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SPRAY IRRIGATION OF TREATED MUNICIPAL WASTEWATER

ECONOMIC AND TECHNICAL REVIEW REPORT
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SPRAY IRRIGATION OF TREATED MUNICIPAL WASTEWATER

Papers Presented

April 9, 1975 at Harrison Hot Springs, B. C.

and

October 30, 1975 at Kelowna, B. C.

These papers were edited for publication by
Dr. W. K. Oldham, Civil Engineering Department,
University of British Columbia, under the
direction of F. G. Claggett

TABLE OF CONTENTS

CASE HISTORY - CITY OF VERNON - DISPOSAL OF EFFLUENT BY SPRAY IRRIGATION

J.P. Anderson, Branch Manager, Stanley Associates Eng.Ltd.,
Kamloops, B.C.

APPENDIX I - OTHER METHODS OF LAND APPLICATION OF WASTEWATER

G. Neurohr, Environmental Protection Service,
Department of Fisheries and the Environment,
Ottawa, Ontario.

APPENDIX II - SPRAY IRRIGATION IN CANADA - A PRELIMINARY REVIEW

G. Neurohr, Environmental Protection Service,
Department of Fisheries and the Environment,
Ottawa, Ontario.

FORWORD

The Environmental Protection Service, Department of Fisheries and the Environment, and the B. C. Water and Waste Association presented a seminar at Harrison Hot Springs, B. C. in April 1975 on spray irrigation of treated wastewater effluents. As a result of the interest generated by this seminar, the Environmental Protection Service and the Pollution Control Branch, B. C. Water Resources Service, co-sponsored a seminar on October 29-31, 1975 in Kelowna, B. C. on alternatives for nutrient control. This volume represents a collection of papers from these seminars, and have been edited to fit the format of a single publication.

These papers were concerned with protection of public health, soil and groundwater, with design and economics and included several case histories. While they were not intended to be an exhaustive review of the subject, the systems deemed to be the most suitable for British Columbia conditions have been dealt with in considerable depth. For example, most of the papers dealt with spray irrigation of biologically-treated effluent. The use of effluent treated to lesser degrees, and alternate systems of land application are mentioned only briefly.

Opinions expressed by the authors, and practices or equipment mentioned in the papers do not necessarily represent endorsement by the sponsoring agencies, and are presented in the hope that they help fill the needs of those contemplating the use of such systems.

HEALTH EFFECTS OF SPRAY IRRIGATION

OF SEWAGE EFFLUENT

by:

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Occupational Health Program

B.C. Dept. of Health Services & Hospital Insurance

HEALTH EFFECTS OF SPRAY IRRIGATION OF SEWAGE EFFLUENT

Spray irrigation of sewage effluent is without question a problem many of us will face increasingly in our professional responsibilities. There have recently been many articles in Okanagan Valley newspapers relating to the serious consideration of utilizing effluent irrigation as a practical and feasible method of sewage disposal. Reference was also made to the lack of specific directions by monitoring and enforcing agencies, and I believe therein lies one of the problems at this time; that is, there is a lack of stated government policy. I have been a member of a provincial committee regarding this subject, which has been chaired by Mr. Dave Parsons, who is the author of another paper at this seminar. This committee has tried, I hope successfully, to put forth a stated policy for this province.

Is our concern justified? I think the first assumption has to be that there really are health concerns associated with spray irrigation of sewage. The degree of risk is, of course, most difficult to quantify. However, the risk the public seems prepared to accept is quite small, in spite of the fact that many do not use seat belts, many smoke and drink to excess, and most are obese. Those personal choices of health abuse somehow seem to be viewed with much less alarm than the infinitely smaller risk associated with spray irrigation of sewage.

An excellent reference article on the agricultural use of sewage is: "The Use of Sewage for Irrigation -- a Literature Review," State of California, Department of Public Health, Bureau of Sanitary Engineering, 1971.

With your permission, Mr. Chairman, I would like to refer to a few documented outbreaks of sewage irrigation-related diseases:

1. Massachusetts - 1899 - 63 inmates suffered typhoid fever from eating celery fertilized with sludge.
2. London - 1903 - 110 cases of typhoid from eating watercress fertilized with sewage.

3. Philadelphia - 1913 - 18 cases of typhoid from contaminated watercress.
4. New Jersey - 1955 - Salmonellosis from watermelon, celery, lettuce and fruit.

I would like to assure you then that sewage does contain a variety of pathogenic organisms and that it is possible to transmit these via spray irrigation to feed and thence to human host.

With reference to the question of spray drift and the possibility of droplet infection - certainly this is a possibility. Investigators in Germany have shown that with spray diameters of 15 to 27 meters and head pressures of 45 - 60 pounds per square inch, downwind travel varied from 90 to 160 meters when wind speeds were between 3 and 7 miles per hour. They concluded that the wind transport distance was independent of the type of sprinkler and spray droplet diameter. They further concluded that mist could be carried up to 1,000 meters if a five meter per second wind (11 miles per hour) were blowing. Other investigators, Brengmann and Trooldenier, showed that coliform travel was influenced by wind velocity and relative humidity. Conversely, investigations in California in 1957 showed, with the use of impinger air samplers, rather than agar plates, coliforms would become airborne only in moisture droplets, and that little if any health hazard existed beyond the mist zone. These authors also felt that the maximum downwind mist zone was about three times the sprinkler radius. For example, a 30 foot radius spray zone should have a downwind buffer distance of not less than 100 feet, in the presence of a five to ten mile per hour wind. To my knowledge, and based on the above mentioned studies, it would seem that the drift problem is related most importantly to prevailing winds, that a buffer zone is important to decrease potential harmful health effects, and that in no case should the mist zone be allowed to extend beyond the irrigated property. It has also been suggested that hedges and trees will decrease the mist drift, and should therefore be considered as part of a good buffer system.

Another possible concern is that effluent irrigation will contaminate water supplies. There can be no debate about the possible hazard of contaminating surface supply, and no responsible public official would entertain the prospect of spray irrigation when potable surface supplies would be contaminated. The possibility of contaminating groundwater is far less likely, though it is possible. It is usually accepted that coliform organisms are incapable of penetrating soil beyond 2 to 3 feet. This broad generalization is, of course, related to soil porosity, since percolation into porous topsoil is much different than percolation into clay.

I believe it is safe to say that coliform bacteria would not contaminate a groundwater supply provided that the basic preventive design factors of depth and distance from the source of sewage irrigation are incorporated into the scheme.

Is there a hazard of direct personal contact such as might be possible in parks, golf courses, and municipal grounds? I doubt that one could ever justify the public health risk of spray irrigating such land. We have all seen the golfer kiss his ball good luck or good-bye, or the young infant crawling around a green, lush lawn. Equally possible, of course, is the golfer who unknowingly drinks from a non-potable sprinkler. I am not an alarmist, but I just do not believe we should expose the public to this degree of risk, nor I suspect would the public tolerate it.

While sprinkler irrigation is the most feasible method of application, ridge and furrow application is also used. This decreases the problem of spray drift which is a significant advantage. The possibility, however, of pollution of groundwaters might be greater since the furrow is similar to a natural water course draining to a lower level ditch. With good design and good operation I think that problem could be easily controlled, but it is a distinct possibility.

The problem of great importance is the possibility of contamination of crops raised for human consumption. It is a matter of record that coliform indicator organisms can be recovered from such crops and that the organisms are very difficult to clean from vegetables. It is apparently quite difficult to clean these bacteria by ordinary washing, and further it appears that the organisms in some cases penetrate both broken and unbroken surfaces. Lettuce, watercress, celery and tomatoes seem to be particularly difficult to wash, and one author has stated that soaking for 5 minutes at 60 degrees C. was the only sure way to clean the above mentioned items. One should not lose sight of the fact that we physicians really do not know the size of an infective dose of any organism and the very fact that a bacterium or worm egg is identified, does not necessarily mean that it is an infective dose. Even less factual information is known about virus transmission and reinfection, but we do know that about 100 types of pathogenic viruses can often be found in sewage. Worm eggs (ascaris lumbricoides) are particularly difficult to remove from vegetables and will survive in soil up to three years. While helminthic infections have not been a public health problem in Canada (i.e. not much risk in sewage), many disease pictures are changing. For that reason helminthic infection must be considered as a risk. The prevailing community level of infection is a factor which also influences the degree of risk.

Currently in this country I doubt that one could justifiably take the risk of irrigating edible crops with sewage that has undergone conventional treatment. While the disease relationship is a remote one, it is nevertheless present, and is an unwarranted and probably unacceptable risk.

If we prohibit the irrigation of crops for human consumption then what of the use of effluent irrigation on animal crops? It would seem ill-advised to allow animals to graze concurrently on pasture under spray irrigation. The "measley beef" problem in Australia where beef has become infected with beef tapeworm (Taenia Saginata) from grazing on irrigated pasture land, and a similar episode in Arizona in 1934 has led generally to a prohibition of pasturing irrigated land. Again, because this infection is practically unknown in Canada, the human-animal risk via sewage irrigation is remote to say the least. However, it has been suggested that milk cows have been infected with typhoid fever from irrigated pasture land, and then spread the disease via milk to humans. Many would argue that this is indeed a remote possibility today with virtually all dairy herds inspected and virtually all milk pasteurized. It has also been postulated that cow udders became contaminated when grazing in sewage irrigated pasture, and generally this practice is also prohibited.

The problem of infection of animals via irrigated forage is difficult to quantify. I think it is safe to say that pelletizing and heat treatment will make forage safe, as will three to four months storage. I am not aware of references to the contrary. It would be unwise to feed animals directly with harvested silage. I referred earlier to the "measley beef" episode and this risk, while remote, is a serious potential problem. For this reason alone forage crops should be stored three to four months or pelletized before use.

The final area that the Chairman has asked me to address myself to was the possibility of contamination of milk. I referred to two possibilities, one being udder contamination, the second being the possibility of animals becoming ill with typhoid fever and subsequently transmitting the organism to milk. Both are possibilities and I would think that under controlled conditions where dairy cattle are not grazed in irrigated land during the period of spray irrigation, the possibility of infection would be remote. If, however, an animal did become infected and the milk was channelled throughout the normal marketing process the question of effect of pasteurization must be considered. In my view, pasteurization would, without question, kill any normal pathogenic organisms.

In conclusion I would like to leave with you the following thoughts:

1. Sewage effluent irrigation is a feasible method of sewage disposal.
2. There are distinct and definite health hazards associated with the practice.
3. Control mechanisms are possible and indeed practical.
4. Public acceptance of spray irrigation may well be a major problem.

DESIGN OF SPRAY IRRIGATION SYSTEMS

by

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DESIGN OF SPRAY IRRIGATION SYSTEMS

I. INTRODUCTION

The purpose of this paper is to illustrate the steps involved in determining the basic design information for spray irrigation systems to be operated in British Columbia.

The standard information for obtaining the design parameters and data is contained in the "Irrigation Design Manual for Farm Systems in British Columbia"[(1)]. There are many textbooks available giving detailed and comprehensive information on the design of spray irrigation systems; some of these are given in the list of references.

In the design of a spray irrigation system, it is important to recognize that the soil plays the dominant role in transferring water from the sprinkler to the vegetation. The portion of the soil which is important in this respect (dictated by the effective rooting depth of the crop and the particular soils conditions) may be considered as a reservoir.

The crop, by the process of evapotranspiration, consumes the water contained in this reservoir. There is a limit to the amount of water which can be removed from the soil reservoir without adversely affecting plant viability, and hence crop productivity.

The purpose of an irrigation system is then to fill the soil reservoir with water, and to replenish this reservoir at intervals such that there will always be water readily available for plant use.

II. DETERMINATION OF BASIC DESIGN INFORMATION

For the following example, frequent reference is made to the Irrigation Design Manual[(1)], and the tables quoted refer to those in the Design Manual. These tables, or portions of the tables, are given in Appendix A.

More detailed explanations of some of the terms and concepts are contained in the appendices.

EXAMPLE

The purpose of this example is to illustrate the use of the "Irrigation Design Manual for Farm Systems in British Columbia" to arrive at the appropriate spray irrigation design information.

Situation: A rancher living near 100 Mile House, growing an alfalfa crop on a sandy loam soil, wishes to irrigate so as to achieve optimum production during periods of peak crop water demands.

Procedure:

Step	Reference	
1		Estimate the effective rooting depth of the crop.
	Table 1	crop: alfalfa effective rooting depth: 4 ft.
2		Estimate or determine the soil textural classes and depths of the soil layers comprising the rooting depth. depth: 0-48 in. textural class: sandy loam
3		Estimate or determine the available water storage capacity (AWSC) in inches of water per foot of soil for each layer.
	Table 2	textural class: sandy loam AWSC: 1.5 in./ft.
4		Calculate the total AWSC in inches of water for the rooting depth from the depths and AWSC of each layer. depth: 0-48 in. (4 ft.) AWSC: 1.5 in./ft. total AWSC: (4 ft.) (1.5 in./ft.) = 6.0 in.

Note: The information required for Steps 2-4 is best obtained from an analysis of the soil profile by a soils specialist.

Step	Reference	
5		Obtain the maximum allowable soil water deficit (see Appendix B) by multiplying the total AWSC of the rooting depth by the appropriate availability coefficient.
	Table 3	crop: alfalfa availability coefficient: 0.50 total AWSC: 6.0 in. maximum allowable soil water deficit: (6.0 in.)(0.50)=3.0 in.

6 Estimate the maximum design application rate (AR) under sprinkler irrigation.

Table 4 textural class: sandy loam sod cover

maximum design AR: 0.45 in./hr.

(for relatively level ground)

Note: As with the AWSC information, the maximum design application rate is best obtained from an expert, site specific, soils analysis. The maximum design application rate is subject to large variations, dependent on the soil surface conditions, which are continually changing. (The maximum design application rate may be determined from actual field tests conducted under normal sprinkler conditions).

7 Estimate or determine the peak rate of evapotranspiration per day (maximum daily water use). (See Appendix C).

Table 5 location: 100 Mile House

maximum daily water use:

- 0.20 in./day if a 10 day interval is encountered
- 0.19 in./day if a 20 day interval is encountered
- 0.18 in./day if a 30 day interval is encountered

8 Determine the safe irrigation interval by dividing the maximum soil water deficit by the maximum daily water use.

$$\frac{3.0 \text{ in.}}{0.20 \text{ in./day}} = 15 \text{ days}$$

(Because the interval is 15 days or less, the figure for the 10 day interval is the appropriate one to use. If this calculation indicated an interval of, say, 18 days, then the ET rate for a 20 day period would be more appropriate).

9 Estimate the application efficiency (AE) (Appendix D).

Table 7 climate: hot

AE: 72% (first approximation)

(100 Mile House would be considered to have a hot climate. The application efficiencies given in Table 7, Appendix A, for a hot climate, range from 72% to 78%, with the majority being 72%. Therefore, an application of 72% would be used as a first approximation).

10 Calculate the depth of irrigation water required at each irrigation by dividing the maximum allowable soil water deficit by the application efficiency.

$\frac{3.0 \text{ in.}}{0.72} = 4.16$ in. (gross water application)

11 Obtain the minimum time of application by dividing the depth of water required at each irrigation by the maximum design application rate.

depth of water required: 4.16 in.

maximum AR: 0.45 in./hr.

minimum time of application: $\frac{4.16 \text{ in.}}{0.45 \text{ in./hr.}} = 9.2$ hrs.

The final design time of application will be dependent on the management practices of the particular irrigation site. In the proceeding, lateral lines will have to be moved at regular intervals, times of application of 11½ hrs. (2 moves per day) or 23 hrs. (1 move per day) are more convenient. These times of application are the most common encountered with handmove or wheelmove systems.

(Note: 12 or 24 hr. periods are not used, as some time must be allowed for moving the lateral lines).

If an 11½ hr. time of application is chosen, the final design application rate becomes:

time of application: 11½ hrs.

depth of application: 4.6 in.

design AR: $\frac{4.16 \text{ in.}}{11\frac{1}{2} \text{ hrs.}} = 0.36$ in./hr.

Note: The final design AR must be equal to or less than the maximum allowable design AR. The final design interval must be less than or equal to the safe irrigation interval.

12 Choose the most suitable sprinkler and determine the relevant data.

For this example, a 40 ft. x 60 ft. spacing is chosen. (A 40 ft. x 60 ft. spacing, meaning that the sprinklers are 40 ft. apart and that the lateral line is moved 60 ft. each move, is the most common spacing used for the irrigation of alfalfa and grass species in British Columbia. There are two reasons as to why the 40 x 60 ft. spacing is so common. Firstly, the common lengths for irrigation pipe are 20, 30, and 40 feet, therefore the common spacings are going to be multiples of these three lengths. Secondly, with a portable system, a 40 ft. length of pipe is the longest length which can be handled conveniently and a 60 ft. distance is the maximum spacing one can use, with small sprinklers, and still maintain a reasonable distribution of water). See Appendix H for comments on various types of sprinkler irrigation systems.

Table 7 The following sprinkler selection and data is obtained:

spacing:	40 ft. x 60 ft.
application rate:	0.36 in./hr.
sprinkler nozzle size:	3/16 in. x 3/32 in.
pressure at nozzle:	49 p.s.i.
flow per nozzle:	9.0 USgpm
coefficient of uniformity:	84%
wind range:	0-1 m.p.h.
application efficiency (hot):	72%

<u>Final Design Information</u>: This example ranch at 100 Mile House, growing alfalfa on a sandy loam soil would use sprinklers with 3/16 in. x 3/32 in. nozzles operating at 49 p.s.i. and with a flow of 9.0 USgpm per sprinkler. The gross water application on a 40 ft. x 60 ft. spacing with an 11½ hr. set time would be 4.16 in. of water. With an application efficiency of 72%, the net amount applied to this crop would be 3.0 inches, and with a maximum daily water use of 0.20 in. per day, the 3.0 inches would last for 15 days.

It is important to keep in mind that the application rate, the time of application, and the irrigation interval are all interdependent and can be adjusted to meet the needs of a particular system.

If, for example, a field to be irrigated was such a size that 12 days were required to move the lateral lines across the field, a 12 day interval could be used, rather than say a 15 day interval.

Referring back to our example, and to Table 7 of the Design Manual, we see that the optimum operating pressure for an application rate of 0.36 in./hr. is 49 p.s.i., whereas the optimum operating pressure for an AR of 0.32 in./hr. is 40 p.s.i. It may be desirable to irrigate at a rate of 0.32 in./hr. and thereby decrease the pressure requirement by 9 p.s.i.

If an AR of 0.32 in./hr. were used, the final design information would be:

AR:	0.32 in./hr.
sprinkler nozzle size:	3/16 in. x 3/32 in.
pressure at nozzle:	40 p.s.i.
flow per nozzle:	8.0 USgpm
coefficient of uniformity:	84%
wind range:	3-6 m.p.h.
application efficiency (hot);	76%

(Note: In this case, there would also be an increase in AE.)

If the time of application were still 11½ hrs.,

the gross application would be

(0.32 in./hr.) (11½ hrs.) = 3.68 in.

the net application would be

gross application x application efficiency

(3.68 in.) (0.76) = 2.80 in.

The safe irrigation interval would be

$$\frac{2.80 \text{ in.}}{0.30 \text{ in./day}} = 14 \text{ days}$$

III. AVERAGE SEASONAL POTENTIAL EVAPOTRANSPIRATION

Average seasonal potential evapotranspiration figures have been calculated by W. N. Sly and M. C. Coligado[7]. The average seasonal ET is the summation of daily estimates of potential ET for the months of May to September. These daily estimates were calculated using a modified version of the regression model proposed by Baier and Robertson[8] and are related to recorded astronomical and meteorological variables. The values presented by Sly and Coligado are based on a 30 year average.

These Seasonal Potential Evapotranspiration figures are presented in Table 6 of the Design Manual, and can be used to determine the maximum application of sewage effluent through spray irrigation. This maximum application is calculated by dividing the average seasonal potential evapotranspiration by the application efficiency of the irrigation system.

<u>Example</u>

Location:	Merritt
Seasonal ET:	17.82 inches
Application Efficiency:	72%

$$\underline{\text{maximum}}\ \text{seasonal application} = \frac{17.82\ \text{in.}}{0.72} = 24.75\ \text{in.}$$

IV. FINAL SYSTEM DESIGN AND LAYOUT

Once the basic design information for a spray irrigation system has been determined, the principles of hydraulic engineering are used to develop a final system design which will meet the basic design requirements and design criteria, including the appropriate safety features. (See Appendix G, "Design Criteria", of this paper. and Part X, "General Design Considerations", of the Irrigation Design Manual.)

In our discussion of the derivation of the basic design information and of the average seasonal potential evapotranspiration, we have considered only the water balance of the area to be irrigated.

In a properly designed irrigation system, there will be no surface runoff, and the water balance equation becomes, neglecting groundwater inflow:

$$\text{Precipitation} + \text{Irrigation Application}$$
$$= \text{Evapotranspiration} + \text{Deep Percolation}$$

An irrigation system, for most agricultural applications, is designed to meet the crop water requirements evapotranspiration with no input from precipitation. Precipitation may be considered when determining seasonal water requirements and when scheduling an irrigation system.

In an effluent spray irrigation system, the contribution of precipitation must be considered. If not, excess application may result, and with effluent, this may have serious consequences.

It should be pointed out that one of the losses considered in the application efficiency is deep percolation losses. Because the water distribution is not perfectly uniform, excess water must be applied to some areas to bring the total area irrigated to Field Capacity (to fill the entire soil reservoir). This excess water is lost to groundwater.

With effluent, more than just water is being applied. It is therefore necessary to consider the composition of the effluent and to consider more than just a water balance. Other factors to consider would include:

- nitrogen
- potassium
- calcium
- sulfates
- boron
- organic material
- pH
- conductivity
- heavy metals
- crop tolerances

Any one of the above, or some other factor which has not been mentioned here, may be the limiting factor in determining the design effluent application rate. Both short and long term effects of sewage application must be considered.

In the scheduling of an effluent spray irrigation system, one must remember that rest periods for re-aeration of the soil must be provided.

Additional factors important in determining the area of land required for an effluent spray irrigation system are:

- lengths of frost free season and growing season
- non-uniformity of soils
- portion of area not suitable for irrigation.

In the final design of an irrigation system, considerations of the following must be made:

- management and cultural practices
  - cropping practices, crop rotations
  - with effluent, a high priority must be given to health aspects and to the uses of the surrounding land
- topography and layout
  - groundwater flow into and out of the design area
  - surface runoff into design area
  - an increase in slope will result in a decrease in maximum design application rate
  - buffer zones required
  - buildings, roads, fences and other permanent structures
  - elevations
- proximity to water sources and power sources
  - distance to water (or effluent) source and power source will effect the cost of the system
  - with effluent irrigation, distance to water courses (including groundwater) is important
- wind conditions
  - affect application efficiency
  - wind distorts the distribution pattern and may cause high application rates in certain areas (amount of distortion dependent on wind velocity and water droplet size).
  - if wind speeds greater than 15 m.p.h. are to be encountered frequently and for long durations, it may be wise to shut the system off during such times; the down-time would then have to be considered in the design of the system.
  - spray (aerosols) may travel a considerable distance. This will influence the size of buffer zones in effluent spray systems (windbreaks may help).
- resources available
  - the relative availabilities of labour and capital will be very important in choosing the type of irrigation system.
- future expansion
  - there should be sufficient system capacity to accommodate future expansion.

Appendix A

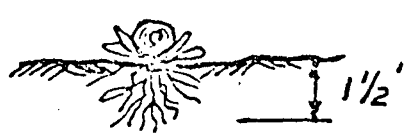
EXCERPTS FROM THE IRRIGATION DESIGN MANUAL[1]

Table I

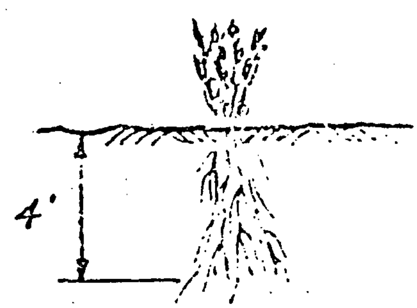
Effective Rooting Depth of Crops for Irrigation System Designs in British Columbia

Providing soil conditions and water tables depths are not limiting

Shallow	Medium Shallow	Medium Deep	Deep
1½ feet	2 feet	3 feet	3 feet plus
Cabbages*	Beans**	Brussels Sprouts*	Alfalfa (4')
Cauliflowers*	Beets**	Cereals*	Asparagus*
Clover (ladino)*	Broccoli**	Clover (red)*	Cane fruits(4')
Cucumbers*	Carrots**	Corn (sweet)*	Corn(field)(4')
Lettuce*	Celery**	Eggplant*	Grapes*
Onions*	Peas**	Peppers*	Hubbard*
Pasture species*	Potatoes***	Squash*	Sugar Beets(4')
Radishes*	Spinach**	Tomatoes*	Tree Fruits(4')
Turnips*	Strawberries***		



Shallow rooted crop (lettuce)



Deep-rooted crop (alfalfa)

* B.C. Irrigation Guide
** 1964 Irrigation Workshop
*** Soil Conservation Service
(4') Conventional Design Depth.

Table 2

A Guide to Available Water Storage Capacities (AWSC) for B.C. Soils

Textural Class	Available Water Storage Capacity (AWSC) in Available Inches of Water Stored in Each Foot of Soil
Sand	1.0 in./ft.
Loamy Sand	1.2 in./ft.
Sandy Loam	1.5 in./ft.
Fine Sandy Loam	1.7 in./ft.
Loam	2.1 in./ft.
Silt Loam	2.5 in./ft.
Clay Loam	2.4 in./ft.
Clay	2.4 in./ft.
Organic Soils (muck)	3.0 in./ft.

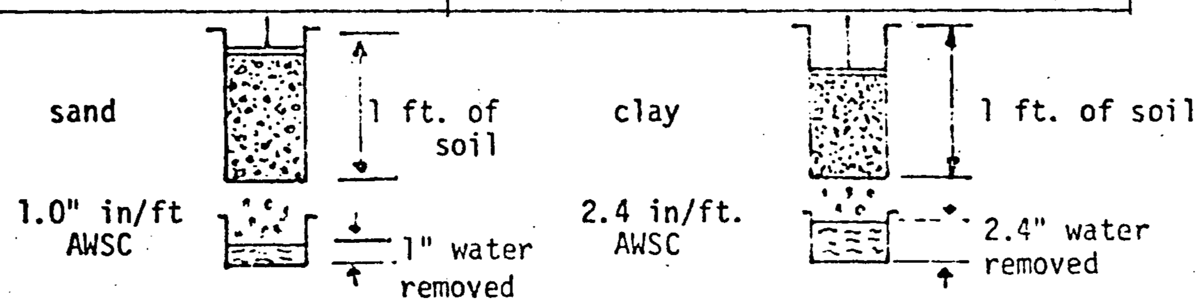


Table 2 has been obtained from the B.C. Irrigation Guide.

Table 3

Availability Coefficients

Maximum Percentage of Available Water Storage Capacity (AWSC) that can be removed from the Soil Before Irrigation is Required

Crop	Maximum Percent (%)
Potatoes	35
Tree Fruits	
- Coarse textures soils	40
- Other soils (see Deficit Budgeting Factor in B.C. Irrigation Guide for more detail)	50
Peas	35
Other crops until additional data becomes available	50

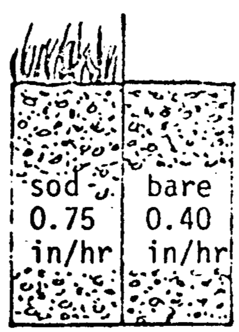
Table 3 has been extracted from the B.C. Irrigation Guide.

Table 4

Maximum Design Application Rates

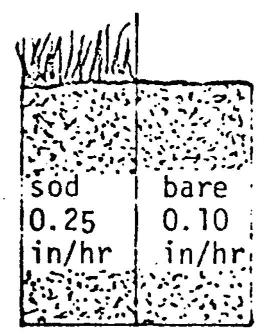
Textural Class	Application Rate in Inches per Hour	
	Grass Sod	Cultivated
Sand	0.75	0.40
Loamy sand	0.65	0.35
Sandy loam	0.45	0.25
Fine sandy loam	0.40	0.25
Loam	0.35	0.20
Silt loam	0.35	0.20
Clay loam	0.30	0.15
Clay	0.25	0.10
Organic soils (muck)	0.50	0.50

sand



High infiltration rate

clay



Low infiltration rate

Table 4 has been obtained from the B.C. Irrigation Guide.

Table 5

Determination of Maximum Daily Water Use for Various Areas in B. C.

(This is a partial reproduction of Table 5)

Location	Maximum Average Daily Water Use for		
	10-day period in inches/day	20-day period in inches/day	30-day period in inches/day
Abbotsford	0.17	0.15	0.13
Cawston	0.32	0.29	0.28
Kamloops	0.24	0.22	0.21
* Kelowna	0.24	0.23	0.22
Merritt	0.26	0.25	0.24
Nanaimo	0.19	0.17	0.16
100 Mile House	0.20	0.19	0.18
Vancouver	0.18	0.17	0.16
Vernon	0.23	0.22	0.21

* Values adjusted to actual field experience.

Table 6

Average Seasonal Potential Evapotranspiration (P.E.)

(This is a partial reproduction of Table 6)

Location	Avg. Seasonal P.E. in inches
Abbotsford	15.00
Kamloops	21.71
Kelowna	19.69
Merritt	17.82
Vernon Col.	18.19

Table 7

Sprinkler Selection for 40' x 60' Spacing

Application Rate (in/hr)	Sprinkler Nozzle Size (in)	Pressure at Nozzle (psi)	Flow per Nozzle (U.S. gpm)	Coefficient of Uniformity (%)	Wind Range (mph)	Application Efficiency Cool Climate (%)	Application Efficiency Hot Climate (%)
0.13	1/8	51	3.25	86	1 - 3	75	73
0.14	9/64	37	3.50	85	1 - 2	74	72
0.15	9/64	43	3.75	86	2 - 5	74	72
0.16	9/64	48	3.95	83	2 - 7	74	72
0.17	5/32	37	4.30	80	0 - 1	74	72
0.18	5/32	41	4.50	86	2 - 7	74	72
0.19	5/32	46	4.76	87	5 - 7	74	72
0.21	11/64	38	5.23	86	2 - 5	74	72
0.22	11/64	42	5.51	86	4 - 6	74	72
0.23	11/64	45	5.70	86	3 - 4	75	73
0.24	5/32x3/32	38	6.01	82	3 - 6	74	72
0.25	5/32x3/32	42	6.25	77	5 -10	74	72
0.26	5/32x3/32	45	6.48	79	5 - 7	74	72
0.27	5/32x3/32	48½	6.73	82	2 - 6	74	72
0.28	11/64x3/32	40	7.03	82	3 - 4	74	72
0.29	11/64x3/32	42½	7.25	83	2 - 3	74	72
0.30	11/64x3/32	45	7.46	85	4 - 7	74	72
0.31	11/64x3/32	47½	7.70	84	3 - 6	77	75
0.32	3/16x3/32	40	8.00	84	3 - 6	78	76
0.34	3/16x3/32	44	8.50	83	3 - 7	74	72
0.36	3/16x3/32	49	9.00	84	0 - 1	74	72
0.38	3/16x1/8	40	9.48	84	1 - 2	74	72
0.40	3/16x1/8	44	10.00	88	3 - 7	80	78
0.42	3/16x1/8	49	10.50	90	0 - 1	80	78
0.46	13/64x1/8	46	11.50	85	4 - 7	78	76
0.48	13/64x1/8	50½	12.00	89	4 - 8	80	78

Sprinkler Selection Charts for other spacings are also contained in the Design Manual(1).

Appendix B

MAXIMUM SOIL WATER DEFICIT

The available water storage capacity (AWSC) of the soil has been defined as the difference between the field capacity (FC) and the permanent wilting point (PWP). Over this available water content range, water is not equally available to the plants. Water is readily available over the upper portion of the range, and becomes increasingly less available as more water is removed from the soil.

That portion of the available water storage capacity over which water is readily available to the plants is referred to as the maximum soil water deficit, and is calculated by multiplying the AWSC by the appropriate availability coefficient.

The availability coefficient is a function of both the crop and the soils. The availability coefficients contained in the Irrigation Design Manual[1] (Table 3) are given as a function of crop only. Experience has shown that use of these figures is adequate for the design of irrigation systems on most B. C. soils.

Appendix C

EVAPOTRANSPIRATION

The evapotranspiration rate (ET) is the sum of two terms:

(1) transpiration, which includes the water which enters the plant through the roots and is used to build plant tissues or enters the atmosphere through the leaves,

(2) evaporation, which is the water which evaporates from the surfaces of the leaves of the plant without first moving through the plant, and from the adjacent soil and water surfaces.

The evapotranspiration rate is a dynamic function of many interacting variables, the major ones being:

(1) crop - ET increases as the crop grows (leaf area increases). When the ground cover is complete, the ET will be similar for all crops. ET rates are also a function of the stage of growth of the crop.

(2) weather - ET increases with increasing sunshine, temperature, and wind, and with decreasing humidity.

(3) soil moisture level - ET decreases with decreasing soil moisture. As the soil moisture is depleted, it becomes increasingly more difficult for the plant to remove water from the soil. As this occurs, the plants growth rates slow down and less water is consumed.

(4) soil fertility - Less water is required per unit growth under conditions of high fertility than under conditions of low fertility. When nutrients are readily available, more efficient use of the available water is made.

Evapotranspiration data can be expressed in various ways, depending upon how it is to be used. It may be expressed as total seasonal ET, as a function of a specific time period such as an irrigation cycle or a peak use period, or it may be expressed as a daily ET.

Maximum daily evapotranspiration values for 10 day, 20 day, and 30 day periods for various locations in British Columbia have been compiled by Dr. J. C. Wilcox[9]. Average seasonal potential evapotranspiration figures have been calculated by W. N. Sly and M. C. Coligado[7].

Other factors which should be considered when making use of ET data are the depth of rooting, depth to rooting, and climatic probabilities.

In situations where the water table is relatively close to the ground surface, the apparent ET, the portion to be satisfied by precipitation and irrigation, will be lower than expected. At present there is no method of estimating the contribution of groundwater sources at individual locations.

Because of climatic variability, the irrigation requirement of a crop will be dependent on the probability of encountering climatic periods which necessitate irrigation. In the design of irrigation systems, peak ET figures must be interpreted in terms of a proportion of years in which such a peak requirement is likely to occur.

Appendix D

APPLICATION EFFICIENCY

Irrigation methods have their inefficiencies in that not all of the applied water becomes available to the plants. The term application efficiency refers to the fraction of the applied water which ultimately becomes available for plant use.

A more formal definition of application efficiency for spray irrigation has been given as "the ratio of the net volume of the desired application to the gross volume of the water delivered by the sprinklers to effect the desired application"[(2)].

Application efficiencies vary with the operating conditions of an irrigation system. The figures presented in Table 7 and Appendix I of the Irrigation Design Manual are the optimum combination of nozzle size, operating pressure, and application efficiency for the desired application rate.

Appendix E

SPRINKER SELECTION

In the design of an irrigation system it is most important that the sprinkler selected meets the specific conditions of the system. Sprinklers are manufactured in many sizes and capacities, and each one has its own specific operating pressure range.

Sprinklers operating at higher than the recommended pressure will disperse the water into a fine spray which is subject to poor distribution because of wind conditions and extensive evaporation losses (application efficiency may be drastically reduced). Sprinklers operating at lower than the recommended pressure will be subject to poor stream breakup and large droplets which may cause poor soil surface conditions and may lead to erosion losses.

Sprinklers not operating within the recommended pressure range will lead to a high irrigation cost per unit harvested.

The Engineering Branch of the Briritsh Columbia Department of Agriculture, with the use of an IBM 360 conputer, has compiled over 10,000 distributions, based on field tests, for commonly used sprinkler spacings.

Tables prepared from these distributions give the application rate, the flow per nozzle, the coefficient of uniformity and the application efficiency for various nozzle sizes operating at the optimum pressure under various wind conditions and sprinkler spacings.

Appendix F

RECOMMENDED DESIGN PROCEDURE

1. Make an inventory of the available resources and operating conditions. Include information on soils, topography, water supply, sources of power, crops, wind conditions and farm operation.
2. Determine the basic design requirements of the system, and make the sprinkler selection, as outlined in Section II.
3. Determine the approximate capacity of the system.

   $$Q = \frac{453\ Ad}{FH}$$

   Q = discharge capacity in USgpm

   A = acreage of the design area

   d = gross depth of application in inches per acre

   F = number of days allowed for completion of one irrigation sequence

   H = number of actual operating hours per day.
4. Determine the number of sprinklers, operating simultaneously, required to meet system requirements.
5. Determine the best layout of main and lateral lines for simultaneous operation of about the required number of sprinklers.
6. Make necessary final adjustments to meet layout conditions.
7. Determine required sizes of lateral line pipe.
8. Determine the maximum total pressure required for individual lateral lines.
9. Determine required sizes for mainline pipe.
10. Check mianline pipe sizes for power economy.
11. Determine maximum and minimum operating conditions.
12. Select pump and power unit for maximum operating conditions.
13. Prepare plans, schedules and instructions for proper layout and operation.

The above design procedure is a slightly modified version of the procedure presented in Section II, Part 1-A of the B. C. Irrigation Guide[2].

Appendix G

DESIGN CRITERIA

1. Design Application Rate

   A properly designed and operated irrigation system should meet the following conditions with respect to water application:

   a) Water should be applied at a rate such that there is no surface accumulation or runoff.
   b) Water application should not exceed the peak water demand of the irrigation cycle.
   c) Application should be such that the minimum application efficiency is 72%. (Analyses of distribution patterns have shown that under most conditions encountered in British Columbia, application efficiencies of 72% or higher can be achieved. The results of these distribution analyses comprise the sprinkler selection tables of the Design Manual[1].)

2. System Capacity

   The capacity of an irrigation system should:

   a) satisfy peak demand
   b) allow time for moving equipment
   c) permit cultural practices on the area
   d) in the case of special uses, supply the designed amount to the design area within the <u>net</u> operating time
   e) provide an additional amount of water for systems located in areas where high wind velocities are likely to be encountered, as application efficiencies may be unavoidably reduced.

3. Amount of Water per Application

   The amount of water applied at each irrigation should be governed by the available water storage capacity of the soil, the effective rooting depth, the availability coefficient of the particular crop, the calculated amount of water consumed between irrigations and the application efficiency.

4. Uniformity of Water Application

   a) Pressure to be supplied at sprinkler – the design pressure at the nozzle should be within the recommended pressure range.

b) Spacing of sprinklers - maximum spacings are a function of the wetted diameter of the sprinkler and the wind conditions.

5. Lateral Lines

Lateral pipe sizes should be such that the pressure variation between any two sprinklers on the lateral does not exceed 20% of the desired sprinkler operating pressure. (This specification will not apply when flow regulators are placed under every sprinkler, but in such conditions the pressure drop through regulators must be considered).

If the topography is such that the pressure variation cannot be controlled to within 20%, suitable controls should be provided. Lateral lines should be placed across slopes. This will give more uniform pressure along the lateral, and hence a more uniform water distribution.

6. Mainlines

Mainlines sizes should be such that a reasonable balance between pumping costs and pipe costs is obtained. Mainlines should be placed with the slope. This will cause a pressure variation along the mainline, but if the design allows for adequate pressure at the lateral takeoff location where the mainline pressure will be the lowest, pressures to other laterals may be controlled by adjusting the opening on the takeoff valves.

Appendix H

COMMENTS ON VARIOUS SPRAY IRRIGATION SYSTEMS

1. Portable Handmove System
   The laterals have sprinklers every 20 to 40 feet and are manually carried to the next lateral position, usually a distance of 40 to 80 feet. Low initial investment but high labour and operator attention requirement.
2. Towmove System
   The laterals with sprinklers are mounted on skids or small wheels and the whole line is towed by a tractor to its next lateral setting. High operator attention requirement and high probability of damaging crop and soil condition when moving.
3. Wheelmove System (or Side-Roll System)
   The laterals are supported on wheels 30 to 40 feet apart with the pipe acting as an axle. A small gasoline engine is used to roll the line to its next position. This type of system is extensively used for hayland application, but is limited to more or less rectangular fields. Fairly high labour requirement (although less than with handmove) and hig operator attention requirement.
4. Boom Type Sprinkler System
   The boom is a nozzled, slowly rotating pipeline which is mounted on a portable tower. The sprinklers are moved by towing the tower from position to position. Not used extensively.
5. Handmove Giant Gun System
   A large volume gun used with portable aluminum pipe. Can do several acres at one set, but there is a relatively high labour and operator attention requirement.
6. Travelling Giant Gun System
   The sprinkler is connected to a flexible high pressure hose. The vehicle is towed by a power winch and cable across the field at regular intervals. The sprinkler is a high volume, high pressure type and in one pass it usually covers an area 330 feet wide by 1,320 feet long.

7. Centre Pivot System

   A single sprinkler lateral is supported on towers anchored at the centre with the other end moving in a circle about the pivot. There is a gradient of sprinkler nozzle sizes and spacings along the lateral to attain a reasonably uniform application rate. Each tower has its own power unit, and these units are sychronized to ensure proper lateral alignment. Large (40 to 160 acre) flat locations with light soils are required. Fields will be circular, and if used on heavier soils, movement of the wheels may lead to compaction and rutting. (Systems are available to irrigate the corners of a rectangular field left by the center pivot system).

8. Solid Set (Permanent) System

   The sprinklers, laterals, submains and mainlines are all permanently installed. These systems can be designed to use all ranges of sprinkler heads from shrub nozzles to giant guns. Can be used with any combination of crop, soil, and topographic conditions (soil and topography may dictate the type of sprinkler to be used). Can be fully automated so that operation becomes primarily a job of inspection. This type of system has the lowest operating costs, but the highest initial cost.

Note: Irrigation with giant gun systems is limited by their high application rates. This may prevent use under certain soil (heavy soils) and topographical (steep slopes) conditions.

The sprinkler systems which would be considered for effluent irrigation would be the handmove system, handmove gun, travelling gun, wheelmove, center pivot, and solid set system.

The handmove system would be considered only for very small effluent irrigation sites because of the high labour and operator attention requirement. Gun systems, both travelling and handmove, have been used, but also require considerable amounts of operator attention and their application rates may be too high for some soil and topographic conditions. Their main advantage would be their ability to irrigate in irregularly shaped areas.

The wheelmove systems are becoming very popular for hay and pasture irrigation. These systems fall between the portable and solid set systems in both capital expenditure and labour requirements, and should be considered for effluent irrigation applications.

The use of center pivot systems are very limited by topographic and soils conditions.

Solid set systems can be designed to operate just about anywhere and lend themselves to complete automation. They should be given prime consideration where labour will be a problem, or on steeply sloped or forested areas.

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CAUTIONARY MEASURES IN EVALUATING SOILS FOR SPRAY IRRIGATION

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CAUTIONARY MEASURES IN EVALUATING SOILS FOR SPRAY IRRIGATION

Many interelated factors have to be considered in selecting soils for spray irrigation of effluents. Some of these may be considered external to the soil, and include such things as climate, topography, type of crop to be grown, effluent quality, site position relative to bodies of water, area drainage pattern, and adjacent land use patterns. Some important internal soil properties include the size of soil particles and their shape or structure, the depth of the soil, depth to the water table, organic matter content, and those chemical characteristics that affect nutrient retention and availability to crops. This paper will focus attention on some of these internal properties and discuss how they influence irrigation practices and system design.

Any irrigation system, whether it utilizes natural waters or wastewater effluents, must be designed to apply the required amount of water to the soil when the plant needs it, and at a satisfactory rate of application. The rate at which water should be applied to soil will be governed by the soil's infiltration capacity or permeability, which in turn is largely determined by soil texture and structure. The relative proportion of different sized mineral particles in the soil mass is termed texture. The way these particles are grouped together into aggregates is termed structure.

Permeability refers to the ability of the soil to allow water to move through the soil, while infiltration capacity refers to the rate at which water can enter the surface of the soil. If the application rate of the irrigation system exceeds the infiltration capacity of the soil, surface ponding, runoff and consequent erosion will occur. The net result is a deterioriation in structure and a further decrease in infiltration capacity. This is particularly important in soils that contain silt and clay. If such soils do not have stable structure in the form of water-stable aggregates, the silt and clay particles will pack tightly together producing soils with very fine pores. This means that such soils will not drain well and will be poorly aerated. It also means that root penetration will be more difficult and perhaps even prevented. Lack of good soil management practices such as crop rotations, manuring, and cover cropping, or the cultivation of heavy-textured soils when they are too wet can seriously reduce the infiltration capacity.

The rate at which water enters the soil is not constant in either time or space, due to variations in both structure and texture within the soil. Most soils show such variation with depth, the surface soil normally being more permeable than the subsoil. In addition, the infiltration rate decreases with increasing duration of water application. The presence of a shallow water table can also reduce the inward movement of water considerably. In irrigation design, therefore, it is extremely important to consider both texture and structure variations with depth particularly in regard to the selection of application rates.

Very little test data is available on infiltration capacities of British Columbia soils. However, through experience and observation of soils under irrigation, some guidelines have been established that relate application rates to soil texture. In general, under good irrigation practices, application rates should normally not exceed 0.40 inches per hour on sandy soils or 0.20 inches per hour on soils that are of a clay-loam nature or heavier. Again, the point should be emphasized that variations in texture and structure within the soil must be considered in the selection of design application rates.

As indicated earlier, one of the major functions of an irrigation system is to supply the required amount of water to the soil at the time the plant needs it. Basic to this function is an understanding of the soil's available water storage capacity, which is a characteristic largely attributable to soil texture and structure. Available water storage capacity is essentially a measure of the soil-water available to plants that is held around the soil particles by surface tension, and in the capillary pore spaces. Water not held by the soil drains under the influence of gravity, moving downward through the larger non-capillary pores. The proportion of small pores to larger pores governs the water holding or storage capacity of a soil. Sandy soils not only have low total porosity, but they also possess relatively large pore spaces. The water storage capacity is therefore low. Silts and clays, on the other hand, have high total porosity, together with a high percentage of small pores. Hence, the water storage capacity is relatively high.

Two defined levels of soil water content are important in determining available water - Field Capacity and Permanent Wilting Point. Field capacity is the amount of water held in the soil after the gravitational water has drained away and after the downward movement of water has materially decreased. The permanent wilting point refers to the water content at which the soil can no longer supply water at a sufficient rate to maintain turgor and the plant permanently wilts. The difference between field capacity and permanent wilting point is known as available water storage capacity and is normally expressed in inches of water per foot of soil.

Information on available water storage capacity for British Columbia soils is limited. However, based upon available research data, guidelines have been established relative to soil texture classifications. In general, the available water storage capacity will be in the order of 1 inch per foot of depth for fine sands, 1.5 inches for sandy loams, 2.0 inches for loams, and 2.5 inches for silts and clays. Because of this variability in water retention relative to texture, and because most soils show such variation with depth, it is important that proper care be taken in selecting soil samples that are representative of the root zone of the crop to be grown. Available water storage capacity is extremely significant in irrigation design.

The amount of water released per irrigation application will be governed by the soil water condition at the time of irrigation, and by the crop being grown. In each situation the amount of water applied should be sufficient to bring the soil within the root zone to field capacity. This is necessary because a given column of soil cannot be wetted to a degree less than the field capacity, since no gravitational movement will occur until that field capacity has been exceeded. Therefore, if it is desired to wet the soil down to a certain depth, it is necessary to wet it to the field capacity all the way down to that depth. The heavier textured soils, having greater storage capacities for water, will therefore require heavier water applications than the light sandy soils.

In irrigating with wastewater effluents particularly, it is important to realize that the higher amounts per application required on the heavier soils does not mean that larger volumes of effluent will also be required on a seasonal or annual basis. The actual consumptive use of water by crops is not markedly affected by the texture of the soil, yet practical irrigation cannot be carried out as efficiently on a very coarse textured soil as it can on one of medium or heavy texture. The more frequent irrigations required on the coarse textured soil will necessarily result in larger evaporation losses and hence a higher seasonal irrigation requirement. In other words, more water will be required over the season under irrigated agriculture on soils with low water storage capacities than on soils with high water storage capacities.

At first glance it would appear that in choosing a soil for irrigation of effluent, one would select a soil with a low water storage capacity. This would necessitate more frequent applications and thus more effluent could be applied to a given area. However, one of the objectives in applying effluents to crop land is to "polish" that effluent through nutrient uptake by the plants and through fixation by the soil. Soils with low water storage capacities, unfortunately, also tend to possess low nutrient retention properties and are subject to higher leaching losses under irrigation. In addition, irrigation system capital costs and operating costs both increase as the frequency of irrigation is increased.

Last but not least, soil depth is an important factor to be considered in effluent irrigation system design, particularly if forage crops are to be grown. Alfalfa, for example, is deep rooted and under irrigation will draw its water requirements from an effective depth of four feet, soil permitting. Where the depth of soil is limited by a high water table, impermeable layer, compact glacial till or bedrock, normal rooting will not take place, the water storage capacity would be reduced and the irrigation frequency would be increased. Should such a restriction affect the internal drainage characteristics of the soil, crop yield and longevity of the stand may be adversely affected, or downslope seepage could develop, thus rendering those areas unsuitable for irrigation.

SOIL CHANGES DUE TO EFFLUENT IRRIGATION

by

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SOIL CHANGES DUE TO EFFLUENT IRRIGATION

INTRODUCTION

The primary function of land is the production of food and feed for humans and livestock, but as the earth's population continues to increase, more and more people urge that land be used for the disposal of their wastes. It is a prime requisite of any disposal system that a waste from one medium, such as soil, be prevented from causing undue pollution elsewhere. If we propose to use land as a receptor of wastes, then an objective must be to integrate the disposal system with local environmental conditions. Such an approach is in direct contrast to basing a decision solely on short term economic considerations or because a given parcel of land is unoccupied and has no projected and specified use.

Historically, waste disposal on soil is as old as the problem of waste disposal itself. The first irrigation system designed primarily for sewage disposal began in 1559 in Prussia and operated for more than 300 years. In England, a Royal Commission on Sewage Disposal (1859) recommended the application of town sewage on land as a means of avoiding river pollution (Bendixen et al. 1963). In more recent times, irrigation of crops with sewage effluent has been advocated in order to utilize the fertilizer potential of the nitrogen and phosphorus in the effluent and to reduce the eutrophication of rivers and lakes that has resulted from the disposal of the effluent through dilution techniques.

Today, relatively large land disposal schemes are in operation or in the planning stages:

1. Muskegon County Project; 10,000 acres of land to handle 44 million US gpd by design year 1990, and serve up to 150,000 people (Bauer 1973)
2. The Netherlands; sewage farm in operation for more than 50 years; 247 acres serving 200,000 people (Beek and de Haan 1973)

3. Braunschweig, W. Germany; 865 acres to handle sewage from 115,600 people; established 1890 (Ewert 1973)
4. Board of Works Farm, Werribee, Australia; 27,000 acres 20 miles west of Melbourne, population served ≃1.9 million; pasture 22,000 cattle and ≃40,000 sheep (1974); established in 1890's
5. Other systems in France and U.S.A.

Because of the large increase in the use of land for the disposal of effluents, and the criticism that has been raised over the technique (Egeland 1973), the problems of potential pollution of the environment are worthy of closer examination.

This presentation is intended to provide a review and discussion of soil properties as they affect the retention, transfer, and mobility of the major contaminants from wastewaters. The fate of added nitrogen and phosphorus has been well studied but there is much controversy over the forms in which heavy metals and synthetic organics are held (Leeper 1972). In practice we have had, until the 1970's, only a few isolated observations. We may expect many more experiments to be reported in the next few years, and some of these will throw more light on the problems of effluent irrigation.

NATURE OF SEWAGE EFFLUENTS

This symposium has been planned to investigate and report on the feasibility of disposing of sewage treatment plant effluents on land. The topic is generally limited to the liquid effluent from a variety of municipal sewage treatment processes; sewage sludges from the treatment processes are not under consideration.

Sewage treatment plant effluents are characteristically high-volume wastes (50 to 150 gpcpd), containing relatively low concentrations of many chemical and organic compounds. The concentrations of many of the elements in sewage effluents are shown in Table 1.

Kardos and Soper (1973) indicated that the effluent was the chlorinated wastewater from primary and secondary (modified activated sludge) treatments plus trickling filters. The treatment facility serves Penn State University and a neighbouring borough. The Guelph Treatment Plant consisted of primary, activated sludge and anaerobic digestion of the sludge. The chlorinated wastewater effluent is currently discharged to the Speed River. The British Columbia effluent (Oldham 1973), was from the trickling filter plant for the City of Vernon, and was used to irrigate alfalfa. Abbott, in 1971, surveyed municipal sewerage systems throughout Southern Ontario to detect the presence and concentrations of several heavy metals in the sewage, to determine the fate of the metals and the levels of the metals in the sewage treatment effluents. The data in Table 1 are the means and standard deviations of the concentrations found in the effluent from 20 to 24 treatment plants sampled several times over two years. These data therefore give the best indication of the ranges of these elements that might be expected in sewage effluents.

In general, effluents show low concentrations of macro and micro nutrients; total nitrogen ranges from 8 to 23 ppm, total phosphorus from 2 to 7 ppm and variable levels for the mono and divalent cations with heavy metals in concentrations below 1 ppm.

It should be noted however, that although the concentrations of plant nutrients in the effluents offer opportunities for beneficial use of the effluent in soil and crop enhancement, there are other constituents that have fates that may be detrimental to the use of waste water for irrigation. The constituents of special concern are the heavy metals, synthetic organic compounds such as pesticides, and the accumulation of salts. Therefore, the benefits of land irrigation with effluent must be evaluated in the light of whether the applied materials will in any way adversely affect the water and soil environment of the region.

Some attention should also be given to the amenity value of a region irrigated by effluent. Schultz, in 1966 pointed out that because of the organic matter in the effluent, it is preferable to use tertiary effluents in irrigation instead of primary or secondary to cut down on problems of putrescible matter and odours.

Table 1

Impurity Concentrations in Treated Sewage

Item	Source: Kardos and Soper (1973)	Oldham (1973)	Guelph (1974)	Abbott (1971)
pH	7.6 - 8.0			
Nitrogen - TKN		14 - 15	19 - 23	
- NH_4	5.3 - 15.7		12 - 16	
- organic	2.9 - 7.8			
- NO_3	4.2 - 5.8	4.6 - 5.6	< 0.1	
Phosphorus - total	4.1 - 7.1	6.6 - 6.7	2.3 - 3.1	
- ortho		0 - 5.6	2.1 - 2.3	
K	13.5 - 17.1			
Ca	20.2 - 34.6			
Mg	10.4 - 17.4			
Na	32.7 - 52.8			
Mn	0.1 - 0.36			
Cl^-	41.2 - 60.6			
Boron	0.29 - 0.4			
Al			0.1	
Fe			0.4	
Mn				0.050 ± 0.078
Cr			0.05	0.060 ± .163
Cu			0.1	0.153 ± .452
Zn			0.63 - 0.64	0.237 ± .428
Ni				0.104 ± .251
Pb				0.038 ± .081
Cd				0.014 ± 0.044

Note: All values are in mg/l, except for pH

METHODS OF WASTEWATER APPLICATION

Wastewaters may be applied to the soil surface by one or more methods, such as:

1. Flood irrigation, in which the wastewater is flooded or ponded on level or specially prepared sites;
2. Grass filtration, usually used on soils of low permeability; wastewater applied on upper part of gentle slope and flows over the soil through grass vegetation;
3. Spray irrigation
4. Ridge and furrow irrigation.

At this symposium several subsequent speakers will discuss in detail these methods of applying wastewater. However, your chairman has asked for a comment on the ridge and furrow method.

Ridge and Furrow

Technical reports describing the ridge-and-furrow technique (R and F) are very limited. A paper discussing the performance and wastewater renovative efficiency (compared to spray and flood irrigation) of the R and F was published by Bendixen et al. (1968).

The basins as described by Bendixen were terraced into the natural hillside. For each acre of land, about 0.75 acres were actually usable; the defining berms or ridges were maintained in reed canarygrass. The data indicated that percentage removals of the wastewater contaminants were: BOD (95); total N (5) and P (96). The authors concluded that there were no major differences in waste treatment among the three methods examined (spray, flood, and R and F) and that the R and F method could operate successfully in northern latitudes, (Bendixen et al. 1968).

In southern Ontario two R and F systems were operational (Parker 1967 and Webber 1969). Parker described a R and F system to dispose of high-pH wastes (>11.0) from a tannery. The wastes were flooded into prepared furrows about 2 feet wide and 2 feet deep with appropriate berms having a base of about 3 feet. The soil was a highly permeable sandy loam underlain by gravel. Mechanical operations were required each year to re-construct the depressions and berms.

In 1969, Webber recommended the construction of furrows 2 feet in depth and 4 feet in width with 8-foot centres. The system was laid out in a permeable fine sandy loam on nearly level topography. The wastewater was an aerated waste from a broiler-chicken processing plant. The system operated throughout the winters of 1970 to 1974 incl.; spray irrigation was used in the summer months. The success of the winter operation appeared to be related to the thermal capacity of water vs soil, water five times greater than soil. The operators were advised to keep a ditch or section of a ditch virtually full of the aerated wastewater to prevent a total freeze-up.

WATER MOVEMENT

When the decision has been made to use land as the disposal medium, the selection of a site becomes of prime importance. The operation of the site must be environmentally safe. A basic question invariably arises. Is the groundwater to be kept in its purest quality or will a certain level of pollution be permitted? A permissible level of pollution often requires a philosophical approach to determine the acceptable risk to society. Once a pollutant reaches the groundwater reservoir, natural renovation could be minimal and a significant attenuation of a pollutant may only occur by dilution and dispersion.

Unsaturated Flow

The most effective use of soil for waste disposal involves two apparently incompatible functions:

(a) the ability to accept large volumes of waste; and

(b) the ability to provide good renovation of water quality.

Coarse gravel satisfies the first function, but not the second; silt and clay soils may satisfy the second but not the first (Bendixen et al 1963).

The kind and extent of microbial degradation of wastes containing organic materials and the subsequent release of by-products are determined by soil aeration, oxygen status and moisture content. Under aerobic soil conditions, the soil moisture status is unsaturated, particularly below the zone of surface application. The magnitude of the movement of liquid wastes in a given soil becomes a soil physics problem to apply the parameters in unsaturated flow. Obviously, flow rates in the order of 10 to 10^{-2} cm sec^{-1} indicate a movement of the water that is too fast for proper soil attenuation of impurities to occur. According to LeGrand (1965), the movement of contaminants through the zone of aeration tends to be vertical. Lateral dispersion above the watertable is generally small unless appreciable amounts of waste are applied to the soil in a localized area. When wastewaters are localized in an area, the watertable may rise as a mound beneath the disposal site and cause radial dispersion. The presence of a mounded watertable decreases the zone of aeration and reduces the aerobic decomposition of applied wastes. This is one of the causes of localized breakout of septic tank effluents and percolates from landfills and sites used for wastewater disposal.

In general, we depend on a deep, well-drained, moderately permeable soil for the biodegradation of organics and a host of chemical reactions. Such a soil remains aerobic and water movement occurs by unsaturated flow. Overloading a site will result in depleted oxygen supplies and a tendency for decomposition to occur under anaerobic rather than aerobic conditions.

Saturated Flow

Almost anything placed on the soil surface may have an effect on groundwater quality through the process of groundwater recharge. The basic considerations related to groundwater in evaluating a proposed site for waste disposal on land are the depth to the seasonal high watertable, the rate and direction of flow, and the location of natural groundwater discharge points, (Westlund 1973). The depth to the watertable is a measure of the zone of aeration in which the infiltrating wastes are renovated.

A knowledge of flow patterns in the groundwater is essential to predict the behaviour of contaminants after reaching the zone of saturation. Generally, lateral dispersion predominates in the saturated zone and contaminants move in the same direction as the groundwater. The groundwater gradient and generalities about the flow system in and around a site can be predicted by installing a network of piezometers.

Fine-textured materials with saturated flow rates of 10^{-6} cm sec^{-1} or less permit the movement of little effluent, but may cause a substantial attenuation by cation exchange. Generally, materials with K-values of 10^{-6} or less are considered reasonably good sealants for landfill sites, and therefore some provision must be made to collect and treat the percolates which can no longer escape through the ground. Such fine-textured materials display a saturated flow rate too slow for the surface application of wastes. However, materials of moderate permeability (10^{-3} and 10^{-4}) and occurring in depths of 10 to 15 feet over the fine-textured silts and clays could become a useful site for waste disposal, if and when reasonable quantities of effluent are applied on the surface.

NUTRIENT TRANSFER AND STORAGE

In this section we propose to discuss several mechanisms and processes that are involved in the transfer of ions or compounds from the applied waste to the soil medium. It is assumed that the reactions occur in a well-drained, aerobic and unsaturated soil.

The substances carried to the soil by irrigation water can interact with the soil in many ways. Leeper (1972) classifies these interactions into four main types.

Firstly, the addition may pass through the soil unchanged. An example would be the chloride ion which may appear in the drainage water in higher concentrations than that added, due to water losses by evapotranspiration from the crop and the soil surface. So slight is the hold of the soil on the chloride ion that it is often used as a marker ion in percolation studies.

Secondly, there may be the formation of gaseous compounds. Such a reaction is most important for nitrogen and carbon additions. Nitrogen may be lost by ammonia volatilization or denitrification of nitrates to nitrogen gas and nitrous oxide. Organic compounds will be aerobically broken down to carbon dioxide. However, nitrogen and carbon are not the only elements that can be lost as gases. Other elements may be lost as gases in small amounts. Chloride ions may be oxidized to chlorine gas by the reduction of manganese oxides (Westermann et al. 1971). Volatile organic compounds of selenium and mercury occur in some biological systems and ethyl arsine can be formed from arsenate and arsenite by microorganisms.

Thirdly, one must consider plant uptake and removal by harvesting. This is the intended interaction for those substances in the effluent that are considered for their fertilizing value. However plant uptake is also the method by which the majority of the toxic substances such as the heavy metals will re-enter the food chain, and has given rise to the greatest concern in recent years. Other speakers here today will address this subject more fully and we will therefore spend little time on it.

Fourthly, the added substance may be immobilized in the soil in an insoluble form. A well known effect in this class is the immobilization in insoluble forms of added phosphates. However, for toxic substances such as the heavy metals, immobilization is the objective since their polluting potential will be reduced. It must be remembered that the two undesirable consequences of effluent irrigation are passage of contaminants into the drainage and groundwater and the re-entry of toxic substances into the food chain. Thus the ability of the soil to immobilize contaminants is of the greatest importance.

The mechanisms of removal of contaminants, particularly the ions of heavy metals, include cation exchange onto organic and inorganic colloids, chelation into organic colloids, adsorption onto the free ferric oxides of the soil, and the formation of amorphous or stoichiometric minerals.

Cation Exchange

A soil exhibits a physical-chemical property of a sorbing positively charged ions to the negatively charged clay micelles and to the soil organic matter. Cations are not held with equal security but usually follow the series:

$$H^+ > Al^{3+} > Ca^{2+} = Mg^{2+} > K^+ = NH_4^+ > Na^+.$$

The adsorption of inorganic ions on the soil exchange sites is primarily a function of the kind of clay and its surface area and of the soil organic matter. It is generally accepted that the relative adsorption capacities (me/100g) of soil fractions and organic matter are as follows:

Material	Exchange capacity, me/100g
Sands, > 0.02 mm	zero
Silt, 0.02 to 0.002 mm	3 to 7
Clay, $\leq$ 0.002 mm	22 to 63
Organic matter	200 to 400

Under field conditions an equilibrium exists between the soluble ions in the soil solution and the ions on the adsorption sites. The quantity of an ion adsorbed depends in a large part on its concentration in the solution phase. While it is believed that the adsorption reactions occur instanteously in a soil, it must be recalled that materials of high permeability (K = 10 to 10^{-2} cm sec^{-1}) do not present adequate volumes of clays or organic matter to be an effective water renovation process.

The effectiveness of cation exchange sites to retain the ions of heavy metals in particular, seems to be pH dependent. At pH 5.5, the bivalent ions of the heavy metals are not notably stronger competitors for exchange sites than Ca^{2+}, but when the pH is increased from 5 to 7 the heavy metals are held more firmly. The explanation is thought by some to be due to the tendency for the double charged metal ions to form singly-charged hydrolyzed ions, therefore reducing the number of exchange sites occupied and thus the competition. The formation of the hydrolyzed copper ion $CuOH^+$ is well known and Leeper (1972) quotes Vydra and Galba as presenting evidence for the same formation by zinc in soil. Other workers (Jenne 1968) dispute this explanation; but it must be recognized that raising the soil pH reduces the mobility of not only Cu^{2+} but also Zn^{2+}, Ni^{2+} and Cd^{2+}, and is probably the single most important aspect of the reaction between heavy metals and soils.

Chelation

As was seen above, organic matter has a much greater exchange capacity than the inorganic soil fractions and for that reason alone would deserve special attention. But the organic matter also has the ability to bind ions to itself by means of chelation. On a few sites on the organic matter, hydroxyl and some imine groups combine with carboxyl groups in holding metal ions in pentagonal or hexagonal chelate rings. Not all ions are held with equal security but in the case of the heavy metals follow the series:

$$Cu^{2+} > Ni^{2+} > Co^{2+} > Fe^{2+} > Mn^{2+} > Zn^{2+}$$

The trivalent ions Al^{3+}, Cr^{3+} and Fe^{3+} are all held very strongly by chelates but the last two tend to be thoroughly precipitated as the hydroxide. Calcium will chelate as strongly as zinc, manganese, and cadmium but copper and nickel are held more strongly.

Toxic substances such as the heavy metals attached to the exchange sites of organic matter or chelated into organic matter remain potentially toxic. The life of the organic link is limited not only by its chemical stability but also by its liability to be broken down by microbial action.

Chelation does not always remove cations from solution but may have the opposite effect and maintain the same metal in solution. Soluble chelates are formed between cations and small organic molecules but it should be noted that it is only a small proportion of the total that will become mobile in this manner.

Free Ferric Oxides

When free ferric oxides are selectively extracted from soil, there is an associated release of heavy metals. Jenne (1968) suggested that the heavy metals are first adsorbed and later buried in the free oxides of the soil, both in the anhydrous oxides and in the hydrated oxides such as geothite.

Amorphous and Stoichiometric Compounds

Stoichiometric compounds of carbonates, silicates, and phosphates are common in the soil and cause the precipitation from solution of substantial amounts of both cations and anions after fundamental re-organizations and recrystallizations of the original adsorption complexes. Such compounds tend to be complex and highly variable and it is probably better to examine them in terms of surface effects and amorphous compounds. For instance Tiller (1968) found that the adsorption of Co^{2+} on montmorillonite doubled when silicic acid was added. Such an effect cannot be due solely to internal substitution in the crystal lattice.

The presence of large quantities of phosphate tends to reduce the plant availability of many cations and is especially useful in reducing the toxic effects of heavy metals especially zinc. It is considered that this antagonism occurs within the plant rather than in the soil, but at the same time, hitherto obscure minerals of very low solubility may yet be discovered in soils such as the plumbogummites described by Norrish (1968). These include crandallite $CaAl_3(PO_4)_2(OH)_5H_2O$ and gorceixite $BaAl_3(PO_4)_2(OH)_5H_2O$, one sample of which contained one per-cent copper.

Having examined the fate of dissolved components of the sewage effluent in general according to Leeper's classification of the consequences of addition, perhaps the mechanism of transport and storage should be put into perspective by examining the changes in the soil of a number of the constituents of the sewage effluent.

Nitrogen

So much has been said about the fate of nitrogen in the soil, one hardly dares to add to it. However, nitrogen is one of the elements that can involve all four of Leeper's classes of movement.

If sewage effluent is used for irrigation and applied in the amounts and schedule common to normal irrigation practice, the nitrogen in the percolate draining through the root zone of the crop can be expected to be principally in the nitrate form. Thus if the amount of nitrogen applied is not much greater than the fertilizer needs of the crop, significant nitrogen removal can occur by harvesting the crop. Parizek et al. (1967) reported that ninety percent of the nitrogen in sewage effluent applied at a rate of one inch per week was removed by a wheat crop and sixty percent of a two inch per week rate. When, however, the amount of water and the nitrogen therein is more than needed for crop growth, the water draining from the root zone will likely contain considerable amounts of nitrate and will pose a potential threat of groundwater contamination. Such a problem is more acute in arid regions where irrigation is used extensively. Evapotranspiration and surface evaporation tends to increase the root zone salts. Regular leaching of the soil is required to maintain a balance of salts around the roots, and this can result in a very high nitrate concentration in the drainage water, since salts are often several times more concentrated in the leachate than in the irrigation water (Bouwer 1969).

Apart from the removal of nitrate nitrogen by plant uptake there are several other methods of nitrogen removal or immobilization which are probably of less significance. Ammonia may be adsorbed onto the clay fraction by exchange, nitrogen may be fixed in the tissue of bacteria and other microflora, and nitrogen may be fixed in the relatively stable organic matter formed by microflora and ammonia adsorbed onto that. Bouwer et al. (1971) reported that there was a small increase in the total nitrogen of the soil at the Flushing Basins project after several years of effluent infiltration but that this increase in nitrogen was probably not significant.

The loss of nitrogen in the gaseous phase by ammonia volatilization or by denitrification has already been mentioned. Bouwer et al. (1971) considered that denitrification was probably not a significant removal process with frequent short inundation periods where aerobic conditions prevail. Some microbial denitrification may occur during drying periods. Nitrate formed from the oxidation of ammonia adsorbed onto the clay or organic fraction may diffuse to the "inner" pores which are still anaerobic and where denitrification can occur. Bouwer et al. (1971) considered however that denitrification is unlikely to occur in the deeper anaerobic zones because although nitrate may be present, organic carbon is deficient leaving an insufficient energy source for denitrifying bacteria.

Soil Immobilization of Phosphorus

The phosphorus added to soil with the sewage effluent causes very few problems. When soluble phosphorus compounds are added to soil they are converted to forms that are virtually water-insoluble. In agricultural soils the concentration of soluble phosphorus in the soil solution rarely reaches 1.0 mg/l; more common values are in the order of 0.1 mg/l. As a result, the amounts of phosphorus leached to the groundwater under normal irrigation practices are so small as to be considered negligible. Since the loss of phosphorus in gaseous forms such as phosphine has not been observed, removal by harvesting and erosion losses are the mechanisms of consequence for the removal of phosphorus from the soil.

Despite plant uptake, supply may exceed demand and phosphorus may accumulate in the soil. In neutral to alkaline soils, the phosphorus is immobilized as a precipitate of calcium hydroxyapatite; in acidic soils the dominant precipitates are oxides of iron and aluminum which have a very low solubility. The phosphorus-fixation capacity of a soil may be estimated in the laboratory by preparing a Langmuir adsorption isotherm. It appears that the degree of phosphorus adsorption increases with increments of phosphorus in the equilibrating solution. Adriano et al. (1974) determined the phosphorus adsorption capacity of a number of soil textures (Table 2).

TABLE 2

PHOSPHORUS ADSORPTION CAPAICTY OF SOILS)Adriano, et al 1974)

(equilibrating solution concentration of P = 10 mg/l)

Soil Texture	lb P adsorbed per acre-foot of soil
Dune sand	77
Rubicon sand, 4 samples	108 to 731
Warsaw loam, 2 samples	602 and 1523
Clay loam, 2 samples	858 and 1898
Gravelly clay loam	426
Sand and gravel	178

Regarding the phosphorus adsorption data in Table 2, the authors noted that:

"The increased iron content then accounts for the increased P-adsorption by the B horizon [in Rubicon sand]. The high values for adsorption of Warsaw loam was apparently accounted for by a high aluminum content."

At the Elora Research Station, Guelph, phosphorus from sludge in the amounts of 0, 550, 1100, and 2200 kg P/ha was added to a loam soil over a two year period (Webber and Hilliard 1974). After two years of cropping with corn, the plant available phosphorus, extracted with 0.05 N sodium bicarbonate solution, was determined in 5 depth increments down to 90 cm (36 in.). It is quite apparent from the results shown diagrammatically in Figure 1 that the phosphorus added was immobilized in the upper 20 cm (8 in.), the zone of incorporation, and very little phosphorus moved into the lower levels of the soil.

Such results illustrate the capacity of the soil to immobilize phosphorus in excess of the amounts likely to be added by effluent irrigation. Since many agricultural soils are deficient in phosphorus, the phosphorus added during irrigation will result in a beneficial raising of the general fertility of the soil, as well as increasing the immediate plant uptake. The added phosphorus also has a positive role in the immobilization of toxic heavy metals.

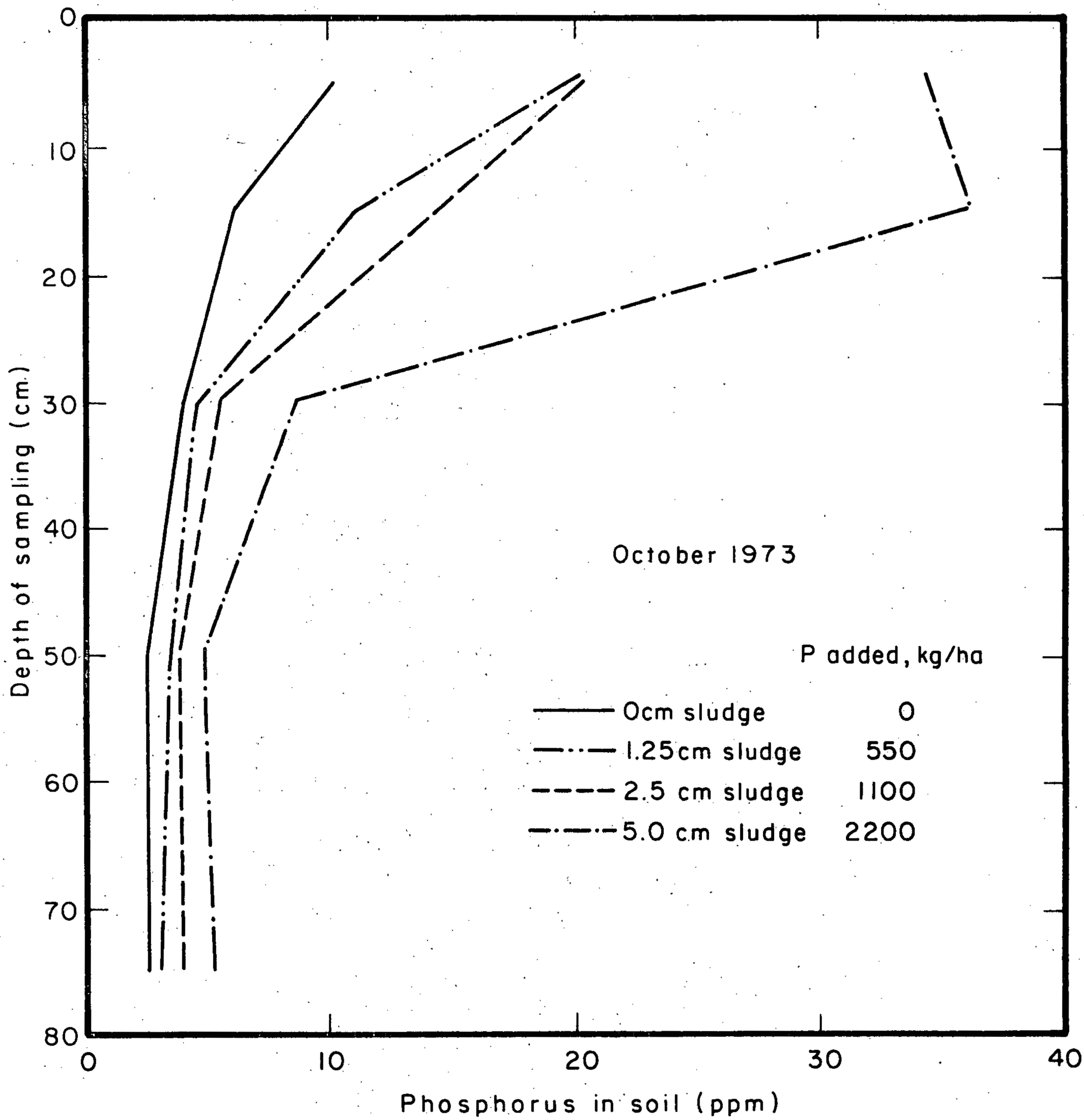

Figure I

VARIATIONS OF PHOSPHORUS IN SOIL WITH DEPTH FOR FOUR RATES OF SLUDGE APPLICATION.

Boron in Irrigation Waters

The boron content of effluents used in irrigation is of interest since the margin between deficiency and toxicity for this element is small. Boron concentrations in irrigation waters in excess of 0.5 ppm are considered undesirable for boron sensitive crops such as grape vines and citrus, stone, and pome trees which may begin to show boron toxicity symptoms (Bingham 1973). The increased use of boron compounds in certain household laundry products has tended to aggravate the problem Bingham reports that in the Santa Ana River system in California as much as 50% of the 0.75 to 1.50 ppm boron in the sewage effluent comes from household sources. Purves and Mackenzie (1974) also showed that boron in sludges and municipal waters is largely in a water soluble form. Lower concentrations of up to 0.4 ppm in effluent were reported by Kardos and Soper (Table 1) and at Flushing Basins near Phoenix Arizona, Bouwer et al. (1971) report levels of 0.4 and 0.7 ppm.

Many soils are capable of immobilizing boron. The most recent literature indicates that boron adsorption occurs mainly onto the mineral fraction of the soil. Boron can be adsorbed onto iron and aluminum hydroxy compounds present as coatings on, or associated with, clay minerals (Hatcher et al. 1967; Sims and Bingham 1968), onto iron or aluminum oxides in the soil (Schurrer et al. 1956) and onto micaceous clays although all clay minerals show some capacity for boron retention (Cough et al. 1968). Rhoades and his co-workers in 1970 concluded that in arid soils boron adsorption is associated with magnesium hydroxy clusters or coatings on the weathering surfaces of ferromagnesium minerals such as olivine, enstatite, diopside, augite, tremoline, and horneblende as well as the micaceous layer silicates.

Successful removal of boron will obviously depend on the presence of these minerals. Bouwer et al. (1971) found that as a consequence of a lack of iron and aluminum oxides in the soil materials of the Salt River bed where Flushing Basins is located, boron was not removed from the effluent and entered the drainage waters in amounts similar to those applied.

Boron adsorption occurs independently of variations of pH in acid soils but increases in pH within the alkaline range increases adsorption.

Such results suggest that boron is adsorbed as boric acid under acid conditions and borate ion as the pH approaches 9.0 (Sims and Bingham 1968). Boron adsorption also takes place independently of concomitant adsorption of other anions. Studies by Schalscha et al. (1973) revealed no effect from the simultaneous adsorption of sulphate or phosphate on boron adsorption.

Heavy Metals

Heavy metals may mean different things according to the user of the term. Those generally included in the term are cadmium, cobalt, chromium, copper, iron, mercury, manganese, molybdenum, nickel, lead and zinc. Aluminum is sometimes included although it is a light metal.

According to the findings of Abbott, (Table 1) the most common metals encountered in municipal sewage are chromium and zinc. Their occurrence probably reflects their use as corrosion inhibitors, in electroplating, and in the tanning of leather. Copper and nickel are the next most common while lead,cadmium and manganese are seldom present in appreciable concentrations, although in industrial areas the concentrations may be very much higher. The concentrations of the metals in the effluent are, in general, proportional to their concentration in the raw sewage but at a very much lower concentration. The precipitation of metals by sewage in the digestion process has been reported by Jenkins and Cooper (1964) and by Jenkins et al. (1964) and probably accounts for the low levels seen in the effluent (Table 1). The efficiency of such metal removal is however, variable and depends on a number of factors. In general, Abbott found that the concentrations in the effluent were rarely in excess of Ontario quality objectives although the total quantity discharged may be cause for concern.

Heavy metals, in the amounts involved in spray irrigation can only be removed from the soil by leaching or by plant uptake. Contamination of the groundwater by heavy metals is undesirable, and it is desirable also that plant uptake be as low as possible. Consequently, it may be very important to have a soil with a high capacity to remove heavy metals from solution and immobilize them in forms that are relatively unavailable to plants. The mechanisms of such immobilization have already been discussed and include cation exchange, chelation, and the formation of amorphous or stoichiometric compounds.

Since heavy metals thus adsorbed into soils are not degradeable and since their rates of removal by plant uptake are very small, there is the danger that their concentrations will increase with increasing use of effluent in irrigation. As a result, detrimental environmental effects will be discovered only after it is too late for remedial measures. At the Berlin sewage farm on acid sandy soil, and at the Paris effluent disposal site where the soil is limy, there are signs of exhaustion and low crop yields. The exhaustion seems to be linked to high copper and zinc levels. Leeper (1972) quotes data from Melbourne Australia which shows that after seventy years of heavy irrigation on a light clay the extractable zinc varies from 830 ppm in the first inch to 44 ppm at a depth of 6 to 14 inches. To reach high levels will however take considerable time and depend upon the concentrations of metals in the effluent and the type of soil irrigated. Ohio State University School of Agriculture has been monitoring plant and soil heavy metals resulting from applications of Celina sludge. Sludge contains higher heavy metals accumulations than does the effluent. After 20 years of application, the heavy metal build up is now only slightly above background levels, but there was concern over the long term effects (Manson and Merritt 1975)

Although these data show that many soils have a great capacity to absorb heavy metals, it should be remembered that long before the levels of heavy metals quoted above are attained, sensitive crops would have shown toxicity symptoms, and non-sensitive crops may have accumulated heavy metals in concentrations that could render them unmarketable. Because the heavy metals tend to accumulate in the top layers of the soil, there are many examples of soils contaminated with copper from Bordeaux Mixture sprays which support good orchards and vineyards simply because the roots avoid the toxic zone. When, however, these orchard soils are ploughed and annual crops planted, severe failure is often observed because roots grow into the toxic zone (Chaney 1973).

One of the more important consequences of using effluent to irrigate crops is the hazard of toxic metals entering the food chain. The elements considered to be a significant potential hazard to the food chain through plant accumulations are cadmium, copper and zinc (Chaney 1973).

In Ontario, the maximum allowable concentration of cadmium in drinking water is 0.01 mg/l, zero content being preferred. However, regulatory agencies have not set levels for maximum human dietary intake. Leeper stated in 1971 that 0.5 ppm cadmium in plants is harmless to both plants and animals.

Our knowledge gap with respect to trace elements, micronutrients, or heavy metals is broad, but much relevent research is planned or underway. Much work still needs to be done on reducing the toxic hazards by investigating the interactions between the heavy metals such as zinc and cadmium. High levels of zinc have been shown to prevent the hazardous concentrations of cadmium in foods (Jones et al. 1973).

Thus, if we are to use our soils not only for food but as sinks to detoxify heavy metals, we must be aware that the sink is not bottomless and that careful control must always be exerted.

<u>Natural and Synthetic Organics</u>

The total organic constituents of sewage effluent are controlled by legislation. Attempts have been made to analyze the organics in the effluent but many analyses have succeeded only in classifying the organic matter into general groups of compounds (Rebhun and Manka 1971). Because of the intense microbial action in the treatment plant, it must be assumed that the organic matter will consist of both those compounds which are resistant to degradation, and the products of microbial metabolism. The latter do not give too much cause for concern as they are probably highly biodegradable but those compounds which are resistant to a greater or lesser extent must be considered in more detail, particularly if there is a toxic hazard. For this reason the Water Pollution Research Laboratory, Stevenage, U.K., has started to determine the nature and concentration of the residual organic compounds in sewage effluents, placing special emphasis on substances known or thought to be toxic.

The soil seems to have an amazing capacity to develop microbial populations that will degrade almost every organic compound added. Under well drained, aerobic conditions the added organic compound will be broken down eventually to carbon dioxide, and other small-molecule compounds of the other elements in the molecule. Organo-chlorines will leave a chloride residue and organo-metallic compounds will leave a metal residue to be immobilized as described above. However because some of the organic compounds are resistant to microbial attack, Robeck et al. (1964) warned that the soil must have a low enough permeability and some adsorptive capacity to allow suspended and dissolved organic matter to be retained long enough for a suitable microbial population to develop. DDT, for instance, is retained upon humic substances (Ballard 1971).

It is difficult to see how pesticides contained in the effluent could cause any greater hazard than those already in use on the crop in normal agricultural practice. There are, however, a number of compounds in sewage that could cause problems.

Before the conversion to "soft" detergents in the mid sixties, a report by Robeck et al (1962) indicated that alkyl benzene sulphonates (ABS) and other synthetic organics in sewage that are not degraded by other methods, could be degraded when applied to non-saturated soils. Organisms usually found in sewage and soil were able to degrade ABS and the herbicides 2,4D, 2,4,5T and O-Cresol, as well as the usual COD components.

Soper in 1972 reported that in an extended experiment spraying municipal effluent on a forest, detergent residues that caused serious foaming at the start of the experiment were rapidly degraded in the surface soil horizons. After the conversion to "soft" detergents in 1965, added Methylene Blue Active Substances (MBA'S) were negligable at the two foot depth. Nitrilotriacetate (NTA) which is sometimes used as a substitute for phosphate in detergents has been shown by Tiedje and Mason (1974) to be degraded in soils, although adequate degradation is known to occur in activated sludge treatments and sewage lagoons. NTA is poorly degraded in anaerobic and septic tanks.

There are a number of organic compounds about which there is growing concern but little data at the moment. These compounds include the polychlorinated biphenyls (PCB's) and the phthalic acid esters (PAE's). PAE's are a recent concern because of their teratogenic and mutagenic potential (Mathur 1974). PAE's are used extensively as plasticizers because of their resistance to microbial attack. No data are yet available concerning their presence in effluent nor of their degradation in soil, but because they can be extracted from plastic pipes with just distilled water (Bingham and Hill 1972) their presence must be anticipated.

The total organic matter content of the soil is little affected by the burden of organic matter added with the effluent in irrigation. Bouwer et al. (1971) reported a slight increase in the organic matter of the soil as a consequence of effluent irrigation; and Day and coworkers (1972) after 14 years of irrigation with effluent, found an increase in organic matter but no more than was seen on plots irrigated with well water.

SALT ACCUMULATION AND SALINITY

One of the persistant problems in irrigation is the build up of salts in the root zone. The presence of sodium in sewage effluent in amounts of 30-50 ppm (Kardos and Soper 1973) would give cause to expect salinity problems.

In southern Ontario, we do not have a saline problem nor the problems of salt-affected soils. For several years, we have monitored the exchangeable cation status of soils used for the disposal of sodium and potassium wastes from lye-peeling operations in vegetable processing plants. The percentage saturation of the cation exchange complex by sodium for several times of sampling is shown in Table 3.

It has been proposed, that a salinity problem could be manifested in soils when 15 percent or more of the exchange complex was occupied by sodium (Bower et al. 1958). In general, the greatest degree of sodium saturation occurred in late fall which corresponded to the end-of-season for discharging alkali wastes (Table 3). Presumably, the winter and spring precipitation encouraged leaching and the removal of the ions from the soil solution in the upper layers.

In soils having free calcium carbonate, hydrolysis occurs with free calcium ions being brought into solution. For this reaction to occur, soil water is required. Presumably, less free calcium is released if the calcium carbonate equivalent of the soil is low or if the pH is particularly high due to sodium compounds in the soil solution. The hydrolysis of the calcium carbonate and the replacement of sodium on the exchange complex by the free calcium is shown in the following equation:

$$2Na_{ad} + CaCO_3 + H_2O \rightarrow Ca_{ad} + 2Na^+ + HCO_3^- + OH^-$$

In an interpretation of the above reaction it was pointed out that the reaction proceeds to the right as the water content of the soil is increased (Bower and Goertgen 1958). If the soil is leached and if sufficient $CaCO_3$ is present the reaction continues to the right owing to the removal of the HCO_3^- and OH^- and Na^+ until the adsorbed sodium (Na_{ad}) is replaced.

Calcium carbonate alone is generally an ineffective source of calcium in soils with a high pH (>8.5) because of the low solubility of the carbonate. In some arid salt-affected soils with an excess of lime, the replacement of sodium by calcium is effected by the addition of elemental sulphur. Soil organisms oxidize the sulphur to form sulphuric acid which reacts with the lime to form gypsum, calcium sulphate. The addition of calcium sulphate is equally effective in inducing the exchange of sodium for calcium.

If more than 15 percent of a soil's exchange complex is occupied more or less permanently by sodium, the soil colloids may be dispersed, aggregation is destroyed, permeability is severely restricted and in general a poor physical condition develops.

TABLE 3

PERCENTAGE SATURATION OF THE CATION EXCHANGE COMPLEX BY SODIUM

Depth	Sodium Saturation*						
	1971	1972			1973		1974
	Fall	Spring	Summer	Fall	Spring	Fall	Spring
0-10"	6.56	1.84	4.85	7.34	7.57	6.63	3.83
33-54"	4.60	3.87	2.77	4.02	4.60	18.40	7.26

* Saturation expressed as a percentage of the total cation exchange capacity occupied by sodium.

SUMMARY

The utilization of sewage effluent in irrigation would appear to be not without merit. Caution would have to be exerted to ensure that excessive amounts of nitrate and heavy metals are not applied. The effects upon the soil would appear to be minor except for the breakdown

of the soil structure due to salt accumulation, a greater problem when effluent is used in irrigation due to its greater salt content. The long term effects should not be overlooked and the slow accumulation of heavy metals should be carefully examined in the light of the present crop rotation and with future crops in mind.

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PLANT AND NUTRIENT ASPECTS OF WASTEWATER IRRIGATION

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PLANT AND NUTRIENT ASPECTS OF WASTEWATER IRRIGATION

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INTRODUCTION

The goal of any wastewater treatment scheme is to renovate the water from a chemical and biological standpoint before returning it to stream flow. Many of the 'pollutants' in wastewater are merely natural resources out of place. By using the water for irrigation, we can return these resources to the food chain, thus using both the nutrients and the water for food production while completely renovating any return flow. Wastewater irrigation is capable of outperforming any water treatment technology now in existence since it can provide complete nutrient removal and control of both bacterial and viral pathogenic organisms.

The soil or 'living filter' is naturally the primary concern since it physically filters out particulate matter and provides a medium for chemical and biological reactions. What makes the system operate effectively is the biosystem operating within the soil-- the vital component. This presentation deals with the vegetative component of that system.

I will be drawing on my experience in irrigating forage species with municipal effluent in research plots at Taber, Alberta, and comparing my results with those reported in the literature. Mr. D.N. Graveland will be presenting details of the working system at Taber in a later discussion.

PURPOSE OF THE CROP

The crop serves many purposes in water renovation. The suitability of the crop depends on the specific requirements of the scheme.

A crop should be capable of:

1) responding to the applied water and nutrients, thus providing food or fiber for society;
2) upon harvesting, removing from the biosystem large amounts of nutrients supplied by the effluent;
3) transpiring water at a high rate over a long growing season;
4) preventing soil erosion by water or wind;
5) maintaining soil structure so as to maintain or improve the water infiltration rate and permeability of the soil;
6) being utilized by society without transmitting any harmful pathogenic organisms, nutrients, or heavy metals into the food chain;
7) providing a cash return to cover operating and maintaining the system and perhaps a return on capital investment.

CROP RESPONSE TO WASTEWATER

An increase in yield from wastewater may be due to the water or to the nutrients it contains. Alfalfa has outyielded the four grass species in research plots at Taber over the past 4 years, especially when plots were irrigated at a rate about equal to evapotranspiration minus precipitation and not supplied with nitrogen fertilizer (Table 1). When the irrigation rate was doubled, average yields were increased from 3.34 to 4.52 tons/acre. This was surprising since the additional water must have leached to the water table. Similarly, when 50 lb additional N and P fertilizer was applied, average yields were increased from 3.52 to 4.35 tons/acre. Clearly, the yield increase from the second 24 inches of wastewater was due to the nutrients in the water. Since soil and plant analysis showed that the P supply was adequate, the forages were evidentally responding to added N. This high rate of irrigation was included only for experimental purposes. If it were used on a field scale, the water table would be raised to the surface and management would be impossible.

The wastewater contained a considerable amount of N, P, and other nutrients, especially in the first year of the study (Table 2). In that year, the water contained about double the N and P levels of subsequent years, due to immaturity of the lagoon or additional loading from a potato processing plant that ceased operation in 1972.

Table 1. Average annual forage yield of five forage species as a function of wastewater and fertilizer level (1972-1975)

Wastewater irrigation (in./yr)	Fertilizer N-P (lb/acre)	DM yield (tons/acre)					
		Alfalfa	Reed canary	Altai wild rye	Brome	Tall wheat	Mean
24	0- 0	3.88	2.59	2.61	2.67	2.36	2.82
	50-50	4.21	3.94	3.74	3.98	3.42	3.86
48	0- 0	4.55	4.17	4.28	4.44	3.53	4.20
	50-50	4.49	5.13	5.24	4.96	4.38	4.84
Mean		4.28	3.96	3.97	4.01	3.42	3.93

Table 2. Nutrient content of Taber effluent

Nutrient	1972	1973	1974	1975
NO_3-N (ppm)	3.0	1.1	1.0	.4
NH_4-N (ppm)	22.9	8.7	8.8	11.5
P (ppm)	5.9	3.4	2.9	3.2
Na (meq/liter)	8.7	6.0	4.3	6.8
Ca + Mg (meq/liter)	6.6	9.3	6.6	11.8
K (meq/liter)	2.1	.5	.5	.4
SO_4 (meq/liter)	.3	7.2	3.7	10.2
HCO_3 (meq/liter)	17.1	6.5	5.8	7.5
Cl (meq/liter)	1.5	1.5	1.6	1.7
Total salts (ppm)	1,261	1,090	720	1,188

Research studies at Swift Current, Sask., have shown that yields of alfalfa were only slightly higher when irrigated with municipal wastewater than when irrigated with creek water in the first year of the study (3.20 vs. 2.65 tons/acre) and were similar in the second year (3.93 vs. 4.09 tons/acre) (V.O. Biederbeck, personal communication). The N in the wastewater was of no benefit to the legume, and soil P was adequate. It is suggested that, as the P level of the creek-water irrigated soil is reduced, a yield differential favoring wastewater irrigation will occur.

It is frequently difficult to proportion the yield response from wastewater irrigation between the effect of water and that of nutrients. In the Taber study, yields of the native Stipa Bouteloua were negligible without irrigation, and cultivated forage would have produced less than 1 ton/acre. The magnitude of any response to effluent irrigation is dependent on the basic yield without irrigation and on the water and nutrient requirements of the crop. Representative yield responses from the literature are shown in Table 3. Yields are frequently doubled with 1 inch of wastewater/week, and further responses are obtained from the additional nutrients at higher irrigation rates. These are the results of well-managed projects, but I am sure unsuccessful projects exist which are not reported in the literature.

NUTRIENT UPTAKE BY CROPS

Crops used in a wastewater irrigation system should absorb as high a proportion of the ions present in the water as possible. Ions will then be withdrawn from the cycle and cannot contribute to secondary pollution of the groundwater or local streams.

Nitrogen is the element of prime concern since large amounts are frequently present and it is readily converted to the mobile nitrate form. Its presence in water bodies can contribute to eutrophication. If the transformation to nitrate is blocked, toxic nitrites can accumulate. There is also the concern that nitrates may combine with amides to form aminonitriles, which are known to be carcinogenic.

Table 3. Yield response (tons/acre) of several crops to effluent irrigation

Crop	Ref	Effluent irrigation (in./wk) 0	1.0	2.0
Alfalfa	Taber	.75	4.0	4.5
	14	2.18-2.43	3.75-4.67	4.36-5.42
Grass	Taber	.75	2.9-3.4	4.0-4.8
- native	7	.9	2.7	-
- golf courses	9, 11	-	-	-
Cereals - forage	3	3.9	4.5	-
- grain	14	1.53-2.88	2.70-4.80	2.48-3.24
	7	.6-.72	4.8	-
	5	0-1.43	1.43-1.92	-
Corn - forage	14	2.47-3.83	3.93-7.29	4.32-8.48
- grain	14	1.98-5.52	4.98-7.26	5.04-6.96
Potatoes	5	2.4-14.3	9.0-14.5	-
Sugar beets	5	6.3-20.0	14.1-24.3	-
Trees (diam - in./yr)	14	.06-.16	.17-.18	.06-.22
(ht - in./yr)		12	20	

In our Taber studies, alfalfa took up considerably more N than did the grass species (259 vs. 160 lb N/acre). Reed canarygrass and bromegrass were intermediate while tall wheatgrass had the lowest N uptake (Table 4). When 50 lb N/acre fertilizer was added annually, the four grass species took up an additional 54 lb N/acre at the low wastewater level, an additional 48 lb N/acre at the high level. Even at the high irrigation level, the forages could apparently use all the additional fertilizer N.

The annual application and utilization of N is shown in Table 5. Only in 1972 was more N applied than was taken up by the plants. Over the 4 years, considerably more N has been taken up by plants irrigated at acceptable rates than was applied in the effluent or fertilizer. With excessive application of effluent, the N uptake approximates N application. No attempt was made to measure N_2 fixation by microorganisms or N mineralized from soil organic N. Periodic soil sampling has shown negligible levels of NO_3-N. Only in 1975 after unusually heavy spring rains were significant amounts of NO_3-N found in the groundwater. In one well the NO_3-N levels exceeded the maximum permissible level for drinking water (10 ppm).

Phosphates have been associated with eutrophication and thus it is desirable that they be taken up by the plants or retained at the site. At the Taber site, phosphates were retained in the surface 6 inches of soil (Table 6). Only with high irrigation and 50 lb/acre/year P fertilizer was P leached to the 6 to 12 inch depth in the first 2 years. Depths from 6 to 48 inches had less available P than the original samples. P uptake varied from 42 to 61 lb/acre, which was 60 to 29% of the P applied. From 63 to 80% of the applied P has been taken up or has been retained in the soil in a form extractable with $NaHCO_3$ and is thus, presumably, still available.

When we assess the suitability of crops considered in a wastewater irrigation scheme, we must consider the amount of nutrients applied. Table 7 shows the normal amounts of nutrients applied per acre. The loadings are relatively low with municipal wastewater but can be increased greatly by the addition of industrial or food processing wastes or liquid sewage sludge.

Table 4. N removal by the five forage species as a function of effluent and fertilizer levels (1972-1975)

Wastewater irrigation (in./yr)	Fertilizer N-P (lb/acre)	N removal (lb/acre)					
		Alfalfa	Reed canary	Altai wild rye	Brome	Tall wheat	Mean
24	0- 0	241	111	95	110	89	129
	50-50	252	172	149	166	130	174
48	0- 0	269	185	176	178	134	188
	50-50	275	243	224	225	175	229
Mean		259	178	161	170	132	179

Table 5. N applied to and N uptake by forage crops at Taber

Treatment*	N applied (lb/acre)			N uptake (lb/acre)	
	Irrig.	Fert.	Total	Range	Mean
			1972		
I_1F_0	162	0	162	147-167	155
I_1F_1	162	50	212	158-204	184
I_2F_0	325	0	325	176-289	215
I_2F_1	325	50	375	201-251	220
			1973		
I_1F_0	66	0	66	82-196	128
I_1F_1	66	50	116	136-197	175
I_2F_0	132	0	132	140-255	196
I_2F_1	132	50	182	194-263	238
			1974		
I_1F_0	46	0	46	49-179	74
I_1F_1	46	50	96	85-189	122
I_2F_0	92	0	92	82-183	126
I_2F_1	92	50	142	120-194	156
			1975		
I_1F_0	49	0	49	70-391	142
I_1F_1	49	50	99	97-378	190
I_2F_0	98	0	98	102-310	195
I_2F_1	98	50	148	163-355	269
			4-yr total		
I_1F_0	324	0	324	-	499
I_1F_1	324	200	524	-	671
I_2F_0	647	0	647	-	732
I_2F_1	647	200	847	-	883

*I_1 and I_2 = irrigation at 24 and 48 in./yr; F_0 and F_1 = no fertilizer or N fertilizer at 50 lb/acre.

Table 6. Levels of P (lb/acre) in the soil in forms extractable with $NaHCO_3$, applied, and taken up by forages (1972 and 1973)

Level of P in soil Depth (in.)	Original	Treatment* I_1F_0	I_1F_1	I_2F_0	I_2F_1
0- 6	9.2	35.0	78.2	58.0	99.0
6-12	6.0	5.4	9.6	10.4	29.2
12-24	12.4	5.3	13.2	8.3	11.6
24-36	9.2	8.3	7.0	2.4	4.8
36-48	6.4	2.6	3.8	.4	.8
Total	43.2	56.6	111.8	79.5	145.4
P applied					
Irrigation		70.8	70.8	141.6	141.6
Fertilizer		0	71.8	0	71.8
Total		70.8	142.6	141.6	213.4
P uptake		42.4	44.9	52.5	61.2

*See footnote Table 5.

Table 7. Amounts of nutrients (lb/acre) applied in wastewater

Nutrient	Municipal (30 in.)				Potato wastes (30 in.)	Liquid sludge (80 tons)	
	Taber	Granum	Cranbrook	Ref 14	Ref 4	Ref 2	Ref 12
N	81	184	61	81	2,860	800-2,400	5,600-9,600
P	18	41	22	18	43	1,920-2,880	1,600-6,400
K	133			74	3,950		320-1,120
Na	666		218	191			
Ca	540		374	172			1,900-12,000
Mg	165		116	88			400-2,560
Fe		4.0				320-800	720-8,500
Mn		.6		.14		24-32	20-64
Cu	.03	.05	.07			24-32	32-190
Zn	.13	.10	.07			104-400	120-560
B			1.4	1.4			3-64
Pb		.03	.07			11-16	64-300
Cd							1.3-45
Cr							30-560

The crops listed in Table 8 vary greatly in the level of nutrients harvested from an acre of soil. The levels of micronutrients in any crop can vary by a factor of 10, depending on the concentration of the nutrients supplied. At Taber, the micronutrient concentrations in the alfalfa were low to moderate and decreased with increasing levels of irrigation. A comparison of Tables 7 and 8 shows that Na, Ca, and Mg can build up while N may be inadequate to supply the maximum yields necessary to remove the amount of nutrients shown in Table 8. The soil contains 4,000 lb/acre Na and more than ten times this much Mg and Ca; thus any increase in cations in the soil is not measurable. As noted earlier, P has built up in the soil at Taber (Table 6). This buildup will occur when more than 20 to 25 lb P/acre is applied to the forages.

WATER TRANSPIRATION

The maximum rate of wastewater irrigation is limited by the total amount of evapotranspiration (ET). The guidelines established by the British Columbia Pollution Control Board suggest 1.3 times the seasonal potential ET as the maximum rate of irrigation. Other provinces have even more restrictive guidelines. When land suitable for irrigation is limited, it is important to select a crop with maximum ET. Sonmore (13) measured ET for several irrigated crops in southern Alberta (Table 9). Only 7 to 16 inches of water was applied and thus higher values could be expected with weekly applications. Since the daily ET did not vary greatly, the longer growing season gives alfalfa, grass, and sugar beets a higher total ET. The longer growing season also lengthens the irrigation season. This is important where wastewater must be stored for the remainder of the year and where soil infiltration characteristics or insufficient equipment makes it difficult to apply the desired amount of wastewater.

EROSION PREVENTION

Any crop maintaining a complete canopy and adequate root growth will prevent erosion by wind or water. Forage crops maintain a cover through the winter and spring and thus are superior to annual crops where erosion may be a problem.

Table 8. Nutrients removed by crops (lb/acre)

Crop	Yield (tons DM/acre)	N	P	K	Na	Ca	Mg	Fe	Mn	Cu	Zn	B	Pb
Alfalfa	4	240	30	120	80	120	15	1.2	.08	.08	.20	.8	.03
Grass	4	120	20	150	40	80	10	.8		.05			
Pasture	.35 Beef*	21	5	1	1	9	.3						
Corn -													
Grain	4	136	32	70	.08	2		.2					
Silage	7	280	32	130		56	35	1.5	1.7	.1	.5	.7	.1
Cereals -													
Grain	2.4	85	12	45		15							
Forage	3.6	100	12	100	10	18	15	2	.20	.02		.3	.01
Vegetables -													
Potatoes	16*	110	17	130	1	100	12	.2	1.3	.10			
Lettuce	50*	180	22	330	25	25		.5				.2	.02
Trees	2	100	12	60	.4	40	4	.3	4	.02	.12	.12	
Fish	1*	57	4	6	.9	1							
Aquatic plants	1.2	35	4	33	15	300	15						

*Moist weight basis.

Table 9. Annual and daily evapotranspiration and length of growing season of several irrigated crops at Lethbridge

Crop	Evapotranspiration in./yr	Evapotranspiration in./day	Length of season (days)
Alfalfa	25.5	.163	155
Grass	23.6	.155	152
Wheat	19.4	.178	102
Field corn	19.2	.160	120
Potatoes	19.9	.149	137
Sugar beets	21.5	.138	156
Tomatoes	14.4	.140	103

SOIL PERMEABILITY MAINTENANCE

If the soil has a coarse texture or if the fine particles are held in stable aggregates, infiltration and permeability will be rapid enough to prevent ponding and runoff. A high ratio of $Na/\sqrt{Ca + Mg}$ (SAR) of the wastewater will disperse clay particles and restrict soil permeability. Organic matter in the soil is important in maintaining soil structure. This organic matter is replenished by crops having a large amount of root growth.

Soil structure is also important in maintaining aerobic conditions in the soil so that roots can absorb ions and microorganisms can break down and transform wastes. It is necessary to have an aerobic layer to allow ammonium ions to be transformed to nitrates so that denitrification can reduce harmful levels of N. Forage crops are effective in maintaining soil structure.

CONTROL OF PATHOGENIC ORGANISMS

We are concerned with the health and safety of any humans or animals utilizing the produce or return flow from wastewater irrigation systems. The operators of the system and any field workers must not be subjected to health hazards. Bacteria, viruses, protozoa, fungi, and ascaris ova are present in sewage wastewater and thus concern is warranted.

Coliform and, particularly, fecal coliform (fc) bacteria are frequently used to indicate the presence of such disease-causing bacteria as Salmonella (typhoid, gastroenteritis), Shigella (dysentery), and cholera-causing organisms. The fc test is relatively simple and is accepted by most workers. Fortunately, effective sanitation has practically eradicated typhoid fever, cholera, and amoebic dysentery in North America; however, they are still a problem in many countries. One infected person will transfer 200 billion pathogenic bacteria per day into the sewage system, which, mixed with a million gallons of wastewater, will give a concentration of 4,400/100 ml. In an excellent review article, Geldreich and Bordner (6) state that 1,000 fc/100 ml water is a realistic guideline for determining the safety of irrigation water. Wastewater used for irrigation at Taber was found to contain 54,000 fc/100 ml, or 54 times the suggested acceptable level (1). Raw sewage was 100 times this level. Certainly, more caution and restrictions on the use of wastewater are required than with normal irrigation.

We must immediately rule out the use of sewage wastewater on vegetable crops, such as lettuce and tomato, consumed raw by humans. With superior management, root crops such as potatoes, beets, and turnips can safely be irrigated with wastewater (5). Pathogens can survive in soil for 2 to 7 weeks (10); however, they will not enter undamaged roots. Root crops not directly consumed by humans, such as sugar beets, are a preferable alternative; however, these crops have a high requirement for field labor. There is a concern for their health and for the public acceptance of the produce.

The irrigation of forages utilized by livestock removes the produce one step farther from humans in the food chain. Animals have been watered directly with treated and even raw wastewater without adverse effects (11, 15). Only after gross contamination with raw sewage have animals been found to be infected (8). There may be more reason for concern if the effluent contains packing plant or abattoir wastes with anthrax, brucellosis, or tuberculosis organisms. Animals can safely be fed forages irrigated with effluent where irrigation was stopped 5 days before harvesting. In fact, Bell (1), working on our Taber plots, has shown that fc organisms on alfalfa plants were completely destroyed by exposure to 10 hours of bright sunlight at temperatures above 11°C. Exposure for 20 hours killed all the fc organisms when plants were irrigated with raw sewage. Little change in the fc population was noted in cool or cloudy weather. The best possible practice would be to dehydrate the forage before feeding.

Another alternative is to produce fiber, pulp, or forestry crops that are not consumed by humans or animals and thus provide pathogenic danger only to field workers.

SUMMARY

Sewage or industrial wastewater can be used to irrigate agricultural crops without endangering humans, wild or domestic animals, or the environment. Many crops can be used satisfactorily provided that they are capable of absorbing most of the applied nutrients, of protecting the soil from erosion, and of maintaining a stable soil structure. A crop should be selected that can transpire a high proportion of the applied water and provide maximum yields and a high monetary return to defray

expenses. Alfalfa has been used successfully at Taber and Granum in Alberta and at Vernon in British Columbia. It satisfies these requirements while being self-sufficient for N if the wastewater supply of N is inadequate. Other forages are used successfully elsewhere and should be considered if winterkilling of alfalfa precludes its use. Supplemental fertilizer N will be required if the wastewater supplies insufficient N for maximum growth of grass.

The system should not be designed without adequate characterization of the wastewater and soil. Ownership of the land or a long-term commitment is required by the municipality, and superior management is necessary. Problems will not arise as long as maximum productivity and human safety are considered as well as waste disposal.

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WATER POLLUTION POTENTIAL OF SPRAY IRRIGATION BY USING SECONDARY EFFLUENT

by

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WATER POLLUTION POTENTIAL OF SPRAY IRRIGATION

BY USING SECONDARY EFFLUENT

For the potential of irrigation water to cause water pollution to be realized, two conditions must generally be satisfied:

1) the treated effluent must reach a body of water that is being used, or may be used, for some purpose;
2) the quality of the applied liquid that finally reaches the particular body of water must be such that it detrimentally affects the usefulness thereof.

If effluent is applied to the land in excess of the crop requirements for water uptake, that excess liquid must enter the water resource inventory of the area. The effect that this lost water will have on the receiving water quality will depend on the impurities that are carried along in solution or suspension.

I <u>Impurities of Concern to Receiving Water Quality</u>

A. Public Health

The public health implications of this method of wastewater disposal are both biological and chemical. Assuming that we are dealing with a municipal effluent with no inordinately large component if industrial waste, the specific materials of concern are primarily as follows;

1. disease causing organisms - Secondary treatment plus chlorination is known to be highly efficient in the removal of pathogenic bacteria, but its ability to kill viruses, cysts and intestinal worm eggs leaves much to be desired.
2. nitrates - This common impurity in biologically treated sewage is of concern with regard to possible ingestion by infants, where it is reported that conversion to nitrites can occur in the gut, with the disease methemoglobinemia resulting. The conversion of organic nitrogen (which is present in raw sewage) to nitrate nitrogen is dependent upon the design and operation of the treatment facilities, as well as on the prevailing climatic conditions. Hence not all secondary treatment plants have high nitrate concentrations in the effluent.

3. heavy metals - In some communities there may be reason for some concern regarding the concentrations of various heavy metals in the municipal wastewater. Examples of heavy metals that are commonly found in municipal sewage include lead, mercury, arsenic and chromium.
4. biocides - Chemical insecticides, herbicides, fungicides and rodenticides do on occasion find their way into municipal sewage. Because a high percentage of these chemicals are extremely toxic, they are of concern even though they may only infrequently enter the system.

In general, the potential public health effects on useable bodies of water caused by impurities contained in the irrigated effluent should be small in comparison to the concern generated by the present policy of discharging effluent directly to receiving waters. The utilization of impurities by crops and the extra treatment occasioned by transport through the soil will assuredly cause a much lower mass of impurities to reach a receiving water.

B. Eutrophication

Where the enrichment of receiving waters to the point of causing nuisance problems is possible, consideration of two impurities from municipal sewage is necessary.

1. Nitrogen - Limiting values of nitrogen are difficult to assess under most conditions. However, concentrations greater than about 0.2 mg/l in the receiving water should be avoided where oligotrophic conditions are considered to be highly desirable.
2. Phosphorus - Concentrations of total phosphorus as low as 0.01 mg/l can give rise to characteristic enrichment symptoms in lakes. Sufficient enrichment to cause resulting taste and odour problems can occur at concentrations as low as 0.05 mg/l.

C. Aquatic Life

The prime pollutants of concern insofar as their potential effects on the viability of desirable aquatic species are specific heavy metals such as zinc, mercury and copper. Copper and zinc should be present at concentrations no higher than 0.1 mg/l, while the desirable mercury concentration would be significantly lower than this value.

II Transportation Pathways for Pollutants Reaching Receiving Waters From Spray Irrigation Sites

In order for pollutants contained in irrigation waters to cause a water pollution problem, they must somehow be transported from the spray irrigation site to a body of receiving water. There are a number of potential transportation pathways which warrant consideration.

A. Overland during irrigation.

This method of pollutant transfer occurs because the application rate of liquid is greater than the rate at which the soil can accept it. If the design application rate does not have a sufficient factor of safety built into it, this problem may arise toward the end of the irrigation season, or after the plot has been in use for a few years. Causes of such a temporal reduction in allowable application rates are:

1. the soil structure may tighten if proper calcium to sodium balance is not maintained;
2. organic content of the effluent may cause excessive bacterial growth in the top layers on the soil.

Any liquid which is allowed to exit from the irrigation site via the surface route will still have undergone some treatment, because of the adsorptive capacity of the soil over which it travels, and because of biological activity in the upper layer of soil which causes the extraction of nutrients.

B. Overland during Spring Snowmelt or Rainstorms

Surface runoff occasioned by rain or by snowmelt has the capability of desorbing previously adsorbed impurities as this relatively pure water flows overland in contact with the soil particles.

C. Vertical Leaching by Excess Irrigation Water

Normal irrigation practice demands that the total amount of irrigation liquid applied be greater than the amount actually utilized by the crops. This practice allows dissolved salts that are deposited in quantities greater than the equilibrium amounts to be flushed away from the root zone of the crops, and hence help prevent the formation of poor chemical conditions that might hinder crop growth.

The question of the most desirable amount of excess water is not answerable in terms of a definite percentage that is universally applicable.

In fact, the actual amounts of water used by various crops under various climatic conditions are not well documented. In general, the more excess water used, the more impurities that will be moved deeper into the soil horizons, and eventually into groundwater. The general logic of this statement is supported by two facts:

1. as more effluent is added to cause more root zone flushing, there is also a greater mass of impurities being added;
2. the higher the water flow, the higher will be the percentage of impurities that do not get a chance to stay adsorbed to the soil particles.

D. Vertical Leaching by Precipitation or Snowmelt

Impurities previously adsorbed onto soil particles can be partially removed by the percolation of relatively pure water from snowmelt or precipitation. This is especially true on irrigated land because the soil is generally close to its maximum water retention content at the time the precipitation or snowmelt occurs, and hence a significant portion of the natural water can pass through the crop root zone, rather than being retained therein for crop use.

This pathway will, of course, be of relatively more importance in regions of high rainfall like the Fraser Valley, as opposed to a region of low rainfall like the Okanagan.

III Movement of Nitrogen Forms

The effluent application water will contain both ammonia nitrogen and nitrate nitrogen, with the relative amounts of each being very dependent upon the degree of nitrification that occurs in the secondary sewage treatment. In areas where there is a significant change in ambient temperature from one season to the other, the relative amounts of ammonia and nitrate forms might be subject to considerable variation.

A. Overland runoff

Any nitrate nitrogen will travel with the carrier water in an essentially unabated concentration, because nitrate is only very slightly adsorbed by any soil particles.

Ammonia nitrogen may very well be adsorbed by surface soils, but with time it will be slowly nitrified to nitrate by the action of aerobic bacteria. If it has not been utilized by crops, then the next occurrence of overland runoff can very easily mobilize the nitrate again and hence transport it to the nearest body of receiving water.

B. Vertical movement

The amount of vertical movement of nitrogen forms depends upon the characteristics of the soil profile and the presence or absence of aerobic conditions therein. Nitrates in the effluent will pass essentially unabated, at least until an anaerobic zone is reached. If such a zone is encountered, nitrate can be converted to nitrogen gas by resident denitrifying bacteria, and hence be lost from the water system.

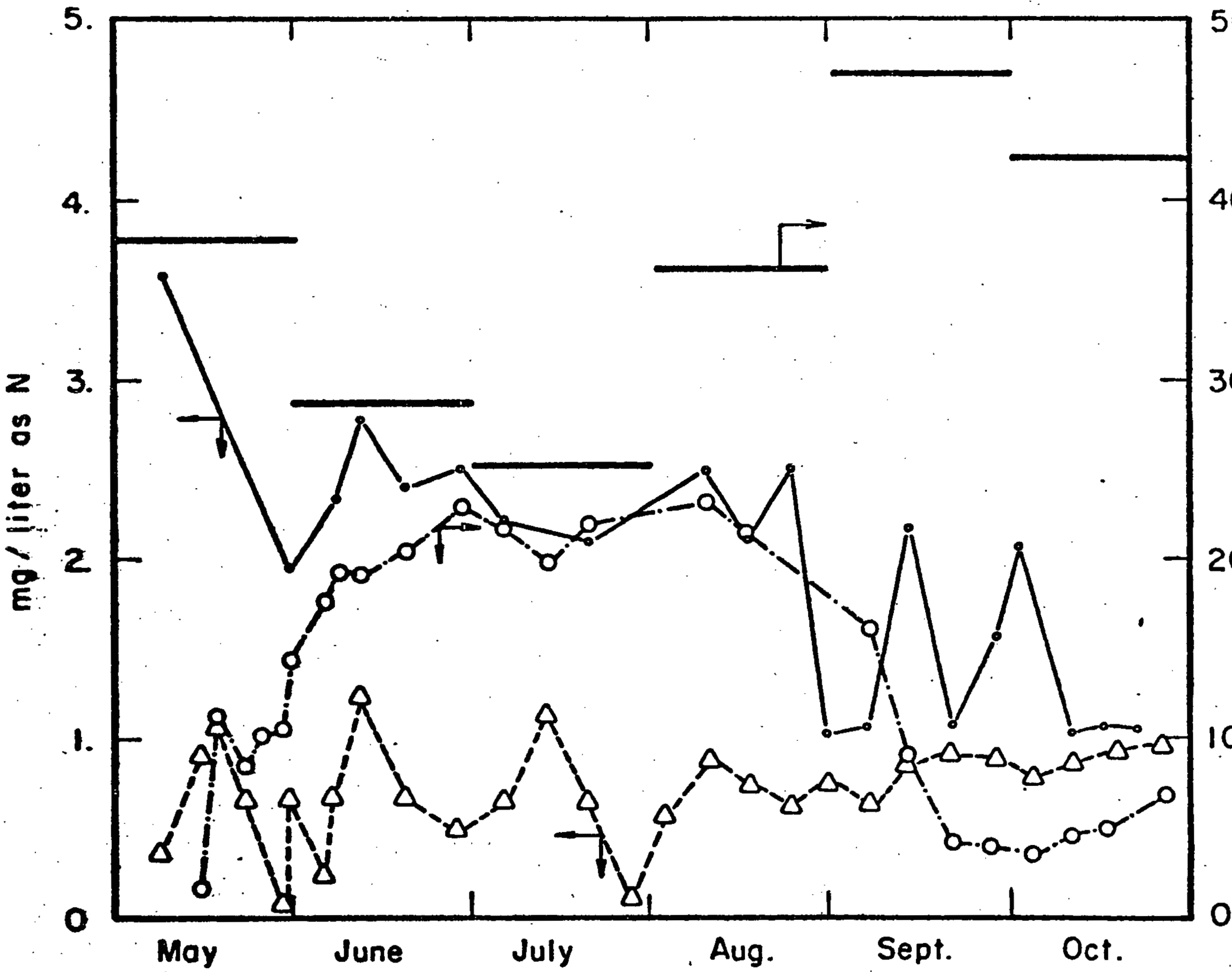
Ammonia nitrogen will be relatively highly adsorbed onto the soil particles as the water passes downward. If conditions are aerobic, nitrification can occur, and the resultant nitrate nitrogen will be re-mobilized, and will act as discussed previously.

Once the nitrate contacts the groundwater table, the potential for reduction to nitrogen gas under anaerobic conditions is lessened, because saturated conditions are not as conducive to the growth of denitrifying bacteria as are unsaturated conditions that prevail during the vertical movement of the irrigation water.

The speed and hence degree of biochemical change in nitrogen forms that occur depends on many factors such as temperature, soil type, and oxidation-reduction potential. It is essentially impossible,therefore, to estimate changes in nitrogen forms that will occur as a simple function of soil depth for instance.

The degree of adsorption of ammonia nitrogen that occurs depends almost entirely upon soil characteristics. Figures 1 and 2 show temporal variations in both total Kjeldahl nitrogen and nitrate nitrogen that were measured in three different types of Okanagan soils that were dosed with septic tank effluent at the following rates[(1)]: silty loam - 5.1 lb./acre-month of total nitrogen; loamy sand - 6.4 lb./acre-month of total nitrogen; sand - 37.8 lb./acre-month of total nitrogen. As a comparison, the nitrogen loading which would occur from conventional spray irrigation rates of secondary effluent would amount to about 27 lb./acre-month. Another major difference in the system described in Figures 1 and 2 from a spray irrigation system is that there was no plant uptake of nutrients in the septic tank system, whereas a spray irrigation system is designed to have a fairly high percentage of crop utilization for its applied nutrients.

FIG. 1
TKN CONCENTRATIONS IN LEACHATE FROM LYSIMETERS.

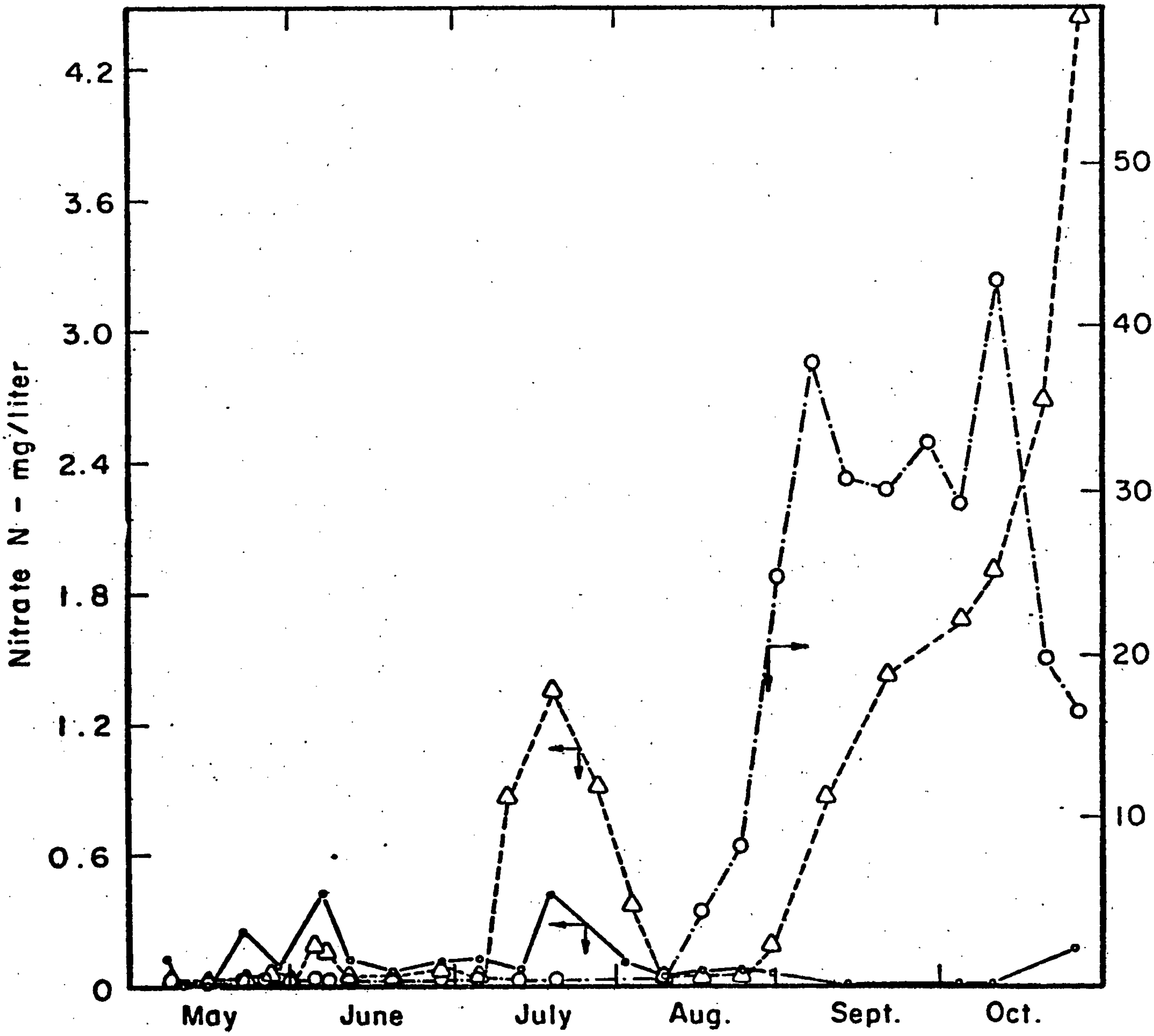


LEGEND:

- • Silty loam
- △ Loamy sand
- o Coarse sand
- — Monthly average concentration applied

FIG. 2

NITRATE NITROGEN CONCENTRATIONS IN LEACHATE FROM LYSIMETERS.



LEGEND:

- ∘ Silty loam
- △ Loamy sand
- o Coarse sand

Average influent concentration of NO_3-N = 0.07mg/liter

IV Movement of Phosphorus Forms

Effluent from secondary treatment plants contains phosphorus primarily in the form of dissolved ortho-phosphate. Okanagan Valley experience indicates that effluent contains about 6 mg/l of phosphorus in the ortho-phosphate form, with about 1 mg/l in other forms such as dissolved polyphosphate and particulate ortho and polyphosphate.

A. Overland runoff

The phosphorus content of effluent lost to the irrigation site by overland runoff will be reduced substantially due to adsorption of the phosphorus onto the surface particles of soil (provided it has not been previously saturated with phosphorus). Thomas[(2)] found that total phosphorus was reduced by about 60% during runoff from grass plots that were loaded at a rate of 3 to 4 inches per week of raw sewage.

B. Vertical Movement

Phosphorus is highly adsorbed to most soils, and is not generally made mobile again by biological action (as nitrogen is). That different soils do have differing adsorptive capacities for phosphorus is amply demonstrated by Figure 3. The phosphorus loadings applied to the lysimeters referred to in Figure 3 were as follows[(1)]: silty loam - 4.3 lb.P/acre-month; loamy sand - 5.4 lb.P/acre-month; sand - 32.2 lb.P/acre-month. By comparison, the loadings from conventional spray irrigation of secondary effluent would be about 8.2 lb.P/acre-month in the Okanagan Valley. As was the case with the nitrogen data presented earlier, Figure 3 presents data obtained from a situation where no plant uptake of nutrients is involved.

V Movement of Bacteria, Ova and Cysts

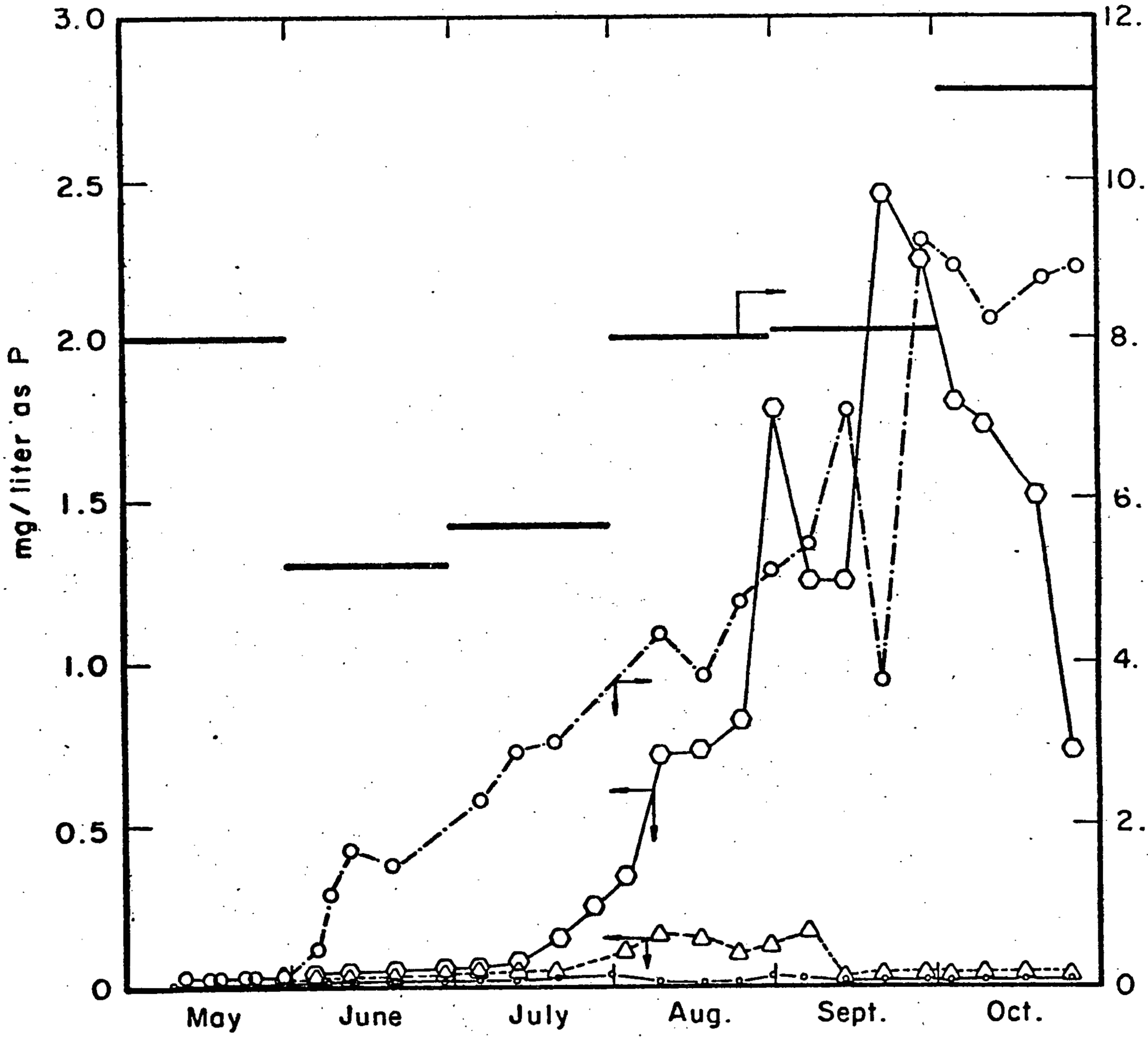
In general, these organisms are completely filtered out by all but coarsest natural soils within a very few feet of travel. Therefore, as long as a few feet of soil are available before the effluent leaches into a body of water that is used for human consumption or contact, no significant problems should arise.

VI Movement of Viruses

Overland movement of irrigation liquid should give rise to significant virus reduction, as the method of removal is deemed to be one of adsorption, rather than filtration[(3)].

FIG. 3

DISSOLVED ORTHO-P CONCENTRATIONS IN LEACHATE FROM LYSIMETERS.



LEGEND:

- • Silty loam
- △ Loamy sand (4' deep)
- ○ Loamy sand (2½' deep)
- o Coarse sand
- — Monthly average concentration applied

Removal of viruses by soil during water percolation should be a function of soil type and time, if adsorption is indeed the removal process. Experience with sand filtration at low rates (50 gpd/ft^2) showed removal rates between 20 and 90%[4]. Fine soils should perform much better than this, but very little definitive work has been done.

VII Movement of Heavy Metals

Heavy metals are, in general, very readily adsorbed to soil particles, and thus are attenuated either by overland flow of effluent in thin sheets, or by movement of effluent through the soil. Water pollution potential is therefore minimal.

Metals, once adsorbed onto the soil particles, are usually very difficult to displace by desorption into excess water. In one investigation[5], added mercury was found to be 70 - 100% adsorbed on the root zone soil, but only 0.2% was desorbed by future additions of water.

If relatively clean sands are involved, then the adsorptive capacity for heavy metals may be quite low, much as was the case for phosphorus as shown in Figure 3.

VIII Exotic Organics

The movement of exotic organics, such as that fraction of the dissolved organics not removed in secondary treatment processes, is usually minimal. One or more of the functional groups making up these complex organic molecules is generally capable of being strongly sorbed to the soil particles. There is probably more danger regarding water pollution from exotic organics such as pesticides that are applied separately from the irrigation water than there is from organics contained in the irrigation water itself.

IX Summary

The danger of water pollution resulting from the spray irrigation of secondary effluent is probably the least worrisome aspect of such a disposal practice. As long as adequate consideration is given to soil type and available depth of unsaturated soil at the time of design, and as long as inordinately high liquid loadings are not imposed on the soil once operation of the facility has begun, water pollution problems will be many times less than that which occurs from water discharge of the same treated effluent.

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FACTORS INFLUENCING THE DESIGN OF SEWAGE EFFLUENT IRRIGATION SYSTEMS

by

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FACTORS INFLUENCING THE DESIGN OF SEWAGE EFFLUENT IRRIGATION SYSTEMS

I. INTRODUCTION

Man has been discharging nutrient-rich, organic wastes to aquatic environments for a long time with an amazing lack of concern. In recent times, however, we are slowly becoming aware of the consequences of indiscriminate waste discharge. "Beach Polluted-No Swimming" signs, aquatic weeds, and algae are blooming in many lake systems as Nature seeks to force an environmental consciousness on us. We are being made aware that if we continue our present waste discharge practices we will have to live with some undesirable consequences.

These consequences are not necessarily unavoidable, however. There are at least two options we can follow to avoid the undesirable effects of waste discharges. We can remove the troublesome organic and nutrient components from the effluent prior to effluent discharge to a water body; or we can remove the discharge from the water body entirely and apply the effluent to a soil-plant system instead, a system where the water, nutrients, and organic matter can be utilized in a beneficial way. This paper, and today's seminar, are devoted to discussion of only the second of these two alternatives. A parallel seminar on in-plant methods for tertiary treatment of domestic wastewaters should be held in the near future, to provide a full basis of information from which rational and intelligent decisions concerning the selection and design of effluent treatment and disposal systems can be made.

The phrase "application of effluent to land" includes all systems in which some use is made of the ability of soil systems to renovate wastes. By accident or design, this normally includes renovation by plants as well. In a very general way, land application techniques can be subdivided into surface and subsurface systems. Subsurface systems are most likely restricted to use in only very small systems and will not be discussed directly, although many of the principles of surface irrigation will apply to subsurface systems. The techniques of surface application of effluent to land are commonly grouped into three categories: irrigation; overland flow; and infiltration-percolation.

I would like to briefly describe each of these three techniques, since each of them could certainly have an application in British Columbia. Further discussion of system design however, will be limited to irrigation systems. It should be understood that most of the principles discussed in connection with irrigation systems will also apply to overland flow and infiltration-percolation systems.

1. Irrigation Systems(6,8)

Effluent irrigation is the most common technique of land application of sewage, and involves the surface or spray application of effluent to land in quantities sufficient to meet plant requirements. The wastewater is incorporated into plant tissues, given off to the atmosphere through evapotranspiration, and in limited quantities, may percolate through the soil to groundwater. Application rates of 1 to 2 inches/week are common, with a maximum of 4 inches/week (systems applying effluent at rates higher than this are arbitrarily regarded as infiltration-percolation systems). Effluent irrigation is practised on a variety of crops and landscapes, including forest and range lands, hay and silage crops, pasture lands, vegetables, golf courses and other recreational areas. Land requirements for effluent irrigation systems are high.

2. Overland Flow Systems(6,8)

Overland flow systems have been used primarily as a means of treating wastes from food-processing plants. Their use is being considered as a means of providing secondary or even tertiary treatment of domestic wastewaters, but this is still regarded as being in the experimental stages. Treatment is accomplished through evapotranspiration soil fixation and plant filtration as the wastewater flows through vegetation on a sloped surface. Optimum sites have 6 or 8 inches of permeable soil overlying an impermeable subsoil. Wastewater is applied by spraying at the upper edge of the slope. Slopes of 2 to 4% are preferred. The degree of treatment achieved is a function of the slope angle, slope length, type of vegetation, soil conditions, climatic conditions, and loading rates. Treated effluent is collected at the toe of the slope, disinfected if necessary, and discharged to a water-course or reused for agricultural irrigation purposes. Due to the impermeability of the subsoil, the opportunity for groundwater contamination under overland flow systems is limited.

3. Infiltration-Percolation Systems (6,8)

In this form of treatment, wastewater is applied to the soil in surface spreading basins or through high-rate spray irrigation systems. Renovation is accomplished by physical, chemical, and biological mechanisms as large volumes of effluent infiltrate the soil surface and percolate through the soil to groundwaters. This approach to effluent application to land permits virtually complete recovery of renovated wastewater through groundwater recharge. Only a small portion of the applied effluent is lost to the atmosphere through the process of evaporation and transpiration. These systems have further advantages of requiring very little land area and greater ease of winter operation. The major limitation to the use of infiltration-percolation systems is the very high potential for groundwater contamination with pathogens and nutrients, especially nitrogen; due to the high rates being applied to a very limited land area, phosphorus retention capacity of the soils may not be of long duration. A depth of 15 feet to the natural groundwater table is regarded as a minimum to ensure adequate treatment. Well-drained, but not excessively drained, soils, with enough fine particles to ensure renovation are required. Provision of resting periods for re-aeration of the soil are essential to prevent pore-clogging.

4. Combined Systems

Limitations of land area, topography, climatic conditions, or public sentiment may make it necessary or desirable to make use of more than one method of effluent treatment and disposal. Consideration should be given to the combination of several methods of surface and subsurface application, possibly in conjunction with in-plant treatment and discharge to a water body. Such combinations may utilize different waste treatment and disposal techniques to handle all of the flow for part of the year, or to handle a portion of the flow for all of the year.

II. FACTORS INFLUENCING SYSTEM DESIGN

Effluent irrigation has been considered in some areas where stream flows are too low to ensure adequate dilution and dispersion of effluent. In other areas, effluent irrigation has been investigated as a means of reducing cultural nutrient additions to receiving waters, thereby slowing the rate of eutrophication. And in some areas effluents are an important source of water, and are recycled for crop irrigation and groundwater recharge. Whatever the reason, it is apparent that the design of the system should strongly reflect the function it is intended to serve.

Similarly, the design of an effluent irrigation system must reflect the nature and composition of the wastewater. The chemical and bacteriological composition of the influent wastewater, in combination with the intended purpose of the system largely determines the nature of the treatment system. In addition, effluent composition is an important parameter determining the long-term viability of the soil-plant system.

Wastewater treatment design and the land area required for irrigation at a given site are functions of wastewater quantity. Information on flow variability and maximum and average flows to be anticipated on an hourly, daily, seasonal, and annual basis must be available for design purposes. Obviously, hourly and daily flow variations will be of greater significance to the design of an activated sludge plant than to a 3-cell lagoon system. Expected annual flows become more important when used in conjunction with climatic data to calculate the required storage volume and the acreage of land needed for irrigation purposes.

Design flow rates are a function of the size of the population serviced and their living habits, and of the rate of groundwater infiltration into the collection system. None of these are constant; they vary from season to season and year to year. However, an assessment of population growth and water usage over at least the next 25 years is very important at the design stage for an effluent irrigation system. The availability of a sufficient area of suitable land for effluent irrigation to meet the present needs of some cities is already limited. To ensure that a system continues to be adequate (at least until the mortgage is paid off), it is important that sufficient land be reserved in advance.

In planning a wastewater treatment and disposal system involving the application of effluent to land, it is necessary to understand the composition, or quality of the wastewater in addition to knowing the quantity. Composition is strongly influenced by cultural phenomena and by the inclusion of stormwater and industrial connections. Conductivity, pH, salt balances, nutrient values, and heavy metal content of the effluent significantly affect the performance and viability of a soil-plant system. In addition to the data normally required on effluent BOD and Suspended Solids, it is essential to know the amounts and forms of nitrogen and phosphorus, of sodium, potassium, calcium, and magnesium, of sulfates and chlorides, and of heavy metals. Values of effluent pH, conductivity, and alkalinity should also be known.

Site characteristics are of equal or perhaps even greater importance than the wastewater itself in the design of an irrigation system. If effluent irrigation is to be practised as an environmentally preferable alternative to discharge to receiving waters, then the system must be designed and operated in harmony with Nature. We must consider the physical, chemical, mineralogical, lithological, and biological properties of soils as they affect effluent renovation and plant growth.

Soil properties or characteristics of concern in the design of irrigation systems include:

- infiltration and percolation rates
- drainage and water storage capacity
- depth to groundwater
- soil structure and permeability
- soil texture and clay mineralogy
- cation exchange capacity
- exchangeable and soluble salts
- pH and conductivity
- organic matter, nitrogen, and phosphorus levels
- soil morphology and horizonation
- lithology and the presence of restricting layers

Plants are an integral component of systems in which effluents are applied to land. The requirements of existing or proposed vegetation for water and nutrients and tolerances to other contaminants should therefore figure strongly in system design.

The land system we are considering begins with the upper parts of the plants being irrigated, and extends down through the soil to a depth that includes at least the upper parts of the groundwater regime. Topographic variations in the landscape of an irrigation site will be reflected by variations in soils. Irrigation of different soils will produce variations in crop response. It is essential therefore that variations in soil characteristics and properties be identified in detail at an early stage in system design. Design and management of the irrigation system must reflect these identified variations in the soil landscapes.

In a similar way, and because soils are natural landscapes, system design must take into consideration the lands outside the system. The topography of the surrounding landscape affects the surface and subsurface movement and distribution of water through the irrigation site. The uses, quality, rate and direction of flow of groundwater both upslope and downslope of an irrigation site must be known and changes to any of these predicted in advance of irrigation.

Regional climate and site microclimate will affect the efficiency of lagoon treatment systems, evaporation from storage ponds, the amount and rate of evapotranspiration (or consumptive use of water by plants), soil moisture, the potential for surface runoff, the length of the irrigation season, and the desired width of any buffer zones. Climatic factors for which information should be available for design purposes include:

- length of frost-free season and growing period
- amount and distribution of precipitation
- record maximum and minimum annual precipitation
- seasonal and annual evaporation rates
- daily, seasonal and annual evapotranspiration rates
- temperature and humidity
- anticipated average and maximum wind velocities and directions

A host of cultural factors constitute the final design criteria for which information must be available. Population projections were mentioned briefly in connection with flow data. Population must also be considered in terms of existing and projected settlement and land use patterns of the region. Adequate protection of the public health must be given high priority in the selection and design of the treatment system, the method of application, the nature of the crop raised, and the location and characteristics of the irrigation site. The nature of the treatment and disposal system will also be influenced by the relative availability of capital and labour.

III. THE DESIGN PROCESS

The information outlined above must be available in order to assess the feasibility of effluent irrigation as an alternative to advanced wastewater treatment and discharge of effluent to a receiving body of water. This same information will be needed to determine the design, location, and operation of the effluent treatment, storage, and application facilities. The purpose of this section is to illustrate the use of information in the design and operation of effluent irrigation systems with particular reference to conditions in British Columbia.

1. Sewage Treatment

Sewage discharges, and subsequent irrigation of produce eaten raw have been known to cause outbreaks of communicable disease. In all documented cases, night-soil, untreated sewage, or primary sludge appear to have been the source of contamination. To limit the spread of disease through sewage irrigation of crops, a number of European countries require that sewage must receive at least primary treatment before the irrigation of any crops[(1)]. A report prepared for the World Health Organization[(2)] suggested that primary and secondary treatment of wastewater, followed by chlorination and perhaps by sand filtration or polishing would produce an effluent suitable for the unrestricted irrigation of agricultural crops; such irrigation would result in only limited health risks. If irrigation was limited to crops which were only to be eaten cooked, then disinfection and/or polishing might not be needed. Only primary treatment was considered necessary if the effluent was to be used for irrigation of forage crops, or crops not intended for direct human consumption.

Primary treated effluent may be considered acceptable for spray irrigation of forage crops in many areas, but it is felt that the associated risk to public health is too large to recommend this practice in British Columbia[(3)]. Because of the large numbers of pathogenic bacteria and viruses which could be present in primary effluents, there is a strong possibility of disease transmission by aerosols occurring. Extensive buffer zones around the irrigation site would be required to reduce the aerosol hazard. Furthermore, it would be absolutely necessary to exclude the public from the spray and buffer areas. Both requirements are likely to be difficult to fulfill.

A separation of one or two months between irrigation with primary effluent and crop harvest would be necessary to provide reasonable assurance that most of the pathogenic bacteria and viruses present in the primary effluent had died off. Complete removal of worm eggs cannot be guaranteed by primary treatment. Spray irrigation of primary effluent would quite probably lead to contamination of the irrigated area with worm eggs and lead to infection of grazing animals. For these reasons, it is believed that irrigation with primary treated effluent cannot be recommended for British Columbia[3].

All sewage which is to be used for irrigation purposes in British Columbia should receive secondary (i.e., biological) treatment to reduce the numbers of pathogenic bacteria and viruses which may be present[3]. Secondary treatment of sewage may be achieved through the use of activated sludge or trickling filter plants or through a variety of lagoon systems.

Selection of a treatment process is based on a number of factors, but as a rule, the nature and condition of existing facilities, and their ease of expansion to meet projected future flows, play a major deciding role. For entirely new systems, the choice will likely be influenced by the lower operation and maintenance costs associated with lagooning. Lagoon construction costs will vary according to the ease of soil excavation and the need for bottom linings. The need for winter storage of effluents in this province is likely to favor the use of lagoon treatment systems since lagoons permit effluent treatment and storage in the same facility, an important cost-saving feature.

A variety of lagoon systems are in common use in Michigan[4] for effluent treatment and storage prior to irrigation. Small systems (population 5,000) often make use of naturally aerobic oxidation ponds (4.5 to 6.5 feet deep); generally 3 cells are provided and operated in series or parallel. Detention time in such lagoons ranges from 3 to 5 months[5]. Cold winter temperatures reduce treatment efficiency and BOD loadings are limited to a maximum of 20 pounds/acre/day[4].

Deeper facultative lagoons or mechanically aerated ponds (10 to 15 feet deep) followed by holding ponds can be used for larger communities. Seasonal temperatures, precipitation and evaporation criteria must be considered in determining the design size and efficiency of lagoon treatment systems.

As a rule, the content of heavy metals, salts, and other contaminants in domestic wastewater is very low. Should analysis of the wastewater indicate that any of these may result in undesirable consequences in the soil-plant system, it may be necessary to provide for their removal prior to irrigation.

In most cases, the effluent should also be disinfected prior to being used for irrigation purposes. In the near future, chlorination will likely continue to be the most common method of disinfection. Where public contact is limited, as in the irrigation of rangelands, hay, or pasture, an O-tolidine chlorine residual of 1.0 ppm after one hour contact time, with proper mixing, should provide adequate disinfection. If the effluents are to be used for irrigation of vegetables or recreational areas, then a greater assurance of public health safety should be provided through chlorination to residuals of 3.0 ppm. The effluents from lagoons of several months detention time (four to six months or longer) are likely to have very high levels of suspended solids, in the form of algal cells, which will significantly reduce the effectiveness of chlorination. Since most pathogenic micro-organisms appear able to survive for periods ranging from only a few days to one or two months, and since parasite eggs will have settled during retention, it is believed that lagoon effluents could be used to irrigate forest and rnagelands without chlorination. However, if such effluents were to be used for irrigating pasture crops, they should be disinfected: treatment to reduce the suspended solids will probably be necessary prior to chlorination[3].

If the irrigated lands are to be used for grazing or pasturing livestock, it will be necessary to ensure that the ova and cysts of parasites have been removed. It is therefore suggested that storage for one week or sand filtration after secondary treatment should be provided. This would not be required if the effluent were treated in a lagoon system.

2. Effluent Storage

Many of the considerations involved in the design of lagoon treatment systems reappear in the design of storage facilities. In many cases, the storage facilities will be an integral component of the treatment facilities. While the feasibility of winter irrigation of forestlands with sewage effluent has been demonstrated in the United States, it is not yet considered a suitable method for British Columbia.

Where a sufficient volume of receiving water is available and where nutrient removal from the effluent is not essential, then winter discharge of effluent to a receiving body of water may be considered in lieu of providing over-winter storage. Subsurface discharge of effluent to tile fields could also be given consideration in some instances. In general, however, it will be necessary to provide storage of the effluent over the winter, so that irrigation is practiced only during the frost-free period.

Effluent storage may also be required during exceptionally wet years when a larger than normal portion of the plant water requirements can be met through precipitation additions. Additional, short-term storage may be needed during periods of intense rainfall occurring in the irrigation season and for a short period at the time of harvest to permit proper drying of crops such as hay.

As a guide, the irrigation season in the Southern Interior of British Columbia is approximately 150 days, from May 1st to October 1st. Local climatic conditions can result in deviations of 1 month up or down at each end of this range, however; storage and irrigation design should reflect local climatic conditions. Storage facilities must be adequate to handle the design sewage flow during the remainder of the year, with an allowance for temporary storage due to heavy rains or crop harvests. Furthermore, there should be sufficient freeboard in the storage structures to provide storage of precipitation received as well; for this calculation, the amount of precipitation received during the wettest year on record should be utilized.

Storage facilities must include pump-back provisions so that partially treated effluent is not discharged to the irrigation system during periods of treatment system overload or failure[6]. It may be necessary to seal storage facilities to prevent exfiltration of stored effluent and contamination of groundwater in areas where naturally impervious storage sites cannot be readily found. A variety of materials (rubber, plastic, asphalt, clay) can be used for this purpose. Comprehensive geohydrological studies should be conducted at all potential effluent storage sites to define the nature of soil materials and the groundwater regime to determine the possibility of exfiltration and groundwater contamination and thereby to determine the need for and design of an appropriate liner.

It is conceivable that odours may develop in systems requiring long-term storage of the effluent over winter. Odours are the product of anaerobic decomposition. In such cases, it may be necessary to consider designing the storage ponds as stabilization ponds (i.e., with partial aeration of the stored wastewater) to prevent odour generation[6].

3. Irrigation Site

a) Land Area and Application Rate

A number of factors bearing on site design were identified earlier. These included the nature and volume of wastewater, topography, soil characteristics and variations (in both areal and vertical senses), plant cover, depth to and nature of the groundwater regime, site climate, and cultural features of the surrounding lands. To some extent, each of these factors is involved in determining the area of land required for effluent applicaiton. The area of land required, or synonomously, the design annual rate of effluent application/acre should be determined through a series of effluent constituent loading rate computations. Not only water balances, but also nitrogen and phosphorus balances, organic loadings, and loadings of dissolved and suspended solids should be determined[6]. Suspended solids may be separated into organic and inorganic components. Dissolved solids may be separated into those which can move freely through the soil to groundwater (i.e., chlorides, sulfates, nitrates, and bicarbonates) and those which may be retained and accumulate in the soil (i.e., sodium, potassium, calcium, magnesium, boron, heavy metals, fluorides) depending on pH, clay content and mineralogy, organic matter, water content, etc.

On the basis of the analysis of wastewater characteristics and requirements for plant growth and groundwater protection, any of these constituents which might have a limiting loading rate should be considered and a resulting land area requirement should be calculated for comparative purposes.

For irrigation systems, the amount of effluent applied, plus precipitation received during the irrigation season, should equal the amount of water lost to the atmosphere through evapotranspiration plus a limited amount of water lost through deep soil percolation.[6] Surface runoff of effluent from fields should not be allowed or should be controlled. The water balance is therefore:

Precipitation + Effluent Application = Evapotranspiration + Percolation.

Seasonal variations in each of these factors should be taken into account through calculation of water loading rates on a monthly basis. The figure used for design precipitation should represent a wetter than normal year (perhaps the wettest year in 10), and can be obtained through analysis of long-term precipitation records. Evapotranspiration rates vary according to a number of climatic factors and the nature and stage of crop growth. Some amount of percolation is necessary to leach or remove the soluble salts which accumulate in the roote zone as a result of evaporation. Calculation of the leaching requirement is explained in the U.S. Department of Agriculture Handbook No. 60, "Diagnosis and Improvement of Saline and Alkali Soils".

Since nitrate-nitrogen is completely free to move through the soil with percolating wastewater unless intercepted by plants, is is important that a nitrogen balance be calculated for prospective irrigation systems. Nitrogen in the ammonia form may be retained for a short time in soils through ion exchange phenomena. However, it is inevitably converted to nitrate and becomes highly mobile. Nitrogen in surface waters or groundwater is very much a resource out of place, capable of causing methemoglobinemia when present in drinking water in the nitrate or nitrate forms in concentrations greater than 10 ppm, and of stimulating algal blooms when present in surface waters in concentrations as low as 0.3 ppm.

On an annual basis, nitrogen applied through irrigation can be accounted for through plant uptake, soil storage, denitrification and volatilization, and leaching to groundwater or surface water. Denitrification and volatilzation losses will generally be of minor importance in effluent irrigation systems. Crop uptake of nitrogen varies with the type of crop and may range from 50 to 600 pounds/acre/year, with most crops removing from 100 to 200 pounds/acre/year[6].

For crop uptake of nitrogen to be an effective method of nutrient removal, the crops must be harvested and removed from the site. Nitrogen which is not utilized by crops and removed from the site will normally be lost to groundwater. As a guide, domestic effluents contain from 15 to 30 ppm nitrogen. During 21 weeks of application at 1.5 inches/week (700,000 gal/ac/yr), we can expect to apply anywhere from 105 to 210 pounds of nitrogen/acre. Actual nitrogen content will vary considerably between effluents. This should always be determined and compared with crop requirements.

Phosphorus budgets should also be calculated during the design of effluent irrigation systems. Effluent phosphorus levels are usually considerably lower than nitrogen, perhaps in the range of 5 to 10 ppm, and since the capacity of most soils to retain phosphorus through fixation and precipitation is quite high, groundwater contamination with phosphorus is not as great a problem.

Organic loading rates of 10 - 25 pounds/acre/day can be handled readily by most soils and in fact may be needed to maintain a static organic matter content in the soil(6). Application of 5000 gpd (1.5"/week) of secondary effluent (BOD = 30 ppm) leads to the addition of only about 1.5 pounds organic matter/acre/day and should create few problems. Resting periods between irrigation applications are necessary to allow drainage and aerobic decomposition of the added organic matter. In some cases resting periods of only 4 or 5 days have been used. Normally irrigation intervals range from about one to three weeks, depending on soil moisture holding capacity and the rate of evapotranspiration.

Ideally then, the acreage required for irrigation purposes should be determined through comparison of balances for water, nutrients, organics and other contaminants; the design area should be based on the most limiting loading rate. In this way, none of water, nitrogen, phosphorus, organics, boron, heavy metals, etc. should create environmental problems on or off the irrigation site.

In determining the total land area required for the treatment and disposal system, consideration must also be given to determining the amount of land lost to roads, buildings, areas unsuitable for irrigation, treatment and storage facilities, and buffer strips.

b) Topography

Topography is an obvious factor controlling the shape and area of an effluent irrigation system as well as the methodology and rate of application. Flood irrigation systems usually require slopes of less than 1%: spray irrigation has been successfully practiced on slopes up to 40%. A detailed evaluation of the topography of the site and adjacent lands should be prepared during the design process. A base map, perhaps of a scale of 1 inch = 50 feet and with 2 foot contour intervals should be prepared.

Such a base map can also be used to evaluate the effects of storm runoff, both from adjacent land onto the site and from the site onto adjacent land and surface water bodies. Storm intensities, irrigation rates, topography, cover crop and soil conditions should be considered together to evaluate the potential for soil erosion from the site. Management plans to control runoff and/or erosion should be prepared if warranted. The topographic base map will also be useful in the design of effluent distribution systems. Plotting groundwater data on the map will be helpful in determining the need for underdrains and for recording changes in the depth to groundwater and its direction of flow due to irrigation.

A review of topographic features of the irrigation site, in conjunction with irrigation methodology, the degree of wastewater treatment provided, and cultural features of the surrounding landscapes will indicate the need for buffer strips around the irrigation site. If a need for buffer strips is identified, then an analysis of wind patterns and irrigation equipment will be necessary to determine the width of the buffer zone. In areas where very wide buffer zones may be required, consideration should be given to reducing the requirement through the provision of additional waste treatment or to the use of the buffer zones for farm roads and buildings or for waste treatment and storage facilities. In some cases where an alternative source of freshwater is available, consideration could also be given to irrigation with fresh water and harvest of crops from the buffer area. Low-pressure and low-trajectory spray systems can be utilized to reduce buffer strip requirements. Similarly, hedgerow plantings of trees and shrubs around the perimeter of spray irrigation fields can be used to intercept spray mists, thereby reducing the need for buffer strips.

c) Crop Selection

Site suitability, design, and operation will be strongly influenced by the type of crop or landscape to be irrigated. There is no single preferred crop for use in effluent irrigation systems. Alfalfa is commonly considered in B.C. because of its value as a hay crop. However, Bermuda Grass will thrive under irrigation with saline waters that would reduce the yield of alfalfa by 50% or more, and make use of 4 or 5 times as much applied nitrogen at the same time. Corn has been grown successfully at some sites in Michigan[4] and elsewhere, but not without supplementary nitrogen. Corn requires cultivation too, which imposes more stringent topographic limitations on site suitability than for many other crops. In many places, perennial grasses such as timothy and tall fescue are popular. Reed's Canary grass is often used, because of its high nutrient requirement and ability to grow under wet conditions, but its market value as hay is limited. Golf courses and other recreational areas are often considered and sometimes utilized, but not without quite extensive pretreatment and storage requirements and perhaps some controls on the method and timing of application. Forest lands may be considered also, often because it is thought that they can accept higher rates of application, perhaps on steeper slopes, and perhaps on a year-round basis. Very likely, this could lead to the adoption of an out of sight - out of mind, low-cost approach to effluent disposal: forests have water balances too, and if these are ignored, over-irrigation can lead to erosion, runoff, and seepage problems.

Crop selection is very obviously the result of community desires and site suitability. If a community wants to irrigate and raise alfalfa and only alfalfa with its sewage effluent, it will have to meet specific treatment requirements and will have to find a sufficient area of land suitable for raising alfalfa. And if a community has one and only one site available (and that a steep slope, high elevation forest) then it will be limited in its choice of application rates and crops.

An ideal site is one that is close to town and at a similar elevation and yet not previously alienated by small farms or suburbia. The soils are deep, well-drained sandy loams or loams and the land surface is nearly level or gently rolling. The groundwater table is at a depth of 20 feet or more: irrigation will cause neither noticeable mounding to develop nor noticeable changes in the quality of regional groundwater resources. Such sites appear to be in very short supply in this Province.

In considering effluent irrigation then, the first design rule must therefore be to discard any preconceived notions about site location, crop selection, and method of treatment and application. Enter into the design process with an open mind.

4. Method of Application

The method of application has been mentioned in connection with site selection, crop selection, and the need for buffer zones. It is worthwhile to expand somewhat on that coverage. To a majority of people in British Columbia, the concept of "effluent irrigation" is synonomous with that of "spray irrigation". While this is a fairly good assumption to make, due to our shortage of arable land, especially of level arable land, it should be noted that there are other methods for applying effluents to land.

a) Flood Irrigation

Flood irrigation is probably the most simple and inexpensive method of applying effluent. The land surface must be flat or very nearly flat however. The irrigation site is divided into small fields and effluent applied to depths of 5 or 6 inches at intervals of 1 to 3 weeks. The size of each field and the instantaneous rate of application are related to the texture and infiltration rate of the soil surface to ensure even distribution. Small fields of 2 or 3 acres are required for sandy soils: larger 10 to 15 acre fields have been used on heavy, fine-textured soils[4]. The length of the resting period also varies with soil texture and waste composition: it must be long enough to ensure organic decomposition and a return to aerobic condiitons in the soil.

Such systems reduce the need for buffer strips as there is little chance for air transfer of microorganisms. Flood irrigation systems could therefore perhaps be considered for use in the buffer strips around effluent spray irrigation sites if topographic conditions were favorable. Because of the need for flat land, flood irrigation in B.C. will probably have its greatest application in meeting the needs of small communities or in handling a small portion of the flow from larger communities.

b) Ridge and Furrow Irrigation

Ridge and furrow irrigation requirements for flat land are not quite as restrictive as flooding systems, but nearly so. They are most commonly used on relatively flat sites with medium to heavy soils[4]. Ridge and furrow systems require low initial outlays of capital, but the costs of site preparation and maintenance are high. Irrigation is accomplished by gravity flow of effluent through parallel furrows or small ditches on the ground surface, spaced several feet apart. The technique is well suited to the irrigation of row crops.

c) Spray Irrigation

Spray irrigation systems are suited to a wider variety of soils, crop types, and topographic conditions. Initial outlays and power requirements can be high however. Site preparation is minimal and even distribution of the effluent can be assured. Spray irrigation of effluent is preferred for proper and effective crop management[4], although because of its potential for dissemination of microorganisms through aerosols, more consideration must be given to effluent treatment, storage, and the need for buffer strips or non-irrigated areas around the spray site.

There is a variety of sprinkler systems available for effluent irrigation purposes. Included are hand-moved portable lines, hand-moved gun sprinklers, travelling gun sprinklers, side-roll wheel moved systems, self-propelled centre pivot systems, and solid set systems. Each has characteristics which make it best suited to particular sites, crops, or economies of scale or labor.

Labor costs will likely preclude consideration of the use of hand-moved irrigation systems from all but the smallest of effluent irrigation sites. Additional pretreatment of the wastewater may also be required to overcome aesthetic and public health objections. Considerable operator attention is required of these systems. Such systems may have a greater possibility for use in the application of effluent to golf courses and other recreational areas. Hand moved gun-type sprinklers and travelling gun sprinklers (with a winch and cable arrangement) have been used in some areas. Such sprinklers can cover up to several acres per setting. They too, however require a lot of operator attention and may apply effluent at rates too high for some soil and topographic conditions. Their main application in effluent irrigation is likely to be as a means of picking up extra acres here and there in irregularly shaped areas of the irrigation site.

Side-roll wheel moved systems are commonly used for irrigation of hay and pasture lands in British Columbia today. This system has a lateral delivery pipe (4" diameter usually) which is supported off the ground by, and serves as an axle form metal wheels spaced 40 feet apart. A gasoline-powered engine mounted on a moveable platform in the centre of the line is used to propel the entire unit forward from one setting to the next. Lines can be up to 1/4" mile in length. With a sprinkler radius of 30 feet, these lines can cover at least 2 acres per setting. Two or 3 settings/day are possible, depending upon the desired rate of application, sprinkler head design, and availability of labor.

Self-propelled centre pivot systems can be used on relatively flat sites with sandy soils. These large irrigation rigs consist of a centre pivot with a long lateral (up to 1300 feet or longer) extending out from centre and supported by wheeled tripods (at intervals of 75 to 100 feet). Full length rigs can cover up to 160 acres. Smaller rigs may be used for irrigating areas of 40 acres or so, but these become more expensive to operate. Fields are circular and must be relatively flat, a potential drawback in many sites. Well drained sandy soils are essential: in heavier soils, the movement of wheels can lead to compaction and rutting.

Solid-set (permanent set, buried) irrigation systems can be used on any type of crop, soil, or topography suitable for irrigation. These have the lowest operation costs but are expensive to install. They can be designed to fit any shape of field. Solid set systems lend themselves to complete automation, so that operation can be limited primarily to inspection. Such systems will have their greatest application in rolling or steeply sloping areas, in forested areas, and perhaps in small systems where labor may be a problem. An important design consideration involves laying the buruied PVC pipes in such a way that all lines can be completely drained in the fall.

IV PROVINCIAL REGULATIONS

Regulations governing the treatment and disposal of all industrial wastewaters and of domestic wastewaters in quantities greater than 5000 gpd are the responsibility of the Pollution Control Branch of the B.C. Water Resources Service. Under the direction of Mr. W.N. Venables, the Pollution Control Branch has developed a procedure for defining waste treatment and discharge objectives after receiving inputs from interested individuals and agencies at public inquiries.

Such an inquiry into the discharge of municipal-type wastes was held in 1973. As a result of that inquiry, objectives governing the treatment and disposal of community wastewaters, including the application of effluent to land by irrigation, will soon be forthcoming. It is interesting to note that two members of the panel formed to conduct the inquiry and to make recommendations to the Director concerning the nature of the objectives have presented papers here today, Dr. Lee Kornder and Dr. Bill Oldham.

I will not attempt to discuss these objectives in detail today. They are still in a draft stage; i.e., the panel has made its recommendations to the Director of the Pollution Control Branch, but they have yet to be approved by the Pollution Control Board*. Suffice to say at this time that the objectives (which are really guidelines to be used in the design and evaluation of waste treatment and disposal systems) reflect the concept that the degree of treatment provided before irrigation should be based on the nature of the site and the type and use of the crop being irrigated. A further concept to be embodied in the objectives is that the area of land available for effluent irrigation should be based on an evaluation of evapotranspiration and precipitation during the irrigation season so that a desirable water balance can be maintained at the site. Winter irrigation is not recommended at this time.

V SOCIAL IMPLICATIONS

Discussion of the social implications of effluent irrigation have been left to the last for a special reason. Public acceptance of the concept of local effluent irrigation is perhaps the single most important aspect determining the feasibility of an irrigation project. As such, it should receive first consideration in the design process. In practice

* The objectives were released in December, 1975.

the public is customarily forgotten and only brought in at the last moment. In many cases, good schemes have had to be abandoned or have created unnecessary agonies because of delayed public involvement.

Effluent irrigation is a new and different concept in British Columbia. Most of us aren't used to the idea. But when another city starts talking about doing it, our general level of environmental consciousness tells us that putting effluent back onto the land makes good sense. Let our own city start talking about it though, perhaps within walking, seeing, breathing, or smelling distance of our own property, and we suddenly remember that besides containing water and nutrients, sewage also contains an immense number and variety of disease organisms and furthermore it has a distinctive odour. In other words, "will my health be endangered and will my land be devalued and will my way of life be disrupted due to sewage effluent irrigation on my neighbour's farm?"

Questions such as these are as valid as they are commonplace. To my mind, these questions should be raised simultaneously and discussed in an atmosphere of peaceful interaction by the public, city council, their consultants, and government agencies. I feel that the process of site selection and system design would be much smoother if the public were invited to participate in the process from the very beginning. Seminars like this one today go a long way towards helping clear a path for the initiation of effluent irrigation in British Columbia. But we are only 250 out of 2½ million and this sort of exercise will have to be extended to the community level and repeated many times before we have reached enough people to gain a large measure of acceptance.

In closing, I would like to repeat a comment I made earlier and offer some advice to councillors and consultants about to embark on feasibility and design studies. Throw out any preconceived ideas about treatment requirements, site selection, crop type, or irrigation methods. Start out fresh, with an open mind, and hand in hand with the community.

APPENDIX

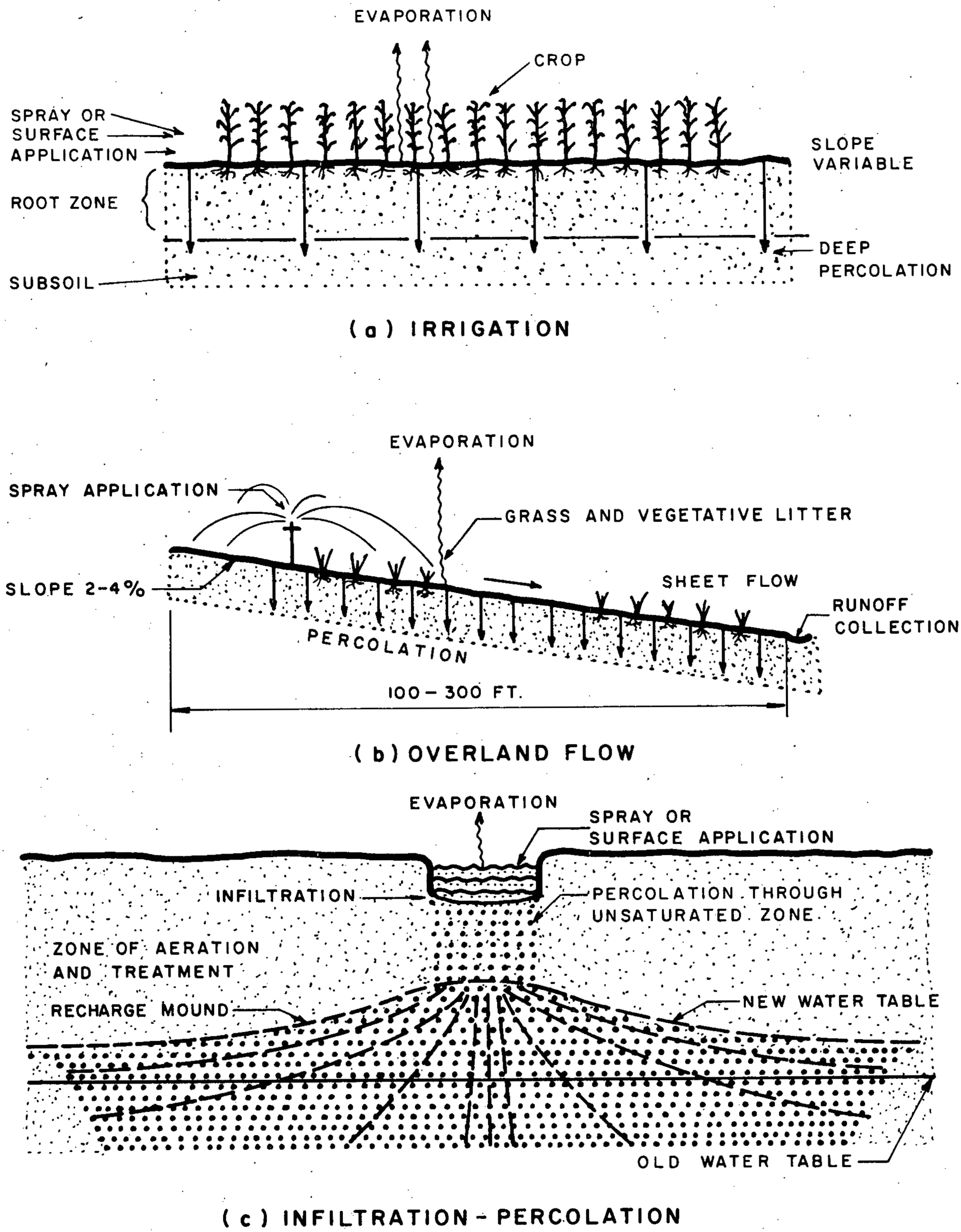

Figure 1
METHODS OF LAND APPLICATION.[6]

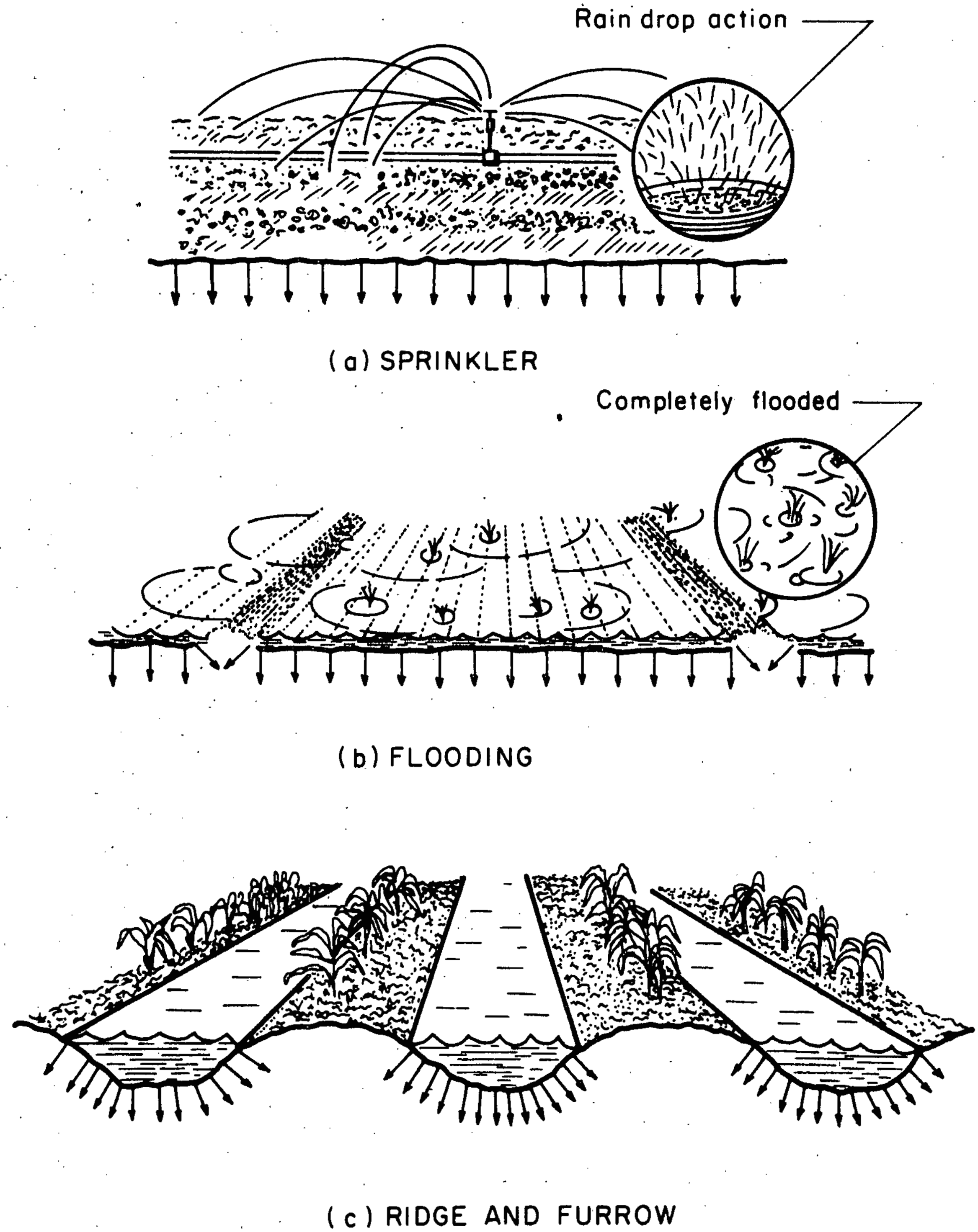

Figure 2
IRRIGATION TECHNIQUES.[6]

Table 1 COMPARISON OF IRRIGATION, OVERLAND FLOW, (6) AND INFILTRATION-PERCOLATION OF MUNICIPAL WASTEWATER

Objective	Type of approach: Irrigation	Overland flow	Infiltration-percolation
Use as a treatment process with a recovery of renovated water[a]	0-70% recovery	50 to 80% recovery	Up to 97% recovery
Use for treatment beyond secondary:			
1. For BOD_5 and suspended solids removal	98+%	92+%	85-99%
2. For nitrogen removal	85+%[b]	70-90%	0-50%
3. For phosphorus removal	80-99%	40-80%	60-95%
Use to grow crops for sale	Excellent	Fair	Poor
Use as direct recycle to the land	Complete	Partial	Complete
Use to recharge groundwater	0-70%	0-10%	Up to 97%
Use in cold climates	Fair[c]	--[d]	Excellent

a. Percentage of applied water recovered depends upon recovery technique and the climate.

b. Dependent upon crop uptake.

c. Conflicting data--woods irrigation acceptable, cropland irrigation marginal.

d. Insufficient data.

Effective Rooting Depths of Crops for Irrigation System Design in British Columbia (13)

Shallow	Medium Shallow	Medium Deep	Deep
(1½')	(2')	(3')	(3' plus)
Lettuce*	Peas**	Cane fruit*	Alfalfa (4')
Onions*	Beans**	Squash*	Asparagus*
Radish*	Spinach**	Sweet Corn*	Tree fruits (4')
Cauliflower*	Celery**	Cereals*	Hubbard*
Cabbage*	Potatoes***	Tomatoes*	Corn (4')
Ladino*	Beets**	Peppers*	Grapes*
Turnip*	Broccoli**	Eggplant*	Sugar Beets (4')
Cucumbers*	Carrots**	Brussels sprouts*	
Pasture species*	Strawberry***	Red clover*	

Available Water Storage Capacity for B.C. Soils (13)

Textural Class	Available Water Storage Capacity (AWSC) Available Inches of Water Stored in Each Foot of Soil
Sand	1.0
Loamy Sand	1.2
Sandy Loam	1.5
Find Sandy Loam	1.7
Loam	2.1
Silt Loam	2.5
Clay Loam	2.4
Clay	2.4
Organic Soils (muck)	3.0

Maximum Design Application Rate (13)

	Inches per Hour	
	Grass Sod	Cultivated
Sand	0.75	0.40
Loamy sand	0.65	0.35
Sandy laom	0.45	0.25
Loam, silt loam	0.35	0.20
Clay loam, silty clay loam	0.30	0.15
Clay	0.25	0.10
Peat and muck	0.50	0.50

Table 5

DETERMINATION OF PEAK DAILY WATER USE FOR VARIOUS AREAS IN BRITISH COLUMBIA[13]

Area	Location	10 Day Inches/Day	20 Day Inches/Day	30 Day Inches/Day
1	Campbell River	.20	.18	.17
* 2	Oyster River	.17	.15	.13
3	Courtenay	.21	.18	.16
4	Port Alberni	.20	.19	.18
5	Parksville	.17	.15	.14
6	Nanaimo	.19	.17	.15
7	Victoria-Duncan	.17	.16	.15
8	Lower Fraser Valley	.17	.15	.13
9	Lytton	.30	.26	.24
10	Lillooet	.26	.25	.24
*11	Ashcroft-Clinton	.24	.22	.21
12	100 Mile House	.20	.19	.18
*13	Williams Lake	.24	.22	.21
*14	Kleena Kleene	.20	.18	.17
*15	Quesnel	.23	.22	.21
16	Hixon	.17	.16	.15
17	Prince George	.22	.18	.16
18	Vanderhoof	.20	.19	.19
19	Fort Fraser	.20	.18	.17
20	Smithers	.17	.14	.12
21	Hazelton	.20	.19	.18
*22	Terrace	.20	.19	.18
*23	Savona	.26	.23	.22
*24	Kamloops	.24	.22	.21
25	Barriere	.20	.18	.16
*26	Pritchard	.22	.21	.20
*27	Salmon Arm	.17	.15	.13
28	Sicamous	.20	.19	.18
*29	Grindrod	.17	.15	.13
30	Enderby-Armstrong	.20	.18	.17
31	Vernon-Kelowna	.24	.22	.21
32	Summerland-Penticton	.26	.24	.23
33	Merritt	.26	.24	.23
34	Douglas Lake	.22	.21	.20
35	Aspen Grove	.23	.20	.19
36	Jura	.23	.21	.19
37	Princeton	.25	.23	.22
38A	Cawston	.32	.29	.28
*38B	Keremeos	.29	.28	.27
39	Oliver	.25	.23	.22
40	Osoyoos	.28	.27	.26
41	Beaverdell	.19	.18	.17
42	Grand Forks	.19	.18	.17
43	Creston	.20	.19	.18
44	Lister	.21	.20	.19
45	Cranbrook	.20	.18	.17
46	Canal Flats	.24	.21	.20
47	Invermere	.22	.21	.20
48	Spillimacheen	.19	.18	.17
*49	Golden	.17	.15	.13
*50	Moberly	.17	.15	.13
*51	Donald	.17	.15	.13

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CASE HISTORY OF THE TABER, ALBERTA WASTEWATER IRRIGATION PROJECT

BY:

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CASE HISTORY OF THE TABER, ALBERTA WASTEWATER IRRIGATION PROJECT

Introduction

During the late 1960's it became apparent that the water quality of the Oldman River was rapidly deteriorating, particularly during the winter months when the discharge of the river may drop to a low of 400 cfs (680,000 l/min.). Therefore various cities, towns and industries were required to substantially reduce their pollution loads to the river. The town of Taber, with a population of about 5,000 and various food processing industries, was required to drastically reduce its pollution load. Various methods of wastewater treatment were considered and wastewater irrigation was selected for detailed feasibility studies in 1969.

The two major industries located in Taber were a potato dehydrating plant and a vegetable canning plant. The dehydrating plant uses the lye peeling process which renders the effluent from the plant unsuitable for irrigation due to the high sodium concentration. However, when its wastewater was diluted with other wastewater, reduction of the sodium concentration to acceptable levels was obtained.

The combined domestic and industrial flows average 0.6 million gallons (2.7 million liters) per day on an annual basis with peaks of a million gallons (4.5 M liters) per day on a monthly basis.

The effluent from the sanitary sewage system now flows by gravity to a syphon under the Oldman River, then discharges to open storage on the north side of the river approximately three miles (4.8 kilometers) from the town. Metering is provided by a Parshall flume at the syphon.

One year after start-up of the system, the potato dehydrating plant ceased operation but two other small food processing plants eventually moved into Taber.

Preliminary Studies

Considerable government land was available for purchase by the Town, and Alberta Department of the Environment conducted a soil investigation for irrigability. This included drilling, logging and sample analysis to a depth of up to 12 meters. The amount of land required for the irrigation scheme was determined by taking into account the volume and quality of effluent available, the consumptive use of the crop, and the mean annual precipitation and its distribution over the growing season. On this basis it was estimated that a four hundred acre (162 ha) area would be sufficient and a suitable portion of land (Chaplin loamy sand underlain by sand and gravel) was selected for effluent irrigation at a rate of 45 cm per year. The soils were non-saline, non-sodic with a water table at a depth of approximately 4 to 5 m from the surface. The land was vegetated with native grass, fairly characteristic of the short grass prairie. The mean total precipitation is 38 inches, 25 of which is received during the growing season.

Research and testing work was conducted in the field, laboratory and greenhouse. The laboratory work consisted of passing the lagoon-treated effluent through 2.5 m of soil obtained from the site and collecting the percolating solution at different depths of the soil column. Analysis was conducted on the soil and effluent before application and also on the percolating solution and the soil after the application of 120 inches (300 cm) of effluent.

TABLE 1

Analysis of Typical Combined Effluent

pH	-	6.5	NH_3-N	-	20 mg/1
EC	-	2.2 mmhos/cm	NO_3-N	-	0.5 mg/1
BOD	-	600 mg/1	Alkalinity	-	500 mg/1
COD	-	1000 mg/1	Ca + Mg	-	150 mg/1
SS	-	400 mg/1	Na	-	180 mg/1
P	-	7 mg/1	SAR	-	6.0
C1	-	50 mg/1			

The results showed that 150 cm of this soil was effective in removing 90 percent of the calcium, 60 percent of the magnesium and practically all of the ammonia, phosphorus and BOD. Nitrates appeared to move freely through the soil. It was felt that some of the calcium and magnesium was precipitated out as carbonates. The effluent did increase the salinity and the sodium status of the soil to some extent but well within acceptable limits. Total nitrogen and phosphorus in the soil were increased considerably by the effluent application.

Application of the effluent to the soil in permeability tubes showed a distinct reduction in permeability during continuous innundation. The permeability was restored after a rest period of a few days.

A test plot of land was established adjacent to a temporary lagoon and a weekly application of about 15 cm was made to a soil similar to that in the selected field. Analyses of soil samples taken inside and outside of the irrigated area indicated an increase in soluble salts, including sodium, similar to that found in the laboratory columns. Soil analyses of the same sites that were undertaken several months after effluent application ceased, showed a significant reduction of salinity problems due to natural leaching. No symptom of toxicity was noted in the native vegetation.

Barley grown in the greenhouse yielded 44 percent more dry matter when watered with the effluent than with tap water.

Design and Installation

Due to cold weather during winter months and the high BOD loading of the sewage, which could not be discharged to the river, open storage facilities with a volume of 400 acre feet (500,000 m^3) were constructed using earth embankments in a natural depression. The main storage unit is preceded by two small anaerobic settling basins each of which has a capacity of two days average flow.

A single pumping unit with a capacity of 1,000 gallons (45,000 l) per minute against a discharge pressure of 100 psi (7,000 gms/cm^2) was installed to pump effluent through 5,000 feet (1500m) of 18-inch (45 cm) pipe and 5,000 feet (1500 m) of surface 12-inch (30 cm) pipe to the irrigation area. Four five-inch (13 cm) laterals, each 1,300 feet (400 m) long, with nozzles at 40 foot (12m) spacings were used for spraying. Lateral connections were provided every 180 feet (54m) along the 12-inch (30 cm) lateral. Nozzle pressures were recorded at 55 to 70 psi (3800 to 5000 gm/cm^2) depending on the number of nozzles used for spraying.

Application of the effluent was at the rate of 0.5 inches (1.2 cm) gross per hour, with the duration of application controlled by the movement of the laterals which are wheel-mounted.

Groundwater observation wells and soil monitoring sites were established by the Alberta Environment Department well in advance of actual irrigation in order to measure changes in groundwater and soils due to the application of effluent. Routine analyses of soils and groundwater samples include conductivity (EC), pH, Ca, Mg, Na, Cl^-, HCO_3^-, $CO_3^=$, Total P, NO_3-N, NH_4-N and Total N. It is also planned to determine "heavy metals" in soils after the system has been operated for 5 years.

Operation and Observations

Storage of effluent began in December 1970 and irrigation was initiated in July 1971 on the native sod. An attempt to establish grass and alfalfa by seeding directly into the sod in the fall of 1971 was not successful although reasonably good germination did result. Competition by the native species was probably responsible for the mortality of the domestic species as the native grasses, although inferior in quality (spear grass) responded to irrigation with the effluent with rapid and dense growth.

Subsequent to this experience one half of the 320 acres (128 ha) was cultivated and seeded to alfalfa on a two year schedule.

The layout of the system is shown in Figure 1.

The data from three groundwater observation wells has been selected for discussion. Well #7 (Figure 2) is immediately adjacent to a slight depression in which water will pond if irrigation is excessive. The water table has risen from a depth of about 13 feet (4m) below ground level prior to irrigation to about four feet (1m) in the fall of 1974. Well #8 (Figure 3) is located at a higher elevation immediately adjacent to the irrigated field where surface drainage is good. The water table at this site has risen from a depth of 13 feet (4m) before irrigation to about seven feet (2m) in the fall of 1974.

The only chemical change apparent and consistent in the groundwater is a considerable increase in the concentration of chloride with time. Nitrate-nitrogen concentrations have varied considerably but inconsistently in some of the wells.

Observation well #5 is located one-half mile (0.8 km) down slope from the irrigated field and in a draw leading from the field to the Oldman River and hopefully in the direction of groundwater flow. Data obtained from this well (Figure 4) has shown no change in water level or chemistry over the duration of the wastewater irrigation project.

Changes in soil chemistry due to wastewater irrigation are largely dependent on the quality of the wastewater. Chemical monitoring of the effluent has shown a gradual continuous reduction of salinity and sodium adsorption ratio since investigations were initiated. The electrical conductivity was reduced from approximately 2.2 mmhos to a value slightly above one, while the SAR lowered to about two from an initial value of around six. This reduction is attributed to the cessation of operation of the potato dehydrating plant.

The mean values of EC and SAR from four test holes in one sampling site (Table 2) show that a slight increase in salinity and a very apparent increase in SAR has occurred since irrigation was initiated.

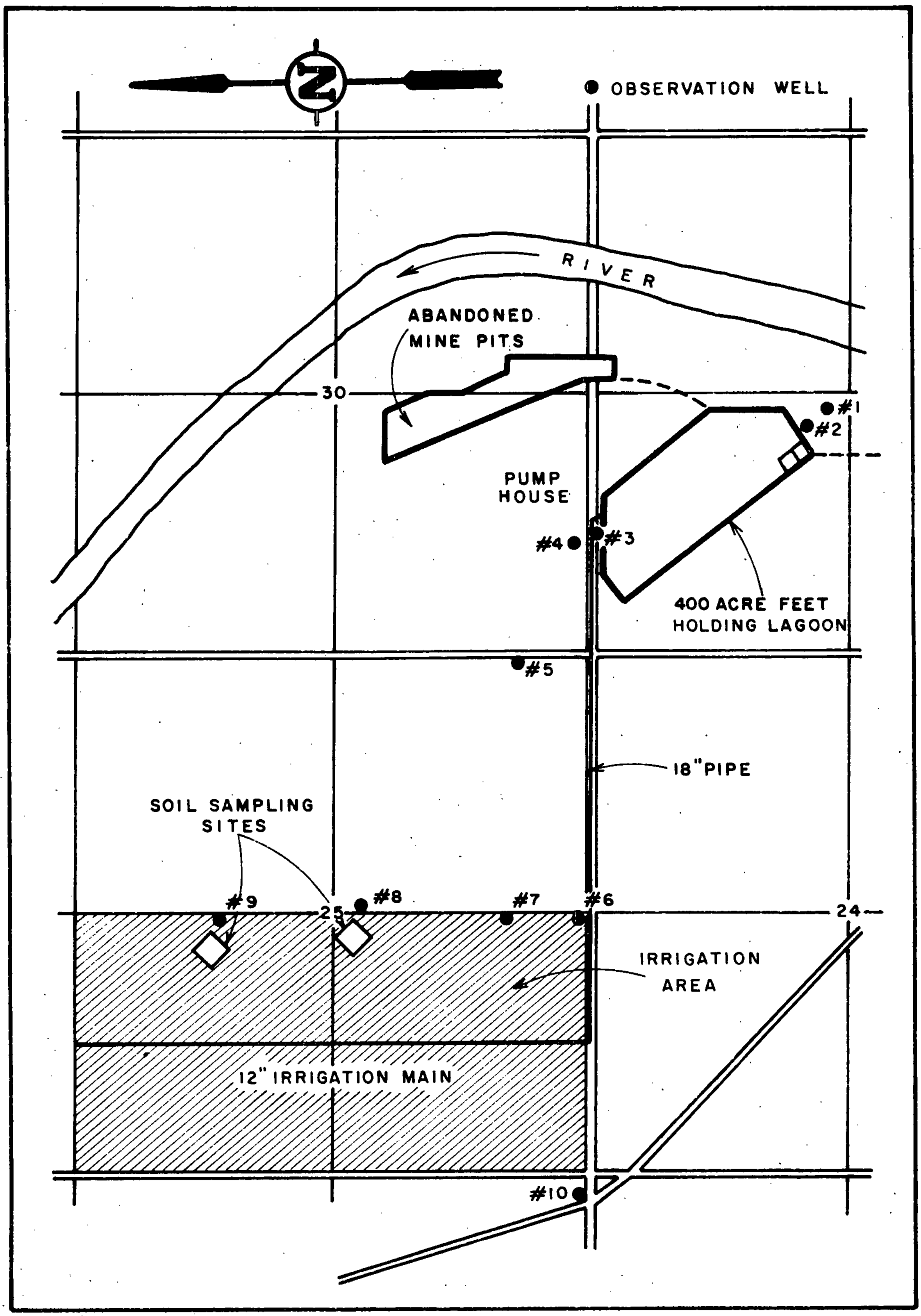

FIGURE I

SITE PLAN.

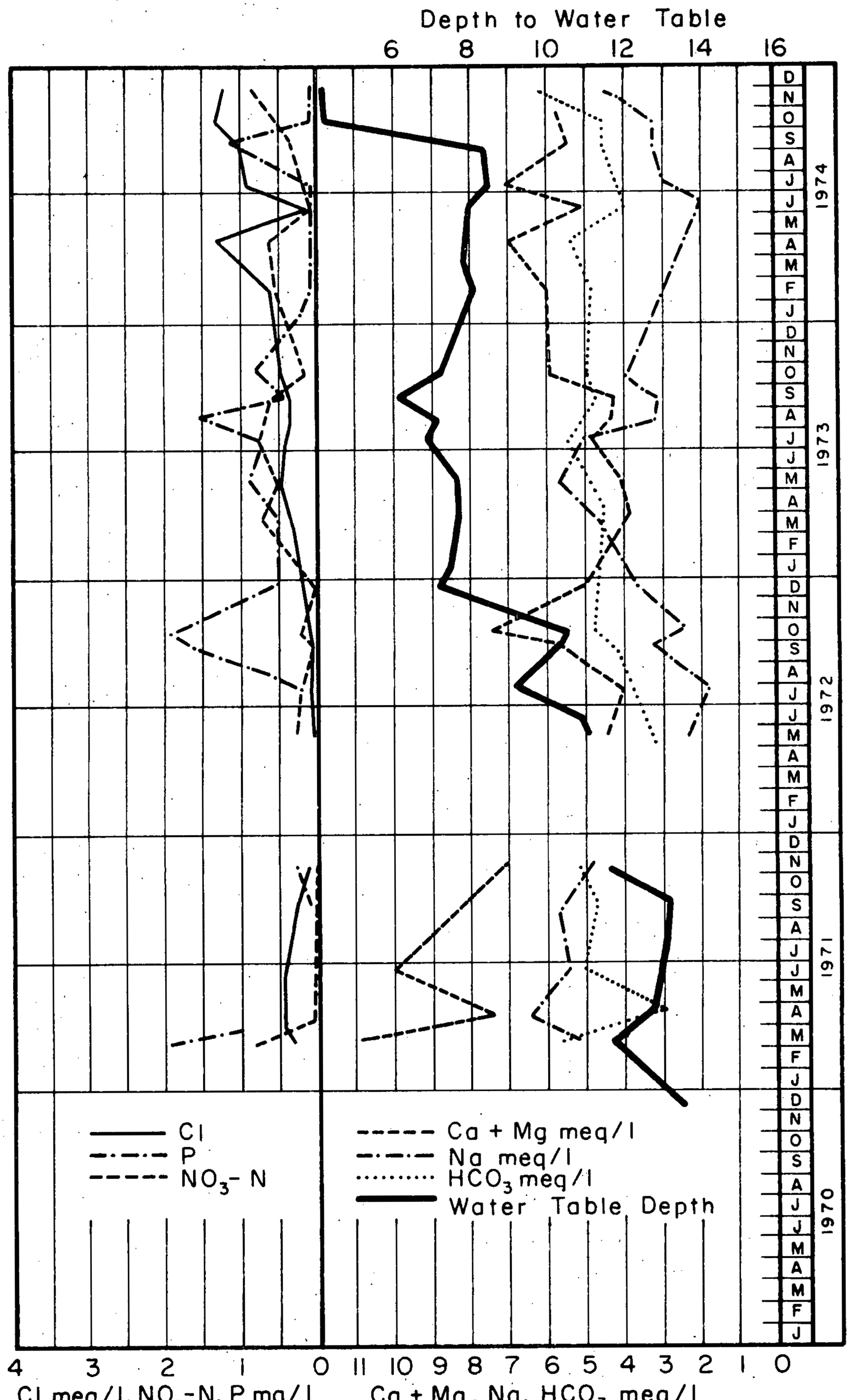

FIGURE 2

WATER QUALITY OBSERVATION WELL #7.

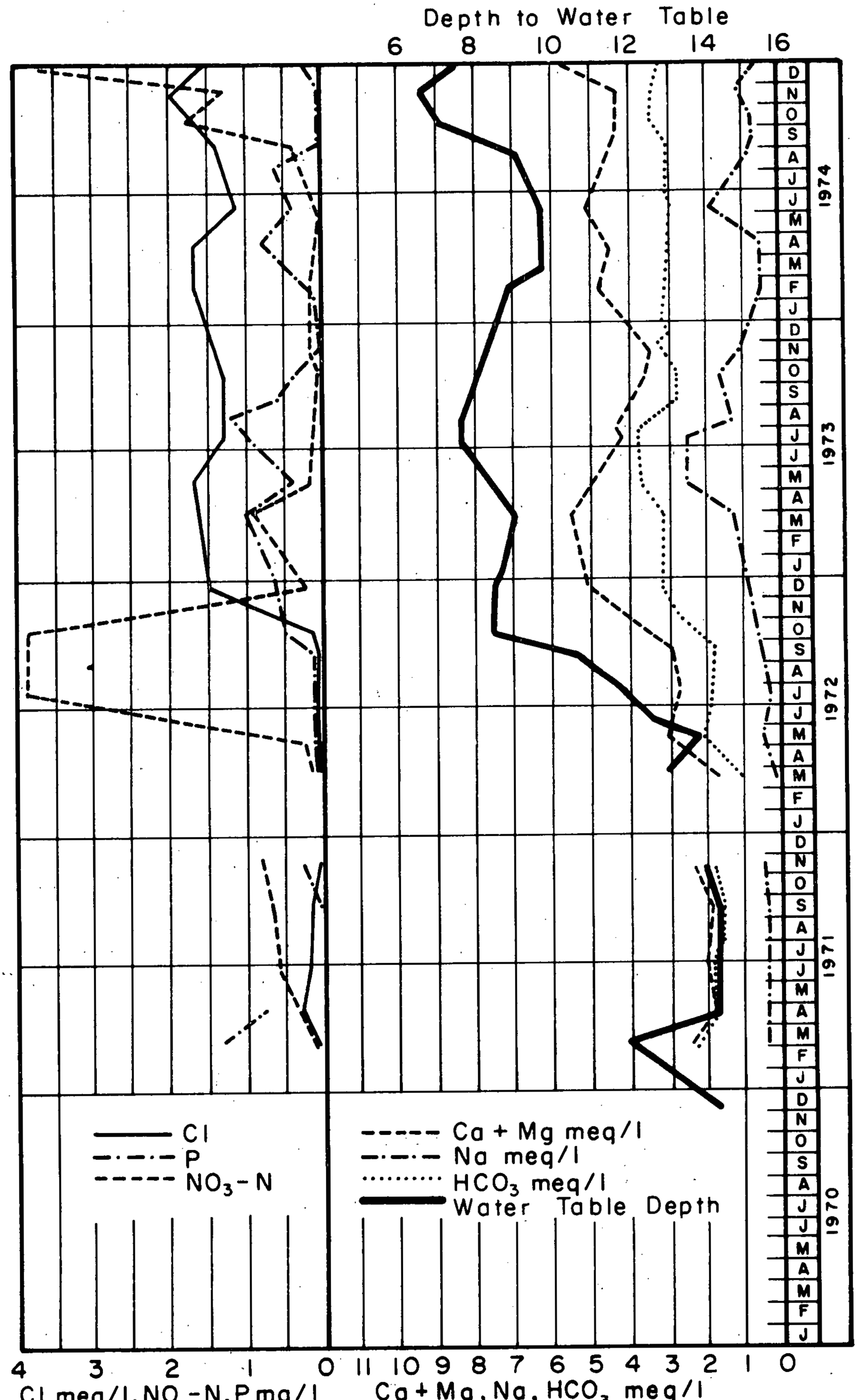

FIGURE 3

WATER QUALITY OBSERVATION WELL #8.

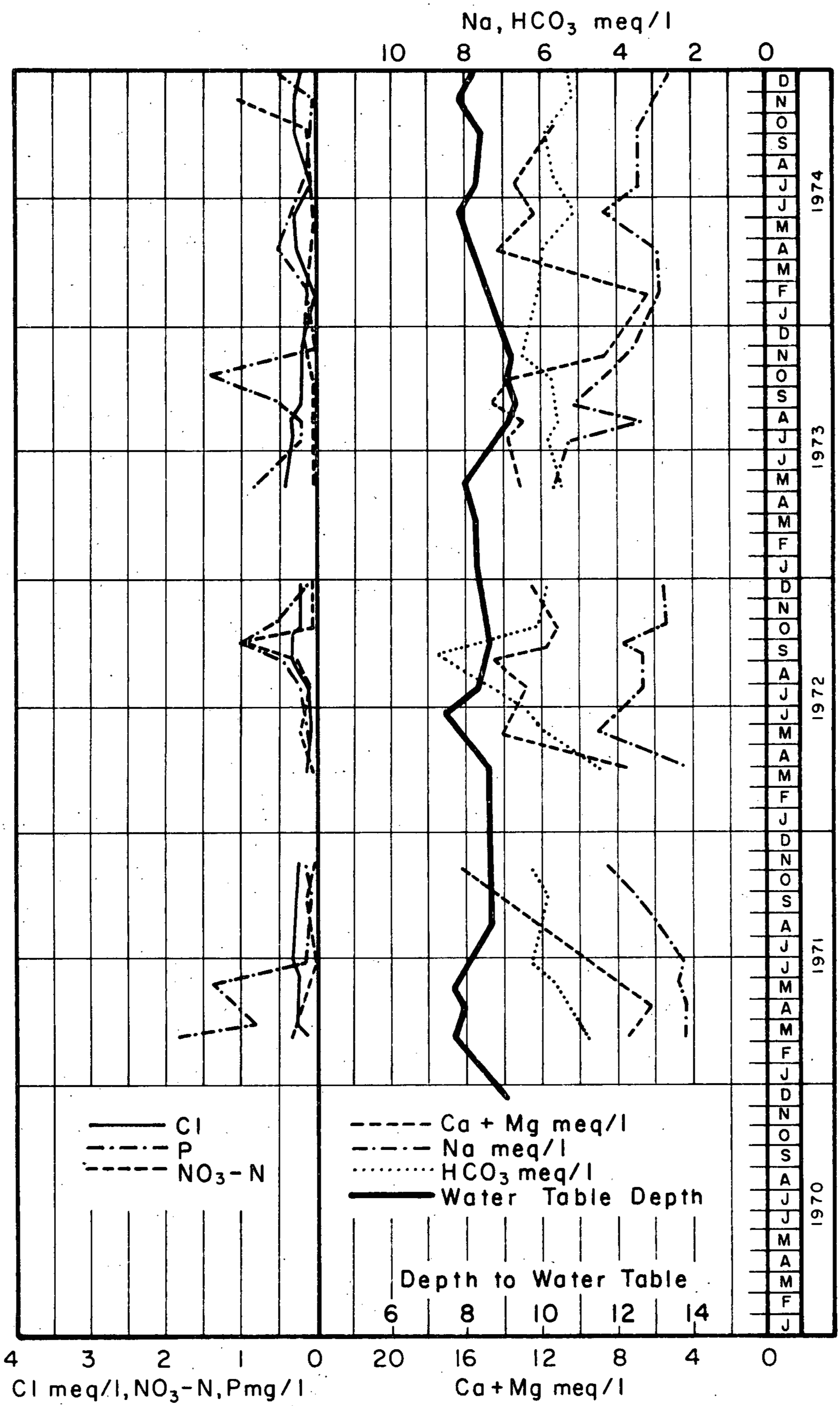

FIGURE 4
WATER QUALITY OBSERVATION WELL #5.

Table 2 Soil Analysis Before and During Irrigation and Comparison with Values Forecast with Soil Columns

	EC mmhos/cm			
	Field Data			
	Apr. '71	Oct. '72	Nov. '74	
Depth in cm	Before Irrigation	After Irrigation		Column data 1970
0 - 15	0.5	0.8	0.7	1.8
15 - 30	0.3	0.5	0.5	1.4
30 - 60	0.4	0.5	0.7	0.7
60 - 90	0.4	0.5	0.6	0.7
90 - 120			0.5	0.9
120 - 150			0.6	
		SAR		
0 - 15	0.3	2.1	1.2	3.7
15 - 30	0.2	1.1	1.7	3.9
30 - 60	0.2	1.5	2.1	4.4
60 - 90	0.3	1.4	1.6	4.8
90 - 120			1.5	4.8
120 - 150			1.8	

The fact that a chemical improvement at the soil surface occurred between 1972 and 1973 is attributed to the fact that the quality of effluent has improved, at least in respect to total salts and sodium adsorption ration. It appears that an equilibrium between the soil and the effluent has been achieved and that no further deleterious effects of salinity and sodium will result from continuous irrigation with this effluent.

The results of the preliminary soil column work are also included in Table 2. Three values for Ec and SAR are considerably higher than what has actually resulted from irrigation, however this is also likely due to the improvement in effluent quality that has occurred over the past few years. Other projects approached in the same way have shown quite good agreement between soil column results and field results after a few years of irrigation.

Conclusion

The utilization of Taber effluent on land has resulted in a zero emission situation for Taber and therefore measureable improvements in water quality of the Oldman River downstream of the town. Considerable revenue was realized in 1974 as about eight metric tons/ha of excellent forage was sold to an alfalfa dehydrating plant. Although salinity and adsorbed sodium have increased in the soil, these values are lower than those forecast by the preliminary research and are well within satisfactory limits. Groundwater quality changes have been restricted to a slight increase in chloride concentration, however water table levels have been gradually rising and some operational changes may be required in the near future for stabilization of the water table. The preliminary soil column work indicates that some increase in hardness of groundwater should be anticipated.

CASE HISTORY OF EFFLUENT REUSE AT LUBBOCK, TEXAS

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CASE HISTORY OF EFFLUCENT REUSE AT LUBBOCK, TEXAS

Reuse of the sewage effluent of Lubbock, Texas, for crop irrigation has been a highly successful venture since its inception in the early 1930's. That such has been the case is due to a happy combination of circumstances, not all of which would be duplicable universally.

Lubbock is situated on featureless plains having a slope of about ten feet to the mile to the southeast. Surface drainage, when it occurs, is to shallow depressions (known locally as playa lakes) with contributing areas averaging about a square mile per lake. The potential reservoir evaporation approaches 75 inches per year; the precipitation averages less than 18. While some lake water is pumped for irrigation and a very small amount of it infiltrates through the lake bottoms, nearly all water reaching the lakes evaporates.

A few streams, normally dry, flow in relatively deep canyons cutting the plains. The area which contributes surface flow to them under natural conditions is a belt of land often a mile or less in width. One of these, the North Fork of the Double Mountain Fork of the Brazos River, winds through Lubbock in a gulch known as Yellow House Canyon. The principal sewage treatment plant of the city is near the canyon at the downstream edge of town. Flow records at a point upstream of the sewage plant for the ten years a gaging station was maintained are given in Table I. It will be noted that total flows for 97 of the 120 months gaged were zero.

Until 1968 the entire water supply of Lubbock was from a fossil aquifer, the Ogallala, which underlies much of the high plains area of Texas, New Mexico, and other prairie states. The Ogallala also supplies the irrigation water on which a thriving agricultural economy is based. In its undistrubed state the Ogallala received an inch or less of recharge per year and supported some springs and seeps in canyon walls and in the escarpment which constitutes the eastern boundary of the High Plains. Under the increasing pumping loads of the past thirty years the water table has been dropping an average of one to three feet per year and most springs have ceased to flow.

The decision to use sewage effluent for crop irrigation was based on the value of the water and of its nutrient content on the one hand, and on the desire to decrease the pollution resulting from discharging effluent into an otherwise dry streambed on the other. The land irrigated with the effluent lies on both sides of the canyon at an elevation such that it can be supplied by gravity flow from reservoirs to which the

Table I

Flow Records at U.S.G.S. Gaging Station on the North Fork of the Double Mountain Fork of the Brazos River at Lubbock: 1939-1949

- Amounts in Acre-Feet -

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1939	-	-	-	-	-	-	-	-	0	0	0	0	-
1940	0	0	0	0	0	0	0	0	0	0	0	0	0
1941	0	0	8.7	-	3,730	2,170	302	.4	.6	477	39	.2	6,727.9
1942	0	0	0	14	0	803	6.3	0	1,040	112	0	34	2,009.3
1943	0	0	0	0	0	0	0	0	0	0	0	0	0
1944	0	0	0	0	210	68	15	0	0	0	0	0	293
1945	0	0	0	0	0	0	0	0	0	0	0	0	0
1946	0	0	0	0	0	0	0	0	0	6.7	0	0	6.7
1947	0	0	0	0	4.6	0	0	0	0	0	0	0	4.6
1948	0	0	0	0	0	0	0	0	0	0	0	0	0
1949	0	0	0	0	2,990	65	.2	0	0	-	-	-	-

effluent is pumped with a 10 to 12 foot lift from the sewage treatment plant.

Frank Gray, a farmer, has been associated with the operation since 1937 (Gray, 1968). Under a series of long-term contracts Gray is required to accept the entire flow from the treatment plant as it occurs and to dispose of it in a manner acceptable to state and local health authorities. In 1937 he was able to accomplish this by spreading a million to a million and a half U.S. gallons per day on 200 acres. By 1968 Lubbock's growth was such that he was using 14.5 to 15 mgd on a land area of more than 2900 acres. In 1974 he applied 14 to 15 mgd to 5,000 acres, of which 3,000 acres are under his personal control and the other 2,000 are owned by neighbors who purchase water from him.

Recent quantities of effluent available for irrigation have been less than the full flow of the plant. Beginning in 1971 a portion of the effluent has been sold to the Southwestern Public Service Company for use as boiler feed and cooling water at a thermal power plant. Gray is paid 1¢ per thousand gallons for effluent diverted at a steady rate, and 2.5¢ per thousand gallons for effluent diverted on demand to the power company. The same rates would be applicable to any other diversion which might be made.

Gray's farming operation is partly on city-owned land for which he pays an annual lease fee based on acreage. The balance is owned by Gray or leased from neighbors. In addition, Gray occasionally supplies water for about 2,000 acres to adjacent land holders.

Under the contract, preparation of the land and construction of water conveyance facilities is to be done at no cost to the city. Gray has bench leveled or field leveled more than 1,600 acres and has constructed about 35 miles of underground concrete and plastic pipeline. The reservoirs which receive the effluent from the treatment plant are capable of holding 60 to 70 hours of flow. In addition, inflow may be diverted to some playa lakes and dammed draws with a holding capacity for slightly over 30 days flow and later pumped from the lakes for irrigation. Raw effluent must not be allowed to reach the canyon which contains one of the very few recreational lakes in the area.

Five center-pivot sprinklers, capable of irrigating about a quarter section each, have been added recently. Cone screens in the intakes have been found to be effective if the screens are changed every 12 hours during long runs. Complete conversion to sprinkler irrigation

TABLE II

SUMMARY OF WATER QUALITY TESTS - MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED

	Southeast Reclamation Plant (SRP) Avg. of 4 Samples (a)	SRP (c)	SRP - Avg. of 2 Chlorinated Samples (a)	Springs Fed by Gray's Irrigation Avg. of 8 Samples (a)	Well on Gray's Farm (b)
Daily Flow (mgd)	5.938	-	5.159	-	-
Dissolved Oxygen	4.8	-	5.8	2.9	6.3
pH	7.47	7.46	7.36	7.48	7.91
Total Coliform (MPN)	2,160,000	-	22	14	0
Fecal Coliform (MPN)	351,000	-	1	*	0
Five-Day BOD	10.5	22	8	0.4	0
COD	129	32	96	7	10
Organic Nitrogen (As N)	3.1	-	4.0	-	0.5
Ammonia Nitrogen (As N)	4.3	2.69	2.5	-	1.1
Nitrate Nitrogen (As N)	4.6	-	8.1	-	50
Total Phosphate	33.5	35.7	33.0	0.56	0.08
Total Dissolved Solids	1194	1212	1235	1449	1692
Hardness as $CaCO_3$	306	268	276	702	820
Total Alkalinity	262	240	236	365	228
Suspended Solids	19	8	13	3.5	0
Chloride	-	318	-	252	-
Date	July 1971	June 1974	July 1971	Feb-Aug 1969	July 1971

(a) Freese & Nichols, 1971a., (b) City of Lubbock. Cited by Sweazy and Wells, 1973., (c) Ralph Rodgers and Rick Norton, City of Lubbock.

* In 17 tests (Aug'69 thru July'71) fecal coliforms were found only twice. The MPN per 100 ml were 26 and 1.

is not contemplated because of winter ice problems and problems of mist drifting across a heavily-used highway.

On balance, the use of long-term contracts at Lubbock has been most successful. The operator has been able to justify capital investments and the city has been assured of competent operation.

Gray has selected crops that are high users of water and nitrogen and has rotated the crops to maintain an effective balance of nutrients in the soil. Crops which have been used include small grains (wheat, barley, oats, and rye), row crops (cotton and several varieties of grain sorghum), hay crops and pasture (alfalfa, sudan, and many varieties of grasses). Legumes, crops residues, weeds, barnyard manure, cotton burrs, and other wastes of high organic content have been used extensively. Usual yields per acre under the climatic and soil conditions found in Lubbock are as follows (Gray, 1968).

	Dry Land	Irrigation With Water From Ogallala Formation	Irrigation With Sewage Effluent Without Commercial Fertilizer
Grain Sorghum (lb)	800-1000	4000-5000	6500
Wheat (bu)	10-12	30-40	80
Lint Cotton (lb)	150-225	600-800	1250

Crop quality, as well as yield, is better under irrigation.

Gray's irrigation has resulted in raising the water table under the farm to within a few feet of the surface. In some low spots this has led to the formation of ponds, particularly in wet weather, and has caused some trouble through excess salinity and through the submergence, and consequent killing, of seedling plants. No deterioration of soil characteristics, other than this salinity, has ever been reported.

It is not anticipated that the areas affected will increase since the raised water table has reactivated springs and seeps in the canyon walls with the result that a natural system of underdrainage has become established. In addition, plans exist for lowering the water table under the farm by pumping the infiltrated effluent for subsequent industrial or recreational use.

The chemical and bacteriological composition of the sewage plant effluent and of the infiltrated effluent as captured in wells on Gray's farm or in seeps or springs in the canyon has been monitored regularly. Some typical data are given in Table II (Freese, Nichols and Endress 1969, 1971; Sweazy and Wells, 1973).

Proposals have been made from time to time for subsequent reuse of the effluent applied to Gray's farm, after it has infiltrated to the water table. Such use would not affect the irrigation operation detrimentally but would, of course, reduce or eliminate the spring and seepage flow. The first of these to be investigated in depth called for the creation of an industrial park which would be supplied with process water pumped from a battery of wells capable of furnishing some 5 mgd of infiltrated effluent.

The study, conducted by a group of faculty members of the School (now College) of Engineering at Texas Tech (School of Engineering, 1967), was undertaken at the request of the Board of City Development and the Chamber of Commerce of the City of Lubbock with the objective of determining the feasibility of providing an industrial water supply which would attract textile manufacturing plants to the city.

The group evaluated three alternative water supplies:

a) The renovation and reuse of industrial water with make-up being supplied from city mains and with disposal of a sufficient proportion of the wastes to maintain appropriate quality of the process water.

b) The supply of treated municipal effluent, with the wastes from the industrial park being returned to the city sewage plant for retreatment after mixing with municipal sewage. Possible complications were investigated but, since the wastes from the industries envisioned would be essentially organic, no major technical difficulties were foreseen.

c) The supply of recovered, infiltrated effluent after its application for irrigation.

The third alternative was consistently the best on both technical and economic evaluations under a wide range of assumed conditions.

A few months after the publication of the Texas Tech report, the Lubbock City Planning Department (1968) issued a feasibility study proposing that the infiltrated effluent be used not only for industrial supply but also as a source of irrigation water for parks, golf courses, and other open spaces; as the water supply for a series of recreational lakes in the canyon; and, ultimately, to provide water for human consumption.

The proposal for park development of the canyon caught the public fancy. For years the canyon had been a handy receptacle for wastes of all description. It was the site of several feedlots, of the municipal garbage dump, of junk car lots, of cess pools and a rendering plant.

It provided the outlet for storm sewers and industrial waste pipes, and was a congenial home for mosquitoes and rodents. The occasional flows, in response to storm precipitation, reach the recreational lakes a few miles downstream.

Freese, Nichols, and Endress, Consulting Engineers were commissioned to prepare a feasibility report (Freese, Nichols and Endress, 1969) on the Canyon Lakes Project. With minor modifications, they found the Planning Department's suggested eight-lake program to be appropriate. They recommended a three-phase development schedule with the first phase to consist of creating six lakes which would constitute a nearly continuous chain eight miles long within the city limits. Lake Seven and the much larger Lake Eight would be developed later as finances became available. This would have the advantage of deferring detailed planning until input from experience on the upper six lakes was available.

Make-up water for the lakes would be pumped through about seven miles of 24-, 20-, and 18-inch pipe from Gray's farm to the uppermost lake. En route, a power plant would be furnished cooling water, and parks, golf courses, and a cemetry would also be serviced.

Particular attention was given to considerations of public health. The infiltrated sewage effluent presents few problems; its quality can be controlled to meet any desired standards. Stormwater drainage, however, is another matter. The bypassing of flows from lesser storms and of the critically contaminated early flows from major storms was found to be economically unjustifiable. Thus primary contact recreation, including swimming, water skiing, diving, dabbling by children, and other activities where there is considerable risk of swallowing significant quantities of water will not be permitted in the upper lakes.

In a second report (Freese, Nichols, and Endress, 1971a) the engineering firm evaluated three potential sources of reclaimed wastewater for supplying the lakes. The infiltrated effluent was found to be more dependable in quality and far less costly than the water producible by two alternative processes of tertiary treatment of the activated sludge plant effluent. Percolation through the soil provides an effective means of removing viruses and bacteria and of reducing phosphorus (see Table II). The water produced from wells on Gray's farm is high in nitrates, but low in other forms of nitrogen. Gray used it as a potable supply for some years without detriment. It is of unsatisfactory quality only in dissolved oxygen - - a deficiency easily remedied. The only treatments anticipated are aeration and chlorination.

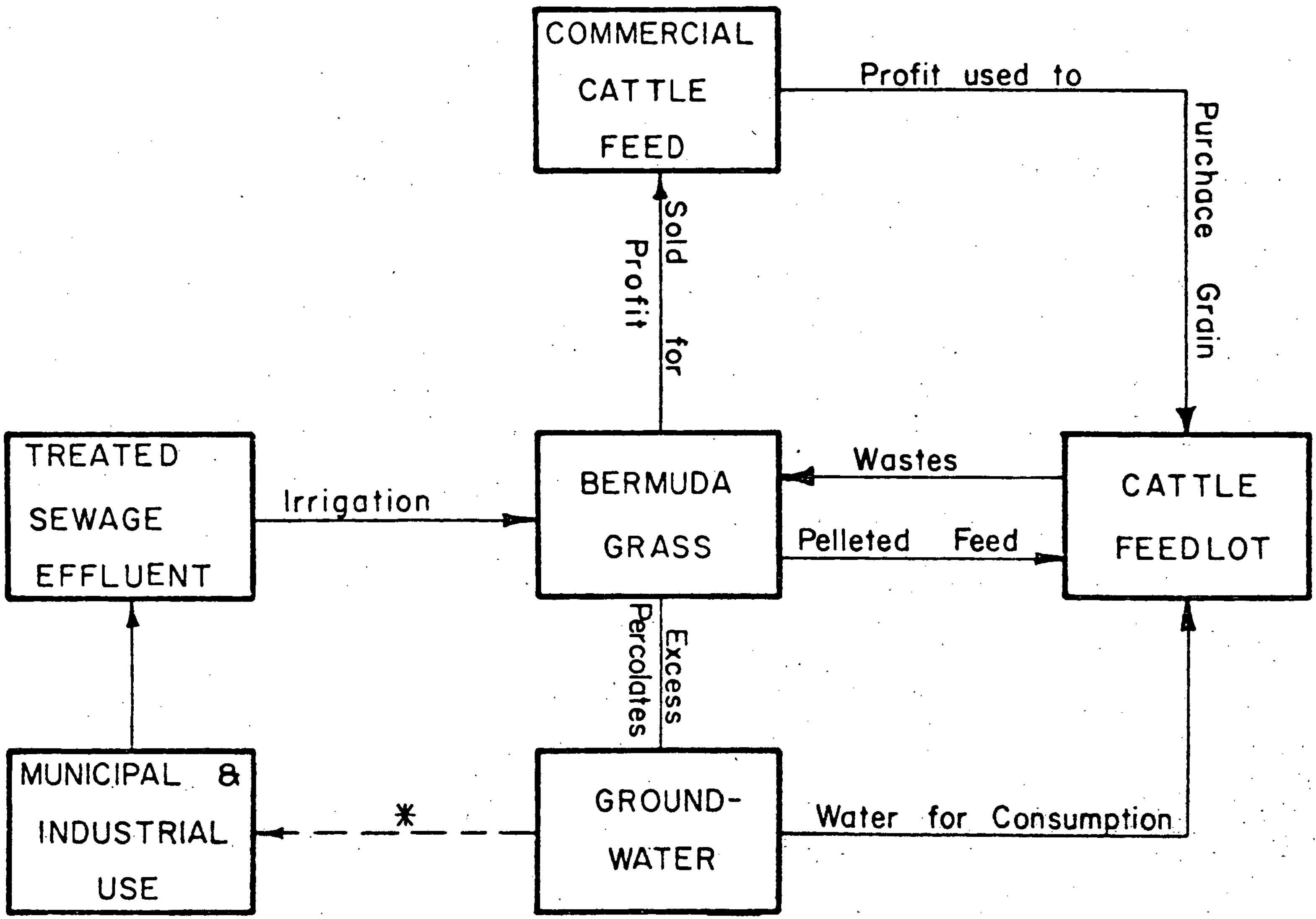
The possibility of eutrophication resulting from the high nitrogen content of the water has been the subject of a series of investigations under the auspices of the Water Resources Center at Texas Tech University. Winn (1973), after a series of quality determinations of water from Lubbock's Northwest Sewage Treatment Plant which had been used for irrigation on agricultural lands on the Texas Tech campus in a manner closely paralleling Gray's operation, found that serious algal growth occurred in only the first and second tanks of the three-tank continuous-flow series which simulates the Canyon Lakes. It was believed that phosphorus limited algal growth in the third tank of each series. This still leaves unanswered questions about growths in the variable proportions of storm water and infiltrated effluent which will be present in the actual lakes.

Headstream et al (1974) concluded from subsequent study of the model Canyon Lakes System that reclaimed infiltrated municipal sewage effluent, provided proper management is furnished, is a suitable source of make-up water for recreational lakes to be used for all purposes, including primary contact recreation.

Funds have been voted, feedlots and other industries have been moved out of the canyon, the old city dump has been closed, and the bulldozers have deprived many a rat of his home. The upper lakes will be a reality by 1976.

It should not, however, be anticlimactic to consider one more proposal which has been advanced for the use of infiltrated effluent pumped from the apparently ever-increasing quantities under Gray's farm or under the Texas Tech farm. Sweazy and Wells (1973), reflecting on some of the categories of problems which have received major attention in the Texas Tech University Water Resources Center -- water reuse, irrigation, and animal waste disposal -- hit on a combination of which many aspects had been investigated in detail, but of which no prototype existed.

By using both sewage effluent and cattle feedlot wastes for irrigation and fertilization of a nutritious crop, such as bermudagrass which is a heavy user of nitrogen, they proposed the mutually-beneficial livestock raising -- crop raising -- pollution abating reuse system depicted in Figure 1.



* Contingent upon Accumulation and Quality

Figure 1. Schematic of Proposed Reuse System. (Sweazy and Wells, 1973)

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CASE HISTORY

CITY OF VERNON - DISPOSAL OF EFFLUENT BY SPRAY IRRIGATION

by

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CASE HISTORY

CITY OF VERNON - DISPOSAL OF EFFLUENT BY SPRAY IRRIGATION

INTRODUCTION

The City of Vernon is situated in Central British Columbia in the Okanagan Valley. It is in an area of low rainfall, and the summer climate combined with the beautiful lakes in the area has made it a prime tourist centre.

The City's sewage treatment plant was constructed in the 1930's and since then has expanded to meet the demands of a growing population which, in 1975, is approximately 15,000. The secondary treatment process utilizes a conventional trickling filter plant with anaerobic digestion of the sludge and chlorination of the effluent prior to discharge to Vernon Creek, approximately two miles before it enters the north arm of Okanagan Lake. The water quality of the north arm of Okanagan Lake has deteriorated in the last 20 years to the point where it is almost useless as a recreational body of water.

Nutrient additions to the Lake from the Vernon Treatment Plant were felt to be principle contributors to the Lake's deterioration, and as early as 1966 the City of Vernon started to investigate spray irrigation as a method of removing its effluent from the Lake.

From 1966 to the present date, the City has pressed ahead with its goal, the removal of all the effleunt from Vernon Creek and Okanagan Lake. The design of the spray irrigation system to do this is now under way and by late 1976, or early 1977, Vernon will have accomplished its goal.

To illustrate the timing and the effort that has been required to reach the present stage of implementing the final design, a chronological list of activities is included:

1966 - 1969 Preliminary investigations, data gathering, attendance at seminars, reference to reports from Pennsylvania State University and a film entitled 'The Living Filter'. Financial assistance was requested from the Mines and Energy Research Board in Ottawa, but none was forthcoming. A preliminary study of the Vernon area for potential spray irrigation sites and reservoir sites was undertaken.

1970	The City of Vernon adopted a bylaw to proceed with a pilot project for the spray irrigation of sewage effluent. Irrigation sites were acquired through negotiations with the Department of National Defence. Senior levels of Government were approached for financial assistance but none was provided.
1971 - 1972	A pilot project was constructed and commissioned at a capital cost to the City of Vernon of $125,000. It has a capacity of 800,000 Igpd and utilizes 150 acres of land for spray irrigation.
	A monitoring program was carried out under the Okanagan Basin Water Study. Lysimeter data was collected, tests were made on the crops produced from the pilot project and a groundwater monitoring study was carried out. Stanley Associates Engineering Ltd. began a study of the feasibility of full scale spray irrigation versus conventional methods of secondary and tertiary treatment.
1973 - 1974	The feasibility study was expanded to examine the suitability of lands north of the City of Vernon for spray irrigation. Public opinion was sought from residents of these areas and Government Agencies were again approached for financial aid.
	The landowners north of Vernon rejected a proposal to spray irrigate in that area and the City of Vernon authorized its consultant to investigate alternative proposals. The final feasibility report was submitted in September 1974.
1975	The City of Vernon authorized the design of a trickling filter sewage treatment plant utilizing spray irrigaiton disposal of the treated effluent. The pre-ordering of equipment has commenced and startup of the new facilities is scheduled for mid 1976.

This timetable of events indicates that it will have taken the City of Vernon ten years to bring a full scale spray irrigation system into operation.

During this period the City will have spent approximately $237,000, excluding final design fees and construction costs for the full scale project. This amount is made up as follows:

Capital Cost of pilot project	$125,000
Operating and monitoring costs of pilot project	72,000
Consultants' Study Fees	40,000
	$237,000

Future direct benefits from this expenditure will be minimal, but the money spent on this research will not be wasted if the information and experience gained is sought by other Municipalities wishing to investigate treatment and disposal of sewage by spray irrigation.

TECHNICAL REVIEW

Pilot Project

In 1970 and 1971 the City of Vernon undertook extensive modifications of their trickling filter plant and constructed a large scale pilot irrigation project. Relevant statistics of the modified plant and the pilot irrigation project are as follows:

A. Sewage Treatment Plant Data:

Primary Clarifiers

No. 1: 45 ft. dia. and 14 ft. sidewater depth

No. 2: 40 ft. dia. and 10 ft. sidewater depth

Trickling Filters

No. 1: 135 ft. dia. and 4.5 ft. depth

No. 2: 120 ft. dia. and 4.0 ft. depth

Capacity: Converted to high rate with 1:1 recirculation rate;
No. 1: 1.0 MIGD and No. 2: 1.32 MIGD

Secondary Clarifiers

No. 1: 45 ft. dia. and 9 ft. deep with 875 sq. ft. of tube settlers

No. 2: 40 ft. dia. and 6.5 ft. deep

Capacity: No. 1 with tube settlers, 1.37 MIGD, with overflow rate of 2 USgpm/sq. ft. for the tube settlers
No. 2 0.83 MIGD

Chlorine Contact Chamber

Designed to provide 1 hour minimum contact at 1976 flows.

Digesters

No. 1: 26 ft. dia. and 28 ft. sidewater depth

No. 2: 22 ft. dia. and 22 ft. sidewater depth

Capacity: Operated in series with external heat applied, the digesters are rated for a maximum population of 18,000 people.

B. Spray Irrigation System Data

Pumps

200 HP, 3,600 RPM, 645 gpm against 882 ft. head

Supply Line

1,500 - 8" dia. lined and coated, welded steel pipe and 2,100 - 8" dia. ductile iron pipe.

Design pressure: 400 psi at treatment plant and 210 psi at the irrigation site.

Sprinkler Irrigation System

Three conventional wheel lines to irrigate 80 acres of alfalfa were provided initially and an additional 50 acres were recently put under irrigation. Normal irrigation rates for the soil and climatic conditions in the Vernon area have been used as recommended by the Provincial Department of Agriculture.

One "rain gun" with hand set laterals is used to irrigate an additional 40 acres. The rain gun is primarily used when changing the wheel lines location and when the alfalfa is being harvested.

During the past four years, the City of Vernon has tried a number of ways of using local farmers to carry out work on the farm. The most successful method found to date is to irrigate using direct labour and sell the standing crop for harvesting.

Good quality alfalfa has been produced with protein contents in excess of the norm for the Vernon area. Tonnage per acre has averaged 4.5 for the last 4 years.

Full Scale Project

The full-scale project is scheduled for construction during 1975 to 1977 and will involve the removal of one of the existing trickling filter plants and the construction of a new 2 MIGPD plant. This will provide future total capacity of approximately 3.4 MIGPD of secondary effluent. The new plant will include screening, aerated grit chamber, primary clarifier, plastic media trickling filter, secondary clarifier, and a smoothing basin with aeration.

A report was prepared by Stanley Associates Engineering Ltd. entitled "Sewage Treatment and Spray Irrigation of Treated Effluent Final Feasibility Report, September 1974". Projected sewage flows from that Report are as follows:

Year	Population	Average Daily Sewage Flow Imgd	Annual Sewage Volume Acre Feet	Maximum Day MGD	Peak Hour MGD
1976	15,600	1.67	2,240	2.84	4.51
1981	18,270	2.00	2,680	3.40	5.40
1986	25,900*	2.92	3,940	4.96	7.42
1991	31,200	3.62	4,850	6.15	6.91
1996	37,400	4.45	6,000	7.57	10.89
2001	45,500	5.59	7,500	9.50	12.86

* Municipality of Coldstream and outlying areas included in services area

A design brief has been prepared for this project and the pertinent facts are as follows:

A. <u>Treatment Plant</u>

Headworks

Intake Manhole

Designed for peak storm flow of 18 MIGD from 3 main sewer lines.

Grit Chamber

Aerated grit chamber with a capacity of 6.25 MIGD combined with air lift into grit settling channels.

Barminutor

Chicago Pump Model C24 relocated from an existing headworks. Capacity 6.7 MIGD with head loss of 6 inches and through-screen velocity of 5 ft/sec.

Primary Clarifier

60 ft. dia., 12 ft. side wall depth 2 MIGD average flow with overflow rates of 700 IGD/sq. ft.

Trickling Filter

Plastic media filters with gravity bypass and recirculating pump. 60 ft. dia. by 20 feet deep

Hydraulic load of 0.58 Igpm/sq. ft.

Biological load 60 lbs. BOD/1,000 sq. ft.-day.

Secondary Clarifier

60 ft. dia. and 12 ft. side wall depth

2 MIGD average flow with overflow rates of 700 IGD/sq. ft.

Smoothing Basin

Designed to hold 2 days of average flows (1976) above the normal operating level.

The basin's purpose is to dampen the hourly peaks in the daily flow so that maximum daily flows can be pumped by the highlift station to the irrigation area. It is also intended to store infrequent excessive peaks due to infiltration of storm waters into sanitary sewers and to provide storage during short power outages.

The basin also acts as a chlorine contact chamber.

Digesters

52 ft. diameter by 20 ft. deep

Retention time is 15 days with a daily raw sludge volume of 2,830 cu. ft./day.

B. <u>Irrigation</u>

Pumping and Storage

<u>High Lift Station</u>

2 - 2,700 USgpm @ 660 ft. TDH pumps, plus space for 2 additional pumps and a standby engine.

<u>Pressure line to reservoir</u>

24 inch diameter

Cement mortar lined steel or concrete cylinder pipe

<u>Booster Pump Station</u>

2 - 2,700 USgpm at 350 ft. TDH plus room for additional pumps and 1 standby engine

<u>Reservoirs</u>

No. 1 reservoir capacity 1,200 Acre feet with 95 ft. dam

No. 2 reservoir capacity 3,000 Acre feet

Spray Irrigation

Stage	Year	Annual Volume Acre Feet	Practical Irrigation Areas
Stage 1	1976	2,240	1,110 Acres
Stage 2	1986	3,940	1,940 "
Stage 3	2001	7,500	3,410 "

- Irrigation will be provided by pumping treated effluent through standard irrigation equipment onto allocated spray irrigation areas.
- Additional acreages for waste spraying by "guns" will be provided.
- Irrigation rates will vary from 14 inches per year to 31 inches per year depending on the soil conditions.

NON TECHNICAL CONSIDERATIONS

The major problems encountered in implementing the Vernon pilot spray irrigation project and the full scale project to date, have not been primarily technical, but rather one of gaining public acceptance and obtaining financial assistance from senior levels of government.

Due to growing public awareness of the environment and the particular local concern for Okanagan Lake water quality, the concept of spray irrigation of effluent as a means of final disposal is currently very popular in Central British Columbia. The Vernon Pilot Project in 1971 was implemented with little opposition mainly because it did not affect anyone directly as it was on Government land and quite isolated from the rest of the community.

The first crops were difficult to sell and farmers were reluctant to work on the fields. As local experience was gained it was found that cattle thrived on the high protein alfalfa; the product became fully acceptable and the crop commanded a premium price. From the point of view of farmers working on the land, harvesting the crop and selling it, the pilot scheme can be termed a success.

The preferred location for the full scale irrigation project was to the north of Vernon, in areas known as the L & A Ranch and the Grandview Flats. Following the preparation of an interim report, a public meeting was held in the area in an attempt to inform the affected people of the City of Vernon's plans and to obtain public reaction. The first meeting did not go smoothly and the project immediately raised a public storm which grew in intensity in the following months. The expressed concerns were for the health of the people in the area; for deflation of values of the land;and for lack of technical information on the very long term effects of irrigation on the lands. Also, it was found that many of the people were satisfied with dry farming their land with specialist crops and did not want to change to irrigated farming with increased labour and material costs.

The public outcry grew to such a point that the City abandoned this proposal.

The alternative now being implemented will use lands immediately adjacent to the pilot project. In this area, there are only a few private holdings with the remainder of the land owned by the federal and provincial governments. In addition, very few people live in the area and the ones that do are familiar with the pilot project and have experienced no problems.

The main disadvantages of the scheme being implemented are the expensive secondary treatment plant which must be continued in operation and expanded, and disposal areas considerably higher than the City with resultant high pumping costs with sites for winter effluent storage small in area and expensive to develop.

The capital cost of the full scale project is estimated to be 5.5 million dollars plus any land costs associated with the scheme. It was felt that to commit this amount of money to the project, it would be necessary to have direct control of the land for the life of the project which would require either outright purchase or long term leases. The costs for land acquisition amount to an additional 2.5 million dollars. Thus, for the first few years of operation,total cost will be approximately $740,000/annum or $50/capita/annum, which is an intolerable financial burden. However, financial participation in sewage collection, treatment and disposal by the Senior levels of Government and all possible sources of assistance have been vigorously examined, some of which are:

1. Central Mortgage and Housing Corporation -
   C.M.H.C. has had for many years a program where 2/3 or the capital costs of a project is loaned to the Municipality at attractive interest rates and 25% of the loan is forgiven.
2. Province of B.C. Bill 88 -
   This Bill provides for the Provincial Government to pay 75% of amortization costs of expenditures in excess of a 3 mill levy throughout the community. In Vernon's case it has substantial benefits.
3. British Columbia Land Commission -
   The B.C. Land Commission has been approached to assist in the acquisition of the necessary lands and indications are that this may be forthcoming.
4. A.R.D.A. Program -
   There would appear to be some possibility of gaining financial assistance through the A.R.D.A. program by which Federal and Provincial Governments and the benefitting landowners share in the cost of the irrigation system. Any financial assistance would apply to the spray irrigation portion of the project only.
5. Urban Demonstration Program -
   This program is under the Ministry of State and Urban Affairs whereby the Federal Government may contribute to innovative programs which demonstrate solutions to urban problems. Indications are that the Vernon project may qualify for this assistance.

The last hurdle to be cleared for the project is that a Pollution Control Board Permit must be obtained. The Board will not give any indication in writing of the acceptability of the project and land must be obtained prior to posting it for a P.C.B. Application.

The City of Vernon is pioneering a new method of sewage disposal in British Columbia and we hope that the experience gained will be of benefit to other communities.

APPENDIX I

OTHER METHODS OF LAND APPLICATION OF WASTEWATER

by

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APPENDIX I - OTHER METHODS OF LAND APPLICATION OF WASTEWATER

1.0 Introduction

The application of wastewater, treated or untreated, to the land has been in use for thousands of years. Recent investigations have revealed that wastewater application to the land was practiced in China and in ancient Greece in the period before the birth of Christ. Berlin, Paris, Melbourne and others are well known long-time users of land disposal. In Canada the first land disposal systems were installed near the turn of the century. Most of these systems were small and were employed to treat and dispose of domestic wastewaters from single family dwellings and farm operations. Within the last thirty years bigger installations have been built and are still in operation.

With the recent concern that even after secondary treatment, effluent is having a deleterious effect on some waterways, land application of wastewater is being re-examined in North America.

The purpose of this Appendix is to provide a review of the various land disposal techniques presently in use and to discuss their applicability to the Canadian environment giving their merits and limitations. A general review is provided as an introduction. This is followed by an intensive assessment and comparison of each land disposal technique.

2.0 General Review

Land application methods can be classified into two main families: surface and subsurface (Fig. 1). Surface application can be further subdivided into

a) irrigation (Fig. 2a)
b) overland flow (Fig. 2b)
c) infiltration percolation (Fig. 2c)

Subsurface disposal can be subdivided into

a) subsurface leaching, and
b) deep well injection.

2.1 Irrigation

Irrigation is the controlled discharge of effluent, by spraying or surface spreading, onto land to support plant growth. The application rate is low enough to prevent surface runoff and to ensure that wastewater is converted into the hydrological cycle by plant uptake or by evapotranspiration or seepage to the groundwater.

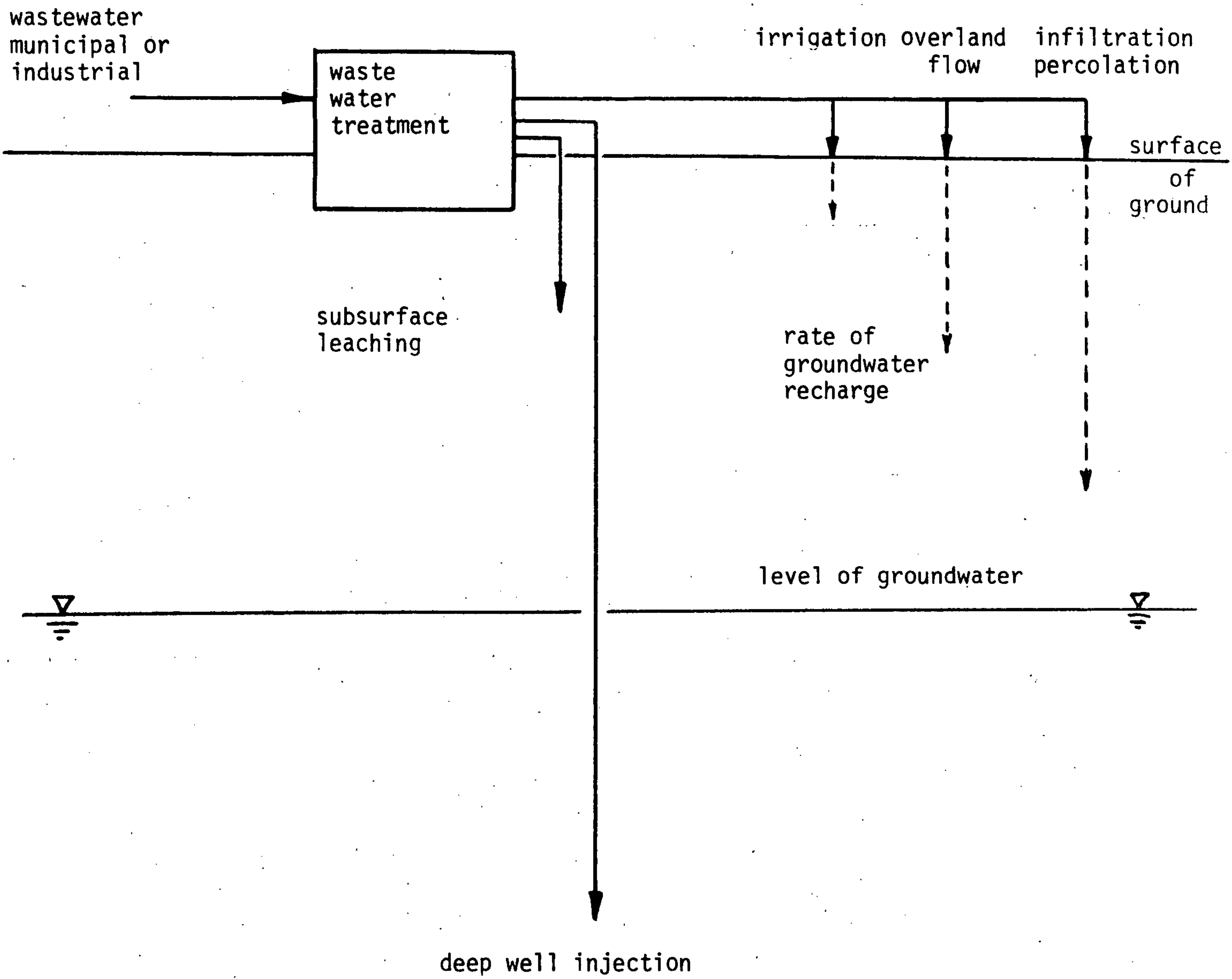


FIGURE 1

A PRESENTATION OF ALL SURFACE AND SUBSURFACE DISPOSAL SYSTEMS AND TECHNIQUES.

There are several established methods of irrigation of wastewater. These are spray irrigation (Fig. 3a), ridge and furrow (Fig. 3c), and flooding (Fig. 3b).

2.1.1. Spray Irrigation

In the spray irrigation method, effluent is applied above the ground surface in a manner similar to rainfall or the sprinkler systems one observes in parks or golf courses. The method of application depends upon the soil, the type of crop, the climate and the topography. These factors, as well as regulatory criteria determine the application rate and hardware to be installed.

2.1.2. Ridge and Furrow

Ridge and furrow is a method whereby wastewaters flow by gravity in long furrows allowing the water to seep into the ground. The ground is landscaped into alternating ridges and furrows, the width and depth varying with soil conditions and quantity of wastewater applied. The width of the ridges are dependent upon the crop to be grown.

2.1.3. Flooding

Flooding is the covering of the land to a certain depth with effluent. The depth is determined by the choice of vegetation and the type of soil. There are three basic techniques in flooding the land: border strip (Fig. 4a), contour check (Fig. 4b), and spreading basin (Fig. 4c).

The border strip method consists of sloped strips of land 600 to 1000 feet long divided by borders or dykes every 20 to 60 feet. Contour check is the creation of dykes along the contour of a hill or slope containing the effluent so it does not run down the slope. The effect is similar to the Oriental rice paddy. Spreading basins are shallow ponds which are periodically flooded with effluent and which hold the effluent until it percolates into the ground, is used by crops, or evaporates into the air. This method is similar to, but much larger than, the border strip method. Spreading basins are generally used for rapid infiltration.

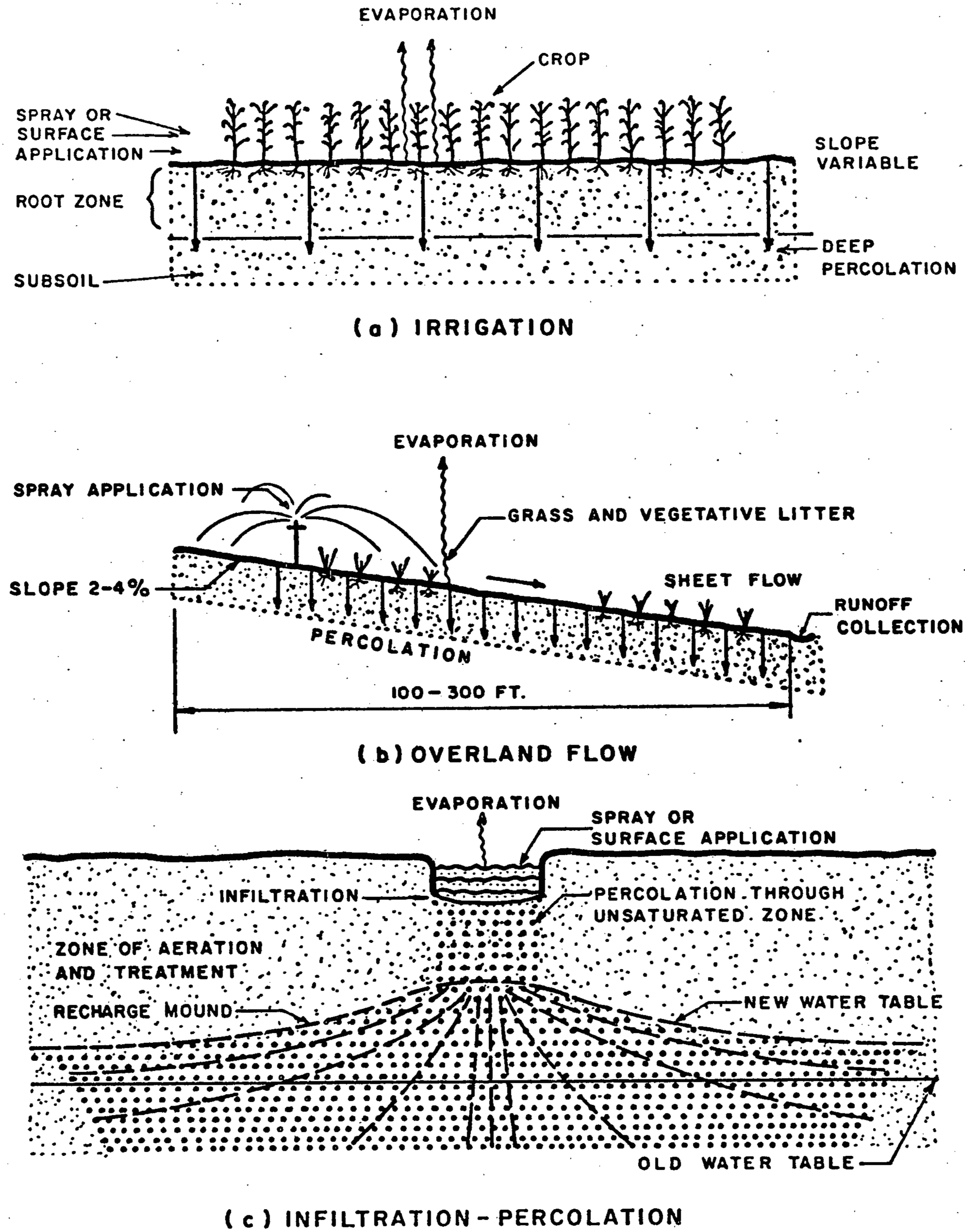
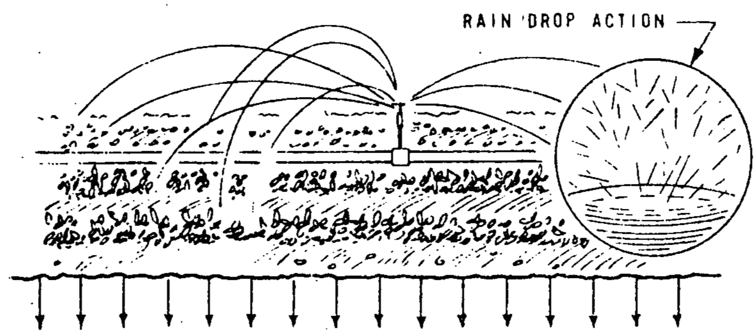
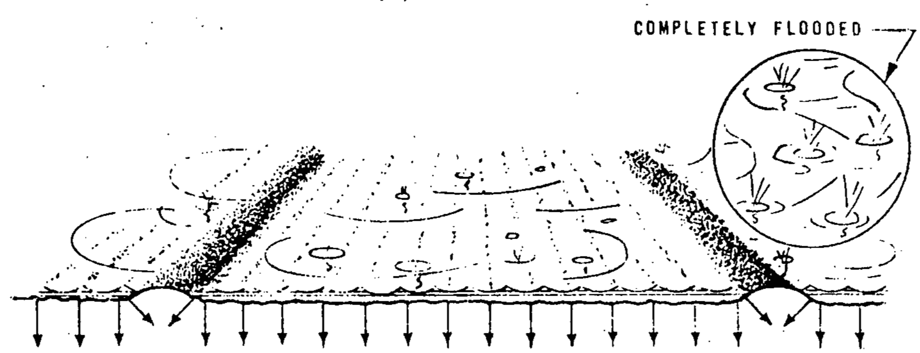


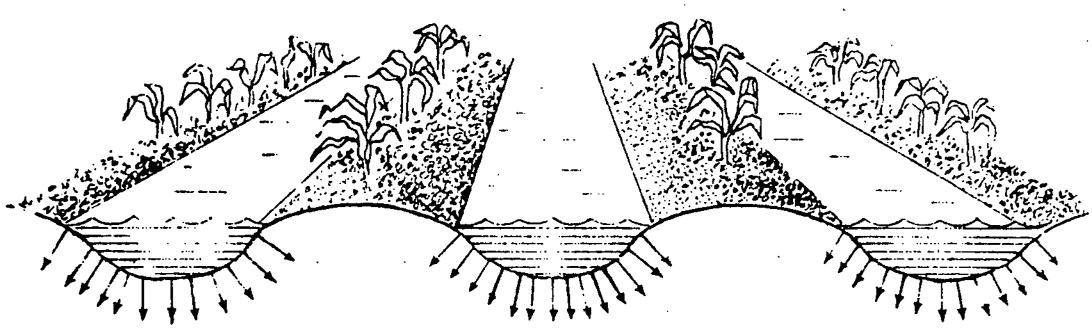
Figure 2
LAND APPLICATION APPROACHES



(a) SPRINKLER

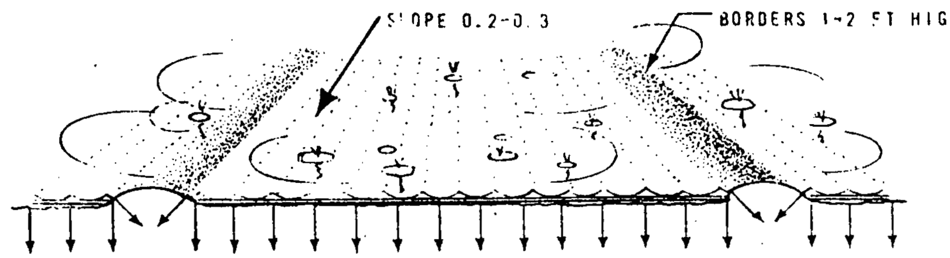


(b) FLOODING

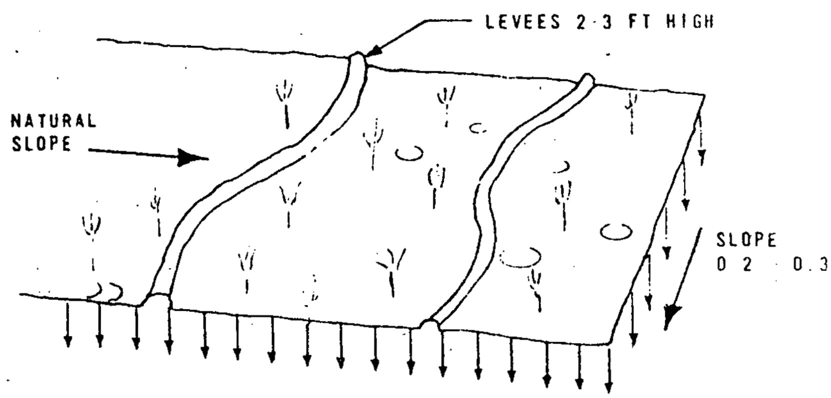


(c) RIDGE AND FURROW

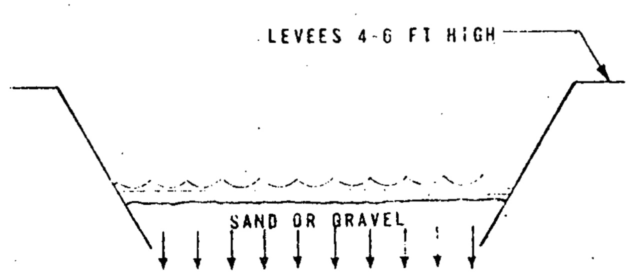
FIGURE 3
BASIC METHODS OF APPLICATION



(a) BORDER STRIP



(b) CONTOUR CHECK



(c) SPREADING BASIN

FIGURE 4
TYPES OF FLOOD IRRIGATION

2.2 Overland Flow

Overland flow (Fig. 2b) is the controlled discharge, by spraying or other means, of effluent onto the land with a large portion of the wastewater appearing as runoff. As the effluent flows down the slope a portion infiltrates into the soil, a small amount evaporates, and the remainder flows to collection channels.

2.3 Infiltration-Percolation

This method of treatment (Fig. 2c) is similar to intermittent sand filtration. The major protion of the wastewater enters the groundwater although there is some loss to evaporation. The spreading basins are generally dosed on an intermittent basis to maintain high infiltration rates. For this method soils must be coarse textured sands, loamy sands, or sandy loams. This process has been developed for groundwater recharge, and thus the distinction between treatment and disposal is quite fine.

2.4 Subsurface Leaching

Subsurface leaching systems are more popularly known as tile fields and leaching pits. They are generally limited in their range of application and are prevalent in rural areas or in un-serviced communities. Since this seminar pertains to land application of municipal wastewater tile fields will not be discussed any further in this presentation.

2.5 Deep Well Injection

This method discharges wastewaters underground by means of deep wells, sometimes hundreds of feet deep. This method has been infrequently used and is being mentioned more to round out this discussion on land application of wastewater than to identify this as an acceptable treatment method.

This practice is a disposal method, not a wastewater treatment method.

3.0 Detailed Review

Having presented in Section 2 a brief and quite general description of all land application methods a detailed comparison of these now follows.

The purpose of this review is to assist the engineer in deciding whether or not land disposal should be investigated and if so which method is most applicable for his situation.

The review will concentrate on the two most widely used methods; irrigation and infiltration-percolation. Overland flow, subsurface leaching and injection wells will not be reviewed since these methods are either infrequently used or outside of the scope of this seminar.

The review, i.e. comparison, describes system design management and operation of irrigation and infiltration-percolation methods and the resulting environmental effects. Where necessary, spray irrigation, ridge and furrow, and flooding techniques are reviewed individually. The method of review is highlighted by Figure 5.

4.0 Notice

information presented herein is a summarization from many different sources and the exercise is on-going. Therefore this is meant to be an interim report. It is expected that a more comprehensive report will be prepared in due course. Empirical data presented should serve only as a guide and should be used with care and discretion.

SYSTEM DESIGN	consists of	- Site Selection - Determination of Wastewater Application Method - Using Design Criteria to design the total system
↓ MANAGEMENT and OPERATION	consists of	- Determination of Extent of Operation - Review of sources of Operational Problems - Monitoring Activities - Expected Treatment Efficiencies
↓ ENVIRONMENTAL EFFECTS	consists of	- Review of expected Environmental Effects on climate, soil, groundwater, crops, humans, etc.
↓ SYSTEM FAILURE	consists of	- Review of case histories of other systems which have failed due to overloading groundwater pollution, mismanagement

FIGURE 5

A CHECK LIST FOR DETERMINING THE FEASIBILITY
OF LAND APPLICATION OF WASTEWATER

(A detailed review of the above items follows)

TOPICS	ELEMENTS	IRRIGATION METHOD: SPRAY IRRIGATION / RIDGE AND FURROW / FLOODING	INFILTRATION-PERCOLATION METHOD
System Design	Factors in Site Selection		
	1. Climate	Temperature range, annual precipitation, humidity, and wind velocity have an effect on the amount of water that can be disposed of at a certain location, on the type of crop that can be grown, on the shape, size and even location of the disposal site, on the method of operation and on the required winter storage. References: 1, 2, 3.	Description is similar to Irrigation Method and should be followed unless otherwise indicated. same references
	2. Soil	Soils generally consist of A,B and C horizons with the A horizon containing most of the organic matter. The B horizon contains more minerals leached from the A horizon while the C horizon is a transition to the present material. The chemistry and texture (particle size and shape) of these horizons will vary considerably. The texture and structure of the soil is influenced by the percentage of sand soil and clay which it contains. These also largely influence the soil drainability. For example clay soils do not drain well. Acceptable soil types include sand, sandy loams and loamy sands. Permafrost and muskeg must be avoided. Well drained soil is preferable. Drainage is dependent upon the soils type as well as upon the absence or presence of lateral and subsurface constraints to the flow of water. The lateral transmissibility and percolation rate must be equal to or higher than the infiltration rate to avoid ponding or waterlogging the soil. Soil borings must be taken at the site to obtain the soil profile and the overall coefficient of permeability. Clay lenses must be identified and sites with extensive clay layers or other	Description is similar to Irrigation Method and should be followed unless otherwise indicated. Very coarse sand or gravel should be avoided.

TOPICS	ELEMENTS	IRRIGATION METHOD			INFILTRATION-PERCOLATION METHOD
		SPRAY IRRIGATION	RIDGE AND FURROW	FLOODING	
		impermeable formations near the surface should be rejected. Soils must have an infiltration rate of at least 2 inches per day. The chemistry of the soil must be known. Salinity, alkalinity and nutrient level of the soil should be determined and monitored. Indicators of adverse soil conditions such as pH, conductivity and sodium adsorption ratio (SAR) should be determined. The crops response and phosphate adsorption in the soils are influenced by pH. Neutral and slightly acid soils are ideal for crops but not for phosphate adsorption. The electrical conductivity indicates the salinity or TDS of the soil. Soils having conductivities in excess of 4000 micromhos per centimeter are known as saline soils. The sodium adsorption ratio determines the sodium hazard to the soil when irrigation water having a high sodium concentration is used. Water having a SAR of 8 or more on certain soils can produce a definite hazard to permeability. Soils remove phosphate by adsorption, mineralization, plant uptake and biological immobilization. References: 1, 2, 3, 6.			Soils must have an infiltration rate on the order of 4 to 12 inches per day or more. Adsorption and mineralization are very important phosphate removal methods. The Langmuir isotherm test will describe phosphate sorption in soils. Mineralization is not well known and is influenced by soil pH and soil formation.
	3. Soil Stratum	Adequate soil depth is important for root development, for retention of wastewater constituents and for biochemical action. As mentioned previously the depth of soil layers and the permeability of each layer will affect the overall percolation rate and thus soil borings must be taken. A minimum soil depth of 5 to			Description is similar to Irrigation Method and should be followed.

TOPICS	ELEMENTS	IRRIGATION METHOD			INFILTRATION-PERCOLATION METHOD
		SPRAY IRRIGATION	RIDGE AND FURROW	FLOODING	
		6 feet is preferred. References: 2, 3, 4, 12.			
	4. Soil Monitoring	A soil inventory and characterization should be prepared for the area. Soil properties to be determined include depth, texture, structure, permeability, moisture holding capacity, pH, conductivity, cation exchange capacities (SAR) organic matter content, total nitrogen, nitrate nitrogen, total phosphorus, sodium, calcium, potassium and magnesium as well as those trace elements likely to be added by the wastewater. Physical and chemical properties should be determined for one or more representative sets of profile samples from the area. The number of soil locations to be taken will vary, depending upon the uniformity of the soil and terrain. Samples should be taken from each major horizon to below rooting depth or five feet, whichever is deeper. Physical data from greater depths may be required for determination of saturated and unsaturated hydraulic conductivity. Values of chemical constituents should be weighted by the thickness of the sampled horizon or layer. Soil samples should be taken for testing based on the hydrologic seasons, e.g. start of growing season, start of soil moisture recharge and maximum ground level. References: 12.			Description is similar to Irrigation Method and should be followed. same reference.
	5. Groundwater	In order to take soil samples for the tests mentioned above one must know various qualities of the groundwater including depth, variation of depth, direction and velocity of groundwater			The groundwater hydrology is the most important hydrologic factor in site selection.

TOPICS	ELEMENTS	IRRIGATION METHOD			INFILTRATION-PERCOLATION METHOD
		SPRAY IRRIGATION	RIDGE AND FURROW	FLOODING	
		flow, and groundwater quality. The soil inventory and characterization should greatly assist the engineer in understanding the behaviour of the groundwater at the site and in determining whether or not land application of treated wastewater is feasible. Since several levels of groundwater may underlie the site, the quality and movement potential of each must be determined unless it is shown that lower zones are separated by impervious strata. To ensure an aerobic zone for roots it is preferred that the groundwater level be maintained at least 5 feet below the ground surface. If this is not possible groundwater may have to be renovated. The groundwater quality should be tested for the following properties: pH, temperature, specific conductivity, total acidity or alkalinity, fecal coliforms, total and soluble organic phosphorus, nitrate N, organic and total N, and chlorides. The location and number of on site wells will vary with hydrogeologic conditions. A minimum density of one well in 8 acres has been suggested. Wells should be located downstream of the groundwater flow. Off-site wells should be located 1000 feet from the area at 1000 foot intervals around the site. References: 2, 12.			The description unless otherwise indicated is similar to Irrigation Method and should be followed. The normal water table must be at least 15 feet from the surface of the ground. A depth of 15 feet from surface to groundwater is considered a minimum for maintenance of long term liquid loading rates and effective renovation. The quality of the groundwater is critical whether it is of high or low quality. same references.

TOPICS	ELEMENTS	IRRIGATION METHOD: SPRAY IRRIGATION / RIDGE AND FURROW / FLOODING	INFILTRATION-PERCOLATION METHOD
	6. Topography	The topography of the site must be such that farm equipment can be used to look after the crops planted. Where necessary landscaping may have to be carried out to make the land acceptable for the method of application and for the type of crop grown. Slopes up to 15 percent are acceptable with or without terracing. Flooding requires slopes of less than 1 percent, areas subject to flooding more than once in 50 years or having poor drainage must be avoided. References: 2, 3, 13.	Since high rate disposal is desired, ponding or flooding the basin is the usual mode of application. A site should be flat or gently sloping so that it can be dyked into basins. Too much slope would create lateral percolation which could affect the percolation rate of lower basins. Areas subject to flooding more than once in 50 years or have poor drainage must be avoided. same references
	7. Hydrology and Geology	Since groundwater is the most important hydrologic and geologic factor it has been highlighted separately. Other important factors are rainfall and storm runoff, the nature of the hydrologic basin and the nature of underlying rock formation. Rainfall will reduce the capacity of the soil to absorb wastewater and will affect the wastewater loading rates. Storm runoff must be routed around the site instead of being allowed access to the site. Areas underlain with limestone must be investigated to determine the possibility of a short circuit to the groundwater. References: 2, 3, 13.	Areas of prolonged and heavy precipitation may not be ideal for this method. The description, unless supplemented by additional information, is similar to Irrigation Method and should be followed. Since the parent material will give the soil its chemical and mechanical properties, knowledge of parent material and existing rock formations is important in assessing the water holding characteristics and transmissibility of a soil system. The specific yield of a soil is an accurate measure of its transmissibility. same references

NOTE: For simplicity purposes the next element for Irrigation i.e. Application Technique will discuss spray irrigation, ridge and furrow, and flooding separately

TOPICS	ELEMENTS	IRRIGATION		
		SPRAY IRRIGATION	RIDGE AND FURROW	FLOODING
	Application Technique	Nozzles are mounted on risers which should be tall enough for the spray to clear mature plant foliage. Applications may be low pressure (5-30 psi), medium pressure (30-60 psi), or high pressure (g.t. 60 psi). High pressure applications above 1/3 in/hr should be avoided to prevent soil compaction. Overlap of the spray is not recommended. A buffer zone around the site is recommended especially along that part of the perimeter downwind of the sprinklers. During high winds spraying should stop. The size of nozzle, water pressure and nozzle spacing will be determined by the application rate. Recommended spray schedules are: Duration - 8 hr or less Spray/Rest ratio - 1:4 or lower Daylight spray only No winter operation No spraying during rain or high winds. References: 2, 8, 11, 13	This method may be used where spray irrigation is not preferred because of high winds, tight soil or higher costs. Extensive land preparation is required. Uniform distribution is fairly difficult to maintain. Wastewater at a depth of 2 to 6 inches travels down the furrows while crops are grown on ridges. Typical ridges are 8 to 10 inches high on 36 to 48 inch centres with furrows 10 to 16 inches wide and 6 to 10 inches deep. same references	On unlevel sloping ground the process of contour check may be used to ensure a uniform distribution. Application of 2 to 4 inches per day with resting periods of 5 to 20 days are typical operations. same references.

TOPICS	ELEMENTS	IRRIGATION METHOD: SPRAY IRRIGATION / RIDGE AND FURROW / FLOODING	INFILTRATION-PERCOLATION METHOD
Design Criteria			
	1. Wastewater Quality and Pretreatment	All wastewaters must receive primary and secondary treatment and disinfection. Equalization and pH control must be provided. Wastes having received secondary treatment and generated outside of the spray season must be stored in a lagoon. Due to the winter climate the capacity of the lagoon will vary between 5 to 7 months Wastewaters applied to the land must meet irrigation water quality standards. These waters should have a total dissolved solids less than 1500-3200 mg/1, a SAR of less than 8, and a boron content of less than 1.0 mg/1. Excessive amounts of Cu, Mn, Li, As and free chlorine can also be detrimental. Excessive bicarbonate can also be harmful since it can precipitate as a carbonate and cause a coating. References: 1, 4, 5	The requirements for pretreatment are similar to Irrigation Methods and may be even more stringent should the concentration of suspended solids and organic material be unacceptable and hasten the clogging of the soil surface. This phenomenon has a direct effect on the application rate and thus the required land area for disposal. Clogging will demand periodic drying. The requirements for the quality of wastewaters applied to the land are similar to Irrigation Methods. same references
	2. Hydraulic Loading Rate	The loading rate of wastewater is affected by conditions of the soil, climate, crop and quality of the wastewater. The loading rate may thus vary from one site to another. Loading rates must prevent surface runoff, ponding and soil clogging. The rate can be determined from existing closely similar operations, consultation with agricultural experts, or from pilot work. The rate should not be made solely on the basis of the percolation test.	The infiltration rate of the soil determines the liquid loading rate. Most rates of loading are in the order of 4 to 21 inches per day. During actual operation the infiltration rate may decrease due to clogging and thus the design rate must be determined on the basis of pilot work. A factor of safety due to the influence of climate, variation in wastewater characteristics and groundwater levels may have to be used.

TOPICS	ELEMENTS	IRRIGATION METHOD			INFILTRATION-PERCOLATION METHOD
		SPRAY IRRIGATION	RIDGE AND FURROW	FLOODING	
		Maximum instantaneous application rate should be 0.25 inches per hour while the maximum daily application rate should be 1.5 inches. A weekly application rate greater than 3 inches should be avoided. References: 1, 2, 4, 5.			same references
	3. Organic Loading	High organic loadings can clog the soil and thus seal the surface. Anaerobic condition may develop if a drying out time is not provided. As mentioned previously a spray use/rest ratio of 1:4 or lower (e.g. 8 hr. spray, 32 hr. rest) is recommended. References: 4			Suggested BOD_5 loading rates vary between 7400 lb/acre/year for silt loam soil and 60,000 lb/acre/year for sandy soil. However actual operations rarely used rates higher than 30,000 lb/acre/year. The BOD_5 should not be the only criterion in organic loadings. The total oxygen demand must also be considered. References: 14
	4. Nitrogen Loading	Nitrogen contained in wastewater applied to the land may be in any of four forms: organic, ammonium, nitrate and nitrite. When applied to the land the soil will eliminate some of the nitrogen as well as crops. In fact the uptake of nitrogen by plants is a significant removal mechanism for irrigation systems. Unfortunately, nitrate nitrogen is not retained by the soil and readily leaches with applied water. The acceptable nitrogen loading rate depends on the type of soil and the type of crop. To avoid adding excess nitrogen to the soil, it may be necessary to limit the nitrogen loading to the amount that crops can assimilate. The			The uptake of nitrogen by plants is not a significant removal mechanism for infiltration-percolation systems. This is due to the high volume of wastewater applied. A significant loss of nitrogen to the groundwater as nitrate can contaminate potable water supply. Correction of this problem may involve 1. Reduction of rate of waste application, 2. Reduction of nitrogen content of the effluent, or 3. Create temporary anaerobic conditions in the soil to favour denitrification, i.e. effluent should be continuously applied until the oxygen in the soil is

TOPICS	ELEMENTS	IRRIGATION METHOD: SPRAY IRRIGATION / RIDGE AND FURROW / FLOODING	INFILTRATION-PERCOLATION METHOD
		designer must be aware that ammonium and nitrite can be oxidized to form additional nitrate nitrogen. References: 2, 4, 12.	depleted. A drying period must then follow. same references.
	5. Phosphorus Loading	Inorganic phosphorus applied to the surface of the land is readily fixed in most soils, either as organic complexes, as Fe or Aℓ phosphates, or Ca phosphates in alkaline soils. It has been reported that the amount of phosphorus removal by fixation is less at pH values between 6 and 7 than for either higher or lower pH values. The degree of phosphorus adsorption will relate to concentrations of Fe and Al and original phosphorus levels. Phosphorus can also be removed by plant uptake. To evaluate a land disposal site for phosphorus removal involves the following: 1. Field survey 2. Literature survey about soils and geology 3. Determine flow pathway in the soil 4. Sample the soil in that pathway 5. Analyze soil for pH, particle size distribution, and rapid phosphate adsorption capacity. 6. Calculate and add the capacities of the various soil volumes involved. One then either designs the system not to exceed the adsorption capacity of the site, conducts further tests, or rejects the site. In most irrigation system the phosphorus loading is not critical. References: 5, 12.	The phosphorus loading with this method is much higher and warrants an analysis of the soil's ability to adsorb the phosphorus. The discussion in irrigation is also applicable to the infiltration percolation method. same references.

TOPICS	ELEMENTS	IRRIGATION METHOD: SPRAY IRRIGATION / RIDGE AND FURROW / FLOODING	INFILTRATION-PERCOLATION METHOD
	6. Heavy Metals	Heavy metals are present in municipal wastewaters in trace amounts. Wastewaters discharged onto the land must meet Provincial irrigation water quality criteria. References: 1, 4.	As with irrigation the infiltration-percolation method must meet Provincial irrigation water quality criteria. same references
	7. Sodium	High salinity will impair the growth of a cover crop and in clay soils will cause sodium to replace calcium and magnesium by ion exchange. This will cause soil dispersion and as a result drainage and aeration in the soil will be poor. A discussion on this has been prepared above. The SAR should be checked and a salinity less than 1000 ppm has been recommended. References: 1, 2, 3, 4.	The requirements for infiltration-percolation are similar to irrigation. same references
	8. Land Requirements	When the controlling loading rate has been established, the approximate acreage necessary for irrigation can be calculated knowing the flow rate of the wastewater. The quantity of winter storage must be known in order to design the area to receive the application of both stored and daily generated effluent. For spray irrigation, buffer zones must be included. Unless provincial guidelines determine the size of the buffer zone a downwind buffer zone on the order of 200 feet is considered adequate. Windbreakers in a line perpendicular to the wind direction may be required in the buffer zone. References: 1, 11.	

TOPICS	ELEMENTS	IRRIGATION METHOD: SPRAY IRRIGATION / RIDGE AND FURROW / FLOODING	INFILTRATION-PERCOLATION METHOD
	9. Drying Period	For irrigation practices a spray use/rest ratio of 1:4 or lower has been recommended. This ratio in addition to maximum hourly rates, daily and weekly rates have been mentioned elsewhere since they will influence land requirements. For flooding or ridge and furrow operations typical rest periods vary between 7 to 14 days while for spray irrigation vary between 5 to 10 days. References: 4, 13.	
	10. Crops	The crops selected for any one site must have certain characteristics advantageous to irrigation. These are 1. High water uptake 2. High nutrient uptake 3. High salt tolerance 4. Market value 5. Low management requirements Information on these characteristics should be available from the Department of Agriculture. References: 2.	At this moment there is no agreement if vegetation should or should not be allowed on the ground surface. The advantages of vegetation are 1. Protection of soil from the impact of water droplets 2. Additional nutrient removal 3. Possible promotion of denitrification The disadvantages of vegetation are 1. Increased maintenance 2. Lower recharge depth 3. Loading cycles must be adjusted to permit plant growth. When vegetation is not used, a gravel layer over the land surface may be used provided that there is no abrupt change in particle size between the gravel and the soil. same reference
	11. Distribution system	For crop irrigation the distribution system consists of four elements: transmission to site, distribution to outlets, outlet configuration and controls. The design of irrigation distribution systems	For infiltration percolation systems the distribution network consists of facilities to transfer wastewater to the site, outlet facilities and hydraulic controls. The design of the distribution system is provided

TOPICS	ELEMENTS	IRRIGATION METHOD: SPRAY IRRIGATION / RIDGE AND FURROW / FLOODING	INFILTRATION-PERCOLATION METHOD
		is provided by the Department of Agriculture and from Agricultural Associations. References: 11, 13	by the Department of Agriculture and from Agricultural Associations. same reference
	12. Climate	Due to the duration of the winter in Canada, wastewater must be stored during that season. Storage requirements will vary across Canada. In addition the uncertainty of precipitation during the summer will warrant a factor of safety in the amount of land used. This is especially true in areas experiencing a high precipitation rate.	The uncertainty of weather patterns may require a factor of safety in the amount of land used. This is important in areas of high precipitation.
Management and Operation	Seasonal Variation in Operation	The operation of a crop irrigation system must adjust to the changing demands of the crop. Usually the rate of evapotranspiration increases as the plants grow until a peak is reached. Afterwards the rate begins to drop until the crop is harvested. The operation is also seasonal since during the winter and during rainfall irrigation is not practiced. Variations in the resting period have been mentioned elsewhere. References: 2	As with the irrigation system, the infiltration-percolation system is often not in operation during the winter and during rainfall. In addition a schedule of intermittent application of wastewater is required to maintain reasonable infiltration rates and renovative capacities. Recommended resting periods have been mentioned previously. Optimum loading cycles depends on the objectives of the system, e.g. increase ammonium adsorption capacity, maximize nitrogen removal, maximize infiltration rate. same reference.
	Operational Problems	Inspection of irrigation facilities have identified a variety of operating problems such as 1. Failure of sprinkler rotation and maintenance of fields. 2. Spray nozzles clogged. 3. Operator not assigned to manage the system. 4. Unanticipated wastes of high strength allowed to enter the disposal system.	Weather, mechanical breakdown and wastewater characteristics are a major source of operational problems. Most of the problems mentioned for the irrigation method are also applicable for infiltration-percolation. In addition clogging due to an abnormally high solids content in the water is a common problem.

TOPICS	ELEMENTS	IRRIGATION METHOD			INFILTRATION-PERCOLATION METHOD
		SPRAY IRRIGATION	RIDGE AND FURROW	FLOODING	
		5. Lack of equalization and detention 6. Excessive pH variation 7. High application rates causing runoff. References: 4, 11.			
	Monitoring	Monitoring of the variables involved in the operation of a wastewater irrigation site should be conducted periodically to ensure reliable operation. These variables are: 1. climate e.g. precipitation, temp., wind 2. soil) 3. soil water) e.g. at several points and various depths 4. groundwater 5. crops Climatological data should be analyzed to obtain weather patterns in order to establish the most efficient crop operation as well as to establish a wastewater application rate that will not waterlog the soil. Wind patterns will affect spray distribution and influence the location and size of buffer zones and vegetation barrier on the buffer zone. The minimum parameters in the wastewater and in the groundwater above and below the site that need to be analyzed have been mentioned previously. The SAR should be checked annually. Wastewater constituents will indicate which elements to test for to avoid a buildup of hazardous substances. References: 5, 12			Due to the high loading rates flow-meters or measuring flumes are necessary to measure the wastewater application rate and changes in the soil infiltration rate. Both the wastewater and the groundwater above and below the site must be sampled on a regular basis, measuring characteristics such as BOD, SS, nitrogen, phosphorus, TDS and coliforms. Minerals and heavy metals should be analyzed at a less frequent interval. Sampling and recording wells should be established around the spreading basin on the basis of the site geology. same references.
	Treatment Efficiency	The following efficiencies have been noted in the literature: BOD - 90-99% SS - 97-99%			The following efficiencies have been noted in the literature: BOD - 88-99% SS - 100%

TOPICS	ELEMENTS	IRRIGATION METHOD			INFILTRATION-PERCOLATION METHOD
		SPRAY IRRIGATION	RIDGE AND FURROW	FLOODING	
		N - 60-90% P - 80-99% E.Coli - 96-99% Most samples were taken at a depth between 3 to 6 feet and wastewater application rates varied between 1 to 4 inches per week. References: 10.			N - 0-80% P - 70-95% E.Coli - 0-100% Most samples were taken at a depth between 7 to 10 feet. Most sites reported an E.Coli removal efficiency between 97 to 100%, however in some sites coliforms tend to regrow in the soil. same reference.
Environ-mental Effects	Climate	The effects of irrigation on the climate are limited and are very localized. References: 1			
	Soil	The application of wastewater onto the soil can be both beneficial and detremental. Increased soil fertility and soil tilth have been reported. However since irrigation depends upon evaporation for a considerable portion of the applied wastewater, concentration of the constituents that remain occurs. Plant toxicity and increased soil impermeability due to buildup of metals and TDS can occur. Most of the effects may take many decades to develop. Due to the low application rate the soil structure, infiltration rate, permeability, soil texture, and other soil properties should not be affected. Most problems are caused by faulty engineering. References: 1, 3, 9.			The effects on the soil are similar to the ones described for irrigation except that since the wastewater application rate is very much higher, detrimental soil changes will occur more frequently and more rapidly. High application rates without proper management will result in clogging and anaerobic conditions. These phenomena have been discussed previously. same reference.

TOPICS	ELEMENTS	IRRIGATION METHOD			INFILTRATION-PERCOLATION METHOD
		SPRAY IRRIGATION	RIDGE AND FURROW	FLOODING	
	Vegetation	The application of wastewater to crops has been found to be beneficial because of the natural fertilizers and nutrients in the liquid. Trace elements in wastewater can be helpful in plant growth and yet may become toxic in high concentrations. References: 3, 15			The effects on vegetation are similar to the ones described for irrigation. An additional effect common to infiltration-percolation is over-watering. same references.
	Groundwater	The application of treated wastewater during irrigation will have a limited influence on the groundwater hydrology since parts of the wastewater will be lost by evaporation and evapotranspiration via plant uptake. References: 2.			A greater effect on the groundwater hydrology is known to occur with infiltration-percolation systems since they have either reversed or slowed the drop in the groundwater level. Some operations have repelled the intrusion of salt water into fresh water aquifers. same reference.
	1. Nitrogen	Nitrate nitrogen is used by plants for growth. The amount varies with plant species and growth season. Nitrates not used will leach into the groundwater and contaminate the groundwater. Water quality standards for drinking purposes identify the recommended limit of nitrate nitrogen. References 2, 3, 10, 12			Nearly every infiltration-percolation system passes nitrate nitrogen in significant quantities into the groundwater. Systems operated with long flooding and drying periods have reversed this problem by allowing denitrification to occur. same references.

TOPICS	ELEMENTS	IRRIGATION METHOD: SPRAY IRRIGATION / RIDGE AND FURROW / FLOODING	INFILTRATION-PERCOLATION METHOD
	2. Phosphorus	Phosphorus in the wastewater may also leach to the groundwater if it is not fixed by the soil or used by the crop. This occurrence is rare in irrigation practice. Soils with appreciable organic or clay contents adsorb almost all of the phosphorus applied by irrigation. References: 3, 5, 12.	Because granular soils are required,the removal of phosphorus may be limited. Phosphorus may be a problem if it reaches a surface body of water, e.g. a lake. A few isolated problems have been noted. same references.
	3. Organics	Organics can appear in groundwater but this is less likely in irrigation due to different soil requirements, loading rates, vegetation and other factors. References: 2.	If organic matter, particularly refractory organic matter reaches the groundwater, a health hazard may be created when the water is recovered for reuse. At present there is no evidence that indicates that organic matter reaches the groundwater. same reference.
	4. Trace Elements	Trace elements are generally changed in the soil by physical chemical and biochemical reactions. Adverse effects have so far not been detected since toxicity to plants and animals may take decades to be noticeable. References: 11.	Trace element retention in soils of infiltration-percolation may be limited because of the granular nature of the soil. Organic humus in the soil will offset this deficiency. same reference.
	5. Total Dissolved Solids	The total dissolved solids (TDS) concentration in the groundwater is affected by the leaching of minerals from the soil. Problems associated with high concentrations of salt in the soil are more common with irrigation operations than with infiltration percolation systems. References: 2, 10.	In general, rapid infiltration of wastewater minimizes salinity increases. Where wastewaters are collected for reuse purposes an increase in TDS has been noted. This usually occurs more rapidly in small closed hydrologic basins. Where reuse is absent this problem has not been identified. same references.

TOPICS	ELEMENTS	IRRIGATION METHOD: SPRAY IRRIGATION / RIDGE AND FURROW / FLOODING	INFILTRATION-PERCOLATION METHOD
	6. Bacteria and Viruses	Most studies indicate a rather rapid die-back of coliforms and bacterial pathogens reaching the soil so that long term hazards to groundwater or surface water is considered minimal. The role of viruses and their die-back is a matter of conjecture. Chlorination of treated wastewaters is required. References: 1, 2.	The behavior of bacteria and viruses is the same with the infiltration method as with irrigation. same references.
System Failure	Limits of Loading 1. Liquid Loading	The maximum loading rate is dependent on the soil, geology, groundwater hydrology and crop. A failure to understand these factors at a site has resulted in over-loadings. Loading rates have been mentioned above and should be a guide rather than the rule.	When a soil is saturated, anaerobic conditions will develop and the soil will seal itself. Without an adequate drying period, aerobic conditions will not return and the system will fail.

TOPICS	ELEMENTS	IRRIGATION METHOD SPRAY IRRIGATION RIDGE AND FURROW FLOODING	INFILTRATION-PERCOLATION METHOD
	2. Organic Loading	The upper limits of organic loadings are rarely approached in wastewater irrigation practice. Literature surveys so far have not identified systems failure due to organic loading using treated municipal wastewaters. References: 1, 2, 3, 4, 10, 11, 12, 13.	The results for infiltration-percolation systems are similar to irrigation systems. same references.
	3. Nitrogen Loading	Despite low hydraulic loading a buildup of nitrates in the groundwater has been detected. Detection of pollution due to the nitrate buildup has sometimes been possible after a few years in operation. However no systems are known to have failed solely due to nitrogen loading. References: 1, 2, 3, 4, 10, 11, 12, 13.	The results for infiltration-percolation systems are similar to irrigation systems.
	4. Toxic Compound Buildup	Buildup of TDS, sodium and heavy metals in the soil can cause site abandonment. Leaching or the addition of soil amendments may alleviate the toxicity; in the case of TDS or boron, a more salt tolerant crop may have to be grown. References: 1, 2, 3, 4, 10, 11, 12, 13.	If a wastewater application - reuse system is operated, TDS, sodium and heavy metals can cause site abandonment. References: 1, 2, 3, 10.
	Groundwater Pollution	Due to the low hydraulic rate, the contamination of groundwater is not considered to be very extensive. In spite of this, wastewaters must be adequately treated and the design engineer must perform a thorough investigation to avoid groundwater contamination. Groundwater, once contaminated, may remain in a deteriorated or unusable state for decades. References: 1, 2, 10, 11	Groundwater contamination is closely tied to overloading, mismanagement and poor design. Infiltration systems will affect the groundwater to some extent. Extensive monitoring and control practices must be maintained. same references.
	Land Use Changes	Changes in land use patterns adjacent to irrigation projects can be serious, especially to systems poorly operated and/or undersized. Changes in urban patterns may change the location of treatment plants and thus abandon the irrigation site. The cost of land and problems associated with land acquisition may also close or prevent the establishment of such systems. References 11.	The comments for irrigation are also applicable for infiltration systems.

TOPICS	ELEMENTS	IRRIGATION METHOD: SPRAY IRRIGATION / RIDGE AND FURROW / FLOODING	INFILTRATION-PERCOLATION METHOD
	Political and Environmental Changes	Requirements for increased levels of treatment and storage prior to land application may lead to irrigation abandonment. Groundwater pollution may control the installation of such sites. Where water is scarce the application of treated effluent to the land may affect summer flow and aquatic organisms and thus may be disallowed. References: 2, 11.	The comments for irrigation are also applicable for infiltration systems.
	Poor or Lack of Management.	The lack of competent management has resulted in the abandonment of many systems. References: 2, 11.	The comments for irrigation are also applicable for infiltration systems.

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APPENDIX II

SPRAY IRRIGATION IN CANADA

A PRELIMINARY REVIEW

by

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APPENDIX II SPRAY IRRIGATION IN CANADA A PRELIMINARY REVIEW

1.0 Introduction

In early 1975 the Environmental Protection Service, Environment Canada, began an investigation into the practice of spray irrigation of treated municipal wastewaters within Canada.

The investigation was specifically designed to:

(a) provide an inventory of all municipal spray irrigation activities in Canada.

(b) identify all spray irrigation research activities in Canada.

Regional staff of the Environmental Protection Service, by means of interviews with provincial regulatory agency personnel, obtained information on all known spray irrigation activities within their areas of jurisdiction as well as provincial and federal research activities.

2.0 Spray Irrigation In Canada

Information received to date indicates that almost every province has spray irrigation systems in operation. Those provinces not listed in this Appendix reported only industrial spray irrigation systems.

The provinces, being aware that adequate information to evaluate the pollution impact associated with the land disposal of treated wastewater is not available, are undertaking various research and demonstration projects. The object is to gain an insight into the applicability of this method of treatment and disposal.

The initial response from contacting the provinces and federal agencies has generated sufficient information to prepare:

(a) a survey of municipal spray irrigation operations in Canada, and

(b) a survey of spray irrigation research projects in Canada.

These surveys, although incomplete, are attached. The response has also provided information which allow the following comments to be made:

1. Land application of wastewaters has been practiced in Canada for several generations in the form of ridge and furrow and spray irrigation systems. The majority of land disposal systems are spray irrigation systems.
2. In Canada the practice is to provide a minimum of secondary treatment prior to spray irrigation of municipal wastewater.
3. Spray irrigation of municipal wastes under proper design and operation is an alternative to tertiary treatment.
4. Spray irrigation is both a treatment and disposal method for municipal wastewaters, and at times possesses the additional function of water reuse by augmenting groundwater sources. Treatment and disposal in the soil are provided physically, chemically and biochemically.
5. Spray irrigation is practiced mainly by small communities and small industries. The majority of operations are found in Southern Ontario.
6. Although at present there are only a relatively few spray irrigation operations in Canada, this should not mean that opportunities for its use do not exist elsewhere.
7. Spray irrigation is not a simple process to design, and requires the input from a variety of disciplines. Engineers, geologists, soil specialists, agronomists, medical health personnel and sometimes social behavioural scientists are required to work together as a design team.
8. Monitoring spray irrigation installations and their effects upon the local environment is not being carried out by the municipalities. The exception to this is where research and demonstration has been or will be undertaken.
9. The nature and quantity of receiving waters must be carefully evaluated prior to diverting wastewater to the land. In some areas of Canada the elimination of direct wastewater discharges to a body of water may unbalance the flow regime.
10. The nature of the ground cover as well as the hydrogeology of the site play an important role in the success of spray irrigation in Canada.

11. Lands identified for spray irrigation must receive high priority for this use over other optional land uses. Lands adjacent to the site should be zoned other than residential.
12. Research and demonstration work in Canada is inadequate to assist those who must decide whether or not spray irrigation is feasible on a long range basis. Information on those systems that have been in operation for many decades is not available. An effort should be made to study long-term effects on the soil ecology, groundwater hydrology and the transmission of pathogens and viruses.

3.0 Conclusion

A preliminary review of spray irrigation activities in Canada indicates that this method, if properly designed, can be used in the treatment and disposal of wastewaters.

The review has also shown that this method is found in almost all provinces of Canada (Table I).

The attached survey forms for municipal spray irrigation operations and research spray irrigation activities in Canada reveal that large scale operations or research investigations do not exist in Canada.

TABLE I

A REVIEW OF ALL SPRAY IRRIGATION ACTIVITIES IN CANADA

	Number of Municipal Spray Irrigation Systems	Federal Spray Irrigation Systems	Number of Research Activities within the Province
BRITISH COLUMBIA	1		2
ALBERTA	2	1	10
SASKATCHEWAN	3	3	3
MANITOBA	(1)		
ONTARIO	4*	1	1
QUEBEC	1	1	3
NEW BRUNSWICK	**		
PRINCE EDWARD ISLAND	**		
NOVA SCOTIA	**		
NEWFOUNDLAND	**		

* Municipal spray irrigation systems identified have been or will be eventually terminated.

** Spray irrigation systems only of an industrial nature exist in these provinces.

(1) A proposal for a small spray irrigation system is being reviewed. More information is not available to date.

SURVEY OF WASTEWATER SPRAY IRRIGATION OPERATIONS IN CANADA-MUNICIPAL

PROVINCE	LOCATION	POPULATION	WASTEWATER			WINTER STORAGE	LAND BEING IRRIGATED			DURATION OF OPERATION	MONITORING ACTIVITIES	COMMENTS
			FLOW, MGD	SOURCE	TREATMENT		SIZE ACRES	TYPE	CROP GROWN			
British Columbia	Vernon	13,200	2.3	Municipal	Secondary	none (being planned)	150	Agricultural	Alfalfa	Summer season, daily application of 5600 gpad	ground water, crops	At present only 0.8 MGD are being irrigated, eventually 4.0 MGD will be irrigated, 7 month storage being planned.
Alberta	Calgary (Springbank Airport)	n.a.	0.003	Municipal	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	Design and construction of a complete wastewater treatment system including spray irrigation being planned in 1975.
	Granum	300		Municipal	Facultative Lagoons	yes	24	Agricultural	Alfalfa	Summer season, 5 spray periods at 4 inch per acre per spray	ground-water, crops, soils	Has been in operation since 1970.
	Taber	4800	n.a. Industial flow is 60-70% of total	Municipal & industrial	Facultative Lagoon	yes	320	Agricultural	Alfalfa	Summer season, application of 3000 gpd every day	ground-water, crops, soils.	Has been in operation since 1971, industrial waste from cannery & potato processing.

SURVEY OF WASTEWATER SPRAY IRRIGATION OPERATIONS IN CANADA-MUNICIPAL

PROVINCE	LOCATION	POPULATION	WASTEWATER			WINTER STORAGE	LAND BEING IRRIGATED			DURATION OF OPERATION	MONITORING ACTIVITIES	COMMENTS
			FLOW, MGD	SOURCE	TREATMENT		SIZE ACRES	TYPE	CROP GROWN			
Saskatchewan	Dana (Canadian Forces Station)	500	0.043	Municipal	Facultative Lagoon	limited	n.a.	Waste land	none	Summer season, daily application	none	A combination of poor soils and high water table have caused operation problems. This will be resolved in 1975 by increasing the acreage.
	Davidson	1,000	n.a.	Municipal	Facultative Lagoons	180 days retention capacity	25	Agricultural	Alfalfa	Summer season	ground water, soil	Recent operation being investigated.
	Moose Jaw	34,000	2.2	Municipal	Aerated Lagoon	yes						Spray irrigation being planned. Site investigation will be carried including hydrogeology vegetation type, acreage, etc.
	Moosomin (IRS school)	n.a.	0.003	Municipal	n.a.	n.a.	5					Acreage is available for irrigation. Studies will be undertaken to determine if this is sufficient.
	Prince Albert National Park	1000 (avg.) 3000 (max.)	n.a.	Municipal	Facultative Lagoons	yes		Recreational				Irrigation as an alternate additional treatment method will be investigated.
	Swift Current	16,000	1.2	Municipal	Facultative Lagoons	n.a.	10	Agricultural	Alfalfa, some corn	Summer season, 18 in/acre per year.	ground water	3rd year in operation and still being investigated.

SURVEY OF WASTEWATER SPRAY IRRIGATION OPERATIONS IN CANADA-MUNICIPAL

PROVINCE	LOCATION	POPULATION	WASTEWATER			WINTER STORAGE	LAND BEING IRRIGATED			DURATION OR OPERATION	MONITORING ACTIVITIES	COMMENTS
			FLOW, MGD	SOURCE	TREATMENT		SIZE ACRES	TYPE	CROP GROWN			
Ontario	Beaver Creek	70	n.a.	Municipal	Facultative Lagoon	yes	n.a.	Agricultural	n.a.	Summer season	n.a.	Irrigation system will be installed in 1975. Investigations are underway.
	Listowel	n.a.	n.a.	Municipal	Facultative Lagoons	yes	150	Agricultural	n.a.	Summer season, 5000-10000 gal/acre/day	Province had undertaken monitoring program.	Operational problems exist. Irrigation system may close.
	Port Rowan	n.a.	n.a.	Municipal	Facultative Lagoon	yes	1	Agricultural	n.a.	n.a.	"	Feasibility of irrigation was investigated. Irrigation not favoured. Poor soils.
	Shelburne	1790	0.2	Municipal	Facultative Lagoon	yes	12	Agricultural	n.a.	Summer season, 2000-1000 gal/acre/day	"	After several years in operation a new wastewater treatment system has replaced the lagoon & spray irrigation.
	Smithville	1090	0.2	Municipal	Facultative	yes	20	Agricultural	n.a.	Summer season 7500 gal/acre/day	"	
Quebec	Lac St. Denis	400	0.045	Municipal	Secondary treatment with P removal	yes	n.a.	n.a.	n.a.	Summer season	n.a.	
	St. Donat	2700										This system is in its design stage. Irrigation is being considered.

SURVEY OF WASTEWATER SPRAY IRRIGATION RESEARCH PROJECTS IN CANADA

PROVINCE	PROJECT CONTACT	PROJECT LOCATION	POPU-LATION	WASTEWATER SOURCE	WASTEWATER TREATMENT	PROJECT SIZE	REMARKS CONCERNING THE PROJECT
British Columbia	Matt K. John Research Stn. Can. Dept. of Agr. Agassiz B.C. VOM 1AO	Agassiz		Municipal	Secondary	Laboratory scale	A laboratory experiment simulating high-rate renovation by soil percolation involved leaching secondary sewage effluent through columns of three differing soils. Mechanism of Preremoval and ion exchange were investigated. Report available. The project has terminated.
	W.K. Oldham Civil Eng. Dept. Univ. of B.C. Vancouver, B.C.	Vernon	13,200	Municipal	Secondary (see survey form)	Full Scale (150 acres)	Research was aimed at determining a water and nutrient budget for spray irrigation of secondary effluent from a municipal wastewater treatment plant in the Okanagan Valley of British Columbia. The project has been in operation since 1971. Several reports are available from the project contact. See inventory.
Alberta	Mr. D.N. Graveland Alberta DOE, Water Resources Br. Lethbridge Alta. (329-0112)	Blairmore	2,050	Municipal Agricultural	n.a.	Pilot Plant	The application of sludge and manure on coal refuse piles is being investigated.
		Calgary	427,000	Municipal	Activated sludge, digester	Pilot Plant (2 acres)	Supernatant from sludge digesters will be irrigated on a 2 acre site and the nitrification-denitrification reaction in the soil will be investigated.
		Canmore	1,540	Municipal	Anaerobic Lagoon	n.a.	The Alberta Research Secretariat will fund research in the disposal of treated wastewater on forest land. Project will commence in 1975.
	Dr. J.B. Bole, Can. DOA Res. Stn. Lethbridge. Alta. (327-4561)	Drayton Valley	4,000	Municipal	Anaerobic Lagoon	n.a.	Project description same as for Canmore.
		Granum	300	Municipal	Facultative Lagoons	Full Scale	Since 1969 treated sewage has been irrigated on 24 acres of agricultural land. Groundwater, soils and crops have been investigated and their response has been investigated. Several reports by D. N. Graveland are available.
		Shaughnessy	n.a.	Industrial	Gas processing Wastewater	n.a.	
		Taber	4,800	Municipal	Facultative Lagoons	Full Scale	The purpose and nature of this project is similar to the Granum project. A study on the virology of land disposal of treated sewage is being planned between Univ. of Alberta and Alta. Research Secretariat.
		Vauxhall	1,020	Industrial	Potato Dehydrating Plant	n.a.	

SURVEY OF WASTEWATER SPRAY IRRIGATION RESEARCH PROJECTS IN CANADA

PROVINCE	PROJECT CONTACT	PROJECT LOCATION	POPULATION	WASTEWATER		PROJECT SIZE	REMARKS CONCERNING THE PROJECT
				SOURCE	TREATMENT		
Alberta	Mr. G. Gibeault, City Eng. (672-4428)	Camrose	8,670	Municipal	Aerobic & Anaerobic Lagoons	Pilot Plant (0.1 acres)	Wastewater from the municipal treatment system will irrigate 4 plots at 1075 sq. ft. each and at a rate of 2 inches per week. Studies will determine the practicability of land disposal of wastewater. Researchers: Dr. Knoess, Okanagan College, B.C. and D.L. Pattie, NAIT, Edmonton, Alberta
	Dr. S.B. Smith Alta DOE Research Secretariat Ed (425-1130)	Lake Wabamun					Possible future involvement in the land disposal of cooling water from the thermal power plant at Lake Wabamun.
Saskatchewan		Davidson	1,000	Municipal	Facultative Lagoon	Full Scale	Monitoring activities being planned.
	Dr. Mineley Sask. Research Council Regiona, Sask. 1523-2020	Moose Jaw	34,000	Municipal	Aerated Lagoon		Comments same as in municipal inventory. Sask. Research Council will provide geological mapping, design a monitoring system. Soils, crops, groundwater will be investigated.
	Dr. W. Nicho Laichuk, Can. DOA, Swift Current (306) 773-4621	Swift Current	16,000	Municipal	Facultative Lagoon		Studies have been underway for 2 years investigating soil and plant response and soil removal mechanisms.
Ontario	Mr. N. Ehlert Ontario MOE Dev. and Research Group	Smithville	1,090	Municipal	Facultative Lagoon	Full Scale	The capacity of soil receiving treated wastewater to remove nutrients was investigated. Report will be available in 1975.
Qubec	Dr. J. R. Ogilvie MacDonald College McGill Univ. (457-6580 ext. 235)			Agricultural	None	n.a.	Spray irrigation of pig manure without pre-treatment is being investigated. The site is an experimental farm.
				Agricultural	Oxidation Ditch	n.a.	Same as above. Project is being planned.
				Agricultural	Facultative	n.a.	Wastewater from 1,500 cattle is treated and irrigated. Site is at Ferme Roda - St. Anicet.