ANALYSIS AND DESIGN OF SETTLING BASINS
FOR IRRIGATION RETURN FLOW

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FOR IRRIGATION RETURN FLOW

ABSTRACT

by

Floyd Leon Ballard

Nine fields under furrow irrigation were studied to determine sediment yield to ponds as a function of crop type, soil type, and topography. Data were collected from seven farm settling ponds located on these fields to gain insight into the factors which affect pond removal efficiency.

Before a complete list of design criteria for on-farm settling ponds can be determined, it is necessary to find the amount of sediment which must be trapped by the pond. Predictive equations for sediment yield using regression analysis were attempted in this study. Flow onto field, average slope, length of furrow, time of run, and area under irrigation were the dependent variables. Utilizing irrigation number as an input variable, two of the six equations were found to be applicable. The collected data showed between 0.339 and 37.00 tons of sediment per acre to be eroded during one irrigation season.

Regression analysis was used in an attempt to find what effect, if any, the parameters overflow rate, length to width ratio, sediment size, and detention time had on pond efficiency. The analysis provided little information with respect to the above mentioned variables. To check the validity of using a mathematical model as a tool for pond design, actual data were tested and the results compared to those observed in the farm pond. The model was found to be a useful tool for evaluating engineering design criteria. However, engineering judgments must be made concerning its use. The pond removal efficiencies ranged from 43.0% to 100% for sediment and from 28.6% to 77.7% for phosphate and nitrogen.

INTRODUCTION

Sediment is the largest single source of stream pollution in Idaho. Particles are detached and removed from their natural habitat by the action of running water used in irrigation and rainfall or snowmelt.

A large part of the irrigated farm land in southern Idaho is under furrow irrigation. Most of the irrigation water is diverted from the Snake River above the areas under cultivation. Once the water has passed through the fields, a percentage of it makes its way back into the Snake River carrying with it sediment and nutrients eroded from the farm land. As the irrigation return flow enters the Snake River, the pollutional effects are then felt.

Several of the problems caused by sediment in natural waterways are as follows:

1. Turbidity decreases the sunlight penetration in the water which in turn decreases photosynthesis and lowers the oxygen content of the stream. It further causes more heat to be absorbed by the water and results in an increase in temperature. As the dissolved oxygen concentration decreases and temperature increases, the desirable flora and fauna are either killed off or move to cleaner and fresher waters.

2. Suspended sediment is deposited along the sides and bottoms of the streams and canals, decreasing the capacity of the river and increasing the possibility of floods in the lower areas. The finer suspended sediment, such as fine silts and clays, are deposited in the reservoirs, decreasing their storage capacity.

3. Nutrients are eroded and transported from the fields to the streams along with the sediment. Phosphate and nitrogen are considered the most important of

these nutrients. Increased nutrients in a stream or reservoir can cause overproduction and create algae blooms. These increased nutrients cause the water to be objectionable for recreational as well as domestic uses.

Erosion is not only a pollution problem, but an economic one as well. Canals, rivers, and reservoirs must be maintained to keep water flowing to irrigated areas. In order to do this, large quantities of sediment must be dredged each year to keep the flow moving. This increases the cost of water to the irrigator. The farmer again loses financially once the sediment is eroded and carried from the field to a canal or stream because the soil which is eroded is usually topsoil and humus. Once this material has left the farmer's property, it cannot be recovered economically. Every year fertilizer is applied to many fields; some of it is utilized by the plants for growth but, like sediment, part is carried away by the irrigation water and is not retrievable. The farmer must pay for more fertilizer each year to replace that which has been transported away. There is also a cost to remove the vegetative growth which results from the increased discharge of nutrients into drainageways and streams.

The farmers utilizing furrow irrigation techniques and the irrigation companies will soon be faced with standards set by the Environmental Protection Agency. It is the major purpose of this study to assist farmers and processors to meet the current and projected effluent water quality requirements and ultimately to improve the water quality of the waters of the state of Idaho.

OBJECTIVES

The objectives of this study were as follows.

1. To determine sediment yield to ponds as a function of crop type, soil type, and topography.
2. To develop engineering design criteria for farm settling ponds. Removal efficiencies for suspended and bed load will be evaluated as a function of pond geometry, inflow discharge, and sediment loading.

Field and laboratory work was coordinated from the Snake River Research Center at Kimberly, Idaho, in cooperation with the Agricultural Research Service, U.S. Department of Agriculture. The Northside Canal Company was instrumental in locating farmer cooperators and constructing a settling basin on the north side of the Snake River in 1973.

SEDIMENT YIELD FROM FIELDS UNDER FURROW IRRIGATION

Scope of Study

The objective of this section was to determine sediment yield to ponds as a function of crop type, soil type, and topography. A functional relationship between the various parameters was desired. Possible adaptation of the Universal Soil Loss Equation and regression analysis was used in an attempt to find a suitable equation for predicting sediment yield.

The only helpful literature found was that from a companion project funded by the Idaho Water Resources Research Institute. This project demonstrated that no simple, direct application of the Universal Soil Loss Equation could be made to predict sediment yield from furrow irrigated fields. Using regression analysis, the equations based on soil type and irrigation number gave better results than equations based on hourly data inputs. These equations were consistently within plus or minus 100% of the measured yields. The hourly equations yielded plus or minus 200% of the actual values. Slope, length of furrow, flow onto field, time of irrigation, area, and soil type were used as the significant variables. No single, general equation was found which gave good predictive results for the sites (Oliver, 1974).

Selection of Field Sites

Field selection was based on several factors including uniform slope and length, crop type, size, distance from the Agricultural Research Station, whether a pond was available or could be constructed, and the farmers' cooperation and cultivation practices.

Due to the great number of variables affecting sediment yield, fields with uniform slope and length were selected when possible. These were typical of the majority of farm land under furrow irrigation in the area.

Row crops of beans, barley, wheat, and potatoes were of interest because they are the main crops grown in the area and have the most significance in determining sediment yield from cultivated land under furrow irrigation. Crops such as alfalfa and grass, unless it is the first year crop, yield very little sediment because the soil is not cultivated every year. The alfalfa and grass root system has the ability to hold the soil and keep it from eroding.

Fields large enough to be representative of other fields with the same characteristics, but small enough so as not to take more than one or two days to sample when the cooperator was irrigating, were selected. Large fields may have topographic features which are not typical of other fields with the same crop type, average slope, length, and area. An example is a large field with a small depression where the water pools before continuing down the furrow. If the field is large enough, the effect of this pool on the overall sediment yield is not as appreciable as it would be on a small field with the same problem. Smaller fields were chosen so that more time could be spent sampling other fields.

The fields on which operating ponds had been constructed were considered first for study before the ones without a pond unless the field was considered unsuitable for data collection.

Farmer cooperation and cultivation practices were usually the deciding factor in field selection. It was important to find cooperators who would provide information as to when the irrigation would occur. This was essential in setting up a sampling schedule. Farmers with consistent and typical irrigation and cultivation methods were sought for this study.

Several factors were added for field selection in 1974. It was found that the fields being studied should be isolated from any runoff from adjoining fields or an irrigation return drain. Therefore, it was necessary to place a ditch at the lower end of each field to catch the runoff and measure it before it entered the waste flows from other fields. Fields were chosen which had easy access to measuring points. Several of the fields studied in 1973 were up to one-third of a mile from the nearest road which required considerable time and some sampling difficulty.

Field Description

Once the guidelines of field selection were generated, nine fields were selected for study, five in 1973 and four in 1974. Seven of the nine fields were used in this study.

Three of the five fields selected for study in 1973 were located on the north side of the Snake River, and the two remaining were on the south side. These two areas represent different soil types. North side soils are predominantly loam to sandy loam, whereas the south side soils are predominantly silt loam. Two grain fields, two bean fields, and a potato field were monitored in 1973. The two grain fields, Bulcher Grain (BG) and Hollifield Grain (HG), were the two fields deleted from this study. The inflow to the BG field could not be measured, and only one irrigation was observed. Outflow from the HG field could not be measured because flow from another field joined it before it entered the Parshall flume. The remaining fields, Bulcher Beans (BB), Walker Beans (WB), and Chojnacky Potato (CS) were monitored throughout the summer.

Fields BB and CS were located on the north side, approximately twenty miles from the research station. The WB field was located eight miles from the station on the south side.

Fields under study for the summer of 1974 were located on the south side of the Snake River. Three of the four fields studied were located at the Twin Falls branch of the Idaho Agricultural Experiment Station. One spring wheat (SG), one winter barley (WG), and a bean field (AB) were used for data collection. The other field, Coiner Potato (CP) was located on private land approximately five miles from the research station. These fields were selected because of their close proximity to the research station and to each other. This enabled greater control over many factors which affected the data collection the previous year.

Each field studied was surveyed and mapped. Topographic characteristics consisting of area, slope, and length of furrow were calculated from these data. (Figures 1 through 7 show mapped fields with contour intervals.) The above parameters are shown in Table 1 along with soil types.

Data Collection in the Field

Measurements of inflow to the field, outflow from the field, and sediment concentration were necessary for calculating the sediment yield and in formulating a predictive equation. During the 1974 irrigation season, in addition to the above parameters, samples were collected for the determination of phosphate, nitrate, total nitrogen, turbidity, and conductivity.

The inflows and outflows were measured using several different types of flumes, current meters, and headgates. Parshall and H flumes were used to measure the outflow from the field. These flumes were fairly easy to install and read. The Parshall flume worked exceptionally well for mixing the sediment at the outlet so that the sediment concentration

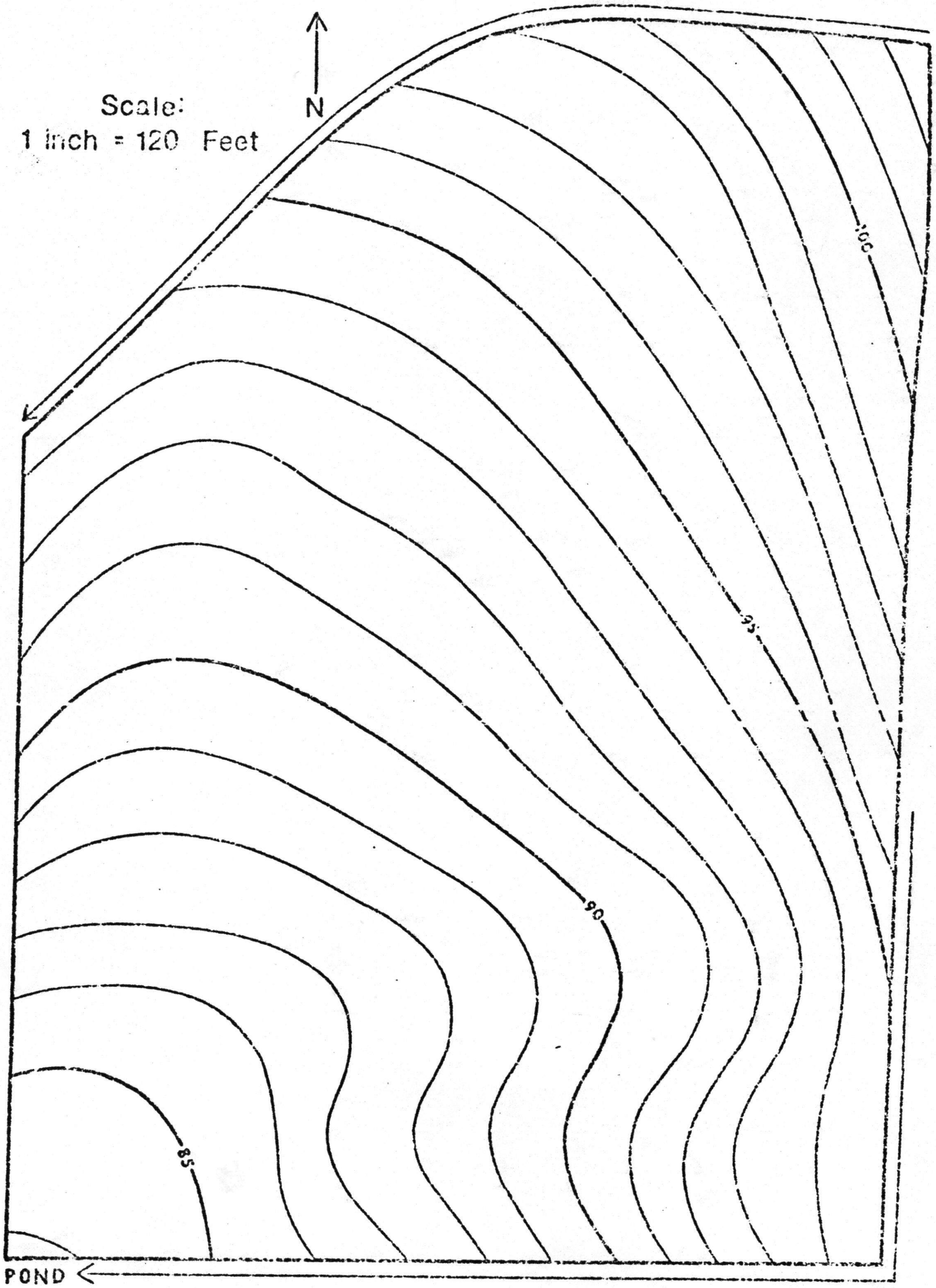


Fig. 1.--Topographic map of Chojnacky Potato (CS) field

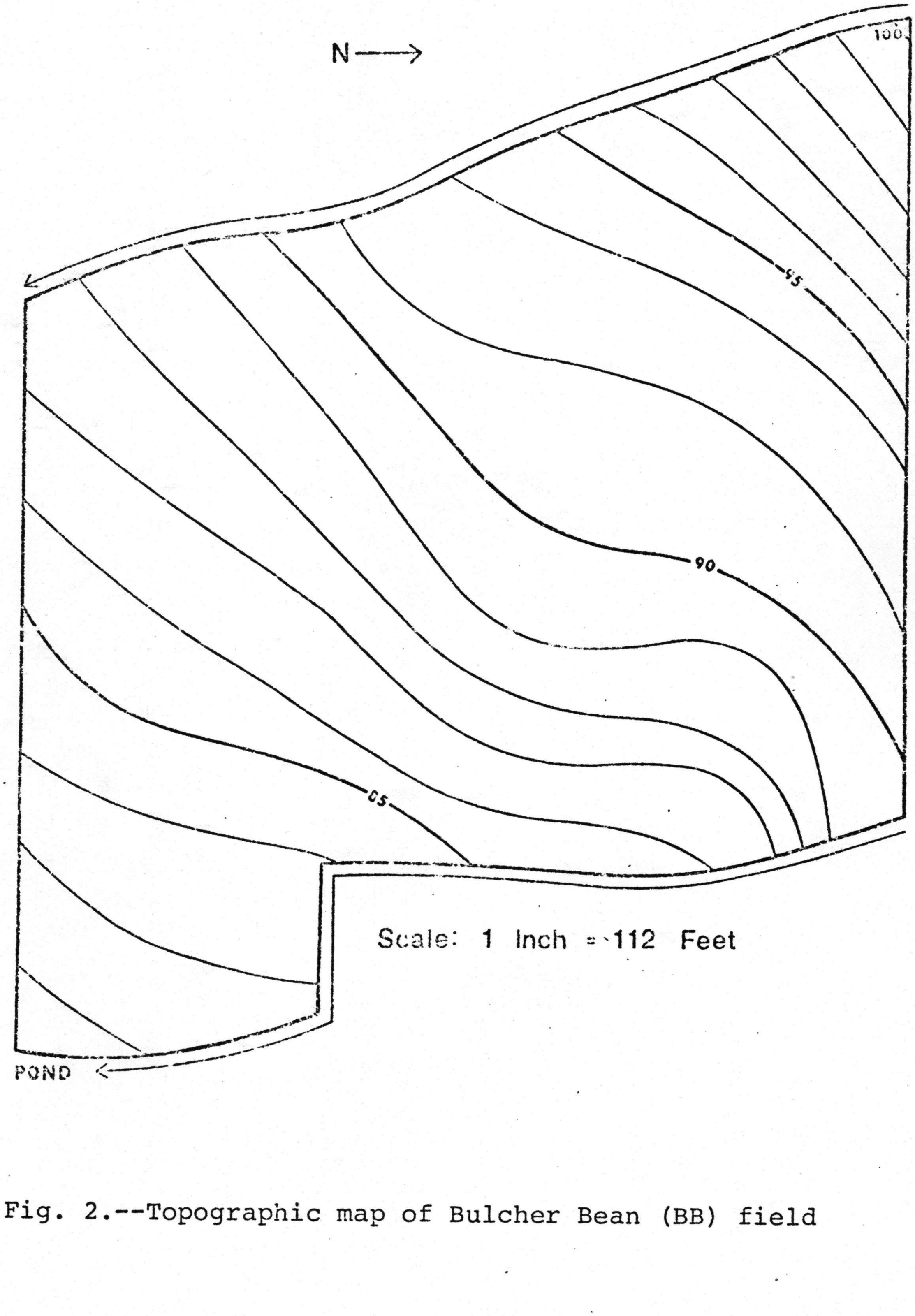


Fig. 2.--Topographic map of Bulcher Bean (BB) field

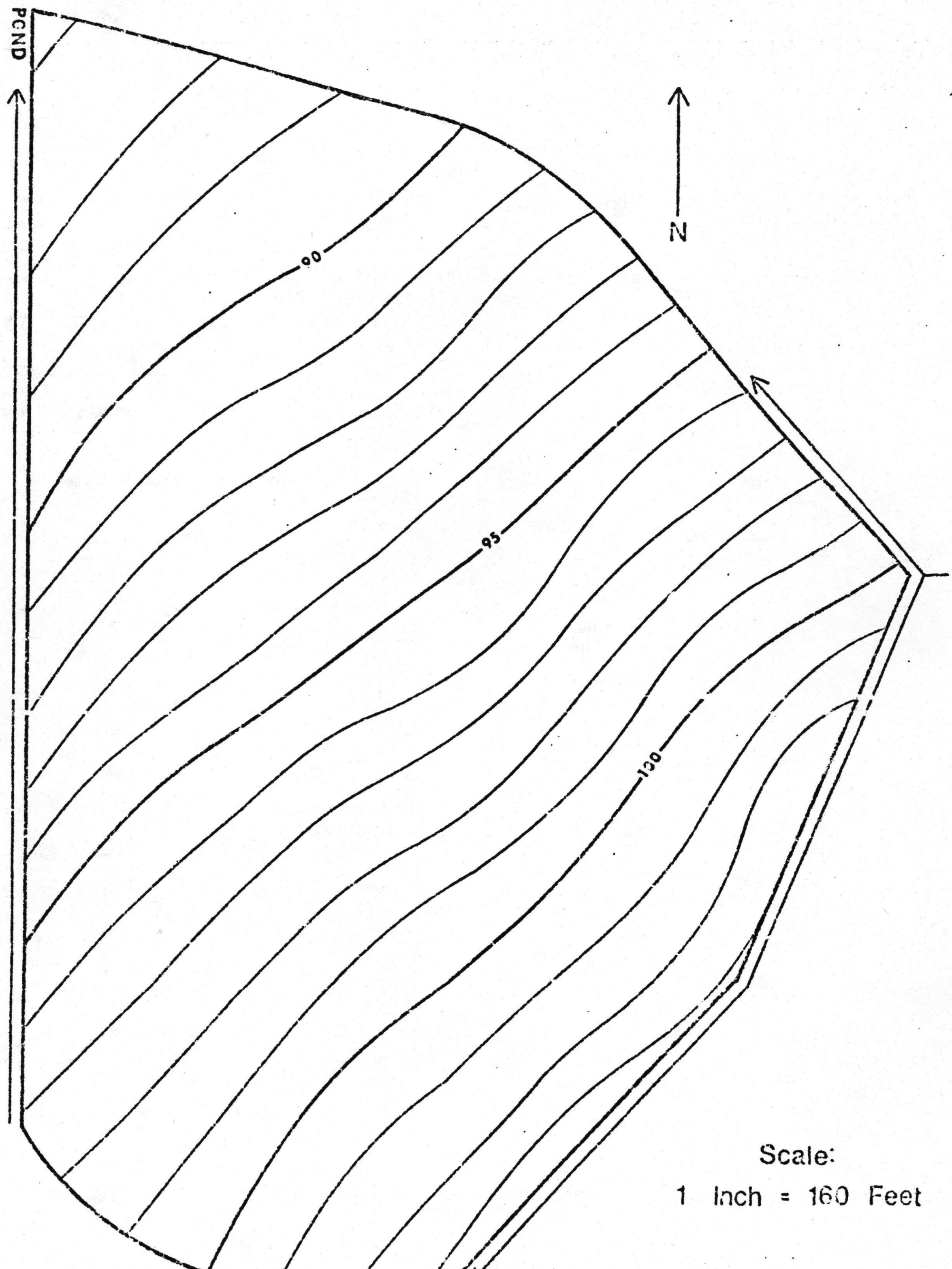


Fig. 3.--Topographic map of Walker Bean (WB) field

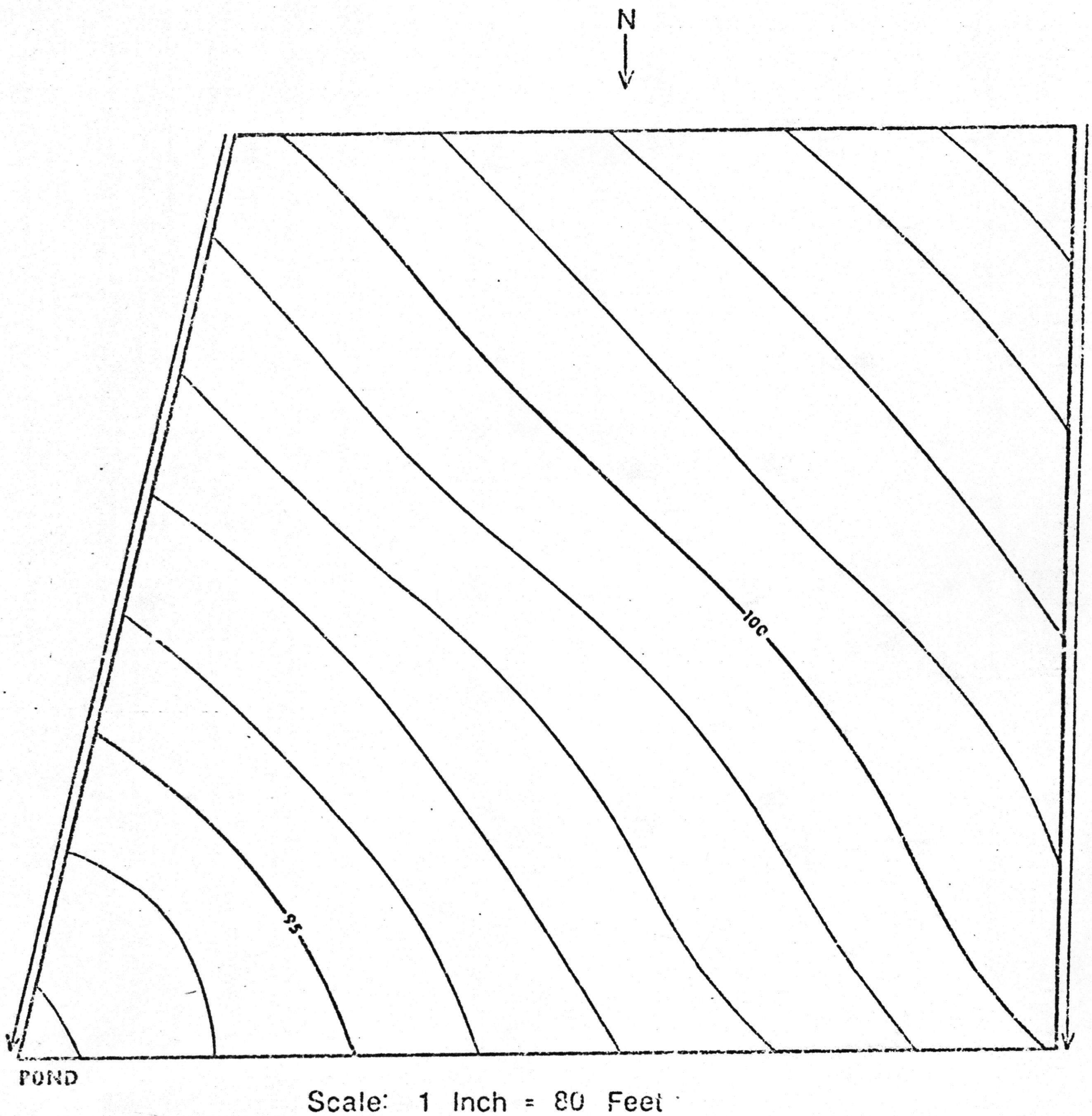


Fig. 4.--Topographic map of Spring Grain (SG) field

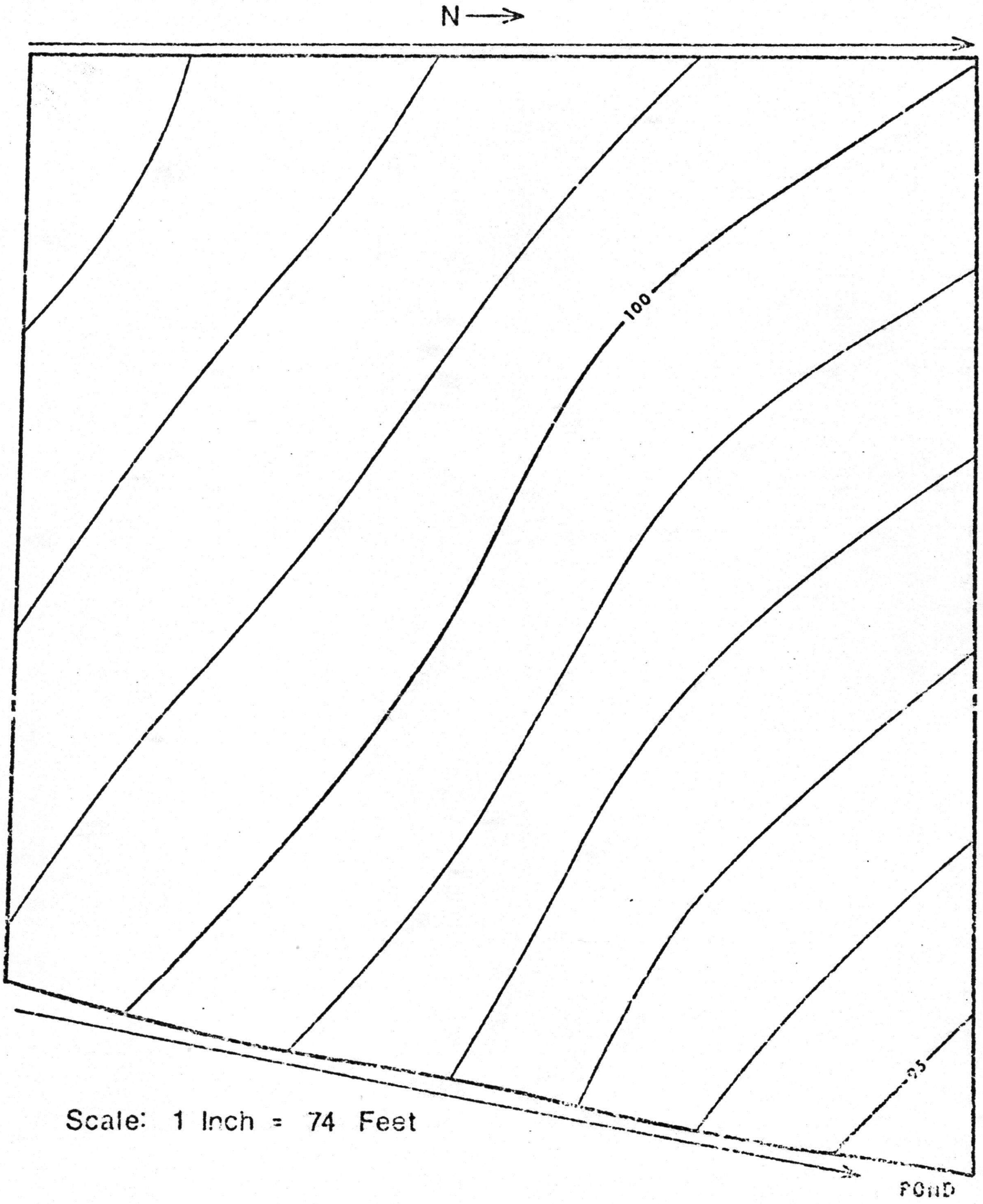
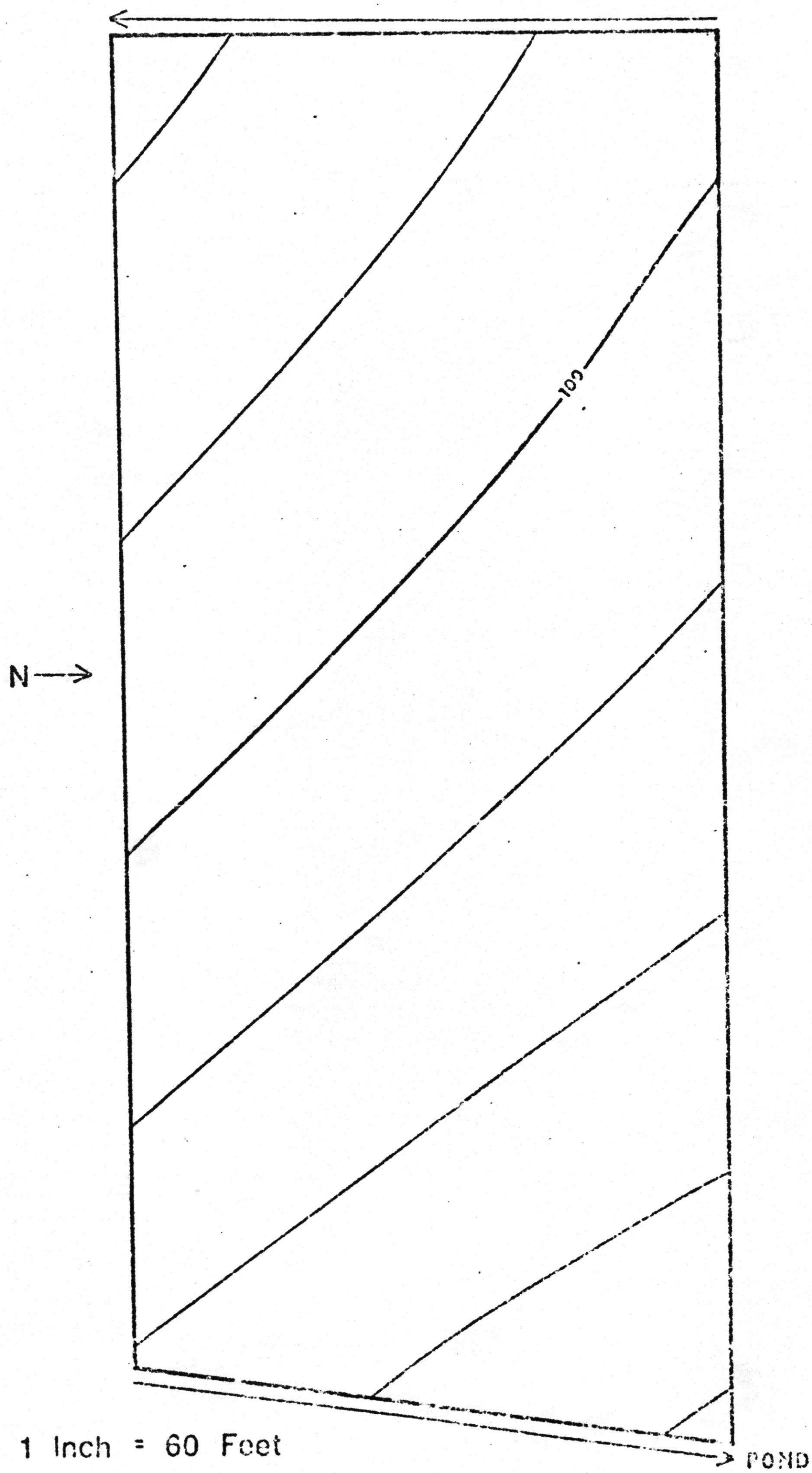
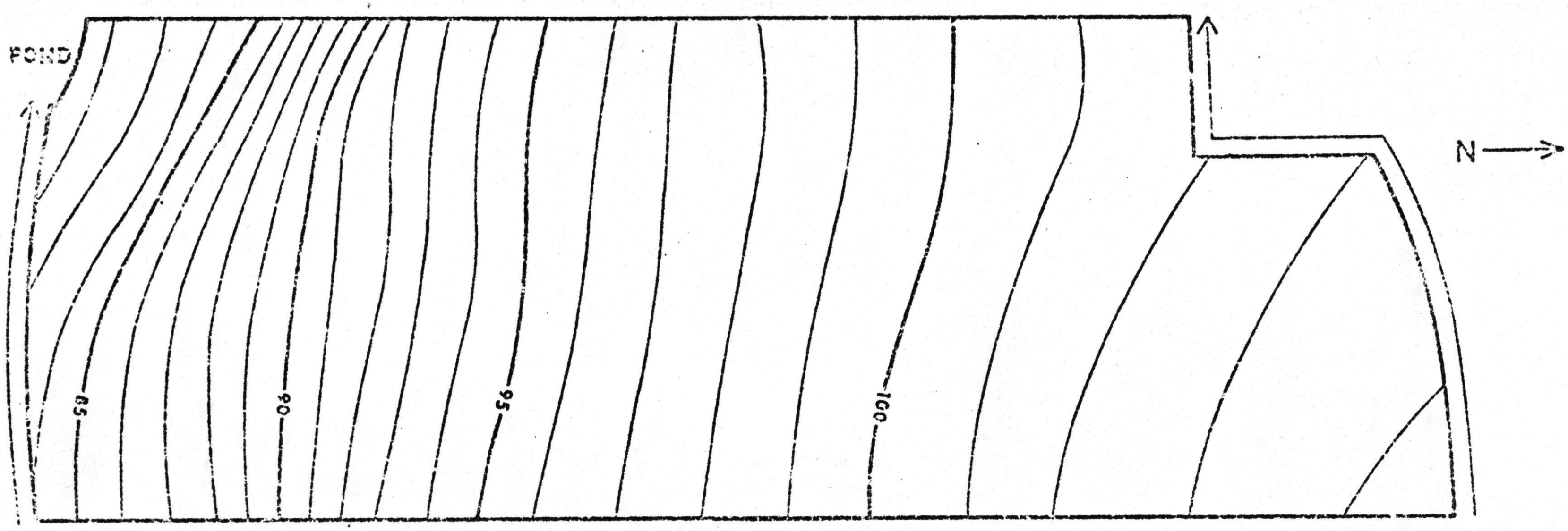


Fig. 5.--Topographic map of Winter Grain (WG) field



Scale: 1 Inch = 60 Feet

Fig. 6.--Topographic map of Bean (AB) field



Scale:
1 Inch = 112 Feet

Fig. 7.--Topographic map of Coiner Potato (CP) field

TABLE 1

FIELD DESCRIPTION

Field	Year	Crop	Previous crop	Area, acres	Average slope, percent	Average length, feet	Soil type
CS	1973	Potatoes	Alfalfa	10.944	1.68	574	Sandy loam
BB	1973	Beans	Grain	5.516	1.79	449	Loam
WB	1974	Beans	Grain	19.762	1.50	859	Silt loam
SG	1974	Wheat	Beans	4.299	1.37	432	Silt clay loam
WG	1974	Barley	Beans	4.897	1.20	407	Silt loam
AB	1974	Beans	Beans	2.170	1.00	465	Silt loam
CP	1974	Potatoes	Alfalfa	7.210	2.60	902	Silt loam

sample would be representative of the total cross section. Water-stage recorders were used on all the outflow flumes in 1974 so that continuous flow rate could be measured. (Figure 8 shows a graph of flow versus time from an actual irrigation.)

The sediment sampler shown in Figures 9 and 10 was used in taking the sample for sediment concentration. To use the sampler it was placed at the outlet of the flume with the long narrow slit facing the flow. The bottle in which the sample was taken held approximately one liter of the soil and water mixture. After the sample was taken, it was placed in an unbreakable plastic container, sealed, and labeled with respect to field, date, time, and sample number. An automatic sampler (shown in Figure 11), built by the Agricultural Research Service, was utilized for several irrigations. It worked fairly well except the intake splitter would clog about every eight to ten hours. When in use it had to be checked at regular intervals. By utilizing the data from one of these irrigations a graph showing the sediment yield change with time was constructed and is shown in Figure 8.

During the summer of 1973, the inflow to each field was measured only once, and it was assumed the flow remained constant throughout the season. The flow was measured by utilizing current meters and weirs. It was found in 1974 that the flow onto the field changed not only from irrigation to irrigation, but throughout the irrigation itself. Therefore, the inflow measurement was taken at the same time as the outflow

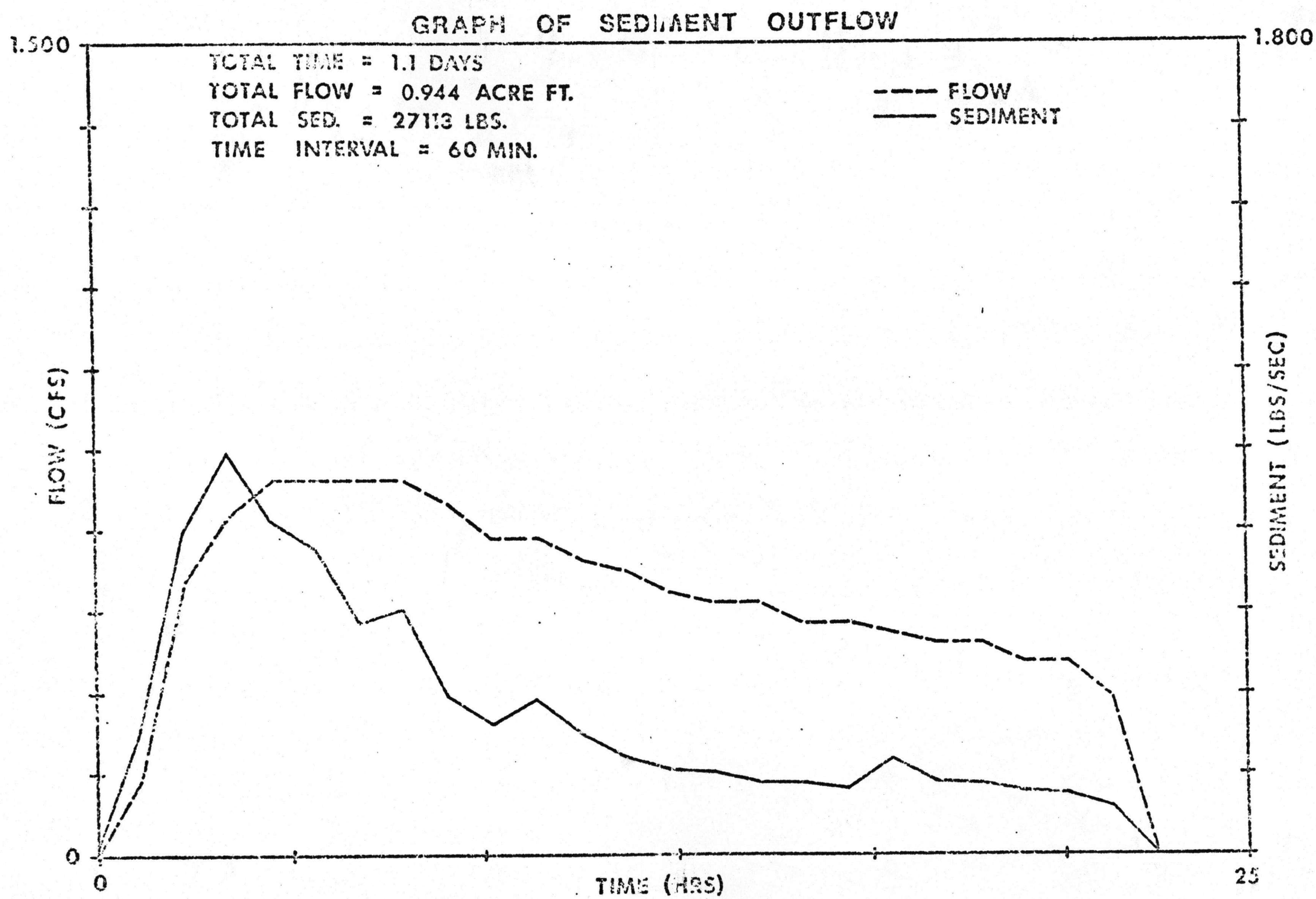


Fig. 8.--Graph of sediment outflow

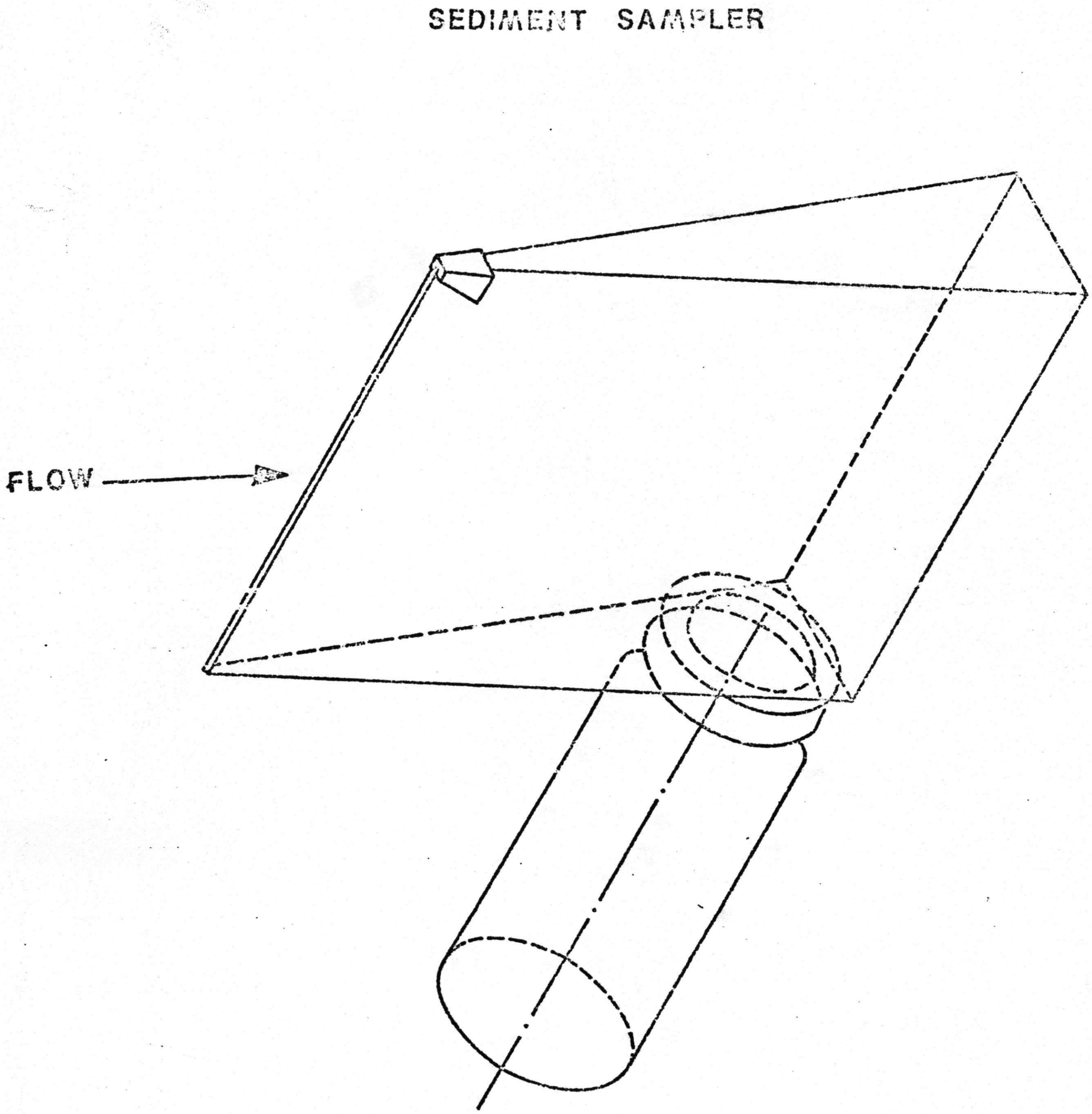


Fig. 9.--Sediment sampler

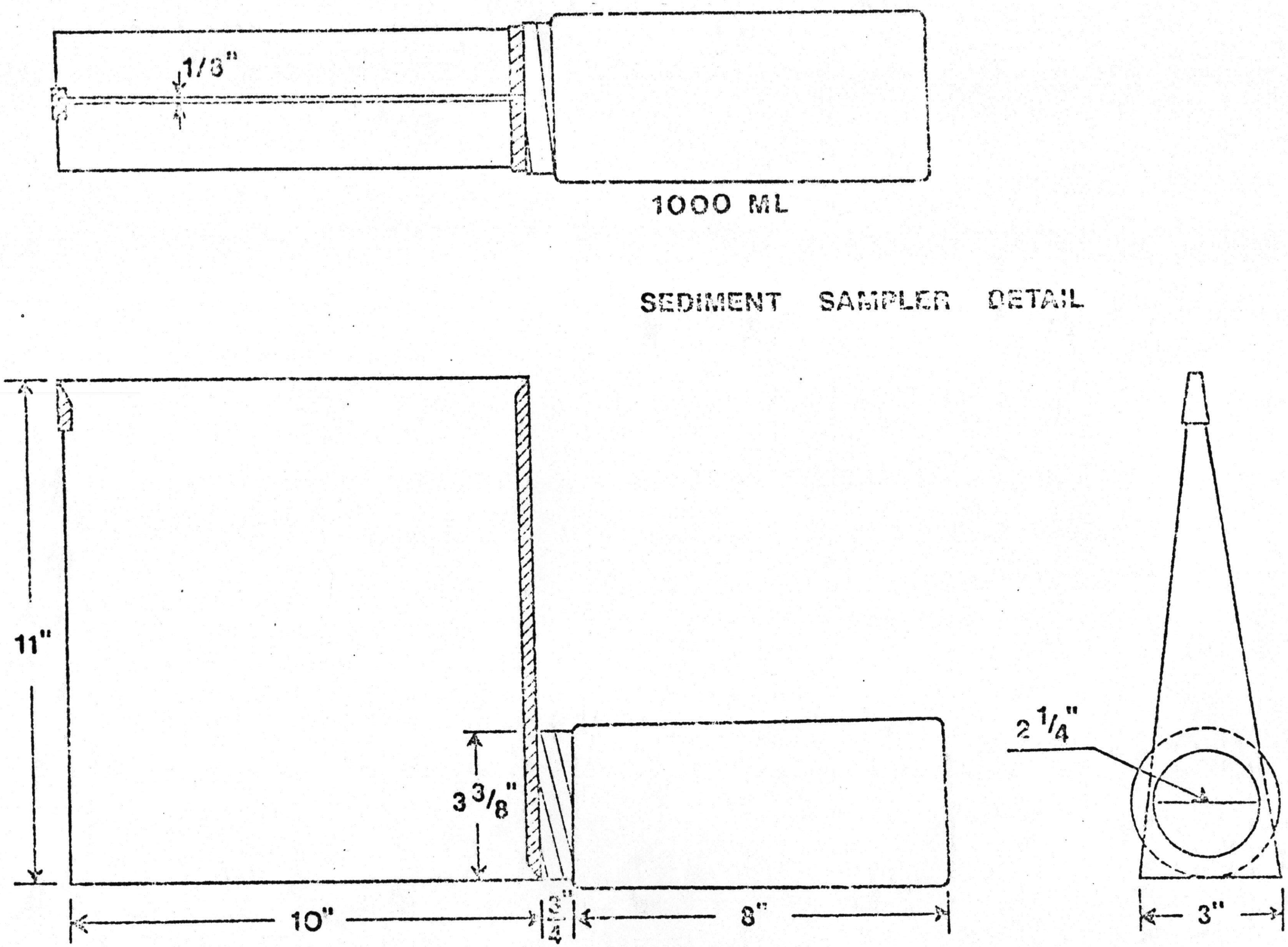


Fig. 10.--Sediment sampler detail

Fig. 11.--Automatic sampler

was observed. Because the flow needed to be measured more often, permanently placed flow devices such as trapezoidal flumes and headgates were utilized.

Sediment samples and flow measurements were taken once every hour for the first few hours and then at four-hour intervals for the remainder of the irrigation period. This time increment was selected because data from a previous study showed the changes over a period of four hours were slight except for the first two hours of the irrigation (Oliver, 1974).

Frequency of irrigation was usually based on antecedent moisture condition, crop, farmer intuition, or other criteria. The potato and bean fields were irrigated approximately every eight days throughout the season. The irrigations on the grain fields varied from seven to sixteen days, with an average of ten to eleven days. Most of the farmer cooperators were consistent in their watering schedule.

The phosphate determination required two samples for each observation, an unfiltered and a filtered sample. The latter sample had to be filtered immediately after being taken. This was accomplished by using a millipore filter with a hand vacuum pump. Both samples were then taken to the laboratory and H_gCl_2 added to each and then refrigerated. The H_gCl_2 was added to keep any microorganisms in the sample from utilizing the phosphate.

Reduction and Compilation of Data

Due to the large number of sediment samples which had to be analyzed for sediment concentration, a simple yet fast and effective vacuum filtration system was set up. It included eight Buckner funnels, eight Pyrex flasks, and a vacuum pump.

Each field sample was weighed and then filtered. The sediment left on the filter was then dried and weighed. The concentration in parts per million could be calculated from the sediment weight and volume of water in the original sample.

In order to calculate the total sediment yield for each irrigation, a computer program was used. The program had the ability to take the flow measurement, which was read from a staff gauge, and calculate the flow from the given flume equation. Therefore, it was necessary to enter only the staff gauge reading, sediment concentration, and the sample time for each observation. Once the above values were entered, the program would calculate and sum up the total amount of sediment and flow accumulated during the irrigation. Recognized laboratory procedures were used for nutrient determination.

Pertinent Variables

There are a great number of parameters affecting sediment yield. Pertinent parameters considered for this study were as follows: flow onto field, flow from the field, crop cover, soil type, slope, length of run, previous crop, climate, antecedent moisture conditions, area under cultivation, tillage and cultivation practices, fertility, and the type of irrigation. Some of the above parameters were consistent from field to field or are included within other variables; therefore, they were not used in the analysis. Flow onto and flow from the field, duration of irrigation, area under irrigation, soil type, crop cover, slope, and length of furrow were considered the most important variables affecting sediment yield for this study. Oliver (1974) found that by combining flow of water onto the field, total time of irrigation, and area under irrigation, a term Y could be formed which characterizes intensity or energy.

$$Y = Qt/A$$

where

Q = flow onto field in cubic feet per second

t = total time of irrigation in hours

A = area under irrigation in acres

Intuitively, the sediment yield from a given sized field will be directly proportional to Q and t. With increased flow, the energy available to erode and move sediment increases. Also the longer the water runs down a furrow, the greater the sediment yield will be for that field. This relationship must be referenced to a specific area to be significant.

An increase in sediment yield should be expected if there is an increase in slope. As the slope increases, the intensity of the flow increases, thus causing more sediment to be eroded away. The actual effect of furrow length on sediment yield cannot be seen as either increasing or decreasing it. As the furrow gets longer, it is necessary to apply more water to it so that it will run to the end of the furrow. This increase in energy at the beginning of the furrow possibly erodes a greater amount of sediment than it would under different conditions, but whether this eroded sediment ever makes it out of the furrow into the return flow is yet to be seen. However, there is a possibility that in earlier irrigations, length has a negative effect on sediment yield whereas in later irrigations the sediment eroded at the upper end of the furrow may start leaving the field thus increasing the sediment yield.

A clay particle can be eroded and carried along much easier than a sand particle because of the differences in size and weight. Therefore, as the particle size decreases, sediment yield should increase. The Bouyoucos Hydrometer Method was used for analyzing the particle sizes for each soil studied. The soils were classified by the triangular classification chart.

Summary of Irrigations

The number of irrigations for each field depended upon the crop, weather, and antecedent moisture conditions. Each of the bean fields (AB, WB, and BB) were irrigated six times not including a pre-irrigation for each. The pre-irrigation was not measured or used in the analysis because it is usually performed sometime in May. Sampling was not started until the early part of June when all the fields had been selected.

The CP field was irrigated twelve times over the season. The CS and SG fields were irrigated six times, the WG field four times.

In 1973, logistics prevented the sampling of every irrigation. This was due in part to several factors: communication between the farmer and technician, distance between the study fields and research station, and the inability to sample two fields at the same time. Therefore, it was necessary to study ponds and fields in 1974 that were closer together and nearer to the research station. It was also necessary to know when the irrigations were to take place. During the summer of 1974, only two and one-half irrigations were not sampled, whereas eight and one-half were missed in 1973.

Analysis

Two methods of analysis were utilized in this study for sediment yield prediction, modification of the Universal Soil Loss Equation and step-wise multiple regression.

The Universal Soil Loss Equation was compiled for heavy rainfall areas rather than irrigated areas by the United States Runoff and Soil Loss Data Laboratory (Ports, 1973). In an attempt to correlate sediment yield from areas under furrow irrigation and the yield given by the Universal Soil Loss Equation, the Y value discussed earlier was investigated to see if there was a relationship between Y and R, the rainfall factor. Using the available data from this study, no good correlation could be found. It was concluded that the

Universal Soil Loss Equation is not suitable for sediment yield prediction for fields under furrow irrigation. Oliver (1974) also found this to be true.

The basic regression program used was step-wise multiple regression with the following characteristic equation:

$$Y = a_o + a_1X_1 + a_2X_2 + a_3X_3 + \ldots + a_nX_n$$

where

Y = dependent variable

a_i = constant

X_1X_j = independent variables

Because of the great quantity of data amassed during the study, the computer program was utilized. By using step-wise regression the effect of each variable in the predictive equation could be determined.

The independent variables, flow onto the field, time the water ran down the furrow, area under irridation, slope, length of furrow, soil type, and crop type, were considered for this analysis.

Crop type was deleted because there were not enough observations for each individual crop to be analyzed. However, by observing the total sediment yields from all fields, the potato fields were consistently higher than the other crops studied. The bean and grain fields had approximately the same range of values. Further observations are needed in order to evaluate the effect of crop type. For the same reason, soil type could not be used as a parameter. The CS field was the only one that had a sandy loam soil. All others were either silt loam or loamy soils. Regression was run on the loamy soils at first, and the CS data were added later. It was found that no significant differences existed. Therefore, the analysis did not differentiate between soil types.

The data were tabulated according to irrigation and field and are shown in Table 2. The data were too sporadic for regression to be applied to the total sediment yield for the season; therefore, it was decided to derive a predictive equation for each irrigation. There were five to six observations available for each irrigation. Predictive equations utilizing Qt/A, length, and slope as the independent variables were found for each irrigation. The results of this analysis are tabulated in Tables 3 and 4.

Inspection of the coefficients show no consistent trends in either their magnitude or sign. The coefficients of determination do show that a high correlation does exist between the sediment yield and the independent variables. Irrigations two and six show the highest correlation and lowest standard error of the estimate, but the coefficients are not consistent. Therefore, the predictive equations are not sufficiently accurate or reliable to be used as such at this particular time.

Regression was also attempted using logarithmic transforms but with poor results. Oliver (1974) also found the

TABLE 2

FIELD SUMMARY SEDIMENT YIELD

Field	Time, hours	Inflow, cfs	Pounds sediment	Area, acres	Sediment yield, pounds/acre
CS1[a]	53	1.248	36622	5.472	6692.62
	53	1.248	24215	5.472	4425.26
CS2	51	1.248	18345	5.472	3352.52
	51	1.248	12130	5.472	2216.74
CS3	51	1.248	11000[b]	5.472	2010.23[b]
	51	1.248	6500[b]	5.472	1187.87[b]
CS4	51	1.248	8259	5.472	1509.32
	53	1.248	3675	5.472	671.60
CS5	42	1.248	5100	5.472	932.02
	41	1.248	2047	5.472	374.09
CS6	41	1.248	2717	5.472	496.53
	53	1.248	546	5.472	99.78
TOTALS			131156	10.944	11984.28
BB1	13	1.500	379	2.76	137.32
	14	1.500	332	2.76	120.29
BB2	13	1.500	581[b]	2.76	210.51[b]
	14	1.500	533[b]	2.76	193.12[b]
BB3	11	1.500	2117	2.76	767.03
	16	1.500	5582	2.76	2022.46
BB4	14	1.500	1850[b]	2.76	670.29[b]
	13	1.500	1427[b]	2.76	517.03[b]
BB5	13	1.500	2148	2.76	778.26
	14	1.500	1973	2.76	714.86
BB6	13	1.500	2195	2.76	795.29
	14	1.500	2526	2.76	929.35
TOTALS			21682	5.52	3927.89

TABLE 2 (CONTINUED)

Field	Time, hours	Inflow, cfs	Pounds sediment	Area, acres	Sediment yield, pounds/acre
WB1	13	1.2	639	9.881	64.67
	14	1.2	3523	9.881	356.54
WB2	13	1.2	593[b]	9.881	60.01[b]
	14	1.2	3815[b]	9.881	386.09[b]
WB3	26	1.2	1777[b]	9.881	179.84[b]
	25	1.2	11430[b]	9.881	1156.77[b]
WB4	25	1.2	2056	9.881	208.08
	26	1.2	2412	9.881	244.11
WB5	25	1.2	383	9.881	38.76
	26	1.2	12891	9.881	1304.63
WB6	25	1.2	314[b]	9.881	31.78[b]
	26	1.2	2023	9.881	204.74[b]
TOTALS			45902	19.762	2322.74
SG1	24	0.367	384	2.15	178.60
	42	0.378	1740	2.15	809.30
SG2	21	0.472	1534	2.15	713.49
	24	0.350	358	2.15	166.51
SG3	26	0.415	1870	2.15	869.77
	24	0.570	1581	2.15	735.35
SG4	25	0.916	2223	4.30	516.98
SG5	24	0.796	1082	4.30	251.63
SG6	25	1.075	477	4.30	110.93
TOTALS			11249	4.30	2616.05
WG1	23	0.554	909[b]	2.45	371.02[b]
	24	0.480	144[b]	2.45	58.78[b]
WG2	23	0.554	1301	2.45	531.02
	24	0.480	206	2.45	84.08
WG3	10	0.383	262	2.45	106.94
	11	0.228	44	2.45	17.96
WG4	14	0.405	127	2.45	51.84
	25	0.464	332	2.45	135.51
TOTALS			3325	4.90	678.57

TABLE 2 (CONTINUED)

Field	Time, hours	Inflow, cfs	Pounds sediment	Area, acres	Sediment yield, pounds/acre
ABPR[c]	29	0.150	932	2.17	429.49
AB1	13	0.338	809	2.17	372.81
AB2	11	0.146	552	2.17	254.38
AB3	16	0.231	1393	2.17	641.94
AB4	19	0.220	1458	2.17	671.89
Ab5	20	0.259	1048	2.17	482.95
AB6	12	0.350	870	2.17	400.92
TOTALS			7062	2.17	3254.38
CP1	22	1.423	24817	3.61	6874.52
	24	1.55	83394[b]	3.61	23100.83[b]
CP2	25	1.664	28520	3.61	7900.28
	27	1.450	16826	3.61	4660.94
CP3	26	2.65	117878	7.21	16326.59
CP4	26	1.0	22508	3.47	6486.46
	21	1.0	28703	3.48	8247.99
CP5	25	2.07	65363	6.95	9404.75
CP6	29	2.09	24465	6.95	3520.14
CP7	25	2.207	36989	6.95	5322.16
CP8	26	1.958	18775	6.95	2701.44
CP9	24	2.012	27113	6.95	3901.15
CP10	25	1.929	16949[b]	6.95	2438.71[b]
CP11	25	1.882	6785	6.95	976.26
CP12	24	1.847	6847	6.95	985.18
TOTALS			525932		74000

[a]Denotes irrigation number.

[b]Predicted values, not observed.

[c]Denotes pre-irrigation.

TABLE 3

REGRESSION EQUATIONS BY IRRIGATIONS

N	C_1	C_2	C_3	C_4	ST	R^2
			$S.Y. = C_1Y + C_2S + C_3L + C_4$			
1	+ 820.12	- 5574.32	+ 809.49	+ 313.90	455.33	0.990
2	+ 114.85	+ 316.85	+ 985.18	- 4718.30	72.66	1.000
3	- 129.13	+ 2462.16	+ 2841.57	-14494.77	638.76	0.998
4	- 271.17	+ 6447.38	- 403.14	- 4466.16	1045.92	0.939
5	- 376.02	+ 6683.93	+ 162.58	- 8002.09	2385.43	0.826
6	- 190.58	+ 1936.28	+ 307.35	- 2616.60	74.65	1.000

Key:
- S.Y. Sediment yield in pounds/acre
- N Irrigation number
- Y Qt/a where Q is in cfs, time T in hours, and area A in acres
- S Percent slope
- L Length of furrow in hundreds of feet
- ST Standard error of the estimate
- R^2 Coefficient of determination

TABLE 4

TABLE OF RESIDUALS FOR REGRESSION EQUATIONS

Irrigation	Field	Sediment yield, pound/acre		Residuals
		Observed	Estimated	
1	SG	494	865	-371
	AB	373	168	205
	BB	140	-12	162
	WB	211	251	-40
	CS	5561	5507	54
2	CP	6289	6279	10
	SG	440	477	-37
	WG	308	250	58
	AB	254	265	-11
	CS	2786	2806	-20
3	CP	16349	16303	46
	SG	802	414	388
	WG	62	-152	214
	AB	642	961	-319
	BB	1395	1723	-328
4	CP	7103	6855	248
	SG	517	1180	-663
	WG	94	556	462
	AB	672	-417	1089
	WB	431	901	-470
	CS	1091	833	258
5	CP	9405	8041	1364
	SG	252	188	64
	AB	483	-1460	1943
	WB	672	2255	-1583
	BB	747	2545	-1798
	CS	653	644	9
6	CP	3520	3528	-8
	SG	111	173	-63
	AB	401	379	22
	BB	862	832	30
	CS	376	358	18

data to be insufficient to produce a reliable predictive equation. He also analyzed sediment yield on an hourly basis with little success. The hourly run showed a poorer correlation than the analysis utilizing irrigations as an input variable; therefore, this analysis was not used in this study. Only the irrigations sampled were used in the analysis. Missing values were predicted either by using a regression equation or by proportioning between two known irrigations so that a sediment yield for the entire season could be derived for each field.

Utilizing the total yields for each field over the entire season, step-wise multiple regression yielded the following equation:

$$S.Y. = -31.072 - 0.096Y + 24.374S + 0.0046L$$

where

S.Y. = sediment yield in tons/acre

Y = Qt/A; Q in cfs, t in hours, A in acres

S = slope in percent

L = length in feet

The coefficient of determination was 0.799, and the standard error of estimate 8.431 tons/acre.

The range of sediment yield for three different crops is as follows:

1. Beans: 1.161 to 1.965 tons/acre
2. Grain: 0.339 to 1.308 tons/acre
3. Potatoes: 5.99 to 37.0 tons/acre

These values may be used to approximate the amount of sediment from a field with a specified crop on sandy loam to silt loam soils in southern Idaho.

Summary and Conclusion

The objective for this study was to determine sediment yield to ponds as a function of crop type, soil type, and topography. Sediment data from 1973 and 1974 were obtained from two potato fields, two grain fields, and three bean fields. The available data were not sufficient to allow evaluation of the applicability of the Universal Soil Loss Equation to fields under furrow irrigation. Step-wise multiple regression was found to have the most potential for analyzing data for sediment yield prediction. Using irrigation number as an input variable and Qt/A, slope, and length of furrow as independent variables, predictive equations for six irrigations were developed. Two of the six equations closely approximated the observed sediment yields. The predicted sediment yields from the second irrigation ranged from 0.16% to 19% lower and from 0.72% to 8.4% higher than the measured values. The predicted sediment yield from the sixth irrigation ranged from 0.23% to 57% higher and 3.5% to 5.5% lower. The fifth irrigation showed the largest range of values, 236% higher to 402% lower than the observed values. The coefficients (Table 3) were not consistent from irrigation to irrigation and therefore no conclusions as to the effect of each variable on the sediment yield could be drawn. It is concluded that the equations formulated are not reasonable enough to be used as predictive equations for sediment yield from fields under furrow irrigation.

Many factors contributed to the failure to obtain the desired results. The large number of variables involved, data collection problems, field selection, and inconsistent irrigation practices are those considered to have caused the greatest discrepancies.

Thirteen variables that were considered to have an effect on sediment yield were stated earlier. Because of the limited number of observations available, only five variables could be considered.

Crop type and cultivation practices are closely related to one another and do affect sediment yield. For example, a bean field may be cultivated each time after the first four irrigations, whereas a potato field is usually cultivated once after the first irrigation and a grain field is very seldom cultivated after the field has been irrigated. Furthermore, bean and grain fields usually have a slick, compacted corrugate, whereas a furrow in a potato field is loosely packed. Differences in sediment yield measured in the wheel and non-wheel row were observed. When a field is tilled, planted, or cultivated with the use of a tractor, two or three of every five furrows are compacted by the weight of the tractor. The farmer is usually careful to always run the tractor wheels in these rows, especially with beans and potatoes. The sediment yield measured from the non-wheel row was always higher than that measured in the wheel row. With additional observations, crop type can be utilized as an input variable for sediment yield.

Variables such as fertility and antecedent moisture conditions were not examined. Additional studies are needed in order to see what effect, if any, these variables have on sediment production.

Soil type was not used in the analysis because there were not enough observations taken to evaluate the sandy loam soil separately from the loam and silt loam soils. Several more observations are necessary in order to evaluate the effect of different soil types on sediment yield.

In 1973 several problems were noted once the fields had been selected and sampling began. There were instances when outflow from adjacent fields flowed through the same waste ditch as the field being monitored. Since only one flume was being used to measure the return flow, accurate measurements could not be obtained for the study field. Also the return flows from the other fields picked up and carried the sediment remaining in the waste from the study field past the flume. Part of the sediment left by flows was then measured when the study field was irrigated. Therefore, in those instances, it was impossible to measure accurately the amount of sediment which actually eroded from the study field.

Most of the fields monitored in 1973 were selected in the month of June. By this time, all the grain fields had been irrigated at least once, and several twice. The bean fields had been pre-irrigated and the first irrigation started. Due to the late start, several irrigations were not sampled.

As stated earlier, the inflow to the field was measured once and assumed constant for each irrigation. The water was found to actually fluctuate during the irrigation due to a number of factors. These included debris clogging tubes and furrow inlets so as to slow down or completely cut off flow to the furrow, fluctuation in the irrigation canal caused by the ditchrider increasing and decreasing flows to other users, and the irrigator making changes in the amount of water going onto the field at different times throughout the irrigations. The data collected in 1973 did not account for these changes.

Several of the fields monitored in 1973 required at least two sets to complete an irrigation. The farmer irrigated one-half of the field and then moved the water to the second half. It was found that the second set would pick up sediment left in the waste ditch by the first set and transport it through the measuring flume. Because the amount of sediment contributed from each set could not be differentiated, it was necessary to combine the sediment yield from the two sets into one total yield per irrigation.

Recommendations

For additional studies on sediment yield from fields under furrow irrigation, the following is recommended:

1. Variables should be evaluated very carefully before they are deleted or assumed constant from field to field or irrigation to irrigation.

2. Sufficient observations should be obtained so that crop type and soil type can be used as input variables.

3. Fields selected for data collection should be isolated from other waste flows which might cause problems with sediment measurement.

4. Monitored fields should be small enough so that a maximum of two days is required for a complete irrigation.

5. If each set is to be used as a complete irrigation unit for the purpose of analysis, the field should be irrigated every other row over the field. This causes the sediment yield from each set to be more uniform.

6. Field selection should be completed by early April, so that sampling can begin with the start of the irrigation season.

7. Smaller time increments for sampling should be used until more is known and understood about how sediment yield changes with time.

SETTLING PONDS

Scope of Study

The objective of this section was to develop engineering design criteria for farm settling ponds. Removal efficiencies for suspended and bed load were to be evaluated as a function of pond geometry, inflow discharge, and sediment loading. In addition to the above, measurements on the effectiveness of ponds to remove various nutrients was studied.

There were no references dealing directly with farm ponds available for this study. Most of the work and research dealing with settling basins has been in the sanitary engineering field. Much of the material found was on T. R. Camp's (1936) concept of the "ideal" settling basin, based on Hazen's (1904) work in 1904.

Description of Ponds

Eight ponds were studied, four in 1973 and four in 1974. They were located near the fields which were studied for sediment yield. The outflow from these fields was used as the inflow to the ponds. The ponds were either built by the farmer or constructed through the project. The Chojnacky Pond (CSP), Bulcher Pond (BBP), Hollifield Pond (HGP), and Walker Pond (WBP) were studied in 1973. The Coiner Pond (CPP), Spring Grain Pond (SGP), Winter Grain Pond (WGP), and Bean Pond (ABP) were observed during the summer of 1974. The WBP pond was not used in this study because accurate measurement at the outflow point was not possible. The lengths, widths, and depths of each pond are listed in Table 5. The ponds built by the farmers were BBP and HGP. The ponds constructed through the project were easier to collect data from and located near good roads for easier access than those built by the farmers.

TABLE 5

POND DIMENSIONS

Pond	Length, feet	Width inflow, feet	Width outflow, feet	Average depth, ft
SCP	47.90	9.60	9.60	6.30
BBP	93.00	57.00	45.00	2.50
HGP	217.00	15.00	22.00	2.40
SGP	40.80	9.60	9.60	5.50
WGP	51.00	9.00	22.00	3.63
ABP	31.50	9.20	9.20	4.60
CPP	56.00	10.00	10.50	3.25

All ponds were rectangular in shape, except for the WGP pond, which was triangular with the inflow at the apex. As the width increased, the depth was decreased, thus causing a sloping bottom. At the outflow of each pond studied in 1974 plastic liners were placed so samples could be taken without sediment being contributed from the waste ditch or overflow section. The Bean pond shown in Figure 12 is typical of the ponds studied.

Fig. 12.--Bean pond (ABP)

Data Collection

The procedures which were used for data collection and lab work were the same as those described earlier in the section on sediment yield. The inflow and outflow of each pond was monitored for sediment concentration, phosphate, nitrogen, nitrate, conductivity, and turbidity. Samples for nutrient determination were not taken until the pond had filled, and then at eight-hour intervals until the end of the irrigation period. The flow measurement was read at the inflow to the pond. During the summer of 1973 flumes were placed at each end of the pond to determine if a substantial amount of water was lost to evaporation and/or seepage. In all cases the difference, if any, between the inflow and outflow was negligible.

Sampling began as soon as the return flow entered the pond. Four-hour sampling increments were used, except during the first two hours after the water started flowing into the pond and after the flow started leaving the pond. During these time periods samples were taken at one-hour intervals.

"Ideal" Settling Basins

To give the reader a better concept of settling basins, the following ideas and "laws" were taken from T. R. Camp's work (1936).

Particles heavier than water are settled out or removed by gravitational settling. A discrete particle is one which retains its individual characteristics and when placed in a column of water will accelerate in velocity until the drag forces and the gravitational forces are in equilibrium. At this point the velocity of the particle will become uniform.

Newton proposed the first law for "drag" and when equated to the weight of a sphere in a fluid, Stokes' law was obtained as follows:

$$V_s = g(\rho_s - \rho)\, d^2/18\mu$$

or approximately

$$V_s = g(s_s - 1)\, d^2/18\nu$$

where

V_s = the settling velocity

g = acceleration due to gravity

ρ_s, ρ = mass densities of the particle and of the fluid, respectively

s_s = specific gravity of the particle

μ = dynamic viscosity

ν = kinematic viscosity

d = particle diameter

The above equation is applicable only for Reynolds numbers less than 1.

A rational theory of clarification for "ideal" settling tanks can be developed if certain simplifying assumptions are made. These were proposed by Camp as follows:

1. At all points in the basin the direction of flow is horizontal and the velocities are equal.

2. The concentration of suspended particles of each size is the same at all points in the vertical plant perpendicular to the direction of flow at the basin inlet.

3. All suspended particles maintain their shape, size, and individuality during settling and settle without interference. Hence, each particle is assumed to settle at constant velocity.

4. A particle is removed when it strikes the bottom.

Given the above assumptions, the path followed by a particle will have a velocity and a direction equal to the vector sum of the flow velocity V and the settling velocity of the particle V_s. The particle will settle in a straight line and all other particles of the same size, shape, and weight will move along parallel paths. All particles with settling velocities greater than the overflow rate, or the velocity at which a particle must travel from the surface of the inlet to the bottom across the length of the basin will be removed. This velocity is denoted as V_o and is shown in Figure 13. Particles with settling velocities less than V_o will be removed in the ratio of the settling velocity to V_o, the overflow rate.

$$r = \frac{V_s}{V_o} = \frac{A_s V_s}{Q}$$

where r is the removal, as a ratio, of particles settling at any velocity V_s less than the overflow rate V_o. A_s is the surface area of the tank corresponding to length L, and Q is the rate of discharge.

To calculate the total removal in a basin, an analysis curve can be constructed using settling velocity V_s as the abscissa and initial concentration X of particles with velocities of V_o or less as the ordinate, where X is expressed as a ratio of the initial concentration to the total concentration. A typical analysis curve is shown in Figure 14. The notation X_o denotes the value of X, corresponding to the overflow rate V_o. As stated earlier, all particles with settling velocity greater than the overflow rate V_o will be removed. The removal of these particles in terms of the total suspension will be $1 - X_o$. For particles having settling velocities less than V_o the following equation is given for their removal in terms of the total suspension:

$$r\,dX = \frac{1}{V_o} V_s\,dX$$

where dX is that ratio of the total suspension with $V_s < V_o$. The total removal of all particles is therefore

$$R = 1 - X_o + \frac{1}{V_o}\int_0^{X_o} V_s\,dX$$

Analysis

To develop engineering design criteria for farm settling ponds, it was necessary to find out what factors affected their normal efficiencies. T. R. Camp found by

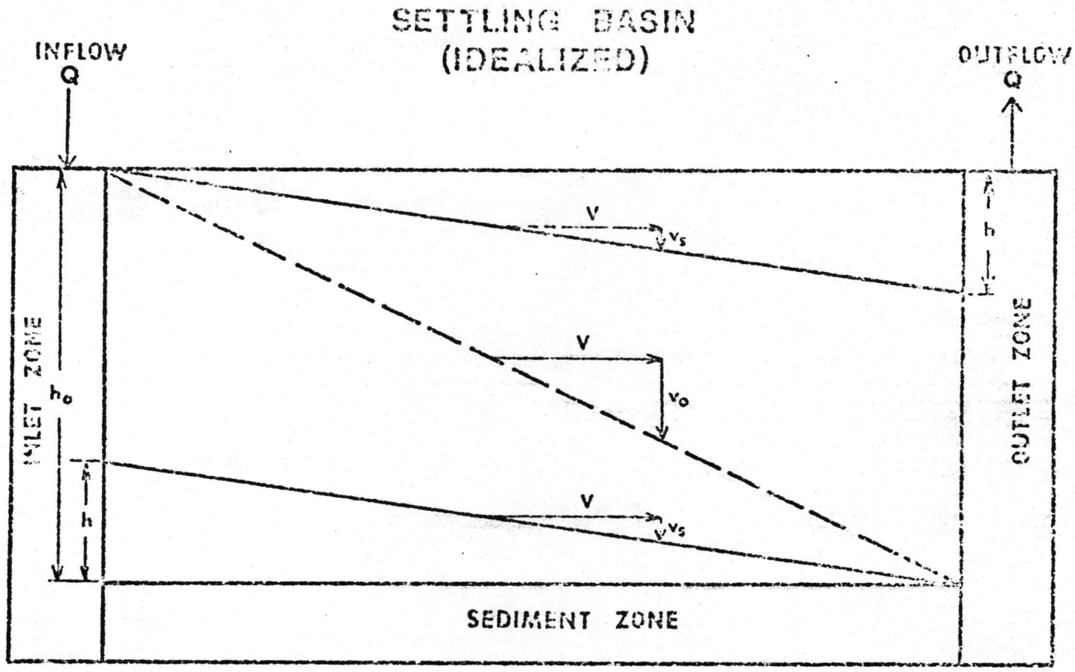


Fig. 13.--Settling basin schematic

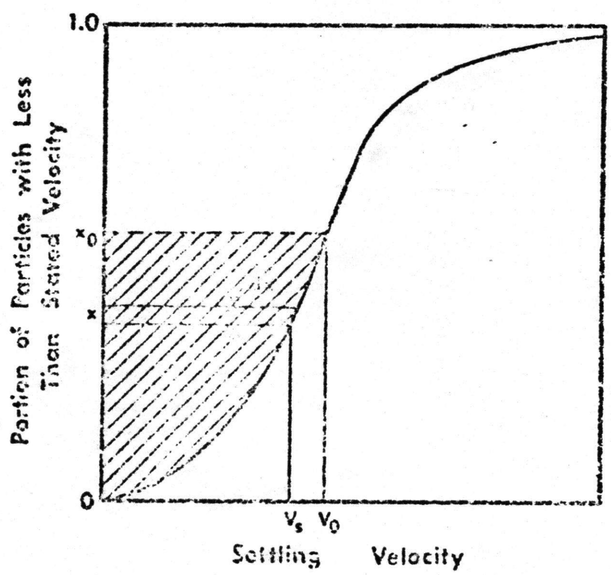


Fig. 14.--Analysis curve

analyzing an "ideal" settling tank that removal is independent of the depth for a given discharge and of the detention time. He also showed that for particles which have a settling velocity V_s less than overflow rate V_o the removal is directly proportional to the surface area of the tank for a given discharge or inversely proportional to the tank overflow rate (Camp, 1936).

The above findings are all based on an "ideal" settling tank which in reality does not exist, but it was proposed by T. R. Camp to be used as a yardstick by which basin performance may be measured.

Two approaches were taken for analyzing the data collected from the farm ponds. First, utilizing efficiency as a dependent variable and sediment size, overflow rate, length to width ratio, and detention time as independent variables, regression was run to determine what effect each had on efficiency. Second, the collected data were used to determine whether a mathematical model developed by Oliver (1974) could be useful as a tool for developing design criteria for farm ponds. The total sediment inflow and outflow for each irrigation are shown in Table 6.

Regression

For the regression analysis, the total removal efficiencies for each irrigation average overflow rates, length to width ratios, detention times, and sediment size (50% size of the field soil) for each irrigation were tabulated and are

TABLE 6

POND SEDIMENT INFLOWS AND OUTFLOWS

Pond	Sediment inflow, lb	Sediment outflow, lb	Sediment settled, lb
CSP1[a]	----	----	----
	24214	1203	23011
CSP2	18345	698	17647
	12130	675	11455
CSP3	----	----	----
	----	----	----
CSP4	8259	875	7384
	3675	230	3445
CSP5	5100	557	4543
	2047	95	1952
SCP6	2717	186	2531
	4117	546	3571
BBP[b]	1083	364	719
	1113	136	977
BBP1	379	88	291
	332	83	249
BBP2	1679	371	1308
	1525	351	1174
BBP3	2117	141	1976
	5582	750	4832
BBP4	----	----	----
	----	----	----
BBP5	2148	194	1950
	1973	137	1836
BBP6	2195	254	1941
	2565	196	2369
HGP3	555	168	387
	366	84	282
	115	65	50
	151	78	73
HGP4	193	56	137
	147	39	108
HGP5	27	3	24
	33	12	21

TABLE 6 (CONTINUED)

Pond	Sediment inflow, lb	Sediment outflow, lb	Sediment settled, lb
CPP1	4921	804	4117
	24817	4488	20329
CPP2	28520	4804	23716
	16826	3234	13592
SGP1	2124	235	1889
SGP2	1892	238	1654
SGP3	3451	328	3123
SGP4	2223	264	1959
SGP5	1082	155	927
SGP6	477	71	406
WGP1	----	----	----
	----	----	----
WGP2	1301	108	1193
	206	43	163
WGP3	262	21	241
	44	0	44
WGP4	127	1	126
	332	22	310
ABP Pre	932	177	755
ABP1	809	22	787
ABP2	552	17	535
ABP3	1393	145	1248
ABP4	1458	172	1286
ABP5	1048	158	890
ABP6	870	103	767

[a]Denotes irrigation.

[b]Observed irrigation for Bulcher Grain.

shown in Table 7. Simple linear regression was performed on each variable, utilizing efficiency as the dependent variable.

The regression analysis, utilizing the data from all ponds, gave no meaningful results as to the effect of each variable on efficiency. However, when running regression analysis on data collected from each pond separately, it was found that five of the seven ponds studied demonstrated the efficiency to be inversely proportional to the overflow rate.

Intuitively lower efficiencies should be expected in both a long narrow pond and a short wide pond. In a long narrow pond the flow velocity would be high compared to a wider pond and thus keeping the particles in suspension. Short circuiting could occur in a short wide pond, and much of the volume would be unused.

A large particle has a greater settling velocity than a small one; therefore, the efficiency of a pond should be higher when the larger particles are allowed to enter the basin, as opposed to smaller particles.

Mathematical Model

The mathematical model simulates the processes stated in the "ideal" settling basin concept discussed earlier. The model was set up so that the pond could be broken up into increments and each increment analyzed for sediment deposition, with respect to depth and volume. The main interest in this model was to input actual data and see how close the model could simulate the efficiencies obtained from the observed ponds.

TABLE 7

VARIABLES USED IN REGRESSION ANALYSIS

Pond	Average overflow rate, ft/sec X 10^{-4}	Average detention time, hr	Length to width ratio	Sediment size (50%) microns	Efficiency, percent
CSP1[a]	----[b]	----	----	200	----
	4.729	3.529	5:1	200	95.03
CSP2	4.410	3.461	5:1	200	96.20
	4.579	3.109	5:1	200	94.44
CSP3	----	----	5:1	200	----
	----	----	5:1	200	----
CSP4	6.222	1.956	5:1	200	89.41
	2.882	4.089	5:1	200	93.74
CSP5	5.881	1.956	5:1	200	89.08
	3.025	3.727	5:1	200	95.36
CSP6	6.222	1.787	5:1	200	93.15
	6.966	1.565	5:1	200	86.74
BBP[c]	1.063	6.53	1.82:1	36	66.39
	0.782	8.86	1.82:1	36	87.78
BBP1	0.270	25.67	1.82:1	36	76.78
	0.527	13.14	1.82:1	36	75.00
BBP2	0.860	8.04	1.82:1	36	77.90
	0.911	7.58	1.82:1	36	76.98
BBP3	0.586	11.76	1.82:1	36	93.34
	0.658	10.42	1.82:1	36	86.56
BBP4	----	----	1.82:1	36	----
	----	----	1.82:1	36	----
BBP5	0.649	10.43	1.82:1	36	90.78
	0.702	9.62	1.82:1	36	93.06
BBP6	1.048	6.43	1.82:1	36	88.43
	0.902	7.44	1.82:1	36	92.36
HGP3	1.385	4.81	11.73:1	22	69.72
	1.285	4.18	11.73:1	22	77.05
	1.793	3.71	11.73:1	22	43.48
	2.260	2.94	11.73:1	22	48.34
HGP4	1.400	4.76	11.73:1	22	70.98
	1.330	5.00	11.73:1	22	73.47

TABLE 7 (CONTINUED)

Pond	Average overflow rate, ft/sec X 10^{-4}	Average detention time, hr	Length to width ratio	Sediment size (50%) microns	Efficiency, percent
HGP5	0.386	17.24	11.73:1	22	88.88
	0.483	13.77	11.73:1	22	63.64
CPP1	1.603	5.99	5.46:1	20	83.66
	3.066	2.89	5.46:1	20	81.91
	----	----	5.46:1	20	----
CPP2	3.336	0.46	5.46:1	20	83.15
	1.514	0.27	5.46:1	20	80.78
SGP1	1.748	8.69	4.25:1	17.5	88.93
SGP2	3.369	4.46	4.25:1	17.5	87.42
SGP3	5.445	2.73	4.25:1	17.5	90.50
SGP4	6.453	2.26	4.25:1	17.5	88.12
SGP5	5.259	2.75	4.25:1	17.5	85.67
SGP6	2.740	10.53	4.25:1	17.5	85.11
WGP1	----	----	3.21:1	18.0	----
	----	----	3.21:1	18.0	----
WGP2	3.110	2.99	3.21:1	18.0	91.70
	1.590	5.82	3.21:1	18.0	79.10
WGP3	2.060	4.49	3.21:1	18.0	91.98
	0.987	9.38	3.21:1	18.0	100.00
WGP4	1.340	6.90	3.21:1	18.0	99.21
	2.470	3.75	3.21:1	18.0	93.37
ABP Pre	1.104	11.51	3.42:1	18.0	81.00
ABP1	1.829	6.89	3.42:1	18.0	97.30
ABP2	1.449	8.62	3.42:1	18.0	96.92
ABP3	2.830	4.36	3.42:1	18.0	89.59
ABP4	3.934	3.08	3.42:1	18.0	88.20
ABP5	3.658	3.27	3.42:1	18.0	84.92
ABP6	2.553	4.64	3.42:1	18.0	88.16

[a]Denotes irrigation.

[b]Irrigations not observed.

[c]Observed irrigation for Bulcher Grain.

The model inputs consist of the basin geometry, flow into the pond, sediment concentration and gradations, time increments, and special parameters used for control. The inputs of flow and sediment concentration and gradation can be changed for each time increment through the pond. (For this study each pond was isolated from any other flows; therefore, the sediment size and gradation were assumed constant from run to run, but the sediment concentration and inflow to the pond was variable.)

Three ponds were used in the analysis, CSP, CCP, and SGP. The actual values derived from the collected data and those obtained from the model are shown in Tables 8 and 9.

The measured and computed values for accumulated flow and sediment flow are not the same in many cases. The program used to calculate the total actual sediment yield uses the average concentration and discharge over the time period for summing up the sediment for each observation. The model assumes the initial concentration and inflow at the beginning to be constant over that time period until the next observation.

The three fields used for this analysis were chosen because the data collected from them were more complete. When the irrigation started, they filled much faster than the others. Also, the other fields were not used because of the large number of observations and subsequent data input required. In order to check the model against the actual data, an observation for each hour was used. Three data cards were needed for

TABLE 8

OBSERVED VALUES FROM SETTLING PONDS

Pond	Irrigation	Cumulative flow, acre feet	Cumulative sediment		Efficiency
			Inflow, tons	Outflow, tons	
SGP	1	0.351	1.0620	0.1175	88.94
SGP	2	0.478	0.9460	0.1190	87.42
SGP	3	0.729	1.7255	0.1640	90.50
SGP	4	0.531	1.1115	0.1320	88.12
SGP	5	0.449	0.5410	0.0775	85.67
SGP	6	0.289	0.2385	0.0355	85.11
TOTALS		2.827	5.6245	0.6455	88.52
CPP	1	0.422	14.869	2.646	82.20
CPP	2	0.578	22.673	4.019	82.27
TOTALS		1.000	37.542	6.665	82.25
CSP	1[a]	0.899	12.1075	0.6015	95.03
CSP	2	1.641	15.2375	0.6865	95.49
TOTALS		2.540	27.3450	1.2880	95.29

[a]Includes only one set of a total of two.

TABLE 9

OBSERVED VALUES FROM MATHEMATICAL MODEL

Pond	Irrigation	Cumulative flow, acre feet	Cumulative sediment		Efficiency
			Inflow, tons	Outflow, tons	
SGP	1	0.364	1.095	0.215	80.36
SGP	2	0.451	0.945	0.249	73.65
SGP	3	0.727	1.726	0.446	74.16
SGP	4	0.537	1.112	0.378	66.00
SGP	5	0.437	0.538	0.159	70.45
SGP	6	0.306	0.245	0.060	75.51
TOTALS		2.822	5.661	1.507	73.38
CPP	1	0.422	14.876	2.745	81.55
CPP	2	0.578	22.711	3.936	82.67
TOTALS		1.000	37.587	6.681	82.22
CSP	1[a]	0.899	12.123	0.550	95.46
CSP	2	1.641	15.260	0.595	96.10
TOTALS		2.540	27.383	1.145	95.82

[a]Includes only one set of a total of two.

each observation so, for example, the SGP pond had a total input time of ten days; this required 720 data cards for this field alone. There was neither time nor money available to run all the pond data. These fields gave good results and show the relationship between the observed values and those given by the model.

The values given in Tables 8 and 9 were for a one-length increment pond. It was found that when using more than one increment, the output was erroneous. The program showed an increase in sediment inflow and a decrease in efficiency as the number of increments increased. This was due to the fact that the program did not keep track of the position of the particles which were not settled in the first increment. The program re-distributes these particles uniformly as was the case when the flow first entered the pond, thus causing the particles to start settling over again. Most of the particles that would have settled in the second increment could not settle (according to the model) because it was shown in the first increment that their settling velocity was too small to settle out in that distance with that particular flow. The same is true as more increments are used. This is the reason why the indicated efficiency was reduced for an increased number of increments. The program computes sediment settled and sediment passed. Combining these two values should give the amount of sediment entering the pond. However, this value increased whenever the number of length increments was increased in the model. This was due to the program picking up and re-distributing that ratio of particles V_sA_s/Q which is assumed to settle out by the "ideal" settling basin theory. For each increment used, this material would be added to the amount settled, but would then be re-distributed and added in the next section.

The actual efficiencies of the SGP pond are shown to be higher than those given by the model. Under actual conditions various currents and interference from the velocity fields of closely spaced particles cause efficiencies to be less than what would be expected under ideal conditions. The reason for obtaining these results was that the model assumes a tank or basin to be full of water when the irrigation began, but in reality the SGP pond would not fill until four to eighteen hours after the inflow had begun. The same is true of the CSP and CPP ponds, though to a lesser extent. The CPP and CSP ponds took from one to four hours to fill, depending on the inflow. The total time which the return flow entered the pond was used because the total volume of sediment settled must be determined for a cleaning schedule to be estimated. These two ponds show the actual and estimated efficiencies to be very close.

The analysis did show the model to be useful as a tool for determining engineering design criteria, but the engineer must use judgment when applying it. The ponds used in the analysis had length to width ratios (L:W) of four to one and five to one; therefore, other ponds with different L:W ratios may not give equivalent results. Also these ponds had uniform geometry and well defined inlets and outlets, whereas most ponds constructed by farmers are somewhat less ideal. The surface area of ponds which have continuous flow throughout the season should be increased above that shown by the model. The model computes a maximum expected efficiency, and actual operating efficiencies will be lower.

Considerations besides those listed above should be studied for on-farm settling ponds. These include location, surface area, depth, cleaning schedule, and shape.

The pond should be placed where it will be out of the way of the farm machinery and so it will take up very little of the field area. Preferably the pond should be located in an area not farmable and away from residences, unless properly fenced.

The surface area should be determined by the amount of flow entering the pond and the sediment size. The writer recommends that the length to width ratio (L:W) be greater than three to one because of the possibility of short circuiting developing in ponds with a smaller L:W ratio.

The depth and cleaning schedule can be determined after the amount of sediment that will enter the pond each season is known. The volume can be adjusted to the capacity necessary to accommodate the incoming sediment for a specified time. If only a certain depth can be attained during construction and a larger volume is required, the surface area should be adjusted to make up the discrepancy.

The shape should be such that it is easy to build, maintain, and locate. The writer recommends rectangular ponds be used, unless ponds with different geometries are found to be better suited. Rectangular ponds are the easiest to build and maintain. Since most fields under furrow irrigation are fairly straight-sided, the rectangular pond normally will require smaller field area than ponds with other shapes. The triangular WGP pond mentioned earlier did not show any appreciable increase in efficiency over any of the other ponds with the same flow and sediment characteristics, but it did take longer to construct and utilized more field area than the rectangular ponds.

Nutrient Analysis

During the summer of 1974, phosphate, nitrogen, nitrate, conductivity, and turbidity samples were taken from ponds to determine removal efficiencies for the parameters. The ranges of values and average removals over the entire season were examined. These values for total nitrogen, total phosphate, and turbidity are tabulated in Table 10. The nitrates and conductivities are not shown because their values were either too small to be significant or showed no change across the pond.

Phosphate analysis was run on both filtered and unfiltered samples. Up to 98.0% of the phosphate can be tied up with the sediment; therefore, if a significant amount of

TABLE 10

NUTRIENT SUMMARY

Pond	Inflow range, mg/l	Outflow range, mg/l	Percentage removal, av. season
	Total phosphate		
WGP	0.120 - 2.867	0.0[a] - 1.206	34.60
SGP	0.240 - 10.802	0.0 - 2.800	39.20
ABP	0.400 - 13.200	0.0 - 1.000	49.70
CPP	0.800 - 62.676	0.0 - 12.660	77.73
	Total nitrogen		
WGP	1.92 - 13.40	0.0 - 12.75	28.60
SGP	3.87 - 159.79	0.0 - 77.47	25.10
ABP	9.80 - 92.99	0.0 - 20.90	58.40
CPP	75.15 - 597.64	0.0 - 83.22	75.20
	Turbidity		
WGP	34 - 300	0 - 100	4.30
SGP	40 - 2100	0 - 700	20.50
ABP	126 - 2000	0 - 400	35.50
CPP	2300 - 16200	0 - 4000	62.10

[a]0.0 because at times there was no outflow.

sediment is removed, a large portion of the phosphate will be reduced. The average efficiencies for phosphate removal across the pond ranged from 34.6% to 77.73%, whereas the sediment removal ranged from 82.2% to 91.4%. Phosphate removals are lower for the runoff from silt loam soils than from sandy soils since the phosphate is mainly tied up with the clay particles which are not effectively settled in the pond. However, a significant degree of phosphate removal can be achieved thereby keeping part of the phosphate from entering the waste stream and eventually a receiving stream.

The removals for total nitrogen ranged from 28.6% to 75.2%. It is believed that the nitrogen removed was organic. Several samples were filtered and analyzed for total nitrogen. These observations showed 89.4% to 96.5% of the total nitrogen to be non-soluble forms.

It was found that the turbidity removals were highest when a high concentration of sediment entered the pond. This was expected, but at the lower concentrations of sediment the turbidity was reduced very little, if any, as it crossed the pond.

Conclusion

The regression analysis did not provide sufficient justification for using overflow rate, L:W, and sediment size as parameters for developing engineering design criteria. A mathematical model based on the concept of "ideal" settling basins was found to be the best tool for pond design.

When using the model, engineering judgments must be made as to the size, shape, and location of each pond. By using different lengths, widths, depths, inflows, sediment concentrations, and gradiations, the model will determine the efficiency attained for these factors. By comparing several different designs, the appropriate one can be chosen. The designer must decide on the cleaning interval for the pond. This can be accomplished by estimating the sediment yield from the particular field and the approximate efficiency of the pond. The size of the pond can be changed depending on the cleaning interval. Also the designer must decide whether the pond should be located in the field or placed on unused land outside the field. Economic decisions must be made as to either having one pond for each field or using one pond to serve for the return flow from several fields.

The study demonstrated that between 43% to 100% of the sediment contained in irrigation return flows can be removed by using on-farm settling ponds. Also nutrients such as phosphate and nitrogen can be reduced through the use of ponds, such that their pollution effects on streams and rivers can be decreased.

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