrix is:

1.000 1.000 1.000 0.333 0.200 0.200 0.250 1.000 0.250 0.200
1.000 1.000 1.000 0.333 0.200 0.200 0.250 1.000 0.250 0.200
1.000 1.000 1.000 0.333 0.200 0.200 0.250 1.000 0.250 0.200
3.000 3.000 3.000 1.000 0.333 1.000 0.500 3.000 0.500 0.333
5.000 5.000 5.000 3.000 1.000 1.000 2.000 5.000 4.000 1.000
5.000 5.000 5.000 1.000 1.000 1.000 2.000 5.000 4.000 1.000
4.000 4.000 4.000 2.000 0.500 0.500 1.000 4.000 1.000 0.500
1.000 1.000 1.000 0.333 0.200 0.200 0.250 1.000 0.250 0.200
4.000 4.000 4.000 2.000 0.250 0.250 1.000 4.000 1.000 0.500
5.000 5.000 5.000 3.000 1.000 1.000 2.000 5.000 2.000 1.000

Do you want to change data in the above matrix?  Y or N ?  N

Please wait ..... 

The matrix just entered is stored in a file named PARA4.LIQ

Press the RETURN key to continue

PARAMETER 5 : Land cost

Do you want to use data from an existing file?  Y or N ?  Y

Name of the existing file is ? PARA5.LIQ

The decision variable matrix is:

1.000 0.333 0.333 0.200 0.111 0.111 0.143 0.500 0.250 0.143
3.000 1.000 1.000 0.333 0.143 0.143 0.200 2.000 0.500 0.200
3.000 1.000 1.000 0.333 0.143 0.143 0.200 2.000 0.500 0.200
5.000 3.000 3.000 1.000 0.200 0.200 0.333 4.000 2.000 0.333
9.000 7.000 7.000 5.000 1.000 1.000 3.000 7.000 5.000 3.000
9.000 7.000 7.000 5.000 1.000 1.000 3.000 7.000 5.000 3.000
7.000 5.000 5.000 3.000 0.333 0.333 1.000 5.000 4.000 1.000
2.000 0.500 0.500 0.250 0.143 0.143 0.200 1.000 0.333 0.167
4.000 2.000 2.000 0.500 0.200 0.200 0.250 3.000 1.000 0.250
7.000 5.000 5.000 3.000 0.333 0.333 1.000 6.000 4.000 1.000

Do you want to change data in the above matrix?  Y or N ?  N

Please wait ..... 

The matrix just entered is stored in a file named PARA5.LIQ

Press the RETURN key to continue
PARAMETER 6 : Local money for construction

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is ? PARA6.LIQ

The decision variable matrix is:

<table>
<thead>
<tr>
<th>1.000</th>
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</table>

Do you want to change data in the above matrix? Y or N? N

Please wait ......

The matrix just entered is stored in a file named PARA6.LIQ

Press the RETURN key to continue

PARAMETER 7 : Foreign money for construction

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is ? PARA7.LIQ

The decision variable matrix is:

<table>
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<tr>
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<td>1.000</td>
</tr>
</tbody>
</table>

Do you want to change data in the above matrix? Y or N? N

Please wait ......

The matrix just entered is stored in a file named PARA7.LIQ

Press the RETURN key to continue
PARAMETER 8: Local skill for construction

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA8.LIQ

The decision variable matrix is:

```
1.000 1.000 1.000 1.000 1.000 2.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 2.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 2.000 1.000 1.000 1.000 1.000
0.500 0.500 0.500 0.500 0.500 1.000 0.500 0.500 0.500 0.500
1.000 1.000 1.000 1.000 1.000 2.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 2.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 2.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 2.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 2.000 1.000 1.000 1.000 1.000
```

Do you want to change data in the above matrix? Y or N? N

Please wait......

The matrix just entered is stored in a file named PARA8.LIQ

Press the RETURN key to continue

PARAMETER 9: Community support

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA9.LIQ

The decision variable matrix is:

```
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
```

Do you want to change data in the above matrix? Y or N? N

Please wait......

The matrix just entered is stored in a file named PARA9.LIQ

Press the RETURN key to continue
PARAMETER 10 : Power source

Do you want to use data from an existing file?  Y or N ? Y

Name of the existing file is ? PARA10.LIQ

The decision variable matrix is:

1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
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1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000

Do you want to change data in the above matrix?  Y or N ? N

Please wait ......

The matrix just entered is stored in a file named PARA10.LIQ

Press the RETURN key to continue

PARAMETER 11 : Availability of local material

Do you want to use data from an existing file?  Y or N ? Y

Name of the existing file is ? PARA11.LIQ

The decision variable matrix is:

1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
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1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000

Do you want to change data in the above matrix?  Y or N ? N

Please wait ......

The matrix just entered is stored in a file named PARA11.LIQ

Press the RETURN key to continue
PARAMETER 12 : Cost of operation & maintenance

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is ? PARA12.LIQ

The decision variable matrix is:

1.000 1.000 1.000 2.000 3.000 4.000 1.000 2.000 3.000 3.000
1.000 1.000 1.000 2.000 3.000 4.000 1.000 2.000 3.000 3.000
1.000 1.000 1.000 2.000 3.000 4.000 1.000 2.000 3.000 3.000
0.500 0.500 0.500 1.000 2.000 3.000 0.500 1.000 2.000 2.000
0.333 0.333 0.333 0.500 1.000 2.000 0.333 0.500 1.000 1.000
0.250 0.250 0.250 0.500 1.000 2.000 0.250 0.333 0.500 0.500
1.000 1.000 1.000 2.000 3.000 4.000 1.000 2.000 3.000 3.000
0.500 0.500 0.500 1.000 2.000 3.000 0.500 1.000 2.000 2.000
0.333 0.333 0.333 0.500 1.000 2.000 0.333 0.500 1.000 1.000
0.333 0.333 0.333 0.500 1.000 2.000 0.333 0.500 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait ......

The matrix just entered is stored in a file named PARA12.LIQ

Press the RETURN key to continue

PARAMETER 13 : Professional skill available for operation & maintenance

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is ? PARA13.LIQ

The decision variable matrix is:

1.000 1.000 1.000 1.000 2.000 3.000 1.000 1.000 1.000 2.000
1.000 1.000 1.000 1.000 2.000 3.000 1.000 1.000 1.000 2.000
1.000 1.000 1.000 1.000 2.000 3.000 1.000 1.000 1.000 2.000
1.000 1.000 1.000 1.000 2.000 3.000 1.000 1.000 1.000 2.000
0.500 0.500 0.500 0.500 1.000 2.000 0.500 0.500 0.500 1.000
0.333 0.333 0.333 0.500 1.000 2.000 0.333 0.333 0.500 0.500
1.000 1.000 1.000 1.000 2.000 3.000 1.000 1.000 1.000 2.000
1.000 1.000 1.000 1.000 2.000 3.000 1.000 1.000 1.000 2.000
1.000 1.000 1.000 1.000 2.000 3.000 1.000 1.000 1.000 2.000
0.500 0.500 0.500 0.500 1.000 2.000 0.500 0.500 0.500 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait ......

The matrix just entered is stored in a file named PARA13.LIQ

Press the RETURN key to continue
PARAMETER 14 : Local technical skill available for operation & maintenance

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA14.LIQ

The decision variable matrix is:

1.000 1.000 1.000 2.000 3.000 4.000 1.000 1.000 2.000 3.000
1.000 1.000 1.000 2.000 3.000 4.000 1.000 1.000 2.000 3.000
0.500 0.500 0.500 1.000 2.000 3.000 0.500 0.500 1.000 2.000
0.333 0.333 0.333 0.500 1.000 2.000 0.333 0.333 0.500 1.000
0.250 0.250 0.250 0.333 0.500 1.000 0.250 0.250 0.333 0.500
1.000 1.000 1.000 2.000 3.000 4.000 1.000 1.000 2.000 3.000
1.000 1.000 1.000 2.000 3.000 4.000 1.000 1.000 2.000 3.000
0.500 0.500 0.500 1.000 2.000 3.000 0.500 0.500 1.000 2.000
0.333 0.333 0.333 0.500 1.000 2.000 0.333 0.333 0.500 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait ..... 

The matrix just entered is stored in a file named PARA14.LIQ

Press the RETURN key to continue

PARAMETER 15 : Administration set-up

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA15.LIQ

The decision variable matrix is:

1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 2.000 1.000 1.000 2.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 2.000 1.000 1.000 2.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 2.000 1.000 1.000 2.000
0.500 0.500 0.500 0.500 1.000 2.000 0.500 0.500 0.500 1.000
0.333 0.333 0.333 0.333 0.500 1.000 0.333 0.333 0.333 0.500
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 2.000 1.000 1.000 2.000
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0.500 0.500 0.500 0.500 1.000 2.000 0.500 0.500 0.500 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait ..... 

The matrix just entered is stored in a file named PARA15.LIQ

Press the RETURN key to continue
PARAMETER 16 : Training

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA16.LIQ

The decision variable matrix is:

\[
\begin{pmatrix}
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 3.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 3.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 3.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 3.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 3.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 3.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
0.333 & 0.333 & 0.333 & 0.333 & 0.333 & 1.000 & 0.333 & 0.333 & 0.333 & 0.333 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 3.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
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1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 3.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 3.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
\end{pmatrix}
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Do you want to change data in the above matrix? Y or N? N

Please wait......

The matrix just entered is stored in a file named PARA16.LIQ

Press the RETURN key to continue

PARAMETER 17 : Professional ethics

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA17.LIQ

The decision variable matrix is:

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1.000 & 1.000 & 1.000 & 2.000 & 3.000 & 4.000 & 1.000 & 1.000 & 1.000 & 3.000 \\
1.000 & 1.000 & 1.000 & 2.000 & 3.000 & 4.000 & 1.000 & 1.000 & 1.000 & 3.000 \\
0.500 & 0.500 & 0.500 & 1.000 & 2.000 & 3.000 & 0.500 & 0.500 & 0.500 & 2.000 \\
0.333 & 0.333 & 0.333 & 0.500 & 1.000 & 2.000 & 0.333 & 0.333 & 0.333 & 1.000 \\
0.233 & 0.250 & 0.250 & 0.333 & 0.500 & 1.000 & 0.200 & 0.200 & 0.250 & 0.500 \\
1.000 & 1.000 & 1.000 & 2.000 & 3.000 & 5.000 & 1.000 & 1.000 & 1.000 & 3.000 \\
1.000 & 1.000 & 1.000 & 2.000 & 3.000 & 5.000 & 1.000 & 1.000 & 1.000 & 3.000 \\
1.000 & 1.000 & 1.000 & 2.000 & 3.000 & 4.000 & 1.000 & 1.000 & 1.000 & 3.000 \\
0.333 & 0.333 & 0.333 & 0.500 & 1.000 & 2.000 & 0.333 & 0.333 & 0.333 & 1.000 \\
\end{pmatrix}
\]

Do you want to change data in the above matrix? Y or N? N

Please wait......

The matrix just entered is stored in a file named PARA17.LIQ

Press the RETURN key to continue

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PARAMETER 18 : Climate

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is ? PARA18.LIQ

The decision variable matrix is:

1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait .....  

The matrix just entered is stored in a file named PARA18.LIQ 

Press the RETURN key to continue

PARAMETER 19 : Local water-borne diseases

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is ? PARA19.LIQ

The decision variable matrix is:

1.000 1.000 1.000 0.500 0.500 0.500 1.000 0.333 0.333 0.500
1.000 1.000 1.000 0.500 0.500 0.500 1.000 0.333 0.333 0.500
1.000 1.000 1.000 0.500 0.500 0.500 1.000 0.333 0.333 0.500
2.000 2.000 2.000 1.000 1.000 1.000 2.000 0.500 0.500 1.000
2.000 2.000 2.000 1.000 1.000 1.000 2.000 0.500 0.500 1.000
2.000 2.000 2.000 1.000 1.000 1.000 2.000 0.500 0.500 1.000
2.000 2.000 2.000 1.000 1.000 1.000 2.000 0.500 0.500 1.000
1.000 1.000 1.000 0.500 0.500 0.500 1.000 0.333 0.333 0.500
3.000 3.000 3.000 2.000 2.000 2.000 3.000 1.000 1.000 2.000
3.000 3.000 3.000 2.000 2.000 2.000 3.000 1.000 1.000 2.000
2.000 2.000 2.000 1.000 1.000 1.000 2.000 0.500 0.500 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait .....  

The matrix just entered is stored in a file named PARA19.LIQ 

Press the RETURN key to continue
PARAMETER 20 : Endemic vector-borne (water-related) diseases

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA20.LIC

The decision variable matrix is:

1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait ......

The matrix just entered is stored in a file named PARA20.LIC

You have already entered all the necessary data

Press the RETURN key to continue

Please wait. Calculation of the ranking of the alternatives is in process.

The ranking is:

<table>
<thead>
<tr>
<th>Alternative</th>
<th>RANKING IN %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative 1</td>
<td>59.66283</td>
</tr>
<tr>
<td>Alternative 2</td>
<td>67.58635</td>
</tr>
<tr>
<td>Alternative 3</td>
<td>67.58635</td>
</tr>
<tr>
<td>Alternative 4</td>
<td>91.93332</td>
</tr>
<tr>
<td>Alternative 5</td>
<td>95.66285</td>
</tr>
<tr>
<td>Alternative 6</td>
<td>84.11186</td>
</tr>
<tr>
<td>Alternative 7</td>
<td>100</td>
</tr>
<tr>
<td>Alternative 8</td>
<td>65.81622</td>
</tr>
<tr>
<td>Alternative 9</td>
<td>88.19032</td>
</tr>
<tr>
<td>Alternative 10</td>
<td>85.22399</td>
</tr>
</tbody>
</table>

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8.4 **Computer Run for Shatin STP (Hong Kong)**

8.4.1 General Selection

This section must be read in conjunction with Section 7.6 of Chapter 7. The following is a record of running the model.

**RANKING OF LIQUID TREATMENT ALTERNATIVES**

Order of decision variable matrix is $n \times n$ where $n = 8$

**PARAMETER 1 : Flow**

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is ? PARA1.LIQ

The decision variable matrix is:

```
1.000 0.333 0.167 0.111 0.111 3.000 0.250 0.250
3.000 1.000 0.200 0.125 0.125 5.000 0.333 0.333
6.000 5.000 1.000 0.333 0.333 7.000 0.500 0.500
9.000 8.000 3.000 1.000 1.000 9.000 5.000 5.000
9.000 8.000 3.000 1.000 1.000 9.000 5.000 5.000
0.333 0.200 0.143 0.111 0.111 1.000 0.143 0.143
4.000 3.000 2.000 0.200 0.200 7.000 1.000 1.000
4.000 3.000 2.000 0.200 0.200 7.000 1.000 1.000
```

Do you want to change data in the above matrix? Y or N? N

Please wait ......

The matrix just entered is stored in a file named 'PARA1.LIQ'

Press the RETURN key to continue
PARAMETER 2 : Influent / Effluent

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA2.LIQ

The decision variable matrix is:

\[
\begin{array}{cccccccc}
1.000 & 1.000 & 0.500 & 0.333 & 9.000 & 0.333 & 0.333 & 0.333 \\
1.000 & 1.000 & 0.500 & 0.333 & 9.000 & 0.333 & 0.333 & 0.333 \\
2.000 & 2.000 & 1.000 & 0.500 & 9.000 & 0.500 & 0.500 & 0.500 \\
3.000 & 3.000 & 2.000 & 1.000 & 9.000 & 1.000 & 1.000 & 1.000 \\
0.111 & 0.111 & 0.111 & 0.111 & 1.000 & 0.111 & 0.111 & 0.111 \\
3.000 & 3.000 & 2.000 & 1.000 & 9.000 & 1.000 & 1.000 & 1.000 \\
3.000 & 3.000 & 2.000 & 1.000 & 9.000 & 1.000 & 1.000 & 1.000 \\
3.000 & 3.000 & 2.000 & 1.000 & 9.000 & 1.000 & 1.000 & 1.000 \\
\end{array}
\]

Do you want to change data in the above matrix? Y or N? N

Please wait.....

The matrix just entered is stored in a file named PARA2.LIQ

Press the RETURN key to continue

PARAMETER 3 : Size of site

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA3.LIQ

The decision variable matrix is:

\[
\begin{array}{cccccccc}
1.000 & 1.000 & 0.200 & 0.111 & 0.111 & 1.000 & 0.111 & 0.111 \\
1.000 & 1.000 & 0.200 & 0.111 & 0.111 & 1.000 & 0.111 & 0.111 \\
5.000 & 5.000 & 1.000 & 0.200 & 0.200 & 7.000 & 0.200 & 0.200 \\
9.000 & 9.000 & 5.000 & 1.000 & 1.000 & 9.000 & 1.000 & 1.000 \\
9.000 & 9.000 & 5.000 & 1.000 & 1.000 & 9.000 & 1.000 & 1.000 \\
9.000 & 9.000 & 5.000 & 1.000 & 1.000 & 9.000 & 1.000 & 1.000 \\
9.000 & 9.000 & 5.000 & 1.000 & 1.000 & 9.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 0.143 & 0.111 & 0.111 & 1.000 & 0.111 & 0.111 \\
9.000 & 9.000 & 5.000 & 1.000 & 1.000 & 9.000 & 1.000 & 1.000 \\
9.000 & 9.000 & 5.000 & 1.000 & 1.000 & 9.000 & 1.000 & 1.000 \\
9.000 & 9.000 & 5.000 & 1.000 & 1.000 & 9.000 & 1.000 & 1.000 \\
\end{array}
\]

Do you want to change data in the above matrix? Y or N? N

Please wait.....

The matrix just entered is stored in a file named PARA3.LIQ

Press the RETURN key to continue
PARAMETER 4 : Nature of site

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is PARA4.LIQ

The decision variable matrix is:

1.000 1.000 2.000 2.000 2.000 7.000 2.000 2.000
1.000 1.000 2.000 2.000 2.000 7.000 2.000 2.000
0.500 0.500 1.000 1.000 1.000 7.000 1.000 1.000
0.500 0.500 1.000 1.000 1.000 7.000 1.000 1.000
0.500 0.500 1.000 1.000 1.000 7.000 1.000 1.000
0.143 0.143 0.143 0.143 0.143 1.000 0.143 0.143
0.500 0.500 1.000 1.000 1.000 7.000 1.000 1.000
0.500 0.500 1.000 1.000 1.000 7.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait.....

The matrix just entered is stored in a file named PARA4.LIQ

Press the RETURN key to continue

PARAMETER 5 : Land cost

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is PARA5.LIQ

The decision variable matrix is:

1.000 0.500 0.250 0.143 0.111 3.000 0.143 0.143
2.000 1.000 0.333 0.167 0.125 5.000 0.167 0.167
4.000 3.000 1.000 0.250 0.167 6.000 0.250 0.250
7.000 6.000 4.000 1.000 0.200 7.000 1.000 1.000
9.000 8.000 6.000 5.000 1.000 9.000 3.000 3.000
0.333 0.200 0.167 0.143 0.111 1.000 0.143 0.143
7.000 6.000 4.000 1.000 0.333 7.000 1.000 1.000
7.000 6.000 4.000 1.000 0.333 7.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait.....

The matrix just entered is stored in a file named PARA5.LIQ

Press the RETURN key to continue
PARAMETER 6: Local money for construction

Do you want to use data from an existing file? Y or N? Y
Name of the existing file is? PARA6.LIQ

The decision variable matrix is:

\[
\begin{array}{ccccccc}
1.000 & 1.000 & 1.000 & 2.000 & 1.000 & 1.000 & 1.000 & 2.000 \\
1.000 & 1.000 & 1.000 & 2.000 & 1.000 & 1.000 & 1.000 & 2.000 \\
1.000 & 1.000 & 1.000 & 2.000 & 1.000 & 1.000 & 1.000 & 2.000 \\
0.500 & 0.500 & 0.500 & 1.000 & 0.500 & 0.500 & 0.500 & 1.000 \\
1.000 & 1.000 & 1.000 & 2.000 & 1.000 & 1.000 & 1.000 & 2.000 \\
1.000 & 1.000 & 1.000 & 2.000 & 1.000 & 1.000 & 1.000 & 2.000 \\
0.500 & 0.500 & 0.500 & 1.000 & 0.500 & 0.500 & 0.500 & 1.000 \\
\end{array}
\]

Do you want to change data in the above matrix? Y or N? N
Please wait ..... 

The matrix just entered is stored in a file named PARA6.LIQ
Press the RETURN key to continue

PARAMETER 7: Foreign money for construction

Do you want to use data from an existing file? Y or N? Y
Name of the existing file is? PARA7.LIQ

The decision variable matrix is:

\[
\begin{array}{ccccccc}
1.000 & 1.000 & 1.000 & 2.000 & 1.000 & 1.000 & 1.000 & 2.000 \\
1.000 & 1.000 & 1.000 & 2.000 & 1.000 & 1.000 & 1.000 & 2.000 \\
1.000 & 1.000 & 1.000 & 2.000 & 1.000 & 1.000 & 1.000 & 2.000 \\
0.500 & 0.500 & 0.500 & 1.000 & 0.500 & 0.500 & 0.500 & 1.000 \\
1.000 & 1.000 & 1.000 & 2.000 & 1.000 & 1.000 & 1.000 & 2.000 \\
1.000 & 1.000 & 1.000 & 2.000 & 1.000 & 1.000 & 1.000 & 2.000 \\
0.500 & 0.500 & 0.500 & 1.000 & 0.500 & 0.500 & 0.500 & 1.000 \\
\end{array}
\]

Do you want to change data in the above matrix? Y or N? N
Please wait ..... 

The matrix just entered is stored in a file named PARA7.LIQ
Press the RETURN key to continue
PARAMETER 8: Local skill for construction

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA8.LIQ

The decision variable matrix is:

1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait ....

The matrix just entered is stored in a file named PARA8.LIQ

Press the RETURN key to continue

PARAMETER 9: Community support

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA9.LIQ

The decision variable matrix is:

1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait ....

The matrix just entered is stored in a file named PARA9.LIQ

Press the RETURN key to continue
PARAMETER 10 : Power source

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA10.LIQ

The decision variable matrix is:

1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait.....

The matrix just entered is stored in a file named PARA10.LIQ

Press the RETURN key to continue

PARAMETER 11 : Availability of local material

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA11.LIQ

The decision variable matrix is:

1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait.....

The matrix just entered is stored in a file named PARA11.LIQ

Press the RETURN key to continue
PARAMETER 12 : Cost of operation & maintenance

Do you want to use data from an existing file? Y or N? Y
Name of the existing file is? PARA12.LIQ

The decision variable matrix is:

1.000 1.000 1.000 2.000 1.000 1.000 2.000 1.000
1.000 1.000 1.000 2.000 1.000 1.000 2.000 1.000
1.000 1.000 1.000 2.000 1.000 1.000 2.000 1.000
0.500 0.500 0.500 1.000 0.500 0.500 0.500 1.000
1.000 1.000 1.000 2.000 1.000 1.000 2.000 1.000
1.000 1.000 1.000 2.000 1.000 1.000 2.000 1.000
1.000 1.000 1.000 2.000 1.000 1.000 2.000 1.000
0.500 0.500 0.500 1.000 0.500 0.500 0.500 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait......

The matrix just entered is stored in a file named PARA12.LIQ

Press the RETURN key to continue

PARAMETER 13 : Professional skill available for operation & maintenance

Do you want to use data from an existing file? Y or N? Y
Name of the existing file is? PARA13.LIQ

The decision variable matrix is:

1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait......

The matrix just entered is stored in a file named PARA13.LIQ

Press the RETURN key to continue
PARAMETER 14 : Local technical skill available for operation & maintenance

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA14.LIQ

The decision variable matrix is:

1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait ......

The matrix just entered is stored in a file named PARA14.LIQ

Press the RETURN key to continue

PARAMETER 15 : Administration set-up

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA15.LIQ

The decision variable matrix is:

1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait ......

The matrix just entered is stored in a file named PARA15.LIQ

Press the RETURN key to continue
PARAMETER 16 : Training

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA16.LIQ

The decision variable matrix is:

1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait......

The matrix just entered is stored in a file named PARA16.LIQ

Press the RETURN key to continue

PARAMETER 17 : Professional ethics

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA17.LIQ

The decision variable matrix is:

1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait......

The matrix just entered is stored in a file named PARA17.LIQ

Press the RETURN key to continue

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PARAMETER 18 : Climate

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA18.LIQ

The decision variable matrix is:

1.000 1.000 2.000 2.000 2.000 7.000 2.000 2.000
1.000 1.000 2.000 2.000 2.000 7.000 2.000 2.000
0.500 0.500 1.000 1.000 1.000 5.000 1.000 1.000
0.500 0.500 1.000 1.000 1.000 5.000 1.000 1.000
0.143 0.143 0.200 0.200 0.200 1.000 0.200 0.200
0.500 0.500 1.000 1.000 1.000 5.000 1.000 1.000
0.500 0.500 1.000 1.000 1.000 5.000 1.000 1.000
0.143 0.143 0.200 0.200 0.200 1.000 0.200 0.200

Do you want to change data in the above matrix? Y or N? N

Please wait.....

The matrix just entered is stored in a file named PARA18.LIQ

Press the RETURN key to continue

PARAMETER 19 : Local water-borne diseases

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA19.LIQ

The decision variable matrix is:

1.000 1.000 1.000 1.000 3.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 3.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 3.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 3.000 1.000 1.000 1.000
0.333 0.333 0.333 0.333 1.000 0.333 0.333 0.333
1.000 1.000 1.000 1.000 3.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 3.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 3.000 1.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait.....

The matrix just entered is stored in a file named PARA19.LIQ

Press the RETURN key to continue
PARAMETER 20 : Endemic vector-borne (water-related) diseases

Do you want to use data from an existing file?  Y or N?  Y
Name of the existing file is? PARA20.LIQ

The decision variable matrix is:

```
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
```

Do you want to change data in the above matrix?  Y or N?  N

Please wait.....

The matrix just entered is stored in a file named PARA20.LIQ

You have already entered all the necessary data

Press the RETURN key to continue

Please wait. Calculation of the ranking of the alternatives is in process.

The ranking is:

<table>
<thead>
<tr>
<th>Alternative</th>
<th>RANKING IN %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative 1</td>
<td>59.72916</td>
</tr>
<tr>
<td>Alternative 2</td>
<td>60.72353</td>
</tr>
<tr>
<td>Alternative 3</td>
<td>67.37144</td>
</tr>
<tr>
<td>Alternative 4</td>
<td>100</td>
</tr>
<tr>
<td>Alternative 5</td>
<td>85.68993</td>
</tr>
<tr>
<td>Alternative 6</td>
<td>58.68803</td>
</tr>
<tr>
<td>Alternative 7</td>
<td>93.35902</td>
</tr>
<tr>
<td>Alternative 8</td>
<td>89.88984</td>
</tr>
</tbody>
</table>

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8.4.2 Refined Selection

This section must be read in conjunction with Section 7.6 of Chapter 7. The following is a record of running the model.

RANKING OF LIQUID TREATMENT ALTERNATIVES

Order of decision variable matrix is \( n \times n \) where \( n = 7 \)

PARAMETER 1 : Flow

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA1.LIQ

The decision variable matrix is:

\[
\begin{align*}
1.000 & \quad 3.000 & \quad 1.000 & \quad 2.000 & \quad 2.000 & \quad 3.000 & \quad 3.000 \\
0.333 & \quad 1.000 & \quad 0.333 & \quad 0.500 & \quad 0.500 & \quad 1.000 & \quad 1.000 \\
1.000 & \quad 3.000 & \quad 1.000 & \quad 2.000 & \quad 2.000 & \quad 3.000 & \quad 3.000 \\
0.500 & \quad 2.000 & \quad 0.500 & \quad 1.000 & \quad 1.000 & \quad 2.000 & \quad 2.000 \\
0.500 & \quad 2.000 & \quad 0.500 & \quad 1.000 & \quad 1.000 & \quad 2.000 & \quad 2.000 \\
0.333 & \quad 1.000 & \quad 0.333 & \quad 0.500 & \quad 0.500 & \quad 1.000 & \quad 1.000 \\
0.333 & \quad 1.000 & \quad 0.333 & \quad 0.500 & \quad 0.500 & \quad 1.000 & \quad 1.000
\end{align*}
\]

Do you want to change data in the above matrix? Y or N? N

Please wait ..... 

The matrix just entered is stored in a file named 'PARA1.LIQ'

Press the RETURN key to continue
PARAMETER 2 : Influent / Effluent

Do you want to use data from an existing file?  Y or N?  Y

Name of the existing file is? PARA2.LIQ

The decision variable matrix is:

\[
\begin{array}{cccccccc}
1.000 & 1.000 & 0.500 & 1.000 & 0.500 & 1.000 & 0.500 \\
1.000 & 1.000 & 0.500 & 1.000 & 0.500 & 1.000 & 0.500 \\
2.000 & 2.000 & 1.000 & 2.000 & 1.000 & 2.000 & 1.000 \\
1.000 & 1.000 & 0.500 & 1.000 & 0.500 & 1.000 & 0.500 \\
2.000 & 2.000 & 1.000 & 2.000 & 1.000 & 2.000 & 1.000 \\
1.000 & 1.000 & 0.500 & 1.000 & 0.500 & 1.000 & 0.500 \\
2.000 & 2.000 & 1.000 & 2.000 & 1.000 & 2.000 & 1.000 \\
\end{array}
\]

Do you want to change data in the above matrix?  Y or N?  N

Please wait......

The matrix just entered is stored in a file named PARA2.LIQ

Press the RETURN key to continue

PARAMETER 3 : Size of site

Do you want to use data from an existing file?  Y or N?  Y

Name of the existing file is? PARA3.LIQ

The decision variable matrix is:

\[
\begin{array}{cccccccc}
1.000 & 3.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
0.333 & 1.000 & 0.333 & 0.333 & 0.333 & 0.333 & 0.333 \\
1.000 & 3.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 3.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 3.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 3.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 3.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
\end{array}
\]

Do you want to change data in the above matrix?  Y or N?  N

Please wait......

The matrix just entered is stored in a file named PARA3.LIQ

Press the RETURN key to continue
**PARAMETER 4 : Nature of site**

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is ? PARA4.LIQ

The decision variable matrix is:

```
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
```

Do you want to change data in the above matrix? Y or N? N

Please wait . . . . .

The matrix just entered is stored in a file named PARA4.LIQ

Press the RETURN key to continue

---

**PARAMETER 5 : Land cost**

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is ? PARA5.LIQ

The decision variable matrix is:

```
1.000 3.000 2.000 0.143 0.500 0.200 0.250
0.333 1.000 0.500 0.111 0.250 0.143 0.167
0.500 2.000 1.000 0.125 0.333 0.167 0.200
7.000 9.000 8.000 1.000 7.000 3.000 4.000
2.000 4.000 3.000 0.143 1.000 0.200 0.250
5.000 7.000 6.000 0.333 5.000 1.000 2.000
4.000 6.000 5.000 0.250 4.000 0.500 1.000
```

Do you want to change data in the above matrix? Y or N? N

Please wait . . . . .

The matrix just entered is stored in a file named PARA5.LIQ

Press the RETURN key to continue
PARAMETER 6 : Local money for construction

Do you want to use data from an existing file?  Y or N?  Y  
Name of the existing file is？ PARA6.LIQ  
The decision variable matrix is:

```
1.000 1.000 1.000 2.000 3.000 2.000 2.000
1.000 1.000 1.000 2.000 3.000 2.000 2.000
1.000 1.000 1.000 2.000 3.000 2.000 2.000
0.500 0.500 0.500 1.000 2.000 1.000 1.000
0.333 0.333 0.333 0.500 1.000 0.500 0.500
0.500 0.500 0.500 1.000 2.000 1.000 1.000
0.500 0.500 0.500 1.000 2.000 1.000 1.000
```

Do you want to change data in the above matrix?  Y or N?  N  
Please wait.....

The matrix just entered is stored in a file named PARA6.LIQ  
Press the RETURN key to continue

PARAMETER 7 : Foreign money for construction

Do you want to use data from an existing file?  Y or N?  Y  
Name of the existing file is? PARA7.LIQ  
The decision variable matrix is:

```
1.000 1.000 1.000 1.000 3.000 3.000
1.000 1.000 1.000 1.000 3.000 3.000
1.000 1.000 1.000 1.000 3.000 3.000
1.000 1.000 1.000 1.000 3.000 3.000
1.000 1.000 1.000 1.000 3.000 3.000
0.333 0.333 0.333 0.333 0.333 1.000 1.000
0.333 0.333 0.333 0.333 0.333 1.000 1.000
```

Do you want to change data in the above matrix?  Y or N?  N  
Please wait.....

The matrix just entered is stored in a file named PARA7.LIQ  
Press the RETURN key to continue
PARAMETER 8 : Local skill for construction

Do you want to use data from an existing file? Y or N? Y
Name of the existing file is ? PARA8.LIQ

The decision variable matrix is:

\[
\begin{array}{cccccccc}
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
\end{array}
\]

Do you want to change data in the above matrix? Y or N? N
Please wait ......

The matrix just entered is stored in a file named PARA8.LIQ
Press the RETURN key to continue

PARAMETER 9 : Community support

Do you want to use data from an existing file? Y or N? Y
Name of the existing file is ? PARA9.LIQ

The decision variable matrix is:

\[
\begin{array}{cccccccc}
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
\end{array}
\]

Do you want to change data in the above matrix? Y or N? N
Please wait ......

The matrix just entered is stored in a file named PARA9.LIQ
Press the RETURN key to continue
PARAMETER 10 : Power source

Do you want to use data from an existing file?  Y or N?  Y
Name of the existing file is ? PARA10.LIQ

The decision variable matrix is :

1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000

Do you want to change data in the above matrix?  Y or N?  N
Please wait ......

The matrix just entered is stored in a file named PARA10.LIQ
Press the RETURN key to continue

PARAMETER 11 : Availability of local material

Do you want to use data from an existing file?  Y or N?  Y
Name of the existing file is ? PARA11.LIQ

The decision variable matrix is :

1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000

Do you want to change data in the above matrix?  Y or N?  N
Please wait ......

The matrix just entered is stored in a file named PARA11.LIQ
Press the RETURN key to continue
PARAMETER 12 : Cost of operation & maintenance

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA12.LIQ

The decision variable matrix is:

1.000 1.000 1.000 2.000 3.000 3.000 3.000
1.000 1.000 1.000 2.000 3.000 3.000 3.000
1.000 1.000 1.000 2.000 3.000 3.000 3.000
0.500 0.500 0.500 1.000 2.000 2.000 2.000
0.333 0.333 0.333 0.500 1.000 1.000 1.000
0.333 0.333 0.333 0.500 1.000 1.000 1.000
0.333 0.333 0.333 0.500 1.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait......

The matrix just entered is stored in a file named PARA12.LIQ

Press the RETURN key to continue

PARAMETER 13 : Professional skill available for operation & maintenance

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA13.LIQ

The decision variable matrix is:

1.000 1.000 1.000 3.000 3.000 1.000 1.000
1.000 1.000 1.000 3.000 3.000 1.000 1.000
1.000 1.000 1.000 3.000 3.000 1.000 1.000
0.333 0.333 0.333 1.000 1.000 0.333 0.333
0.333 0.333 0.333 1.000 1.000 0.333 0.333
1.000 1.000 1.000 3.000 3.000 1.000 1.000
1.000 1.000 1.000 3.000 3.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait......

The matrix just entered is stored in a file named PARA13.LIQ

Press the RETURN key to continue
PARAMETER 14: Local technical skill available for operation & maintenance

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA14.LIQ

The decision variable matrix is:

1.000 1.000 1.000 2.000 2.000 1.000 1.000
1.000 1.000 1.000 2.000 2.000 1.000 1.000
1.000 1.000 1.000 2.000 2.000 1.000 1.000
0.500 0.500 0.500 1.000 1.000 0.500 0.500
0.500 0.500 0.500 1.000 1.000 0.500 0.500
1.000 1.000 1.000 2.000 2.000 1.000 1.000
1.000 1.000 1.000 2.000 2.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait......

The matrix just entered is stored in a file named PARA14.LIQ

Press the RETURN key to continue

PARAMETER 15: Administration set-up

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA15.LIQ

The decision variable matrix is:

1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait......

The matrix just entered is stored in a file named PARA15.LIQ

Press the RETURN key to continue
PARAMETER 16 : Training

Do you want to use data from an existing file? Y or N? Y
Name of the existing file is? PARA16.LIQ

The decision variable matrix is:

1.000 1.000 1.000 2.000 2.000 1.000 1.000
1.000 1.000 1.000 2.000 2.000 1.000 1.000
1.000 1.000 1.000 2.000 2.000 1.000 1.000
0.500 0.500 0.500 1.000 1.000 0.500 0.500
0.500 0.500 0.500 1.000 1.000 0.500 0.500
1.000 1.000 1.000 2.000 2.000 1.000 1.000
1.000 1.000 1.000 2.000 2.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait.....

The matrix just entered is stored in a file named PARA16.LIQ

Press the RETURN key to continue

PARAMETER 17 : Professional ethics

Do you want to use data from an existing file? Y or N? Y
Name of the existing file is? PARA17.LIQ

The decision variable matrix is:

1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait.....

The matrix just entered is stored in a file named PARA17.LIQ

Press the RETURN key to continue
PARAMETER 18 : Climate

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA18.LIQ

The decision variable matrix is:

1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait......

The matrix just entered is stored in a file named PARA18.LIQ

Press the RETURN key to continue.

PARAMETER 19 : Local water-borne diseases

Do you want to use data from an existing file? Y or N? Y

Name of the existing file is? PARA19.LIQ

The decision variable matrix is:

1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000

Do you want to change data in the above matrix? Y or N? N

Please wait......

The matrix just entered is stored in a file named PARA19.LIQ

Press the RETURN key to continue.
PARAMETER 20 : Endemic vector-borne (water-related) diseases

Do you want to use data from an existing file? Y or N? Y
Name of the existing file is? PARA20.LIQ

The decision variable matrix is:

\[
\begin{array}{cccccccc}
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
\end{array}
\]

Do you want to change data in the above matrix? Y or N? N

Please wait......

The matrix just entered is stored in a file named PARA20.LIQ

You have already entered all the necessary data

Press the RETURN key to continue

Please wait. Calculation of the ranking of the alternatives is in process.

The ranking is:

<table>
<thead>
<tr>
<th>Alternative</th>
<th>RANKING IN %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>89.36844</td>
</tr>
<tr>
<td>2</td>
<td>69.29602</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>83.26269</td>
</tr>
<tr>
<td>5</td>
<td>87.32095</td>
</tr>
<tr>
<td>6</td>
<td>77.60319</td>
</tr>
<tr>
<td>7</td>
<td>87.51058</td>
</tr>
</tbody>
</table>
PART 4

FURTHER DEVELOPMENT AND CONCLUSION
9.1 Sensitivity Analysis

The model has been tested in Chapters 7 and 8 and the results obtained are found to be satisfactory. The next question, now, is: how will the appropriate technology change as social and environmental conditions in a given situation change with time, or in other words, how sensitive is the model developed? Sensitivity analysis is concerned with investigating the sensitivity of the response of the model to changes in data input. In the context of this research, sensitivity analysis means the investigation of the change of optimal treatment alternative resulting from a change of decision variable matrices of certain parameters.

It must be pointed out that a detailed and thorough sensitivity analysis of the technique of eigenvector prioritization requires a profound mathematical knowledge background. It is an area in which, perhaps, only mathematicians should carry out the investigation. A limited approach to the topic was initiated by Vargas in 1983(3). His work was confined to $3 \times 3$ reciprocal matrices only and he concluded that higher-dimension reciprocal matrices do not have a generalized property and the sensitivity analysis of the latter is very complex(3).
To the knowledge of the author, no further work has so far been done by others after Vargas. Therefore, there is a large amount of work in this area left to be explored by mathematicians, and it is beyond the scope of the present research to enter deeply into the theory of sensitivity analysis of the mathematical technique applied in the model. The intention of the author, however, is to, before ending the thesis, throw out an idea by which the technique of sensitivity analysis may be applied in order that the model developed in this research can be extended to be able to forecast a change of the appropriate technology required as conditions described by certain parameters alter with time.

9.2 Application of Sensitivity Analysis to The Model

There are certain parameters (e.g. Parameter 18: climate) which will not alter with time. The parameters which are most vulnerable to changes are the subjective / intangible factors (see Section 4.2.2 of Chapter 4). Professional skill for O & M (i.e. Parameter 13), for instance, in a given situation may improve with time. In the perfect case, the decision variable matrix will become an all-one matrix (i.e. matrix with all its elements equal to 1). The Taiwan Min Shen STP is used as an example. The original decision variable matrix of Parameter 13 is reproduced in Fig. 9.1. If the professional skill is forecast to improve in fifteen years time, say, then the
<table>
<thead>
<tr>
<th>Alt No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
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<tbody>
<tr>
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<td>1</td>
<td>1</td>
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<td>3</td>
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<td>1</td>
<td>1</td>
<td>2</td>
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<tr>
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<td>5</td>
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<td>1/2</td>
<td>1/2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>All lower triangular elements = $a_{ij}$</td>
<td>1</td>
<td>1/3</td>
<td>1/3</td>
<td>1/3</td>
<td>1/2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>= $\frac{1}{a_{ij}}$</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>8</td>
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<td>1</td>
<td>2</td>
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<td>2</td>
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</tr>
<tr>
<td>10</td>
<td>1</td>
<td>2</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 9.1: Original Decision Variable Matrix for Para 13 (Taiwan)

<table>
<thead>
<tr>
<th>Alt No.</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<td>1</td>
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<tr>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<td>1</td>
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<tr>
<td>5</td>
<td>1</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>All lower triangular elements = $a_{ij}$</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>= $\frac{1}{a_{ij}}$ = 1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 9.2: New Decision Variable Matrix for Para 13 (Taiwan)
Decision variable matrix of this parameter will become an all-one matrix as shown in Fig. 9.2 after fifteen years. This means that the professional skill at that time will be capable of handling all types of treatment alternatives without finding one more difficult than another.

Decision variable matrices of other parameters may change in the same manner with time. Some of them will, of course, remain the same, depending on the situation in question. The new ranking of the alternatives will be calculated using the same mathematical technique as described in Chapter 5 by a computer program named SENSIANA with the amended set of decision variable matrices as inputting data. A full example of the forecasting exercise will be given in Section 9.4. The computer program SENSIANA is to be described in the following section.

9.3 The Computer Program

A new computer program is written for carrying out the sensitivity analysis (or forecasting exercise). The name of the program is, as mentioned above, called SENSIANA. It is again written in IBM BASIC language (2) and can be run on an IBM personal computer (or any XT or AT) after compilation (1).

The parameter matrix, similar to the one used in MODEL, is again a built-in feature of SENSIANA. Users do
not have to know what are the values inside the parameter matrix when they use the program. They only have to input new values of the decision variable matrices of the parameters which they forecast will change. A user's manual of SENSIANA is given in Appendix B.2.1. A flow chart of the program and a listing of it are given in Appendices B.2.2 and B.2.3 respectively.

It should be borne in mind that values of the decision variable matrices should be entered in six decimal places, but they will be shown on the screen in three decimal places. This, however, will not affect the accuracy of the calculation in which data of six decimal places will be used throughout.

After running SENSIANA, k new files will be created where k is the total number of parameters whose decision variable matrices are amended. The names of these k new files are "PARA*.LIQ" where * represents the parameter number. The k old files of the original decision variable matrices will be erased automatically. In addition, a new COMPOMAT.LIQ file, storing the data of the new composite matrix, and another file named SENSIRUN.LIQ, storing the record of the dialogue between the user and the computer when the program was in use, will be formed. One can view the contents of these two files by using the "TYPE" command.
9.4 Example --- Min Shen STP of Taiwan

9.4.1 Forecasting Changes

The computer program MODEL was run in Section 8.3 of Chapter 8 and the background was described in Section 7.5 of Chapter 7 for Min Shen STP of Taiwan. In this Section, SENSIANA will be run for the same plant.

Assuming that the training of professionals and technicians (ie. Parameter 16) in Taiwan is already good, it is then forecast that in fifteen years both the professional skill and the local technical skill available for operation and maintenance (ie. Parameters 13 and 14) will become very much better. In addition, after fifteen years of good training, professional ethics (ie. Parameter 17) of the personnel involved with the STP will also be excellent. In such a situation, it is assumed that the decision variable matrices of Parameters 13, 14, 16 and 17 will become all-one matrices (see Fig. 9.2).

Based on the above assumptions, the decision variable matrices of Parameters 13, 14, 16 and 17 are to be amended and their elements are all re-entered as 1 when the computer program SENSIANA is run. A complete record of the dialogue between the user and the computer is shown in Section 9.4.2. The computer run gives a result on P.189 that primary clarifier + high-purity oxygen activated
sludge process + tertiary treatment (i.e. Decision Variable 5) is the most appropriate treatment alternative instead of primary clarifier + RBC + tertiary treatment (i.e. Decision Variable 7) as obtained previously (see Section 7.5 of Chapter 7).

9.4.2 Running The Computer Program

This section must be read in conjunction with Appendix B.2.1, the user's manual of SENSIANA. The ten decision variables to be ranked as given on Page 116 (Section 7.5) should also be referred to. The following is record of running the program.

Order of decision variable matrix is n x n where n = 10

Enter the parameter number whose matrix is to be reviewed.
The number (i.e. the Kth parameter, K = 1 to 20) is ? 13

The decision variable matrix is:

1.000 1.000 1.000 1.000 2.000 3.000 1.000 1.000 1.000 2.000
1.000 1.000 1.000 1.000 2.000 3.000 1.000 1.000 1.000 2.000
1.000 1.000 1.000 1.000 2.000 3.000 1.000 1.000 1.000 2.000
1.000 1.000 1.000 1.000 2.000 3.000 1.000 1.000 1.000 2.000
0.500 0.500 0.500 0.500 1.000 2.000 0.500 0.500 0.500 1.000
0.333 0.333 0.333 0.333 0.500 1.000 0.333 0.333 0.333 0.500
1.000 1.000 1.000 1.000 2.000 3.000 1.000 1.000 1.000 2.000
1.000 1.000 1.000 1.000 2.000 3.000 1.000 1.000 1.000 2.000
1.000 1.000 1.000 1.000 2.000 3.000 1.000 1.000 1.000 2.000
0.500 0.500 0.500 0.500 1.000 2.000 0.500 0.500 0.500 1.000

Do you want to change data in the above matrix? Y or N ? Y

You only have to enter the upper triangular elements

A( 1 , 1 ) = 1
A( 1 , 2 ) = 1
A( 1 , 3 ) = 1
The decision variable matrix is:

\[
\begin{align*}
A(1, 4) &= 1 \\
A(1, 5) &= 1 \\
A(1, 6) &= 1 \\
A(1, 7) &= 1 \\
A(1, 8) &= 1 \\
A(1, 9) &= 1 \\
A(1, 10) &= 1 \\
A(2, 2) &= 1 \\
A(2, 3) &= 1 \\
A(2, 4) &= 1 \\
A(2, 5) &= 1 \\
A(2, 6) &= 1 \\
A(2, 7) &= 1 \\
A(2, 8) &= 1 \\
A(2, 9) &= 1 \\
A(2, 10) &= 1 \\
A(3, 3) &= 1 \\
A(3, 4) &= 1 \\
A(3, 5) &= 1 \\
A(3, 6) &= 1 \\
A(3, 7) &= 1 \\
A(3, 8) &= 1 \\
A(3, 9) &= 1 \\
A(3, 10) &= 1 \\
A(4, 4) &= 1 \\
A(4, 5) &= 1 \\
A(4, 6) &= 1 \\
A(4, 7) &= 1 \\
A(4, 8) &= 1 \\
A(4, 9) &= 1 \\
A(4, 10) &= 1 \\
A(5, 5) &= 1 \\
A(5, 6) &= 1 \\
A(5, 7) &= 1 \\
A(5, 8) &= 1 \\
A(5, 9) &= 1 \\
A(5, 10) &= 1 \\
A(6, 6) &= 1 \\
A(6, 7) &= 1 \\
A(6, 8) &= 1 \\
A(6, 9) &= 1 \\
A(6, 10) &= 1 \\
A(7, 7) &= 1 \\
A(7, 8) &= 1 \\
A(7, 9) &= 1 \\
A(7, 10) &= 1 \\
A(8, 8) &= 1 \\
A(8, 9) &= 1 \\
A(8, 10) &= 1 \\
A(9, 9) &= 1 \\
A(9, 10) &= 1 \\
A(10, 10) &= 1
\end{align*}
\]
Do you want to change data in the above matrix? Y or N? N

Do you want to change another decision variable matrix? Y

Enter the parameter number whose matrix is to be reviewed.
The number (i.e. the Kth parameter, K = 1 to 20) is? 14

The decision variable matrix is:

1.000 1.000 1.000 2.000 3.000 4.000 1.000 1.000 2.000 3.000
1.000 1.000 1.000 2.000 3.000 4.000 1.000 1.000 2.000 3.000
1.000 1.000 1.000 2.000 3.000 4.000 1.000 1.000 2.000 3.000
0.500 0.500 0.500 1.000 2.000 3.000 0.500 0.500 1.000 2.000
0.333 0.333 0.333 0.500 1.000 2.000 0.333 0.333 0.500 1.000
0.250 0.250 0.250 0.333 0.500 1.000 0.250 0.250 0.333 0.500
1.000 1.000 1.000 2.000 3.000 4.000 1.000 1.000 2.000 3.000
1.000 1.000 1.000 2.000 3.000 4.000 1.000 1.000 2.000 3.000
0.500 0.500 0.500 1.000 2.000 3.000 0.500 0.500 1.000 2.000
0.333 0.333 0.333 0.500 1.000 2.000 0.333 0.333 0.500 1.000

Do you want to change data in the above matrix? Y or N? Y

You only have to enter the upper triangular elements

A( 1 , 1 ) = 1
A( 1 , 2 ) = 1
A( 1 , 3 ) = 1
A( 1 , 4 ) = 1
A( 1 , 5 ) = 1
A( 1 , 6 ) = 1
A( 1 , 7 ) = 1
A( 1 , 8 ) = 1
A( 1 , 9 ) = 1
A( 1 , 10 ) = 1
\[ A(2, 2) = 1 \]
\[ A(2, 3) = 1 \]
\[ A(2, 4) = 1 \]
\[ A(2, 5) = 1 \]
\[ A(2, 6) = 1 \]

\[ A(9, 9) = 1 \]
\[ A(9, 10) = 1 \]
\[ A(10, 10) = 1 \]

The decision variable matrix is:

\[
\begin{array}{cccccccccccc}
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
\end{array}
\]

Do you want to change data in the above matrix? Y or N? N

Do you want to change another decision variable matrix? Y

Enter the parameter number whose matrix is to be reviewed.

The number (ie. the Kth parameter, K = 1 to 20) is? 16

The decision variable matrix is:

\[
\begin{array}{cccccccccccc}
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
0.333 & 0.333 & 0.333 & 0.333 & 0.333 & 1.000 & 0.333 & 0.333 & 0.333 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \\
\end{array}
\]

186
Do you want to change data in the above matrix? Y or N? Y
You only have to enter the upper triangular elements

\[
\begin{align*}
A(1,1) &= 1 \\
A(1,2) &= 1 \\
A(1,3) &= 1 \\
A(1,4) &= 1 \\
A(1,5) &= 1 \\
A(1,6) &= 1 \\
A(1,7) &= 1 \\
A(1,8) &= 1 \\
A(1,9) &= 1 \\
A(1,10) &= 1 \\
A(2,2) &= 1 \\
A(2,3) &= 1 \\
A(2,4) &= 1 \\
A(2,5) &= 1 \\
&\vdots \\
A(9,9) &= 1 \\
A(9,10) &= 1 \\
A(10,10) &= 1 \\
\end{align*}
\]

The decision variable matrix is:

\[
\begin{align*}
1.000 & 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 \\
1.000 & 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 \\
1.000 & 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 \\
1.000 & 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 \\
1.000 & 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 \\
1.000 & 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 \\
1.000 & 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 \\
1.000 & 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 \\
1.000 & 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 \\
1.000 & 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 \\
\end{align*}
\]

Do you want to change data in the above matrix? Y or N? N

Do you want to change another decision variable matrix? Y

Enter the parameter number whose matrix is to be reviewed.
The number (ie. the Kth parameter, K = 1 to 20) is? 17

187
The decision variable matrix is:

```
1.000 1.000 1.000 2.000 3.000 5.000 1.000 1.000 1.000 3.000
1.000 1.000 1.000 2.000 3.000 4.000 1.000 1.000 1.000 3.000
1.000 1.000 1.000 2.000 3.000 4.000 1.000 1.000 1.000 3.000
0.500 0.500 0.500 1.000 2.000 3.000 0.500 0.500 0.500 2.000
0.333 0.333 0.333 0.500 1.000 2.000 0.333 0.333 0.333 1.000
0.200 0.250 0.250 0.333 0.500 1.000 0.200 0.200 0.250 0.500
1.000 1.000 1.000 2.000 3.000 5.000 1.000 1.000 1.000 3.000
1.000 1.000 1.000 2.000 3.000 5.000 1.000 1.000 1.000 3.000
1.000 1.000 1.000 2.000 3.000 4.000 1.000 1.000 1.000 3.000
0.333 0.333 0.333 0.500 1.000 2.000 0.333 0.333 0.333 1.000
```

Do you want to change data in the above matrix? Y or N? Y

You only have to enter the upper triangular elements

```
A(1 , 1 ) = 1
A(1 , 2 ) = 1
A(1 , 3 ) = 1
A(1 , 4 ) = 1
A(1 , 5 ) = 1
A(1 , 6 ) = 1
A(1 , 7 ) = 1
A(1 , 8 ) = 1
A(1 , 9 ) = 1
A(1 , 10 ) = 1
A(2 , 2 ) = 1
A(2 , 3 ) = 1
A(9 , 9 ) = 1
A(9 , 10 ) = 1
A(10 , 10 ) = 1
```

The decision variable matrix is:

```
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000
```

Do you want to change data in the above matrix? Y or N? N
Do you want to change another decision variable matrix? N

Please wait. Calculation of ranking of the alternatives is in process.

The ranking is:

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Ranking in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>38.60932</td>
</tr>
<tr>
<td>2</td>
<td>66.74297</td>
</tr>
<tr>
<td>3</td>
<td>66.74297</td>
</tr>
<tr>
<td>4</td>
<td>94.03391</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td>6</td>
<td>90.31671</td>
</tr>
<tr>
<td>7</td>
<td>99.60104</td>
</tr>
<tr>
<td>8</td>
<td>64.86311</td>
</tr>
<tr>
<td>9</td>
<td>88.51567</td>
</tr>
<tr>
<td>10</td>
<td>89.39321</td>
</tr>
</tbody>
</table>

9.5 Observation

It can be seen from Section 9.4 that there will be a change of appropriate technology for Min Shen STP if certain social and environmental conditions change with time. The author has also tried to run SENSIANA to carry out forecasting exercises for wastewater treatment plants other than Min Shen, but these were not successful in obtaining different rankings compared to those obtained previously shown in Chapters 7 and 8. The reason may probably be this: if in the original ranking (i.e. result obtained by running MODEL) the difference in % between the first best and the second best alternatives is 10% or more
then the first alternative will not easily become the second or lower in the sensitivity analysis. The best alternatives for situations of Malaysia, Thailand and Hong Kong do not change in the forecasting exercise, because they are all higher by more than 10% than their respective second best alternatives. The above statement is merely an informed guess of the author from the limited trials on the exercise and is suggested without a sound support of mathematical theories. However, this issue can be an interesting area which mathematicians and engineers should be able to find a lot more to explore.

9.6 A Further Illustration

It is a bit unfortunate that the wastewater treatment plants under test except the Min Shen STP in Taiwan have results which are so overwhelmingly in one direction that the forecasting function (sensitivity analysis) of the model cannot be easily demonstrated. An imaginary treatment plant, therefore, is employed here to further illustrate this particular function of the model.

The imaginary plant is situated just outside Tun Mun (a newly developed and modern town quite far away from the city) of Hong Kong. As it is a relatively remote area the land there at present is not very costly. The plant has to serve a population of about 3,000 persons (an average flow of about 1,000 m$^3$/day), who live in a low density
residential housing estate near Tun Mun. The site given for the plant is located at a corner of the estate. It is not a large site and treatment methods requiring large area are therefore not suitable. Effluent standard of "Royal Commission Recommendation" is required. As the residents would like to see only minimal exposed sewage, the management of the housing estate has decided that only package sewage treatment plants should be used.

It should be noted that in a vigorous selection the decision of using package plants should be obtained from an initial ranking of the alternatives in category A, B, .... ..., H or category a, b, ......, 1 of Fig. 4.1 of Chapter 4. The initial ranking is neglected here because the purpose of this section is only to give a further illustration of how the sensitivity analysis can be practically applied. Now, the problem is to select the best alternative out of four, namely, decision variables 43, 44, 45 and 46 as described in Section 4.3 of Chapter 4. They are reproduced hereunder for easy reference.

<table>
<thead>
<tr>
<th>Treatment Alternative</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Package activated sludge plant</td>
</tr>
<tr>
<td>2</td>
<td>Package activated sludge plant + Tertiary treatment</td>
</tr>
<tr>
<td>3</td>
<td>Package high-purity oxygen plant</td>
</tr>
<tr>
<td>4</td>
<td>Package high-purity oxygen plant + Tertiary treatment</td>
</tr>
</tbody>
</table>
The 20 decision variable matrices for the parameters are as follows:

PARAMETER 1 : Flow
1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000

PARAMETER 2 : Influent / Effluent
1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000

PARAMETER 3 : Size of site
1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000

PARAMETER 4 : Nature of site
1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000

PARAMETER 5 : Land cost
1.000 2.000 0.333 0.333
0.500 1.000 0.333 0.333
3.000 3.000 1.000 2.000
3.000 3.000 0.500 1.000

PARAMETER 6 : Local money for construction
1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000

192
PARAMETER 7 : Foreign money for construction

1.000 1.000 2.000 2.000
1.000 1.000 2.000 2.000
0.500 0.500 1.000 1.000
0.500 0.500 1.000 1.000

PARAMETER 8 : Local skill for construction

1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000

PARAMETER 9 : Community support

1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000

PARAMETER 10 : Power source

1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000

PARAMETER 11 : Availability of local material

1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000

PARAMETER 12 : Cost of operation & maintenance

1.000 1.000 2.000 2.000
1.000 1.000 2.000 2.000
0.500 0.500 1.000 1.000
0.500 0.500 1.000 1.000

PARAMETER 13 : Professional skill for operation & maintenance

1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000
1.000 1.000 1.000 1.000
<table>
<thead>
<tr>
<th>PARAMETER 14: Local technical skill for operation &amp; maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PARAMETER 15: Administration set-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PARAMETER 16: Training</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PARAMETER 17: Professional ethics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PARAMETER 18: Climate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PARAMETER 19: Local water-borne diseases</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PARAMETER 20: Endemic vector-borne (water related) diseases</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
<tr>
<td>1.000 1.000 1.000 1.000</td>
</tr>
</tbody>
</table>
The above twenty decision variable matrices are input into the MODEL and the ranking calculated is:

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>99.59249</td>
</tr>
<tr>
<td>3</td>
<td>98.8111</td>
</tr>
<tr>
<td>4</td>
<td>97.58864</td>
</tr>
</tbody>
</table>

The best alternative obtained is Package activated sludge plant (ie. Alternative 1). As can be seen from the result, the final decision is not so overwhelmingly in one direction as compared to previous cases. It may be possible that the final decision will be changed by altering one of the parameters.

If the management would like to use the effluent for watering grass lawns surrounding the housing estate, a higher effluent standard would be needed. Hence, the decision variable matrix of Parameter 2 (ie. effluent standard) would need to be amended. This could be done by running SENSIANA. The following shows a record of running the program.

Order of decision variable matrix is \( n \times n \) where \( n = 4 \)

Enter the parameter number whose matrix is to be reviewed.

The number (ie. the \( k \)th parameter, \( k = 1 \) to 20) is \( 2 \)
The original decision variable matrix is:

1.000 1.000 1.000 1.000  
1.000 1.000 1.000 1.000  
1.000 1.000 1.000 1.000  
1.000 1.000 1.000 1.000  

Do you want to change data in the above matrix? Y or N ? Y

You only have to enter the upper triangular elements

\[
A(1,1) = 1 \\
A(1,2) = 0.333333 \\
A(1,3) = 1 \\
A(1,4) = 0.333333 \\
A(2,2) = 1 \\
A(2,3) = 3 \\
A(2,4) = 1 \\
A(3,3) = 1 \\
A(3,4) = 0.333333 \\
A(4,4) = 1 \\
\]

The new decision variable matrix is:

1.000 0.333 1.000 0.333  
3.000 1.000 3.000 1.000  
1.000 0.333 1.000 0.333  
3.000 1.000 3.000 1.000  

Do you want to change data in the above matrix? Y or N ? n

Do you want to change another decision variable matrix ? n

Please wait. Calculation of ranking of the alternatives is in process.

The ranking is:

<table>
<thead>
<tr>
<th>Alternative</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>83.71777</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>82.62343</td>
</tr>
<tr>
<td>4</td>
<td>98.15552</td>
</tr>
</tbody>
</table>
It can be seen that the best alternative has now changed to Package activated sludge plant + Tertiary treatment (ie. Alternative 2).

Some years later, as development has been taking place rapidly in this part of Hong Kong, more people are coming to live in Tun Mun and its surrounding areas. There is a great demand for new houses in the housing estate. The management has an idea of expanding the estate and is thinking of building new houses on the surrounding grass lawns. As such, reuse of effluent is no more required. The current land cost, however, is much higher than in those earlier years and the management may have to expand the housing project at the expense of the curtailment of the site for sewage treatment. Now, the decision variable matrix of Parameter 5 (ie. land cost) should be amended. The program SENSIANA is run again as follows.

Order of decision variable matrix is \( n \times n \) where \( n = 4 \)

Enter the parameter number whose matrix is to be reviewed.
The number (ie. the \( k \)th parameter, \( k = 1 \) to 20) is \( 5 \)

The original decision variable matrix is:

\[
\begin{bmatrix}
1.000 & 2.000 & 0.333 & 0.333 \\
0.500 & 1.000 & 0.333 & 0.333 \\
3.000 & 3.000 & 1.000 & 2.000 \\
3.000 & 3.000 & 0.500 & 1.000 \\
\end{bmatrix}
\]
Do you want to change data in the above matrix? Y or N? y

You only have to enter the upper triangular elements

A( 1 , 1 ) = 1
A( 1 , 2 ) = 3
A( 1 , 3 ) = .142857
A( 1 , 4 ) = .166666
A( 2 , 2 ) = 1
A( 2 , 3 ) = .125
A( 2 , 4 ) = .142857
A( 3 , 3 ) = 1
A( 3 , 4 ) = 3
A( 4 , 4 ) = 1

The new decision variable matrix is:

\[
\begin{bmatrix}
1.000 & 3.000 & 0.143 & 0.167 \\
0.333 & 1.000 & 0.125 & 0.143 \\
7.000 & 8.000 & 1.000 & 3.000 \\
6.000 & 7.000 & 0.333 & 1.000
\end{bmatrix}
\]

Do you want to change data in the above matrix? Y or N? n

Do you want to change another decision variable matrix? n

Please wait. Calculation of ranking of the alternatives is in process.

The ranking is:

<table>
<thead>
<tr>
<th>RANKING IN %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative 1</td>
</tr>
<tr>
<td>Alternative 2</td>
</tr>
<tr>
<td>Alternative 3</td>
</tr>
<tr>
<td>Alternative 4</td>
</tr>
</tbody>
</table>

It can be seen that the best alternative has changed again to Package high-purity oxygen plant (ie. Alternative 3).
The above is an imaginary situation by which the application of sensitivity analysis / SENSIANA is illustrated. It is the author's hope that readers could have appreciated it better after going through this section.
CHAPTER 10 --- DISCUSSIONS AND ACKNOWLEDGMENT

10.1 Suggestion for Further Works

This research has proposed a new approach to select the most appropriate technology in wastewater treatment alternatives. The major advantages of this approach have been described in Section 5.3 of Chapter 5 and will not be repeated here. It is a macro-level approach as opposed to detailed micro-level analysis given by the existing optimization techniques as described in Chapter 3. There are limitations, however, in the model developed in this research. The following will give an account of the limitations and the author's suggestion for possible further work which can be done to improve the model.

A major drawback is that sludge treatment alternatives are not considered in the model. Sludge treatment is an inseparable part of wastewater treatment and should be planned and designed together with liquid treatment. It is suggested that further works should be done on developing as well as integrating a sludge treatment alternative selection model to the one developed in this research. It is envisaged that many of the parameters used in this liquid treatment selection model will also be used in the sludge treatment selection model. Only a few parameters might need to be deleted and a few added. The first 3 best alternatives from running the liquid treatment model and
the first 3 best ones from the sludge treatment model will be combined to form a total of 9 (i.e. 3 x 3) decision variables. They will then be ranked by using a similar approach so that the best liquid-cum-sludge treatment alternative can be obtained. It may be possible that a computer program be written such that this whole process will be done internally and automatically by the computer and require no input of extra data.

Another drawback to this model lies in the difficulty in constructing decision variable matrices. At present it is a very tedious and time consuming task. The author has spent weeks in constructing the matrices as shown in Chapter 8. In order that the model will be of a practical value in engineering application an easier and a less time consuming method in this respect should be investigated. A method to improve this drawback is to identify an order of preference for the decision variables with respect to each parameter. Once the order of preference is identified a decision variable matrix can be formed automatically by incorporating an additional sub-routine in the computer program. The matrices constructed in this way, however, will be totally consistent. Therefore, this suggested method will have the advantage of shortening the time of construction but will also have the disadvantage of ignoring the inconsistency usually existing in real situations which can only be reflected when individual pair-wise comparisons are made. Secondly, a more
systematic procedure in considering the indicators as described by the parameters should also be developed so that the construction of decision variable matrices can be carried out in a more scientific manner. It may be possible that some subjective parameters be quantified and measured systematically by using certain measurable indicators which describe the subjective parameters. This systematic procedure should be looked into along side with the problem associated with matrix construction discussed in the earlier part of this paragraph.

As mentioned in Section 9.5 of Chapter 9, further works should be done on the sensitivity analysis (or forecasting exercise), both in theory and in systematic application. The author has only thrown out an idea in the chapter and a large amount of possible development will need to be explored.

Although it is the author's belief that the parameter matrix proposed in this thesis is a sound one, yet it does not mean that no further improvement will be necessary in the future. It is self-evident that "two heads are better than one", and in this case, several heads will be even better. The use of expert opinion, the Delphi technique\(^1\),\(^2\), may be applied to improve the parameter matrix. The technique involves the findings of the most reliable consensus of opinion of a group of experts, and this is achieved by means of a series of intensive
questionnaires interspersed with summarized information and opinion feedback derived from earlier responses. The details involved in the Delphi technique can be found in References 1 and 2. The application of the technique is outside the scope of this thesis.

In the Delphi method, each expert selected responds anonymously to the series of questionnaires to avoid disproportionate influence of strong personalities. Another method, differing appreciably from the Delphi approach, is to gather the experts together for open discussion. In attempting to present their arguments openly, the experts provide judgements by mutual agreement and revision of views. This second method is a simpler and quicker procedure than Delphi and its results can be highly effective. Its only disadvantage is that some strong personalities in the group may influence the views of the others in face to face discussion. Nevertheless, both methods of analysing the problem will improve the quality of judgements. The author believes that the accuracy of the model will be improved if either one of the methods be employed in judging the parameter matrix.

Furthermore, the 46 decision variables listed in Section 4.3 of Chapter 4 are in no way a complete list of wastewater treatment alternatives. Other treatment alternatives may be added to the list and by doing so the hierarchical structure of the decision variables may
probably need some adjustments. The existing list of decision variables, however, is believed by the author to be adequate in normal engineering applications.

10.2 Word of Thanks

The author wishes to take this opportunity to express his sincere thanks to his research supervisors, Mr K.V. Ellis and Dr H.S. Ward, for their invaluable advice and their kind assistance in various aspects during the course of the research.

The author was also fortunate to have the assistance of those who gave answers to the questionnaires and who received him and/or brought him to visit sewage treatment plants in various countries. There were many people who were involved with this and it is impossible to have all the names listed down here. Nevertheless, the following persons must be given special acknowledgment for their help:

Mr K. Ariyathavaratnam (Malaysia)
Prof P.S. Cheung (Taiwan)
Mr R.Y. Chung (Taiwan)
Mr Y.P. Kong (Malaysia)
Mr Thomas Lau (Hong Kong)
Mr K.F. Leung (Hong Kong)
Mr S.C. Lee (Malaysia)
Prof C.T. Li (Taiwan)
Mr W.K. Liu (Taiwan)
Mr C.D. Ponniiah (Malaysia)
Mr A. Sekarajasekaran (Malaysia)
Mr F.S. Shi (Taiwan)
Mr K.M. Siah (Malaysia)
Dr P. Suchint (Thailand)
Mr M. Suriya (Thailand)
Mr E. Sutham (Thailand)
Mr K.H. Tan (Malaysia)
Mr David Wu (Hong Kong)
Prof W.F. Yang (Taiwan)

While the others remain nameless, they are gratefully and fully acknowledged for the kind assistance, in whatever way, they have given the author. Without their support, this research thesis would never have materialized.

Last of all, the author wishes to express his love and thanks to his wife who has been giving him continual spiritual support and encouragement in the course of the study, and to her patience and diligence in helping him transfer the original manuscript onto a computer word processor in the middle of many nights.

--- END ---
PART 5

APPENDICES
Chapter 1


Chapter 2


17. Oluwande; P.A. "The Merits and Demerits of Package Sewage Treatment Plants in the Developing Countries", Journal Water Pollution Control, V.73, 1979, pp.143 - 146.


Chapter 3


Chapter 4


Chapter 5

14. Williams, I.P. "Matrices for Scientists", Hutchinson, 1972, Chapter 4, p.79f and p.85f.
Chapter 6


Chapter 7


CHAPTER 8


CHAPTER 9


CHAPTER 10


B.1.1.1

Type "Model" against the "A>" prompt (or "C>" prompt if a hard-disc of XT or AT is used) and then press <ENTER>. The following will be shown on the screen:

```
********************************************
* RANKING OF LIQUID TREATMENT ALTERNATIVES *
* Order of decision variable matrix is n x n where n = *
********************************************
```

Then, type the number of decision variables to be ranked and press <ENTER>. The computer will respond as follows:

```
********************************************
* PARAMETER 1: Flow *
* Do you want to use data from an existing file? Y or N? *
********************************************
```

The answer can either be (i) No or (ii) Yes

If the answer is No then see (i) hereunder. If the answer is Yes then see (ii) in Section B.1.1.2.

(i) No: Respond by typing "N" and then pressing <ENTER> if the data are not already stored in an existing data file. The computer will then respond as follows:
You only have to enter the upper triangular elements

\[ A_{1,1} = \]

So, input \( a_{11} \) (up to six decimal places) against the "?" prompt and press <ENTER>. The computer will then continue to ask one to enter \( a_{12}, a_{13} \) and so on until all the upper triangular elements (i.e., \( a_{ij} \) for \( 1 \leq i < j \leq n \)) are entered.

After the last element, \( a_{nn} \), has been entered, the following will appear on the screen:

\[ \text{The } n \times n \text{ matrix just entered is:} \]

\[
\begin{bmatrix}
(\text{all elements are shown here up to three decimal places although they have been entered in six decimal places})
\end{bmatrix}
\]

Do you want to change data in the above matrix? Y or N?

If the answer is yes, type "Y" and press <ENTER>. The user will then be asked to enter data again in the same manner as just described. If the answer is no, type "N" and press <ENTER>. The computer will tell one to wait for a short while, and will then show on the screen that this matrix is stored in a file named "PARA1.LIQ." After that, the user
will be told by the computer to press <ENTER> to continue. So press <ENTER>, and the screen will respond as follows:

```
******************************************************ttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttttt
The decision variable matrix is:

\[
\begin{pmatrix}
1
\end{pmatrix}
\]

(all elements of the matrix are shown here)

Do you want to change data in the above matrix? Y or N?

If the answer is no, then continue to interact with the computer as previously described. If the answer is yes, then the computer will ask the user to re-enter \( a_{11}, a_{12}, \ldots, a_{nn} \).

B.1.1.3

Another feature of the program is that it automatically tests the consistency of the data entered. It allows them to have a certain degree of inconsistency but not too much (see Section 5.3.3). If the data entered are too inconsistent, the computer will inform the user of it and ask if he wants to revise the data.

B.1.1.4

Keep on responding to the computer until all data are entered into the model. After the data for Parameter 20 have been entered, one will see the following on the screen:
You have already entered all the necessary data.
Press the RETURN key to continue.

If the user presses <ENTER>, he will be told to wait as the calculation of the ranking of the treatment alternatives is in progress. After a short while, the result of the final ranking will appear on the screen. The user will then be asked whether to run the program again. If your answer is yes, the whole program will be run again, and if no, the program will end.
APPENDIX B.1.2 --- FLOW CHART (MODEL)

MAIN CHART

START

OPEN OUTPUT DOCUMENTATION FILE "REPORT"

INPUT NUMBER OF DECISION VARIABLES TO BE RANKED

K=0

K=K+1

A

INPUT DATA FOR PARAMETER K (SUB-Routine 1)

B

CALCULATE PRIORITY VECTOR (SUB-Routine 1-1)

C

K<20 ?

YES

OPEN FILE "COMPOMAT"

STORE ALL 20 PRIORITY VECTORS IN "COMPOMAT" (SUB-Routine 2)

E

CLOSE "COMPOMAT"

F

CALCULATE COMPOSITE PRIORITY VECTOR (SUB-Routine 3)

CLOSE "REPORT"

RUN PROGRAM AGAIN ?

NO

END

YES
**SUB-ROUTINE 1**

A

DATA INPUT FROM EXISTING FILE?

INPUT NAME OF EXISTING FILE

YES

INPUT NAME OF EXISTING FILE

INPUT UPPER TRIANGULAR ELEMENTS

NO

SEE SUB-ROUTINE 1.1

SUB-ROUTINE 1

INPUT NAME OF EXISTING FILE

OPEN INPUT DATA FILE

OPEN OUTPUT DATA FILE "TEMPDATA"

STORE INPUT DATA IN "TEMPDATA"

CLOSE INPUT DATA FILE

LIST OUT DATA ON SCREEN

CLOSE "TEMPDATA"

NAME "TEMPDATA" AS "PARA*.LIQ"

WANT TO CHANGE ANY DATA ENTERED?

YES

NO

B

STORE INPUT DATA IN "TEMPDATA"

OPEN OUTPUT DATA FILE "TEMPDATA"

STORE INPUT DATA IN "TEMPDATA"

CLOSE "TEMPDATA"
ASSUME AN INITIAL VECTOR WITH ELEMENT CORRESPONDING TO THE MAXIMUM ROW SUM OF MATRIX \( A = 1 \) AND ALL OTHER ELEMENTS = 0

\[
p = 1 \\
k_0 = 0
\]

CALCULATE \( k_p \)
(See References 3 & 6 of Chapter 5)

\[
k_p \text{ AND } k_{p-1} \text{ DIFFER BY LESS THAN 0.1 % ?}
\]

YES

TEST FOR CONSISTENCY

YES

WANT TO CHANGE DATA ?

NO

NO

CONSISTENCY WITHIN LIMIT ?

YES

COMPUTE NORMALIZED EIGENVECTOR FOR EIGENVALUE = \( k_p \)

See SUBROUTINE 1
SUB-ROUTINE 3

1. OPEN AN EXISTING FILE "PARAMAT"
2. INPUT DATA FROM "PARAMAT"
3. OPEN "COMPOMAT"
4. INPUT DATA FROM "COMPOMAT"
5. CLOSE "PARAMAT" AND "COMPOMAT"
6. CALCULATE PRIORITY VECTOR FOR "PARAMAT"
7. PERFORM MATRIX MULTIPLICATION TO FIND FINAL PRIORITY VECTOR
8. LIST OUT RESULT OF MULTIPLICATION — RANKING OF DECISION VARIABLES

E → F

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APPENDIX B.1.3 --- PROGRAM LISTING (MODEL)

100 REM **********************************************************************************************
110 REM
120 REM
130 REM PROGRAM NAME : MODEL
140 REM AUTHOR : S.L. TANG
150 REM DATE WRITTEN : 1986
160 REM
170 REM **********************************************************************************************
180 REM
190 REM
200 REM
210 REM PROGRAM DESCRIPTION:
220 REM THIS IS A PROGRAM FOR FINDING THE RANKING OF DIFFERENT WASTEWATER TREATMENT ALTERNATIVES
230 REM
240 REM
250 REM **********************************************************************************************
260 REM
270 REM
280 REM
290 REM DATA DICTIONARY:
300 REM
310 REM
320 REM INPUT VARIABLES:
330 REM
340 REM N = ORDER OF DECISION VARIABLE MATRIX
350 REM EX.FILE = ANSWER FOR WHETHER TO USE AN EXISTING FILE
360 REM NAME = NAME FOR AN EXISTING FILE
370 REM CON = PRESS RETURN KEY TO CONTINUE
380 REM A = ARRAY FOR DATA INPUT INTO DECISION VARIABLE MATRIX
390 REM CH.DAT = ANSWER FOR WHETHER TO CHANGE DATA IN A MATRIX
400 REM REV = ANSWER FOR WHETHER TO REVISE DATA IN A MATRIX
410 REM PARA, MAT = ARRAY FOR PARAMETER MATRIX FILE NAMED "PARAMAT"
420 REM MAT = ARRAY FOR COMPOSITE MATRIX FILE NAMED "COMPMAT"
430 REM RERUNS = ANSWER FOR WHETHER TO RE_RUN THE PROGRAM
440 REM
450 REM
460 REM INPUT/OUTPUT VARIABLES:
470 REM
480 REM DECVAR.MAT = ARRAY FOR DECISION VARIABLE MATRIX
490 REM COMPO.MAT = ARRAY FOR COMPOSITE MATRIX
500 REM
510 REM
520 REM OUTPUT VARIABLES:
530 REM
540 REM PERCENT = ARRAY FOR COMPOSITE PROBABILITY VECTOR EXPRESS IN TERMS OF PERCENTAGE
550 REM
560 REM
570 REM
**OUTPUT FILES:**

- REPORT.LIQ = REPORT SHOWING THE DIALOGUE OF THE USER AND THE COMPUTER WHEN RUNNING THE MODEL
- COMPOMAT.LIQ = THE COMPOSITE MATRIX
- PARAN.LIQ = DECISION VARIABLE MATRIX OF PARAMETER # (k=1-26)

**WORKING VARIABLES:**

- \( \mathbf{x} \) = THE \( k \)th PARAMETER
- \( \text{PARAM} \) = NAME OF PARAMETER
- \( \text{LIG} \) = FILE NAME OF DECISION VARIABLE MATRIX
- \( \text{TMPDATA} \) = TEMPORARY FILE FOR STORING DECISION VARIABLE MATRIX
- \( \text{ROW} \) = NUMBER OF ELEMENTS IN EACH ROW OF A MATRIX
- \( \text{ROW} \) = ROW NUMBER OF MAXIMUM EIGENVALUE
- \( \text{VECTOR} \) = ARRAY FOR INITIAL VECTOR AND SUBSEQUENT VECTORS
- \( \text{C} \) = ARRAY FOR TEMPORARY EIGENVECTOR DURING ITERATIONS
- \( \text{MAX} \) = MOST RECENT MAX ELEMENT IN VECTORS DURING ITERATIONS
- \( \text{PRE.MAX} \) = MAXIMUM ELEMENT IN VECTOR AT THE PREVIOUS ITERATION
- \( \text{DIFF} \) = DIFFERENCE OF MAX AND PRE.MAX
- \( \text{EIGEN} \) = ARRAY FOR EIGENVECTOR
- \( \text{NOR.EIGEN} \) = ARRAY FOR NORMALIZED EIGENVECTOR
- \( \text{EIGEN.SUM} \) = SUM OF ELEMENTS IN EIGENVECTOR
- \( \text{CONSIST} \) = CONSISTENCY INDEX
- \( \text{MAX} \) = LIMIT OF CONSISTENCY INDEX
- \( \text{Q} \) = THE \( k \)th COLUMN OF COMPOSITE MATRIX
- \( \text{NOR.PARAVEC} \) = ARRAY FOR NORMALIZED EIGENVECTOR OF PARAMETER MATRIX
- \( \text{COMPO.VEC} \) = ARRAY FOR COMPOSITE PRIORITY VECTOR
- \( \text{COMPO.MAY} \) = MAXIMUM ELEMENT OF COMPOSITE PRIORITY VECTOR

**MAIN CONTROL MODULE**

- REM INITIALIZE
- REM PERFORM SUB-Routine 1
- REM PERFORM SUB-Routine 2
- REM PERFORM SUB-Routine 3

**SUB-PROGRAMS:**

1100 REM **********

1110 REM **********
INITIALIZE

RE M **************

1130 REM
1140 REM
1150 REM
1160 REM **************

1170 REM
1180 REM
1190 DIM A(20,20), DECVAR,MAT(20,20), PARA,MAT(20,20), PDD, SUM(20)
1200 DIM VECTOR(20), C(20), EIGEN(20), NDR.EIGEN(20), NDR.PARAVEC(20)
1210 DIM COMPO,MAT(20,20), MAT(20,20), COMPO,VEC(20), PERCENT(20)
1220 REM
1230 REM
1240 OPEN "O", #1, "REPORT.LIB"
1250 REM
1260 REM
1270 PRINT "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1280 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1290 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1300 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1310 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1320 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1330 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1340 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1350 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1360 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1370 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1380 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1390 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1400 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1410 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1420 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1430 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1440 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1450 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1460 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1470 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1480 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1490 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1500 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1510 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1520 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1530 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1540 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1550 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1560 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1570 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1580 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1590 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1600 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1610 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1620 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1630 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1640 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"
1650 PRINT #1, "RANKING OF LIQUID TREATMENT ALTERNATIVES"

SUB-Routine 1:

THIS IS A SUB-Routine FOR Inputting DATA (i.e. DECISION VARIABLE MATRICES) TO THE MODEL, StORING THEM IN SEPARATE FILES AND CALCULATING BY SUB-Routine 2 THE PRIORiTy VECTOR.

SUB-Routine 1 CONTROL Module

1559 FOR K = 1 TO 20
1560 READ PARA
1570 READ LIG
1580 PRINT PARA
1590 PRINT "PRINT #1, **
1600 PRINT "PRINT #1, **
1610 PRINT "PRINT #1, **
1620 PRINT "PRINT #1, **
1630 PRINT "PRINT #1, **
1640 PRINT "PRINT #1, **
1650 PRINT "PRINT #1, **
SUB  2020  : REM  INPUT DATA FOR DECISION VARIABLE MATRIX
1570  PRINT : PRINT #1, "*
1580  PRINT : PRINT #1, "*
1590  PRINT : PRINT #1, "*
1600  PRINT : PRINT #1, "*
1610  PRINT "Please wait .......  
1720  PRINT #1, "Please wait .......  
1730  SUBB  3480  : REM  PERFORM SUB-Routine I.1
1740  PRINT : PRINT #1, "*
1750  PRINT : PRINT #1, "*
1760  PRINT "The matrix just entered is stored in a file named "; FILE$  
1770  PRINT #1, "The matrix just entered is stored in a file named "; FILE$  
1780  PRINT : PRINT #1, "*
1790  PRINT : PRINT #1, "*
1800  INPUT "Press the RETURN key to continue", CON$  
1810  PRINT #1, "Press the RETURN key to continue"  
1820  PRINT : PRINT #1, "*
1830  PRINT : PRINT #1, "*
1840  PRINT : PRINT #1, "*
1850  PRINT : PRINT #1, "*
1860  PRINT : PRINT #1, "*
1870  PRINT : PRINT #1, "*
1890  NEXT V  
1900  REM  
1910  PRINT "You have already entered all the necessary data"  
1920  PRINT #1, "You have already entered all the necessary data"  
1930  PRINT : PRINT #1, "*
1940  PRINT : PRINT #1, "*
1950  PRINT : PRINT #1, "*
1960  PRINT : PRINT #1, "*
1970  RETURN  
1970  REM  
1980  REM  
1990  REM  ******************************************************
2000  REM  
2010  REM  
2020  REM  INPUT DATA FOR DECISION VARIABLE MATRIX  
2030  REM  
2040  REM  
2050  INPUT "Do you want to use data from an existing file? Y or N? ", EX, FILE$  
2060  PRINT #1, "Do you want to use data from an existing file? Y or N? "; EX, FILE$  
2070  IF EX, FILE$ = "Y" THEN 2140  
2080  IF EX, FILE$ = "N" THEN 2140  
2090  IF EX, FILE$ = "Y" THEN 2760  
2100  IF EX, FILE$ = "N" THEN 2760  
2110  GOTO 2050  
2120  REM  
2130  REM  
2140  REM  INPUT DATA FROM EXISTING FILE  
2150  REM  
2160  REM  
2170  PRINT : PRINT #1, "*
2180  PRINT : PRINT #1, "*
2190  INPUT "Name of the existing file is ? ", NAM$  
2200  PRINT #1, "Name of the existing file is ? "; NAM$  
226
STOP THE FILE DATA IN A TEMPORARY FILE NAMED "TEMPDATA"

OPEN "1", #1, NAME
OPEN "0", #3, "TEMPDATA"
FOR I = 1 TO N
    FOR J = 1 TO N
        INPUT #2, A(I,J)
        PRINT #3, A(I,J);
    NEXT J
NEXT I
PRINT #3, **
CLOSE #2
CLOSE #3
REM
REM LIST OUT THE DECISION VARIABLE MATRIX (FROM EXISTING FILE)
REM
FOR I = 1 TO N
    FOR J = 1 TO N
        INPUT #2, DECIVAR.MAT(I,J)
        PRINT USING "#8.######"; DECIVAR.MAT(I,J);
        PRINT #3, USING "#8.######"; DECIVAR.MAT(I,J);
    NEXT J
NEXT I
PRINT #3, **
CLOSE #2
CLOSE #3
REM
REM INPUT *Do you want to change data in the above matrix? Y or N? *;CH.DATAS
PRINT #1,*Do you want to change data in the above matrix? Y or N? *;CH.DATAS
IF CH.DATAS = "Y" THEN 2760
IF CH.DATAS = "Y" THEN 2760
IF CH.DATAS = "N" THEN 2690
IF CH.DATAS = "N" THEN 2690
GOTO 2630
GOTO 2630
REM
REM REMAKE "TEMPDATA"
REM
NAME "TEMPDATA" AS LIGS
GOTO 3000
REM
2750 REM MANUAL DATA INPUT
2770 REM
2780 REM
2790 PRINT: PRINT #1, "*
299A PRINT: PRINT #1, " *
310 PRINT "You only have to enter the upper triangular elements" 
320 PRINT #1, "You only have to enter the upper triangular elements" 
330 PRINT: PRINT #1, " *
340 PRINT: PRINT #1, " *
350 FOR I = 1 TO N
360 FOR J = 1 TO N
380 PRINT "A(\%I;\%J) = " : INPUT A(I,J)
385 PRINT #1, "A(\%I;\%J) = " : A(I,J)
390 A(J,I) = 1/A(I,J)
395 NEXT J
400 NEXT I
410 NEXT I
420 REM STORE THE DATA JUST ENTERED IN A DATA FILE NAMED *TEMPDATA*
430 REM
440 REM
450 PRINT "STORE THE DATA JUST ENTERED IN A DATA FILE NAMED *TEMPDATA*"
460 PRINT
470 REM
480 REM
490 REM
500 OPEN #O, ", TEMPDATA"
510 FOR I = 1 TO N
520 FOR J = 1 TO N
530 PRINT #2, A(I,J);
535 NEXT J
550 NEXT I
560 PRINT #2, " *
580 OPEN "I", #2, "TEMPDATA"
590 FOR I = 1 TO N
600 PRINT #2, A(I,J);
610 PRINT USING "8.### "; A(I,J); 
620 NEXT J
630 NEXT I
640 LIST OUT THE DECISION VARIABLE MATRIX (FROM MANUAL INPUT)
650 REM
660 REM
670 REM
680 REM
690 REM
700 PRINT: PRINT #1, " *
710 PRINT: PRINT #1, " *
720 PRINT: PRINT #1, " *
730 PRINT: PRINT #1, " *
740 FOR I = 1 TO N
750 INPUT #2, DECVAR,MAT(I, J)
760 PRINT USING "8.### "; DECVAR,MAT(I, J);
770 PRINT #1, USING "8.### "; DECVAR,MAT(I, J);
780 NEXT J
790 NEXT I
800 PRINT: PRINT #1, " *
810 NEXT I
820 NEXT I
830 OPEN #1, TEMPDATA
840 PRINT #1, "Do you want to change data in the above matrix? Y or N? " ;CH,DATAS
850 PRINT #1, "Do you want to change data in the above matrix? Y or N? " ;CH,DATAS
3340 REM
3350 REM     FIND THE MAXIMUM OF ROW-SUMS
3360 REM
3370 REM
3380 MAT = ROW.SUM(I) : ROW = 1
3390 FOR I = 2 TO N STEP 1
3400 IF MAX > ROW.SUM(I) THEN 3220
3410 MAX = ROW.SUM(I) : ROW = I
3420 NEXT I
3430 RETURN
3440 REM
3450 REM     ASSUME AN INITIAL VECTOR
3460 REM
3470 REM
3480 REM
3490 FOR J = 1 TO N
4000 IF J = ROW THEN 4020
4010 VECTOR(J) = 0 : GOTO 4030
4020 VECTOR(J) = 1
4030 NEXT J
4040 RETURN
4050 REM
4060 REM
4070 REM     PERFORM THE ITERATIONS
4080 REM
4090 REM
4100 PRE.MAT = 0
4110 FOR I = 1 TO N
4120 C(I) = 0
4130 FOR J = 1 TO N
4140 C(I) = C(I) + DECIMAL.MAT(I,J) * VECTOR(J)
4150 NEXT J
4160 NEXT I
4170 MAX = C(1) : ROW = 1
4180 FOR I = 2 TO N STEP 1
4190 IF MAX > C(I) THEN 4210
4200 MAX = C(I) : ROW = I
4210 NEXT I
4220 REM
4230 REM
4240 REM     TEST FOR THE NEED OF FURTHER ITERATION
4250 REM
4260 REM
4270 IF N = 3 THEN DIFF = .003
4280 IF N = 4 THEN DIFF = .004
4290 IF N = 5 THEN DIFF = .005
4300 IF N = 6 THEN DIFF = .006
4310 IF N = 7 THEN DIFF = .007
4320 IF N = 8 THEN DIFF = 3.000001E-05
4330 IF N = 9 THEN DIFF = 5.000001E-05
4340 IF N = 10 THEN DIFF = .01
4350 IF N = 11 THEN DIFF = .011
4360 IF N = 12 THEN DIFF = .012
4370 IF N = 13 THEN DIFF = .013
4380 IF N = 14 THEN DIFF = .014
420 IF N = 15 THEN DIFF = .015
440 IF N = 16 THEN DIFF = .02
4410 IF (5MAX - PRE.MAX) < .0001 THEN 4470 ELSE 4420
4420 FOR I = 1 TO N
4430 VECTOR(I) = C(I)/MAX
4440 NEXT I
4450 PRE.MAX = MAX
4460 GOTO 4110
4470 RETURN
4480 REM
4490 REM
4500 REM \CALCULATE THE EIGENVECTOR
4510 REM
4520 FOR I = 1 TO N
4540 EIGEN(I) = C(I)/MAX
4550 NEXT I
4560 RETURN
4570 REM
4580 REM
4590 REM \CALCULATE THE NORMALIZED EIGENVECTOR
4600 REM
4610 REM
4620 EIGEN.SUM = 0
4630 FOR I = 1 TO N
4640 EIGEN.SUM = EIGEN.SUM + EIGEN(I)
4650 NEXT I
4660 FOR I = 1 TO N
4670 NORM.EIGEN(I) = EIGEN(I)/EIGEN.SUM
4680 NEXT I
4690 RETURN
4700 REM
4710 REM
4720 REM \TEST FOR CONSISTENCY
4730 REM
4740 REM
4750 CONSIS.IDX = (MAX - N)/(N - 1)
4760 IF N = 3 THEN MAXI = 3.09
4770 IF N = 4 THEN MAXI = 4.24
4780 IF N = 5 THEN MAXI = 5.41
4790 IF N = 6 THEN MAXI = 6.59
4800 IF N = 7 THEN MAXI = 7.75
4810 IF N = 8 THEN MAXI = 8.95
4820 IF N = 9 THEN MAXI = 10.11
4830 IF N = 10 THEN MAXI = 11.3
4840 IF N = 11 THEN MAXI = 12.5
4850 IF N = 12 THEN MAXI = 13.7
4860 IF N = 13 THEN MAXI = 14.9
4870 IF N = 14 THEN MAXI = 15.2
4880 IF N = 15 THEN MAXI = 17.5
4890 IF N = 16 THEN MAXI = 19.0
4900 IF MAX > MAXI THEN 4910 ELSE 5050
4910 PRINT : PRINT 41, "*
4920 PRINT \PRINT 41, "*

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430 PRINT *"The decision variable matrix is not very consistent"* 440 PRINT #1, *"The decision variable matrix is not very consistent"* 450 PRINT *"The consistency index is "; CONSIST.INDX 460 PRINT #1, *"The consistency index is "; CONSIST.INDX 470 PRINT : PRINT #1, *" 480 INPUT *"Do you want to revise the data in this matrix? Y or N? "*, REV 490 PRINT #1, *"Do you want to revise the data in this matrix? Y or N? "*, REV 500 IF REV = "Y" THEN Kill #120 ; GOTO 2740 510 IF REV = "Y" THEN Kill #120 ; GOTO 2740 520 IF REV = "N" THEN 5950 530 IF REV = "N" THEN 5950 540 GOTO 4980 550 RETURN 550 REM 560 REM STORE THE NORMALIZED EIGENVECTOR 570 REM 580 REM 590 REM 600 REM 610 REM 620 REM 630 FOR I = 1 TO N 640 COMPOS.MAT(I,0) = NOP.EIGEN(I) 650 NEXT I 660 RETURN 670 REM 680 REM 690 REM 700 REM 710 REM 720 REM ********************* 730 REM 740 REM 750 REM SUB-Routine 2: 760 REM THIS IS A SUB-Routine FOR CONSTRUCTING THE 770 REM COMPOSITE MATRIX "COMP.MAT" 780 REM 790 REM 800 REM 810 REM 820 REM ********************* 830 REM 840 REM 850 REM 860 REM 870 REM 880 OPEN **2", #2, "COMP.MAT" 890 FOR I = 1 TO N 900 FOR J = 1 TO Q 910 PRINT #2, COMPOS.MAT(I,J); 920 PRINT #2, " "; 930 NEXT J 940 NEXT I 950 CLOSE #2 960 RETURN 970 REM 980 REM 990 REM 100 REM 101 REM 102 REM
SUB-Routine 1:

This is a sub-routine for calculating composite priority vector.

SUB-Routine 3 Control Module

Sub-routine 2:

Please wait. Calculation of ranking of the alternatives.

Sub-routine 2:

Please wait. Calculation of ranking of the alternatives.

SUB-Routine 1:

Sub-routine 2:

Sub-routine 1:

Sub-routine 2:

Sub-routine 1:

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Sub-routine 1:

Sub-routine 2:

Sub-routine 1:

Sub-routine 2:

Sub-routine 1:

Sub-routine 2:
5000 REM
5010 REM
5015 REM CALL THE EIGENVECTOR OF "PARAMAT"
5020 REM
5025 REM
5030 REM FIND THE SUM OF ELEMENTS IN EACH ROW OF MATRI
5035 REM
5040 REM
5045 FOR I = 1 TO K
5050 ROW.SUM(I) = 0
5055 FOR J = 1 TO K
5060 ROW.SUM(I) = ROW.SUM(I) + PARA.MAT(I,J)
5065 NEXT J
5070 NEXT I
5075 REM
5080 REM FIND THE MAXIMUM OF ROW-SUMS
5085 REM
5090 REM
5095 MAX = ROW.SUM(1) : ROW = 1
5100 FOR I = 2 TO K
5105 IF MAX > ROW.SUM(I) THEN 5110
5110 MAX = ROW.SUM(I) : ROW = I
5115 NEXT I
5120 REM
5125 REM ASSUME AN INITIAL VECTOR
5130 REM
5135 REM
5140 FOR J = 1 TO K
5145 IF J = ROW THEN 5150
5150 VECTOR(J) = 0 : 6070 5170
5160 VECTOR(J) = 1
5170 NEXT J
5175 REM
5180 REM
5185 REM PERFORM THE ITERATIONS
5190 REM
5195 REM
5200 PRE.MAT = 0
5205 FOR I = 1 TO K
5210 C(I) = 0
5215 FOR J = 1 TO K
5220 C(I) = C(I) + PARA.MAT(I,J) * VECTOR(J)
5225 NEXT J
5230 NEXT I
5235 REM
5240 REM
5245 REM
5250 MAX = C(1) : ROW = 1
5255 FOR I = 2 TO K STEP 1
5260 IF MAX > C(I) THEN 5265
5265 MAX = C(I) : ROW = I
5270 NEXT I
5275 REM
5280 REM
5285 REM
570 REM TEST FOR THE NEED OF FURTHER ITERATION
5710 REM
5720 IF ABS(MAX - PRE.MAX) < .02 THEN 6680 ELSE 6610
5730 FOR I = 1 TO K
5740 VECT(I) = C(I)/MAX
5750 NEXT I
5760 PRE.MAX = MAX
5770 GOTO 6440
6660 REM
6670 REM
6680 REM CALCULATE THE EIGENVECTOR OF *PARAMAT*
6690 REM
6700 REM
6710 FOR I = 1 TO K
6720 EIGEN(I) = C(I)/MAX
6730 NEXT I
6740 REM
6750 REM CALCULATE THE NORMALIZED EIGENVECTOR OF *PARAMAT*
6760 REM
6770 REM
6780 EIGEN.SUM = 0
6790 FOR I = 1 TO K
6800 EIGEN.SUM = EIGEN.SUM + EIGEN(I)
6810 NEXT I
6820 FOR I = 1 TO K
6830 FOR J = 1 TO K
6840 NOR.PARAVEC(I) = EIGEN(I)/EIGEN.SUM
6850 NEXT J
6860 RETURN
6870 REM
6880 REM
6890 REM INPUT DATA FROM THE COMPOSITE MATRIX
6900 REM
6910 REM
6920 FOR I = 1 TO N
6930 FOR J = 1 TO K
6940 INPUT #3, MAT(I,J)
6950 NEXT J
6960 NEXT I
6970 RETURN
6980 REM
6990 REM
7000 REM PERFORM THE MULTIPLICATION
7010 REM
7020 REM
7030 FOR I = 1 TO N
7040 COMPO.VEC(I) = 0
7050 FOR J = 1 TO K
7060 COMPO.VEC(I) = COMPO.VEC(I) + MAT(I,J) * NOR.PARAVEC(J)
7070 NEXT J
7080 NEXT I
7090 RETURN
7100 REM
7110 REM
**REM** EXPRESS COMPOSITE PRIORITY VECTOR IN TERMS OF W

**REM**

7120 REM
7130 REM
7140 REM
7150 COMPO.MAX = COMPO.VEC(I)
7160 FOR I = 2 TO N STEP 1
7170 IF COMPO.MAX > COMPO.VEC(I) THEN 7190
7180 COMPO.MAX = COMPO.VEC(I)
7190 NEXT I
7200 FOR I = 1 TO N
7210 PERCENT(I) = (COMPO.VEC(I)/COMPO.MAX) * 100
7220 NEXT I
7230 RETURN
7240 REM
7250 REM
7260 REM PRINT THE RESULT OF RANKING
7270 REM
7280 REM
7290 PRINT "The ranking is:"
7300 PRINT "The ranking is:"
7310 PRINT "The ranking is:"
7320 PRINT "The ranking is:"
7330 PRINT "The ranking is:"
7340 PRINT "The ranking is:"
7350 PRINT "The ranking is:"
7360 PRINT "The ranking is:"
7370 PRINT "The ranking is:"
7380 PRINT "The ranking is:"
7390 PRINT "The ranking is:"
7400 FOR I = 1 TO N
7410 PRINT "Alternative "; I, PERCENT(I)
7420 PRINT "; Alternative "; I, PERCENT(I)
7430 NEXT I
7440 RETURN
7450 REM
7460 REM
7470 REM
7480 REM
7490 REM
7500 REM
7510 REM
7520 REM
7530 REM
7540 REM
7550 REM
7560 REM
7570 REM
7580 DATA "PARAMETER 1 : Flow"
7590 DATA "PARAMETER 1 : Flow"
7600 DATA "PARAMETER 2 : Influent / Effluent"
7610 DATA "PARAMETER 2 : Influent / Effluent"
7620 DATA "PARAMETER 3 : Size of site"
7630 DATA "PARAMETER 3 : Size of site"
7640 DATA "PARAMETER 4 : Nature of site"
7650 DATA "PARAMETER 4 : Nature of site"
DATA "PARAMETER 5 : Land cost"
DATA "PARAMETER 6 : Local money for construction"
DATA "PARAMETER 7 : Foreign money for construction"
DATA "PARAMETER 8 : Local skill for construction"
DATA "PARAMETER 9 : Community support"
DATA "PARAMETER 10 : Power source"
DATA "PARAMETER 11 : Availability of local material"
DATA "PARAMETER 12 : Cost of operation & maintenance"
DATA "PARAMETER 13 : Professional skill for operation & maintenance"
DATA "PARAMETER 14 : Local technical skill for operation & maintenance"
DATA "PARAMETER 15 : Administration set-up"
DATA "PARAMETER 16 : Training"
DATA "PARAMETER 17 : Professional ethics"
DATA "PARAMETER 18 : Climate"
DATA "PARAMETER 19 : Local water-borne diseases"
DATA "PARAMETER 20 : Endemic vector-borne (water related) diseases"
DATA "PARAMETER 21 : Other diseases"
DATA "PARAMETER 22 : Support for local technical skill for operation & maintenance"
Type "SENSIANA" against the "A>" prompt (or "C>" prompt if a hard-disc of XT or AT is used) and then press <ENTER>. The following will be shown on the screen:

```
**********************************************************
* Order of decision variable matrix is n x n where n = *
**********************************************************
```

Then, type the number of decision variables to be ranked and press <ENTER>. The computer will respond as follows:

```
**********************************************************
* Enter the parameter number whose matrix is to be reviewed.*
* The number (ie. the kth parameter, k = 1 to 20) is? *
**********************************************************
```

So, type the number next to the "?" prompt and press <ENTER>. The computer will show the original matrix on the screen and ask if the matrix should be revised as follows:

```
**********************************************************
* The decision variable matrix is:
* 
* (the elements shown are those of the original matrix)
* 
* Do you want to change data in the above matrix? Y or N? *
**********************************************************
```
Usually the answer should be Yes because this is a sensitivity analysis program. (The answer would be No only if the user has entered a wrong parameter number and in such a case the computer will ask him to re-enter the parameter number.) So type "Y" and then press <ENTER>. The computer will respond as follows:

```
* You only have to enter the upper triangular elements
* A(1,1) =
* ?
```

So, input $a_{11}$ (up to six decimal places) against the "?" prompt and press <ENTER>. The computer will then continue to ask the user to enter $a_{12}$, $a_{13}$ and so on until all the upper triangular elements (i.e. $a_{ij}$ for $1 \leq i < j \leq n$) are entered. After the last element, $a_{nn}$, has been entered, the following will appear on the screen:

```
* The decision variable matrix is:
* (the elements shown are those newly entered)
* Do you want to change data in the above matrix? Y or N?
```

If the user has entered wrong data, then answer "Y" and the computer will allow him to input the data once again. If
the answer is "N", the computer will ask you another question:

* Do you want to change another decision variable matrix? *

If the user has decision variable matrices of other parameters needed to be revised, then type "Y" and press <ENTER>. The computer will repeat to ask the whole set of questions as described in the previous paragraphs of this manual and the users will have to respond to them accordingly. If the user has finished revising the decision variable matrices, then type "N" and press <ENTER>. The computer will tell the user to wait as the calculation of the ranking of the treatment alternatives is in progress. After a short while, the result of the final ranking will appear on the screen and the program will end.
APPENDIX B.2.2 - FLOW CHART (SENSIANA)

START

OPEN OUTPUT DOCUMENTATION FILE "SENSIRUN"

INPUT ORDER OF DECISION VARIABLE MATRIX

INPUT PARAMETER NUMBER WHOSE DECISION VARIABLE MATRIX IS TO BE REVISED

REVISE DECISION VARIABLE MATRIX (SUB-Routine 1)

YES

REVISE ANOTHER MATRIX?

NO

END

K=0

K=K+1

CALCULATE PRIORITY VECTOR (SUB-Routine 2)

K<20?

YES

OPEN FILE "COMPOMAT"

STORE ALL 20 PRIORITY VECTORS IN "COMPOMAT" (SUB-Routine 3)

CLOSE "COMPOMAT"

CALCULATE COMPOSITE PRIORITY VECTOR (SUB-Routine 4)

CLOSE "SENSIRUN"
OPEN INPUT DATA FILE

OPEN OUTPUT DATA FILE "TEMPDATA"

STORE INPUT DATA IN "TEMPDATA"

CLOSE INPUT DATA FILE

LIST OUT ORIGINAL DATA ON SCREEN

REVISE DATA IN "TEMPDATA" (INPUT UPPER TRIANGULAR ELEMENTS ONLY)

CLOSE "TEMPDATA"

NAME "TEMPDATA" AS "PARA_LIQ"
SUB-ROUTINE 2

ASSUME AN INITIAL VECTOR WITH ELEMENT CORRESPONDING TO THE MAXIMUM ROW SUM OF MATRIX A=1 AND ALL OTHER ELEMENTS=0

\[ p = 1 \]
\[ k_0 = 0 \]

CALCULATE \( k_p \) (See References 3 and 6 of Chapter 5)

\[ p = p + 1 \]

AND \( k_p - 1 \) DIFFER BY LESS THAN 0.1 % ?

NO

YES

COMPUTE NORMALIZED EIGENVECTOR FOR EIGENVALUE = \( k_p \)
SUB-ROUTINE 4

OPEN AN EXISTING FILE "PARAMAT"

INPUT DATA FROM "PARAMAT"

OPEN "COMPOMAT"

INPUT DATA FROM "COMPOMAT"

CLOSE "PARAMAT" AND "COMPOMAT"

CALCULATE PRIORITY VECTOR FOR "PARAMAT"

PERFORM MATRIX MULTIPLICATION TO FIND FINAL PRIORITY VECTOR

LIST OUT RESULT OF MULTIPLICATION — RANKING OF DECISION VARIABLES
APPENDIX 3.2.3 --- PROGRAM LISTING (SENSIANA)

100 REM**************************************************************
110 REM
120 REM
130 REM PROGRAM NAME : SENSIANA
140 REM AUTHOR : S.L. TANG
150 REM DATE WRITTEN : 1988
160 REM
170 REM**************************************************************
180 REM
190 REM
210 REM PROGRAM DESCRIPTION:
220 REM THIS IS A PROGRAM FOR SENSITIVITY ANALYSIS OF RANKING
230 REM WASTEWATER TREATMENT ALTERNATIVES
240 REM
250 REM**************************************************************
260 REM
270 REM
290 REM DATA DICTIONARY:
300 REM
310 REM INPUT VARIABLES:
320 REM
330 REM N = ORDER OF DECISION VARIABLE MATRIX
340 REM A = ARRAY FOR DATA INPUT INTO DECISION VARIABLE MATRIX
350 REM CH.DATAS = ANSWER FOR WHETHER TO CHANGE DATA IN A MATRIX
370 REM PARA.NAT = ARRAY FOR PARAMETER MATRIX FILE NAMED "PARAMAT"
380 REM MAT = ARRAY FOR COMPOSITE MATRIX FILE NAMED "COMPOMAT"
390 REM
400 REM INPUT/OUTPUT VARIABLES:
410 REM
430 REM DECIVAR.NAT = ARRAY FOR DECISION VARIABLE MATRIX
440 REM COMPO.NAT = ARRAY FOR COMPOSITE MATRIX
450 REM
460 REM OUTPUT VARIABLES:
470 REM PERCENT = ARRAY FOR COMPOSITE PROBABILITY VECTOR EXPRESS IN
480 REM TERMS OF PERCENTAGE
490 REM
500 REM OUTPUT FILES:
510 REM
550 REM SENSINU.L12 = REPORT SHOWING THE DIALOGUE OF THE USER
550 REM AND THE COMPUTER WHEN RUNNING THE MODEL
570 REM COMPOMAT.L12 = THE COMPOSITE MATRIX
580 REM PARA.L12 = DECISION VARIABLE MATRIX OF PARAMETER # (N=1-20)
510 REM WORKING VARIABLES:
520 REM K = THE Kth PARAMETER
530 REM LID= FILE NAME OF DECISION VARIABLE MATRIX
540 REM TENDATA = TEMPORARY FILE FOR STORING DECISION VARIABLE MATRIX
550 REM I, J = LOOP CONTROL
560 REM ROW.SUM = ARRAYS FOR SUM OF ELEMENTS IN EACH ROW OF A MATRIX
570 REM ROW = ROW NUMBER OF MAXIMUM EIGENVALUE
580 REM VECTOR = ARRAY FOR INITIAL VECTOR AND SUBSEQUENT VECTORS
590 REM D = ARRAY FOR TEMPORARY EIGENVECTOR DURING ITERATIONS
600 REM MAX = MOST RECENT MAX ELEMENT IN VECTOR DURING ITERATIONS
610 REM PRE.MAX = MAXIMUM ELEMENT IN VECTOR AT THE PREVIOUS ITERATION
620 REM DIFF = DIFFERENCE OF MAX AND PRE.MAX
630 REM EIGEN = ARRAY FOR EIGENVECTOR
640 REM NOR.EIGEN = ARRAY FOR NORMALIZED EIGENVECTOR
650 REM EIGEN.SUM = SUM OF ELEMENTS IN EIGENVECTOR
660 REM CONS.IDI = CONSISTENCY INDEX
670 REM LIMIT = LIMIT OF CONSISTENCY INDEX
680 REM Q = THE Kth COLUMN OF COMPOSITE MATRIX
690 REM NOR.PARAVEC = ARRAY FOR NORMALIZED EIGENVECTOR OF PARAMETER MATRIX
700 REM COMPO.VEC = ARRAY FOR COMPOSITE PRIORITY VECTOR
710 REM COMPO.MAX = MAXIMUM ELEMENT OF COMPOSITE PRIORITY VECTOR
720 REM
730 REM
740 REM
750 REM
760 REM
770 REM
780 REM
790 REM
800 REM
810 REM
820 REM
830 REM
840 REM
850 REM
860 REM
870 REM
880 REM
890 REM
900 REM
910 REM
920 REM
930 REM
940 REM
950 GOSUB 1080 : REM INITIALIZE
960 GOSUB 1360 : REM SUB-Routine 1
970 GOSUB 3130 : REM SUB-Routine 2
980 GOSUB 4980 : REM SUB-Routine 3
990 GOSUB 5220 : REM SUB-Routine 4
1000 END
1010 REM
1020 REM
1030 REM
1040 REM
1050 REM
1060 REM
1070 REM
1080 REM
1090 REM
1100 REM
1110 REM
1120 REM
1130 REM
1140 DIM A(20,20), DECVAR.MAT(20,20), PARA.MAT(20,20), ROW.SUM(20)
1150 DIM VECTOR (20), C(20), EIGEN(20), NOR.EIGEN(20), NOR.PARAVEC(20)
SUB-ROUTINE I.

THIS IS A SUB-Routine FOR INPUTTING THE DECISION VARIABLE MATII' OF PARAMETER K

SUB-ROUTINE 1 CONTROL MODULE

PRINT "Enter the parameter number whose matrix is to be reviewed."
PRINT #1, "Enter the parameter number whose matrix is to be reviewed."
PRINT #1, "The number (i.e. the Kth parameter, K = 1 to 20) is ?", K
PRINT #1, "The number (i.e. the Kth parameter, K = 1 to 20) is ?", K

IF K = 1 THEN LlQS = "PAPA1.LIQ"
IF K = 2 THEN LlQS = "PAPA2.LIQ"
IF K = 3 THEN LlQS = "PAPA3.LIQ"
IF K = 4 THEN LlQS = "PAPA4.LIQ"
IF K = 5 THEN LlQS = "PAPA5.LIQ"
IF K = 6 THEN LlQS = "PAPA6.LIQ"
IF K = 7 THEN LlQS = "PAPA7.LIQ"
IF K = 8 THEN LlQS = "PAPA8.LIQ"
IF K = 9 THEN LlQS = "PAPA9.LIQ"
IF K = 10 THEN LlQS = "PAPA10.LIQ"
IF K = 11 THEN LlQS = "PAPA11.LIQ"
IF K = 12 THEN LlQS = "PAPA12.LIQ"
IF K = 13 THEN LlQS = "PAPA13.LIQ"
IF K = 14 THEN LlQS = "PAPA14.LIQ"
IF K = 15 THEN LlQS = "PAPA15.LIQ"
IF K = 16 THEN LlQS = "PAPA16.LIQ"
IF K = 17 THEN LlQS = "PAPA17.LIQ"
IF K = 18 THEN LlQS = "PAPA18.LIQ"
IF K = 19 THEN LlQS = "PAPA19.LIQ"
1710 IF K = 20 THEN LIG$ = "PARAM.LIG"
1720 OPEN 1", #2, LIG$
1730 OPEN 0", #3, "TEMPODATA"
1740 FOR I = 1 TO N
1750 FOR J = 1 TO N
1760 INPUT #2, A(I, J)
1770 PRINT #3, A(I, J);
1780 NEXT J
1790 PRINT #3, "*
1800 NEXT I
1810 CLOSE #2
1820 CLOSE #3
1830 REM
1840 REM LIST OUT THE DECISION VARIABLE MATRIX (FROM EXISTING FILE)
1850 REM
1860 REM
1870 REM
1880 PRINT : PRINT #1, "*
1890 PRINT : PRINT #1, "*
1900 PRINT 'The decision variable matrix is: '
1910 PRINT #1, 'The decision variable matrix is: '
1920 PRINT : PRINT #1, "*
1930 OPEN 1", #2, "TEMPODATA"
1940 FOR I = 1 TO N
1950 FOR J = 1 TO N
1960 INPUT #2, DECIVAR.MAT(I, J)
1970 PRINT USING "0.### "; DECIVAR.MAT(I, J);
1980 PRINT #1, USING "0.### "; DECIVAR.MAT(I, J);
1990 NEXT J
2000 PRINT : PRINT #1, "*
2010 NEXT I
2020 CLOSE #2
2030 PRINT : PRINT #1, "*
2040 PRINT : PRINT #1, "*
2050 KILL LIG$
2060 INPUT "Do you want to change data in the above matrix? Y or N? ", CH.DATAS
2070 PRINT #1,"Do you want to change data in the above matrix? Y or N? ",CH.DATAS
2080 IF CH.DATAS = "Y" THEN 2260
2090 IF CH.DATAS = "Y" THEN 2260
2100 IF CH.DATAS = "N" THEN 2150
2110 IF CH.DATAS = "N" THEN 2150
2120 SDTO 2060
2130 REM
2140 REM
2150 REM PENDATA *TEMPODATA"
2160 REM
2170 REM
2180 NAME "TEMPODATA" AS LIG$
2190 PRINT : PRINT #1, "*
2200 PRINT : PRINT #1, "*
2210 PRINT : PRINT #1, "*
2220 PRINT : PRINT #1, "*
2230 SDTO 2240
2240 REM
2250 REM
REM MANUAL DATA INPUT
REM
PRINT : PRINT #1, "*"
PRINT : PRINT #1, "*"
PRINT "You only have to enter the upper triangular elements"
PRINT #1, "You only have to enter the upper triangular elements"
PRINT : PRINT #1, "*"
PRINT #1, "*"
PRINT : PRINT #1, "*"
FOR I = 1 TO N
FOR J = 1 TO N
PRINT "A("#I#",#J#)" = " : INPUT A(I,J)
PRINT #1, "A(#I#",#J#)" = " : A(I,J)
A(J,I) = 1/A(I,J)
NEXT J
NEXT I
REM STORE THE DATA JUST ENTERED IN A DATA FILE NAMED "TEMPDATA"
OPEN "O", #2, "TEMPDATA"
FOR I = 1 TO N
FOR J = 1 TO N
PRINT #2, A(I,J);
NEXT J
PRINT #2, "*"
NEXT I
CLOSE #2
REM LIST OUT THE DECISION VARIABLE MATRIX (FROM MANUAL INPUT)
OPEN "I", #2, "TEMPDATA"
FOR I = 1 TO N
FOR J = 1 TO N
PRINT #2, DECIVAR.MAT(I,J)
PRINT USING "#.###" ; DECIVAR.MAT(I,J);
PRINT #1, USING "#.###" ; DECIVAR.MAT(I,J);
NEXT J
PRINT : PRINT #1, "*"
NEXT I
CLOSE #2
PRINT : PRINT #1, "*"
PRINT : PRINT #1, "*"
PRINT "Do you want to change data in the above matrix? Y or N? ";CH.DATAS
PRINT #1,"Do you want to change data in the above matrix? Y or N? ";CH.DATAS
IF CH.DATAS = "Y" THEN 2260
IF CH.DATAS = "Y" THEN 2260
2810 IF CH. DATAS = "Y" THEN 2860
2820 IF CH. DATAS = "N" THEN 2860
2830 GOTO 2770
2840 REM
2850 REM
2860 REM PENAME "TEMPEXAS"
2870 REM
2880 REM
2890 NAME *TEMPEXAS* AS LIQ1
2900 PRINT : PRINT #1, "*
2910 PRINT : PRINT #1, "*
2920 PRINT : PRINT #1, "*
2930 PRINT : PRINT #1, "*
2940 INPUT "Do you want to change another decision variable matrix ?",CH.DATAS
2950 PRINT #1, "Do you want to change another decision variable matrix ?",CH.DATAS
2960 PRINT #1, "*
2970 PRINT : PRINT #1, "*
2980 PRINT : PRINT #1, "*
2990 PRINT : PRINT #1, "*
3000 IF CH. DATAS = "Y" THEN 1470
3010 IF CH. DATAS = "N" THEN 1470
3020 IF CH. DATAS = "N" THEN 3050
3030 IF CH. DATAS = "Y" THEN 3050
3040 GOTO 2940
3050 RETURN
3060 REM
3070 REM
3080 REM
3090 REM
3100 REM ***********SUB-ROUTINE 2:***********
3110 REM
3120 REM SUB-ROUTINE 2:
3130 REM THIS IS A SUB-ROUTINE TO CALCULATE THE 20 PRIORITY VECTORS
3140 REM
3150 REM
3160 REM
3170 REM ***********SUB-ROUTINE 2:***********
3180 REM
3190 REM
3200 PRINT "Please wait. Calculation of ranking of the alternatives"
3210 PRINT "is in process."
3220 PRINT #1, "Please wait. Calculation of ranking of the alternatives"
3230 PRINT #1, "is in process."
3240 FOR K = 1 TO 20
3250 60SUB 3290
3260 NEXT K
3270 RETURN
3280 IF K = 1 THEN LIQ4 = "PARA1.LIQ"
3290 IF K = 2 THEN LIQ4 = "PARA2.LIQ"
3300 IF K = 3 THEN LIQ4 = "PARA3.LIQ"
3310 IF K = 4 THEN LIQ4 = "PARA4.LIQ"
3320 IF K = 5 THEN LIQ4 = "PARA5.LIQ"
3330 IF K = 6 THEN LIQ4 = "PARA6.LIQ"
3340 IF K = 7 THEN LIQ4 = "PARA7.LIQ"
3350 IF K = 8 THEN LIQ4 = "PARA8.LIQ"
3250 IF K = 3 THEN LIG = "PARA9.LIG"
3270 IF K = 10 THEN LIG = "PARA10.LIG"
3300 IF K = 11 THEN LIG = "PARA11.LIG"
3320 IF K = 12 THEN LIG = "PARA12.LIG"
3340 IF K = 13 THEN LIG = "PARA13.LIG"
3360 IF K = 14 THEN LIG = "PARA14.LIG"
3380 IF K = 15 THEN LIG = "PARA15.LIG"
3400 IF K = 16 THEN LIG = "PARA16.LIG"
3420 IF K = 17 THEN LIG = "PARA17.LIG"
3440 IF K = 18 THEN LIG = "PARA18.LIG"
3460 IF K = 19 THEN LIG = "PARA19.LIG"
3480 IF K = 20 THEN LIG = "PARA20.LIG"
3500 OPEN "I", #2, LIG
3520 FOR I = 1 TO N
3540 FOR J = 1 TO N
3560 INPUT #2, DECVAR.MAT(I,J)
3580 NETT I
3600 REM SUB-Routine 2.1:
3610 REM THIS IS A SUB-Routine FOR FINDING MAXIMUM EIGENVALUE AND ITs
3620 REM CORRESPONDING PRIORITY VECTOR OF A SQUARE MATRIX OF ORDER N
3630 REM
3640 REM
3650 REM SUB-Routine 2.1 CONTROL MODULE
3660 REM
3670 REM
3680 REM
3690 REM
3700 REM
3710 gosub 3840 : REM FIND THE SUM OF ELEMENTS IN EACH ROW OF MATRIX
3720 gosub 3960 : REM FIND THE MAXIMUM OF ROW-SUMS
3730 gosub 4070 : REM ASSUME AN INITIAL VECTOR
3740 gosub 4180 : REM PERFORM THE ITERATIONS
3750 gosub 4610 : REM CALCULATE THE EIGENVECTOR
3760 gosub 4700 : REM CALCULATE THE NORMALIZED EIGENVECTOR
3770 gosub 4830 : REM STOPP THE NORMALIZED EIGENVECTOR
3780 RETUR
3790 REM
3800 REM
3810 REM
3820 REM
3830 REM
3840 REM FIND THE SUM OF ELEMENTS IN EACH ROW OF MATRIX
3850 REM
3860 REM
3370 FOR I = 1 TO N
3380 ROW.SUM(I) = 0
3390 FOR J = 1 TO N
3400 ROW.SUM(I) = ROW.SUM(I) + DECVAR.MAT(I,J)
3410 NEXT J
3420 NEXT I
3430 RETURN
3440 REM
3450 REM
3460 REM FIND THE MAXIMUM OF ROW-SUMS
3470 REM
3480 REM
3490 MAX = ROW.SUM(I) ; ROW = I
4000 FOR I = 2 TO N STEP 1
4010 IF MAX > ROW.SUM(I) THEN 4030
4020 MAX = ROW.SUM(I) ; ROW = I
4030 NEXT I
4040 RETURN
4050 REM
4060 REM
4070 REM ASSUME AN INITIAL VECTOR
4080 REM
4090 REM
4100 FOR J = 1 TO N
4110 IF J = ROW THEN 4130
4120 VECTOR(J) = 0 ; GOTO 4140
4130 VECTOR(J) = 1
4140 NEXT J
4150 RETURN
4160 REM
4170 REM
4180 REM PERFORM THE ITERATIONS
4190 REM
4200 REM
4210 PRE.MAX = 0
4220 FOR I = 1 TO N
4230 C(I) = 0
4240 FOR J = 1 TO N
4250 C(I) = C(I) + DECVAR.MAT(I,J) * VECTOR(J)
4260 NEXT J
4270 NEXT I
4280 MAX = C(I) ; ROW = I
4290 FOR I = 2 TO N STEP 1
4300 IF MAX > C(I) THEN 4320
4310 MAX = C(I) ; ROW = I
4320 NEXT I
4330 REM
4340 REM
4350 REM TEST FOR THE NEED OF FURTHER ITERATION
4360 REM
4370 REM
4380 IF N = 3 THEN DIFF = .003
4390 IF N = 4 THEN DIFF = .004
4400 IF N = 5 THEN DIFF = .005
4410 IF N = 6 THEN DIFF = .006
4420 IF N = 7 THEN DIFF = .007
4430 IF N = 9 THEN DIFF = 8.000001E-03
4440 IF N = 13 THEN DIFF = 9.000001E-03
4450 IF N = 10 THEN DIFF = .01
4460 IF N = 11 THEN DIFF = .011
4470 IF N = 12 THEN DIFF = .012
4480 IF N = 13 THEN DIFF = .013
4490 IF N = 14 THEN DIFF = .014
4500 IF N = 15 THEN DIFF = .015
4510 IF N = 16 THEN DIFF = .02
4520 IF ABS(MAX - PRE.MAX) < DIFF THEN 4590 ELSE 4530
4530 FOR J = 1 TO N
4540 VECTOR(J) = C(J)/MAX
4550 NEXT J
4560 PRE.MAX = MAX
4570 GOTO 4220
4580 RETURN
4590 REM
4600 REM
4610 REM CALCULATE THE EIGENVECTOR
4620 REM
4630 REM
4640 FOR I = 1 TO N
4650 EIGEN(I) = C(I)/MAX
4660 NEXT I
4670 RETURN
4680 REM
4690 REM
4700 REM CALCULATE THE NORMALIZED EIGENVECTOR
4710 REM
4720 REM
4730 EIGEN.SUM = 0
4740 FOR I = 1 TO N
4750 EIGEN.SUM = EIGEN.SUM + EIGEN(I)
4760 NEXT I
4770 FOR I = 1 TO N
4780 NOR.EIGEN(I) = EIGEN(I)/EIGEN.SUM
4790 NEXT I
4800 RETURN
4810 REM
4820 REM
4830 REM STORE THE NORMALIZED EIGENVECTOR
4840 REM
4850 REM
4860 Q = K
4870 FOR I = 1 TO N
4880 COMPD.MAT(I, Q) = NOR.EIGEN(I)
4890 NEXT I
4900 RETURN
4910 REM
4920 REM
4930 REM
4940 REM
SUB-Routine 3:
This is a sub-routine for constructing the composite matrix "COMPOMET.LIQ"

SUB-Routine 4:
This is a sub-routine for calculating composite priority vector

SUB-Routine 4 Control Module

SUB-Routine 5:
5460 REM **************************************************************************
5470 REM
5480 REM
5490 REM  INPUT DATA FROM THE PARAMETER MATRIX
5500 REM
5510 REM
5520 FOR I = 1 TO K
5530 FOR J = 1 TO K
5540 INPUT #2, PARA.MAT(I,J)
5550 NEXT J
5560 NEXT I
5570 RETURN
5580 REM
5600 REM
5610 REM  CALCULATE THE EIGENVECTOR OF "PARA.MAT"
5620 REM
5630 REM
5640 REM
5650 REM
5660 REM
5670 REM  FIND THE SUM OF ELEMENTS IN EACH ROW OF MATRIX
5680 REM
5690 REM
5700 FOR I = 1 TO K
5710 ROW.SUM(I) = 0
5720 FOR J = 1 TO K
5730 ROW.SUM(I) = ROW.SUM(I) + PARA.MAT(I,J)
5740 NEXT J
5750 NEXT I
5760 REM
5770 REM
5780 REM  FIND THE MAXIMUM OF ROW-SUMS
5790 REM
5800 REM
5810 MAX = ROW.SUM(1) : ROW = 1
5820 FOR I = 2 TO K
5830 IF MAX > ROW.SUM(I) THEN 5850
5840 MAX = ROW.SUM(I) : ROW = I
5850 NEXT I
5860 REM
5870 REM
5880 REM  ASSUME AN INITIAL VECTOR
5890 REM
5900 REM
5910 FOR J = 1 TO K
5920 IF J = ROW THEN 5940
5930 VECTOR(J) = 0 : GOTO 5950
5940 VECTOR(J) = 1
5950 NEXT J
5960 REM
5970 REM
5980 REM  PERFORM THE ITERATIONS
5990 REM
6000 REM

255
5010 PRE. MAX = 0
5020 FOR I = 1 TO K
5030 C(I) = 0
5040 FOR J = 1 TO K
5050 C(I) = C(I) + PAPA.MAT(I,J) * VECTOR(J)
5060 NEXT J
6070 NEXT I
5080 MAT = C(I) : ROW = 1
5090 FOR I = 2 TO K STEP 1
6100 IF MAT > C(I) THEN 6120
6110 MAT = C(I) : ROW = 1
6120 NEXT I
6130 REM
6140 REM TEST FOR THE NEED OF FURTHER ITERATION
6150 REM
6170 REM
5180 IF ABS(MAT - PRE. MAX) < .02 THEN 6250 ELSE 6190
6190 FOR J = 1 TO K
5200 VECTOR(J) = C(J)/MAX
6210 NEXT J
5220 PRE. MAX = MAT
5230 6070 6020
5240 REM
5250 REM
5260 REM CALCULATE THE EIGENVECTOR OF *PAPA.MAT*
5270 REM
5280 REM
5290 FOR I = 1 TO K
5300 EISEN(I) = C(I)/MAX
6310 NEXT I
5320 REM
5330 REM
5340 REM CALCULATE THE NORMALIZED EIGENVECTOR OF *PAPA.MAT*
5350 REM
5360 REM
5370 EISEN.SUM = 0
5380 FOR I = 1 TO K
5390 EISEN.SUM = EISEN.SUM + EISEN(I)
6400 NEXT I
5410 FOR I = 1 TO K
6420 NORM.PARAVEC(I) = EISEN(I)/EISEN.SUM
6430 NEXT I
5440 RETURN
5450 REM
5460 REM
5470 REM INPUT DATA FROM THE COMPOSITE MATRIX
5480 REM
5490 REM
5500 FOR I = 1 TO K
5510 FOR J = 1 TO K
5520 INPUT #3 MAT(I,J)
5530 NEXT J
5540 NEXT I
5550 RETURN

256
**PERFORM THE MULTIPLICATION**

5590 REM

5610 FOR I = 1 TO N

5620 COMPO.VEC(I) = 0

5630 FOR J = 1 TO K

5640 COMPO.VEC(I) = COMPO.VEC(I) + MAT(I,J) * VAPAVEC(J)

5650 NEXT J

5660 NEXT I

5670 RETURN

**EXPRESS COMPOSITE PRIORITY VECTOR IN TERMS OF %**

5710 REM

5720 REM

5730 COMPO.MAX = COMPO.VEC(I)

5740 FOR I = 2 TO N STEP 1

5750 IF COMPO.MAX > COMPO.VEC(I) THEN 5770

5760 COMPO.MAX = COMPO.VEC(I)

5770 NEXT I

5780 FOR I = 1 TO N

5790 PERCENT(I) = (COMPO.VEC(I)/COMPO.MAX) * 100

5800 NEXT I

5810 RETURN

5820 REM

5830 REM

5840 REM **PRINT THE RESULT OF RANKING**

5850 REM

5860 REM

5870 PRINT: PRINT #1, ''

5880 PRINT: PRINT #1, ''

5890 PRINT *The ranking is: *

5900 PRINT #1, *The ranking is: *

5910 PRINT: PRINT #1, ''

5920 PRINT: PRINT #1, ''

5930 PRINT *", *RANKING IN I"

5940 PRINT #1, *", *RANKING IN I"

5950 PRINT *", *-------------------

5960 PRINT #1, *", *-------------------

5970 PRINT: PRINT #1, ''

5980 FOR I = 1 TO N

5990 PRINT "Alternative "; I, PERCENT(I)

6000 PRINT #1, "Alternative "; I, PERCENT(I)

6010 NEXT I

6020 RETURN
APPENDIX C.1.1 --- MALAYSIA

QUESTIONNAIRE

(A) Sewerage

1. Total population \(14,000,000\) (including East Malaysia)
   a) \(35\%\) in urban areas
   b) \(65\%\) in rural areas
   \[\text{Total} \ 100\%\]

2. Percentage of population served by public sewers:
   a) \(13\%\) in urban areas
   b) \(\text{negligible}\) in rural areas
   c) \(4.5\%\) overall of (a) (b)

3. The sewerage systems used in (2) above are mainly:
   a) Combined sewers: Yes or No
   b) Separate sewers: Yes or No
   c) Both combined & separate sewers: Yes or No

If the answer is (c), please give details:


4. Names of 3 largest cities:
   a) Kuala Lumpur (population 1,000,000)
   b) Ipoh (population 300,000)
   c) Georgetown (population 250,000)

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5. Total length of sewers: Only 3 cities have sewerage systems.
   a) in City K.L. / Shah Alam is Not known km
   b) in City George Town is _______ km
   c) in City Kota Kinabalu is _______ km
   d) Overall total length of sewers in the whole country is _______ km. Butterworth, Ipoh, Johor Bahru etc. are under planning stage.

6. a) Largest diameter of sewers used:
   ___________ mm ø (City ______________)
   ___________ mm ø (City ______________)
   ___________ mm ø (City ______________)

   b) Smallest diameter of sewers used:
   ___________ mm ø (City ______________)
   ___________ mm ø (City ______________)
   ___________ mm ø (City ______________)

   c) Average depth unknown:
   ___________ m (City ______________)
   ___________ m (City ______________)
   ___________ m (City ______________)

   d) Materials of pipes mainly used in the country:
   
   
   
   steel
   
   concrete
   
   other: Vitrified clay pipes (please specify)

7. Average cost of sewers $ _______ per km.
   including / excluding pumping stations

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(B) Treatment Plants

8. How many wastewater treatment plants altogether, whether large or small, industrial or municipal, are there in the country?
   a) Not possible to give (public)
   b) The exact number (private) e.g. in-house plants in factories, etc.

9. Whether or not a name list of the plants in (8) can be provided.

10. Quantities of wastewater produced per day:
    a) Industrial estates: \( \frac{80}{3} \) m\(^3\)/Ha/day (average)
    b) Municipal: 20-45 l/capita/day (average)

11. How is the charge collected from the users:
    a) through "sanitation fee"? Yes \( \checkmark \) or No
    b) through water consumption fee? Yes \( \checkmark \) or No
    If yes, 30 \( \% \) of water fee is for wastewater treatment.
    c) through general tax revenue? Yes \( \checkmark \) or No
    d) through property tax? Yes \( \checkmark \) or No
    e) through other means? Connection charge from households (please specify) to public system

12. Average charge: \$ \___________ per m\(^3\).

13. The charges recovers:
   \{ Sewerage systems only
   treatment plants only
   \both \( \checkmark \)
14. Whether or not equitable? **Yes** or **No**

15. Names of 3 largest wastewater treatment plants:
   a) **Pantai STP** (location: **Kuala Lumpur**)
      i) treating { **municipal** }
      ii) method of treatment: **Aerated lagoons**
      iii) size: **250,000** population equivalent.
   b) **Lower Kerayong STP** (location: **Kuala Lumpur**)
      i) treating { **municipal** }
      ii) method of treatment: **Stabilisation pond**
      iii) size: **22,000** population equivalent.
   c) **Johor Bahru STP** (location: **Kuala Lumpur**)
      i) treating { **municipal** }
      ii) method of treatment: **Stabilisation pond**
      iii) size: **12,000** population equivalent.
   d) **Puching STP** at Puching, size: **8,000 p.e.**
16. Future development in treatment plants:

   a) Centralization or decentralization:

      i) One plant for a few nearby towns/cities? 
         Yes or No

      ii) Each town/city has several plants? 
         Yes or No

   b) Size:

      i) tends to be larger? Yes or No
      ii) tends to be smaller? Yes or No
      iii) No change? Yes or No

17. Is there or will there be any provision for effluent reuse? 

   Yes or No

   If yes, in what way? ____________________________________________
   ____________________________________________
   ____________________________________________

(C) Legislation and Management

18. The authorities dealing with fresh water and wastewater are:

   the same

   separate

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19. Names of the authorities which formulates policies concerning wastewaters are:

a) On national basis: Ministry of Science, Technology & Environment

b) On regional basis: Ministry of Housing & Local Government

c) On city basis: Municipal Council / District Council

d) Others: ____________________________

The relationship of a, b, c and d above is: ____________________________

No formal relationship. No authority is submissive to another.

20. Are the authorities mentioned in (19) responsible for setting effluent standards?

[ ] Yes or [ ] No

If no, what authorities? ____________________________ But only (x) in 19.

21. The division of region (see 19.b above) is based on:

a) the existing administrative boundaries.

[ ] Yes or [ ] No

b) another set of boundaries divided according to the water courses.

[ ] Yes or [ ] No
22. Names of the authorities responsible for enforcing the legislation and controlling the industrial discharges are:

- a) On national basis: Department of Environment (Ministry of Science, Technology & Environment)
- b) On regional basis: 
- c) On city basis: Local authorities (e.g. Municipal Council, District Council)
- d) Others: 

The relationship of a, b, c and d is:

No rigid relationship between (a) and (c).

23. Names of the authorities responsible for the planning, design and construction of wastewater facilities are:

- a) On national basis: Ministry of Housing & Local Government
- b) On regional basis: 
- c) On city basis: Local authorities
- d) Others: 

The relationship of a, b, c and d is:

(a) plays a coordinating role.

(c) plays the actual implementation role.

24. Names of authorities responsible for the operation and maintenance of the sewer and treatment plants are:

- a) On national basis: 
- b) On regional basis: 
- c) On city basis: Local authorities
- d) Others: 

The relationship of a, b, c and d is: 

------------------------------------------------------------------------
28. Have the following points in general been provided for in the legislations for industrial wastewater discharges?

a) Staged implementation (geographically)  
   [Yes] or [No]

b) Different effluent standards for different zones.  
   [Yes] or [No]  
   Two different standards: Standards A & B

c) Standards expressed quantitatively  
   [Yes] or [No]

d) Are there existing discharge exemptions  
   [Yes] or [No]

29. Expenditure spent in (i) sewerage and (ii) treatment plants:

<table>
<thead>
<tr>
<th>Year</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before 1980</td>
<td>$</td>
</tr>
<tr>
<td>1981</td>
<td>$</td>
</tr>
<tr>
<td>1982</td>
<td>$</td>
</tr>
<tr>
<td>1983</td>
<td>$</td>
</tr>
<tr>
<td>1984</td>
<td>$</td>
</tr>
<tr>
<td>1985 to ultimate</td>
<td>$</td>
</tr>
</tbody>
</table>

   M$ 2,980 (based on 1983 price level)

30. Please outline some difficulties faced in the implementation of these schemes, technically or managerially.

   1. Lack of Fund
   2. Shortage of trained manpower
   3. No central authority to be wholly responsible for the matter

   Aug. 1984
APPENDIX C.1.2 --- THAILAND

QUESTIONNAIRE

(A) Sewerage

1. Total population: 55,000,000
   a) % in urban areas: 72 million in 72 cities: 22%
   b) % in rural areas: 78%

There are 72 provincial cities

2. Percentage of population served by public sewers:
   a) % in urban areas: 100,000 persons served by public sewers
   b) % in rural areas: 0%
   c) % overall of (a) (b): practically 0%

3. The sewerage systems used in (2) above are mainly:
   a) Combined sewers: Yes or No
   b) Separate sewers: Yes or No
   c) Both combined & separate sewers: Yes or No

If the answer is (c), please give details: Combined sewers are used to cater for storm water originally.

4. Names of 3 largest cities:
   a) Bangkok (population 6 million)
   b) Chiangmai (population 101,000)
   c) Pattaya (population 50,000)
(B) Treatment Plants

8. How many wastewater treatment plants altogether, whether large or small, industrial or municipal, are there in the country?
   a) \[ 16 \text{ (municipal) (public) } + 14 \text{ (Bangkok) } + 2 \text{ (Pataya) } = 16 \]
   b) \[ 700 \text{ (industrial) (private) e.g. in-house plants in factories, etc.} \]

9. Whether or not a name list of the plants in (8) can be provided.

10. Quantities of wastewater produced per day:
    a) Industrial estates: \[ \text{not known } \text{ m}^3/\text{Ha/day} \text{ (average)} \]
    b) Municipal: \[ 150 \text{ l/capita/day} \text{ (average)} \]
        future target: 250

11. How is the charge collected from the users:
    a) through "sanitation fee"? \[ \text{Yes} \text{ or } \text{No} \]
    b) through water consumption fee? \[ \text{Yes} \text{ or } \text{No} \]
        If yes, \[ \text{___} \% \text{ of water fee is for wastewater treatment.} \]
    c) through general tax revenue? \[ \text{Yes} \text{ or } \text{No} \]
    d) through property tax? \[ \text{Yes} \text{ or } \text{No} \]
    e) through other means? \[ \text{No charge. No such a system at present. (please specify) There is a plan to charge industrialists who discharge wastewater, but the plan is not yet implemented.} \]

12. Average charge: \[ \$ \text{ _______ per m}^3 \]

13. The charges recovers:
    \[ \{ \text{Sewerage systems only} \]
    \[ \text{treatment plants only} \]
    \[ \text{both} \]
14. Whether or not equitable? [Yes] or [No]

15. Names of 3 larges wastewater treatment plants:

a) **Huay Khwng STP** (location: Huay Khwng, Bangkok)

   i) treating (both)

   ii) method of treatment: Activated sludge

   iii) size: 20,000 population equivalent.

b) **Khlong Chao STP** (location: Khlong Chao, Bangkok)

   i) treating (both)

   ii) method of treatment: Activated sludge

   iii) size: 38,000 population equivalent.

c) **Pattaya New STP** (location: Pattaya)

   i) treating (both)

   ii) method of treatment: **KBC**

   iii) size: 25,000 population equivalent.
16. Future development in treatment plants:
   a) Centralization or decentralization:
      i) One plant for a few nearby towns/cities? [Yes] or [No]  
      ii) Each town/city has several plants? [Yes] or [No]  
   b) Size: Difficult to answer. Depends on situation.
      i) tends to be larger? [Yes] or [No]  
      ii) tends to be smaller? [Yes] or [No]  
      iii) No change? [Yes] or [No]  

17. Is there or will there be any provision for effluent reuse? [Yes] or [No]
    If yes, in what way? __________________________________________________
    ____________________________________________________________
    ____________________________________________________________
    ____________________________________________________________

(C) Legislation and Management
18. The authorities dealing with fresh water and wastewater are:
    { the same
       separate

19. Names of the authorities which formulates policies concerning wastewaters are:
   a) On national basis: "National Environment Board"—municipal
   b) On regional basis: ____________________________
   c) On city basis: "Bangkok Metropolitan Administration" in Bangkok
   d) Others: ____________________________

The relationship of a, b, c and d above is: ____________________________

(c)/(d) follows the principles set by (a).

20. Are the authorities mentioned in (19) responsible for setting effluent standards?

   [ ] Yes  [ ] No

If no, what authorities? ____________________________

21. The division of region (see 19.b above) is based on:
   a) the existing administrative boundaries.
      [ ] Yes  [ ] No
   b) another set of boundaries divided according to the water courses.
      [ ] Yes  [ ] No

      but the government is thinking of doing so.
22. Names of the authorities responsible for enforcing the legislation and controlling the industrial discharges are:

a) On national basis: Industrial Works Department (i.e. IWD)

b) On regional basis: Branches of IWD

c) On city basis: ________________________________

d) Others: ________________________________

The relationship of a, b, c and d is: ________________________________

23. Names of the authorities responsible for the planning, design and construction of wastewater facilities are:

a) On national basis: No such an establishment on national basis.

b) On regional basis: IWD (e.g. Nakhon Pathom STP)

b) On city basis: National Housing Authority

b) Others: Department of Health - STPs for hospitals all over Thailand.

The relationship of a, b, c and d is: ________________________________

No proper relationship.

Division of responsibilities is very confused.

24. Names of authorities responsible for the operation and maintenance of the sewer and treatment plants are:

a) On national basis: ________________________________

b) On regional basis: Similar to (23).

b) Each authority take care of their own STPs.

c) On city basis: ________________________________

d) Others: ________________________________

The relationship of a, b, c and d is: ________________________________

Not yet materialized.

There is a policy that in the future all plants in Bangkok will be under "Bangkok Metropolitan Administration" and all other plants (in other municipalities) will be under IWD.
25. The authorities responsible for monitoring wastewater discharges are the same as the ones mentioned in (24).

Yes or No

If no, what authorities?

- Industrial wastewater — IWD
- Municipal wastewater — No authority is controlling it.

26. Briefly describe the methods used in monitoring wastewater discharges. (e.g. the number of times in a month taking wastewater samples from a factory, etc.)

IWD takes samples once a month to 4 times a year.

27. How many legislations currently are there concerning with water pollution control?

1. Bangkok Metropolitan Administration Act (Date: 1975)
2. National Environmental Quality Act (Date: 1978)
3. Building Control Act (Date: 1979)
4. Domestic Effluent Standards (Date: 1980 (draft only))

The approximate time of enforcement after the publication of legislation:

- 1 year
- 2 year
- 3 year
- Others

(please specify)
28. Have the following points in general been provided for in the legislations for industrial wastewater discharges?

a) Staged implementation (geographically)
   - [Yes] or [No]

b) Different effluent standards for different zones.
   - [Yes] or [No]
   - 4 standards: A, B, C and D.

c) Standards expressed quantitatively
   - [Yes] or [No]

d) Are there existing discharge exemptions
   - [Yes] or [No]

29. Expenditure spent in (i) sewerage and (ii) treatment plants:

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<thead>
<tr>
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<tbody>
<tr>
<td>National</td>
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<tr>
<td>Before 1980</td>
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<td>1981</td>
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<td>1983</td>
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<td>No planning</td>
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<td>1984</td>
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<td>1985 to</td>
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<tr>
<td>Ultimate</td>
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</tbody>
</table>

30. Please outline some difficulties faced in the implementation of these schemes, technically or managerially.

1. Lack of funds: costs are too high in the politicians' eyes.
2. Lack of enthusiasm on the part of general public.
3. Lack of training in both technical and professional levels.
4. Management problems — problems occur during operation, usually due to management difficulties.

A) Sewerage

1. Total population approx. 18 million
   a) % in urban areas 20
   b) % in rural areas 80

STORM SEWER
(used currently to convey wastewater) 1983 1991
SEPARATE SEWER

2. Percentage of population served by public sewers:
   a) % in urban areas
      Taipei 82% 90%
      Kaohsiung 50% 75%
   b) % in rural areas
   c) % overall of (a) (b):
      13% 42% 1% 23.6%

3. The sewerage systems used in (2) above are mainly:
   a) Combined sewers:
      Yes or No
   b) Separate sewers:
      Yes or No
   c) Both combined & separate sewers:
      Yes or No

If the answer is (c), please give details:
separate sewerage system constructed since 1970 in several urban areas or large cities.

4. Names of 3 largest cities:
   a) Taipei (population 2,250,000)
   b) Kaohsiung (population 1,250,000)
   c) Tai chung (population 600,000)
(B) Treatment Plants

8. How many wastewater treatment plants altogether, whether large or small, industrial or municipal, are there in the country?
   a) _______17_________ (public)
   b) _______200 (Kaohsiung)_________ (private) e.g. in-house plants in factories, etc.

9. Whether or not a name list of the plants in (8) can be provided.

10. Quantities of wastewater produced per day:
    a) Industrial estates: _______50 - 200_________ m$^3$/Ha/day (average)
    b) Municipal: _______250 - 320_________ l/capita/day (average)

11. How is the charge collected from the users:
    a) through "sanitation fee'? Yes or No
    b) through water consumption fee? Yes or No
       If yes, _______% of water fee is for wastewater treatment.
    c) through general tax revenue? Yes or No
    d) through property tax? Yes or No
    e) through other means? (please specify)

12. Average charge: $1.5_________ per m$^3$. (for municipal sewerage and treatment plants, not industrial.)

13. The charges recovers:
    \[
    \begin{cases} 
    \text{Sewerage systems only} \\
    \text{treatment plants only} \\
    \text{both} \\
    \end{cases}
    \]
16. Future development in treatment plants:
   a) Centralization or decentralization:
      i) One plant for a few nearby towns/cities?  
         [Yes] or [No]  
      ii) Each town/city has several plants?  
         [Yes] or [No]

   b) Size:
      i) tends to be larger?  [Yes]  or [No]  
      ii) tends to be smaller?  [Yes]  or [No]  
      iii) No change?  [Yes]  or [No]

17. Is there or will there be any provision for effluent reuse?  
   [Yes]  or [No]
   If yes, in what way?  
   Yes, but very little paper mill industries (not pulp)  
   Min Shen effluent - irrigation of glasses.

(C) Legislation and Management

18. The authorities dealing with fresh water and wastewater are:
   \{  
   \text{the same}  
   \}/  
   \{  
   \text{separate}  
   \}
19. Names of the authorities which formulates policies concerning wastewaters are:
   a) On national basis: ___________________________ National Bureau of Env. Protection.
   b) On regional basis: ___________________________ Bureau of Env. Protection, City based e.g. Taipei, Kaohsiung.
   c) On city basis: ___________________________
   d) Others: ___________________________

The relationship of a, b, c and d above is: ___________________________
__________________________________________________________
__________________________________________________________
__________________________________________________________

20. Are the authorities mentioned in (19) responsible for setting effluent standards?
   [ ] Yes or [ ] No

   If no, what authorities? ___________________________
   ___________________________
   ___________________________
   ___________________________

   By National Bureau only ___________________________
   ___________________________
   ___________________________
   ___________________________

21. The division of region (see 19.b above) is based on:
   a) the existing administrative boundaries. ___________________________
   b) another set of boundaries divided according to the water courses. ___________________________

   under consideration, during planning stage.
22. Names of the authorities responsible for enforcing the legislation and controlling the industrial discharges are:

a) On national basis: _________________________
b) On regional basis: _________________________
c) On city basis: _________________________
d) Others: ___________________________________

The relationship of a, b, c and d is: _________________________

Municipal wastewater: same as 19

Industrial district wastewater: industrial district Management Centre

23. Names of the authorities responsible for the planning, design and construction of wastewater facilities are:

a) On national basis: _________________________
b) On regional basis: _________________________
c) On city basis: _________________________
d) Others: _________________________

The relationship of a, b, c and d is: _________________________

24. Names of authorities responsible for the operation and maintenance of the sewer and treatment plants are:

a) On national basis: _________________________
b) On regional basis: _________________________
c) On city basis: _________________________
d) Others: _________________________

The relationship of a, b, c and d is: _________________________
same as 23.

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25. The authorities responsible for monitoring wastewater discharges are same as the ones mentioned in (24).

Yes or No

If no, what authorities?

26. Briefly describe the methods used in monitoring wastewater discharges. (e.g. the number of times in a month taking wastewater samples from a factory, etc.)

Taking samples from the factory several times in a month by each sewerage treatment plant or pollution control division.

27. How many legislations currently are there concerning with water pollution control?

1.  (Date: 1977/7/11)

2.  (Revision) (Date: 1983/5/27)

3.  (Date: 1984/1985)

4.  (Date: 

The approximate time of enforcement after the publication of legislation:

1 year  2 year  3 year

Others immediate (please specify)

Standard: Entering public sewers

BOD

not exceeding 600 mg/l

s.s. not exceeding 600 mg/l
28. Have the following points in general been provided for in the legislations for industrial wastewater discharges?
   a) Staged implementation (geographically)  
      [Yes] or [No]
   b) Different effluent standards for different zones.  
      [Yes] or [No]
   c) Standards expressed quantitatively  [Yes] or [No]
   d) Are there existing discharge exemptions  [Yes] or [No]

29. Expenditure spent in (i) sewerage and (ii) treatment plants:

<table>
<thead>
<tr>
<th></th>
<th>National</th>
<th>City : Kaohsiung</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before 1980</td>
<td>$</td>
<td></td>
</tr>
<tr>
<td>1981</td>
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<td>1984</td>
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<tr>
<td>1985 to</td>
<td>NT $305 00 m</td>
<td>3640 m</td>
</tr>
<tr>
<td>ultimate</td>
<td>$</td>
<td></td>
</tr>
</tbody>
</table>

30. Please outline some difficulties faced in the implementation of these schemes, technically or managerially.
   1. financial problem
   2. land available
   3. technical problem
   4. traditional idea

1984
APPENDIX C.1.4 --- HONG KONG

QUESTIONNAIRE

(A) Sewerage

1. Total population __nearly 6 million__
   a) % in urban areas ______ 90 ______
   b) % in rural areas ______ 10 ______
   \{ Total 100% \}

2. Percentage of population served by public sewers:
   a) % in urban areas ______ 98 ______
   b) % in rural areas ______ 16 ______
   c) % overall of (a) (b) : 90

3. The sewerage systems used in (2) above are mainly:
   a) Combined sewers : Yes or No
   b) separate sewers : Yes or No
   c) both combined & separate sewers : Yes or No

   If the answer is (c), please give details:
   ______________________________
   ______________________________
   ______________________________

   Urban area have separate sewerage system

4. Names of 3 largest cities:
   a) ___________________ (population ___________________)
   b) ___________________ (population ___________________)
   c) ___________________ (population ___________________)
5. Total length of sewers:
   a) in City __________ is __________ km
   b) in City __________ is __________ km
   c) in City __________ is __________ km
   d) Overall total length of sewers in the whole country is __________ km.

6. a) Largest diameter of sewers used:
   __________ mm ø (City __________)
   __________ mm ø (City __________)
   __________ mm ø (City __________)

   b) Smalles diameter of sewers use:
   __________ mm ø (City __________)
   __________ mm ø (City __________)
   __________ mm ø (City __________)

   c) Average depth
   __________ m (City __________)
   __________ m (City __________)
   __________ m (City __________)

   d) Materials of pipes mainly used in the country:
   \[
   \begin{cases}
   \text{steel} \\
   \text{concrete} \\
   \text{other} : \text{(please specify)}
   \end{cases}
   \]

7. Average cost of sewers $6000 per m (for 2100 mm ø)
   \[
   \begin{cases}
   \text{including} \\
   \text{excluding}
   \end{cases}
   \]
8. How many wastewater treatment plants altogether, whether large or small, industrial or municipal, are there in the country?
   a) 31 (public)
   b) (private) e.g. in-house plants in factories, etc.

9. Whether or not a name list of the plants in (8) can be provided.

10. Quantities of wastewater produced per day:
    a) Industrial estates: 550,000-1000,000 m³/ha/day (average)
    b) Municipal: 210-450 l/capita/day (average)

11. How is the charge collected from the users:
    a) through "sanitation fee"? Yes or No
    b) through water consumption fee? Yes or No
       If yes, _______ % of water fee is for wastewater treatment.
    c) through general tax revenue? Yes or No
    d) through property tax? Yes or No
    e) through other means? (please specify)

12. Average charge: $ ________ per m³.

13. The charges recovers:
    { Sewerage systems only
      treatment plants only
      both
    } Not applicable
14. Whether or not equitable? \[\text{Yes}\] or \[\text{No}\].

15. Names of 3 large wastewater treatment plants:

a) Shek Wu Hui (location: Sheung Shui)

   \[
   \begin{align*}
   &\text{i) treating} \\
   &\quad \{ \begin{array}{l}
   \text{industrial} \\
   \text{municipal} \\
   \text{both}
   \end{array} \}
   \end{align*}
   \]

   \[
   \begin{align*}
   &\text{wastewaters} \\
   &\text{ii) method of treatment: secondary treatment} \\
   &\text{iii) size: 293,000 population equivalent.}
   \end{align*}
   \]

b) Shatin STP (location: Shatin)

   \[
   \begin{align*}
   &\text{i) treating} \\
   &\quad \{ \begin{array}{l}
   \text{industrial} \\
   \text{municipal} \\
   \text{both}
   \end{array} \}
   \end{align*}
   \]

   \[
   \begin{align*}
   &\text{wastewaters} \\
   &\text{ii) method of treatment: secondary treatment} \\
   &\text{iii) size: 376,800 population equivalent.}
   \end{align*}
   \]

c) Tai Po STP (location: Tai Po)

   \[
   \begin{align*}
   &\text{i) treating} \\
   &\quad \{ \begin{array}{l}
   \text{industrial} \\
   \text{municipal} \\
   \text{both}
   \end{array} \}
   \end{align*}
   \]

   \[
   \begin{align*}
   &\text{wastewaters} \\
   &\text{ii) method of treatment: secondary treatment} \\
   &\text{iii) size: 140,000 population equivalent.}
   \end{align*}
   \]
16. Future development in treatment plants:

a) Centralization or decentralization:
   i) One plant for a few nearby towns/cities? [Yes] or [No]
   ii) Each town/city has several plants? [Yes] or [No]

b) Size:
   i) tends to be larger? [Yes] or [No]
   ii) tends to be smaller? [Yes] or [No]
   iii) No change? [Yes] or [No]

17. Is there or will there be any provision for effluent reuse? [Yes] or [No]

If yes, in what way? being considered, working party set up recently (early 1984), No specific proposal yet.

(C) Legislation and Management

18. The authorities dealing with fresh water and wastewater are:

   \{ the same \}

   \{ separate \}
22. Names of the authorities responsible for enforcing the legislation and controlling the industrial discharges are:

a) On national basis: _______________________

b) On regional basis: _______________________

c) On city basis: ___________________________

d) Others: ______________________________________

The relationship of a, b, c and d is: _______________________

Liquid & solid wastes of Engineering Development Dept. (EPP)

23. Names of the authorities responsible for the planning, design and construction of wastewater facilities are:

a) On national basis: _______________________

b) On regional basis: _______________________

c) On city basis: ___________________________

d) Others: ______________________________________

The relationship of a, b, c and d is: _______________________

CEO of EDD

24. Names of authorities responsible for the operation and maintenance of the sewer and treatment plants are:

a) On national basis: _______________________

b) On regional basis: _______________________

c) On city basis: ___________________________

d) Others: ______________________________________

The relationship of a, b, c and d is: _______________________

Electrical & Mechanical Services Dept.
25. The authorities responsible for monitoring wastewater discharges are same as the ones mentioned in (24).

Yes  or  No

If no, what authorities? ____________________________

POLLUTION CONTROL DEPT. OF LIQUID & SOLID WASTE DIVISION,
EDD

26. Briefly describe the methods used in monitoring wastewater discharges. (e.g. the number of times in a month taking wastewater samples from a factory, etc.)

fortnightly to once a year

27. How many legislations currently are there concerning with water pollution control?

1. Engineering Development Dept. (Date: Not ordinance)
2. Agriculture & Fisheries Dept. (Date: But merely regulations)
3. Marine Dept. (Date: )
4. Water Pollution Control Ordinance (EPA) (Date: 1980)

The approximate time of enforcement after the publication of legislation:

1 year  2 year  3 year

Others  4 year (please specify)
28. Have the following points in general been provided for in the legislations for industrial wastewater discharges?
   a) Staged implementation (geographically) [Yes] or [No]
   b) Different effluent standards for different zones. [Yes] or [No]
   c) Standards expressed quantitatively [Yes] or [No]
   d) Are there existing discharge exemptions [Yes] or [No]

29. Expenditure spent in (i) sewerage and (ii) treatment plants:

   National

   Before 1980 -- $
   1981 -- $
   1982 -- $
   1983 -- $
   1984 -- $
   1985 to 1995 $2,000 m (1983 money)
   ultimate $ $

30. Please outline some difficulties faced in the implementation of these schemes, technically or managerially.
   too early to say
   1. space limited
   2. discharge to storm drain.

   April 1984.
### Name of Wastewater Plant

Puchong STP

### Location

Puchong, K. L., Malaysia, Precinct (Selangor)

### Detail Address

Tel:

### Name of the person responsible

Mr. K. Asririnathan / Mr. Ahmed Thani

### Date of filling this form

1987

### Treatment methods used in this plant:

<table>
<thead>
<tr>
<th>Type of Treatment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Preliminary</td>
<td>Screening (e.g. screening, grit removal etc)</td>
</tr>
<tr>
<td>b) Primary</td>
<td>Stabilization pond + Maturation pond (e.g. sedimentation etc)</td>
</tr>
<tr>
<td>c) Secondary</td>
<td>trickling filter, oxidation ditch, etc (e.g. trickling filter, oxidation ditch, etc)</td>
</tr>
<tr>
<td>d) Tertiary</td>
<td>sand filtration, microstrainer, grass plots etc (e.g. sand filtration, microstrainer, grass plots etc)</td>
</tr>
</tbody>
</table>

### Sludge treatment method(s):

- aerobic/anaerobic digestion, thickening etc

### Sludge dewatering method(s):

- drying beds, filter press, centrifuge, etc

### Existing total area of the plant:

4 Ha

### Wastewaters from what industries?

- mainly: All municipal wastewater
- others: ____________________________
Construction cost (excluding land cost): $ ........................ (based on the value of money in 19 ....)

(a) Civil works:
- road works .......... 5 %
- foundation engineering works ....77 .... 7 %
- buildings (excluding staff quarters) ... 2 .... 2 %
- staff quarters ........ 1 %
- others ........ 17 .... 17 %

Sub-total 96 .... 96 %

Total 100%

(b) Equipment ............ 4 %

Capacity of the plant based on the capital cost in (7) above:

(a) ................... population equivalent

and

d) ................... m³/day (average)

in which

.......................... % is industrial wastewater

.......................... % is municipal wastewater

Total 100%

Ultimate capacity of the plant: .................... population equivalent

in Year 19 ......, i.e. .................. m³/day (average).

Not yet known but ultimate capacity will be larger.

Estimated ultimate total construction cost, including capital cost in (7):

$ .................. (based on value of money in 19 ....)

Ultimate Total area: ...................... Ha

Cost that the users of the treatment facilities have to pay: mainly

$ ........................ per m³ (average) through rates/property tax

(a) The total income can cover:

(i) operation/maintenance cost of the plant

(ii) construction cost of the plant

(iii) both operation/maintenance and construction costs

(iv) the total incomes is even more than what is required in (iii)

(b) If the answer of (a) above is (iv), whether or not it includes cost of sewers construction? including or excluding
11. Operation and maintenance costs (based on the value of money):

- Chemical: $\ldots\ldots\ldots\ldots$ per month
- Energy: $\ldots\ldots\ldots\ldots$ per month
- Personnel: $\ldots\ldots\ldots\ldots$ per month
  (including staff, chemist & labourers etc.)
- Repair & unkeeping: $\ldots\ldots\ldots\ldots$ per month
- Others: $\ldots\ldots\ldots\ldots$ per month

\[ \text{Total} = \ldots\ldots\ldots\ldots \]

12. Number of persons associated with the operation on the plant:

- Number of executive staff: $\ldots\ldots\ldots\ldots$
- Number of staff in laboratory: $\ldots\ldots\ldots\ldots$
- Number of technical/operational staff: $\ldots\ldots\ldots\ldots$ (1 x 1 week)
- Number of supporting staff: $\ldots\ldots\ldots\ldots$
  (e.g. general clerk, accounts clerks, typist etc.)
- Number of labourers: $\ldots\ldots\ldots\ldots$
- Others: $\ldots\ldots\ldots\ldots$

\[ \text{Total} = \ldots\ldots\ldots\ldots \]

13. Average degree of pollution of incoming wastewaters:

- BOD$_5$: $10.8$ mg/l
- S.S.: $8.2$ mg/l
- COD: $6.8$ mg/l
- pH: $7.0$

Major chemicals:
  - $NH_4 - N$: $24.3$ ppm
  - $NO_3 - N$: $45.7$ ppm
  - Others: $\ldots\ldots\ldots\ldots$ ppm

14. Average degree of pollution of wastewater after primary treatment but before secondary treatment (i.e. between the 1st & 2nd ponds):

- BOD$_5$: $1.7$ mg/l
- S.S.: $7$ mg/l
- COD: $2.26$ mg/l
- pH: $7.3$

Major chemicals:
  - $NH_4 - N$: $12.7$ ppm
  - $NO_3 - N$: $4.4$ ppm
  - Others: $\ldots\ldots\ldots\ldots$ ppm
15. Average effluent standard after secondary treatment but before tertiary treatment:

- **BOD**<sub>5</sub> = 2.9 mg/l
- **S.S.** = 2 mg/l
- **COD** = 8 mg/l
- **pH** = 7.7

Major chemicals:
- **NH<sub>4</sub>-N** = 17 ppm
- **Cr<sub>6+</sub>-N** = 8 ppm
- **........................**

16. Average effluent standard when it is discharged out of the plant:

- **BOD**<sub>5</sub> = 2.9 mg/l
- **S.S.** = 2 mg/l
- **COD** = 8 mg/l
- **pH** = 7.7

Major chemicals:
- **NH<sub>4</sub>-N** = 17 ppm
- **Cr<sub>6+</sub>-N** = 8 ppm
- **........................**

17. Distribution of the total plant cost:

   a. Preliminary and primary treatment: .......... % of total cost
   b. Secondary treatment: .......... % of total costs
   c. Tertiary treatment: .......... % of total costs

Note: Total cost is the cost shown in Item 7.

18. Average volume of the sludge produced per day:
   - Untreated: .......... m³/day, treated: .......... m³/day

Average percentage of water content of sludge:
   - Treated: .......... % moisture
   - Untreated: .......... % moisture

How is the treated sludge disposed?
   - ...............................................................
   - ...............................................................
   - ...............................................................
   - .............................................................
19. Whether or not the gas produced in sludge treatment is used to produce energy for use in the plant? 

Yes or No

If yes,

a. The percentage of the total energy required in the plant from the source, \( x = \) ........ %

b. Whether the energy cost quoted in (11) expresses this \((100 - x)\%\)?

Yes or No

If no, how the gas is used or disposed? .................................................. 

..................................................................................................................

.................................................................

20. Equipments used in the plant (see Question 7(b)):

(a) ........ % is imported (in terms of value)

(b) .......... % is locally manufactured (in terms of value)

21. Is there or will there be any provision for effluent reuse?

Yes or No

If yes, in what way? ................................................................. 

..................................................................................................................

.................................................................

If no, how is the effluent discharged?

[Diagram: sea \(\searrow\) with \(\uparrow\) without submarine outfall, length of outfall \(\searrow\) river \(\searrow\) other \(\searrow\) km (please specify)]

22. Briefly describe the methods used in monitoring wastewater discharging to this plant. (e.g. the number of times in a month taking wastewater samples from a factory, etc.)

..................................................................................................................

..................................................................................................................

..................................................................................................................
23. In your opinion, do you think that this plant is running successfully?

- Very ✓ Successful
- Fairly Successful
- Not Successful

24. What difficulties do you find in operating the treatment plant?

Financial problem: Yes or No
Economical problem: Yes or No
Social-cultural problem: Yes or No
Operational/technical problem: Yes or No
Environmental problem: Yes or No
Legislational problem: Yes or No
Administrational/organisational problem: Yes or No
Other problem: Yes or No

(please briefly describe)

25. Please elaborate on the problems found in (24) above:

........................................................................................................
........................................................................................................
........................................................................................................
........................................................................................................

(Thank you very much for your cooperation)

By the way, could you please supply me with a flow diagram of the plant and an introductory brochure/pamphlet of it, if any.
APPENDIX C.2.2 --- THAILAND

Name of Wastewater Plant: South Pattaya STP
Location: South Pattaya, Precinct (Pattaya)
Detail address: Phra Sam Nak Road, South Pattaya, Thailand

Tel: (038) 429175

Name of the person responsible: Thunya Srichar
Date of filling this form: Jan. 1987

1. Name of the Consulting Engineer designing this plant:
   Public Works Department, Pattaya, Thailand
   Address: City Hall, Tai 6, Pattaya, Thailand
   Tel: (038) 429175

2. Treatment methods used in this plant:
   a) Preliminary treatment: (e.g. screening, grit removal etc)
   b) Primary treatment: (e.g. sedimentation etc)
   c) Secondary treatment: Activated sludge (extended aeration),
      (e.g. trickling filter, oxidation ditch, etc)
   d) Tertiary treatment: Chlorination
      (e.g. sand filtration, microstrainer, grass plots etc)

3. Sludge treatment method(s): Sludge drying bed
   (e.g. aerobic/anaerobic digestion, thickening etc)

4. Sludge dewatering method(s): Sludge drying bed
   (e.g. drying beds, filter press, centrifuge, etc)

5. Existing total area of the plant: 0.2 Ha

6. Wastewaters from what industries?
   mainly: Municipal sewage
   others: 

300
Construction cost (excluding land cost): ₦ 27 millions
(based on the value of money in 1982.)

a. Civil works:
road works .................. %  
foundation engineering works .................. %  
buildings (excluding staff quarters) .......... %  
staff quarters .................. %  
others ......................... %  

Sub-total .................. %  

total 100%  

b. Equipment .................. %  

Capacity of the plant based on the capital cost in (7) above:

a) ........................ %  

population equivalent  

and  
d) ........................ %  

m³/day (average)  

in which  

........................ % is industrial wastewater  

........................ % is municipal wastewater  

Total 100%  

Ultimate capacity of the plant: ........................ %  

population equivalent  
in Year 19 ......, i.e. ........................ m³/day (average).  

Same as (8).  

Estimated ultimate total construction cost, including capital cost in (7):

$ ........................ (based on value of money in 19 ....)  

Ultimate Total area: ........................ Ha  

D. Cost that the users of the treatment facilities have to pay:

$ ........................ per m³ (average)  

a. The total income can cover:

(i) _____ - operation/maintenance cost of the plant  
(ii) _____ - construction cost of the plant  
(iii) _____ - both operation/maintenance and construction costs  
(iv) _____ - the total incomes is even more than what is required in (iii)  

b. If the answer of (a) above is (iv), whether or not it includes cost of sewers construction? [including] or [excluding]
11. Operation and maintenance costs (based on 1983 value of money):

- Chemical: $ ................. per month
- Energy: $ ................... per month
- Personnel: $ ................... per month
  (including staff, chemist & labourers etc.)
- Repair & unkeeping: $ ................. per month
- Others: (................ $ ................. per month
  ..................)

Total = ................ known

12. Number of persons associated with the operation on the plant:

- Number of executive staff: ................
- Number of staff in laboratory: ................
- Number of technical/operational: ................
- Number of supporting staff: ................
  (e.g. general clerk, accounts clerks, typist etc.)
- Number of labourers: ................

Total = ................

Others: (........................

please specify

13. Average degree of pollution of incoming wastewaters:

- BOD$_5$ = ................ mg/l
- S.S. = ................ mg/l
- COD = ................ mg/l
- pH = ................

Major chemicals: ................ ppm

14. Average degree of pollution of wastewater after primary treatment

- but before secondary treatment.

- BOD$_5$ = ................ mg/l
- S.S. = ................ mg/l
- COD = ................ mg/l
- pH = ................

Major chemicals: ................ ppm

The plant is not operating
15. Average effluent standard after secondary treatment but before tertiary treatment:

- BOD$_5$ = \(\ldots\) mg/l
- S.S. = \(\ldots\) mg/l
- COD = \(\ldots\) mg/l
- pH = \(\ldots\)
- Major chemicals: \(\ldots\) ppm
- \(\ldots\) ppm
- \(\ldots\) ppm

16. Average effluent standard when it is discharged out of the plant:

- BOD$_5$ = \(\ldots\) mg/l
- S.S. = \(\ldots\) mg/l
- COD = \(\ldots\) mg/l
- pH = \(\ldots\)
- Major chemicals: \(\ldots\) ppm
- \(\ldots\) ppm
- \(\ldots\) ppm

17. Distribution of the total plant cost: *Figures not available*

   a. Preliminary and primary treatment: \(\ldots\) % of total cost
   b. Secondary treatment: \(\ldots\) % of total costs
   c. Tertiary treatment: \(\ldots\) % of total costs

   Note: total cost is the cost shown in Item 7.

18. Average volume of the sludge produced per day:

   - untreated: \(\ldots\) m$^3$/day; treated: \(\ldots\) m$^3$/day

   Average percentage of water content of sludge:

   - (treated) \(\ldots\) % moisture
   - (untreated) \(\ldots\) % moisture

   How is the treated sludge disposed?

   \(\ldots\)
19. Whether or not the gas produced in sludge treatment is used to produce energy for use in the plant?

Yes  or  No

If yes,

a. The percentage of the total energy required in the plant from the source, \( x = \ldots \ldots \% \)

b. Whether the energy cost quoted in (11) expresses this \((100 - x)\%\) ?

Yes  or  No

If no, how the gas is used or disposed?

Sludge drying beds do not produce gas.

20. Equipments used in the plant [see Question 7(b)]:

(a) \ldots \ldots \% is imported (in terms of value)

(b) \ldots \ldots \% is locally manufactured (in terms of value)

21. Is there or will there be any provision for effluent reuse?

Yes  or  No

If yes, in what way?

If no, how is the effluent discharged?

To: submarine outfall, length of outfall \( \ldots \ldots \) km

To Khlong Pattaya and then to beach.

(please specify)

22. Briefly describe the methods used in monitoring wastewater discharging to this plant. (e.g. the number of times in a month taking wastewater samples from a factory, etc.)

No control
23. In your opinion, do you think that this plant is running successfully?

- **Very Successful**
- **Fairly Successful**
- **Not Successful**

24. What difficulties do you find in operating the treatment plant?

- Financial problem: **Yes** or **No**
- Economical problem: **Yes** or **No**
- Social-cultural problem: **Yes** or **No**
- Operational/technical problem: **Yes** or **No**
- Environmental problem: **Yes** or **No**
- Legislatonal problem: **Yes** or **No**
- Administrative/organisational problem: **Yes** or **No**
- Other problem: **Yes** or **No**

(please briefly describe)

25. Please elaborate on the problems found in (24) above:

- Operation and maintenance funds are not easily obtained.
- No way can be found to charge the users.

(Thank you very much for your cooperation)

By the way, could you please supply me with a flow diagram of the plant and an introductory brochure/pamphlet of it, if any.
APPENDIX C.2.3 --- TAIWAN

Name of Wastewater Plant: Min Shen STP (民生污水處理場)
Location: Min Shen Community, Precinct (Taipei)
Detail address: 1159, Min-Chen 1 Road, Taipei City, By the side of Keelung River
Tel: (02) 78-38-703
Name of the person responsible: Mr. F. S. Shiu
Date of filling this form: 1985

1. Name of the Consulting Engineer designing this plant:

Sewage Engineering Department, Public Health Bureau, Taipei
Address: 41, Sec. 3, Xinyi Rd., Taipei City.
Tel: 378-2848

2. Treatment methods used in this plant:

a) Preliminary treatment: Screening, grit removal etc
b) Primary treatment: Sedimentation tank

(c) Secondary treatment: Activated sludge + Sedimentation

(d) Tertiary treatment: Rapid Sand Filtration

(e.g. aerobic/anaerobic digestion, trickling filter, oxidation ditch, etc)

3. Sludge treatment method(s): Aerobic Digestion, Thickening, Mechanical

4. Sludge dewatering method(s): Centrifuge

(e.g. drying beds, filter press, centrifuge, etc)

5. Existing total area of the plant: 0.76 Ha

6. Wastewaters from what industries?

mainly: Municipal Wastewater

others:
Construction cost (excluding land cost): $ N.T.$ 10,000,000 (approx.)
(based on the value of money in 19...)

(a) Civil works:
- road works ............ %
- foundation engineering works ............ %
- buildings (excluding staff quarters) ........ %
- staff quarters ........ %
- others ............ %

Sub-total ...... %

Total 100%

(b) Equipment ............ %

Capacity of the plant based on the capital cost in (7) above:

a) ......................... population equivalent

and

d) ......................... m³/day (average)

in which

% is industrial wastewater

% is municipal wastewater

Total 100%

Ultimate capacity of the plant: ......................... population equivalent in Year 19......, i.e. .................. m³/day (average).

Estimated ultimate total construction cost, including capital cost in (7):

$ .................. (based on value of money in 19......)

Ultimate Total area: ......................... Ha

Cost that the users of the treatment facilities have to pay:

$ .................. per m³ (average)

a. The total income can cover:

(i) - operation/maintenance cost of the plant

(ii) - construction cost of the plant

(iii) - both operation/maintenance and construction costs

(iv) - the total incomes is even more than what is required in (iii)

b. If the answer of (a) above is (iv), whether or not it includes cost of sewers construction? including or excluding
11. Operation and maintenance costs (based on 1995 value of money):

Chemical: $........................... per month
Energy: $........................... per month
Personnel: $........................... per month
  (including staff, chemist & labourers etc.)
Repair & unkeeping: $........................... per month
Others: $........................... per month

please specify

12. Number of persons associated with the operation on the plant:

Number of executive staff: ........................
Number of staff in laboratory: ........................
Number of technical/operational: 9 (3 x 8 h)
Number of supporting staff: 5
  (e.g. general clerk, accounts clerks, typist etc)
Number of labourers: ........................
Others: (...........................): ........................

please specify

13. Average degree of pollution of incoming wastewaters:

BOD₅ = .......................... mg/l
S.S. = .......................... mg/l
COD = .......................... mg/l
pH = ..........................

Major chemicals: .......................... ppm
  .......................... ppm
  .......................... ppm

14. Average degree of pollution of wastewater after primary treatment but before secondary treatment:

BOD₅ = .......................... mg/l
S.S. = .......................... mg/l
COD = .......................... mg/l
pH = ..........................

Major chemicals: .......................... ppm
  .......................... ppm
  .......................... ppm

Total per year excluding salaries: NTS 10,000,000

Please specify
15. Average effluent standard after secondary treatment but before tertiary treatment:

- BOD$_5$ = 10 to 15 (KRC) mg/l
- S.S. = 30 (KRC effluent) mg/l
- COD = .......................... mg/l
- pH = ............................

**Major chemicals:**
- (................. ppm)
- (................. ppm)
- (................. ppm)

16. Average effluent standard when it is discharged out of the plant:

- BOD$_5$ = .......................... mg/l
- S.S. = .......................... mg/l
- COD = .......................... mg/l
- pH = ............................

**Major chemicals:**
- (................. ppm)
- (................. ppm)
- (................. ppm)

17. Distribution of the total plant cost:

- a. Preliminary and primary treatment: ............ % of total cost
- b. Secondary treatment: ............ % of total costs
- c. Tertiary treatment: ............ % of total costs

Note: total cost is the cost shown in Item 7.

18. Average volume of the sludge produced per day:

- Untreated: ............. m$^3$/day, treated ............. m$^3$/day

Average percentage of water content of sludge:

- (treated) 75% moisture
- (untreated) 97% moisture

How is the treated sludge disposed?

- by trucks to sanitary landfill
19. Whether or not the gas produced in sludge treatment is used to produce energy for use in the plant?

Yes or No

If yes,

a. The percentage of the total energy required in the plant from the source, \(x\) = ........ %

b. Whether the energy cost quoted in (11) expresses this \((100 - x)\) % ?

Yes or No

If no, how the gas is used or disposed? .................................................................

.................................................................

.................................................................

20. Equipments used in the plant [see Question 7(b)]:

(a) ........ % is imported (in terms of value)

(b) ...../0. % is locally manufactured (in terms of value)

21. Is there or will there be any provision for effluent reuse?

Yes or No

If yes, in what way? Effluent from the primary treatment (rapid sand filtration) is used in a scenic fountain in the San Miw Park .................................................................

If no, how is the effluent discharged?

To:

- sea with
- submarine outfall, length of outfall
- river without ............ km
- other

(please specify)

22. Briefly describe the methods used in monitoring wastewater discharging to this plant. (e.g. the number of times in a month taking wastewater samples from a factory, etc.)

.................................................................

.................................................................

.................................................................
23. In your opinion, do you think that this plant is running successfully?

- Very Successful
- Fairly Successful
- Not Successful

24. What difficulties do you find in operating the treatment plant?

- Financial problem: Yes or No
- Economical problem: Yes or No
- Social-cultural problem: Yes or No
- Operational/technical problem: Yes or No
- Environmental problem: Yes or No
- Legislative problem: Yes or No
- Administrative/organisational problem: Yes or No
- Other problem: Yes or No

(please briefly describe)

25. Please elaborate on the problems found in (24) above:

- Insufficient primary treatment design should have 2
- Primary sedimentation tanks instead of one
- Insufficient design in operation tank (for A.S.)
- Legislative problem is directly related to industrial waste treatment plant but not in this plant.

(Thank you very much for your cooperation)

By the way, could you please supply me with a flow diagram of the plant and an introductory brochure/pamphlet of it, if any.
Construction cost (excluding land cost) HK$ 36.5 million (Stage I only)
(based on the value of money in 1980.)
stage 2: HK$ 28.6 million (1984 money)

a. Civil works:
road works ............... %
foundation engineering works .............. %
bildings (excluding staff quarters) ....... %
staff quarters ............. %
others ......................... %

b. Equipment .............. 42 %

Capacity of the plant based on the capital cost in (7) above:
a) stage 1: 240,000 population equivalent stage 1+2: 505,000 p.e.
and
d) stage 1: 103,600 m³/day (average) stage 1+2: 206,000 m³/day
in which
40% is industrial wastewater
60% is municipal wastewater

Ultimate capacity of the plant: 670,000 population equivalent
in Year 1999, i.e. 275,000 m³/day (average).

Estimated ultimate total construction cost including capital cost in (7):
$ ....................... (based on value of money in 1984)

Ultimate Total area: ........................... Ha

Cost that the users of the treatment facility have to pay:
$ ................ per m³ (average)

a. The total income can cover:
(i) - operation/maintenance cost of the plant
(ii) - construction cost of the plant
(iii) - both operation/maintenance and construction costs
(iv) - the total income even more than what is required in (iii)

b. If the answer of (a) above is (iv) whether or not it includes
cost of sewers construction? [include] or [excluding]
Construction cost (excluding land cost) HK$ 365 million (Stage 1 only)
(based on the value of money in 1980)
Stage 2: HK$ 280 million (1984 money)

a. Civil works:
road works .................... %
foundation engineering works ........... %
built hings (excluding staff quarters) ........ %
staff quarters ............ %
others ......................... %

Sub-total 58 %
total 100 %

Equipment 42 %

b. Equipment ............... %

Capacity of the plant based on the capital cost in (7) above:

a) Stage 1: 240,000 population equivalent Stage 1+2: 505,000 p.e.
and

b) Stage 1: 103,000 m³/day (average) Stage 1+2: 206,000 m³/day
in which
40 % is industrial wastewater
60 % is municipal wastewater

Total 100 %

Ultimate capacity of the plant: 670,000 population equivalent
in Year 1979, i.e. 275,000 m³/day (average).

Estimated ultimate total construction cost, including capital cost in (7):
$ ............... (based on value of money in 1980)

Ultimate Total area: ................. Ha

Cost that the users of the treatment facilities have to pay:
$ ............... per m³ (average)

a. The total income can cover:
(i) - operation/maintenance cost of the plant
(ii) - construction cost of the plant
(iii) - both operation/maintenance and construction costs
(iv) - the total incomes is even more than what is required in (iii)

b. If the answer of (a) above is (iv), whether or not it includes
   cost of sewers construction? including or excluding
11. Operation and maintenance costs (based on 1984 value of money):

- **Chemical**: $51,967.00 per month
- **Energy**: $31,541.00 per month
- **Personnel**: $39,715.00 per month
  (including staff, chemist & labourers etc.)
- **Repair & unkeeping**: $14,629.45 per month
- **Others**: ($................. $................. per month
  .........................)

Total = HK$ 930,839 per month
(Stage 1 capacity only)

12. Number of persons associated with the operation on the plant:

- **Number of executive staff**: 11
- **Number of staff in laboratory**: 5
- **Number of technical/operational**: 61
- **Number of supporting staff**: 4
  (e.g. general clerk, accounts clerks, typist etc)
- **Number of labourers**: 17
- **Others**: ($................. $................. per month
  .........................)

Total 96
(Stage 1 capacity only)

13. Average degree of pollution of incoming wastewaters:

- **BOD$_5$**: 2500 mg/l
- **S.S.**: 220 mg/l
- **COD**: 710 mg/l
- **pH**: 11.0

Major chemicals:
- $\text{NH}_4^- - N$ (......... 30 mg/l ..... ppm)
- $\text{Org} - N$ (......... 19 mg/l ..... ppm)
- Chloride (......... 340 mg/l ..... ppm)

14. Average degree of pollution of wastewater after primary treatment
but before secondary treatment.

- **BOD$_5$**: 160 mg/l
- **S.S.**: 22 mg/l
- **COD**: 7.0 mg/l

Major chemicals:
- $\text{NH}_4^- - N$ (......... 29 mg/l ..... ppm)
- $\text{Org} - N$ (......... 6.4 mg/l ..... ppm)
- Chloride (......... 310 mg/l ..... ppm)
15. Average effluent standard after secondary treatment but before tertiary treatment:

- BOD$_5$ = 10 to 15 mg/l
- S.S. = 15 to 25 mg/l
- COD = 6.8 mg/l
- pH = 5.5
- Major chemicals:
  - NH$_4^+$ - N (0.3 mg/l, ppm)
  - NO$_3^-$ - N (0.7 mg/l, ppm)
  - Chloride (320 mg/l, ppm)

16. Average effluent standard when it is discharged out of the plant:

- BOD$_5$ = 10 to 15 mg/l
- S.S. = 15 to 25 mg/l
- COD = 6.8 mg/l
- pH = 5.5
- Major chemicals:
  - NH$_4^+$ - N (1.5 mg/l, ppm)
  - NO$_3^-$ - N (0.7 mg/l, ppm)
  - Chloride (320 mg/l, ppm)

17. Distribution of the total plant cost:

a. Preliminary and primary treatment: .......... % of total cost
b. Secondary treatment: ........... % of total costs
c. Tertiary treatment: ........... % of total costs

Note: total cost is the cost shown in Item 7.

18. Average volume of the sludge produced per day:

- Untreated: Before digestion: 92 m$^3$/day, treated: 200 m$^3$/day
- After digestion: 365

Average percentage of water content of sludge: ........ 80 % moisture

(treated)

...95 % moisture

(untreated)

How is the treated sludge disposed?

Delivered by trucks to Toshen Wan, Taipoo, N.T.
19. Whether or not the gas produced in sludge treatment is used to produce energy for use in the plant?

Yes / No

If yes,

a. The percentage of the total energy required in the plant from the source, \( x = \ldots \% \)

b. Whether the energy cost quoted in (11) expresses this \((100 - x)\%\)?

Yes / No

If no, how the gas is used or disposed? ........................................

.................................................................

.................................................................

20. Equipments used in the plant [see Question 7(b)]:

(a) \( \ldots 100 \% \) is imported (in terms of value)

(b) \( \ldots \ldots \) % is locally manufactured (in terms of value)

21. Is there or will there be any provision for effluent reuse?

Yes / No

If yes, in what way? ...................................................

.................................................................

.................................................................

If no, how is the effluent discharged?

- With submarine outfall, length of outfall \( \ldots \ldots \ldots \) km

- Without

To: river other

(please specify)

22. Briefly describe the methods used in monitoring wastewater discharging to this plant. (e.g. the number of times in a month taking wastewater samples from a factory, etc.)

..........................................

..........................................

..........................................

..........................................

No control at source currently
23. In your opinion, do you think that this plant is running successfully?

Very Successful
Fairly Successful
Not Successful

24. What difficulties do you find in operating the treatment plant?

- Financial problem: Yes or No
- Economical problem: Yes or No
- Social-cultural problem: Yes or No
- Operational/technical problem: Yes or No
- Environmental problem: Yes or No
- Legislative problem: Yes or No
- Administrative/organisational problem: Yes or No
- Other problem: Yes or No

(please briefly describe)

25. Please elaborate on the problems found in (24) above:

- Pump blocked by grit

(Thank you very much for your cooperation)

By the way, could you please supply me with a flow diagram of the plant and an introductory brochure/pamphlet of it, if any.
Interviewing Questionnaire

Name of Wastewater Treatment Plant: Puchong S.I.P.

Detail address: Puchong, K.L., Malaysia

Name of responsible person: Haji K. Asbirnachan
Rank: Plant Manager
Name: Mr. Ahmad Thani


Is it a local or a foreign firm? Foreign/Local

2. Treatment methods used in this plant
   a. Preliminary treatment: Screening
   b. Primary treatment: Two stabilization ponds in series
   c. Secondary treatment: 
   d. Tertiary treatment: 
   e. Sludge treatment: 
   f. Vol. of dry sludge produced: m³ per day
   g. Sludge disposal:

3. Site area of the plant
   a. Present: A Ha
   b. Ultimate: A Ha

4. Nature of site
   a. Topography: Flat land, very little earth work is involved in construction.
   b. Proximity to sludge disposal facility: No such facility is required

5. Strength of Influent
   a. BOD₅: 108 mg/l
   b. S.S.: 83 mg/l
   c. pH: 7.9

   Major chemicals
   NH₄-N: (24.3 ppm)
   NO₃-N: (41.1 ppm)
   ...

6. Effluent quality
   a. BOD₅: 79 mg/l
   b. S.S.: 23 mg/l
   c. pH: 7.9

   Major chemicals
   NH₄-N: (12.4 ppm)
   NO₃-N: (5.1 ppm)
   ...

Is the effluent quality up to the required standard? 3/4

7. How frequent and by what method (grab or composite etc) were the samples of (5) & (6) above collected? Grab samples taken every 36 hours written.

In the morning.

APPENDIX C.3.1 —— MALAYSIA
8. Capacity of treatment of the plant: \( \text{population equivalent (present)} \) \( \text{population equivalent (ultimate)} \)

9. Name and address of the Contractor who constructed this plant: ……
   Tel: 02-794 920
   Is it a local or a foreign contractor? ……

10. Cost of construction (excluding land cost)
    a. In local currency
       Civil works: \( \text{M} 2,780, \text{c} \text{t} \text{c} \text{t} \)
       M & E works: \( \text{M} 9,150 \)
    b. In foreign currency
       Civil works: \( \text{US} \$14,780 \)
       M & E works: \( \text{US} \$45,780 \)

11. What is your opinion on the local skill for construction? ……

12. Cost of operation and maintenance
    a. In local currency
    b. In foreign currency

13. What is your opinion on the local skill for operation and maintenance?
    a. Professional level: ……
    b. Technical level: ……

14. Are materials and components readily available locally for operation and maintenance? ……

15. Name(s) of the local administration which support(s) the treatment plants' operation: ……
   City Hall (Festival Authority), etc.

16. Do you consider the set-ups in (15) above are appropriate and efficient? ……

17. Power source for operating the plant
    a. Capacity of power req'd: ……
    b. Is the power supply reliable? ……

18. Training of local people
    a. How is the situation of training professionals in the country? ……

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b. How is the situation of training technicians in the country? 

19. Social cultural factors
a. Is there any religious factors that affect the hygiene practices and technology choice in the country? 

b. Are the people willing and enthusiastic to improve the existing hygienic facilities? 

20. Social ethics
a. What is the general attitude of social responsibility of the people? 

b. How are the professionals committed to their jobs? 

c. How are the technical staff and supporting staff committed to their jobs? 

21. Climate
a. Average monthly maximum temperature: 32 °C
   Month(s) having such temperature: June, July, November
   Average humidity: 74.4% 

b. Average monthly minimum temperature: 21.5 °C
   Month(s) having such temperature: January, April
   Average humidity: 67.2% 

c. Length of dry season: 2 months, 
   from June to July 

d. Intensity and duration of sunshine in a year: Average daily sunshine hours: 6.5 hours/day

22. Endemic local diseases
a. Malaria, filariasis, yellow fever: Under control 
b. Human round worm and hook worm, fish-borne parasites: Under control 
c. Infectious hepatitis, diarrhoeal diseases: Removed 
d. Cholera, typhoid, bilharzia: Under control
8. Capacity of treatment of the plant: 5,000 population equivalent (present)
   5,050 population equivalent (ultimate)
9. Name and address of the Contractor who constructed this plant: ....
   Name cannot be traced.
   Is it a local or a foreign contractor? .... Local.
10. Cost of construction (excluding land cost)
    a. In local currency
        Civil works: £ 2.7 million
        M & E works: £ ....
    b. In foreign currency
        Civil works: £ ....
        M & E works: £ ....
11. What is your opinion on the local skill for construction?
    Local skill can be good. Quality of work largely depends on...,
    the contractor's expertise, and on the construction team.
12. Cost of operation and maintenance
    a. In local currency
        The plant is not in operation.
    b. In foreign currency
13. What is your opinion on the local skill for operation and maintenance?
    a. Professional level: Go, general but too good. Some 2 3
       are good, but many are inferior. But not opposed to the import of
       maintenance.
       Suggest training. Need support to look at the manual or operation guide.
14. Are materials and components readily available locally for
    operation and maintenance? .... Yes, except for spare parts of sophisticated
    equipment.
15. Name(s) of the local administration which support(s) the treatment
    plants' operation:
        Public Health Division, City Hall, Piano...
16. Do you consider the set-ups in (15) above are appropriate and
    efficient? ...
17. Power source for operating the plant
    a. Capacity of power req'd: ....
       It is readily available? .... Yes.
    b. Is the power supply reliable? .... Yes.
18. Training of local people
    a. How is the situation of training professionals in the country?
       Usually good, academic training is provided, but practical
       experience is inadequate in design or operation, etc.
b. How is the situation of training technicians in the country?

Social cultural factors

a. Is there any religious factors that affect the hygiene practices and technology choice in the country?

b. Are the people willing and enthusiastic to improve the existing hygienic facilities?

Social ethics

a. What is the general attitude of social responsibility of the people?

b. How are the professionals committed to their jobs?

c. How are the technical staff and supporting staff committed to their jobs?

Climate

a. Average monthly maximum temperature: 25 °C

b. Average monthly minimum temperature: 25 °C

c. Length of dry season: 6 months, from November to April

d. Intensity and duration of sunshine in a year: quite high

Endemic local diseases

a. Malaria, filariasis, yellow fever: under control

b. Human round worm and hook worm, fish-borne parasites: moderately serious

c. Infectious hepatitis, diarrhoeal diseases: widely spread, dysentry also.

d. Cholera, typhoid, bilharzia: under control
Interviewing Questionnaire

Name of Wastewater Treatment Plant: Min. Shou STP

Detail address: 1187 Min. Clg. East Road, Taipei

Name of responsible person: Mr. F. S. Shi, Rank: Engineer

1. Name and address of the Consulting Engineer designing this plant:...
   Is it a local or a foreign firm? Local/Government

2. Treatment methods used in this plant:
   a. Preliminary treatment: Bar screen, grit chamber, ... Investigate
   b. Primary treatment: Concerned with... (i.e., sand filtration bed): 500 m²
   c. Secondary treatment: Aerobic digestion, ... Records kept
   d. Tertiary treatment: Anaerobic digestion, ... Records kept
   e. Sludge treatment: Aerobic digestion, Records kept
   f. Vol. of dry sludge produced: 4.1 m³ per day
   g. Sludge disposal:

3. Site area of the plant:
   a. Present: 0.76 Ha
   b. Ultimate: 5.76 Ha

4. Nature of site:
   a. Topography: Flat, near Keelung River and the effluent is discharged to...
   b. Proximity to sludge disposal facility: 1.5 km from plant, at location:

5. Strength of Influent:
   a. BOD₅: 200 mg/l
   b. S.S.: 70 mg/l
   c. pH: 7.0

   Major chemicals:
   MgO: ppm
   CaO: ppm
   Na₂O: ppm
   K₂O: ppm

6. Effluent quality (RFCC c.d.):
   a. BOD₅: 10 to 15 mg/l before tertiary treatment,
   b. S.S.: 10 mg/l after tertiary treatment
   c. pH: 7

   Major chemicals:
   MgO: ppm
   CaO: ppm
   Na₂O: ppm
   K₂O: ppm

   Is the effluent quality up to the required standard? Yes

7. How frequent and by what method (grab or composite) were the samples of (5) & (6) above collected? Yes, monthly, at 9 points.
   (Composite samples were taken at various points... for the first year of operation but are not used now.)
8. Capacity of treatment of the plant: 15,500 m³/day
   - Activated sludge: 13,000 m³/day (present)
   - RC: 2,500 m³/day (ultimate)
   - Population-equivalent

9. Name and address of the Contractor who constructed this plant:
   - Activated sludge: 13,000 m³/day
   - RC: K & E
   - Is it a local or a foreign contractor? Yes

10. Cost of construction (excluding land cost)
   a. In local currency:
      - Civil works: 1,000,000,000
      - M & E works:...
   b. In foreign currency:
      - Civil works: ...
      - M & E works: ...

11. What is your opinion on the local skill for construction?
    - Very good
    - ...

12. Cost of operation and maintenance
   a. In local currency:
      - M & E works:...
   b. In foreign currency:
      - M & E works: ...

13. What is your opinion on the local skill for operation and maintenance?
   a. Professional level: Good
   b. Technical level: Fairly good, sometimes have minimal problems

14. Are materials and components readily available locally for operation and maintenance?
    - Yes

15. Name(s) of the local administration which support(s) the treatment plants' operation:
    - ...

16. Do you consider the set-ups in (15) above are appropriate and efficient?
    - Yes

17. Power source for operating the plant
   a. Capacity of power req'd: 100 kW (approx. for RC & tertiary treatment)
   b. Is the power supply reliable? Yes

18. Training of local people
   a. How is the situation of training professionals in the country?
      - Adequate
b. How is the situation of training technicians in the country? [.....]

c. How is the situation of training supporting professions in the country? [.....]

19. Social cultural factors
a. Is there any religious factors that affect the hygiene practices and technology choice in the country? [.....]

b. Are the people willing and enthusiastic to improve the existing hygienic facilities? [.....]

c. How is the situation of training supporting professions in the country? [.....]

20. Social ethics
a. What is the general attitude of social responsibility of the people? [.....]

b. How are the professionals committed to their jobs? [.....]

c. How are the technical staff and supporting staff committed to their jobs? [.....]

21. Climate
a. Average monthly maximum temperature: [27 °C]
   Month(s) having such temperature: [June, August]
   Average humidity: [80%]

b. Average monthly minimum temperature: [15 °C]
   Month(s) having such temperature: [January, February]
   Average humidity: [50%]

c. Length of dry season: [6 months]
   from [May] to [October]

d. Intensity and duration of sunshine in a year: [May to October]

22. Endemic local diseases
a. Malaria, filariasis, yellow fever: [M]

b. Human round worm and hook worm, fish-borne parasites: [unknown]

c. Infectious hepatitis, diarrheal diseases: [unknown]

d. Cholera, typhoid, bilharzia: [unknown]
APPENDIX C.3.4 --- HONG KONG

Interviewing Questionnaire

Name of Wastewater Treatment Plant: Shatin STP

Detail address: Mei Sha Road, Shatin, N.T., Hong Kong
Tel: 2653 3275

Name of responsible person: Mr. David K.C. Wu, Rank: Plant Manager

1. Name and address of the Consulting Engineer designing this plant:
   Watanabe, Harriyashi, 86, Dundas Street, Kowloon, Hong Kong
   Is it a local or a foreign firm? Foreign (U.K.)

2. Treatment methods used in this plant
   a. Preliminary treatment: Screening, grit removal
   b. Primary treatment: Primary sedimentation tanks
   c. Secondary treatment: Activated sludge
   d. Tertiary treatment: Biological treatment, Mechanical screening
   e. Sludge treatment: Incineration, Chemical dewatering
   f. Vol. of dry sludge produced: 299 m³ per day
   g. Sludge disposal: Delivered to trash incinerating, land fill

3. Site area of the plant
   a. Present: 16 Ha
   b. Ultimate: 16 Ha

4. Nature of site
   a. Topography: Reinforced, flat
   b. Proximity to sludge disposal facility: 12 km from the plant

5. Strength of Influent
   a. BOD₅: 250 mg/l
   b. S.S.: 7.5 mg/l
   c. pH: 7.1

   Major chemicals
   Ammonia nitrogen: (30 ppm)
   Organic nitrogen: (10 ppm)
   Chloride: (50 ppm)

6. Effluent quality
   a. BOD₅: 10 ~ 15 mg/l
   b. S.S.: 10 ~ 15 mg/l
   c. pH: 6.8

   Major chemicals
   Ammonia nitrogen: (1.5 ppm)
   Organic nitrogen: (0.7 ppm)
   Chloride: (2.8 ppm)

   Is the effluent quality up to the required standard? Yes

7. How frequent and by what method (grab or composite etc) were the samples of (5) & (6) above collected? Composite sample, twice a week.
8. Capacity of treatment of the plant: 50,000. population equivalent (present)
   60,000. population equivalent (ultimate)

9. Name and address of the Contractor who constructed this plant: Aoki Construction Co. Ltd.
   Is it a local or a foreign contractor? Foreign (Japan)

10. Cost of construction (excluding land cost)
    a. In local currency
       Civil works: HK$ 4.00 million (approx.)
       M & E works: ____________________________
    b. In foreign currency
       Civil works: HK$ 4.00 million (approx.)
       M & E works: ____________________________

11. What is your opinion on the local skill for construction?
    Very good

12. Cost of operation and maintenance
    a. In local currency
       HK$ 9,100. per month
    b. In foreign currency

13. What is your opinion on the local skill for operation and maintenance?
    a. Professional level: Very good
    b. Technical level: Very good

14. Are materials and components readily available locally for operation and maintenance? Yes

15. Name(s) of the local administration which support(s) the treatment plants' operation:
    Electrical & Mechanical Services Department

16. Do you consider the set-ups in (15) above are appropriate and efficient?
    Yes

17. Power source for operating the plant
    a. Capacity of power req'd: ____________________________
    b. Is it readily available? Yes
    b. Is the power supply reliable? Yes

18. Training of local people
    a. How is the situation of training professionals in the country?
       Very good
19. Social cultural factors
   a. Is there any religious factors that affect the hygiene practices and technology choice in the country? 
      [Yes/No]

   b. Are the people willing and enthusiastic to improve the existing hygienic facilities? 
      [Yes/No]

20. Social ethics
   a. What is the general attitude of social responsibility of the people? 
      [Very good] [Fairly good] [Para-social] [Industrial] [Illgal]

   b. How are the professionals committed to their jobs? 
      [Very good] [Fairly good] [Para-social] [Industrial] [Illgal]

   c. How are the technical staff and supporting staff committed to their jobs? 
      [Very good] [Fairly good] [Para-social] [Industrial] [Illgal]

21. Climate
   a. Average monthly maximum temperature: \(28\) °C
      Month(s) having such temperature: July, Sept
      Average humidity: 90%.

   b. Average monthly minimum temperature: 15 °C
      Month(s) having such temperature: Dec, Feb
      Average humidity: 40%.

   c. Length of dry season: 4 months, from Nov to Feb.

   d. Intensity and duration of sunshine in a year: 8 months

22. Endemic local diseases
   a. Malaria, filariasis, yellow fever: \(\text{Mid}\)
   b. Human round worm and hook worm, fish-borne parasites: \(\text{Occasional but under control}\)
   c. Infectious hepatitis, diarrhoeal diseases: \(\text{Occasional}\)
   d. Cholera, typhoid, bilharzia: \(\text{Mid}\)