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ANALYSIS AND DESIGN OF SETTLING BASINS FOR IRRIGATION RETURN FLOW

by

F.J. Watts
C.E. Brockway
A.E. Oliver

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INTRODUCTION

The purpose of this study was to develop and evaluate design criteria for sedimentation basins for irrigation return flow concentrated in drainage ditches.

Irrigation return flow can contain large quantities of silt, salts, nutrients and other matter resulting from farm irrigations and subsequent runoff. Even though all constituents entrained by the flow do not remain in transport, significant amounts eventually reach a receiving stream. Upon entering the stream, these materials are deposited or remain in the flow and are deposited at a later time and place. As a result, turbidity and total suspended solids of the receiving stream are increased by the influx of sediment, and the nutrient and salt content may be increased significantly.

Concern over the quality of surface water runoff from agricultural lands prompted this project to determine the quantities of sediment generated from gravity irrigated fields and the feasibility of remedial action by irrigation districts to improve water quality of return flow and subsequently that of the receiving stream. The University of Idaho College of Engineering, the Agricultural Research Service, USDA, at the Snake River Conservation Center at Kimberly, Idaho and the Northside Canal Company of Jerome, Idaho were involved in this study.

The sediment yield data were obtained from bean fields, sugar beet fields and a corn field located in the vicinity of Jerome, Idaho.

Each field was surveyed and mapped and measurements of discharge onto and off the field and sediment concentrations in the outflow were obtained for each irrigation. Sediment yield equations for sandy loam and loamy soil were developed and average sediment yield per acre per season was determined from the data.

The sediment removal efficiency of a settling basin on an irrigation return flow stream at the Jerome Golf Course near Jerome, Idaho was determined. Sediment content and discharge quantities in the pond influent and effluent were monitored. Velocity and temperature profiles and depths of settled sediment were obtained at two cross sections in the basin. The shape of the basin and location of the inlet precluded a rigorous analysis of the basin.

A computer program for simulating settling basin performance was developed and should be useful in basin design.

OBJECTIVES

The objectives of this study were as follows:

1. To determine sediment yield in tons per acre for several irrigated fields as a function of soil type and local topography, specie and age of cover crop, and the quantity and application rate of irrigation water.
2. To develop a procedure for determining the sediment input function for a settling basin constructed on a drain which served an irrigated area. This was to be accomplished by estimating the quantity of sediment entering the drain using data developed in objective one. Stream routing techniques in conjunction with appropriate sediment transport equations were to be utilized to estimate the quantity of sediment actually transported to the settling basin. The model was to be checked against data collected at a settling basin constructed on a drain.
3. To develop design criteria for determining geometric dimensions of a settling basin as a function of inflow discharge, associated sediment load, and the cleaning frequency specified for the basin.

Supervision for the experimental work and construction of facilities was divided among the three principal parties mentioned above. The results from this project and related studies are to be compiled and guidelines developed for pond design. These guidelines will be distributed to canal companies and other interested parties.

At the time the proposal was submitted it was assumed that financial support for the study would be obtained from the Office of Water Resources Research (O.W.R.R.), currently the Office of Water Research and Technology (O.W.R.T.) and from funds provided by irrigation and canal companies from southern Idaho. Two graduate students stationed at the ARS station in Kimberly under the supervision of University of Idaho personnel would conduct the studies on sediment yield from fields, sediment routing in drains, and would develop a computer model for sizing sediment basins.

Personnel associated with the Agricultural Research Service (ARS) at Kimberly accepted the responsibility of monitoring a large settling basin on the drain, provided office space and equipment needed for the studies, and provided personnel and supervision for analysis of data as well as a portion of the field data collection program.

The Northside Canal Company of Jerome constructed the settling basin, was helpful in recruiting participating farmers and provided useful suggestions relative to accomplishing the research objectives.

After the project was approved by OWRT the irrigation and canal companies were unable to produce the anticipated funds and it was necessary to curtail the scope of the project. After a careful review of objectives, the studies related to the routing of sediment were deferred and this report covers only the subjects described in objectives one and three listed above. The studies conducted by the ARS are scheduled to be completed in June of 1976. At that time all information will be compiled and a field manual describing the design of settling basins will be prepared.

SEDIMENT YIELD FROM IRRIGATED FIELDS

Scope of Study

The objective of this segment of the project was the development of design curves or regression equations for predicting the sediment production from irrigated fields. Sediment yield was to be determined as a function of soil type and local topography, specie and age of cover crop, and the quantity and application rate of irrigation water. A literature review was conducted to find pertinent information concerning sediment production from irrigated fields; however, few applicable references were found.

General Procedure

The hydrograph of total flow and associated samples of water-sediment mixtures were obtained for each field. The concentration of sediment in conjunction with the field hydrograph yielded sediment production on a total weight basis.

The hydrograph of inflow to the field was obtained to determine irrigation efficiencies and the effect of water quantity on the sediment yield. The topography and areas of the fields were necessary for calculating slope and yield per unit area.

Field Sites

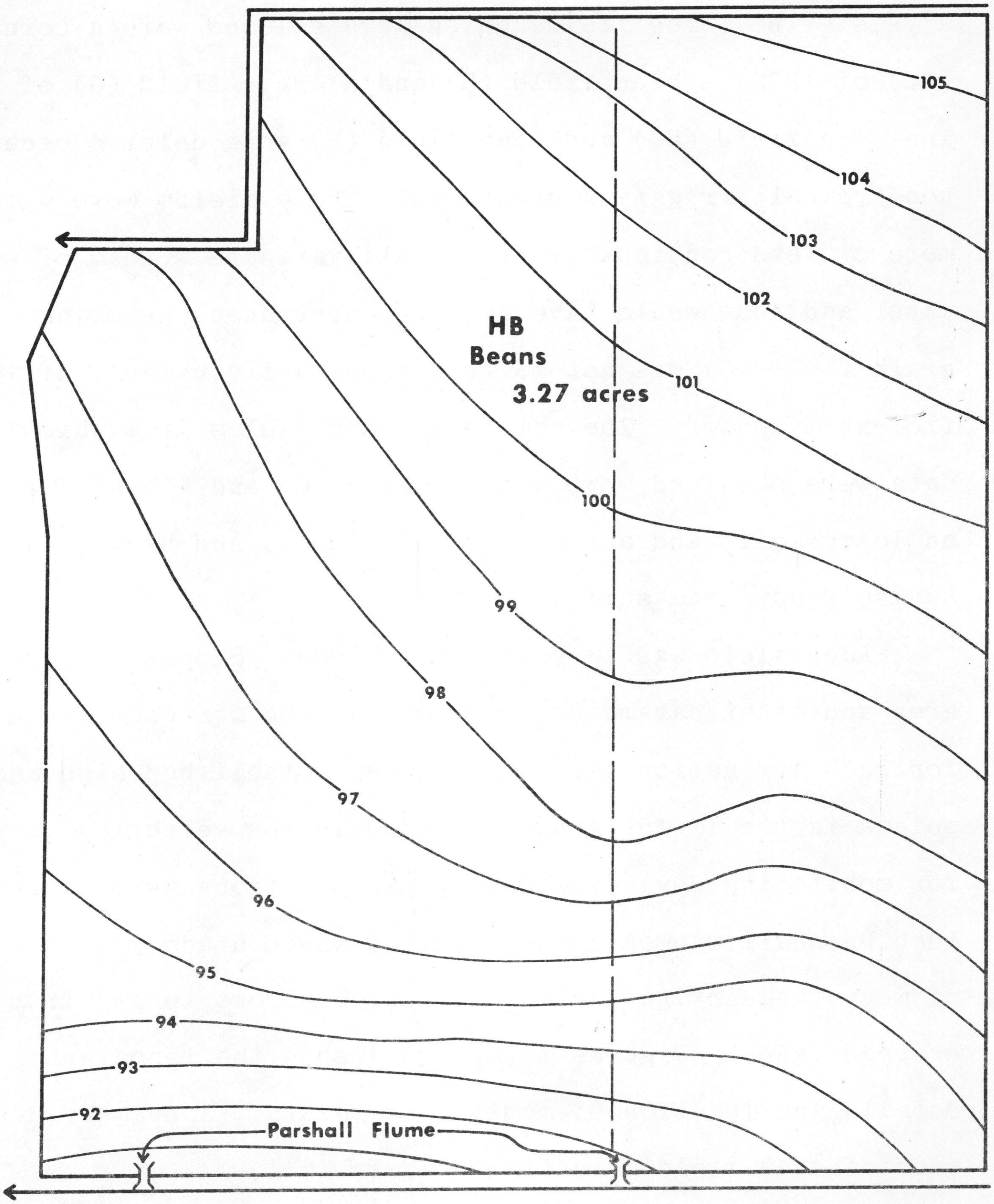
Seven fields north of the Snake River in the Jerome, Idaho area were selected for the study. During the summer of 1972 two bean fields and one corn field were monitored. One bean field, one corn field, one sugarbeet field and one wheat field were studied in 1973.

Of the seven fields monitored, four were selected for analysis. The three fields which were deleted were a corn field (HC) of 1972, a bean field (B) and a grain field (G) of 1973. The corn field (HC) and bean field (B) were deleted because of non-typical irrigation practices. These fields were watered more or less continually by a small variable stream of waste water and thus would have required continuous sampling. The grain field (G) was not monitored primarily because of insufficient manpower. The remaining four fields from which useful data were obtained were a corn field (C) and a bean field (HB) on loamy soil, and a sugar beet field (S) and bean field (RB) having sandy loam soil.

Each field was surveyed and mapped. Slopes, furrow lengths, area and other parameters were calculated for each field and for each irrigation set. The survey established high and low points in the fields and thus aided in the selection of positions for monitoring devices. Once these positions were chosen, three-inch Parshall flumes were installed where needed for the purpose of measuring irrigation inflows and outflows to and from the cropped lands. Figures 1 through 4 show the topography, general details and location of monitoring points. A summary description of each field is outlined in Table 1.

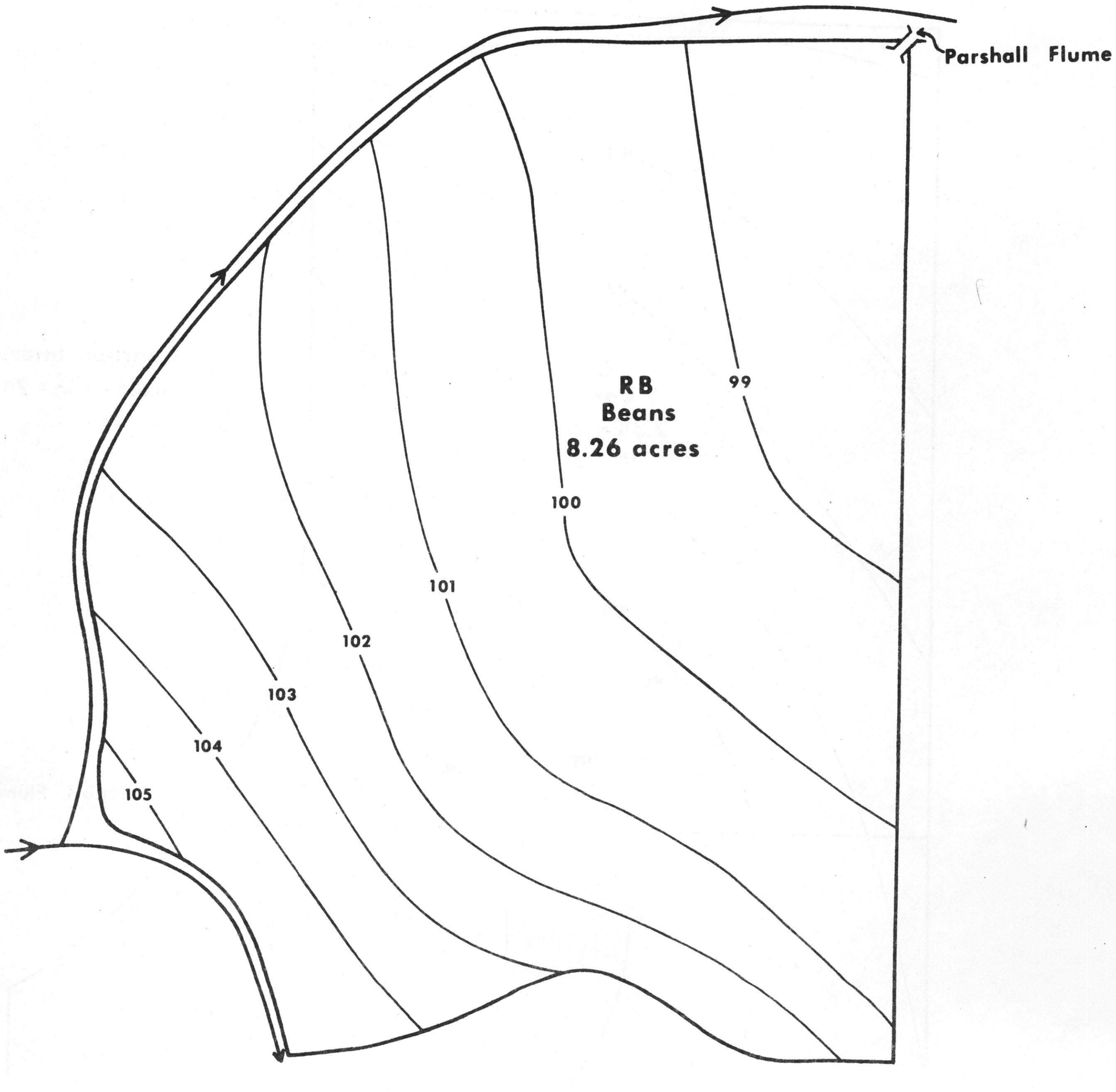
Sampling and Data Collection

For each field and each irrigation it was necessary to determine the total inflow onto the field, the outflow from the field and the concentration of sediment in the outflow. Since inflow remained constant during each irrigation, only



Contour Interval = 1 ft.
Scale: 1 in. = 95 ft.

Figure 1
Topographic Map of Bean Field HB



Contour Interval = 1 ft.
Scale: 1 in. = 118 ft.

Figure 2
Topographic Map of Bean Field RB

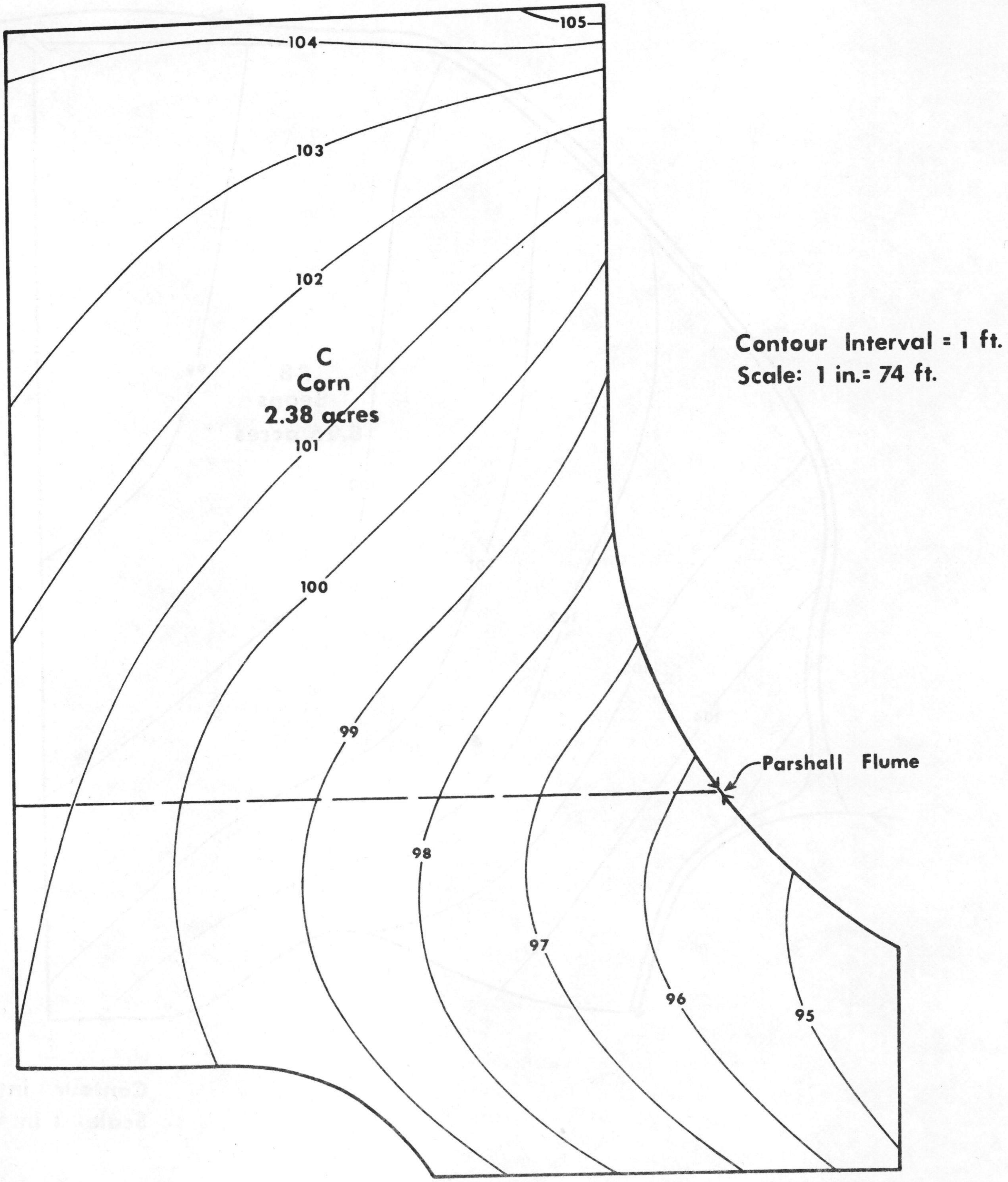


Figure 3
Topographic Map of Corn Field C

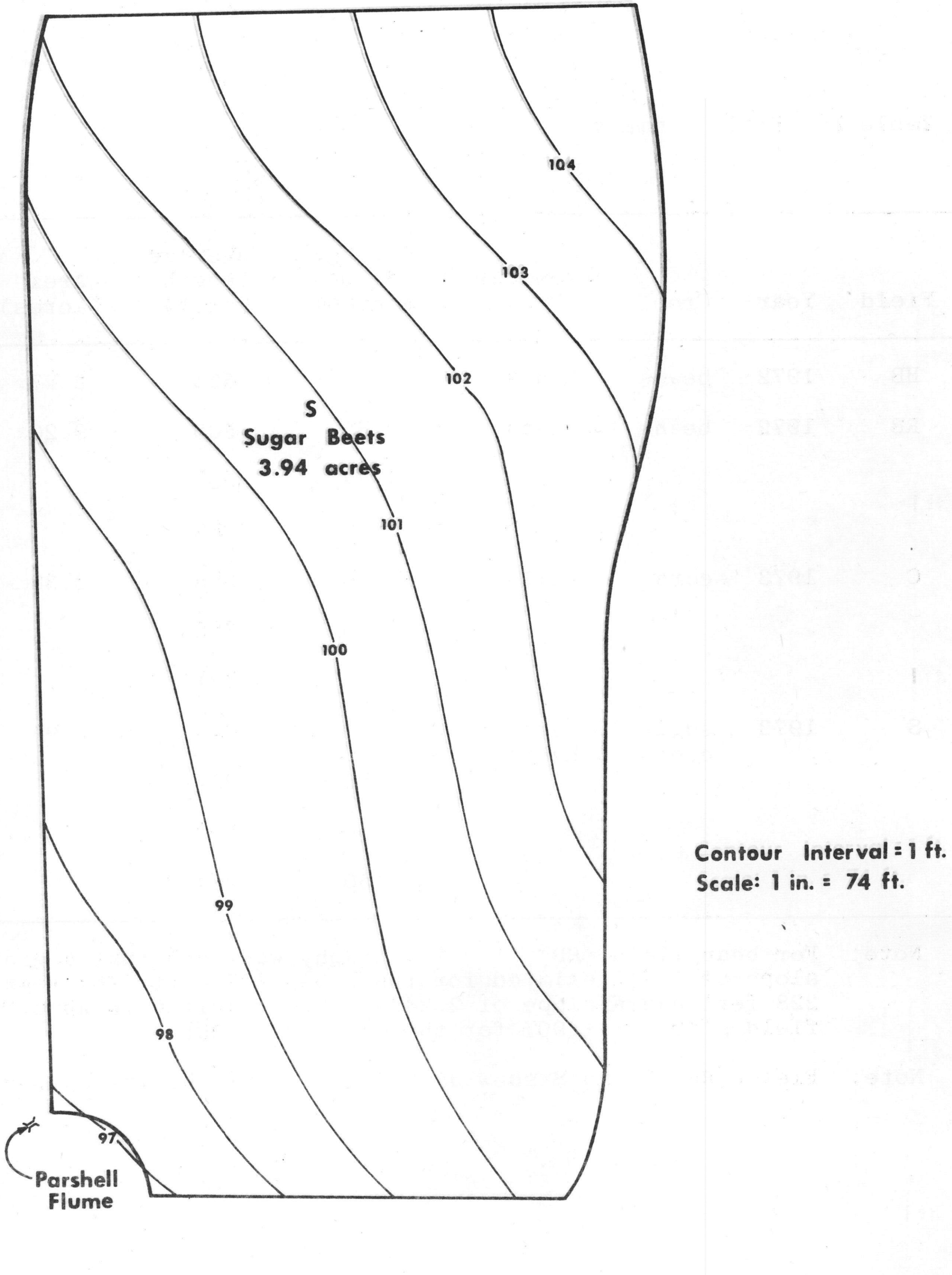


Figure 4
Topographic Map of Sugar Beet Field S

Table 1: Field Summary

Field	Year	Crop	Previous Crop	Average Slope (percent)	Average Length (feet)	Area (acres)	Soil Type
HB	1972	beans	beans	1.90	665	3.27	loam
RB	1972	beans	beans	0.85	505	9.26	sandy loam
				0.77	555		
				0.72	423		
C	1973	corn	fallow	1.50	288	2.38	loam
				1.30	280		
				1.40	281		
S	1973	sugar beets	sugar beets	1.43	320	3.94	sandy loam to sandy clay loam
				1.50	287		
				1.36	310		
				1.50	284		

Note: For bean field (HB), the topography was such that a gradual slope of 1.71% existed for the upper 437 feet; the remaining 228 feet had a slope of 2.24%. This resulted in an overall field slope of 1.90% for the 665 foot length.

Note: Fields RB, C and S show data for each of the irrigation sets.

one inflow measurement was taken. The other two quantitites were variable during the irrigation period. Discharge from the field and a one liter sample of water-sediment mixture were obtained at regular intervals ranging from thirty minutes to two hours or more during the irrigation set.

Samples of dry soil were taken at various points across each field for laboratory analysis to determine soil type and texture. Particle size distributions of the soils from the test fields were determined using the Buoyoucos hydrometer method. The results of this soil analysis of the four fields and the classifications are shown in Tables 2 and 3.

Table 2: Particle Size Analysis: 1972 Fields

Sample	1*HB	2 HB	3HB
% clay	21.2	20.2	17.2
% silt	40.0	43.6	38.0
% sand	38.8	36.2	44.8
soil	loam	loam	loam

Sample	1 RB	2 RB	3 RB
% clay	16.2	15.4	16.6
% silt	32.4	30.2	30.0
% sand	51.4	54.4	53.4
soil	sandy loam	sandy loam	sandy loam

* denotes sample number

Table 3: Particle Size Analysis: 1973 Fields

Sample	1* C	2 C	3 C
% clay	25.3	25.3	25.3
% silt	31.2	31.2	31.2
% sand	43.5	43.5	43.5
soil	loam	loam	loam

Sample	1 S	2 S	3 S
% clay	18.3	20.3	20.3
% silt	21.2	23.4	18.2
% sand	60.5	56.3	61.4
soil	sandy loam	sandy clay loam	sandy clay loam

Sample	1 B	2 B	3 B
% clay	23.3	22.1	22.3
% silt	27.2	26.2	24.2
% sand	49.5	51.7	53.5
soil	sandy clay loam	sandy clay loam	sandy clay loam

Measuring Devices and Equipment

Standard, three-inch galvanized Parshall flumes were used for measuring the flow from test fields.

The sampler shown in Figure 5 was designed and operated to obtain a representative sample of the full vertical profile of the sediment-water mixture at the end of the Parshall flume. The hydraulic jump which occurs in the throat of the Parshall flume afforded adequate mixing of the flow and field samples were obtained at that point. The sampler was rapidly placed

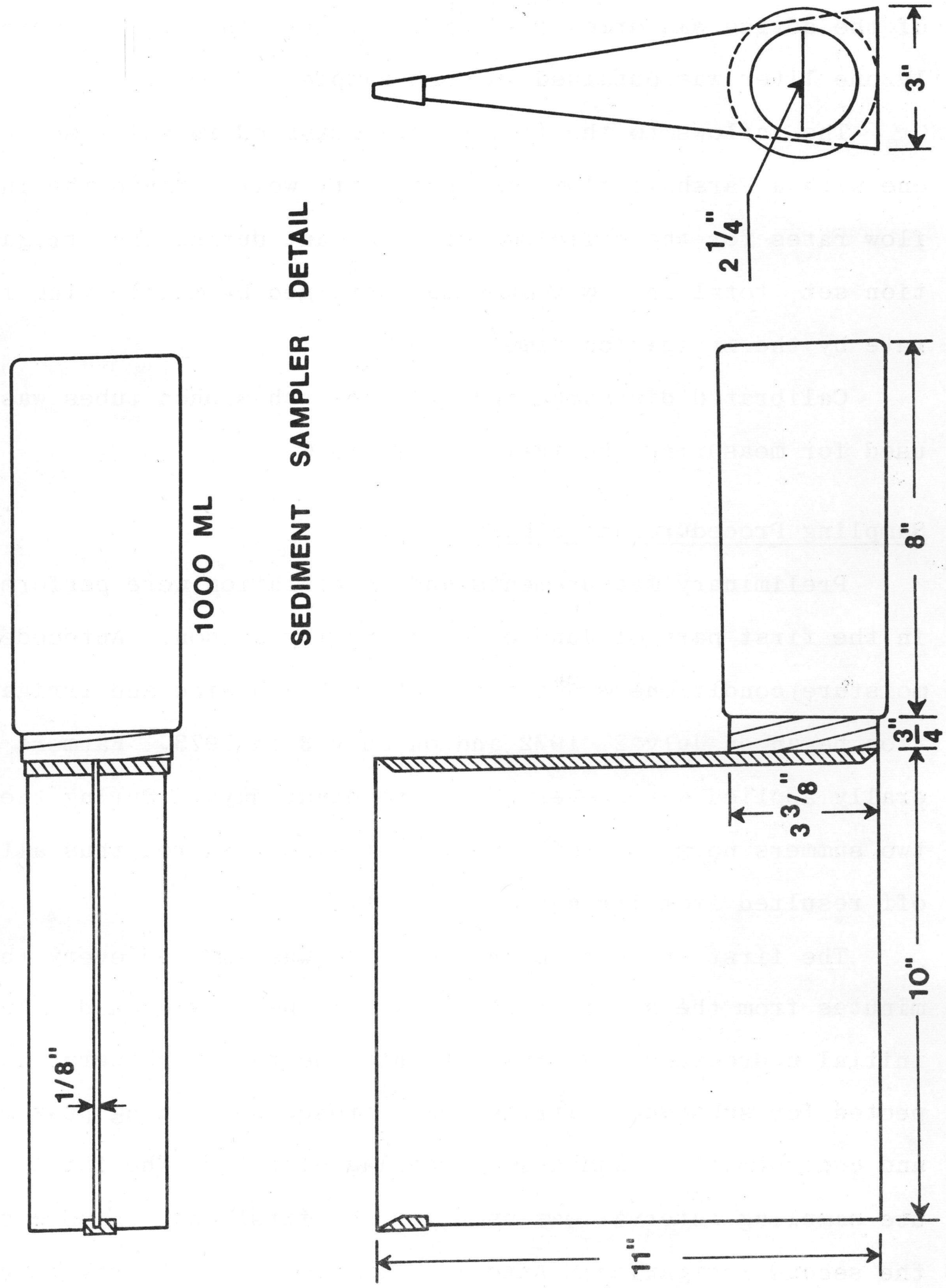


Figure 5
Sediment Sampler Detail

into the flow at the downstream end so that the vertical opening of the device was orientated directly into the flow. Approximately one liter was obtained in each sample.

The inflows to the fields were measured in all cases except one with a Parshall flume or Cipolletti weir. Since the inflow rates for these fields were constant during the irrigation set, total inflow volume was obtained by multiplying flow rate by the irrigation time.

Calibrated discharge through one-inch siphon tubes was used for measuring the inflow to field C.

Sampling Procedure and Schedule

Preliminary measurements and installation were performed in the first part of June of each growing season. Antecedent moisture conditions were consistent for each site and irrigation began on July 2, 1972 and on July 3 in 1973. Farmers generally applied water every seven to eight days. During the two summers no storms of significant size occurred thus all runoff resulted from irrigation activity.

The first irrigation on each site was sampled every thirty minutes from the start of runoff until the flow ceased. The initial hydrograph gave insight into the runoff patterns expected for subsequent irrigations, trends concerning peak runoffs and concentrations and associated lag effects. The thirty minute sampling interval was used for the first and, in some cases, the second irrigation. After the initial runs, thirty minute samples were obtained until the discharge stabilized; thereafter, samples were obtained every two hours until the flow ceased. For each of the sites the flow stabilized within the sixty to ninety minutes from the time runoff first reached the flume.

Irrigation Summary

Data on inflow and outflow discharge and sediment samples were collected for each field and for each irrigation throughout the growing season. The number of irrigations for each field was approximately the same. The two bean fields (HB) and (RB) for 1972 each had six irrigations. Field HB was watered in one irrigation set, but three sets per irrigation were required for field RB. The 1973 test sites were a corn field (C) having five irrigations of one set, and a sugar beet field (S) having up to three sets for each of the six irrigations. For computation purposes, however, only four of the five irrigations of the corn field (C) were utilized. The third irrigation of this field was abnormally small in comparison to the other runs, and was therefore not used in the predictive analyses.

Sediment samples of the inflowing irrigation water were not taken and evaluated. Field observations indicated that this contribution of sediment was small and would not alter the results obtained.

Reduction and Compilation of Data

The determination of total suspended solids was obtained by filtration using the procedure for nonfiltrable residue (APHA Standard Methods, 148C).

A computer program was developed and utilized to calculate and print total flow and total sediment loss from a field for each half hour increment of irrigation. When samples were taken at intervals longer than one half hour, the program interpolated between the actual data values and calculated the results at half hour intervals.

Input data for the program included the sampling interval in minutes (variable between samples), the Parshall flume staff gage readings in feet and the concentrations in parts per million. The program calculates the mass sediment flow for each time interval, integrates the total flow and prints the results. A sample computer output is shown in Table 4. A summary of sediment yields for the test fields is shown in Tables 5 and 6.

Analysis: Universal Soil Loss Equations

Measured sediment yields from irrigated test plots were compared to predicted yields using a modification of the universal soil loss equation. Large and inconsistent discrepancies existed between estimated values and measured values of sediment yield. It was concluded that based on this limited data, the universal soil loss equation cannot be used for predicting sediment losses from individual fields under furrow irrigation.

Analysis: Regression Equations

A second method of analysis was performed on the sediment yield data using regression techniques. A stepwise multiple regression program was used to examine the significance of each variable in the equation:

$$y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + \ldots\ldots a_nx_n \qquad (1)$$

where a_i is a constant and the x_j are the variables.

Table 4: Sample Computer Printout for Sediment Yield

Discharge Computations

Desc: HB3 720-21 0930Z Q and Sed
Time Interval = 30 min
Previous Accumulation of Acre Feet = 0

Equation of Rating Curve:	A	B	C	RANGE	N	M
	0.	0.99	0.	0. - 1.0	1.5	0.

Time (hrs)	Flow (cfs)	Acc. Flow (acre ft.)	Sed. Conc. (ppm)	Sed. Conc. (lbs/sec)	Acc. Sed. (lbs)
0.	0.	0.	14485.	0.	0.
0.5	0.204	0.004	14485.	0.185	166.134
1.0	0.308	0.015	15193.	0.292	595.486
1.5	0.319	0.028	13861.	0.276	1105.798
2.0	0.329	0.041	15217.	0.312	1636.072
2.5	0.339	0.055	15572.	0.351	2233.205
3.0	0.345	0.069	15492.	0.333	2849.089
3.5	0.350	0.083	14412.	0.315	3432.359
4.0	0.355	0.098	13051.	0.289	3976.132
4.5	0.361	0.113	11689.	0.263	4473.362
5.0	0.366	0.128	13330.	0.305	4984.243
5.5	0.372	0.143	14971.	0.347	5570.661
6.0	0.382	0.159	14166.	0.368	6187.841
6.5	0.393	0.175	13361.	0.328	6786.671
7.0	0.388	0.191	12518.	0.303	7354.569
7.5	0.382	0.207	11675	0.279	7877.996
8.0	0.388	0.223	11363.	0.275	8376.253
8.5	0.393	0.239	11051.	0.271	8867.962
9.0	0.366	0.255	10350.	0.251	9337.583
9.5	0.382	0.271	9648.	0.230	9770.240
10.0	0.382	0.287	8399.	0.200	10157.805
10.5	0.382	0.302	7149.	0.171	10491.702
11.0	0.382	0.318	7076.	0.169	10797.186
11.5	0.382	0.334	7002.	0.167	11099.514
12.0	0.386	0.350	6448.	o.156	11390.343
12.5	0.393	0.366	5893.	0.145	11660.999
13.0	0.393	0.382	6023.	0.148	11924.263
13.5	0.393	0.399	6152.	0.151	12193.250
14.0	0.388	0.415	5413.	0.131	12447.092
14.5	0.382	0.431	4674.	0.112	12665.389
15.0	0.382	0.447	4728.	0.113	12867.295
15.5	0.382	0.462	4781.	0.114	13071.499

$$Q = A + BH_a^{n} + CH_a^{m}$$

H_a is the gage height reading in the flume.

Table 5: Field Summary Total Sediment Yield

Field and Irrigation	Time Hours	Inflow cfs	Pounds Sediment	Area Acres	Yield Ton/Acre
HB1*	25.0	0.69	10850	3.27	1.659
HB2	20.0	0.69	23359	3.27	3.572
HB3	15.5	0.69	13071	3.27	1.999
HB4	23.5	0.69	18268	3.27	2.793
HB5	28.5	0.69	15492	3.27	2.369
HB6	27.0	0.69	7572	3.27	1.158
Total			88612	3.27	13.549
RB1	11.0	0.90	18	2.75	0.003
	11.0	0.90	51	2.75	0.009
	16.0	0.90	32	2.75	0.006
RB2	9.0	0.90	55	2.75	0.010
	11.5	0.90	135	2.75	0.025
	13.5	0.90	103	2.75	0.019
RB3	10.5	0.90	161	2.75	0.029
	10.5	0.90	432	2.75	0.079
	13.5	0.90	223	2.75	0.041
RB4	11.5	0.90	108	2.75	0.020
	10.5	0.90	97	2.75	0.018
	13.0	0.90	98	2.75	0.018
RB5	11.0	0.90	116	2.75	0.021
	11.5	0.90	39	2.75	0.007
	13.5	0.90	50	2.75	0.009
RB6	10.5	0.90	115	2.75	0.021
	12.5	0.90	13	2.75	0.002
	12.5	0.90	43	2.75	0.008
Total			1889	8.25	0.114

* denotes irrigation number

Table 5 (continued): Field Summary Total Sediment Yield

Field	Time Hours	Inflow cfs	Pounds Sediment	Area Acres	Yield Ton/Acre
C1**	21.5	1.008	560	2.593	0.108
C2	22.0	0.874	1155	1.992	0.290
C3	19.5	0.364	68	1.230	0.028*
C4	21.0	0.565	386	1.640	0.118
C5	23.5	0.850	1745	1.983	0.440
Total			3914	1.888	1.037
S1	23.0	1.200	1740	1.135	0.767
	21.5***	1.200	632	1.271	0.249
	23.0***	1.200	200	1.226	0.082
S2	23.0	1.200	98	1.600	0.031
	29.0	1.200	366	1.500	0.122
S3	21.0	1.200	460	1.700	0.135
	17.5	1.200	410	1.618	0.127
S4	23.5	1.200	756	2.099	0.180
S5	14.5	1.200	2.7	1.269	0.086
S6	9.5	1.200	166	1.041	0.080
	11.0	1.200	235	1.191	0.100
Total			5280	2.61	1.142

* This irrigation was not included in other calculations since it was so small in comparison to other irrigations; it was not representative. It is included here since it did contribute to the total sediment loss.

** Denotes irrigation number.

*** Denotes irrigation set.

Table 6: Time Distribution of Sediment Yield (pounds)

Field HB

	Irrigation Number					
Hr	1	2	3	4	5	6
2	482	2659	1636	2116	1202	816
4	1440	6190	3976	3963	2558	1749
6	2331	9428	6187	5520	3989	2671
8	3230	12438	8376	7147	5346	3627
10	4191	15434	10158	8379	6629	4387
12	5060	17936	11390	9737	7831	5127
14	5795	19734	12447	11028	8888	5676
16	6567	21214	14000*	12868	9804	6114
18	7573	22443	16000*	14590	10635	6488
20	8714	23359	18000*	16092	11303	6811
Q	0.69	0.69	0.69	0.69	0.69	0.69 cfs
A	3.27	3.27	3.27	3.27	3.27	3.27 acre

Field C

	Irrigation Number			
Hr	1	2	4	5
2	32	58	48	239
4	70	150	97	431
6	116	176	142	609
8	166	251	179	791
10	217	468	215	970
12	284	659	252	1134
14	351	789	287	1275
16	412	876	322	1392
18	468	1003	351	1486
20	523	1102	373	1576
Q	1.008	0.874	0.565	0.850 cfs
A	2.593	1.992	1.640	1.983 acres

* Denotes estimate values

Table 6 (continued): Time Distribution of Sediment Yield (pounds)

Field RB

	Irrigation Number					
Hr	1	2	3	4	5	6
			Set 1			
2	2.5	11.7	27.3	20.4	20.6	18.4
4	5.4	25.7	58.0	51.1	39.3	48.2
6	8.7	39.2	85.9	73.6	57.5	67.3
8	12.3	51.7	121.5	91.3	95.9	97.8
10	16.4	60.9*	158.2	104.2	112.6	114.7
			Set 2			
2	7.1	28.7	23.8	7.9	6.5	4.6
4	17.8	61.8	56.6	26.4	19.5	8.7
6	30.7	87.8	105.9	48.5	28.1	10.2
8	42.3	108.4	356.8	73.4	34.1	11.8
10	50.2	123.9	418.0	95.8	37.1	12.7
			Set 3			
2	0.9	20.4	53.2	9.3	10.1	4.1
4	4.6	39.6	114.3	28.2	22.5	13.5
6	9.0	57.7	164.0	47.9	32.3	22.4
8	14.2	73.4	191.3	66.4	41.0	32.2
10	18.8	88.5	209.7	81.7	48.4	41.0
12	23.5	100.9	223.8	96.8	50.1	42.6
Q	0.9	0.9	0.9	0.9	0.9	0.9 cfs
A	2.75	2.75	2.75	2.75	2.75	2.75 acre

* Denotes estimated values

Table 6 (continued): Time Distribution of Sediment Yield (pounds)

Field S

Hr.	Irrigation Number 1	2	3	4	5
			Set 1		
2	96	9	41	23	39
4	222	25	84	58	79
6	358	38	134	104	115
8	509	46	175	179	147
10	675	55	213	290	175
12	848	62	249	434	199
14	1027	70	290	571	216
Q	1.20	1.20	1.20	1.20	1.20 cfs
A	1.135	1.600	1.700	2.099	1.041 acre
			Set 2		
2	96	9	41	23	
4	222	25	84	58	
6	358	38	134	104	
8	509	46	175	179	
10	675	55	213	290	
12	848	62	249	434	
14	1027	70	290	571	
16	1212	78	356	665	
18	1400	85	397	696	
20	1579	91	444	716	
22	1716	96	448*	742	
Q	1.200	1.200	1.200	1.200 cfs	
A	1.135	1.600	1.700	2.099 acre	
			Set 3		
2	76	21	56		
4	178	46	116		
6	291	68	164		
8	379	86	204		
10	432	101	239		
12	473	117	276		
14	510	167	320		
16	544	214	369		
Q	1.200	1.200	1.200 cfs		
A	1.271	1.500	1.618 acre		

* Denotes estimated values

The program selects the independent variable having the greatest correlation with the dependent variable and develops an equation based on least squares analysis. The next succeeding significant variable is entered and the resulting equation using two variables is obtained. This process continues until all independent variables have been processed. In this manner, a comparison of the derived equations can be made and the significance of any single variable can be established.

The parameters selected for analysis were the soil type or characteristics, field slope, furrow length, the irrigation number, and the terms QT/A and QT/AL. Q is the inflow in cubic feet per second, T is the duration of water application, A is the area irrigated and L is the length of furrow. The cover crop was not used as a variable in the analysis since the plants did not grow into the furrow in any of the four test fields, and in no case was flow hindered by the cover crop.

The regression analysis was performed using data on all irrigations for each soil type. Two fields (C and HB) had soils classified as loam; the other two fields (RB and S) were sandy loam. Predictive equations for sediment yield were therefore developed for a loamy soil and for a sandy loam soil. This division was adhered to throughout the analysis.

Sediment yield for each field was tabulated according to soil type, field, irrigation number, time of sample after the initial flow started, inflow, and total area. Two significant trends were observed. The highest sediment yield rate occurred in the initial hours of irrigation, suggesting that perhaps the furrows became armoured to some extent once the easily eroded sediments were removed. The second trend was that the greatest sediment loss from a field occurred around the third irrigation rather than the first. This may indicate that sediment routing within the furrows is highly significant. Supposedly, not all of the sediment loosened by the first irrigations reached the sampling point until subsequent irrigations completed the transport.

One method of approaching the problem of sediment yield by regression methods suggested processing the data according to the irrigation sequence. Since magnitudes of sediment appeared to increase until the third irrigation, this approach seemed reasonable. For each of the soil types (loam and sandy loam) the data from all the first irrigations were combined; likewise, the information for each of the subsequent irrigations was incorporated as data sets for irrigations 1, 2, 3, . . . etc. Equations for predicting sediment yield were determined for: loam-irrigation 1, loam-irrigation 2, etc., sandy loam-irrigation 1, sandy loam-irrigation 2, etc. These results are tabulated in Tables 7 and 8. There were two forms for each of these equations. One utilized the independent variables slope, length and QT/A, the other slope and QT/AL. It should be noted that for the loam soil (Table 7) field slopes were not significantly different and consequently the slope parameter was not significant in the multiple regression.

As can be seen from these tables, there were no consistent equations or trends. The magnitudes of the coefficients of the variables were not consistent; the signs for the coefficients also were not consistent from equation to equation. It was

Table 7: Regression Equations
Loam Soil by Irrigations

Three Variable (example)

Irrigation Number		R^2
1	$SY = - 88.7 L + 535.7 Y + 23517$	0.70
2	$SY = -290.3 L + 1151.4 Y + 78598$	0.76
3	$SY = -224.6 L + 1150.6 Y + 58759$	0.76
4	$SY = -191.9 L + 842.0 Y + 59040$	0.74

Two Variable (example)

Irrigation Number		R^2
1	$SY = 6835 S + 167878 Y' - 12481$	0.74
2	$SY = 22917 S + 368741 Y' - 40005$	0.79
3	$SY = 11860 S + 345333 Y' - 19866$	0.79
4	$SY = 11721 S + 256398 Y' - 19722$	0.77

S	Percent slope
L	Length of furrow in feet
Y	QT/A with Q in cfs, time T in hours and A in acres
Y'	QT/AL
SY	Sediment yield (pounds)
R^2	Coefficient of determination

Table 8: Regression Equations
Sandy Loam Soil by Irrigations

Three Variable (example)

Irrigation Number		R^2
1	$SY = -\ 7.59\ S + .004\ L + 73.9\ Y - 127.6$	0.94
2	$SY = -\ 7.64\ S + .136\ L + 7.7\ Y - 19.1$	0.44
3	$SY = 0.00\ S + .309\ L + 30.9\ Y - 87.0$	0.84
4	$SY = +\ 66.29\ S + .178\ L + 71.5\ Y - 230.7$	0.94
5	$SY = +\ 65.41\ S + .051\ L + 14.6\ Y - 73.4$	0.88
6	$SY = +348.38\ S + .164\ L + 18.7\ Y - 215.6$	0.82

Two Variable (example)

Irrigation Number		R^2
1	$SY = -\ 87.40\ S + 22915\ Y' - 8.33$	0.91
2	$SY = -\ 59.01\ S + 2397\ Y' + 92.92$	0.44
3	$SY = -177.27\ S + 9654\ Y' + 243.42$	0.76
4	$SY = -\ 74.73\ S + 22520\ Y' + 15.51$	0.97
5	$SY = -\ 16.14\ S + 4632\ Y' + 6.85$	0.90
6	$SY = -448.00\ S + 8946\ Y' + 352.00$	0.73

S	Percent slope
L	Length of furrows in feet
Y	QT/A with Q in cfs, time T in hours and A in acres
Y'	QT/AL
SY	Sediment yield (pounds)
R^2	Coefficient of determination

apparent that the equations were inadequate for prediction of sediment yield from a field.

Time of run at sampling rather than irrigation number was used as an input variable in a second attempt at arriving at a predictive equation. For each of the two soil classifications, all of the data which were collected at a specified time after runoff began were grouped together. This procedure yielded grouping in the form of: loam-2 hour sample, loam-4 hour sample, etc., sandy loam-2 hour sample, sandy loam-4 hour sample, etc. Although some irrigation sets ran longer than twenty hours, data for only the first twenty hours was used, thus data from all irrigations could then be utilized. These data also were processed for the variable sets of slope, length, QT/A, and slope and QT/AL. The results are shown in tables 9 and 10. No trends of significant value for a predictive tool were apparent. The equations and individual coefficients varied from period to period and R^2 values were not satisfactory.

Conclusions

A design curve or a regression equation to determine sediment yield from a field or basin was an important objective of the project. The regression analysis of the data did not yield a single general equation that gave good predictive results for the sites. It was found, however, that the equations for a given soil type based upon irrigation number gave significantly better results than those obtained using hourly data input. The irrigation number equations provided yield estimates which were consistently within plus or minus 100% of the actual

Table 9: Regression Equations
Loam Soil by Time Increments

Three Variable (example)

Hour		R^2
2	SY = 355 S - 25 L + 854 Y + 6104	0.58
4	SY = 988 S - 51 L + 687 Y + 12065	0.60
6	SY = 1604 S - 74 L + 603 Y + 17435	0.61
8	SY = 2247 S - 96 L + 581 Y + 22550	0.62
10	SY = 3004 S - 115 L + 630 Y + 26370	0.62
12	SY = 3697 S - 131 L + 632 Y + 29436	0.62
14	SY = 4227 S - 144 L + 608 Y + 32103	0.63
16	SY = 4777 S - 157 L + 563 Y + 34914	0.65
18	SY = 5440 S - 169 L + 527 Y + 37225	0.67
20	SY = 6034 S - 180 L + 494 Y + 39406	0.68

Two Variable (example)

Hour		R^2
2	SY = 1416 S + 288,528 Y' - 1296	0.57
4	SY = 3132 S + 283,132 Y' - 2669	0.59
6	SY = 4733 S + 294,656 Y' - 3696	0.60
8	SY = 6329 S + 291,231 Y' - 5354	0.61
10	SY = 7871 S + 256,230 Y' - 7095	0.61
12	SY = 9209 S + 231,016 Y' - 8585	0.61
14	SY = 10279 S + 213,791 Y' - 9701	0.62
16	SY = 11391 S + 209,924 Y' - 10690	0.64
18	SY = 12561 S + 204,460 Y' - 11823	0.66
20	SY = 13627 S + 199,477 Y' - 12835	0.67

S	Percent slope
L	Length of furrow in feet
Y	QT/A with Q in cfs, time T in hours and A in acres
Y'	QT/AL
SY	Sediment yield (pounds)
R^2	Coefficient of determination

Table 10: Regression Equations
Sandy Loam Soil by Time Increments

Three Variable (example)

Hour		R^2
2	$SY = 9.8\,S + 0.014\,L + 21.9\,Y - 14.2$	0.41
4	$SY = 21.8\,S + 0.049\,L + 25.7\,Y - 40.4$	0.41
6	$SY = 82.0\,S + 0.005\,L + 41.3\,Y - 42.6$	0.43
8	$SY = 0.0\,S + 0.022\,L + 30.1\,Y - 21.7$	0.48
10	$SY = 38.6\,S + 0.503\,L + 43.0\,Y - 317.4$	0.34
12	$SY = 64.6\,S + 0.418\,L + 41.4\,Y - 317.3$	0.38
14	$SY = 3136.2\,S + 16.798\,L + 30.6\,Y - 9461.9$	0.62

Two Variable (example)

Hour		R^2
2	$SY = -60.8\,S + 17742\,Y' + 38.1$	0.55
4	$SY = -140.3\,S + 21064\,Y' + 88.9$	0.55
6	$SY = -218.4\,S + 21275\,Y' + 136.0$	0.55
8	$SY = -260.3\,S + 19723\,Y' + 177.7$	0.42
10	$SY = -164.5\,S + 15372\,Y' + 121.8$	0.39
12	$SY = -266.3\,S + 20242\,Y' + 92.9$	0.40
14	$SY = -237.3\,S + 18262\,Y' + 91.6$	0.15

S	Percent slope
L	Length of furrow in feet
Y	QT/A with Q in cfs, time T in hours and A in acres
Y'	QT/AL
SY	Sediment yield (pounds)
R^2	Coefficient of determination

values. The other equations yielded results which were in the plus or minus 200% range.

For a sandy loam soil, a representative equation for predicting sediment yield from a furrow irrigated field was obtained by utilizing all of the data for this soil type. This equation is:

$$\text{Sed Yield} = 0.015\ L + 48\ QT/A - 67$$

with an R^2 value of 0.632.

The equation for a loamy soil was obtained in a similar manner. The resulting equation is:

$$\text{Sed Yield} = 2887\ S - 136\ L + 1032\ QT/A - 30469$$

with an R^2 value of 0.528.

For the above equations, the slope (S) is used as a percentage; the length of furrow (L) is in feet. The units for discharge (Q), length of irrigation (T), and the area (A) are in cubic feet per second, hours, and acres, respectively. This gives sediment yield as pounds of sediment leaving the field per irrigation.

For each of the test fields the total sediment yield for the growing season was determined. The yield was divided by the average area irrigated to find the production rate in tons per acre per field. The sediment yield obtained in this manner are as follows:

Corn field (C) with five irrigations	1.037 tons/acre
Sugar beet field (S) with six irrigations	1.143 tons/acre
Bean field (HB) with six irrigations	13.549 tons/acre
Bean field (RB) with six irrigations	0.114 tons/acre

The maximum yield from the bean field (HB) is not representative of the fields in that area. A rock ledge which extends across the field has created an exceptionally steep slope (2.24%) and this contributes to high velocity in the furrow. Good water management was practiced on the field with the minimum yield, indicating the level of improvement which can be achieved with no capital investment. For design, a sediment yield of 1.2 to 1.3 tons/acre is suggested.

It should be emphasized that these predictive equations and average sediment yields were derived from specific fields in a particular region and should be used accordingly.

Additional field data are needed before any predictive equations which are applicable to a wide range of field conditions can be developed. This study indicates that there is a good possibility of developing reasonable equations if sufficient interest and funds are available.

SETTLING BASINS

Objective number three of this project was oriented toward settling basin performance and the development of design criteria for obtaining the geometric dimensions of a basin.

Preliminary measurements of velocity, temperature and distribution of deposited sediment in an existing basin were obtained. A two dimensional digital model for the simulation of a settling basin was developed.

Preliminary Measurements in a Settling Basin

A settling basin located on the Jerome Golf Course approximately five miles south-southeast of Jerome, Idaho was available for study. The basin was constructed parallel to an existing canal with diversion structures at each end of the pond. Pond influent and effluent were monitored for discharge and sediment concentration. A slight curvature in the alignment of the pond and the location of the entrance of the canal at a right angle to the basin axis complicated the analysis. The settling basin, however, is strategically located with respect to the thirty-five square mile drainage; it was the only large basin available with known inflow and outflow quantities and therefore was selected for preliminary measurements.

The basin was approximately 500 feet long, 60 feet wide and averaged five feet in depth. The inflow entered at the head end of the basin at a right angle to the pond axis; no baffle or inlet control devices were present. The outlet from the pond consisted of a weir which served as the discharge measuring device. An automatic stage recorder was used in conjunction with the weir.

The average daily discharge through the basin ranges from 2 to 26 cubic feet per second with a mean daily flow of 11.4 cfs.

Two sections of the pond were selected where velocity and temperature profiles, depths of water, and the associated depths of sediment were measured. The first section was approximately 35 feet downstream from the inlet and the second was 50 feet downstream from the first station.

A cable marked in ten-foot intervals was stretched across the stream at the measuring section. A small row boat attached to the cable was used for a measuring platform. Temperature and velocity measurements were taken at the 0.2, 0.5 and 0.8 depths. At each of these depths temperature was measured with a probe (manufactured by Precision Scientific Company) attached to a rod. The probe was lowered into the flow such that very little interference was realized from the rod or the boat. The calibration of the unit was checked in the laboratory; readout was correct to plus or minus $0.2^{o}C$. At each of the three depths a velocity measurement was obtained with a Neyrpic propeller type midget current meter.

A soil probe was pushed through the soft sediment until it reached the hard soil of the basin bottom and the depth of settled sediment determined. The probe consisted of a long steel rod with a point on one end for easy penetration. Circular discs, concave upward and spaced at two-inch intervals were attached to the lower portion of the rod. By observing the positions of the retained sediments, the sediment depth was read to the nearest two inches. The velocity data, temperature profiles and depths of sediment are plotted on Figures 6 and 7.

Basin Characteristics

Various phenomena in the pond were readily visible to an observer or can be deduced from a study of Figures 6 and 7. Curvature of the basin near the inlet caused the stream to concentrate on the outside of the bend, forming a large eddy at the head of the pond. Although the geometry of the pond was simple and the velocity small, negative velocities were recorded.

The temperature profile data exhibited no specific trends and no temperature stratification within the basin was evident. This implied that considerable mixing of the flow in the basin occurred, possibly enhanced by the shallow depth of the basin.

From the soil probe data, it was qualitatively evident that the heavier particles settled out near the entrance while the smaller ones settled farther downstream as was expected. The depths of sediment at the head end of the basin are shown in Figures 6 and 7. The depths of sediment at the lower end of the basin were only two to three inches.

Basin Performance

Even though the inflow velocity distribution and pond geometry were not as uniform as desired, the Golf Course pond removal efficiencies are reasonably good. The overall trap

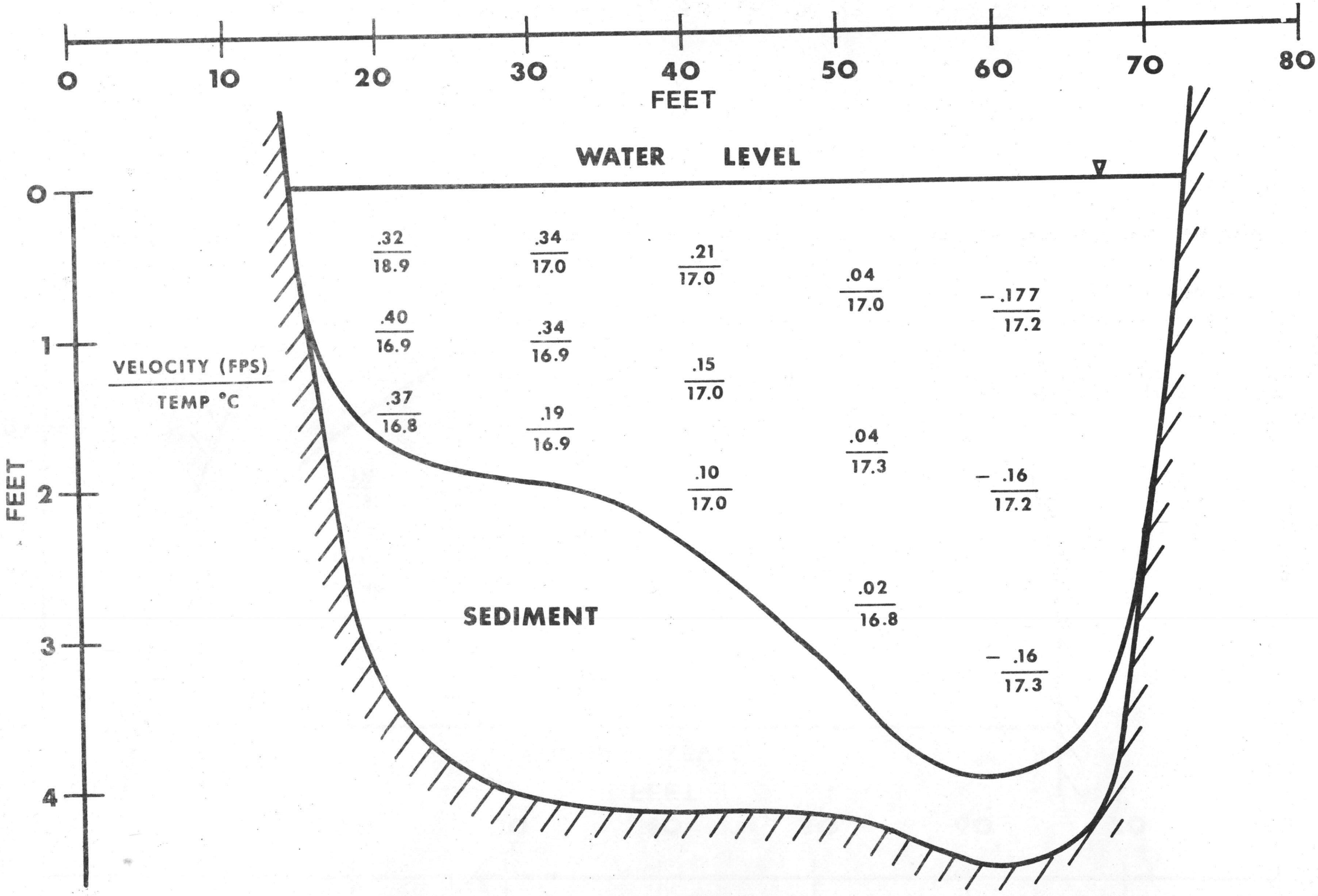


Figure 6

Velocity and Temperature Profile, Jerome Golf Course, Section 1

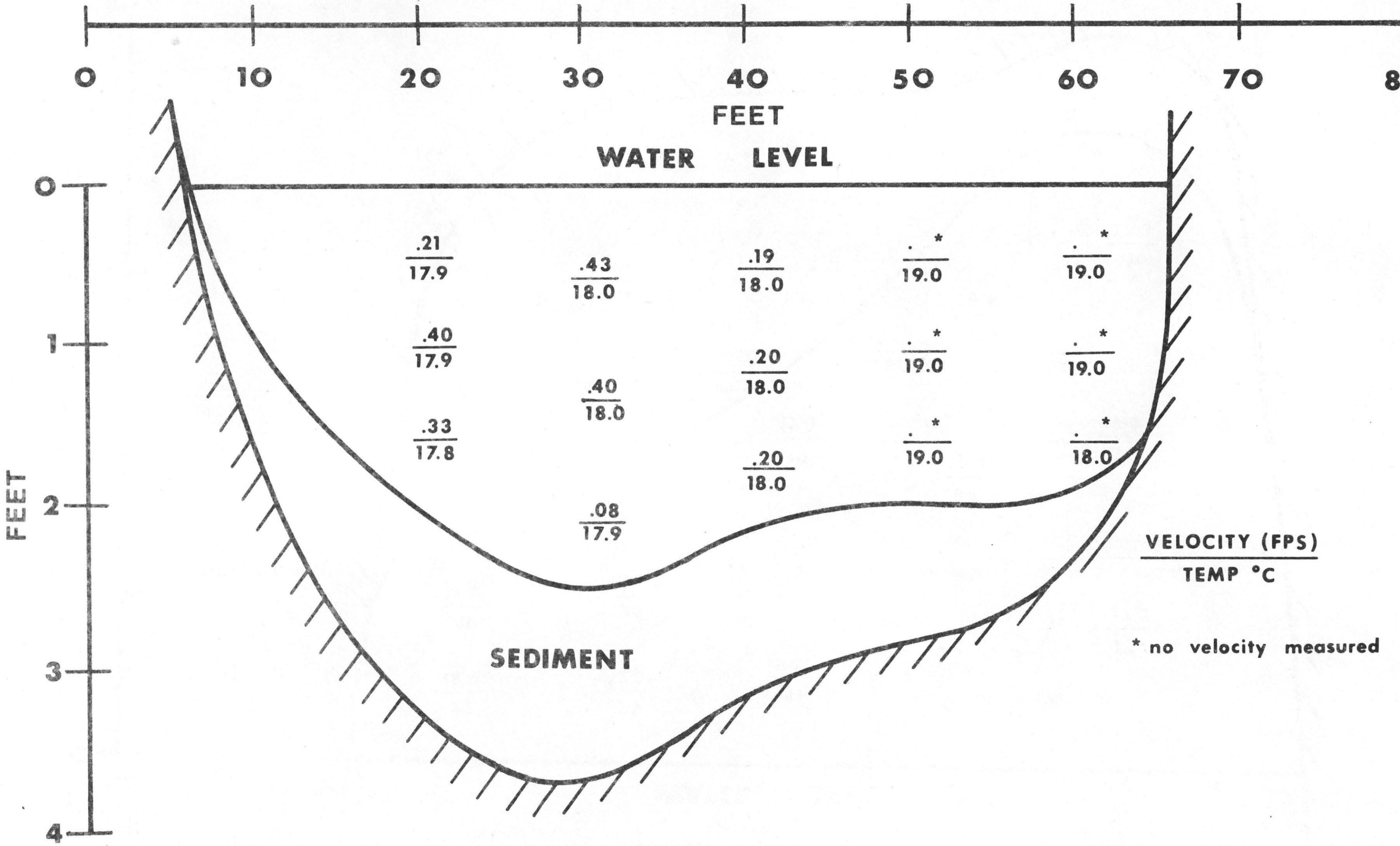


Figure 7
Velocity and Temperature Profile, Jerome Golf Course Pond, Section 2

efficiency for sediment for this pond based on average discharge and average concentrations was 65 percent in 1972 and 64 percent in 1973. The total amount of sediment removal was 808 tons in 1972 and 553 tons in 1973. Removal efficiencies for phosphates were slightly lower than the sediment removal efficiencies because only about 90 percent of the phosphate is attached to the sediment.

Figure 8 shows the 1973 sediment data obtained by the Agricultural Research Service, the measured discharges on sampling dates and the sediment removal efficiencies for the Golf Course Pond.

Discharge through the pond varies from 2 to 26 cfs and sediment concentrations of inflow water vary from 30 to 480 mg/l. Figure 8 shows that in general the removal efficiencies are highest during times when sediment concentrations are high and decrease as concentration decreases. This is expected since the particle sizes are generally smaller when the concentrations are low. Inflow concentrations generally decrease toward the end of the season.

Computer Model for a Settling Basin

To assist in developing design criteria for geometric dimensions of a settling basin, a mathematical model to simulate basin operation was developed. The computer model enables a formulation of a tentative design, the simulation of the basin and the revision of the design as necessary. The basis for the computer model is sedimentation or removal of particles heavier than water by gravitational settling. A discrete particle will

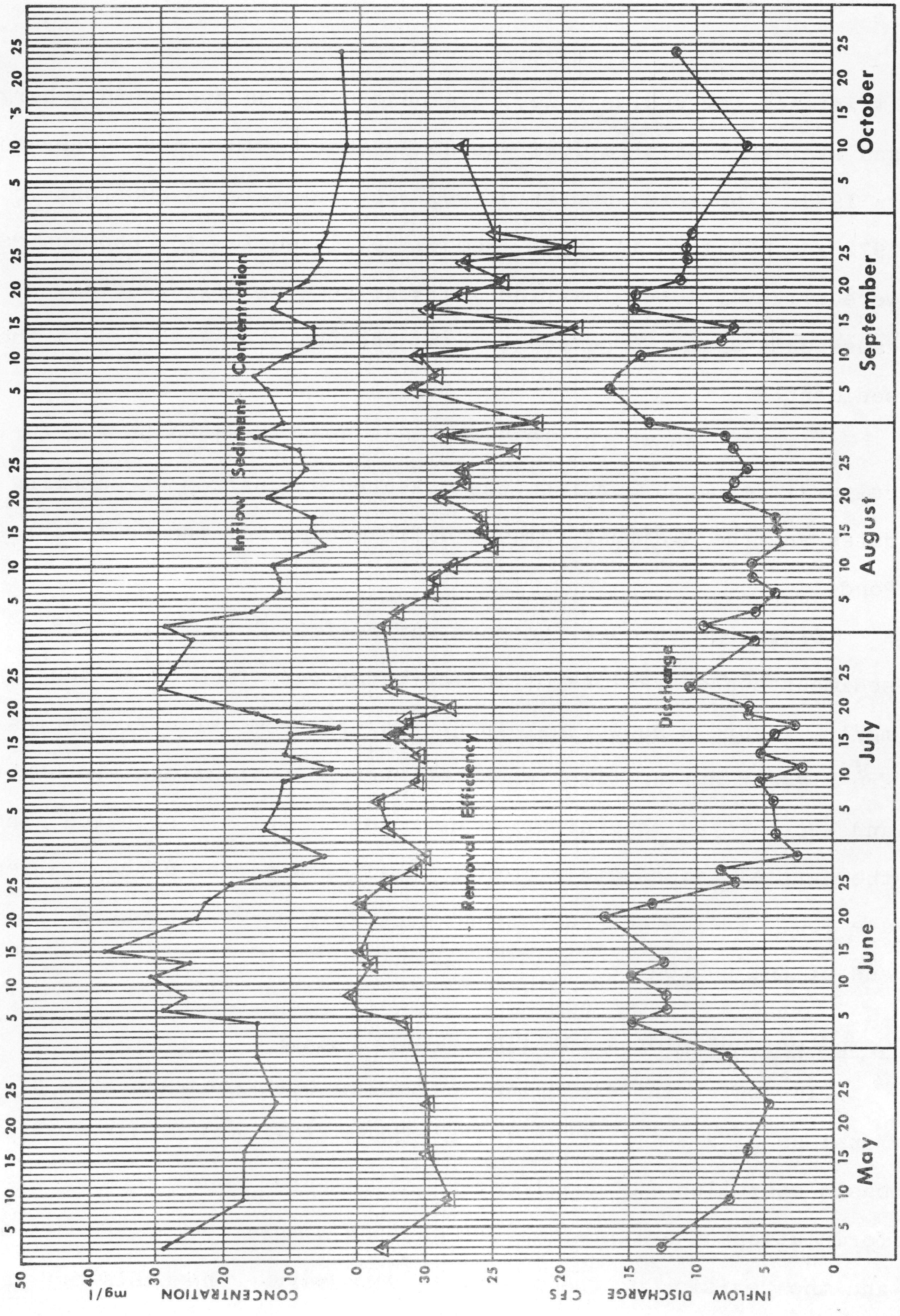


Figure 8

Jerome Golf Course Settling Basin Performance (1973) fall through a medium and accelerate until the frictional drag of the medium on the particle equals the gravitational force. Once this equilibrium is achieved, the particle will settle at a uniform velocity which can be derived from Stokes law. This law for viscous resistance and low Reynolds number ($R_E < 0.5$) states that:

$$v_s = g \cdot (\rho_s - \rho) \ d^2/(18 \ \mu)$$

or approximately:

$$v_s = g \cdot (S_s - 1) \ d^2/(18 \ \gamma)$$

where g is the acceleration due to gravity, ρ_s and ρ are the mass densities of the particle and of the fluid respectively, S_s is the specific gravity of the particle, μ is the dynamic viscosity, γ is the kinematic viscosity and d is a characteristic particle diameter.

For purposes of discussion a longitudinal cross section of a horizontal flow sedimentation tank is shown in Figure 9. In an actual field pond the uniform inlet and outlet zones would not exist. However, for preliminary design considerations, the conditions shown in Figure 9 are applicable with the following simplifying assumptions:

1) Within a horizontal flow tank sedimentation occurs in the settling zone exactly as settling occurs in a quiescent tank of equal depth.

2) For a given interval of time the flow is steady through the tank, and the concentration of suspended particles is uniform throughout the cross section.

3) A particle which reaches the sediment zone is removed and is not re-entrained by the flow.

The paths of three discrete particles are shown in Figure 9. These paths are the resultant of the two primary vector

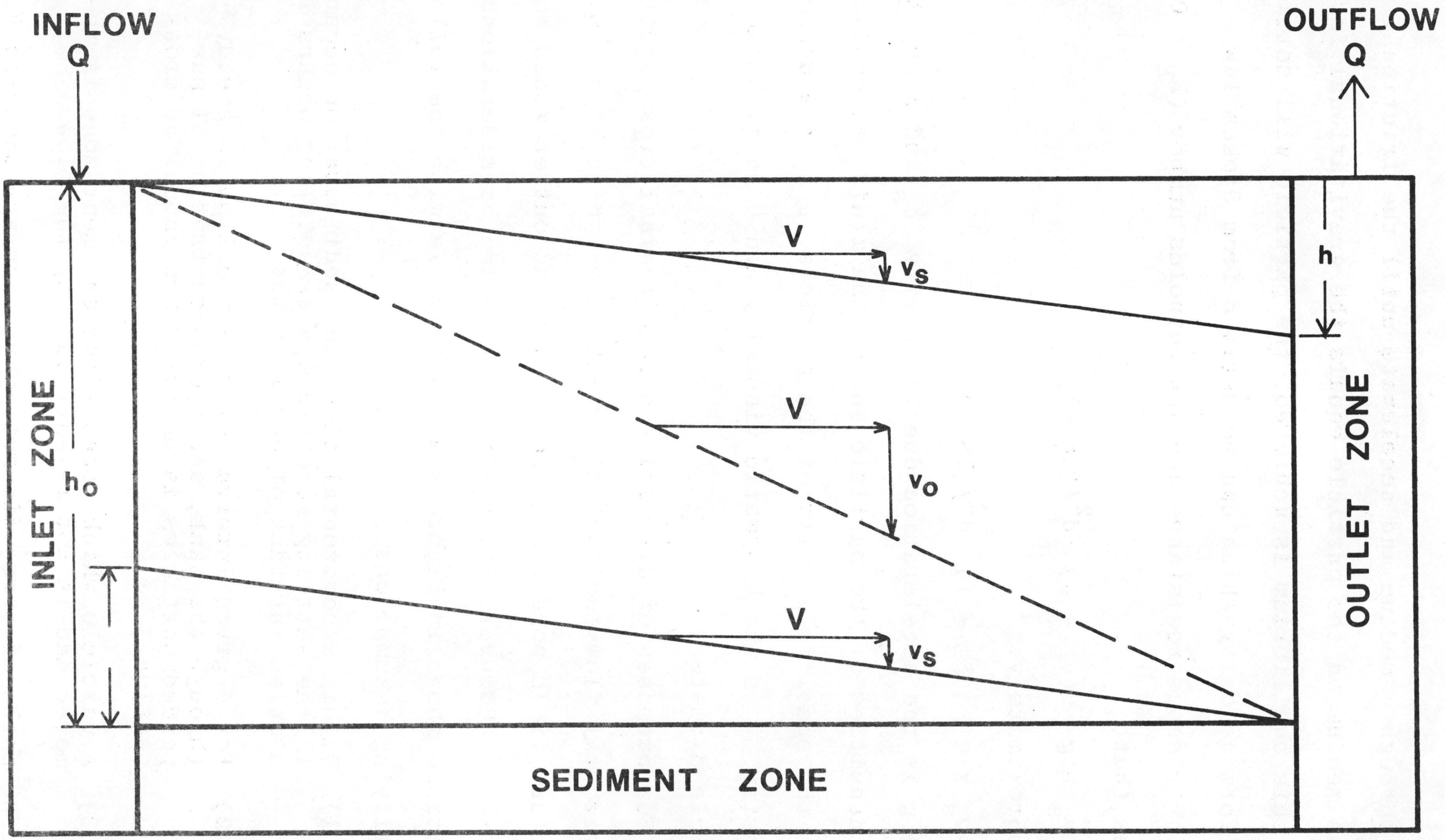


Figure 9
Schematic Diagram of Settling Basin

quantities, that is, the sum of the displacement velocity V of the basin and the settling velocity v_s of the particles. These particles do not enter or exit the tank at the same depths or elevations as can be seen from the figure. All particles do not have the same settling velocities v_s due to differences in size, shape and density of the various particles. The initial elevation of the particle in the flow also is a determining factor in deciding the exit elevation. These two factors are highly significant in controlling the efficiency of the basin.

For discrete particles and unhindered settling, the efficiency of a basin is solely a function of the settling velocity of the particles and of the surface and rate of flow of the basin which, in combination, constitute the surface loading or overflow velocity. The efficiency is independent of the depth of the basin and of the displacement time or detention period.

Model Limitations

Basin efficiency is reduced by the following factors:

1) Interference from closely spaced particles.
2) Eddy currents established by the inertia of the inflow.
3) Wind-induced currents occurring in uncovered basins.
4) Thermal-induced convection currents.
5) Density currents resulting from cold or heavy water underrunning warm or light water.

Because of these factors, the surface area of a basin must be larger than the theoretical value to attain specified removal efficiencies (Fair, Geyer, 1965).

Program Description

The model was designed to function with either constant or variable parameter input. A variable flow or variable sediment load can be processed.

The program consists of a main program and two subroutines. Interpolations of percentages or particles greater than a given particle size are performed by the subroutines for given input particle size and distributions. The basin length is divided into increments ΔL and each increment is handled as a "minibasin". The output of a minibasin is sequentially transferred to the downstream, adjacent increment. For a specified time increment Δt, calculations are performed incrementally throughout the length of the pond; the results are tabulated for each ΔL and also for the total basin. The time Δt is incremented and new variables are read in where necessary. The new data are again incremented throughout the pond length. This sequence continues until a total time T is completed. This results in $T/\Delta t$ runs through the basin containing $X/\Delta L$ segments where X is the total basin length. After each time period both instantaneous and accumulative results are printed.

Data Input

Data input consists of basin geometry, discharge through the basin, sediment concentrations and gradations, and time and spacial increments used for control. The basin geometry along with the increment values of time and location are read into the program once; these values remain fixed once they have been specified.

Since the inflowing sediment is usually not of a uniform size, a gradation curve must be utilized in the operation of the model. The gradation is specified in tabular form by specifying a particle diameter and the associated percentage of particles greater than or equal to this diameter. The manner in which the original gradation curve was obtained may not give the particle sizes which the user prefers to work with. The program has the capability to interpolate from the original curve to a new working curve based upon particle sizes specified by the user. Both the original curve diameters and percentages as well as the working curve particle diameters are read into the program. The first subroutine computes a working curve from the original curve and uses the working curve for all subsequent operations.

Discharge and sediment concentration can be read in for each time increment $T/\Delta t$, thus allowing variable inflows to be handled by the model. Theoretically $T/\Delta t$ changes in flow can be processed through the basin.

The kinematic viscosity of the fluid in centistokes, the specific gravity of the material of which the sediment is comprised, and the percentages of sand, silt and clay in the inflowing sediment, are read in for each time increment. The percentages of sand, silt and clay are necessary in the formulation of a value for the mass density of the accumulated sediment.

Inflow to the pond in cubic feet per second and the concentrations of sediment in the flow given in parts per million by weight are required for every Δt.

Finally the percentages of particles greater than a given particle size for the original gradation curve are listed for each time increment.

Program Output

The program processes the input data and prints the initial parameters, the basin length, width and depth, followed by the increment length, time increment and total run time for the pond. The next item is a calculated product for the value of the mass density of the accumulated sediment. The mass density is obtained from the following expression:

$$\delta = 0.26\ P_c + 0.70\ P_m + .97\ P_s$$

where P_c, P_m and P_s are the percentages of clay, silt and sand, respectively (Design of Small Dams, 1973).

As an example, assume that Δt is 0.5 days or 12 hours. The program will simulate the pond performance of section one for a 12 hour run; it will then move to section two for 12 hours. This continues through the last section of the basin. The removal and other quantities are calculated for each section as the program progresses; at the conclusion of the last section, the average basin values are printed for that run. Accumulated average basin values are also reported for the period just ended which cover the entire performance up to the last Δt increment. This operation continues through time T. For each section in this sequence the section number and location, the sediment concentration at the start of the section, and the range of particle size diameters is given for the sediment gradation. For each of these ranges, the percentage of material removed is printed as tons of sediment settled and tons of sediment passed. The volume of the settled sediment is reported and the average resulting depth change shown.

For each section the instantaneous efficiency of removal is printed based upon total weight of sediment removed from the flow. The incremental change in average depth along with the total section depth change is printed for each section. After the program has progressed through the entire basin, the accumulated totals at the end of the simulation are given, along with the total discharge through the pond. The total basin efficiency for sediment removal is reported as a percentage and the actual weights for sediment settled and passed is printed out. The volumetric amount of retained sediment is also printed.

Model Restrictions

Certain restrictions must be met in using the program. Only full length segments can be accommodated, i.e., the basin length (X) divided by the increment length (L) must be an integer. Also, only full time segments are allowed so that the total time of run (T) divided by the time increment (Δt) must be an integer. The range of values for particle size diameters for the working curve must equal or lie within the range of diameters for the original curve. All particle diameters are to be listed in descending orders of magnitude. All input data require a decimal point when applicable. The computer input format for the settling basin model, a design example, and a printout of the computer program are given in the Appendix.

Conclusions

The model developed for the simulation of sedimentation basins can provide information to assist in the design of basins; however, the model makes no design decisions on its own. It is the responsibility of the designer to determine if his design is acceptable and applicable to the situation which exists in the field. Other factors which may affect the overall impact and effectiveness of the structure include:

1) Cleaning or dredging schedules for the basin. If the basin is cleaned often, a large volume for the settling zone may not be necessary.
2) Secondary currents within the basin. These must be anticipated and allowed for by oversizing the basin.
3) Inlet conditions (jet effect). If a significant jet will exist, a longer pond should be used.

The program is only an aid in the design of settling basins. The engineer must still exercise judgment and discretion in the selection of the final design.

NOTATIONS

Symbol	Explanation	Dimension
A	area under irrigation	L^2
A_s	surface area of settling basin zone	L^2
C_o	volumetric capacity of basin settling zone	L^3
d	characteristic particle diameter	L
g	acceleration due to gravity	L/T^2
H	settling basin depth	L
h_o	depth of basin settling zone	L
L	length of irrigation furrow	L
ΔL	settling basin length increment	L
ppm	concentration in parts per million also, mg of sediment/kg of water	-
Q	volumetric flow rate	L^3/T
S	average field slope (%)	-
S_s	specific gravity of a particle	-
T	total basin simulation time	T
t_o	particle detention time in basin	-
Δt	basin time increment	T
v_o	critical particle settling velocity	L/T
v_s	particle settling velocity	L/T
W	settling basin width	L
X	settling basin length	L
X_x	basin section number	-
Y	energy term (QT/A)	L
Y'	energy term (QT/AL)	-

Symbol	Explanation	Dimension
ρ	mass density of the fluid	M/L^3
ρ_s	mass density of the particle	M/L^3
δ	mass density of settled sediment	M/L^3
μ	dynamic viscosity	M/LT
γ	kinematic viscosity	L^2/T

REFERENCES

American Society for Testing Materials. Tentative method for grain-size analysis of soils. D422-54T:1756-1766. 1954.

Design of Small Dams, A Water Resources Technical Publication, United States Department of the Interior, Bureau of Reclamation, second edition, 1973.

Fair, Gordon M., and John C. Geyer, Elements of Water Supply and Waste Water Disposal. New York, N.Y., John Wiley and Sons, Inc., 1965.

Lara, J.M. and E.L. Pemberton, "Initial Unit Weight of Deposited Sediments", Proceedings of Federal Interagency Conference - 1963, Miscellaneous Publication Number 970, pp 818-845. United States Department of Agriculture, Agricultural Research Service, June 1965.

Oliver, A.E., "Analysis of Settling Basins", Thesis presented to the University of Idaho, Moscow, Idaho in partial fulfillment of the requirements for the degree of Masters of Science, 1974.

Olson, T.C. and W.H. Wischmeier, 1963, Soil-erodibility evaluation for soils on the runoff and erosion stations. Soil Sci. Soc. Amer. Proc., v. 27, pp 590-592.

Ports, Michael A., "Use of the Universal Soil Loss Equation as a Design Standard", ASCE Water Resources Engineering Meeting - 1973, Hydraulic Division, February 1, 1973.

Standard Specifications for Highway Materials and Methods of Sampling and Testing. Standard methods of mechanical analysis of soils. A.A.S.H.O. Designation T88-45:257-266. 1955.

University of Idaho, "Step-wise Multiple Regression Program", Computer Services Programs, p. II 94.

Wilson, Lee "Seasonal Sediment Yield Patterns of U.S. Rivers". Water Resources Research, v. 8, no. 6, December, 1972.

Wischmeier, W.H. and J.V. Mannering, 1969. Relation of soil properties to its erodibility. Soil Sci. Soc. Amer. Proc., v. 23, pp. 131-137.

REFERENCES

American Society for Testing [illegible] "Tentative method for grain-size analysis [illegible] -54T, 1756-1765. 1954.

Design of Small Dams. [illegible] Technical Publication. United States [illegible] Interior. Bureau of Reclamation, [illegible]

Fair, Gordon [illegible] and John [illegible] Elements of Water Supply and Waste Water Disposal. [illegible] N.Y.: John Wiley and Sons, Inc., 195[illegible]

Lara, J.M. and E.L. Pemberton. "Initial Unit Weight of Deposited Sediments", Proceedings [illegible] Federal Interagency Conference 1963. Miscellaneous Publication Number 970, pp 818-8[illegible]. United States Department of Agriculture, Agricultural Research Service. June 1965.

Oliver, J.E. "Analysis of Sediment Basins". Thesis presented to the University of Idaho, Moscow, Idaho in partial fulfillment of the [illegible] the degree of Master of Science. 1974.

Olson, T.C. and W.H. Wischmeier. "Soil-erodibility evaluation for soils [illegible] erosion stations." Soil Sci. Soc. Amer. [illegible] 592.

Porte, Michael [illegible] Soil Loss [illegible] Design Stage [illegible] Engineering [illegible] ing. 1975 [illegible]

Standard Specifications [illegible] and Methods of Sampling and Testing [illegible] Mechanical Analysis of Soils [illegible] Designation: T88-[illegible] 1958.

University of Idaho. "Stepwise [illegible] Regression Program". Computer Services, Program [illegible]

Wilson, [illegible] Sediment Production [illegible] Water Resources Research [illegible] 6, December 1972.

Wischmeier, W.H. [illegible] soil properties to its erodibility". Soil Sci. Soc. Amer. Proc., V. 23, [illegible] 131-137.

APPENDIX

COMPUTER FORMAT FOR SETTLING BASIN MODEL

Explanation

Column Numbers

card 1

1 - 10	X	length of settling basin in feet
11 - 20	W	width of settling basin in feet
21 - 30	H	depth of settling basin in feet
31 - 40	ΔL	incremental length for basin in feet
41 - 50	Δt	time increment for each run in hours
51 - 60	T	total time of model operation in days

card 2

1 - 10	NN	number of diameters for original gradation curve (integer)
11 - 20	NW	number of diameters for working gradation curve (integer)
21 - 30	Dial	minimum diameter of working curve
31 - 40	Diak	maximum diameter of working curve

card 3

1 - 10	D(1)	maximum diameter of original gradation curve in inches
11 - 20	D(2)	diameter of original gradation curve in inches
.		
.	D(NN)	minimum diameter of original gradation curve in inches
.		

card 4

1 - 10	Dia (1)	maximum diameter of working gradation curve in inches
11 - 20	Dia (2)	diameter of working gradation curve in inches
.		
.	Dia (NW)	minimum diameter of working gradation curve in inches
.		

card 5

1 - 10	Viscs	viscosity of the inflowing water $(10^{-2}\ cm^2/sec)$
11 - 20	SS	specific gravity of sediment particles
21 - 30	Sand	percentage of sand in inflow in %
31 - 40	Silt	percentage of silt in inflow in %
41 - 50	Clay	percentage of clay in inflow in %

card 6

1 - 10	Q	discharge into the basin in cfs
11 - 20	Conc	concentration of sediment in the inflow in ppm

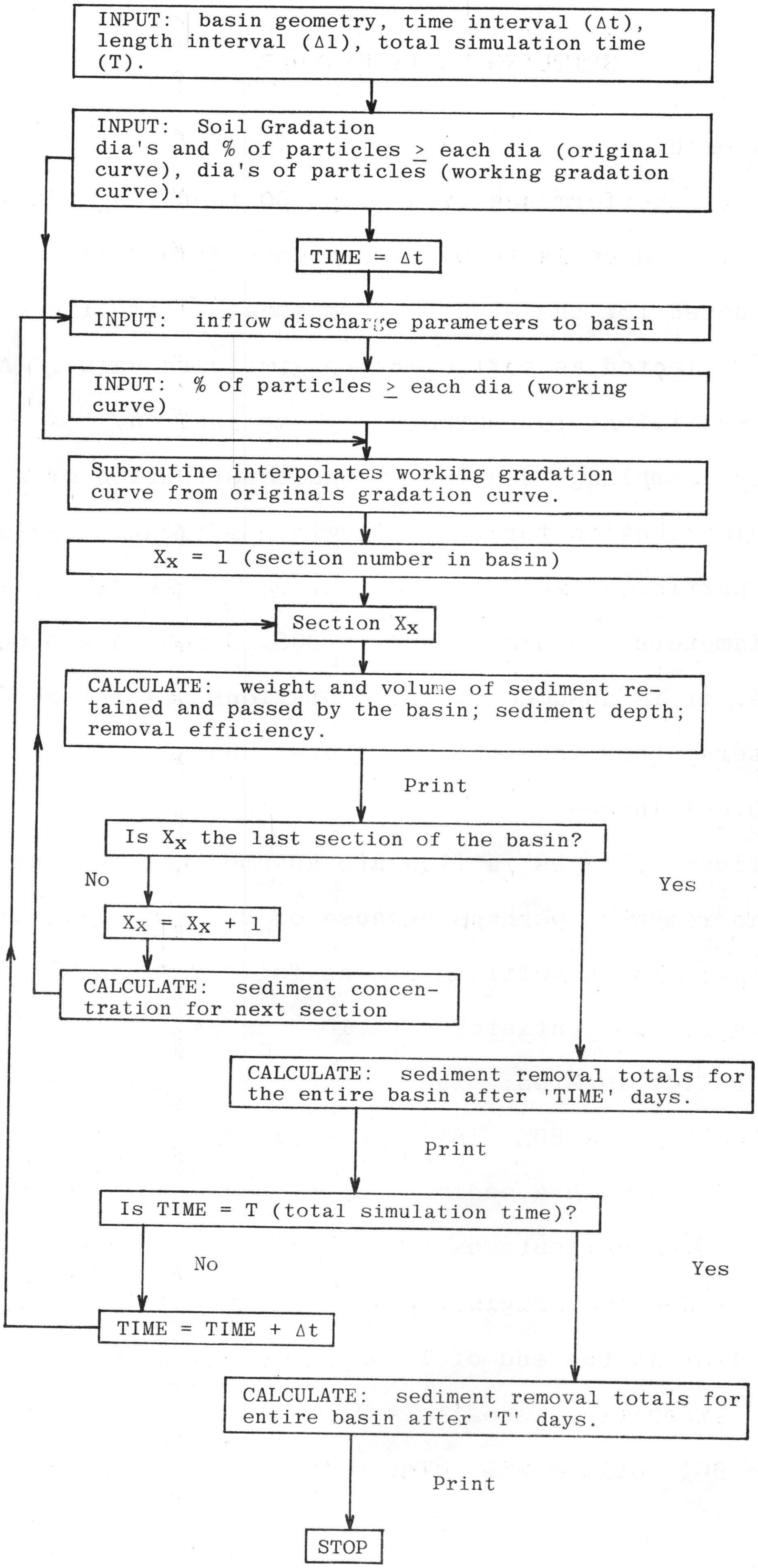
card 7

1 - 10	P(1)	percentage of sediment having a diameter D(1)
11 - 20	P(2)	percentage of sediment having a diameter D(2)

P(NN) percentage of sediment having a diameter D(NN)

Note: Cards 5, 6 and 7 are inputed for each run through the basin.

FLOW CHART FOR SETTLING BASIN MODEL



SETTLING BASIN EXAMPLE

Problem Statement:

Assume the performance of a pond 100 feet long, 40 feet wide and 10 feet deep is to be simulated. Five 20 foot increments are chosen for the study. A reasonable time increment of 12 hours is selected as sufficient to give data value. A 1.5 day run is sufficient for purposes of explanation.

Previous sampling resulted in the construction of a particle size distribution for the inflowing sediment. The sampling provided a particle size distribution curve with five points at particle diameters: 0.012, 0.008, 0.005, 0.003, and 0.001 inches. For example, it is assumed that calculations are referenced to four diameters other than the above ones, namely: 0.01, 0.006, 0.003 and 0.001 inches.

Significant changes in flow are assumed to occur at twelve hour time increments, perhaps because of diurnal fluctuations. Assume initial flow conditions are as follows: the kinematic viscosity is 1.0105 centistokes (x 10^{-2} cm^2/sec), the specific gravity of solids is 2.65. The percentages of sand, silt, and clay were found to be 80%, 15% and 5% respectively. The initial inflow is 122 cfs with a sediment concentration of 1000 ppm. The corresponding percentages of particles greater than a given diameter size for the original gradation are 0%, 10%, 50%, 70%, 100%. The flow at the end of 12 hours is characterized by the following: kinematic viscosity = 1.0, specific gravity of solids = 2.6, sand = 60%, silt = 25%, clay = 15%. The discharge decreased to 24 cfs with an associated concentration of 500 ppm. The corresponding particle percentages are 0%, 5%, 20%, 60%, 100%. The conditions at the 24 hour period are as follows: kinematic viscosity = 1.85, specific gravity = 2.5, sand = 30%, silt = 50%, clay = 20%. The flow subsided to 15 cfs with a concentration of 2000 ppm. The corresponding percentages of particles greater than the diameters for the original gradation are: 0%, 10%, 20%, 50%, and 100%.

To use the program the above data is entered on data cards in the manner presented as Table 11.

Table 11: Input Data for Settling Basin Program

	Column Numbers						
Card No.	10	20	30	40	50	60	70
card 1							
100.	40.	10.	20.	12.	1.5		
card 2							
5	4	.01	.001				
card 3							
.012	.008	.005	.003	.0009			
card 4							
.010	.006	.003	.001				
card 5							
1.0105	2.65	80.	15.	5.			
card 6							
122.	1000.						
card 7							
0.	10.	50.	70.	100.			
card 8	(*card 5)						
1.0	2.6	60.	25.	15.			
card 9	(*card 6)						
24.	500.						
card 10	(*card 7)						
0.	5.	20.	60.	100.			
card 11	(*card 5)						
1.85	2.5	30.	50.	20.			
card 12	(*card 6)						
.15	2000.						
card 13	(*card 7)						
0.	10.	20.	50.	100.			

The program and subroutine listings are shown on pages through and the computed output for the example problem is shown on pages through .

SETTLING BASIN PROGRAM

```
      SUBROUTINE CURVE
      COMMON D(10),P(10),DIA(10),PER(10),DQ,PQ,K
      DOUBLE PRECISION PER,DIA,PQ,DQ
      DO 4 I=1,K
      IF(DQ-D(I)) 4,3,5
    3 PQ=P(I)
      GO TO 6
    4 CONTINUE
    5 IB=I-1
      IA=I
      PQ=P(IB)+(P(IA)-P(IB))*(D(IB)-DQ)/(D(IB)-D(IA))
    6 CONTINUE
      RETURN
      END
      SUBROUTINE INTER
      COMMON D(10),P(10),DIA(10),PER(10),DQ,PQ,K
      DOUBLE PRECISION PER,DIA,PQ,DQ
      DO 104 I=1,K
      IF (DQ-DIA(I)) 104,103,105
  103 PQ=PER(I)
      GO TO 106
  104 CONTINUE
  105 IB=I-1
```

```
      IA=I
      PG=PER(IB)+(PER(IA)-PER(IB))*(DIA(IB)-DG)/(DIA(IB)-DIA(IA))
  106 CONTINUE
      RETURN
      END
      DIMENSION PASSN(10),DHL(100),DIAM(10),PERCT(10)
      DIMENSION PPER(10),ADIA(10),APER(10),PDIA(10)
      COMMON D(10),P(10),DIA(10),PER(10),DG,PG,K
      DOUBLE PRECISION PER,DIA,PG,DG
      READ(1,10) X,W,H,DL,DT,T
   10 FORMAT(6F10.0)
      READ(1,14)NN,NW,DIA1,DIAK
   14 FORMAT(2I10,2F10.0)
      READ(1,16)(D(I),I=1,NN)
   16 FORMAT(8F10.0)
      READ(1,18)(DIA(I),I=1,NW)
   18 FORMAT(8F10.0)
      WRITE(3,215)X,W,H,DL,DT,T
  215 FORMAT(T1,F6.1,'FT LONG',T15,F5.1,'FT WIDE',T29,F4.1,'FT DEEP',
     CT43,F5.1,'FT INCREMENTS',T63,F4.1,'HOUR INCREMENTS',T84,
     CF5.1,'DAY RUN')
      DO 500 I=1,NW
      PDIA(I)=DIA(I)
  500 CONTINUE
      SEDRE=0.0
      SEDPA=0.0
      TVCL=0.0
```

```
      GT=0.0
      TIME=DT/24.
      LDT=T*24./DT
      LL=X/DL
      WRITE(3,407) TIME,LDT,LL
  407 FORMAT(T20,'TIME',F10.4,2I10)
      DO 301 I=1,LL
      DHL(I)=0.0
  301 CONTINUE
      K=NW
      DO 100 LT=1,LDT
      READ(1,12) VISCS, SS, SAND, SILT, CLAY
   12 FORMAT (5F10.0)
      READ(1,15) Q,CONC
   15 FORMAT(2F10.0)
      READ(1,17) (P(I),I=1,NN)
   17 FORMAT (8F10.0)
      WRITE(3,400)(P(I),I=1,NN)
  400 FORMAT(T10,5F10.2)
      WRITE(3,402)(D(I),I=1,NN)
      WRITE(3,402)(DIA(I),I=1,NW)
  402 FORMAT(T10,5F10.4)
      N1=NW-1
      K=NW
      GAMA= .26*CLAY+ .70*SILT+ .97*SAND
      WRITE (3,409) GAMA
  409 FORMAT (T6,'GAMA= ',F10.3)
```

```
      DO 20 J=2,N1
      DG=DIA(J)
      CALL CURVE
      PER(J)=PG
      WRITE(3,401)DG,PG
  401 FORMAT(T10,2F10.4)
   20 CONTINUE
      DIA(1)=DIA1
      PER(1)=0.0
      DIA(K)=DIAK
      PER(K)=100.0
      VISCS=VISCS*.00001075
      DO 90 LX=1,LL
      TOTAL= CONC*Q*DT*.225
      D100=((80.5*VISCS*Q)/((SS-1.)*DL*W))**.5
      DG=D100
      CALL INTER
      P100=PG
      WRITE(3,410) D100,DG,P100,PG
  410 FORMAT(T5,'D100',4F10.4)
      SET1=P100*TOTAL/200000.
      VOL1=SET1*2000./(GAMA*27.)
      TOTRE=SET1
      TOTPA=0.0
      VOLT=VOL1
      TOTH=(VOL1*27.)*12./(W*DL)
      POS2=LX*DL
```

```
      POS1=POS2-DL
      WRITE(3,201)TIME
  201 FORMAT(T1,F6.2,'DAYS'/)
      WRITE(3,202)LX,POS1,POS2,CONC
  202 FORMAT(T6,'SECTION ',I4,T22,'LOCATION ',F5.1,'-',F5.1,'-FT',
     CT49,'CONC (PPM) ',F6.0 /)
      WRITE(3,203)
  203 FORMAT(T11,'DIAM',T21,'( REMOVED',T36,'TON SETTLED',T53,
     C'TONS PASSED',T70,'VOL YDS',T83,'DEPTH CHANGE'/)
      WRITE(3,204) D100,SET1,VOL1,TOTH
  204 FORMAT(T14,F5.3,T24,'100',T38,F7.3,T56,'00.',T71,F7.3,T87,F7.3)
      DO 30 I=1,K
      IF(D100-DIA(I)) 31,33,32
   31 GO TO 30
   32 II=I
      GO TO 36
   33 II=I+1
      GO TO 36
   30 CONTINUE
   36 CONTINUE
      IF(LX-1) 37,38,37
   38 K=NW-II+2
   37 CONTINUE
      ADIA(1)=D100
      APER(1)=PG
      NII=II
      DO 39 I=2,K
```

```
      ADIA(I)=DIA(NII)
      APER(I)=PER(NII)
      NII=NII+1
   39 CONTINUE
      DO 41 I=1,K
      DIA(I)=ADIA(I)
      PER(I)=APER(I)
   41 CONTINUE
      II=2
      DAV=(D100+DIA(II))/2.
      VS=(SS-1.)*(DAV**2.)/(VISCS*80.5)
      CENT=VS*DL*W*100./Q
      TOT=TOTAL*(PER(II)-P100)/200000.
      AMT=CENT*TOT/100.
      VOL=AMT*2000./(GAMA*27.)
      PASS=(100.-CENT)*TOT/100.
      PAST=PASS
      TOTLN=PASS
      TOTRE=TOTRE+AMT
      TOTPA=PASS
      VOLT=VOLT+VOL
      DH=(VOL*27.)*12./(W*DL)
      TOTH=TOTH+DH
      WRITE(3,205) D100,DIA(II),CENT,AMT,PASS,VOL,DH
  205 FORMAT(T8,F5.3,T14,F5.3,T24,F5.2,T38,F7.3,T56,F7.3,T71,F7.3,
     CT87,F7.3)
      NK=K-1
```

```
      IF(NK-2) 40,42,42
   42 DO 40 I=2,NK
      IK=I+1
      TOT=TOTAL*(PER(IK)-PER(I))/200000.
      DAV=(DIA(I)+DIA(IK))/2.
      VS=(SS-1.)*(DAV**2.)/(VISCS*80.5)
      CENT=VS*DL*W*100./Q
      AMT=CENT*TOT/100.
      PASS=(100.-CENT)*TOT/100.
      PASSN(I)=PASS
      TOTLN=TOTLN+PASS
      VOL=AMT*2000./(GAMA*27.)
      DH=(VOL*27.)*12./(W*DL)
      TOTH=TOTH+DH
      TOTRE=TOTRE+AMT
      TOTPA=TOTPA+PASS
      VOLT=VOLT+VOL
      WRITE(3,205) DIA(I),DIA(IK),CENT, AMT,PASS,VOL,DH
   40 CONTINUE
      EFF=TOTRE*100./(TOTRE+TOTPA)
      DHL(LX)=DHL(LX)+TOTH
      CONC=TOTPA*2000./(Q*DT*.225)
      WRITE(3,207)EFF,TOTH,DHL(LX)
  207 FORMAT(T6,'INSTANT SECTION EFF ',F8.2,'(',/,T6,
     C'INSTANT DEPTH CHANGE',F8.3,'IN'/,T6,
     C'TOTAL SECT DEPTH CHANGE',F8.3,'IN'///)
      PPER(1)=0.0
```

```
      PPER(2)=PAST*100./TOTPA
      IF(K-3) 53,53,52
   52 DO 50 I=3,NK
      IN=I-1
      PPER(I)=PPER(IN)+(PASSN(IN)*100./TOTPA)
   50 CONTINUE
   53 PPER(K)=100.
      DO 60 I=1,K
      PER(I)=PPER(I)
   60 CONTINUE
      WRITE(3,600)(DIA(I),I=1,K)
      WRITE(3,600)(PER(I),I=1,K)
  600 FORMAT(T10,F10.4)
      SEDPA=SEDPA+TOTPA
      SEDRE=SEDRE+TOTRE
      TVOL=TVOL+VOLT
   90 CONTINUE
      QT=QT+Q*DT/12.1
      EBAR=SEDRE*100./(SEDRE+SEDPA)
      WRITE(3,209)TIME
  209 FORMAT(T2,'TOTALS AFTER ',F6.2,'DAYS'/)
      WRITE(3,210)QT,EBAR,SEDRE,SEDPA,TVOL
  210 FORMAT(T8,'Q ACRE-FT',T21,'( REMOVED',T36,'TONSETTLED',T53,
     C'TONS PASSED',T70,'VOL YDS'/T10,F7.3,T24,F5.2,T38,F8.3,
     CT56,F8.3,T71,F8.3///)
      TIME=TIME+DT/24.
      DO 700 I=1,NW
```

SETTLING BASIN PROGRAM OUTPUT

```
 100.0FT LONG  40.0FT WIDE  10.0FT DEEP    20.0FT INCREMENTS  12.0HOUR INCREMENTS    1.5DAY RUN
                    TIME    0.5000           3          5
                   0.0       10.00      50.00      70.00      100.00
                 0.0120     0.0080     0.0050     0.0030      0.0009
                 0.0100     0.0060     0.0030     0.0010
         GAMA=     89.400
                 0.0060    36.6667
                 0.0030    70.0000
       D100     0.0090     0.0090     9.2577     9.2577
     0.50DAYS
```

```
SECTION   1   LOCATION   0.0- 20.0-FT    CONC (PPM)  1000.

      DIAM        % REMOVED       TON SETTLED     TONS PASSED      VOL YDS       DEPTH CHANGE

         0.009      100             15.247          00.              12.634          5.117
   0.009 0.006      69.51           31.377           13.766          25.998         10.529
   0.006 0.003      25.06           13.755           41.145          11.397          4.616
   0.003 0.001       4.95            2.445           46.965           2.026          0.821
 INSTANT SECTION EFF    38.14%
 INSTANT DEPTH CHANGE  21.082IN
 TOTAL SECT DEPTH CHANGE  21.082IN


         0.0090
         0.0060
         0.0030
         0.0010
         0.0
        13.5125
        53.8998
       100.0000
 0100    0.0090    0.0090    0.0        0.0
0.50DAYS
 SECTION    2    LOCATION  20.0- 40.0-FT    CONC (PPM)    619.

      DIAM        % REMOVED       TON SETTLED     TONS PASSED      VOL YDS       DEPTH CHANGE

         0.009      100              0.0            00.               0.0            0.0
   0.009 0.006      69.51            9.568            4.198           7.928          3.211
   0.006 0.003      25.06           10.309           30.836           8.542          3.459
   0.003 0.001       4.95            2.324           44.640           1.926          0.780
 INSTANT SECTION EFF    21.79%
 INSTANT DEPTH CHANGE    7.450IN
 TOTAL SECT DEPTH CHANGE   7.450IN


         0.0090
         0.0060
         0.0030
         0.0010
         0.0
         5.2688
        43.9713
       100.0000
 0100    0.0090    0.0090    0.0        0.0
0.50DAYS
```

```
   SECTION    3    LOCATION  40.0- 60.0-FT    CONC (PPM)   406.

      DIAM        % REMOVED       TON SETTLED      TONS PASSED      VOL YDS       DEPTH CHANGE

          0.009     100             0.0            00.               0.0              0.0
     0.009 0.006     69.51          2.918             1.280          2.418            0.979
     0.006 0.003     25.06          7.726            23.110          6.401            2.593
     0.003 0.001      4.55          2.209            42.431          1.831            0.741
   INSTANT SECTION EFF     16.13%
   INSTANT DEPTH CHANGE   4.313IN
   TOTAL SECT DEPTH CHANGE    4.313IN


          0.0090
          0.0060
          0.0030
          0.0010
          0.0
          1.9157
         36.5004
        100.0000
  0100    0.0090     0.0090     0.0       0.0
0.50DAYS

   SECTION    4    LOCATION  60.0- 80.0-FT    CONC (PPM)   406.

      DIAM        % REMOVED       TON SETTLED      TONS PASSED      VOL YDS       DEPTH CHANGE

          0.009     100             0.0            00.               0.0              0.0
     0.009 0.006     69.51          0.890             0.390          0.737            0.299
     0.006 0.003     25.06          5.790            17.320          4.798            1.943
     0.003 0.001      4.95          2.100            40.331          1.740            0.705
   INSTANT SECTION EFF     13.14%
   INSTANT DEPTH CHANGE   2.946IN
   TOTAL SECT DEPTH CHANGE    2.946IN


          0.0090
          0.0060
          0.0030
          0.0010
          0.0
          0.6726
         30.5128
        100.0000
  0100    0.0090     0.0090     0.0       0.0
0.50DAYS
```

```
     SECTION     5     LOCATION  80.0-100.0-FT     CONC (PPM)   352.

           DIAM        % REMOVED        TON SETTLED       TONS PASSED       VOL YDS        DEPTH CHANGE

               0.009       100              0.0              00.              0.0              0.0
         0.009 0.006       69.51            0.271             0.119           0.225            0.091
         0.006 0.003       25.06            4.339            12.980           3.596            1.456
         0.003 0.001        4.95            1.956            38.335           1.654            0.670
     INSTANT SECTION EFF     11.38%
     INSTANT DEPTH CHANGE    2.217IN
     TOTAL SECT DEPTH CHANGE    2.217IN


               0.0090
               0.0060
               0.0030
               0.0010
               0.0
               0.2314
              25.4678
             100.0000
  TOTALS AFTER    0.50DAYS

        Q ACRE-FT     % REMOVED        TONSETTLED        TONS PASSED       VOL YDS
         120.992        24.04            113.266           357.844          93.848


               0.0        5.00      20.00      60.00     100.00
               0.0120     0.0080    0.0050     0.0030     0.0009
               0.0100     0.0060    0.0030     0.0010
     GAMA=       79.600
               0.0060     15.0000
               0.0030     60.0000
     0100    0.0040     0.0040    44.5781    44.5781
   1.00DAYS

     SECTION     1     LOCATION   0.0- 20.0-FT     CONC (PPM)   500.

           DIAM        % REMOVED        TON SETTLED       TONS PASSED       VOL YDS        DEPTH CHANGE

               0.004       100              7.222            00.              6.720            2.722
         0.004 0.003       76.10            1.901             0.597           1.769            0.717
         0.003 0.001       24.65            1.557             4.883           1.487            0.602
     INSTANT SECTION EFF     66.18%
     INSTANT DEPTH CHANGE    4.040IN
     TOTAL SECT DEPTH CHANGE   25.122IN


               0.0040
               0.0030
               0.0010
               0.0
              10.8948
             100.0000
     0100    0.0040     0.0040     0.0       0.0
   1.00DAYS
```

```
SECTION    2    LOCATION  20.0- 40.0-FT    CONC (PPM)   169.
        DIAM       % REMOVED       TON SETTLED      TONS PASSED       VOL YDS       DEPTH CHANGE

           0.004      100              0.0            00.               0.0             0.0
     0.004 0.003      76.10            0.454            0.143           0.423           0.171
     0.003 0.001      24.65            1.204            3.570           1.120           0.454
INSTANT SECTION EFF      30.26%
INSTANT DEPTH CHANGE    0.625IN
TOTAL SECT DEPTH CHANGE    8.075IN


           0.0040
           0.0030
           0.0010
           0.0
           3.7328
         100.0000
  D100     0.0040     0.0040    0.0       0.0
1.00DAYS
SECTION    3    LOCATION  40.0- 60.0-FT    CONC (PPM)   118.
        DIAM       % REMOVED       TON SETTLED      TONS PASSED       VOL YDS       DEPTH CHANGE

           0.004      100              0.0            00.               0.0             0.0
     0.004 0.003      76.10            0.109            0.034           0.101           0.041
     0.003 0.001      24.65            0.907            2.772           0.844           0.342
INSTANT SECTION EFF      26.57%
INSTANT DEPTH CHANGE    0.383IN
TOTAL SECT DEPTH CHANGE    4.696IN


           0.0040
           0.0030
           0.0010
           0.0
           1.2147
         100.0000
  D100     0.0040     0.0040    0.0       0.0
1.00DAYS
SECTION    4    LOCATION  60.0- 80.0-FT    CONC (PPM)    87.
        DIAM       % REMOVED       TON SETTLED      TONS PASSED       VOL YDS       DEPTH CHANGE

           0.004      100              0.0            00.               0.0             0.0
     0.004 0.003      76.10            0.026            0.008           0.024           0.010
     0.003 0.001      24.65            0.683            2.089           0.636           0.258
INSTANT SECTION EFF      25.28%
INSTANT DEPTH CHANGE    0.267IN
TOTAL SECT DEPTH CHANGE    3.214IN


           0.0040
           0.0030
           0.0010
           0.0
           0.3885
         100.0000
  D100     0.0040     0.0040    0.0       0.0
1.00DAYS
```

```
   SECTION    5    LOCATION  80.0-100.0-FT     CONC (PPM)     65.

         DIAM        % REMOVED        TON SETTLED        TONS PASSED        VOL YDS        DEPTH CHANGE

             0.004      100              0.0              00.                0.0              0.0
      0.004 0.003       76.10            0.006              0.002            0.006            0.002
      0.003 0.001       24.65            0.515              1.574            0.479            0.194
   INSTANT SECTION EFF     24.85%
   INSTANT DEPTH CHANGE    0.196IN
   TOTAL SECT DEPTH CHANGE    2.413IN


             0.0040
             0.0030
             0.0010
             0.0
             0.1235
           100.0000
 TOTALS AFTER    1.00DAYS

      Q ACRE-FT     % REMOVED        TONSETTLED        TONS PASSED        VOL YDS
       144.793        25.50            127.890           373.623          107.457


             0.0        10.00       20.00       50.00      100.00
             0.0120     0.0080      0.0050      0.0030     0.0009
             0.0100     0.0060      0.0030      0.0010
   GAMA=       69.300
             0.0060     16.6667
             0.0030     50.0000
    D100     0.0030     0.0030     49.6415    49.6415
  1.50DAYS

   SECTION    1    LOCATION   0.0- 20.0-FT    CONC (PPM)  2000.

         DIAM        % REMOVED        TON SETTLED        TONS PASSED        VOL YDS        DEPTH CHANGE

             0.003      100              20.105           00.               21.490            8.703
      0.003 0.003       98.94             0.144             0.002            0.154            0.062
      0.003 0.001       43.50             8.810            11.440            9.416            3.814
   INSTANT SECTION EFF      71.75%
   INSTANT DEPTH CHANGE  12.579IN
   TOTAL SECT DEPTH CHANGE   37.702IN


             0.0030
             0.0030
             0.0010
             0.0
             0.0135
           100.0000
    D100     0.0030     0.0030     0.0        0.0
  1.50DAYS
```

```
   SECTION     2     LOCATION  20.0- 40.0-FT    CONC (PPM)    565.

        DIAM       % REMOVED       TCN SETTLED      TCNS PASSED       VOL YDS      DEPTH CHANGE

            0.003      100              0.0            00.              0.0             0.0
      0.003 0.003      98.94            0.002            0.000          0.002           0.001
      0.003 0.001      43.50            4.977            6.463          5.320           2.155
   INSTANT SECTION EFF     43.51%
   INSTANT DEPTH CHANGE    2.155IN
   TOTAL SECT DEPTH CHANGE  10.230IN


            0.0030
            0.0030
            0.0010
            0.0
            0.0003
          100.0000
   D100    0.0030    0.0030    0.0        0.0
 1.50DAYS
   SECTION     3     LOCATION  40.0- 60.0-FT    CONC (PPM)    319.

        DIAM       % REMOVED       TCN SETTLED      TCNS PASSED       VOL YDS      DEPTH CHANGE

            0.003      100              0.0            00.              0.0             0.0
      0.003 0.003      98.94            0.000            0.000          0.000           0.000
      0.003 0.001      43.50            2.812            3.652          3.006           1.217
   INSTANT SECTION EFF     43.50%
   INSTANT DEPTH CHANGE    1.217IN
   TOTAL SECT DEPTH CHANGE    5.513IN


            0.0030
            0.0030
            0.0010
            0.0
            0.0000
          100.0000
   D100    0.0030    0.0030    0.0        0.0
 1.50DAYS
   SECTION     4     LOCATION  60.0- 80.0-FT    CONC (PPM)    180.

        DIAM       % REMOVED       TCN SETTLED      TCNS PASSED       VOL YDS      DEPTH CHANGE

            0.003      100              0.0            00.              0.0             0.0
      0.003 0.003      98.94            0.000            0.000          0.000           0.000
      0.003 0.001      43.50            1.539            2.063          1.698           0.688
   INSTANT SECTION EFF     43.50%
   INSTANT DEPTH CHANGE    0.688IN
   TOTAL SECT DEPTH CHANGE    3.901IN


            0.0030
            0.0030
            0.0010
            0.0
            0.0000
          100.0000
   D100    0.0030    0.0030    0.0        0.0
 1.50DAYS
```

```
SECTION    5    LOCATION  80.0-100.0-FT    CONC (PPM)   102.

      DIAM        % REMOVED       TON SETTLED      TONS PASSED      VOL YDS      DEPTH CHANGE

         0.003       100             0.0              0.0              0.0            0.0
   0.003 0.003      98.94            0.000              0.000          0.000          0.000
   0.003 0.001      43.50            0.897              1.166          0.959          0.389
INSTANT SECTION EFF      43.50%
INSTANT DEPTH CHANGE    0.389IN
TOTAL SECT DEPTH CHANGE    2.802IN


         0.0030
         0.0030
         0.0010
         0.0
         0.0000
       100.0000
TOTALS AFTER    1.50DAYS

     C ACRE-FT     % REMOVED      TONSETTLED       TONS PASSED      VOL YDS
      159.669        29.56         167.224            358.408        149.502
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