APPENDIX 4-14

Silt Control Study– Internal Bord na Móna Report 1984

Meamram

BORD NA MÓNA

Do: Manager: Coolnagun | Ó: Chief Engineer (Civil Division)

Do Thag.	Ár dTag.	Ábhar	Dáta
	HCF/SG	SILT CONTROL	5.1.1984

Luaitear an uimhir tagartha

As you are aware the Board has been engaged for several years in the development of a system of silt control involving the construction and maintenance of a large number of silt traps in order to reduce to an acceptable level the silt content of effluent discharged from our bogs and factories.

Silt control has now become an essential and an integral part of our drainage designs and while considerable progress has been made, the system is by no means perfect and we must continue to seek improvements in both the economics and the effectiveness of silt reduction.

/ The attached study, complied by Mr. Hannon, Civil Works, Head Office, considers the question in some depth and attempts to evaluate the costs involved in various possible methods of controlling silt discharge.

I will be glad to receive any suggestions you may wish to make.

Chief Engineer
(Civil Division)

BORD NA MÓNA
COOLNAGUN
DATE REC'D. -6 JAN 1984
FOR ATTENTION

B O R D N A M O N A

CIVIL ENGINEERING DIVISION

Silt Control Study

No. 1

G. Hannon,
Civil Works Section,
Head Office.

December 1983.

INTRODUCTION

The objective of this report is to establish a framework for rationalisation of silt control and thereby provide a sound basis for discussion prior to making firm decisions.

It attempts also to highlight the areas where policy decisions are needed.

Comments and criticisms would be appreciated.

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CHAPTER I

Quantity and Relevent Characteristics of Suspended Solids and Settled Sludge

1.1 This chapter deals with the quantity and characteristics of suspended peat solids and peat sludge relevant to silt control.

This will show:-

1. The scale of the silt control operation required to produce effluent of acceptable suspended solids concentration. *Ref Appendix I.

2. The basic principles of producing acceptable effluent, common to all feasible methods of silt control.

1.2 Quantity of Suspended Solids and Settled Sludge

Before any investigation or comparison as to the feasibility of solving the silt problem it is of course essential to estimate the quantity of silt to be dealt with.

In trying to assess <u>finitely</u> the capacity requirement of any type of trapping system it is imperative to be able to relate:-

1. Runoff and Rainfall.
2. Runoff and suspended solids concentration.

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1.3 The problem of identifying these relationships under realistic conditions in the case of milled peat bogs are many, the main ones being:-

1. The runoff factor for other land conditions is generally quoted as a single number ranging between zero and unity. The runoff factor for milled peat bogs will have a range of values depending on the bog condition.

2. The suspended solids concentration of the runoff will be effected by machine activity especially ditching and the degree to which the concentration is effected will depend on the intensity of the machine activity and period over which it is carried out relative to sampling time.

1.4 Electronic equipment to continuously monitor flow and associated suspended solids concentration upstream and down-stream of pond system at specified intervals has been installed at settlement ponds at Culliagh (Blackwater Works) June 1983.

Examination of the results plotted by the flow monitoring device has verified the fact that the runoff factor is more complex than the normal land runoff factor, the former being a function of bog conditions and rainfall as distinct from the more optimistically hoped for dependence of runoff on rainfall with identifiable distortions due to machine activity, bog condition etc.

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It is to be noted, however, that the rainfall for June, July and August (1983) was low. This meant in effect that water flowing to drains from the water table accounted for a much larger percentage of runoff flow than is normal and hence aided in rendering the distortions due to machine activity and bog conditions unidentifiable.

The suspended solids concentrations recorded were also generally very low and when compared with normal suspended solids concentrations previously recorded are not found to be truly representative.

1.5 To summarise: Testing so far has established:

1. Concentration of suspended solids varies with flow but not directly, generally when flow rate is high the suspended solids concentration is high, the converse being true also.

2. Runoff factor is not readily determinable. The effects of bog condition on runoff factor is much greater than appreciated.

1.6 The following points should be considered at this stage

1. The runoff 'equation' (as distinct from factor) will involve a large number of parameters.

2. The use of the runoff equation to determine the sludge capacity requirement of a silt trapping system would require accurate forward planning of ditching and other machine activities which would introduce many non finite elements and estimates of very doubtful reliability.

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3. The ultimate aim at this point is to relate quantity of suspended solids inflowing to trapping system to volume required for their storage. This introduces an even more illusive parameter i.e. the moisture content of settled sludge.

The points listed above are confirmed by the mathematical model and associated graph.
*Ref. Appendix 2.

1.7 It is justifiable to conclude from the latter that when considering the question of sludge capacity required, neither a finite answer nor the answer's parish can be found by theoretical methods, since the variables involved can be identified but defy analysis.

The only value of the theoretical model in this case is to provide a structure for analysis of observed results.

1.8 As a result of the above conclusions we must rely heavily on experience. In this we are fortunate in that silt pond behaviour as observed by Blackwater staff suggests.

1. 1 acre produces approximately 525 ft^3 of sludge 4 times per year.

2. Ponds may fill within as little as a fortnight after ditching.

To state somewhat differently ponds require cleaning once every 4 months on average and once after ditching i.e. 4 times yearly.

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1.9 This result may be extended to all silt trapping systems and stated generally as follows:-

<u>1 acre produces 525 ft^3 of sludge 4 times yearly</u>

The result above is used throughout the remainder of this report as the basis for silt pond/lagoon sizing.

1.10 On examination of this estimate for sludge capacity calculations *(Ref. Appendix 3) show that the equivalent of approximately 152,000 tonnes of peat at 55% moisture content are lost every year from milled peat areas.

1.11 <u>Characteristics of suspended solids and settled sludge relevant to silt control</u>

The following facts were established by the Laboratoire Central D'Hydraulique de France:-

1. Significant settling of peat solids from suspension occurs only when mean velocity of flow is less than 0.15 to 0.17 m/s.

2. Specific gravity of dry suspendable peat particles is in the range 1.02 to 1.04.

3. Peat sludge has no measurable cohesion and resistance to current results only from interlocking of peat fibres and not from any initial rigidity or from the viscosity of the deposits such as can be noticed in silty sediments.

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1.12 The points above have many implications, the most important of which are:- *Ref. Appendix 4.

1. To allow peat solids to settle from suspension during normal flow conditions we require:-

   Ratio cross sectional area of flow in trapping system to cross sectional area flow in outfall = 8.0 minimum.

2. To allow peat solids to settle from suspension during periods of heavy flow we require:-

   Ratio cross sectional area of flow in trapping system to cross sectional area flow in outfall = 13 minimum.

3. From examples 1 and 2 when channel established through surface of sludge in trapping system, no settlement is taking place.

4. A 25 ft. wide pond with depth of flow 6 inches can at most cater for an outfall with a cross sectional area of 1.5 m^2 during normal flow conditions.

5. To install an efficient trapping system on a large outfall or small river of dimension 8 ft. wide with 1 ft. depth of flow during normal flow conditions, the minimum width requirement for the trapping system is 66 ft. (therefore it is inefficient if not pointless to install 27 ft. wide ponds on small rivers or large outfalls.

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6. Since cohesion negligible settled sludge can only be protected from resuspension by maintaining quiescent conditions more specifically by protecting settled sludge from flooding from downstrean and heavy flows from upstream.

7. It is incorrect to compare the estimate of silt sludge produced 525 ft^3/acre/ 3 months with the quantity of silt which settles on river banks, farmers drains etc. where no trapping systems exist since the settling conditions are not ideal and therefore it can be said that the silt which settles on river banks etc. is only a small fraction of the actual settleable suspended solids in our outfalls.

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CHAPTER 2

DESIGN OF TRAPPING SYSTEMS - GENERAL

2.1 This chapter deals generally with the efficient design of trapping systems.

2.2 Those involved in the location and design of treatment systems for outfalls discharging to external receiving waters are confronted by many faits accomplis adversely effecting their efforts or at least restricting their choices.

2.3 The major constraint is imposed by the fact that drainage systems are already in existance prior to consideration of silt control systems. The former generally involved getting water off the bog as quickly and as easily as possible.

2.4 Any system of silt trapping depends to a large extent on general ground level in the area of the outfall. Very often the general ground level is not suitable and is rarely ideal. Particular difficulty in choosing a silt trapping location arises where lands are susceptible to flooding.

2.5 In brief the designer often finds himself inhibited by:-

1. The efforts of his predecessor regarding drainage systems and a tendency to arrange production areas to follow the bog edge as closely as possible.

2. The efforts of his contemporary engaged in production whose immediate objective is to maximise production and minimise production costs.

2.6 At this stage some general design principles which are common to all forms of silt trapping system will be considered.

2.7 Given that the designer often finds himself in an undesirable situation due to the already existing outfall system it would be non practical to recommend generally the alteration of the bog drainage system to suit the desires of those involved in the installation of silt trapping systems as the work involved would be cost prohibitive and in many cases technically impossible.

It may be possible, however, in certain cases to rearrange drainage systems. This possibility should be examined when individual outfalls are being examined e.g. Bloomhill - Blackwater Works.

2.8 Bearing in mind that our efforts are aimed at treating bog drainage waters the temptation to treat intermediate receiving waters should be avoided if at all possible. * Ref. 1.12.

2.9 In some cases silt trapping systems have been located below flood level. Bearing in mind the ease with which settled silt may be disturbed *Ref. 1.12 it can be said that any system which is to be located below flood level must be protected by an embankment or other protection device e.g. one-way valve. **Ref. Appendix 5. Failing this approach it might well be better from the silt control point of view to neglect the installation of a trapping system rather than to install an 'unprotected' system. The reasoning being as follows: On an unprotected outfall, water with high suspended solids concentration discharges to receiving waters. However, to install a trapping system which collects peat silt and subsequently allows the silt to be discharged in bulk during periods of flooding is a step in the wrong direction.

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2.11 The ease with which settled silt can be re-suspended and washed out of a trapping system must not be underestimated, e.g. Blackwater Works - Clonfert Bridge - Agricultural land damaged due to washing out of ponds by flood back up.

2.12 Bypassing of trapping system during periods of heavy rainfall involves the allowed discharge of untreated bog drainage water to receiving waters. Due to the ease with which deposited silt may be resuspended and washed out by heavy flows the work done by a silt trapping system since its previous cleaning may be completely undone. This said, we may conclude that bypassing during periods of heavy rainfall is the lesser of two evils (e.g. Blackwater Works - Clonascra Bog - ponds which were approaching full August 12th 1983 - empty August 20th 1983 following heavy rainfall August 15th 1983).

2.13 There are five methods of providing bypasses to be considered. *Ref. Appendix 6. The most practical method involves bypassing using a weir or pipe, the invert level of which is the same as that of the pipe at inlet to trapping system. During normal flow conditions (flows which allow settled silt to remain out of suspension) the pipe or weir would be closed; During periods of heavy flow the pipe forming inlet to trapping system would be closed and the bypass pipe opened.

2.14 Distribution of flow over complete settling system area:- Present practice involves feeding ponds directly from outfalls by means of open channel or piping. The flow therefore, in the initial stages of the pond is changing from outfall velocity to velocity at full pond cross sectional area. This has a number of adverse effects:-

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(a) The settling area is not used to full advantage since flow velocity not below critical 'settling velocity' of 0.15 m/s in initial stages of pond.

(b) Wash out due to runoff encouraged.

(c) Channelling rendering pond ineffective is encouraged.

2.15 If the excavation of settlement ponds is to be continued the following modification should be considered.

By allowing walls running the full width of the pond to remain unexcavated the advantages would be as follows:- *Ref. Appendix 7.

(a) Channelling would be discouraged.

(b) In the event of disturbance due to high velocities caused by heavy flows shelter would be provided for settled particles below the top level of wall since velocity increase would mainly be above this level.

(c) In the event of ponds being cleaned by sludge pump these walls would simplify double pumping if such were necessary.

2.16 If weirs are to be used for purposes outlined in 2.15 they should run full width of pond and hence force water to <u>flow over</u> them. Walls which stop short will not be effective since if velocity increased at depth the effect of the wall is negatived.

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2.17 Cleaning of Ponds by (a) Excavators (b) Pumping and (c) Others

(a) Present practice involves the use of excavators in cleaning ponds (generally hymac/dragline).

For any Works with its full compliment of silt ponds the main requirements are as follows:-

Due to large number of ponds at different locations requiring frequent cleaning and the nature of the material to be handled excavators are required which are fast moving, fast working and non violent. This said it is clear that the dragline excavator (being the most slow moving, violent and unreliable of the Board's excavators) is far from being the ideal machine for the task.

Hence, if the excavation of silt ponds is to be continued all future ponds should be excavated in accordance with the capabilities of the standard hymac under the prevailing ground conditions.
*Ref. Appendix 8.

Many ponds exist whose widths are excessive for cleaning by hymac. Bearing in mind the backlog of proposed ponds to be excavated, no attempt should be made at present to alter these ponds so as to render them independent of dragline maintenance as this would be premature Lilly Guilding.

Recycling of silt accumulated in ponds and subsequently emptied by excavators has two major problems which make it impracticable.

(i) Practice among excavator drivers is to continue digging until subsoil is excavated, hence, the excavated material contains subsoil.

(ii) No economic method of moving excavated material to production fields exists.

(b) The sludge pump presently under development while not fully tested may well prove to be the most economic longterm approach to the problem. The system may be briefly described as follows. A pump, incorporating an agitator and powered by a tractor, pumps agitated sludge from pond to production field or waste ground. The sludge filled drains are subsequently ditched and the sludge is left to dry. The system is as yet in the development stage.

(c) Work carried out in England on sewage involving the formation of cylindrical blocks has met with much success and praise. We are presently examining the applicability of this method to our particular problem.

2.18 <u>Silt Pond Cross Section</u>

The factors effecting design are as follows.

(a) Capabilities of hymac
(b) Capabilities of sludge pump
(c) Nature of bog regarding excavation
(d) Maximisation of volume available for sludge retention.

(e) Reduction of flow velocity.

Present practice involves digging ponds of almost vertical side slopes to an overall depth of approximately 7 feet so as to provide 3.5 ft. depth below invert level inlet. While excavation to a depth of 7 ft. may seem excessive in bog conditions it must be remembered that the effective depth should be measured between water surface and general ground level i.e. approx. 3.5 ft. and hence stability is not critical *(Ref. Appendix 8) therefore the use of 1 : 1 side slopes is unwarranted along with being capacity reducing.

CHAPTER 3

Possible Silt Control System

Description and Comparison

3.1 Many different silt trapping systems have been discussed and written about individually.

This chapter describes and compares these systems.

3.2 The various approaches visualised may be divided into three main categories:-

A. Systems involving excavation and maintenance of settlement ponds only.

B. Systems involving provision and maintenance of lagoons only.

C. Composites of A, B.

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3.3 Expanding:

A	A1	Excavate ponds - clean by excavator - Rehandle spoil when dumping of new spoil becomes a problem.
	A2	Excavate ponds - clean using sludge pump, pumping sludge to production area - ditch drains as required.
	A3	Excavate ponds - clean using sludge pump to waste ground.
B	B1	Construct lagoon - full bog lifespan capacity - abandon when full.
	B2	Construct lagoon - partial bog lifespan - abandon when full and repeat.
C	C1	Excavate ponds - gravity fed - form embankments from spoil to retain remaining year's sludge.

3.4 Comparison of the various systems is complicated by the following:

1. Undefined present and future commitment with regard to expenditure on silt control.

2. Some of the methods to be compared are as yet untested or being tested.

The following realistic assumption will be made to allow comparison aimed at identifying the optimal solution:-

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The optimal economic solution based on criterion of treating all outfalls so as to produce effluent of acceptable suspended solids concentration will remain the optimal solution following compromise between

1. Board policy's definition of 'reasonable expenditure'.

2. Expenditure required to produce effluent of acceptable suspended solids concentration.

3.5 In attempting to identify the optimal solution it is essential to compare like with like.

3.6 If at this stage one considers in detail the conditions prevailing at each outfall location the problem becomes indeterminate to a very high degree.

3.7 Bearing in mind the variation in nature and cost of land and often times inability to acquire the exact amount of land required without surplus the costing of land for silt ponds will be ignored during the comparison. The cost of land area required for 'lagoons' over and above the area of land required for silt ponds will be considered. The costing of this land will involve the use of an 'average cost' value. Error incurred due to surplus land will be regarded as insignificant due to the large areas required.

3.8 In the comparison stage the amount of excavation already carried out will not be considered. This is justified by the fact that existing ponds are full and hence require cleaning and spoil removal roughly equivalent to initial excavation.

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3.9 The order of optimality for catchment sizes of 100, 300 and 600 acres (i.e. small, medium, large catchments) will be sought. This in turn will be applied to the outfall system at a particular Works to calculate the minimum overall cost of silt control at that Works.

3.10 The patterns of expenditure for each system applied to small, medium and large catchment sizes (i.e. 100, 300 and 600 acres) are tabulated in the following pages. The associated graphs shows a comparison between the pattern of expenditure of each system for each catchment size over a period including initialisation and subsequent 20 years.

3.11 The initialisation period is as yet undefined. For graphical purposes it is represented as one year but the implications of a longer initialisation period may be easily calculated.

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3.12 For Calculations and Assumptions relating to Costing reference the following appendices:-

Appendix No.	
9	Number of years before spoil rehandling essential (A1, C1).
10	Hymac hours required for pond cleaning, spoil rehandling and initial excavation (A1, A2, A3, C1).
11	Sludge pump hours required/acre/year (A2, A3).
12	Ratio Hymac hours to sludge pump hours required for maintenance.
13	Area over which spoil to be spread and ditching hours required (A2, A3).
14	Quantity of peat recycled by sludge pumping (A2)
15	Area required for lagoon - general (B1, B2, C1).
16	Number of years spoil to produce embankment to serve remaining lifespan (C1).
17	Lagoon construction (B1, B2).
18	Initial cost adjustment for cases in which flood embankments necessary (A1, A2, A3, C1).
19	Cost of machine hours (A1,A2,A3, B1, B2, C1). Cost of land Profit per tonne of peat
20	Cost of pump installation and maintenance.

<u>The following abreviations are used:</u>

Hymac Hours ...... HHrs
Sludge Pump Hours . SPHrs
Ditcher Hours ..... DHrs.

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3.13 METHOD A1 Excavate ponds - clean by excavator. Rehandle spoil when dumping of new spoil becomes a problem.

Year		Catchment (Acres)		
		100	300	600
Initialisation	Excavate (HHrs)	78	234	468
1	Cleaning (HHrs)	156	468	936
2	do.	156	468	936
3	do.	156	468	936
4	do.	156	468	936
5	do.	156	468	936
	Rehandle (HHrs)	130	390	780
6	Cleaning	156	468	936
7	do.	156	468	936
8	do.	156	468	936
9	do.	156	468	936
10	do.	156	468	936
	Rehandling (HHrs)	130	390	780
11	Cleaning	156	468	936
12	do.	156	468	936
13	do.	156	468	936
14	do.	156	468	936
15	do.	156	468	936
	Rehandling (HHrs)	130	390	780
16	Cleaning	156	468	936
17	do.	156	468	936
18	do.	156	468	936
19	do.	156	468	936
20	do.	156	468	936

Allowance made in cost comparison for cases in which flood embankments necessary.

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3.14 METHOD A2

Excavate ponds - clean using sludge pump. Pump sludge to production area - ditch drains as required.

Year		Catchment (Acres)		
		100	300	600
Initialisation	Excavate	78	234	468
1	Sludge Pump (SPHrs)	74	222	444
	Ditching (DHrs)	135	405	810
	*Tonnes Produce (T)	190.5	571.5	1143
2				
3				
4				
5				
6				
7				
8				
9				
10	(As per year 1)			
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				

*Tonnes Produce @ 55% M.C.
Allowance made in cost comparison for cases in which flood embankments necessary.

3.15 METHOD A3 Excavate Ponds - clean using sludge pump to waste ground.

Year		Catchment (Acres) 100	300	600
Initialisation	Excavate (HHrs)	78	234	468
	Acquire Area Spreading ft^2	210,000	630,000	1,260,000
	Acres	4.82	14.46	28.93
1	Sludge Pumping	74	222	444
2				
3				
4				
5				
6				
7				
8				
9				
10	AS PER YEAR 1			
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				

3.16 METHOD B1 Construct Lagoon - full bog lifespan capacity - abandon when full.

Year		Catchment (Acres)		
		100	300	600
Initialisation	Construct Embankment (HHrs)	922	1,596	2,257
	Install Pump (IR£)	25,000	32,000	47,000
	Acquisition/ Designation ft^2	403,128	1, 097,592	2,105,832
1	Pump Maintenance	1,000	2,000	4,500
2		"	"	
3		"		
4		"		
5		"		
6		"		
7		"		
8		"		
9		As Per Year 1		
10		"		
11		"		
12		"		
13		"		
14		"		
15		"		
16		"		
17		"		
18		"		
19		"		
20		1,000	2,000	4,500

*Test for Optimality Required - Irrespective of silt control; pump may be necessary for drainage purposes.

3.17 METHOD B2 Construct Lagoon - partial bog lifespan capacity* - Abandon when full - repeat

*Partial Bog Lifespan = 5 years

Year		Catchment (Acres)		
		100	300	600
Initialisation	Construct Embankment (HHrs)	460	797	1127
	Install Pump (IR£	25000	32000	47000
	Acquisition/ Designation (ft^2)	44064	76296	107848
	(Acres)	1.01	1.75	2.47
1	Pump Power (IR£)	1000	2000	4500
2				
3				
4				
5	Pump Power (IR£)	1000	2000	4500
	Construct Embankment (HHrs)	460	797	1127
	Reposition Pump(£)	4000	7000	10000
	Acquisition (ft^2)	44064	76296	107848
	(Acres)	1.01	1.75	2.47
6	Pump Power (£)	1000	2000	4500
7	do.			
8	do.			
9	do			
10	As per year 5			
11	Pump Power (IR£)	1000	2000	4500
12	do.			
13	do.			
14	do.			
15	As per year 5			
16	Pump Power (IR£)	1000	2000	4500
17	do.			
18	do.			
19	do.			
20	do.			

3.18 METHOD B2 Construct Lagoon - Partial Bog Lifespan Capacity* - Abandon when full.

*Partial Bog Lifespan = 10 years.

Year		Catchment (Acres)		
		100	300	600
Initialisation	Construct Embankment (HHrs)	640	1128	1596
	Install Pump (IR£)	25000	32000	47000
	Acquisition/Designation (ft^2)	166200	422848	782592
	(acres)	3.81	9.71	17.96
1	Pump Power	1000	2000	4500
2	do.			
3	do.			
4	do.			
5	do.			
6	do.			
7	do.			
8	do.			
9	do.			
10	Pump Power (IR£)	1000	2000	4500
	Construct Embankment (HHrs)	640	1128	1556
	Reposition Pump	4000	7000	10000
	Acquisition/ Designation (ft^2)	166200	422848	782592
	(Acres)	3.81	9.71	17.96
11	Pump Power (IR£)	1000	2000	4500
12	do.			
13	do.			
14	do.			
15	do.			
16	do.			
17	do.			
18	do.			
19	do.			
20	do.			

3.19 METHOD C1

Year		Catchment (Acres)		
		100	300	600
Initilis- ation	Excavate (HHrs)	78	234	468
1	Cleaning (HHrs)	156	468	936
2	do.	156	468	936
3	do.	156	468	936
4	do.	156	468	936
5	do.	156	468	936
	Rehandle Forming Emb. HHrs.	260	– 780	– 1560
6	Cleaning	156	468	936
7	do.	156	468	936
8	do.	156	468	936
	Complete Emb. Install Pump (IR£)		– 464 32000	– 928 47000
9	Cleaning	156	2000	4500
10	Cleaning	156	2000	4500
	Rehandle Forming Emb. HHrs	260		
11	Cleaning	156	2000	4500
12	Cleaning	156	2000	4500
	Complete Emb. Install Pump (IR£)	102 25000		
13		1000	2000	4500
14		1000	2000	4500
15		1000	2000	4500
16		1000	2000	4500
17		1000	2000	4500
18		1000	2000	4500
19		1000	2000	4500
20		1000	2000	4500

*Allowance made in cost comparison for cases in which flood embankments necessary.

3.20

METHOD A1
CATCHMENT = 100 ACRES

Year	HHrs	Cost HHrs	Total Annual Expenditure	Cumulative Expenditure
* Initil-isation	78	1799.0	1799.0	1799
**	345	7955.0	7955.0	
1	182	4196.0	4196.0	5995
2	182	4196.0	4196.0	10191
3	182	4196.0	4196.0	14387
4	182	4196.0	4196.0	18583
5	182	4196.0	4196.0	22779
6	182	4196.0	4196.0	26975
7	182	4196.0	4196.0	31171
8	182	4196.0	4196.0	35367
9	182	4196.0	4196.0	39563
10	182	4196.0	4196.0	43759
11	182	4196.0	4196.0	47955
12	182	4196.0	4196.0	52151
13	182	4196.0	4196.0	56347
14	182	4196.0	4196.0	60543
15	182	4196.0	4196.0	64739
16	156	3597.0	3597.0	68336
17	156	3597.0	3597.0	71933
18	156	3597.0	3597.0	75530
19	156	3597.0	3597.0	79127
20	156	3597.0	3597.0	82724

*Flood Embankments not necessary

**Flood Embankments necessary

3.21 METHOD A1
CATCHMENT 300

	Year	HHrs	Cost HHrs	Total Annual Expenditure	Cumulative Expenditure
*	Initilis-ation	234	5,396	5,396	5,396
**		692	15,957	15,957	
	1	546	12,590	12,590	17,986
	2	546	12,590	12,590	30,576
	3	546	12,590	12,590	43,166
	4	546	12,590	12,590	55,756
	5	546	12,590	12,590	68,346
	6	546	12,590	12,590	80,936
	7	546	12,590	12,590	93,526
	8	546	12,590	12,590	106,116
	9	546	12,590	12,590	118,706
	10	546	12,590	12,590	131,296
	11	546	12,590	12,590	143,886
	12	546	12,590	12,590	156,476
	13	546	12,590	12,590	169,066
	14	546	12,590	12,590	181,656
	15	546	12,590	12,590	194,246
	16	468	10,792.0	10,792	205,038
	17	468	10,792.0	10,792	215,830
	18	468	10,792.0	10,792	226,622
	19	468	10,792.0	10,792	237,414
	20	468	10,792.0	10,792	248,206

* Flood Embankment not required.

** Flood Embankment required.

3.22

METHOD A1
CATCHMENT 600 ACRES

	Year	HHrs	Cost HHrs	Total Annual Expenditure	Cumulative Expenditure
*	Initilis-ation	468	10,792.0	10,792.0	10,792
**		1028	23,705.0	23,705.0	
	1	1092	23,705.0	23,705.0	34,497
	2	1092	23,705.0	23,705.0	58,202
	3	1092	23,705.0	23,705.0	81,907
	4	1092	23,705.0	23,705.0	105,612
	5	1092	23,705.0	23,705.0	129,317
	6	1092	23,705.0	23,705.0	153,022
	7	1092	23,705.0	23,705.0	176,727
	8	1092	23,705.0	23,705.0	200,432
	9	1092	23,705.0	23,705.0	224,137
	10	1092	23,705.0	23,705.0	247,842
	11	1092	23,705.0	23,705.0	271,547
	12	1092	23,705.0	23,705.0	295,252
	13	1092	23,705.0	23,705.0	318,957
	14	1092	23,705.0	23,705.0	342,662
	15	1092	23,705.0	23,705.0	366,367
	16	936	21,584	21,584.0	387,951
	17	936	21,584	21,584.0	409,535
	18	936	21,584	21,584.0	431,119
	19	936	21,584	21,584.0	452,703
	20	936	21,584	21,584.0	474,287

*Flood Embankment not required.

**Flood Embankment required.

METHOD A2
CATCHMENT 100 ACRES

	Year	HHrs	Cost HHrs	SPHrs	Cost SPHrs	DHrs	Cost DHrs	Recycl-ing (T)	Cost Recycl-ing	Total Annual Expend.	Cumul-ative Expend.
*	Init.	78	1798							1798	1798
**		345	7955							7955	
	1			74	2803	135	2241	190.5	- 571	4473	6271
	2			74	2803	135	2241	190.5	- 571	4473	10744
	3			74	2803	135	2241	190.5	- 571	4473	15217
	4			74	2803	135	2241	190.5	- 571	4473	19690
	5			74	2803	135	2241	190.5	- 571	4473	24163
	6			74	2803	135	2241	190.5	- 571	4473	28636
	7			74	2803	135	2241	190.5	- 571	4473	33109
	8			74	2803	135	2241	190.5	- 571	4473	37582
	9			74	2803	135	2241	190.5	- 571	4473	42055
	10			74	2803	135	2241	190.5	- 571	4473	46528
	11			74	2803	135	2241	190.5	- 571	4473	51001
	12			74	2803	135	2241	190.5	- 571	4473	55474
	13			74	2803	135	2241	190.5	- 571	4473	59947
	14			74	2803	135	2241	190.5	- 571	4473	64420
	15			74	2803	135	2241	190.5	- 571	4473	68893
	16			74	2803	135	2241	190.5	- 571	4473	73366
	17			74	2803	135	2241	190.5	- 571	4473	77839
	18			74	2803	135	2241	190.5	- 571	4473	82312
	19			74	2803	135	2241	190.5	- 571	4473	86785
	20			74	2803	135	2241	190.5	- 571	4473	91258

*Flood Embankment not required

**Flood Embankment required.

METHOD A2
CATCHMENT = 300 ACRES

	Year	HHrs	Cost HHrs	SPHrs	Cost SPHrs	DHrs	Cost DHrs	Recycl. (T)	Cost Recycle	Total Annual Expend.	Cumul-ative Expend.
*	Init.	234	5396							5396	5396
**		692	15957							15957	
	1			222	8409	405	6723	571	- 1713	13419	18815
	2			222	8409	405	6723	571	- 1713	13419	32234
	3			222	8409	405	6723	571	- 1713	13419	45653
	4			222	8409	405	6723	571	- 1713	13419	59072
	5			222	8409	405	6723	571	- 1713	13419	72491
	6			222	8409	405	6723	571	- 1713	13419	85910
	7			222	8409	405	6723	571	- 1713	13419	99329
	8			222	8409	405	6723	571	- 1713	13419	112748
	9			222	8409	405	6723	571	- 1713	13419	126167
	10			222	8409	405	6723	571	- 1713	13419	139586
	11			222	8409	405	6723	571	- 1713	13419	153005
	12			222	8409	405	6723	571	- 1713	13419	166424
	13			222	8409	405	6723	571	- 1713	13419	179843
	14			222	8409	405	6723	571	- 1713	13419	193262
	15			222	8409	405	6723	571	- 1713	13419	206681
	16			222	8409	405	6723	571	- 1713	13419	220100
	17			222	8409	405	6723	571	- 1713	13419	233519
	18			222	8409	405	6723	571	- 1713	13419	246938
	19			222	8409	405	6723	571	- 1713	13419	260357
	20			222	8409	405	6723	571	- 1713	13419	273776

* Flood Embankment not required.

** Flood Embankment required.

3.25

METHOD A2
CATCHMENT = 600 ACRES

Year	HHrs	Cost HHrs	SPHrs	Cost SPHrs	DHrs	Cost DHrs	Recycle (T)	Cost Recycle	Total Annual Expend.	Cumulative Expend.
* Init.	468	10792							10792	10792
**	1028	23705							23705	
1			444	16818	810	13446	1143	- 3429	26835	37627
2			444	16818	810	13446	1143	- 3429	26835	64462
3			444	16818	810	13446	1143	- 3429	26835	91297
4			444	16818	810	13446	1143	- 3429	26835	118132
5			444	16818	810	13446	1143	- 3429	26835	144967
6			444	16818	810	13446	1143	- 3429	26835	171802
7			444	16818	810	13446	1143	- 3429	26835	198637
8			444	16818	810	13446	1143	- 3429	26835	225472
9			444	16818	810	13446	1143	- 3429	26835	252307
10			444	16818	810	13446	1143	- 3429	26835	279142
11			444	16818	810	13446	1143	- 3429	26835	305977
12			444	16818	810	13446	1143	- 3429	26835	332812
13			444	16818	810	13446	1143	- 3429	26835	359647
14			444	16818	810	13446	1143	- 3429	26835	386482
15			444	16818	810	13446	1143	- 3429	26835	413317
16			444	16818	810	13446	1143	- 3429	26835	440152
17			444	16818	810	13446	1143	- 3429	26835	466987
18			444	16818	810	13446	1143	- 3429	26835	493822
19			444	16818	810	13446	1143	- 3429	26835	520657
20			444	16818	810	13446	1143	- 3429	26835	547492

* Flood Embankment not required.

** Flood Embankment required.

3.26

METHOD A3
CATCHMENT = 100 ACRES

	Year	HHrs	Cost HHrs	SPHrs	Cost SPHrs	Area Spread		Cost Area	Total Annual Expend.	Cumul-ative Expend.
						ft^2	Acres			
*	Init.	78	1798			210000	4.82	7230	9028	9028
**		345	7955			210000	4.82	7230	15185	
	1			74	2803				2803	11831
	2			74	2803				2803	14634
	3			74	2803				2803	17437
	4			74	2803				2803	20240
	5			74	2803				2803	23043
	6			74	2803				2803	25846
	7			74	2803				2803	28649
	8			74	2803				2803	31452
	9			74	2803				2803	34255
	10			74	2803				2803	37058
	11			74	2803				2803	39861
	12			74	2803				2803	42664
	13			74	2803				2803	45467
	14			74	2803				2803	48270
	15			74	2803				2803	51073
	16			74	2803				2803	53876
	17			74	2803				2803	56679
	18			74	2803				2803	59482
	19			74	2803				2803	62285
	20			74	2803				2803	65088

METHOD A3
CATCHMENT = 300 ACRES

Year	HHrs	Cost HHrs	SPHrs	Cost SPHrs	Area Spread		Cost Area	Total Annual Expend.	Cumul-ative Expend.
					ft^2	Acres			
* Init.	234	5396			630000	14.46	21690	27086	27086
**	692	15957			630000	14.46	21690	37647	
1			222	8409				8409	35495
2			222	8409				8409	43904
3			222	8409				8409	52313
4			222	8409				8409	60722
5			222	8409				8409	69131
6			222	8409				8409	77540
7			222	8409				8409	85949
8			222	8409				8409	94358
9			222	8409				8409	102767
10			222	8409				8409	111176
11			222	8409				8409	119585
12			222	8409				8409	127994
13			222	8409				8409	136403
14			222	8409				8409	144812
15			222	8409				8409	153221
16			222	8409				8409	161630
17			222	8409				8409	170039
18			222	8409				8409	178448
19			222	8409				8409	186857
20			222	8409				8409	195266

METHOD A3
CATCHMENT = 600 ACRES

	Year	HHrs	Cost HHrs	SPHrs	Cost HHrs	Area Spread		Cost Area	Total Annual Expend.	Cumul-ative Expend.
						ft^2	Acres			
*	Init	468	10792			1260000	28.93	43395	54187	54187
**		1028	23705			1260000	28.93	43395	67100	
	1			444	16818				16818	71005
	2			444	16818				16818	87823
	3			444	16818				16818	104641
	4			444	16818				16818	121459
	5			444	16818				16818	138277
	6			444	16818				16818	155095
	7			444	16818				16818	171913
	8			444	16818				16818	188731
	9			444	16818				16818	205549
	10			444	16818				16818	222367
	11			444	16818				16818	239185
	12			444	16818				16818	256003
	13			444	16818				16818	272821
	14			444	16818				16818	289639
	15			444	16818				16818	306457
	16			444	16818				16818	323275
	17			444	16818				16818	340093
	18			444	16818				16818	356911
	19			444	16818				16818	373729
	20			444	16818				16818	390547

3.29

METHOD B1
CATCHMENT = 100 ACRES

Year	HHrs	Cost HHrs	Install Pump	Pump Maint.	Area Required ft^2	Area Required Acres	Cost Area	Total Annual Cost	Cumulative Cost
Init.	922	21261	25000		403128	9.25	13875	60136	60136
1				1000				1000	61136
2				1000				1000	62136
3				1000				1000	63136
4				1000				1000	64136
5				1000				1000	65136
6				1000				1000	66136
7				1000				1000	67136
8				1000				1000	68136
9				1000				1000	69136
10				1000				1000	70136
11				1000				1000	71136
12				1000				1000	72136
13				1000				1000	73136
14				1000				1000	74136
15				1000				1000	75136
16				1000				1000	76136
17				1000				1000	77136
18				1000				1000	78136
19				1000				1000	79136
20				1000					80136

METHOD B1
CATCHMENT = 300 ACRES

Year	HHrs	Cost HHrs	Install Pump	Pump Maint.	Area Required ft^2	Area Required Acres	Cost Area	Total Annual Expend.	Cumulative Expend.
Init.	1596	36803	32000		1097592	25.20	37800	99603	99603
1				2000				2000	101603
2				2000				2000	103603
3				2000				2000	105603
4				2000				2000	107603
5				2000				2000	109603
6				2000				2000	111603
7				2000				2000	113603
8				2000				2000	115603
9				2000				2000	117603
10				2000				2000	119603
11				2000				2000	121603
12				2000				2000	123603
13				2000				2000	125603
14				2000				2000	127603
15				2000				2000	129603
16				2000				2000	131603
17				2000				2000	133603
18				2000				2000	135603
19				2000				2000	137603
20				2000				2000	139603

3.31

METHOD B1
CATCHMENT = 600 ACRES

Year	HHrs	Cost HHrs	Install Pump	Pump Maint.	Area Required		Cost Area	Total Annual Expend.	Cumulative Expend.
					ft^2	Acres			
Init.	2257	52046	47000		2105832	48.34	72510	149556	149556
1				4500				4500	154056
2				4500				4500	158556
3				4500				4500	163056
4				4500				4500	167556
5				4500				4500	172056
6				4500				4500	176556
7				4500				4500	181056
8				4500				4500	185556
9				4500				4500	190056
10				4500				4500	194556
11				4500				4500	199056
12				4500				4500	203556
13				4500				4500	208056
14				4500				4500	212556
15				4500				4500	217056
16				4500				4500	221556
17				4500				4500	226056
18				4500				4500	230556
19				4500				4500	235056
20				4500				4500	239556

METHOD B2 - 5 YEAR LIFESPAN
CATCHMENT = 100 ACRES

Year	HHrs	Cost HHrs	Instal Pump	Pump Maint.	Area Required ft^2	Area Required Acres	Cost Area	Total Annual Expend.	Cumulative Expend.
Init.	460	10607	25000		44064	1.01	1515	37122	37122
1	92	2121		1000	44064	1.01	1515	4636	41758
2	92	2121		1000				3121	44879
3	92	2121		1000				3121	48000
4	92	2121		1000				3121	51121
5	92	2121		1000				3121	54242
6	92	2121	4000	1000	44064	1.01	1515	8636	62878
7	92	2121		1000				3121	65999
8	92	2121		1000				3121	69120
9	92	2121		1000				3121	72241
10	92	2121		1000				3121	75362
11	92	2121	4000	1000	44064	1.01	1515	8636	83998
12	92	2121		1000				3121	87119
13	92	2121		1000				3121	90240
14	92	2121		1000				3121	93361
15	92	2121		1000				3121	96482
16			4000	1000				5000	101482
17				1000				1000	102482
18				1000				1000	103482
19				1000				1000	104482
20				1000				1000	105482

3.33

METHOD B2 - 5 YEAR LIFESPAN
CATCHMENT = 300 ACRES

Year	HHrs	Cost HHrs	Install Pump	Pump Maint.	Area Required ft^2	Area Required Acres	Cost Area	Total Annual Expend.	Cumulative Expend.
Init.	797	18378	32000		76296	1.75	2625	53003	53003
1	159	3666		2000	76296	1.75	2625	8291	61294
2	159	3666		2000				5666	66960
3	159	3666		2000				5666	72626
4	159	3666		2000				5666	78292
5	159	3666		2000				5666	83958
6	159	3666	7000	2000	76296	1.75	2625	15291	99249
7	159	3666		2000				5666	104915
8	159	3666		2000				5666	110581
9	159	3666		2000				5666	116247
10	159	3666		2000				5666	121913
11	159	3666	7000	2000	76296	1.75	2625	15291	137204
12	159	3666		2000				5666	142870
13	159	3666		2000				5666	148536
14	159	3666		2000				5666	154202
15	159	3666		2000				5666	159868
16			7000	2000				9000	168868
17				2000				2000	170868
18				2000				2000	172868
19				2000				2000	174868
20				2000				2000	176868

METHOD B2 - 5 YEAR LIFESPAN
CATCHMENT = 600 ACRES

Year	HHrs	Cost HHrs	Install Pump	Pump Maint.	Area Required		Cost Area	Total Annual Cost	Cumulative Cost
					ft^2	Acres			
Init.	1127	25988	47000		107848	2.47	3705	76693	76693
1	225	5188		4500	107848	2.47	3705	13393	90086
2	225	5188		4500				9688	99774
3	225	5188		4500				9688	109462
4	225	5188		4500				9688	119150
5	225	5188		4500				9688	128838
6	225	5188	10000	4500	107848	2.47	3705	23393	152231
7	225	5188		4500				9688	161919
8	225	5188		4500				9688	171607
9	225	5188		4500				9688	181295
10	225	5188		4500				9688	190983
11	225	5188	10000	4500	107848	2.47	3705	23393	214376
12	225	5188		4500				9688	224064
13	225	5188		4500				9688	233752
14	225	5188		4500				9688	243440
15	225	5188		4500				9688	253128
16			10000	4500				14500	267628
17				4500				4500	272128
18				4500				4500	276628
19				4500				4500	281128
20				4500				4500	285628

METHOD B2 - 10 YEAR LIFESPAN
CATCHMENT = 100 ACRES

Year	HHrs	Cost HHrs	Install Pump	Pump Maint.	Area Required ft.^{2}	Area Required Acres	Cost Area	Total Annual Expend.	Cumul-ative Expend.
Init	640	14758	25000		166200	3.81	5715	45473	45473
1	64	1475		1000	166200	3.81	5715	8190	53663
2	64	1475		1000				2475	56138
3	64	1475		1000				2475	58613
4	64	1475		1000				2475	61088
5	64	1475		1000				2475	63563
6	64	1475		1000				2475	66038
7	64	1475		1000				2475	68513
8	64	1475		1000				2475	70988
9	64	1475		1000				2475	73463
10	64	1475	4000	1000				6475	79938
11				1000				1000	80938
12				1000				1000	81938
13				1000				1000	82938
14				1000				1000	83938
15				1000				1000	84938
16				1000				1000	85938
17				1000				1000	86938
18				1000				1000	87938
19				1000				1000	88938
20				1000				1000	89938

3.36

METHOD B2 - 10 YEAR LIFESPAN
CATCHMENT = 300 ACRES

Year	HHrs	Cost HHrs	Install Pump	Pump Maint.	Area Required		Cost Area	Total Annual Expend.	Cumulative Expend.
					ft^2	Acres			
Init	1128	26011	32000		422848	9.71	14565	72 576	72576
1	113	2605		2000	422848	9.71	14565	19170	91746
2	113	2605		2000				4605	96351
3	113	2605		2000				4605	100956
4	113	2605		2000				4605	105561
5	113	2605		2000				4605	110166
6	113	2605		2000				4605	114771
7	113	2605		2000				4605	119376
8	113	2605		2000				4605	123981
9	113	2605		2000				4605	128586
10	113	2605	7000	2000				11605	140191
11				2000				2000	142191
12				2000				2000	144191
13				2000				2000	146191
14				2000				2000	148191
15				2000				2000	150191
16				2000				2000	152191
17				2000				2000	154191
18				2000				2000	156191
19				2000				2000	158191
20				2000				2000	160191

3.37

METHOD B2 – 10 YEAR LIFESPAN
CATCHMENT = 600 ACRES

Year	HHrs	Cost HHrs	Install Pump	Pump Maint.	Area Required		Cost Area	Total Annual Expend.	Cumulative Expend.
					ft^2	Acres			
Init	1596	36803	47000		782592	17.96	26940	110743	110743
1	160	3689		4500	782592	17.96	26940	35129	145872
2	160	3689		4500				8189	154061.
3	160	3689		4500				8189	162250
4	160	3689		4500				8189	170439
5	160	3689		4500				8189	178628
6	160	3689		4500				8189	186817
7	160	3689		4500				8189	195006
8	160	3689		4500				8189	203195
9	160	3689		4500				8189	211384
10	160	3689	10000	4500				18189	229573
11				4500				4500	234073
12				4500				4500	234073
13				4500				4500	243073
14				4500				4500	247573
15				4500				4500	252073
16				4500				4500	256573
17				4500				4500	261073
18				4500				4500	265573
19				4500				4500	270073
20				4500				4500	274573

3.38

METHOD C1
CATCHMENT = 100 ACRES

Year	HHrs	Cost HHrs	HHrs Rehandle	Cost HHrs	Install Pump	Total Annual Expend.	Cumul-ative Expend.
* Init	78	1798				1798	1798
**	345	7955				7955	
1	156	3597	52	1199		4796	6594
2	156	3597	52	1199		4796	11390
3	156	3597	52	1199		4796	16186
4	156	3597	52	1199		4796	20982
5	156	3597	52	1199		4796	25778
6	156	3597	52	1199		4796	30574
7	156	3597	52	1199		4796	35370
8	156	3597	52	1199		4796	40166
9	156	3597	52	1199		4796	44962
10	156	3597	52	1199		4796	49758
11	156	3597	52	1199	25000	29796	84350
12					1000	1000	85350
13					1000	1000	86350
14					1000	1000	87350
15					1000	1000	88350
16					1000	1000	89350
17					1000	1000	90350
18					1000	1000	91350
19					1000	1000	92350
20					1000	1000	93350

*Flood Embankment not required.

**Flood Embankment required - not included in Cumulative Cost.

3.39 METHOD C1
CATCHMENT = 300 ACRES

	Year	HHrs	Cost HHrs	HHrs Rehandle	Cost HHrs	Install Pump	Total Annual Expend.	Cumulative Expend.
*	Init	234	5396				5396	5396
**		692	15957				15957	
	1	468	10792	156	3597		14389	19786
	2	468	10792	156	3597		14389	34175
	3	468	10792	156	3597		14389	48564
	4	468	10792	156	3597		14389	62953
	5	468	10792	156	3597		14389	77342
	6	468	10792	156	3597		14389	91731
	7	468	10792	156	3597		14389	106120
	8	468	10792	156	3597	32000	46389	152509
	9					2000	2000	154509
	10					2000	2000	156509
	11					2000	2000	158509
	12					2000	2000	160509
	13					2000	2000	162509
	14					2000	2000	164509
	15					2000	2000	166509
	16					2000	2000	168509
	17					2000	2000	170509
	18					2000	2000	172509
	19					2000	2000	174509
	20					2000	2000	176509

*Flood Embankment not required.

**Flood Embankment required - not included in cumulative cost.

3.40 METHOD C1
CATCHMENT = 600 ACRES

	Year	HHrs	Cost HHrs	HHrs Rehandle	Cost HHrs	Pump Install	Total Annual Expend.	Cumul-ative Expend.
*	Init	468	10792				10792	10792
**		1028	23705				23705	
	1	936	21584	312	7194		28778	39570
	2	936	21584	312	7194		28778	68348
	3	936	21584	312	7194		28778	97126
	4	936	21584	312	7194		28778	125904
	5	936	21584	312	7194		28778	154682
	6	936	21584	312	7194		28778	183460
	7	936	21584	312	7194		28778	212238
	8	936	21584	312	7194	47000	75778	288016
	9					4500	4500	292516
	10					4500	4500	297016
	11					4500	4500	301516
	12					4500	4500	306016
	13					4500	4500	310516
	14					4500	4500	315016
	15					4500	4500	319516
	16					4500	4500	324016
	17					4500	4500	328516
	18					4500	4500	333016
	19					4500	4500	337516
	20					4500	4500	342016

*Flood Embankment not required.

**Flood Embankment required - not included in cumulative cost.

3.41 For Graphical Representation of Cumulative Expenditure versus year for systems A1, A2, A3, B1, B2, C1

Reference Graphs 2, 3 and 4.

3.42 Due to undefined initialisation period identification of the optimal solution based on both initial capital cost and subsequent expenditure is not possible.

For the moment therefore the following definitions of optimality are considered.

1. Optimal Solution = Solution incurring lowest total cost (i.e. sum of expenditure during initialisation and subsequent 20 years).

2. Optimal Solution = Solution incurring lowest initial capital cost.

3.43 <u>By Definition 1*</u>

Optimal Solution	100 acre catchment	-	A3
" "	300 acre catchment	-	B1
" "	600 acre catchment	-	B1

<u>By Definition 2*</u>

Optimal Solution	100 acre catchment	-	A1
" "	300 acre catchment	-	C1
" "	600 acre catchment	-	C1

*Ref. Graph 2, 3 and 4.

3.44 EXAMPLE:

Application of Optimal Solutions based on definition 1 to Outfall System at Blackwater Works

Catchment sizes ranging between taken as "100 acres"	1 - 200 acres
Catchment sizes ranging between taken as "300 acres"	201 - 450 acres
Catchment sizes ranging between taken as "600 acres"	451 - 1000 acres

For Blackwater Works (excluding Cornafulla, Drumlosh)

No. 100 acre catchment areas	=	36
No. 300 acre catchment areas	=	14
No. 600 acre catchment areas	=	10

For the moment it will be assumed that optimal solutions are technically possible at each location. Adjustments will be introduced later to take account of necessity at some locations for flood embankments.

3.45 Optimal Solution = Solution incurring lowest total cost

Year	A3		B1		B1		Total Annual	Cumul-ative
	1 No. 100 acre	36 No. 100 acre	1 No. 300 acre	14 No. 300 acre	1 No. 600 acre	10 No. 600 acre		
Init	9,028	325,008	99,603	1,394,442	149,556	1,495,560	3,215,010	3,215,010
1	15,185	546,660	2,000	28,000	4,500	45,000	619,660	3,834,670
2	2,803	100,908	2,000	28,000	4,500	45,000	173,908	4,008,578
3	2,803	100,908	2,000	28,000	4,500	45,000	173,908	4,182,486
4	2,803	100,908	2,000	28,000	4,500	45,000	173,908	4,356,394
5	2,803	100,908	2,000	28,000	4,500	45,000	173,908	4,530,302
6	2,803	100,908	2,000	28,000	4,500	45,000	173,908	4,704,210
7	2,803	100,908	2,000	28,000	4,500	45,000	173,908	4,878,118
8	2,803	100,908	2,000	28,000	4,500	45,000	173,908	5,052,026
9	2,803	100,908	2,000	28,000	4,500	45,000	173,908	5,225,934
10	2,803	100,908	2,000	28,000	4,500	45,000	173,908	5,399,842
11	2,803	100,908	2,000	28,000	4,500	45,000	173,908	5,573,750
12	2,803	100,908	2,000	28,000	4,500	45,000	173,908	5,747,658
13	2,803	100,908	2,000	28,000	4,500	45,000	173,908	5,921,566
14	2,803	100,908	2,000	28,000	4,500	45,000	173,908	6,095,474
15	2,803	100,908	2,000	28,000	4,500	45,000	173,908	6,269,382
16	2,803	100,908	2,000	28,000	4,500	45,000	173,908	6,643,290
17	2,803	100,908	2,000	28,000	4,500	45,000	173,908	6,827,198
18	2,803	100,908	2,000	28,000	4,500	45,000	173,908	7,001,106
19	2,803	100,908	2,000	28,000	4,500	45,000	173,908	7,175,014
20	2,803	100,908	2,000	28,000	4,500	45,000	173,908	7,348,922

3.46 Optimal Solution = Solution incurring lowest capital cost

	A1		C1		C1		Total Annual	Cumul-ative
	1 no. 100 acre	36 no. 100 acre	1 no. 300 acre	14 no. 300 acre	1 no. 600 acre	10 no. 600 acre		
* Init	1799	64764	5396	75544	10792	107920	248228	248228
**	7955	286380	15957	223398	23705	237050	746828	
1	4196	151056	14389	201446	28778	287780	640282	888510
2	4196	151056	14389	201446	28778	287780	640282	1528792
3	4196	151056	14389	201446	28778	287780	640282	2169074
4	4196	151056	14389	201446	28778	287780	640282	2809356
5	4196	151056	14389	201446	28778	287780	640282	3449638
6	4196	151056	14389	201446	28778	287780	640282	4089920
7	4196	151056	14389	201446	28778	287780	640282	4730202
8	4196	151056	46389	649446	75778	757780	1558282	6288484
9	4196	151056	2000	28000	4500	45000	224056	6512540
10	4196	151056	2000	28000	4500	45000	224056	6736596
11	4196	151056	2000	28000	4500	45000	224056	6960652
12	4196	151056	2000	28000	4500	45000	224056	7184708
13	4196	151056	2000	28000	4500	45000	224056	7408764
14	4196	151056	2000	28000	4500	45000	224056	7632820
15	4196	151056	2000	28000	4500	45000	224056	7856876
16	3597	129492	2000	28000	4500	45000	202492	8059368
17	3597	129492	2000	28000	4500	45000	202492	8261860
18	3597	129492	2000	28000	4500	45000	202492	8464352
19	3597	129492	2000	28000	4500	45000	202492	8666844
20	3597	129492	2000	28000	4500	45000	202492	8869336

CHAPTER 4

Comparison of Expenditure on Present System with Expenditure on Visualised Systems

4.1 In the previous chapters the various visualised systems of silt control have been costed and the optimal solution identified for small, medium and large catchment sizes. The question still remains, however, as to whether the most economical of the visualised systems remains economical when compared to the present system. To facilitate this comparison the present system must be costed.

4.2 Costing of Present System

Present expenditure in the area of silt control may be viewed under three main headings:-

a. Expenditure on installation and maintenance of silt control systems.

b. Expenditure on 'clean up operations' i.e. to placate farmers.

c. Compensation to farmers, sports clubs etc.

d. Cost of damaged public relations*

4.3 It is possible to record relatively clearly expenditure on excavation and maintenance of silt ponds.

Similarly it would be relatively easy to record expenditure in the form of compensation.

Expenditure on 'clean up' operations however, which represents a major fraction of the total expenditure on silt control is not readily identifiable since due to the present subhead system expenditure, in this area loses identity

*Cost of damaged public relations not considered as it is outside scope of this report.

amid expenditure on drainage. Any such work is a direct consequence of the inefficiencies of our approach to silt control and as such should be regarded as expenditure on silt control.

4.4 Rather than trying to assess finitely the amount of expenditure presently incurred due to silt control the following approach may be adopted:

The present system is optimal if the amount of expenditure presently incurred is less than the expenditure which would be incurred if the most economic of the visualised systems were adopted; bearing in mind the difference in efficiency.

4.5 Example:

Blackwater Works

Period June to September 1983

Total no. of Hymac hours to silt control (maintenance only) approx.	=	640	HHrs
Expected total no. of Hymac hours for 1 year	=	2,560	HHrs
Equivalent annual expenditure	=	£59,033	
Lowest possible annual expenditure to maintain system which produces acceptable suspended solids concentrations at all outfalls*	=	£640,282	

4.6 From this it follows that if more than £580,000 is spent annually in the present system by way of compensation etc. (i.e. expenditure on silt control excluding silt pond maintenance expenditure) that the present system is non optimal. This is clearly not the case and hence it is reasonable to conclude that the present system is optimal.

*Ref. 3.46

4.7 It should be noted however that the comparison above compares (a) visualised system which is designed to produce acceptable suspended solids effluent to all outfall locations with (b) present system which is not 100% efficient.

4.8 At this point it is necessary to distinguish between two definitions of silt control.

1.	Rational/ Preventative	To produce effluent of acceptable suspended solids concentrations at all outfalls.
2.	Corrective	To rely for the most part on siltation 'cleanup operations' where complaints are received or anticipated.

4.9 Due to the present budgetary system arrangements expenditure on silt control effectively raises production costs. If it is intended to rationalise silt control it will be essential to introduce some form of budgetary separation. Evidence of the latter is already available from the low degree of priority which Works Managers (find it possible to) afford silt control. This low degree of priority is in turn reflected in the shortage (oftentimes virtual absence) of machinery available for silt control.

CHAPTER 5

Conclusions and Recommendations

Conclusions:

1. When considering the question of sludge capacity required neither a finite answer nor the answers parish can be derived by theoretical methods based on monitoring since the variables involved while identifiable defy analysis (ref. 1.2 - 1.7 inc.)

2. Silt trapping systems which allow for accumulation of 525 ft^3 of sludge/acre 4 times per year function satisfactorily (ref. 1.8 - 1.9 inc.).

3. The quantity of suspended solids to be dealt with in attempting to produce effluent of acceptable suspended solids concentration is generally underestimated.

   The amount of silt giving rise to complaints from external individuals and bodies represents only a small fraction of the overall suspended solids discharged via our outfalls.

   Unfortunately to prevent this small proportion from giving rise to complaints it would be necessary to trap almost all suspended solids (ref. 1.12.7).

4. The equivalent of approx. 152,000 tonnes of milled peat at 55% M.C. is discharged annually from milled peat production areas in the form of suspended solids (ref. 1.10).

5. The ease with which settled peat solids may be put back into suspension is generally underestimated (ref. 1.11).

6. The installation of trapping systems which are not protected against heavy flows from upstream and/or flooding from down-stream is futile. Protection may be afforded by means of by-passing, valves, embankments etc. (ref. 1.11; 1.12; 2.9, 2.10; 2.11; 2.12; 2.13).

7. When flow through a trapping system is in the form of a narrow channel no settlement of suspended solids is taking place (ref. 1.12.2).

8. It is grossly inefficient to install settlement ponds on large outfalls or rivers (ref. 1.12.5).

9. It is generally cost prohibitive and/or technically impossible to rearrange existing bog drainage systems.

10. The dragline is not suitable for silt pond maintenance (ref. 2.17). The hymac is suitable for silt pond maintenance (ref. 2.17).

11. The recycling of sludge removed from silt trapping systems by excavator is non practicable (ref. 2.17).

12. The use of 1 to 1 side slopes to silt pond is unwarranted (ref. 2.18).

13. The existance of "walls" would be highly beneficial as regards efficiency and quiescent conditions (ref. 2.14; 2.15).

14. The present system involving reliance to a large extent on cleanup operations and compensation costs less than any rationalised method of producing acceptable effluent at all outfall locations.

The above statement does not take account of costs incurred by damaged public relations or responsibility toward protection of the environment.

15. The optimal rationalised system has been identified. In the light of paragraph 2 of conclusion 14 it is outside the scope of this report to identify the overall optimal solution (ref. 4.1-4.9 inc.).

16. To adopt a rationalised approach the following points must be clarified.

(a) identification of the overall optimal solution

(b) Finite cost of the present system (ref. 4.1-4.9 inc.).

17. The present budgetary system does not facilitate

(a) Accurate costing of the present system

(b) Rationalised approach (ref. 4.9).

18. The maintenance of silt ponds by sludge pumping may prove to be more economical than the present method. The system is as yet untried.

Recommendations

1. Trapping systems should be designed on the basis of 525 ft.^{3} of sludge accumulating four times per year (ref. conclusion 2).

2. Trapping systems should not be installed unless adequate protection to ensure against resuspension of the settled particles and regular maintenance can be provided (ref. conclusion 5 and 6).

3. Future trapping systems should be modified in accordance with 2.15 (ref. conclusions 7 and 13).

4. In general settlement ponds should not be installed on large outfalls or rivers (ref. conclusion 8).

5. Trapping system designs based on overall re-arrangement of outfall systems should not be entertained. Consideration should, however, be given to localised re-arrangement of outfall system when individual outfalls are being considered for silt removal (ref. conclusion 9).

6. The practice of providing trapping systems, the dimensions of which are based on capabilities of the dragline excavator rather than the hymac, should be discontinued.

7. As an essential starting point for the rationalisation of silt control, consideration should be given to conclusions 14, 15, 16 and 17.

8. Development of the sludge pump should be continued.

9. Prior to a rationalised plan for a Works being discussed and decided upon, no. 7 above should be complied with.

APPENDIX 1

Acceptable Suspended Solids Concentration

Following the 1977 Water Pollution Act threshold values for maximum allowable suspended solids concentration are left by and large to the discretion of the local authorities involved.

The "Eight Report of the Royal Commission on Water and Sewage" (1912) recommended that "maximum suspended solids concentration" be regarded as 30 ppm (in the case of peat solids = 30 mg/l) assuming an outfall to receiving water flow rate ratio of 1 : 8.

Although the situation is not clarified, it is reasonable to assume that suspended solids concentrations of the order of 100 mg/l should be deemed acceptable by the authorities since the outfall to receiving water flow rate ratio in our case is rarely less than 1 : 25.

The outlet suspended solids concentration of functioning silt ponds rarely exceeds 100 mg/l and is often considerably less.

The retention time required to provide acceptable effluent is less critical than the lifespan requirement when the length and volume of silt ponds is being considered.

N.B.

Our legal obligation to treat drainage waters with high suspended solids concentration is presently being investigated in the light of the 1977 Water Pollution Act and the 1946 Turf Development Act.

APPENDIX 2

Mathematical Expression for Lifespan of Trapping System

Trapping System = Settlement Pond, Say

Parameter	Symbol	Units
Top Width Pond	W	m
Overall Depth Pond	D	m
Effective Depth Pond	H	m
Length of Pond	L	m
Relative Density Dry Solids	g	-
% Suspended Solids which settle	100 E	-
Annual Average Rainfall	R	mm/yr
Run off Equation	X	-
Area Catchment	A	acres
Average M.C. settled sludge	M	-
Inflow to Pond	Qi	m^3/hr
Lifespan Pond	C	days

$$Qi = \left(\frac{R}{(24 \times 365.25)\,(10^3)} \right) \left(\frac{A \times 0.00405}{10^{-6}} \right) \left(\frac{X}{1} \right)$$

$$= RAX \; (4.62012 * 10^{-4})$$

Weight solids inflowing to pond in 1 hour

$$= (RAX)\;(4.62012 \times 10^{-4})\;(S_1 \times 10^3)\ \text{mg}$$

Volume of solids inflowing to pond in 1 hour =

$$\left(\frac{RAX}{1}\right) \left(\frac{S_1}{g}\right) \left(\frac{4.62012 * 10^{-10}}{1}\right) \quad m^3/hr$$

Volume sludge formed in 1 hour =

$$\left(\frac{RAX\ S_1}{(1-m)\,(g)} \right) \left(\frac{e}{1}\right) \left(\frac{4.62012 * 10^{-10}}{1}\right) \quad m^3$$

Volume available for sludge deposition =

$$(\ (W-2D + H) * (H.L.)\ )$$

$$\text{Lifespan} = C = \frac{\text{vol. available for sludge deposition}}{\text{vol. required for sludge deposition per unit time.}}$$

$$C = \frac{\left((W-2D+H) \quad (H.L.) \right)}{\left(\frac{RAX\ S_1}{(1-m}\right) \left(\frac{e}{g}\right) \left(\frac{4.62012 * 10^{-10}}{1}\right) \left(\frac{24}{1}\right)} \text{ days}$$

Demonstration of sensitivity of capacity to moisture content sludge.

Assume 1. Runoff equation (X) can be evaluated and has value 0.7.

2. W = 8; D = 3; H = 2; g = 1.5;
S_1 = 800 mg/1   A = 100; e = 0.85;
R = 1320 mm/yr*; C = 120; m, L variable.

R = Average yearly rainfall calculated by assuming monthly rainfall equal to average monthly rainfall based on wettest three months of year (value above for November, December, January at Ahascragh, Co. Galway - Derryfadda.

General Equation Derived above:-

$$C = \frac{(W-2D+H) \quad (H.L)}{\left(\frac{RAX\ s,\ e}{(1-m)\ g}\right) \left(\frac{4.62012 * 10^{-10}}{1}\right) \left(\frac{24}{1}\right)} \text{ days}$$

For values listed above.

$$120 = \frac{(8-2(3)+2) \quad (2 * L)}{\left(\frac{(1320)\ (100)\ (0.7)\ (800)\ (0.85)}{(1-m)\ \ (1-5)}\right) \left(\frac{4.62012*10^{-10}}{}\right) \left(\frac{24}{1}\right)}$$

L =

Values of L for various values of m

m	(1-m)	L
0.81	0.19	
0.83	0.17	
0.85	0.15	
0.87	0.13	
0.89	0.11	
0.91	0.09	
0.93	0.07	
0.95	0.05	
0.97	0.03	
0.99	0.01	

Ref. Graph 1

L (Pond Length)

Vs m (Moisture Content)

APPENDIX 3

Estimated Peat Losses

525 ft^3/acre/3 months

i.e. 2100 ft^3/acre/year at 95% moisture content

$= \frac{2100}{20}$ ft^3/ at 0% moisutre content

$= \frac{100}{45} \left(\frac{2100}{20}\right)$ ft^3 at 55% moisutre content.

Density of peat at 55% M.C. = 18 lbs/ft^3 i.e. 2204 lbs = IT.

Therefore $\left(\frac{100}{45}\right) \left(\frac{2100}{20}\right) \left(\frac{18}{2204}\right)$ = 1.905 tonnes/acre/year

Total milled peat production area = 80,000 acres.

Therefore (80,000) * (1.905) = 152,000 T milled peat at 55% M.C. lost every year.

Assuming average lifespan for all milled peat bogs = 20 years

Total losses = 152,000 * 20
= 3,040,000 tonnes at 55% M.C. from all milled peat areas in 20 years.

APPENDIX 4

Implications of Findings of Laboratoire Central D'Hydraulique de France

Continutity Equation

(Flow Rate) = (cross sectional) * (Mean Flow)
(Area Flow) (Velocity)

Normal flow conditions : Mean Velocity flow O/F = 1.25 m/s
Heavy flow conditions : Mean Velocity flow O/F = 2.00 m/s
Hence: for normal conditions and efficiency:

$$\frac{\text{Cross Sectional Area Flow Trapping System}}{\text{Cross Sectional Area Flow O/F}} = \frac{1.25}{0.15} = 8.3$$

For Heavy Flow Conditions and Efficiency

$$\frac{\text{Cross Sectional Area Flow Trapping System}}{\text{Cross Sectional Area Flow O/F}} = \frac{2.00}{0.15} = 13.3$$

For 25 ft. wide pond with depth of flow = 6 inches
i.e. cross sectional area flow pond = 12.5 ft^2.

During normal conditions and efficiency
max. cross sectional area flow O/F $= \frac{12.5}{8.3} = 1.5\ ft^2$

For large O/F or small river with flow
Dimensions 8 ft * 1 ft. trapping system with
flow depth = 1 ft efficient only when

Width of flow in trapping system $= 8 \left(\frac{1.25}{0.15}\right) = 66$ ft.

APPENDIX 5

Protection of Silt Ponds from Flooding

Ref. Figure 1:

In the case of the unprotected system settled peat particles are resuspended and settle on surrounding land. The problem may be solved by providing flood embankments with pond outlet piped underneath and fitted with a simple flap valve. The rise in water level upstream of the embankment is caused solely by runoff. No additional flooding is caused upstream of the embankment since if hydrostatic pressure upstream of the embankment becomes greater than the hydrostatic pressure downstream a flow will take place through valve until hydrostatic pressures balance. Any resuspension and subsequent settling of peat particles takes place within the area surrounded by embankment. A valve in the form of a hinged lid would suffice requiring virtually no maintenance.

APPENDIX 6

Bypassing

There are five methods to be considered:-

1. Surge storage - I.L. storage inlet = I.L. pond inlet
2. " " - I.L. storage inlet I.L. pond inlet
3. Bypassing - I.L. Bypass inlet I.L. pond inlet
4. Bypassing - I.L. Bypass inlet I.L. pond inlet
5. Bypassing - Small diam. pond inlet pipe to restrict heavy flows by causing backup.

Considering 1 and 2 : Storage capacity required excessive. Solutions 1 and 2 impracticable.

Considering 3 : During normal conditions the flow would be via the pipe with the lower I.L. and hence through trapping system. During periods of heavy rainfall the flow would be partly through the pipe with lower I.L. and partly through the pipe with the higher invert level.

This system is not suitable because (a) during periods of heavy flow the cross sectional area of flow passing through pond inlet pipe may be equal to cross sectional area flow during normal conditions but head and consequently velocity is greater and hence danger of resuspending settled peat particles not reduced to degree required.

(b) The relative invert levels involved would be critical. The very nature of the bog does not lend itself to this type of technology.

Considering 4:	This method would involve the installation of a bypass pipe/weir the invert level of which would be equal to that of the pond inlet pipe. During normal flow conditions the bypass weir/pipe would be shut off. During heavy rainfall the bypass weir/pipe would be open and the inlet pipe to pond shut. This method although not automatic is practicable.
Considering 5:	The use of small diameter pipes under bog conditions is not practical due to blockages.

APPENDIX 7

Provision of Walls in Silt Ponds

Fig. 2 (a) shows the effect on the velocity pattern through pond due to presence of wall. It can be clearly seen that the presence of a wall at the inlet is of advantage in producing uniform flow velocity across the full width of pond while not interfering with the flow rate and consequently providing greater pond efficiency and off-setting the onset of channeling.

Fig. 2 (b) shows how quiescent conditions may be maintained during high flow conditions due to presence of walls.

Fig. 2 (c) shows how cleaning of pond by pumping can be achieved in cases where part of the pond is out of reach (pump capability wise) of area onto which sludge is to be pumped.

APPENDIX 8

Stability of Silt PonJ Excavation

Fig. 3 (a) shows the result of excessive excavating and reason for failure.

Fig. 3 (b) shows stability diagram for the case of a water or sludge filled pond.

It should be noted that if flow through pond is stopped during cleaning and pond completely emptied (sludge and water) that failure may result.

APPENDIX 9

Number of years before silt pond spoil rehandling essential

Max. allowable cross sectional area spoil = A

$$A = 45 * 6 = 270 \text{ ft}^2$$

Vol Sludge to be removed from pond/year/acre

$$= 525 * 4 = 2100 \text{ ft}^3$$

Moisture Content Sludge = 95%

Specific Gravity Dry Peat Particles = 1.0

Vol. spoil at 0% M.C. accumulating/year/acre = 2100 * (1-0.95)

= 105 ft^3 @ 10% M.C.

Moisture Content Spoil = 70%

Vol. spoil @ 70% M.C. accumulated/year/acre $= 105 * \left(\frac{100}{30}\right)$

= 350 ft^3 @ 70% M.C.

Length available for deposition of spoil/acre $= \left(\frac{150}{25}\right)*2$

Cross sectional area spoil @ 70% M.C./year/acre $= \frac{350}{12} *2$

$= 58.32 \text{ ft}^2$

therefore number of years before spoil rehandling essential $= \frac{270}{58.32}$

= 4.6 years

say 5 years.

Vol. of spoil and length over which it is to be distributed vary linearly with catchment size.

i.e. TIME AT WHICH SPOIL REHANDLING ESSENTIAL IS SAME FOR ALL CATCHMENT AREAS = 5 YEARS.

APPENDIX 10

Hymac Hours (HHrs) Required for Pond Cleaning, Spoil Rehandling and Initial Excavation

Rate of Excavation 30 ft^3/min. @ 75% efficiency

= 1350 ft^3/hr.

Time to clean 100 acre pond/year = $\frac{(525)\ (100)\ (4)}{(1350)}$

= 156 HHrs

Time to rehandle spoil - 100 acre pond/year = $\frac{(100)\ (350)}{1350}$

= 25.92 HHrs/year

= 130 HHrs/5 years

Time for initial excavation 100 acre pond assuming overall depth = 7 ft. = $\frac{(525)\ (2)\ (100)}{1350}$

= 78 HHrs.

APPENDIX 11

Sludge Pump Hours (SPHrs) Required/Acre/Year

Quantity to be pumped/acre/year $= (525)^4$

$= 2100\ ft^3$

Spec. Pumping Rate = 780 IMPG.P.M. @ Total Head = 50 ft.

Pumping Rate = 780 G.P.M. @ 50% Efficiency

$= 7{,}511\ ft^3/hr.$ @ 50% Efficiency

$= 3{,}756\ ft^3/hr.$

Time to clean 100 acre pond/year $= \frac{(525)\ (4)\ (100)}{3{,}756}$

= 74 SPHrs

APPENDIX 12

Ratio Hymac Hours -- Sludge Pump Hours Required for Maintenance

Hymac Cleaning Rate = 1350 ft^3/Hr.

Sludge Pump Cleaning Rate = 3756 ft^3/Hr.

$$\text{Ratio} = \frac{3756}{1350} = 2.78$$

APPENDIX 13

Area over which spoil from sludge pump to be spread

Ditching Hours Required

Vol. sludge produced per acre/year = (525) (4)

= 2100 ft^3

Initial depth sludge after pumping = 3 ins.

Area covered by sludge from one acre/cleaning = $\left(\frac{2100}{4}\right)(4)$

= 2100 ft^2

If area for sludge spreading square : 2100 ft^2 = 46 * 46 ft.
Area in which ditching necessary after pond cleaning
- 100 acre catchment 460 * 460 ft.

Drains @ 45 ft. centres
Total length ditching/cleaning/100 acres = 460 * 11

= 5060 ft.

Ditching rate = 300 ft./Hr @ 50% efficiency

= 150 ft/Hr.

Ditching Hours (DHrs)/Cleaning/100 acres = $\left(\frac{5060}{150}\right)$

= 33.7 DHrs

Ditching Hours required/year/100 acres = 135 DHrs

Ratio spreading area to catchment area = $\frac{210,000}{4,356,000}$ = 4.8%

APPENDIX 14

Quantity of Peat Recycled by Sludge Pumping

Quantity of Sludge Pumped per 100 acres/year

$$= (100)\ (4)\ (525)\ ft^3 \ @\ 95\%\ M.C.$$

$$= \frac{(100)\ (4)\ (525)}{20}\ ft^3 \ @\ 0\%\ M.C.$$

$$= \frac{(100)}{(45)}\ \frac{(100)\ (4)\ (525)}{20}\ ft^3 \ @\ 55\%\ M.C.$$

$$= 23,333\ ft^3 \ @\ 55\%\ M.C.$$

Density of peat @ 55% M.C. = 18 lbs/ft^3

(2204 lbs = 1 tonne)

$$23,333\ ft^3 \ @\ 55\%\ M.C. = \left(\frac{18}{2204}\right)\ (23,333) = 190.5 \text{ tonnes}$$

i.e. 190.5 tonnes peat @ 55% M.C. from 100 acres/year.

APPENDIX 15

Area Required for Lagoon - General

Ref. Figure 5

For Cost comparison area required for
Lagoon = Area required lagoon less
area required for ponds

A = Surface area lagoon + Plan area embankment
- area pond system.

= (S.A.) + (34). 1 - 6(25 + 60 + 90)*Catchment Area

Catchment Area = x

A = (S.A.) + (34)(1) - (1050) (x)

Area required for Lagoons to Method Cl

Area = (Surface Area) + (Emb. Length) (34) - 1050 x

100 acres:

$$S.A. = \frac{(8)\ (525)\ (4)\ (100)}{10} = 168{,}000$$

L = (S.A.) (4)
= (409.87)* (4)
= 1639

A = (168,000) + (1,639) (34) - (1050) (100)
= 223,726 - 105,000

Area required for lagoon area required for ponds

Therefore area to be acquired/designated = zero.

300 acres:

A = (S.A.) + L.34 - 1050 x

$$(S.A.) = \frac{(12)\ (525)\ (4)\ (300)}{10}$$

= 756,000

L = (756,000) (4)

= 3,477

A = (756,000) + (3,477) (34) - (1,050) (300)

= 874,218 - 315,000

Area required for Lagoon area required for ponds

Therefore area to be acquired/designated = zero

600 acres:

A = (S.A.) + L.34 - 1050 x

$$S.A. = \frac{(12)\ (525)\ (4)\ (600)}{10}$$

= 1,512,000

L = (1,512,000) (4)

L = 4918.0

A = 1,512,000 + (4,918) (34) - (1,050) (600)

A = 1,049,212

APPENDIX 16

Number of years spoil to produce embankment to serve remaining bog lifespan

Lifespan	=	20 years
Catchment	=	x acres
No. years Spoil	=	y

Quantity of spoil available for embankment construction after y years from x acre catchment $= \frac{(350)(x)(y)}{1}$

Cross sectional area embankment $= 240 \text{ ft}^2$

Length embankment from x acres after y years constructed from available spoil $= \frac{350\,xy}{240}$

$= \frac{3}{2}\,xy$

If embankment square, capacity $= \left(\frac{\frac{3}{2}\,xy}{4}\right)^2 * 10$

Capacity required for (20-y) years $= (20-y)\,(4)\,(525)\,(x)$

$= (2100)\,(20-y)\,(x)$

Compatability: $(2100)\,(20-y)\,(x) = \left(\frac{3xy}{8}\right)^2 * 10$

$$42{,}000\,x - 2100\,yx = \frac{(9)\,(10)}{(64)}\,x^2\,y^2$$

$$9x^2\,y^2 + 13{,}440\,xy - 268{,}800\,x = 0.$$

For 100 acres:

$x = 100; \quad y = ?$

$9\,x^2y^2 + 13{,}440\,xy - 268{,}800x = 0$

$90{,}000\,y^2 + 1{,}344{,}000\,y - 26{,}880{,}000 = 0$

$90\,y^2 + 1{,}344\,y - 26{,}880 = 0$

$$y = \left(\frac{(-1344) \pm (1344)^2 + 4\,(90)\,(26{,}880)}{180} \right)$$

$$= \left(\frac{-\,1344 \pm 3388}{180} \right)$$

$$= 11.35$$

For 300 Acres:

$x = 300; \; y = ?$

$9\,x^2\,y^2 + 13{,}440\,xy - 268{,}800\,x = 0$

$810{,}000\,y^2 + 4{,}032{,}000\,y - 80{,}640{,}000 = 0$

$810\,y^2 + 4032\,y - 80{,}640 = 0$

$$y = \left(\frac{-\,4032 \pm (4032)^2 + 4(810)\,(80{,}640)}{1620} \right.$$

$$y = 7.79$$

For 600 acres:

$9\,x^2\,y^2 + 13{,}440\,xy - 268{,}800\,x = 0$

$1620\,y^2 + 8064\,y - 161{,}280 = 0$

$$y = \frac{(-8064 \pm (8064)^2 + 4(1620)\,(161{,}280)}{(3240}$$

$y = 7.78$ years

Optimal year for completion of embankment:

100 acres	-	12th
300 acres	-	8th
600 acres	-	8th

<u>Quantity Material</u>:

100 acres - (100) (12) (350) = 420,000 ft^3
300 acres - (300) (8) (350) = 840,000 ft^3
600 acres - (600) (8) (350) =1,680,000 ft^3

Rate of Construction 675 ft^3/HHr.

Hymac Hours Required:

100 acres - $\frac{420,000}{675}$ = 622 HHrs

300 acres - $\frac{840,000}{675}$ = 1,244 HHrs

600 acres - $\frac{1,680,000}{675}$ = 2,488 HHrs

APPENDIX 17

Lagoon Construction:-

Cross sectional area embankment

$= 24 * 10 = 240\ ft^2$

Embankment length = L

Vol. material to embankment = (240) (L) ft^3

Lagoon capacity for 100 acres/year = (100) (525) (4)

= 21,000 ft^3

Average height embankment = 10 ft.

Rate of construction = $\frac{1350}{2}$ = 675 ft^3/HHr

Bottom width embankment = 34 ft.

Top width embankment = 14 ft. (to facilitate hymac/dozers)

Area required = surface area + (L) (34) - area required *Ref. 3.7 for ponds.

= S.A. + L.34 - 1050 Catchment Area.

Catchment (Acres)	Capacity (ft^3)	Surface Area (ft^3)	Square Dims. (ft x ft)	Embank. Length ft.	Embank. Material ft^3	Hymac Hours	Area (ft^2)	Area (Acres)	
100	1050000	105000	324 x 324	1296	311040	460	44064	1.01	5 year
300	3150000	315000	561 x 561	2244	538560	797	76296	1.75	
600	6300000	630000	793 x 793	3172	761280	1127	107848	2.47	Lagoon
100	2100000	210000	450 x 450	1800	432000	640	166200	3.81	10 year
300	6300000	630000	793 x 793	3172	761280	1128	422848	9.71	
600	12600000	1260000	1122 x1122	4488	1077120	1596	782592	17.96	Lagoon
100	4200000	420000	648 x 648	2592	622080	922	403128	9.25	20 year
300	12600000	1260000	1122 x1122	4488	1077120	1592	1097592	25.20	
600	25200000	2520000	1587 x1587	6348	1523520	2257	2105832	48.34	Lagoon

APPENDIX 18

Adjustment for Method A1, A2, A3, C1 for cases in which flood embankment necessary ref. Fig. ____.

Variation in Shannon at Blackwater Works approx. = 8½ ft.
Allowing 1½ ft. = difference G.G.L. to normal S.L. Shannon
Therefore 8 ft. high embankment gives 1 ft protection.

Cross sectional area embankment = 8 * 22 = 176 ft^2

If embankment to run three sides:-

for 100 acres - length = 1025 ft.
for 300 acres - length = 1755 ft.
for 600 acres - length = 2150 ft.

Volume material required and time to construct:-

100 acres	- 1025 * 176	= 180,400 ft^3	--	267 HHrs
300 "	- 1755 * 176	= 308,880 ft^3	--	458 HHrs
600 "	- 2150 * 176	= 378,400 ft^3	--	560 HHrs

APPENDIX 19

Cost Machine Hours

Hymac Hour:

Internal hireage rate Hymac	=	9.50
Cost of 1 man-hour	=	10.00
Cost of fuel (consumption @ 9 litres/hour)	=	3.56
Total cost 1 Hymac hour	=	23.06

Sludge Pump Hour:

Internal hireage rate pump	=	2.42
Internal hireage rate tractor	=	1.50
Cost of 3 man hours	=	30.00
Cost of fuel to tractor (consumption @ 10 litres/hour)	=	3.96
Total cost 1 sludge pump Hr		37.88

Ditcher Hour:

Internal hireage rate ditcher (Merri)	=	1.14
Internal hireage rate tractor	=	1.50
Cost of 1 man-hour	=	10.00
Cost of fuel to tractor	=	3.96
Total cost 1 ditcher hour		16.60

Land Purchase/acre approximate average = £1,500.00

Profit/Tonne Peat @ 55% M.C. approximately = £3.00

APPENDIX 20

Cost of Pump Installation and Maintenance

The following cost estimates for provision of pumps at treatment sites are based on most accurate figures available to date.

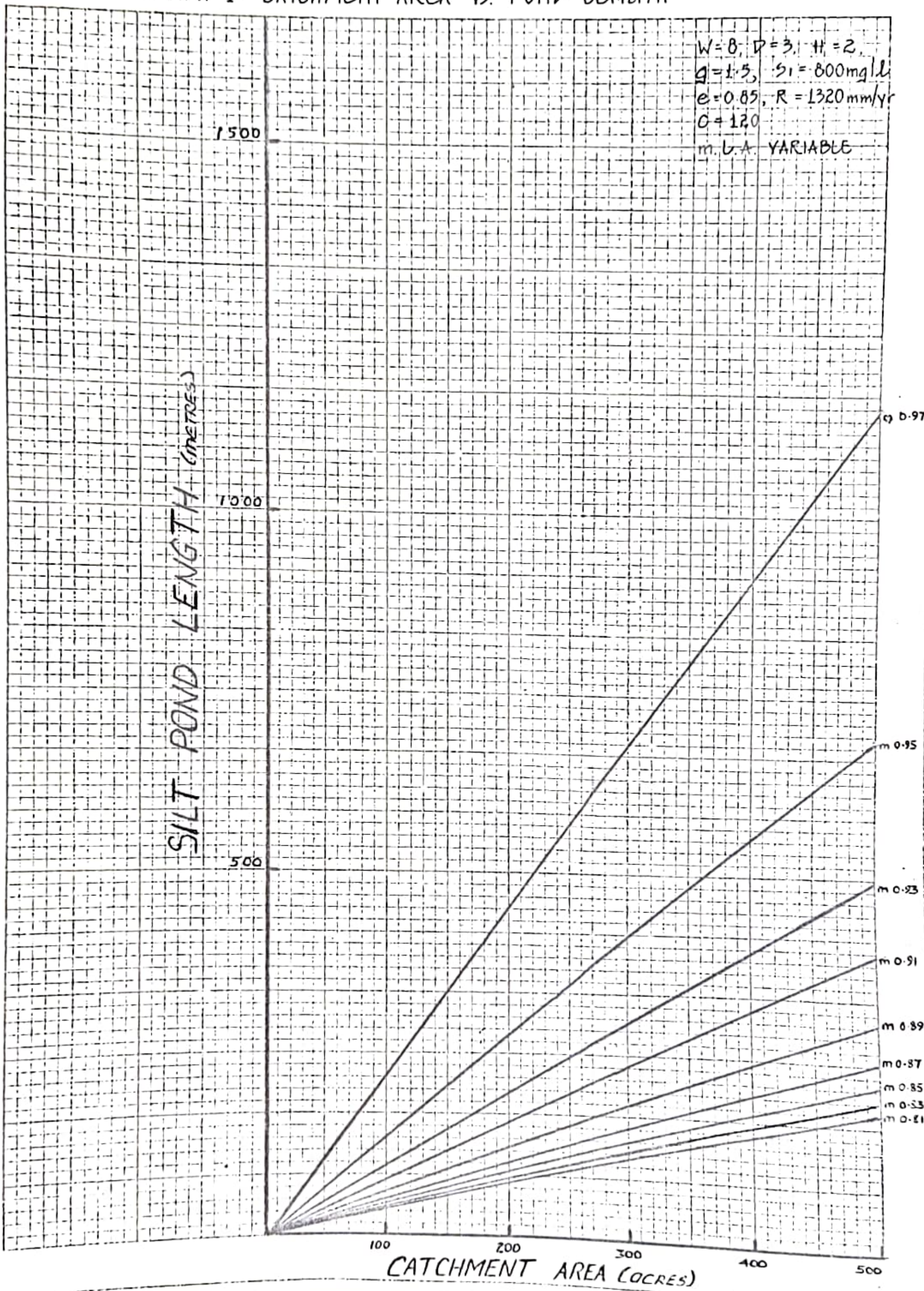
Inaccuracies may arise due to the following:

1. Pump may be necessary for bog drainage purposes now or at sometime in the future; the cost is attributed to silt control.

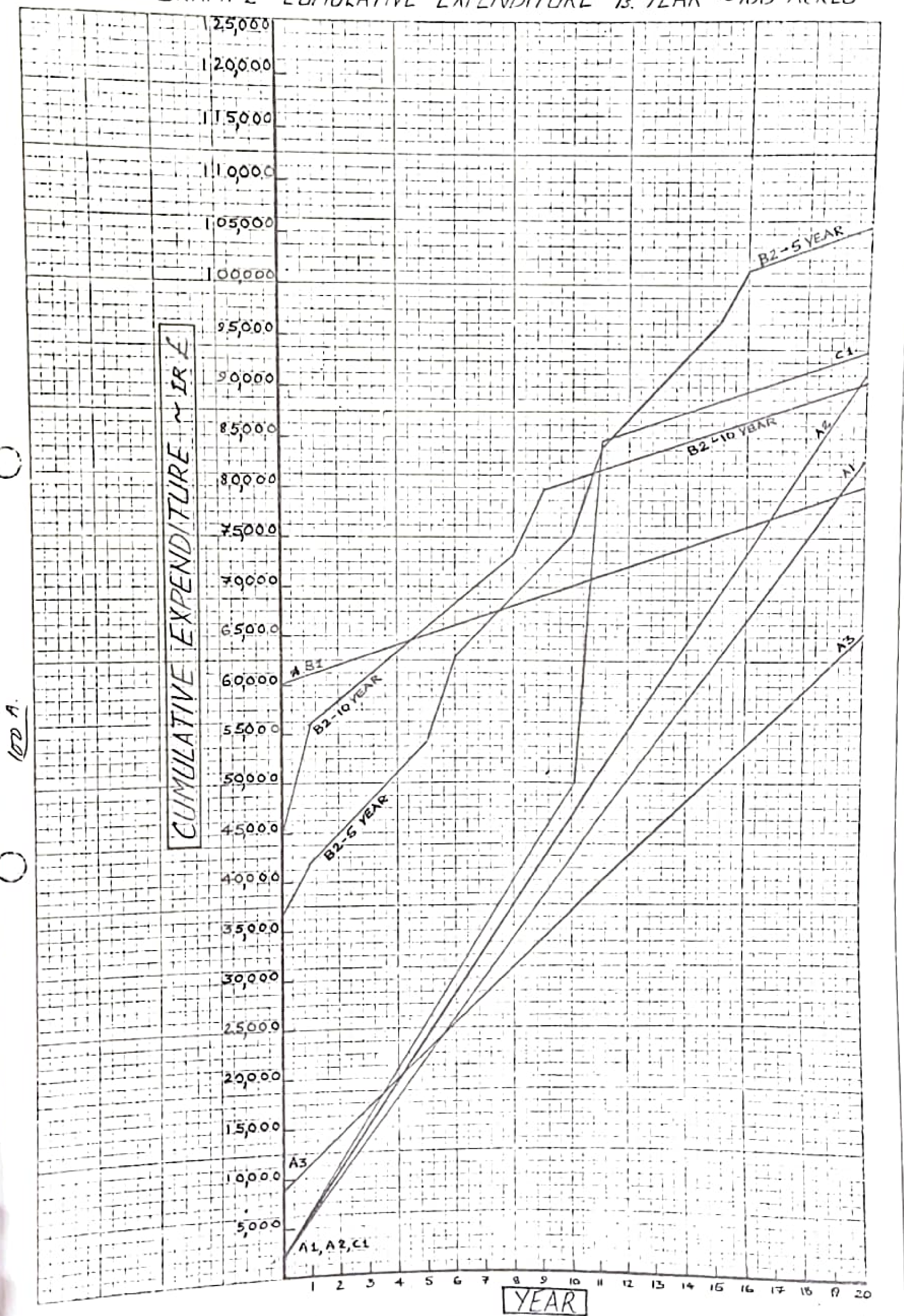
2. The distance over which power lines must be provided for each pump is taken as 1½ miles.

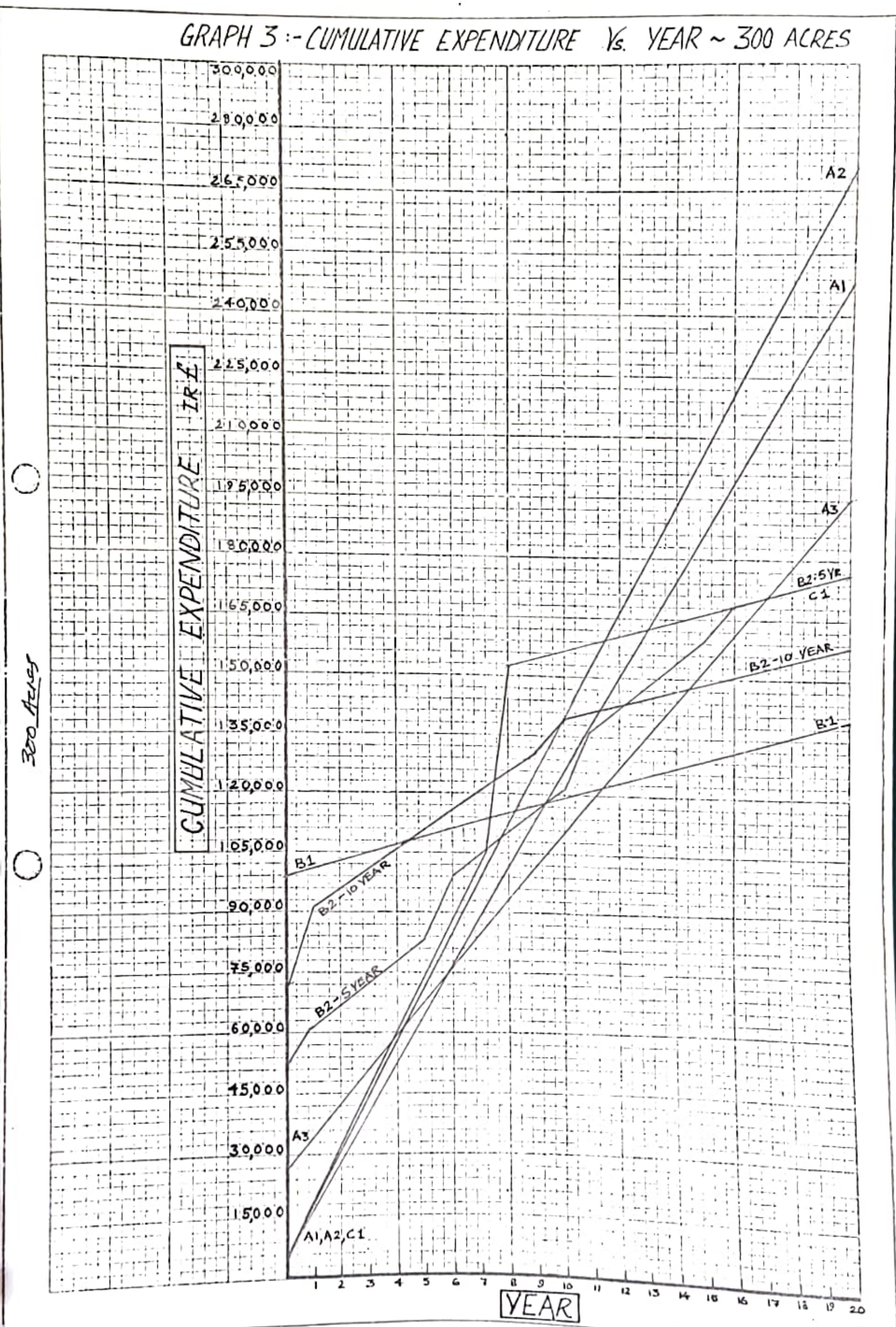
	Catchment (acres)		
	100	300	600
Power Line 1½ miles @ £10,000/mile	15,000	15,000	15,000
Pump Cost	6,000	10,000	22,000
Installation:			
Materials	2,000	3,500	5,000
Labour	2,000	3,500	5,000
Total :	£25,000	£32,000	£47,000
Repositioning	4,000	7,000	10,000
Power Units (P.A.)	1,000	2,000	4,500

GRAPH 1:- CATCHMENT AREA Vs. POND LENGTH



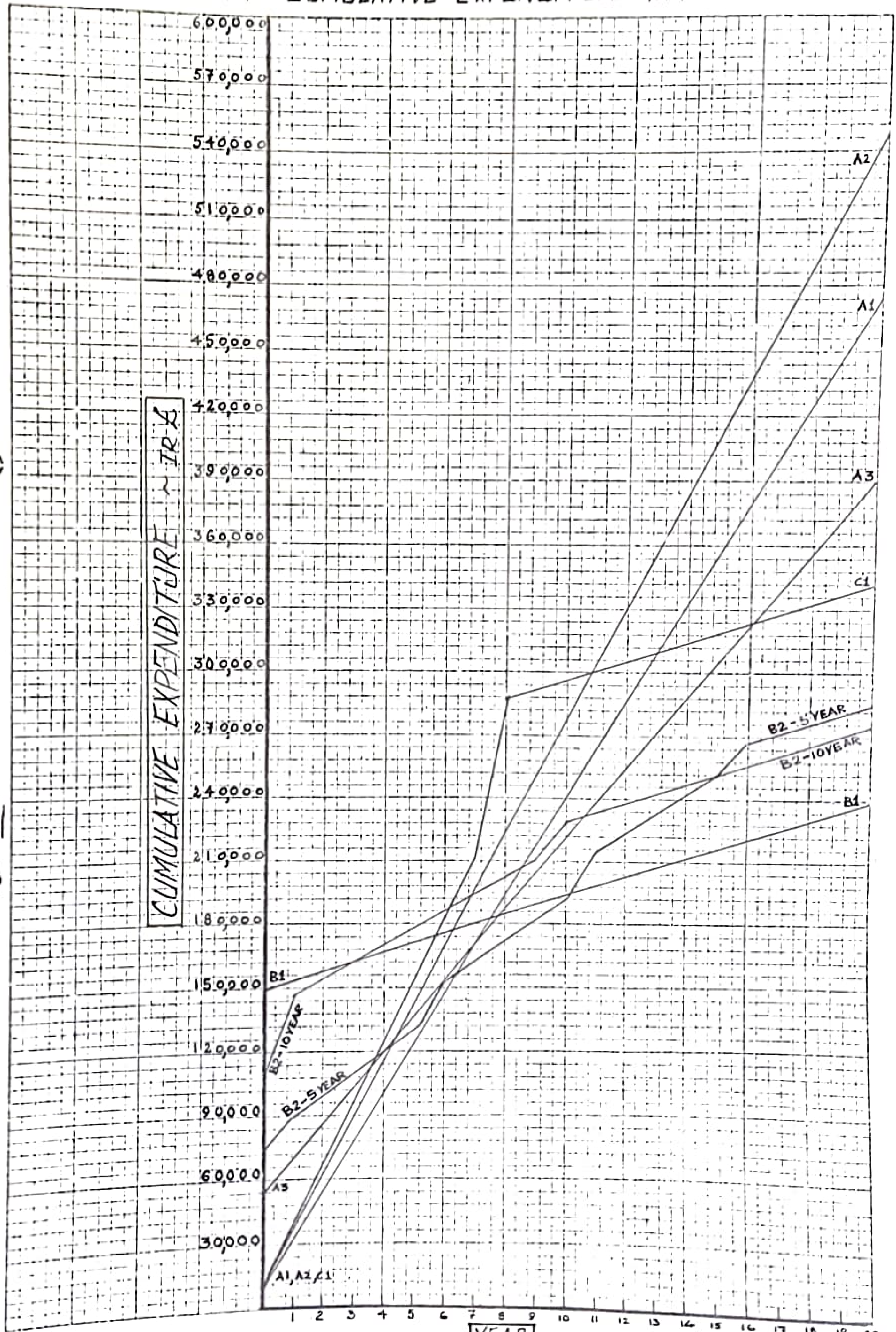
GRAPH 2:- CUMULATIVE EXPENDITURE Vs. YEAR ~ 100 ACRES





GRAPH 3 :- CUMULATIVE EXPENDITURE Vs. YEAR ~ 300 ACRES
CUMULATIVE EXPENDITURE IR £
YEAR
300,000
280,000
265,000
255,000
240,000
225,000
210,000
195,000
180,000
165,000
150,000
135,000
120,000
105,000
90,000
75,000
60,000
45,000
30,000
15,000
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
A2
A1
A3
B2:5YR
C1
B2-10 YEAR
B1
B2-5YEAR
A1,A2,C1
300 Acres

GRAPH 4 :- CUMULATIVE EXPENDITURE Vs. YEAR ~ 600 ACRES



GRAPH 5:- CUMULATIVE EXPENDITURE V. YEAR ~ BLACKWATER WORKS (EXC. CORNAFULLA, DRUMLOSH)

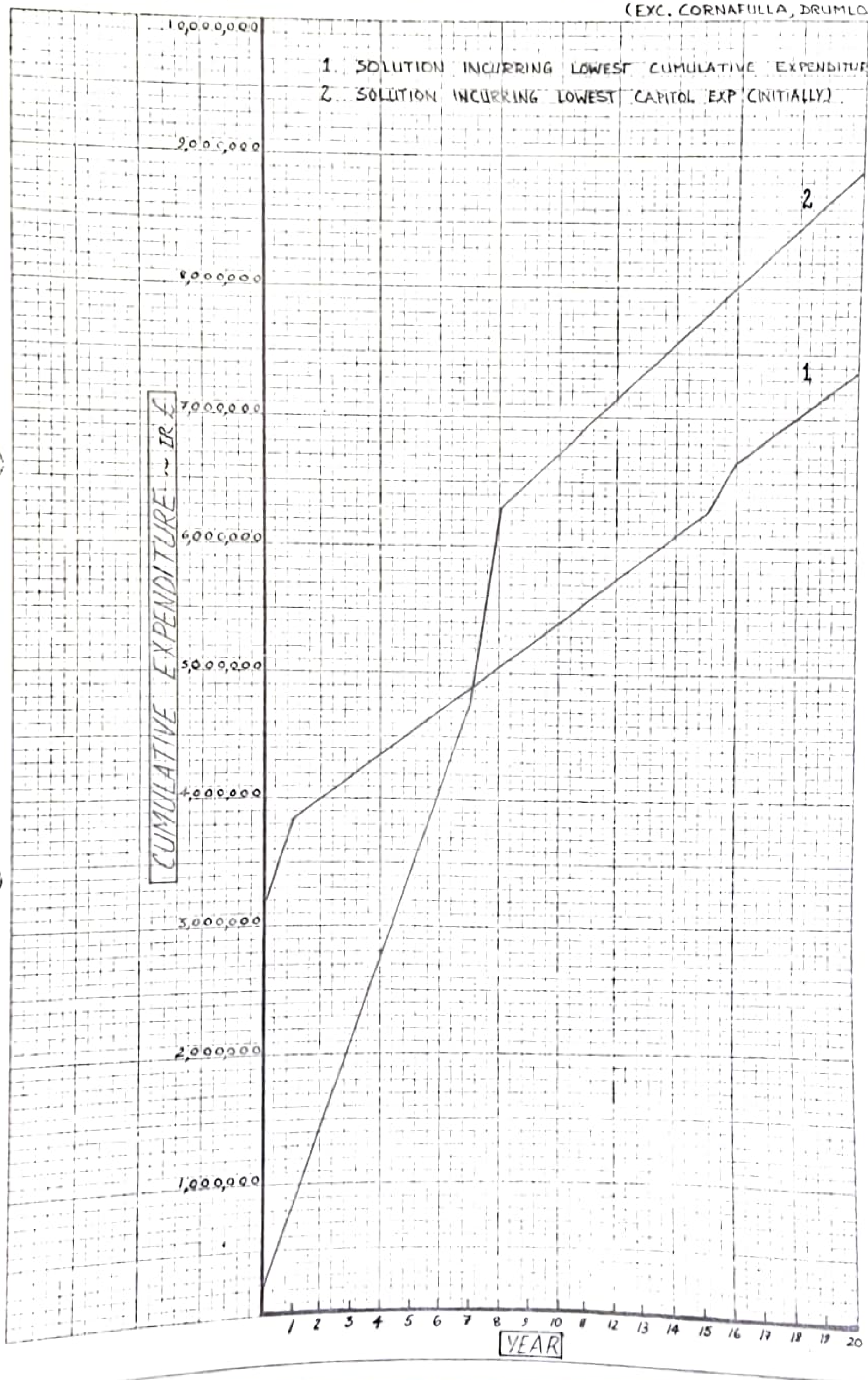


FIG. 1 PROTECTION OF TREATMENT SYSTEM FROM FLOODS

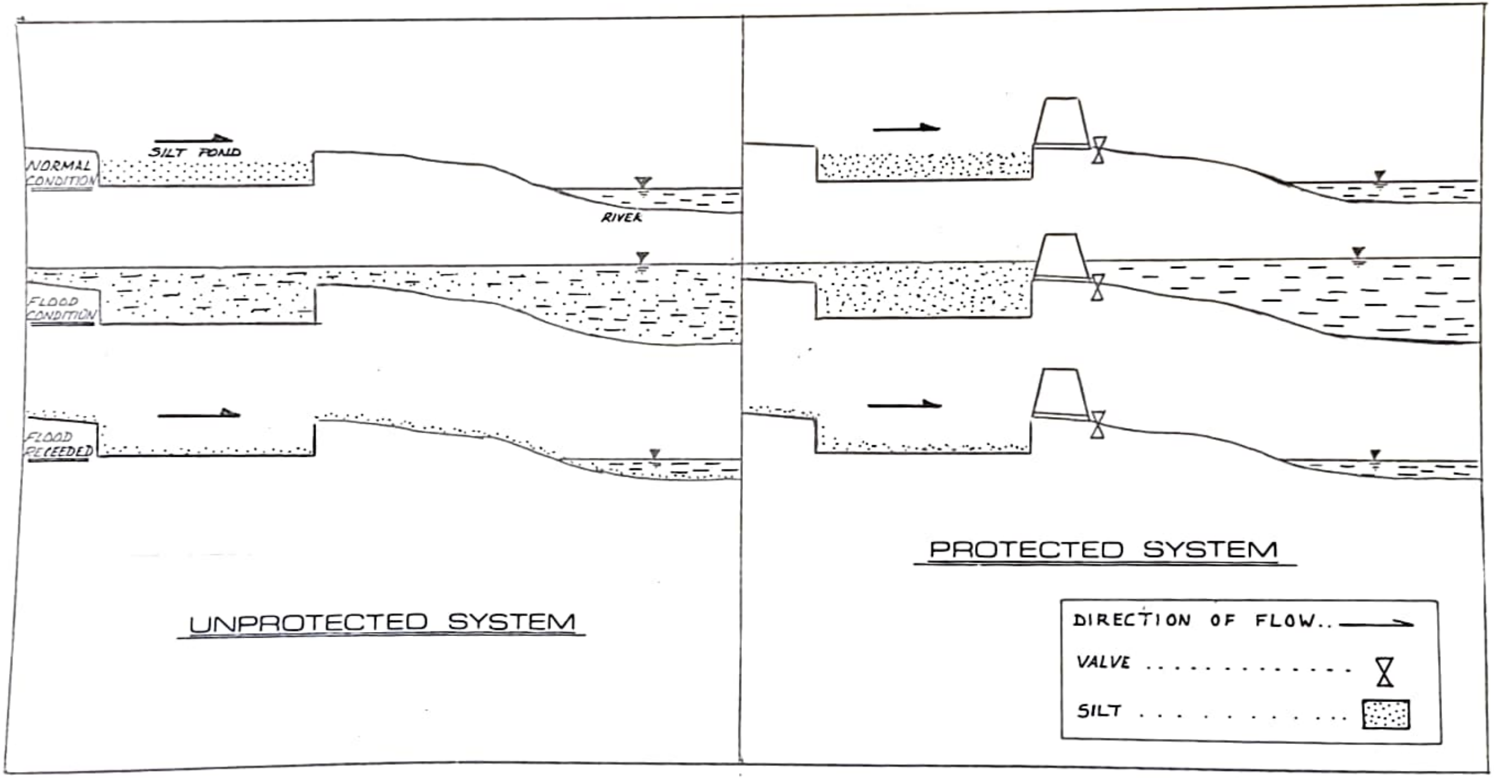


FIG. 2 PROVISION OF WALLS IN SILT PONDS

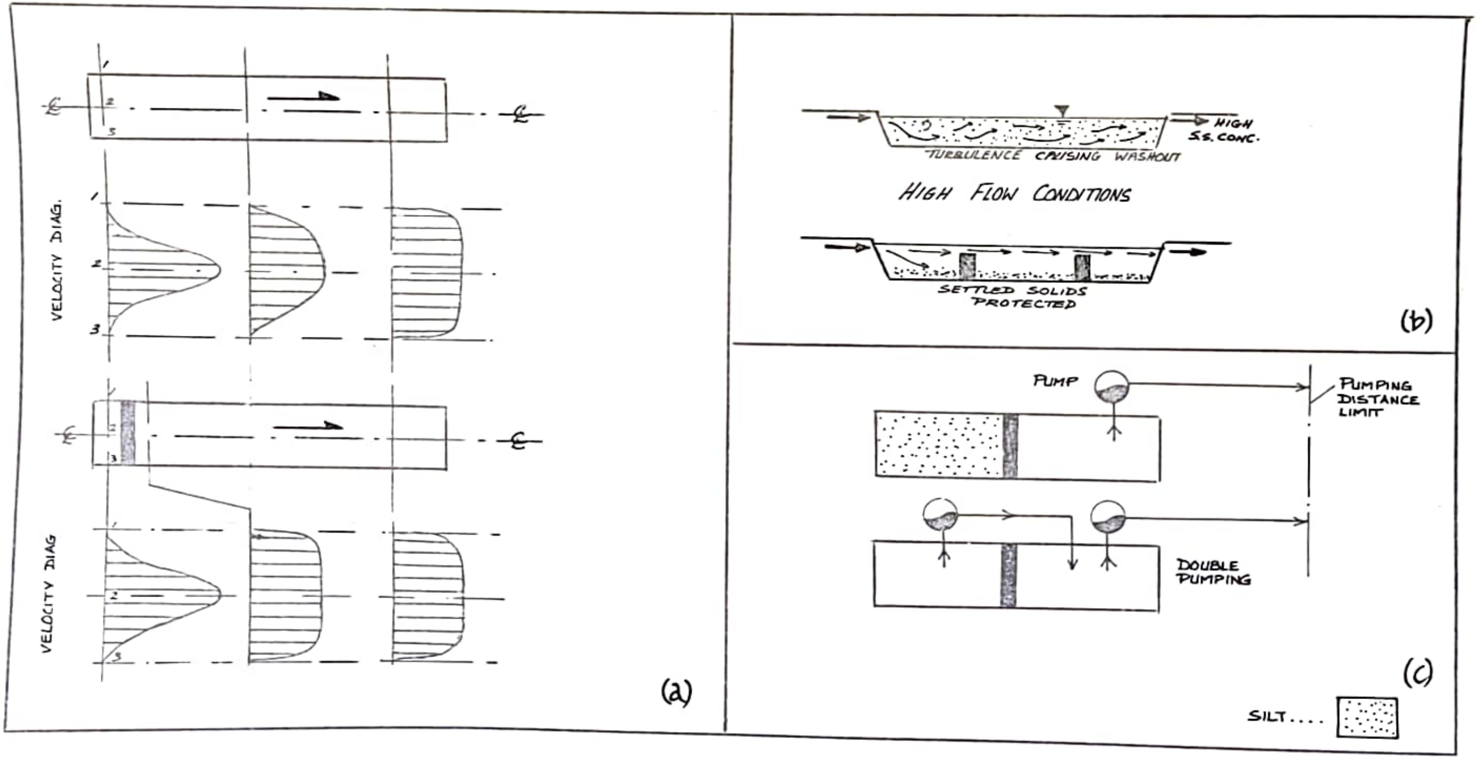


FIG. 3 STABILITY OF POND EXCAVATION

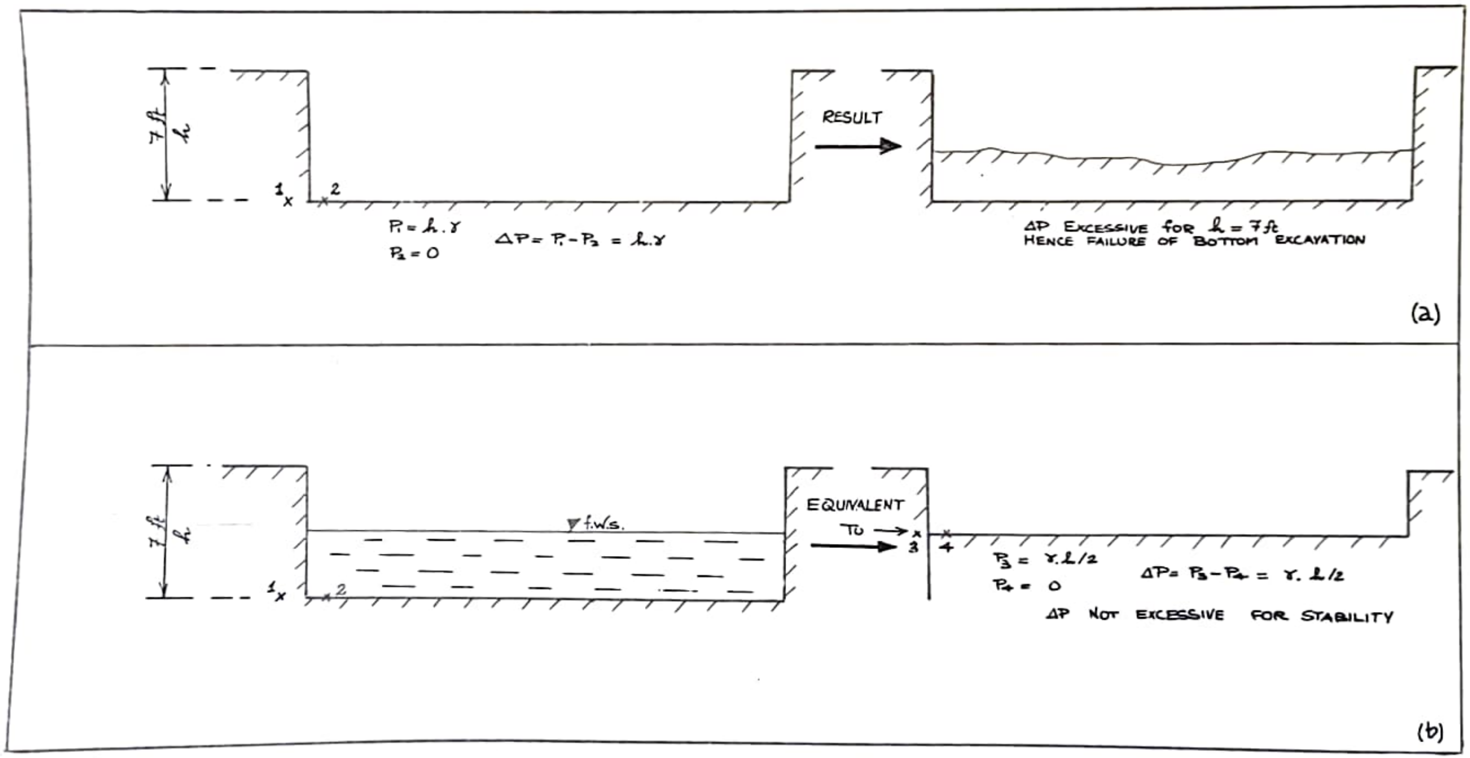
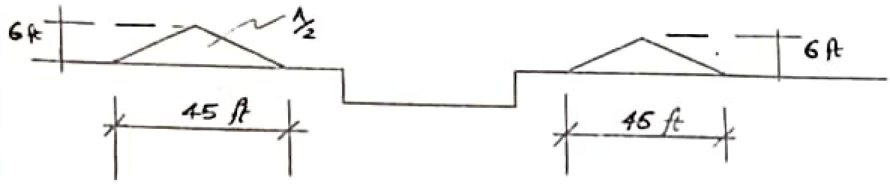


FIG. 4 MAX. ALLOWABLE X-SECTIONAL AREA SPOIL



$A = 6 \times 45 = 270\ ft^2$

CATCHMENT AREA = x acres

AREA abcd = $1050x\ ft^2$ = AREA REQUIRED FOR SILT POND

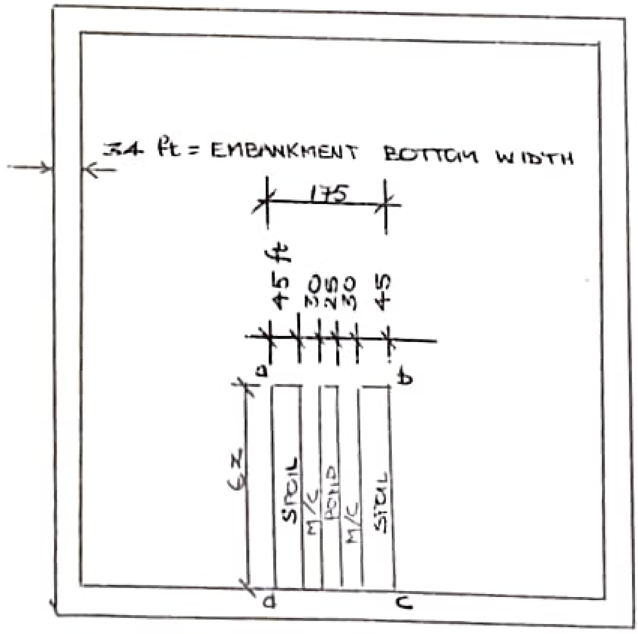


FIG. 5 AREA REQUIRED FOR LAGOON

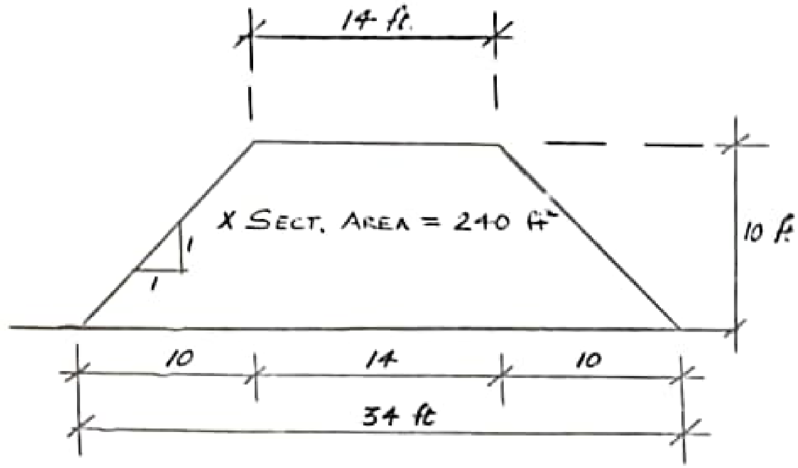


FIG. 6 CROSS SECTIONAL AREA – LAGOON EMBANKMENT

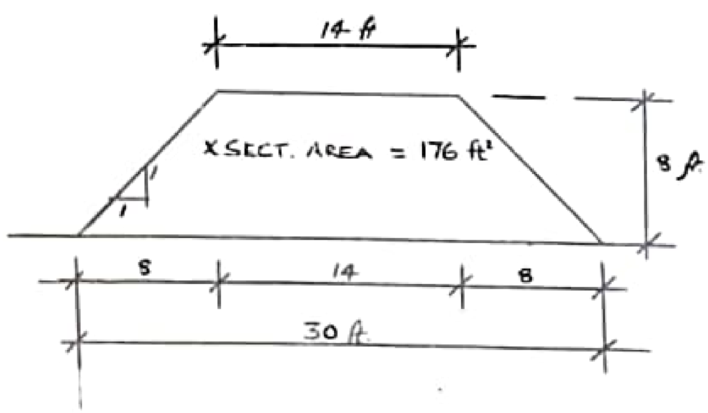


FIG. 7 CROSS SECTIONAL AREA – FLOOD EMBANKMENT