LARGE LIFT PLANTS - PERFORMANCE

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ABSTRACT

Large lift irrigation plants (LIPs) are a recent development in parts of Gujarat (India). These are commonly sited on old tanks, some on intermittent streams and canals. Water is lifted to a high point of command through a riser and then led by gravity through pipes to various distribution chambers.

A need had arisen to examine their performance. Accordingly, a discrete, deterministic mathematical model of a typical LIP has been made. The system is viewed as a negative feedback, automatic (on/off) control.

Curve number method is used to compute runoff and moisture balance method, for effective rainfall. Simulations using actual (historical) daily rainfall were carried out to determine irrigation needed and possible. Long term value of latter is taken as a more realistic index of system capability than that originally projected. Actual performance is compared with it.

Possible additional uses of simulation in design and operations are highlighted.

Key Words

Lift Irrigation, Feedback Control, Mathematical Model, Simulation

INTRODUCTION

Large lift irrigation plants (LIPs) are a recent development in Panchmahal, a drought-prone district of Gujarat (India). These are commonly sited on old tanks, some on intermittent streams and canals. Water is lifted to a high point of command through a riser and then led by gravity through pipes to various distribution chambers (Fig 1). Many LIPs work large heads, and are equipped with large power plants. Nearly a hundred are in operation. More are coming up.

A need had arisen to examine their performance. In order to determine its 'true' capability it appeared appropriate to use simulation. Accordingly, a deterministic mathematical model has been made of a typical LIP. The system has been viewed as a negative feedback, automatic (on/off) control (Fig 2).

Hydrological aspects of catchment, tank and command are briefly described. It is followed by modelling of a typical LIP. Finally, working of a existing LIP is simulated. Besides performance evaluation, possible additional uses of the model are highlighted.

Catchment

Catchment is a dynamic entity. Curve number method is employed to compute runoff from day's rainfall. Details of this method can be seen in USDA (1976). A brief outline is given below.

Runoff from day's rainfall is given by

$$R = \frac{(P-0.2*S)^2}{(P-0.2*S) + S} \qquad P>0.2S \qquad (1)$$

where

R runoff (L),

P rainfall (L),

S maximum potential retention plus initial abstraction (L)

S depends on cover, treatment, soil type, land use, hydrological properties, and antecedent moisture condition (AMC). Soil conservation service (SCS) of the US has grouped AMC conditions into three (I, II and III) using cumulative rainfall of past five days (Table 1). Soils are grouped into four types (A, B, C and D), and each into three hydrological condition- types (good, fair and poor).

Given the soil type, hydrological condition and AMC condition one can pick the curve number (CN) from tables. Values of S can then be obtained by

$$S = \frac{1000}{CN} - 10 \qquad (2)$$

CN and hence S is computed anew each day.

Tank

Rainfall over its own water spread area and runoff from catchment is stored in the tank. Tank may also gain water from nearby aquifers when the water table is high. Considering the geological formations and terrain of Panchmahal this possibility will presently be ignored. Charges on stored water include irrigation, seepage and evaporation (eqn 10, 7 and 6).

Evaporation

Pan evaporation data from a location in Panchmahal, near the site of LIPs, has been used to estimate evaporation. It is given in Table 2.

Seepage

Actual seepage measurements from old tanks of this area are not available. Dewivedi and Sarkar (1982) and Grewal *et al* (1982) have reported some measurements. Grewal reported monthly average seepage for some soil type and various heads using 3 to 5 year data. Seepage rates inferred from his data would appear to be between 0.0007 to 0.004 cum/sq m -day of wetted area. Panchmahal is hard rock area. Such rocks have low primary porosity. In absence of actual measurement we will take seepage rates reported by Grewal.

Command

Available soil water, Z(t), in root zone is the variable of interest. It is depleted by evapo-transpiration and deep percolation and replenished by precipitation, irrigation and transport through capillary. Z should be maintained above moisture stress limit (MSL) to avoid stress and yield loss.

Evapo-transpiration

Evapo-transpiration is computed by procedure outlined by Doorenbos and Kassam (1979). The actual evapo-transpiration (ETa) equals maximum evapo-transpiration (ETm) if the water availability is not limited. When, available water has depleted by a factor, called soil water depletion factor (p), the ETa declines below ETm. It is then directly proportional to Z(t) as shown later in eqn (11b). ETm is determined from free water surface evaporation (ETo) modified by crop factor (kc). The ETo in turn is determined from pan evaporation data. The crop factor is shown in Table (3) and depletion factor in Table (4).

Capillary water

The capillary rise could be upto 0.66 m in case of fine sand and 3.3 m in clayey soils (Baver 1942). Water table in Panchmahal lies 3 to 9 m deep. Presently the contribution of capillaries is, therefore, neglected.

Effective rainfall

Daily soil moisture balance method outlined by Dastane (1974) is used to compute effective rainfall. Rain water first meets the root zone deficit. Excess rain water is lost as runoff, percolation etc (Eqn 9).

Evaporation from bare soil

For short periods between harvest and planting of next crop, fields remain bare. Usually it is about one month between kharif (rainy season, mid June to Oct.) and rabi (winter, Nov. to March) and two weeks between rabi and summer (April- mid June) crop. Estimates of evaporation are necessary for these periods.

When soil surface is within capillary fringe, evaporation is known to vary with the moisture content and texture of soil. It virtually stops when water table falls below the limit of capillary rise. If the surface is saturated, evaporation is reported to be about 75% to 90% of the free water surface evaporation for clayey soils and close to free water for sandy soils (Lee 1942).

Capillary fringe has been considered too distant to contribute moisture to the root zone. Nonetheless, soil will be moist due to moisture left over from prior irrigations or precipitation. Thus, estimation of evaporation from bare (moist) soil is required.

A provisional equation is suggested

$$Eb = \frac{k.\ ETo.\ (Z(t) + PWP)}{(Sa + PWP)} \qquad (3)$$

$$\emptyset \qquad \text{if} \quad Z(t) = \emptyset$$

where

- Eb = evaporation from soil surface (L/T)
- Z(t) = available water per unit depth of root zone (L/L)
- Sa = maximum available soil water (L/L)
- PWP = moisture at permanent wilting point (L/L)
- k = rate coefficient, here taken to be Ø.9Ø
- ETo = free water surface evaporation (L/T)

Equation (3) states that evaporation will be high when moisture content is high and reduce with the fall in moisture. It should be stated that this relationship has yet to be tested.

Irrigation

As stated, the system is viewed as a negative feedback automatic on/off control. Here, Z is (pretended to be) monitored and compared with prespecified MSL. When Z touches MSL, pump is turned on. It is switched off only when the root zone reaches field capacity. MSL changes with the stage of growth of plants.

Mathematical Model

Various elements will now be linked together to form a system.

Assumptions:

1. Transience in rainfall-runoff process is ignored. Similarly, spatial distribution of moisture in the root zone and time dimension is ignored.

2. Fields in the command are lumped. That is as if the command were fitted with sprinklers, all of which are turned on simultaneously. In reality irrigation is done on rotation, that is parts watered in a cyclic sequence. This assumption

will not make difference to the main objective here, namely determination of system capability.

3. Root depth constant; assumption is necessary as satisfactory models of root growth are not available. The assumption will in effect cause some over irrigation, especially in early phases of growth.

Recall also the simplifications already stated- contribution of capillary is ignored.

Let

t = time (days)

Ac = area of catchment (sq m)

Ao = cropped area (sq m)

Af = water spread area, at full supply level (FSL) (sq m)

As(Q) = water spread area of tank at storage Q (sq m)

Aw(Q) = wetted area at storage Q (sq m)
water spread and wetted area are derived from current volume of water

D = depth of root zone (m), constant

ETm(t) = maximum evapo-transpiration (m/day)

ETa(t) = actual evapo-transpiration (m/day)

Eb = evaporation from bare soil (m/day)

Ec = conveyance efficiency, taken here as 0.80

Ea = application efficiency, taken here as 0.60

E(t) = total evaporation from tank surface (cum/day)
(rate, e(t), from Table 2)

Ir = depth of water added to fields in a day, when irrigation is on (m/day)

kc(t) = crop factor (from Table 3)

p = soil water depletion factor (from Table 4)

P = daily rainfall (m/day) (from Table 8)

Q(t) = storage in the tank at time t (cum)

R = runoff from unit catchment area from day's rainfall (m/day), (from Eqn (1))

Re = effective rainfall (m/day)

Sa = maximum available soil water(m/m)

S = total seepage from tank (cum/day) (rate, s = 0.004 cum/sq m-day)

T = rain falling over the tank surface (cum/day)

Wp = volume of water pumped out in a day when irrigation is on (cum/day)

Z(t) = available soil water per unit depth of root zone (m/m)

Water balance in tank

$$Q(t+1) = Q(t) + R*Ac + T - E(t) - S - Wp \quad (4)$$

$$T = Af*P \quad (5)$$

$$E(t) = As(Q)*e(t) \quad (6)$$

$$S = Aw(Q)*s \quad (7)$$

Water balance in root zone

$$Z(t+1)*D = Z(t)*D + Re + Ir - ETa(t) \quad (8)$$

$$Re = ETa + (Sa - Z(t))*D \quad \text{if } P > ETa+(Sa-Z(t))*D \quad (9a)$$

$$P \quad \text{otherwise} \quad (9b)$$

$$Ir = Wp*Ec*Ea/Ao \quad (10)$$

$$ETa = ETm(t) \quad \text{if} \quad Z(t)*D > (1-p)*Sa*D \quad (11a)$$

$$\frac{ETm(t)*Z(t)*D}{(1-p)*Sa*D} \quad \text{if} \quad Z(t)*D < (1-p)*Sa*D \quad (11\ b)$$

$$\frac{k.\ ETo.\ (Z(t) + PWP)}{(Sa + PWP)} \quad \text{when bare} \quad (11\ c)$$

Moisture stress limit (MSL)

$$Z(t)*D = (1-p)*Sa*D.$$

In addition following conditions operate

Irrigation is turned on when Z(t)*D falls to MSL and remains on until Z(t)*D is raised to field capacity. Note that it is not really necessary that it be raised all the way to field capacity. Any thing between MSL and FC will do. Only it will lead to more frequent watering.

When storage reaches FSL, further inflow is discharged.

When storage touches lower water level (LWL), i.e. dead storage, pump is shut down; no irrigation is permitted even if there is demand.

Pump will not come on if fields are bare.

No evaporation from bare surface if Z(t)=Ø

The model is coded in BASIC. Figure 3 shows the flow diagram. Number of the equation used is indicated in the blocks.

Operating Characteristics- Shankarpura LIP

Working of one LIP, located in Shankarpura, will now be simulated to see irrigation needed and possible under different conditions of rainfall. Details of this LIP are given below

Catchment 1Ø.5Ø sq. km

Conditions in the area of study -shallow soils, hard rock subterrain- will suggest closeness to type C. Type C, relates to soils that have high runoff, and low infiltration. Cover in catchment is a composite one -parts cropped, parts thinly wooded pastures. Here it is taken as (fair) pastureland. Compositeness is ignored.

Tank Shape - frustrum of inverted cone

FSL volume= 1.49 mcm	LWL volume= Ø.28 mcm
Radius at FSL= 317 m	Bottom radius= 143 m
Height (tank bottom to FSL)=8.5 m	

Free surface evaporation (ETo) from Table 2.
Seepage rate= Ø.ØØ4 cum/sq m-day

Command is assumed

To be planted with	Sown	Harvested
Maize (14Ø ha)	26 June	22 Sept
Wheat (14Ø ha)	1 Nov	2 April
Alfalfa (8Ø ha)	15 April	15 June

Command soil taken as clay loam, Sa Ø.167 m/m and PWP Ø.15Ø m/m and FC' Ø.317 m/m (Eagleson 197Ø). Depth of root zone Ø.6Ø m.

Pump : 12 hour day assumed for pumping, discharge 1ØØ lit/sec

Input

Daily rainfall sequence of 1968-82, excluding 1971 and 1972, is shown in Table 8 for Zalod taluka, where Shankarpura LIP is situated. Daily data for excluded years was not available.

Computation interval- one day.

Initial conditions

Simulation starts on May 3Ø which is time zero.
Water in tank Ø.28 mcm, i.e at dead storage.
Available water in rootzone Ø, i.e. at PWP.

Runs carried out one year at a time with identical initial conditions.

Results

First, we shall briefly look at the broad features revealed by simulation.

Irrigation being done (in practice) only in <u>rabi</u>, storage at the beginning of <u>rabi</u> is relevant. Table 5 shows water in the tank at the end of _kharif_ (Sept 22) and beginning of _rabi_ (Nov 1) seasons. Storage was close to FSL on Sept 22 every year except in 1974, when the rainfall was very low. Commonly, tanks do not have stage indicator installed. Therefore it is difficult to ckeck it out with data. But FSL being easily observable, is remembered by people on site. They corroborated that tank did get nearly full in most years of the above sequence except in 1974.

The table also shows the time when water goes below LWL, and the water spilled during the rainy season. Generally, water depleted to LWL by end of Feburary. In 1974, of course it went below LWL during the rainy season itself. Thus irrigation of summer crops, grown in April-June will not be feasible.

Use of curve number method makes the effect of distribution readily apparent. For instance, annual rainfall in 1970 and 1978 were almost equal, 762mm and 757 mm. However, spill in 1970 was only 31% of FSL while in 1978 it was 145%. In 1970, when the spill was less, distribution was nearly even during four months, 20% in June, 24% in July, 30% in August and 24% in September. While in 1978, it was 8% in June, 28% in July, 59% in August and only 3% in September.

Similarly, 1980 results indicate that even though this year rainfall was higher than in 1979, the tank did not fill up. This is an aspect that is significant from design point of view. We shall return to it later.

Irrigation needed (and possible) will now be examined. Figure 4.1 shows the simulated results for the year 1968. Total rainfall in the year was 1059 mm, nearly 30% above annual mean. Fig 4.1a shows the daily rainfall. Volume of water in tank is shown in fig (4.1b). Figure (4.1c) shows available soil water, the MSL and the spans of time the pump was on.

As rains begin, storage in tank and available soil water rises. Dry spells cause decline. Water reached FSL in August. Rains withdrew towards end of September leaving the tank nearly full. No irrigation was required in <u>kharif</u> as rains were able to keep the available water in root zone above MSL. LIP was able to give only 4 irrigations in <u>rabi</u>. The graph shows that one more would have been needed towards the end but was not possible. The crop will thus experience stress towards the end for about 34 days. The number of stress days in the remaining years varied from 14 to 39. Water in the tank reached dead storage in first week of Feburary leaving no water for summer crop.

Rainfall in 1974 was unusually low, only 186 mm. This was a year of severe drought. Supplementary irrigations were required in <u>kharif</u>, but only one could be possible (Figure 4.2). No water was available for subsequent requirements.

Graphs of all the thirteen years are available but have not been included for space. Table 6 summarises the results of 13 years. If above sequence is taken as representative, and if the crops grown are the ones listed, it can be stated that the Shankarpura LIP has the capacity to provide four irrigations to 129 ha (mean of 13 years) of rabi command on a long term basis. Possibility of summer irrigation appears unlikely.

Note, the results obtained by use of this sequence should be treated as a random sample. If a longer sequence is used, or more samples of similar span, better estimates of capability could result.

Between 1980-86, Shankarpura LIP has served an average of 103 ha of rabi crop. This is a fairly good performance.

ECONOMIC ASPECTS

Above LIP is able to irrigate only in rabi and not in other seasons as stipulated originally. It still works out economical however as discussed presently. Availability of water can trigger several changes- extension of cropping from one season to two or more, change in crop and or variety etc. Reliable supply of water can also stimulate other enterprises such as dairying, tree plantation etc. We shall limit ourselves to benefit derived by opening up cropping in rabi.

Computation of benefit cost ratio, shown in Table 7, is worked out in retrospect for Shankarpura LIP using the results of the foregoing analysis. The B/C ratio turns out to be lower (1.32) than that originally projected (1.85). But being above that usually insisted upon for minor works (1.25), the project still rates as a profitable one.

Needless to remind that B/C ratio, is specific to electricity tarrif and the switchover crop. Where these be different, it will need to be computed anew.

Possible Additional Uses

The performance of one LIP has been simulated, and its expected capability determined. We shall now explore what can be learned that is of wider applicability. A relevant question could be for instance- should one look upon all available tanks in the district as possible (and profitable) candidates for installation of LIPs.

Site selection

Two things are vital to suitability of a site- the command topography and capacity-reliability graph of the tank.

Commands at higher elevation from water source call for larger heads. Large heads will have two-fold impact on cost - the capital cost will rise on account of large machinery and running cost, on account of greater energy used per unit of water pumped. If we assume that cost of power plant will rise linearly with its power (ignoring a slight economy of scale that exists) and given the electricity tariff (proportional to kW at present), one can find a relationship between the size of LIP and the size of minimum command it must serve in order to be economical for a given switch-over crop. This has been done and is shown in fig.5 The figure shows the minimum command a LIP of given size (kW) must have in order for B/C ratio to be above 1.25. The figure also shows the points representing a few of the existing plants.

There are three that are significantly below the viability line. One that is off the mark most is Anas. Sited on river, this LIP has a two stage pump (total 324 kW) with a head of 92 m and total command 360 ha (120 ha in each season). Indeed it was found too expensive to operate both the stages. Now only the first stage is worked.

Broadly, a desirable topography (apart ofcourse from level lands) would be that if water is taken to a high point, there is around it large enough area to which it can then be sent through gravity.

Capacity-reliability graph

The method presently prevalent of constructing capacity-reliability graph consists of identifying design rainfall by one of the plotting position method, usually the Wiebull's formula, then converting it into volume of runoff by a linear transformation, usually the rational formula. The probability of exceedence is taken to be the reliability of the system.

The above, ignores the distribution of (daily) rainfall which has significant effect on runoff. Curve number method appears to be a better means of constructing capacity-reliability graph. Taking daily rainfall of a sequence of years, simulation can be carried out. Several different sequences will yield several values of total runoff. Wiebull's formula can then be used for runoff instead of rainfall.

The model can be used to screen all the existing tanks, for their irrigation potential and to classify them accordingly. This will require knowledge of daily rainfall at the site, catchment characteristics, tank shape and command topography.

Size of Pumping Plant

Determination of size of pump and prime mover is an aspect of design. The model can easily enable construction of discharge (hence size) and length of rotation relationship. One can choose the size that is economical which meets the acceptable length of rotation.

Operations

Presently the time for important decisions regarding crop mix and area allocation comes in the beginning of _rabi_. By this time the storage is known. The crop-area decision may relate not only to _rabi_ but also summer. These decision problems lend themselves to formulation and solution by mathematical programming. Once allocation and mix are obtained through a separate program, the results could be checked out by using the present model.

Conclusion

The mathematical model presented here, was built primarily for the purpose of evaluation of performance. It appears to serve the purpose well. It can be useful also for designing new systems.

Model does stand in need of improvement. Further improvement will need to include better root growth equation. Equation describing evaporation from bare surface also needs to be tested and possibly improved. Using actual sequence of daily rainfall requires large computer storage and is tedious to input. Probability distribution of daily rainfall will need to be developed, so that observations could be generated internally. Rotational water supply needs to be built into the program. Latter, ofcourse, is a matter of improving the program which can be done relatively easily.

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Table 1: AMC classification

AMC grouping	Total 5 day antecedent rainfall (mm) Dormant season	Growing season
I	<12.7	<35.56
II	12.7-27.94	35.56-53.34
III	>27.94	>53.34

Source: USDA (1976)

Table 2: Estimated monthly evaporation- Free surface

Month	Evaporation (cm/month)	Month	Evaporation (cm/month)
January	13.7	July	14.5
Feburary	14.7	August	9.5
March	21.5	September	12.2
April	30.7	October	13.6
May	34.2	November	13.2
June	25.1	December	10.7

Source: Irrigation Department, Gujarat. Values are average of two years'(1987-1988); and corrected for pan and location; Correction factor- pan 0.6; location 1.414.

Table 3: Crop factor (kc)

Crop	Crop stage Initial	Crop devp	Mid season	Late season	At harvest	Total growin period
Maize	0.30-0.50	0.70-0.85	1.05-1.20	0.80-0.95	0.55-0.60	0.75-0.
Wheat	0.30-0.40	0.70-0.80	1.05-1.20	0.65-0.75	0.20-0.25	0.80-0.
Alfalfa	0.30-0.40	0.85-1.05	0.85-1.05	0.85-1.05	1.05-1.20	0.85-1.

Source: Doorenbos and Kassam (1979)
Alfalfa values were available only for initial, at harvest and total growing period. Missing values are replaced by average over growing period.

Table 4: Soil water depletion factor (p)

ETm (mm/day)	p 2	3	4	5	6	7	8	9	10
Maize	0.875	0.80	0.70	0.60	0.55	0.500	0.450	0.425	0.400
Wheat/ Alfalfa	0.80	0.70	0.60	0.50	0.45	0.425	0.375	0.350	0.300

Source: Doorenbos and Kassam (1979)

Table 5 : Storage in Tank and Spill

Rain (mm)	Year	Storage (% of FSL) at *Kharif* end (Sept 22)	*Rabi* beg. (Nov 1)	Spill (% of FSL)	Reached LWL on
186	1974	14.1	11.8	0	Aug 14
518	1979	94.7	87.9	21	Feb 1
636	1980	93.5	86.8	0	Feb 3
671	1975	98.8	92.5	7	Feb 21
731	1982	95.1	88.3	104	Feb 2
757	1978	96.4	89.6	145	Feb 4
762	1970	97.7	91.2	31	Feb 16
847	1969	98.3	91.4	142	Feb 13
1059	1968	97.9	91.1	332	Feb 6
1065	1981	95.1	89.1	388	Feb 13
1186	1973	98.6	93.6	270	Feb 11
1301	1977	99.5	92.5	302	Feb 19
1760	1976	98.9	91.9	611	Feb 16

FSL volume=1.49 mcm

Table 6: Irrigation needed and possible (1968-82)
Simulated results - Shankarpura LIP

Rain (mm)	Year	Waterings drawn (no) *Kharif*	*Rabi*	Summer	Remarks
1059	1968	0	4	0	*kharif* does not require irrigation; *rabi* needed one more (see graph) but not possible
847	1969	0	4	0	-do-
762	1970	0	4	0	-do-
1186	1973	0	4	0	-do-
186	1974	1	0	0	Even *kharif* requirement could not be met fully as level went below LWL.
671	1975	0	4	0	*kharif* requirements met fully; *rabi* needed one more but not possible
1760	1976	0	4	0	-do-
1301	1977	0	4	0	-do-
757	1978	0	4	0	-do-
518	1979	0	4	0	-do-
636	1980	0	4	0	-do-
1064	1981	0	4	0	-do-
731	1982	0	4	0	-do-

Crops: Maize 140 ha (*kharif*), Wheat 140 ha (*rabi*), Alfalfa 80 ha (summer).

Table 7: Economic Aspects- Shankarpura LIP

	Before LIP	After LIP
Crop	Gram	Wheat
Area (ha)	140	129
Yield (q/ha)*	11.1	37
Gross value of produce (Rs)	622,000	956,000
Cost of pdn (other than irrign)	40%	40%
Net income (Rs)	372,000	573,000
	Net additional income (Rs)	201,000
Capital cost (Rs)	800,000	
Operating costs (Rs/year) **	41,000	
B/C ratio	1.32	
Payback period (yrs)	4	

* Before LIP, gram was grown in rabi, yields as per Department of Agriculture (Gujarat) were 11.1 q/ha. After LIP, wheat is grown, yield 37 q/ha, prices- gram, Rs.400/q, wheat Rs 200/q.

Cost of Shankarpura plant was Rs 366,000 in 1976. We assume, cost will be Rs 800,000 if it were built now.

** Includes operation & maintenance cost (Rs 4,432/year), staff salaries (Rs 12,082/year) and electicity charges Rs 256/kW/year i.e. Rs 19,200/year. In addition we include 15% more to account for diesel stand-by occasionaly used.

Computations of B/C are based on interest rate 12.5%, life 20 years, and salvage zero.

Table 8
Daily rainfall in Zalod (mm)

Year	Month\ Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31*
1968	June	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	0	0	0	0	0	0	0	0	0	0	20	31	0
	July	17	0	9	0	62	87	0	0	33	93	148	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	August	66	50	115	5	51	126	7	0	0	3	0	0	0	0	0	0	22	0	0	0	46	0	0	0	0	0	0	0	0	0	0
	September	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	22	29	0	0	0	0	0	0	0	0	0	0	4	
1969	June	0	0	0	0	0	2	54	31	0	0	0	0	0	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	July	1	0	0	0	0	0	22	0	0	0	0	75	0	56	5	0	3	45	6	33	103	0	0	4	6	0	0	0	4	3	0
	August	0	37	0	0	0	0	0	0	23	42	15	14	6	4	0	42	20	0	0	0	0	3	0	0	0	0	4	8	0	0	0
	September	0	0	0	0	0	2	0	9	20	55	62	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1970	June	12	3	0	4	0	0	0	0	0	0	0	0	7	48	0	18	26	2	0	0	0	0	6	0	0	0	0	0	22	12	0
	July	35	35	7	28	19	0	0	1	9	0	29	0	1	0	0	0	0	11	0	2	0	0	0	0	0	9	0	0	0	0	0
	August	5	0	4	30	1	2	0	0	3	0	70	3	0	3	0	0	0	0	10	42	11	5	7	0	6	2	3	0	0	0	25
	September	60	7	3	0	50	0	33	7	0	0	3	0	0	0	0	0	0	0	0	0	0	0	17	0	4	0	0	0	0	0	
1973	June	4	0	0	0	0	0	4	0	0	0	0	6	82	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	July	0	0	0	0	5	14	4	4	38	6	43	12	1	0	10	21	13	2	20	21	0	5	11	0	3	0	3	0	0	0	2
	August	0	0	0	0	0	0	0	0	0	18	4	0	0	4	0	5	22	0	3	43	15	0	34	10	0	3	10	3	15	53	128
	September	42	21	15	18	23	24	143	78	7	2	0	0	0	0	0	0	0	0	0	0	25	10	18	13	32	0	1	4	0	0	
1974	June	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	4	0	0
	July	0	0	0	0	0	0	20	0	0	0	2	12	42	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
	August	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	12	4	2	1	0	0	0	0	0	0	0	0
	September	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	9	0	0	0	
1975	June	0	0	0	18	0	26	0	0	0	0	0	0	0	0	0	0	0	0	13	0	30	0	2	0	0	0	0	10	0	0	0
	July	11	0	0	0	0	0	0	0	0	52	4	25	13	1	16	14	4	0	0	37	0	1	6	0	0	0	0	0	0	2	4
	August	0	1	0	0	0	0	50	55	1	1	0	12	14	1	30	8	0	0	0	0	0	6	0	0	6	0	10	19	0	0	0
	September	0	14	5	10	1	5	0	0	0	0	3	32	50	0	10	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	
1976	June	0	0	0	10	10	5	27	90	28	8	0	0	0	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	July	0	0	6	0	0	5	0	23	10	2	21	78	22	12	0	1	56	124	46	5	0	119	10	0	0	0	0	8	79	17	29
	August	96	4	2	17	244	102	7	0	7	0	0	0	0	21	4	6	59	3	1	0	0	0	0	0	1	0	13	13	137	33	10
	September	4	0	39	5	3	0	1	6	9	26	2	0	0	3	10	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	
1977	June	0	0	0	0	0	0	0	0	0	0	3	2	0	0	0	0	0	16	1	24	2	0	1	1	4	9	72	1	75	5	0
	July	15	51	15	13	10	27	53	55	4	5	106	10	0	0	0	6	12	0	0	0	0	0	2	7	5	15	72	17	2	0	0
	August	7	5	4	2	2	0	3	223	9	0	0	1	1	0	3	0	2	0	0	0	0	0	0	0	5	17	27	18	6	0	0
	September	75	37	35	1	0	0	0	2	0	0	0	0	11	52	1	0	0	0	7	9	10	8	0	0	0	0	0	0	0	0	
1978	June	0	0	0	0	0	0	0	0	15	0	0	0	0	0	38	0	7	2	0	0	0	0	0	0	0	0	0	0	1	0	0
	July	0	0	15	0	0	0	3	12	22	13	0	2	0	63	0	0	0	2	3	0	0	0	17	6	0	40	0	7	5	2	0
	August	0	0	2	0	0	0	3	0	0	0	0	7	4	0	0	27	77	0	6	0	13	0	4	0	0	60	10	0	21	83	135
	September	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1979	June	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	17	0	0	0	0	0	0	13	10	1	2	16	0
	July	0	0	0	0	0	0	0	0	0	16	49	1	0	0	0	21	2	0	17	0	0	0	0	0	0	0	40	25	0	0	4
	August	0	9	4	25	2	2	31	3	6	90	46	0	13	14	0	6	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0
	September	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	
1980	June	0	0	34	0	2	20	0	0	0	0	22	0	20	20	14	0	0	20	0	0	20	21	13	0	4	0	35	6	0	2	0
	July	2	0	12	20	31	8	7	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	5
	August	21	37	20	33	3	12	13	5	2	0	0	0	0	0	0	0	0	0	41	0	0	0	0	0	0	0	20	0	0	29	23
	September	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1981	June	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	July	6	0	0	0	0	0	0	0	31	276	30	0	4	7	29	0	3	3	1	7	9	0	0	9	15	0	1	4	4	0	11
	August	0	0	0	0	4	7	9	0	0	0	181	35	0	22	6	5	264	3	1	0	4	4	3	0	0	0	0	0	7	0	0
	September	0	0	0	0	0	0	0	0	0	0	1	0	12	0	0	0	10	0	0	0	0	0	0	33	0	0	0	4	0	0	
1982	June	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	56	0
	July	0	0	0	0	0	0	0	0	0	0	0	0	10	50	4	22	0	0	0	0	0	65	96	25	73	1	0	19	32	0	0
	August	4	0	3	6	5	31	42	0	1	2	2	0	14	7	77	10	47	1	0	0	0	19	0	2	0	0	0	0	0	0	0
	September	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

* June 31 shows rainfall of May 31

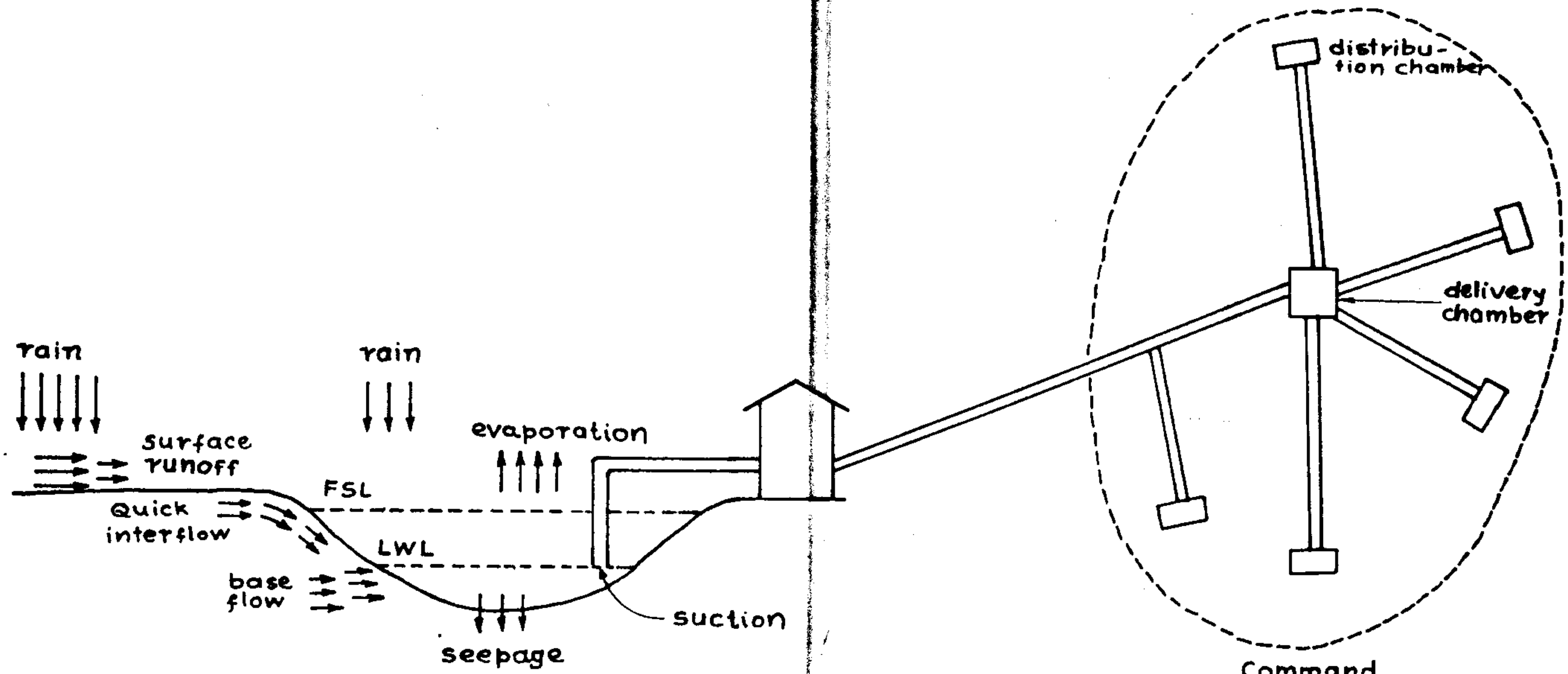
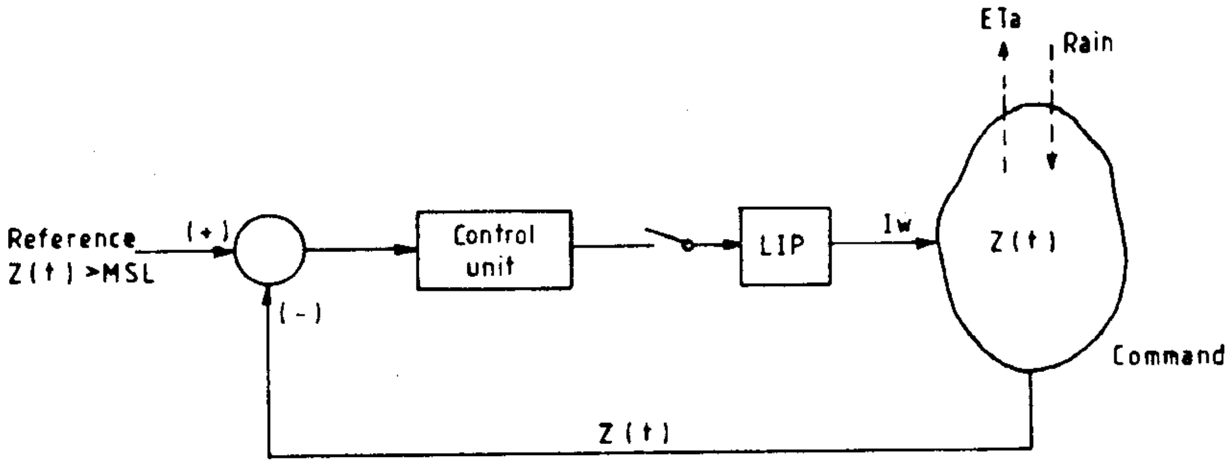


Fig 1 : LIP Schematic



Control algorithm

Pump on when Z(t).D = (1 - p). Sa.D (MSL)

off when Z(t).D = Sa.D (Field capacity)

or Q(t) = LWL

Fig 2 : Block diagram

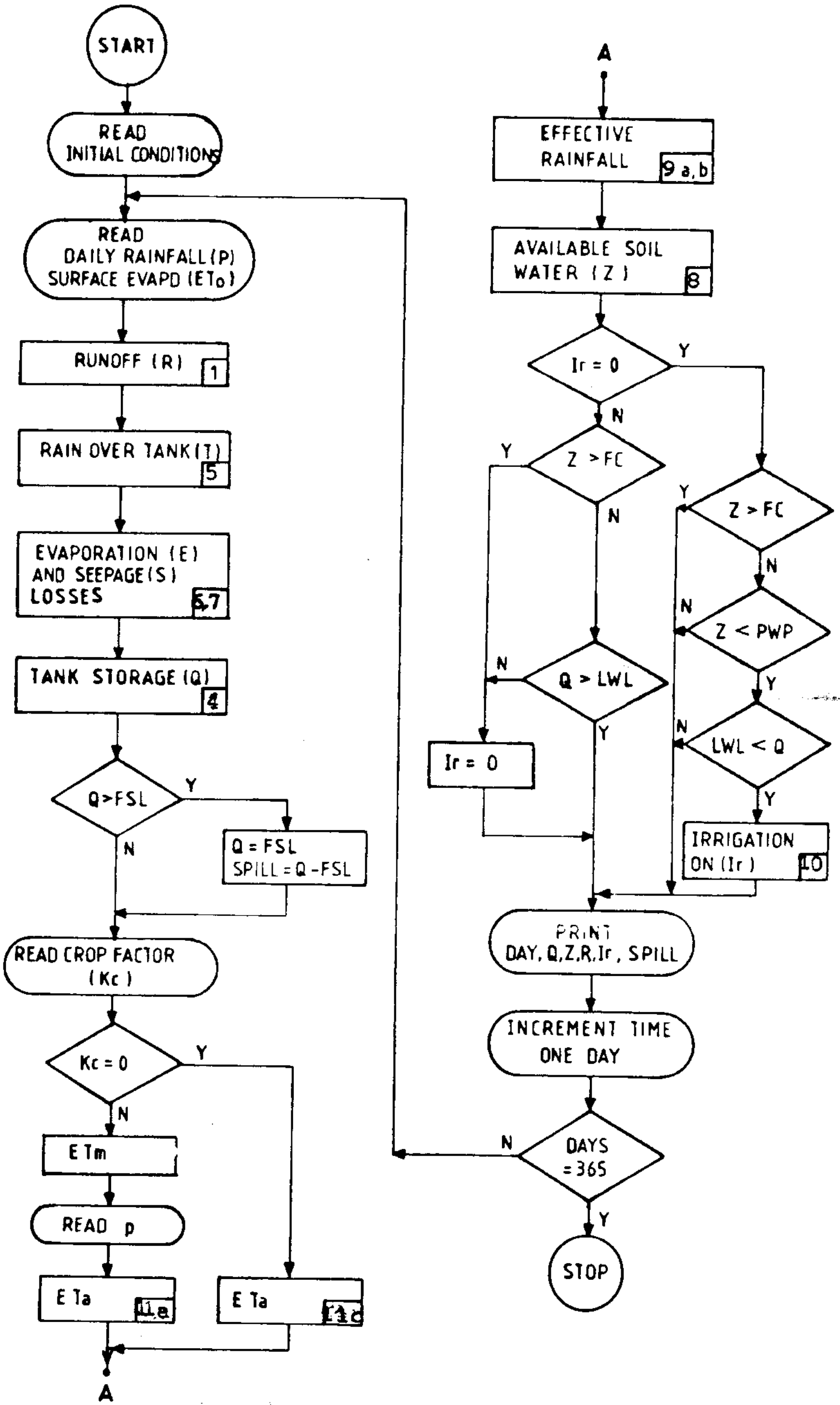


Fig 3: Flow Diagram

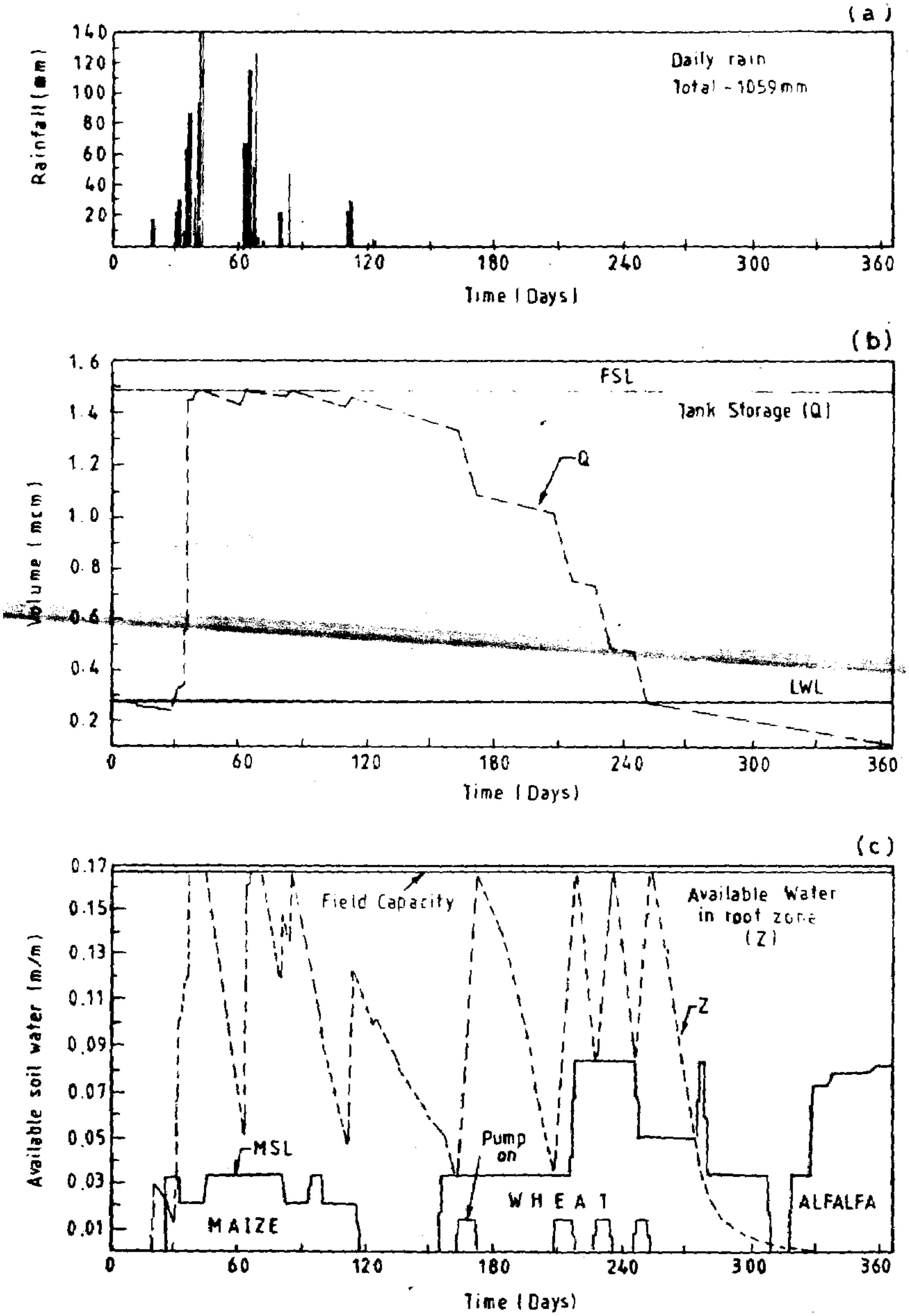


Fig. 4.1 : Simulated results (1968)

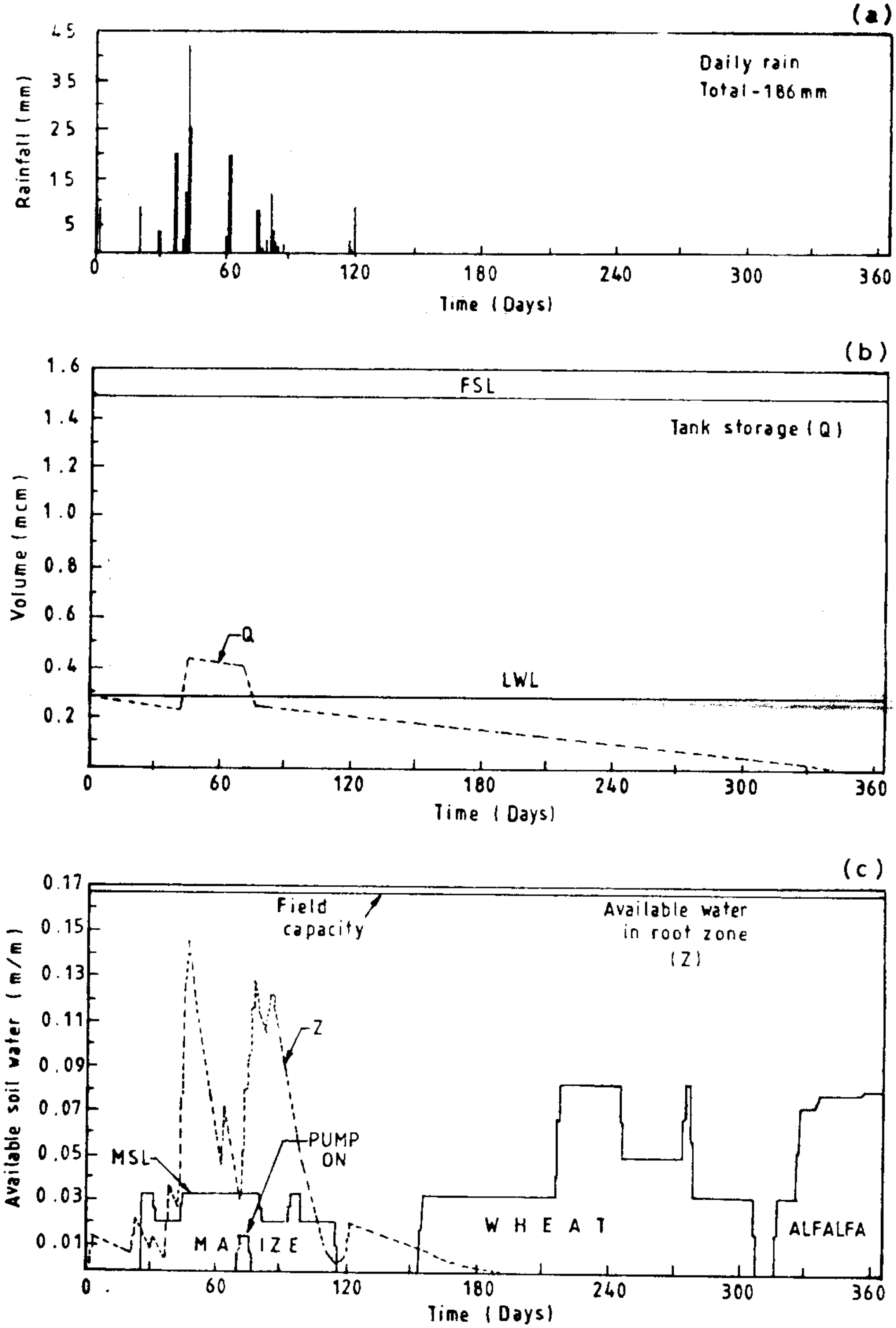


Fig 4.2 : Simulated results (1974)

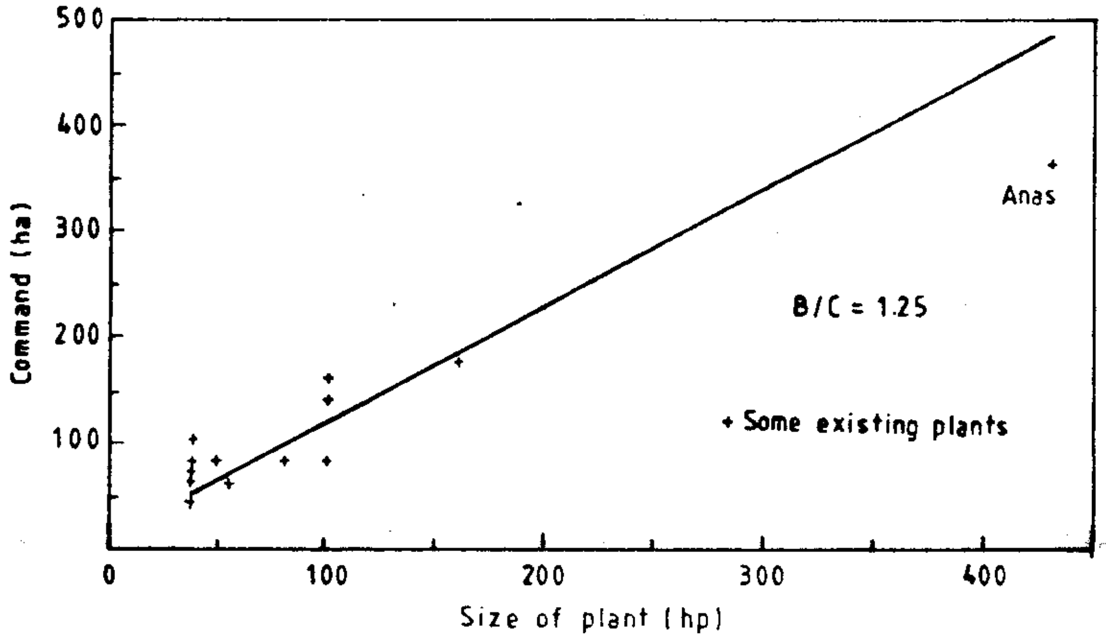


Fig. 5 : Viability Line