Software utilizing Imhoff cone volumes to estimate furrow-irrigation erosion

R. E. Sojka, R. D. Lentz, and J. A. Foerster

ABSTRACT: Data analysis required for furrow-irrigation induced erosion research is greatly facilitated with the aid of computational software. Several programs have been developed at Kimberly, Idaho, that compute infiltration, runoff, and sediment loss from the following inputs: inflow and runoff rates, sediment concentration in runoff determined by Imhoff cones, sampling times, furrow spacing, and row length. We found that more than one program type was required to meet various user needs. Two PC-based programs are presented for intense furrow monitoring, one employs spreadsheet software and the other is a PASCAL program. They produce accurate estimates and display output in formats suited to quantitative evaluation or for further data reductions needed in research applications. An HP-IIC hand calculator program provides coarse diagnostic information that can easily be used by farm advisors to assess potential severity of furrow erosion in farmer's fields. The software have been extensively tested and are reliable. They can be used to quantify any component of runoff removal.

Erosion from irrigated land is an important component of global soil loss. Stewart and Nielsen (13) estimated the global inventory of irrigated land at 250 million ha. The area irrigated in the United States has been estimated at between 19 and 24 million ha (*4,1*), of which about 60% is surface irrigated. Worldwide, the proportion of surface irrigated to total irrigated land is probably greater than 60% because of the technical and capital constraints to more complex types of irrigation, and the predominant location of irrigated land in developing countries (*4, 9*). The magnitude of soil loss from irrigation, especially furrow irrigation, has been recognized in recent years (*5, 8*).

Growers in the Pacific Northwest surface irrigate 1.5 million ha of highly erodible soils, threatening the sustainability of irrigated agriculture. Crop productivity in eroded areas is reduced, requiring higher inputs per unit of yield (*5*). In some fields of the region, complete loss of surface horizons has occurred in only decades. Soil loss ranges from 5 to 50 t ha^{-1} yr^{-1}, and triple that rate occurs near furrow inlets where furrow streams are larger (*2,10*).

The ability to predict and control soil surface erosion requires techniques to rapidly and accurately assess the sediment concentration in irrigation runoff, and the extent of erosion associated with given concentrations and runoff amounts. Use of Imhoff cones to rapidly and inexpensively assess sediment concentrations of irrigation runoff was described by Sojka, Carter, and Brown (*12*). This technique involves correlating the total sediment concentration of a runoff sample with the volume of sediment at the bottom of graduated Imhoff cones after settling one half hour. Coupled with measurement of furrow inflow rates, runoff rates, and iterative software, one can estimate total soil loss for a fixed time interval, for an irrigation event, or for an irrigation season.

This paper describes software for personal computer and hand calculator estimates of erosion. The hand calculator program was written for the HP-11C[1], but can easily be adapted to other similar calculators. It is suitable for coarse diagnostic estimates by farmers, conservationists, or extension agents, making quick initial assessments of erosion from surface irrigation. Two programs for use on personal computers are described that require more intensive field monitoring and inputs, but which provide greater accuracy and precision of erosion estimates. One program uses spreadsheet software. The second, FRWSED, is programmed in Turbo Pascal, and the latter is designed for research applications. FRWSED and the Spreadsheet can also be employed to monitor other runoff constituents (e.g., salts, pathogens, weed seeds, etc.). The software and sample input/output are available from the authors[2] at no charge.

Computations

The software estimates the quantity of soil lost in furrow outflow during an irrigation, and over the entire season. Each irrigation is divided into a number of periods (n), of length (P_i) min, where $i = 1,....,n$. The first period begins when water first exits the furrow. Inflow rate (QIN_i) and runoff rate ($QOUT_i$), given in L min^{-1}, and Imhoff cone settling volume ($SVOL_i$), recorded as mL sediment per 1-L outfall sample, are measured at the beginning of each period. Exceptions are the first and final periods. In the first period, more representative values are obtained when measurements are taken 5-10 mins after runoff begins. The final period should begin at the time that inflow is stopped. A runoff measurement is made at the beginning of this period and the time runoff ceases is noted. In order to adjust for the rapidly declining outflow, however, experience has shown that using only one-half the last measured runoff rate provides accurate computation.

The software requires a calibration function, which converts settled sediment volume observed in one-liter Imhoff cone samples to weight of sediment per liter of runoff (*12*). Imhoff cone measurements for sediment concentrations <0.5 g L^{-1} are poor, but these concentrations represent negligible erosion rates. An estimate of sediment concentration, in g L^{-1} for each period ($SCONC_i$), is derived from the calibration equation:

$$SCONC_i = B \cdot SVOL_i + C \qquad [1]$$

where B is the slope of the calibration line and C is the Y-intercept. Additional program inputs include duration

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[1] Mention of trademarks, proprietary products, or vendors does not constitute a guarantee or warranty of the product by the USDA-ARS or the Idaho Agricultural Experiment Station, and does not imply its approval to the exclusion of other products or vendors that many also be suitable.

[2] An updated FRWSED version, soon to be completed, will add routines that 1) aid in debugging data input files, 2) permit more sophisticated grouping of data for comparison purposes, 3) make statistical comparisons (ANOVA) between calibration curves and output a graphical comparison of calibration functions, 4) add support for HPGL plotters, 5) Increase data input capacity of the program, and 6) compute and plot group-averaged values of cumulative sediment loss and outflow sediment concentration, as a function of irrigation duration.

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of the irrigation event (*IRRDUR*), the number of irrigations in the cropping year (*IRRNUM*), and an estimate of soil surface bulk density (*BD*) in Mg m^{-3}, in the furrow.

Net infiltration (*INFILT*) in L during the irrigation is computed from

$$INFILT = \sum_{i=1}^{n} (QIN_i - QOUT_i)\, P_i \quad [2]$$

Total soil loss from the furrow (*SLOSS*), in grams, is computed from equation [1], with

$$SLOSS = \sum_{i=1}^{n} SCONC_i \cdot QOUT_i \cdot P_i \quad [3]$$

and converted to an area basis using

$$SLOSS_A = (SLOSS \cdot 10)\,(FRWLEN \cdot FRWSP)^{-1} \quad [4]$$

where $SLOSS_A$ has units kg ha^{-1}, *FRWLEN* is furrow length (m), *FRWSP* is the mean distance between furrows (m), and *SLOSS* is given in grams. Depth of total soil loss ($SLOSS_D$) in mm is calculated from

$$SLOSS_D = SLOSS_A\,(K \cdot BD)^{-1} \quad [5]$$

where the conversion constant K = 10^4 kg m^{-3} (Mg ha $mm)^{-1}$. If inflow rate is not provided, erosion is estimated, but not infiltration.

FRWSED (Pascal program). FRWSED was designed for researchers investigating the effect of variables on furrow erosion. It processes large data sets more efficiently than the spreadsheet or calculator programs. For example, FRWSED easily accommodates 50 measurement periods (n = 50) and 10 inflow adjustments per irrigation. Field data are entered into a formated ASCII file that is read by the program. FRWSED can compute separate Imhoff cone calibration equations for different furrow groups, or treatments, and use them to compute erosion losses. Optionally, FRWSED can employ user-supplied calibration coefficients to compute sediment losses. The program computes results on a per irrigation basis and does not estimate seasonal erosion losses.

The following hardware is required to run FRWSED: an IBM compatible desktop, laptop, or notebook computer with 640k memory, and DOS 2.0 or higher operating system. FRWSED provides driver support for MCGA, CGA, EGA, VGA, and Hercules graphics modes; it also supports several printers, although output has been confirmed only on an Epson 86e (9 pin) and HP Laserjet IIIsi (PCL and postscript modes).

Spreadsheet. The spreadsheet, unlike FRWSED, does not calculate Imhoff cone calibrations. The calibration is supplied by the user, but for coarse diagnostic work it can be roughly estimated from textural and organic matter content relationships (*12*). For greater accuracy, however, these relationships should be determined beforehand for the soils in question. For research purposes separate calibrations (equation [1]) should be made for field conditions likely to influence soil aggregation, and hence settling volume relationships (e.g., trafficked vs nontrafficked conditions, or initial irrigation vs subsequent irrigations). Other calculations are identical to those in FRWSED, except that only 20 measurement periods (n = 20) may be included per irrigation, only 5 inflow adjustments are allowed per irrigation, and seasonal soil loss $SLOSS_S$ (kg ha^{-1} $season^{-1}$) is computed from

$$SLOSS_S = SLOSS_A \cdot IRGNUM \quad (6)$$

where *IRGNUM* is the total number of irrigations during the season. The

Table 1. Input file format for Pascal program with sample data.

INPUT FILE FORMAT

Actual File						Explanation of File Entries
Test data (Cntrl.dat)						Title
06/19/91						Irrigation date
1	0	170				Irrig. #, irrig. type, day of year
6	1	0	0			Furrow #, rep., trtmt., furrow type (optional)
1.12		171.8				Furrow spacing (m), furrow length (m)
3						# of inflow records (≥3, Including 1st & last)
10	01	0				hr and min 1st rate began, inflow rate (gpm)
10	01	6				hr and min 2nd rate began, inflow rate (gpm)
18	01	0				hr and min 3rd rate began, inflow rate (gpm)
10	33	0	0	0	-1	Time flow reaches flume (flow & sediment = 0)
10	38	4.3	9.0	15.5	-1	hr, min, outflow (cm & L min^{-1}), Imhoff sediment vol. & wt. (mL & g/L)
11	03	4.4	10.0	-1*	-1	*If no sediment vol. available enter –1, but first sample record must
11	33	4.5	12.0	17.5	14.8	include sediment value.
12	03	4.6	12.0	19.5	16.5	
12	33	4.6	11.0	15.5	-1*	*If No filtered sediment wt. for calibration, enter -1 in last column
13	03	4.6	12.0	13.0	11 .0	
13	33	4.6	12.0	11.5	9.7	
14	03	4.6	11.0	9.5	-1	
14	33	4.6	11.0	11.0	-1	
15	03	4.8	13.0	11.0	-1	
15	33	4.8	13.0	11.3	9.5	
16	03	4.6	12.0	12.5	10.5	
16	33	4.6	12.0	13.0	11 .0	
17	03	4.4	10.0	10.2	-1	
17	33	4.5	11.0	8.0	-1	
18	03	4.4	10.0	8.0	-1	
18	10	0	0	0	-1	Time flow ends at flume (flow & sediment = 0)
-99						Code to mark end of data for current furrow

Table 2. Output file format for Pascal program with sample data. The output file is named: <input filename>.OUT.

•Treatment = 0 (Control) sediment concentrations computed with: Sed (g/L) = -0.0636 + 0.8485-Sed (mL)
rsqr = 0.98 n = 20

DOY	IRG #	IRGT	FRW #	REP	FRWT	TRT	Mean Out-Flow L/min	Total Sediment Loss kg/ha	Total In-flow (mm)	Total Out-flow (mm)	Total Infil-tration (mm)	Mean Sediment Conc. (g/L)	Total Sediment Loss (mm)	Total Infil-tration (in)	Date (text)	Furrow Advance Time (min)
170	1	0	6	1	0	0	11.3	2924.7	56.7	26.8	29.8	10.94	0.2659	1.17	6/19/91	32
170	1	0	33	2	0	0	10.1	1986.5	56.7	23.5	33.1	8.44	0.1806	1.30	6/19/91	40
170	1	0	24	3	0	0	11.0	2849.0	56.7	25.8	30.8	11.03	0.2590	1.21	6/19/91	42
171	2	0	12	4	0	0	7.7	2279.6	39.9	18.4	21.6	12.41	0.2051	0.85	6/20/91	39
171	2	0	13	4	1	0	7.0	2116.8	39.1	16.2	22.9	13.08	0.1839	0.90	6/20/91	36
171	2	0	14	5	0	0	7.3	1311.3	40.8	16.7	24.2	7.88	0.1187	0.95	6/20/91	48
171	2	0	16	5	1	0	5.7	2034.7	37.9	13.2	24.7	15.40	0.1841	0.97	6/20/91	41
171	2	0	19	6	0	0	7.9	1357.3	40.5	18.3	22.3	7.42	0.1227	0.88	6/20/91	42
171	2	0	22	6	1	0	6.9	867.3	39.2	15.9	23.3	5.45	0.0787	0.92	6/20/91	43
176	3	0	35	7	0	0	7.0	1120.8	39.6	16.5	23.1	6.81	0.1018	0.91	6/25/91	39
176	3	0	1	8	0	0	7.4	884.2	39.3	17.7	21.6	5.00	0.0802	0.85	6/25/91	39
176	3	0	39	9	0	0	7.3	511.2	39.7	17.2	22.5	2.97	0.0465	0.89	6/25/91	44
189	4	0	1	8	0	0	9.5	4222.8	72.4	33.6	38.8	12.59	0.3837	1.53	7/08/91	39

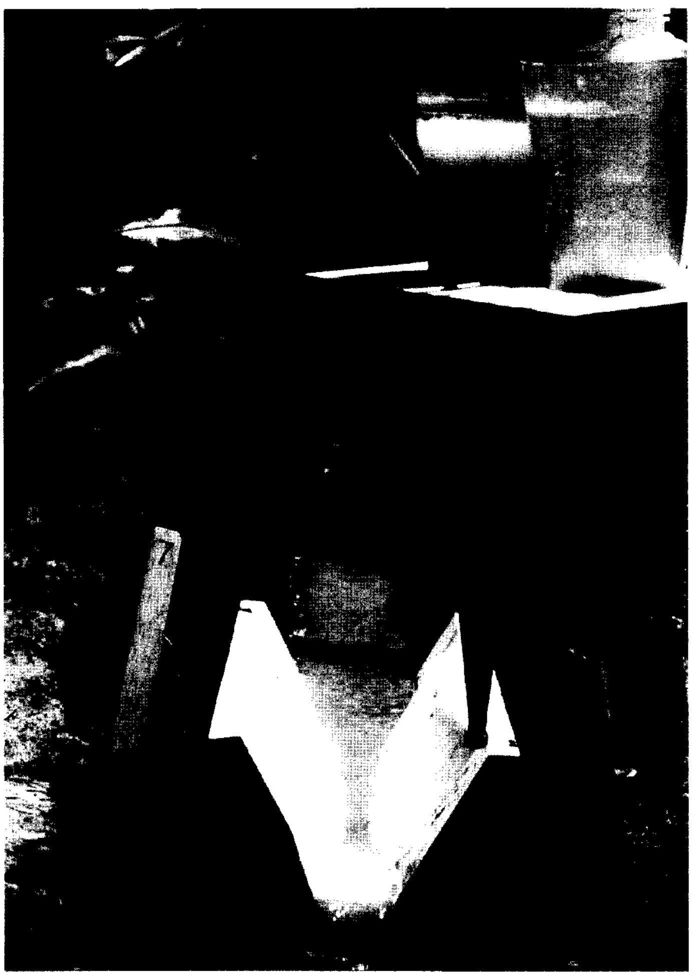


Figure 1. Flume and Imhoff cones containing outflow samples installed at the furrow tail.

spreadsheet, running on a portable computer, can be used for real-time estimates of soil loss in the field where data collection is ongoing (e.g., in erosion studies on farmer cooperator fields).

The spreadsheet hardware requirements are identical to those listed for FRWSED. The Quattro Pro spreadsheet is compatible with Quattro Pro 3.0 or higher, and requires a mouse. The Lotus 123 spreadsheet requires Lotus version 2.2 or higher, but no mouse.

HP-11C (Hand calculator). Extension agents, consultants, and SCS personnel are often called to assess irrigation-induced erosion problems on farmer fields. Typically they are called out and arrive on-site while an irrigation is in progress. These personnel can make a rough assessment of erosion severity using a program written for the HP-11C hand calculator. Necessary measurements can be made using a stop watch, a 3.78-L (1-gal) bucket, a one-liter Imhoff cone, and a flume. If a flume is not available, one can place a trough in the furrow to collect the flow, then simply measure the time required to fill a container of convenient volume. The program gives a farmer a general estimate of erosion severity from his field. Set duration and number of irrigations per year can be varied with each program iteration to provide a series of diagnostic estimates of erosion based on a number of scenarios.

HP-11C program computations differ from the other applications in that they employ only one measurement period (n = 1). A one-time measurement of QIN_i, $QOUT_i$, and $SVOL_i$ is taken midway through an irrigation and used in equations [1–6] to compute estimates representing an entire irrigation set, and an entire irrigation season. Such extrapolations assume a steady state of all parameters, which is not a valid assumption for accurate erosion estimates. Therefore, the program's projections should only be regarded as diagnostic. Hand calculator estimates can be improved by making separate estimates for individual irrigations. However, if accuracy of this level is needed, using the PC-software and more intensive observation is recommended.

Field measurements

Irrigation monitoring method. Data used to demonstrate the software were collected in 1991 from a conven-

STUDY:Test data
DATE:6-19-91

IRRIG: One
IRRIG.TYPE: Initial on fresh corrugates

Furrow # 1	Rep 1	Trt 1
Type 2	FurrowSp	FurrowLen
	1.12	183
INFLOW		
	TIME	RATE (GPM)
BEGIN	10:00	0
	10:00	6
END	18:01	0
OUTFLOW		
TIME	RATE % cm/L min^{-1}	SED (mL)
11:02		0
11:07	2.8/3.5	1.4
11:32	3.8/7.0	19.0
12:02	4.0/8.0	19.0
12:32	4.2/8.0	13.0
13:02	4.0/8.0	9.5
13:32	4.3/9.0	8.0
14:02	4.4/10.0	7.7
14:32	4.6/11.0	4.5
16:02	4.5/11.0	1.8
17:02	4.5/11.0	1.8
18:02	4.5/11.0	1.5
18:10	0/0	0

Furrow #6	Rep 1	Trt 0
Type 0	FurrowSp	FurrowLen
	1.12	171.8
INFLOW		
	TIME	RATE (GPM)
	10:01	0
	10:01	6
	18:01	0
OUTFLOW		
TIME	RATE % cm/L min^{-1}	SED (mL)
10:33		0
10:38	4.3/9.0	15.5
11:03	4.4/10.0	-1
11:33	4.5/12.0	17.5
12:03	4.6/12.0	19.5
12:33	4.6/11.0	15.5
13:03	4.6/12.0	13.0
14:03	4.6/11.0	9.5
14.33	4.6/11.0	11.0
16:03	4.6/12.0	13.0
16:33	4.6/12.0	8.0
18:03	4.4/10.0	8.0
18:10	0/0	0

Figure 2. Field data sheet

tionally-tilled field in Kimberly, Idaho, on a Portneuf silt loam soil (coarse-silty, mixed, mesic, Durixerollic Calciorthids). Furrows were spaced 1.12 m (44 in), were 171.8 m long (558 ft), had a 1.6% slope, and had been formed into 75 degree, 20 cm deep (approximately), V-shaped channels. The crop was dry edible beans ('Viva Pink' *Phaseolus vulgaris* L.). Irrigation was by individually regulated siphon tubes from a cement-lined head ditch. Only wheel-trafficked furrows were used. Water application to each monitored furrow was predetermined and periodically measured. Snake River water was used for irrigation. Average electrical conductivity is 0.5 dS m-1 (0.5 mm cm-1), and mean Sodium Absorption Ratio is 0.6 (*5*).

Good estimates of inflow and runoff rates are important if erosion estimates are to be meaningful (*14,15*). Inflow rate was determined by measuring the filling-time for a 3.78-L (1-gal) container to the nearest 0.1 second (using a stopwatch). Runoff rates at the end of the furrow were measured by manually reading calibrated V-notch flumes at hourly or shorter intervals throughout the course of each irrigation set. The V-notch flumes, developed and calibrated by Robinson and Chamberlain (*11*), are marketed by Honkers Supreme, Twin Falls, ID, and satisfy the hydraulic requirements for long-throated flumes (*3*) up to a flow depth of 9 cm (3.5 in) [a gauge reading of 10 cm (4 in), or 100 L min^{-1} (26.5 gpm) flow rate]. One-liter (0.26 gal) runoff samples were collected from free-flowing flume discharge at each flume reading, and placed in Imhoff cones[3] (Figure 1) to determine sediment concentration (*12*). Samples were usually collected every 30 min during the first 2–3 hr of irrigation, and every 60 min thereafter.

Use of the HP-11C program requires a single measurement of inflow rate (QIN_i), runoff rate ($QOUT_i$), and Imhoff cone settling volume ($SVOL_i$). Examination of extensive data from this site has shown that, for a single observation to be representative of an entire irrigation, the measurement should be made between 3.8 and 4 hrs after runoff begins.

Field data sheet (FRWSED and spreadsheet). The field data sheet shown in Figure 2 can be used to manually record data in an entry format compatible with both the FRWSED and spreadsheet programs. Most entry fields are self explanatory.

Table 3. Inputs and outputs for the HP-1 1C program. Sample data appear in order of program execution.

Register	Input description	Input
0	furrow length (m)	171.8
1	furrow width (m)	1.12
2	current inflow gal fill time (sec)	10
3	current outflow rate (L min^{-1})	11
4	set duration (min)	480
5	# of irrigations/season	6
6	30 min settling volume (mL)	11
7	calibration slope	0.8485
8	calibration y-intercept	-0.0636
9	bulk density (Mg/m3)	1.1
Order	**Output description**	**Output**
1	inflow rate (L min^{-1})	22.7
2	inflow rate (L/hr)	1362.6
3	total inflow (L/set)	10900.8
4	runoff percent	48.4
5	runoff rate (L/hr)	660.0
6	total runoff (L/set)	5280.0
7	infiltration percent	51.6
8	infiltration rate (L/hr)	702.6
9	total infiltration (L/set)	5620.8
10	sediment concentration (g/L)	9 3
11	sediment loss (kg/hr/ha)	318.0
12	total sediment loss (Mg/set/ha)	2.5
13	potential sediment loss (Mg/season/ha)	15.3
14	total soil depth loss (mm/set)	0.23
15	potential soil depth loss (mm/season)	1.39

[3] 1,000 ml Imhoff cones are manufactured by Nalgen Company, Rochester, NY, and are available through most scientific supply houses.

Worksheet date:	11/18/92		
Irrigation date:	06/19/91		
Irrigation day of year:	170		
Irrigations per season:	6		
Furrow number:	6	Furrow advance:	
Furrow spacing (m):	1.12	32	minutes
Furrow length (m):	171.80	5.4	meters/minute
Bulk density (Mg/m3):	1.10		
Calibration slope:	0.8485		
Calibration y-intercept:	-0.0636		

INFLOW:	Time (hr.min)	Inflow rate (gpm)			
Begin	10.01	6.0	Inflow duration:	480	minutes
End	18.01	0.0	Inflow total:	2880.0	gallons

OUTFLOW:	Time (hr.min)	Outflow rate (L/min)	Imhoff cone vol (mL/L)	Sediment conc (g/L)	Interval sediment total(g)	Accum. sediment total(g)	Accum. runoff total(L)
Begin	10.33	0.0	0.0	0.00	0.0	0.0	0.0
(5 min)	10.38	9.0	15.5	13.09	3533.8	3533.8	270.0
.	11.03	10.0	-1.0	13.09	3926.4	7460.2	570.0
.	11.33	12.0	17.5	14.79	5322.7	12782.9	930.0
.	12.03	12.0	19.5	16.48	5933.6	18716.5	1290.0
.	12.33	11.0	15.5	13.09	4319.1	23035.6	1620.0
.	13.03	12.0	13.0	10.97	3948.1	26983.6	1980.0
.	13.33	12.0	11.5	9.69	3489.9	30473.5	2340.0
.	14.03	11.0	9.5	8.00	2639.1	33112.6	2670.0
.	14.33	11.0	11.0	9.27	3059.1	36171.7	3000.0
.	15.03	13.0	11.0	9.27	3615.3	39786.9	3390.0
.	15.33	13.0	11.3	9.52	3714.5	43501.5	3780.0
.	16.03	12.0	12.5	10.54	3795.4	47296.8	4140.0
.	16.33	12.0	13.0	10.97	3948.1	51244.9	4500.0
.	17.03	10.0	10.2	8.59	2577.3	53822.2	4800.0
.	17.33	11.0	8.0	6.72	2219.1	56041.3	5130.0
.	18.03	10.0	8.0	6.72	235.4	56276.6	5165.0
End	18.10	0.0	0.0	0.00	0.0	56276.6	5165.0
				0.00	0.0	56276.6	5165.0
				0.00	0.0	56276.6	5165.0

Total furrow sediment loss:	56276.6	grams
Total sediment loss as equivalent depth of soil:	0.2659	millimeters
Total sediment loss per hectare:	2924.7	kilograms/hectare
Potential sediment loss per hectare per season:	17548	kg/ha/season

Total furrow...	liters	mm	inches
Inflow:	10900.8	56.7	2.23
Outflow:	5165.0	26.8	1.06
Infiltration:	5735.8	29.8	1.17

Figure 3. Quattro Pro spreadsheet input and output screen display (bordered data at time 14.33 were used for HPIIC calculations.

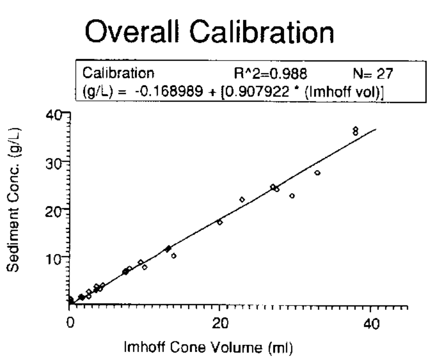


Figure 4. Portion of the graphic display showing an example of FRWSED calibration for desired data grouping

The data field labeled "Type" provides another optional identifying code. Data fields labeled "Furrowsp" and "Furrowlen" identify the spacing between irrigated furrow centers and furrow length in meters. "Inflow" fields record the beginning and ending time of irrigation inflows and the inflow rates at specific times during the irrigation. The multiple entry fields allow for variations in the inflow rate, or for inflow management treatments such as surge treatments.

"Outflow" fields describe runoff monitoring/sampling times, runoff rate at the time monitored, and the Imhoff cone sediment volume for each runoff sample collected. Long throated flumes (3) were used to measure runoff, both as cm of water depth in the flume and as L min^{-1} flow. Both parameters were recorded to provide a further check on data entries. In practice, once entries are reconciled from these paired readings, flow rate in L min^{-1} is entered as input data for both FRWSED and for the spreadsheet version of the software.

Program input

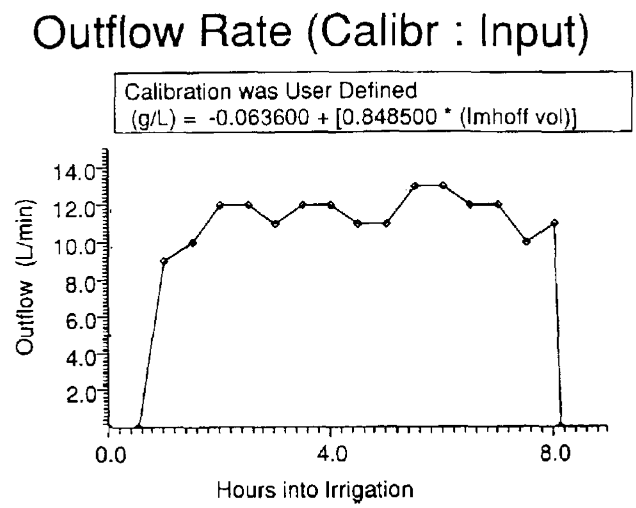
FRWSED (Pascal program). The input file format (Table 1) is very similar to that of the field data sheet. The first line is the data file title. The next nine lines of data entry identify and characterize the field variables for the particular furrow. Beginning on the eleventh line outflow data are entered using the same format recorded on the data sheet. Inputs include sampling/monitoring time, outflow depth and flow rate and Imhoff cone settling volume. Imhoff cone settling volumes for each sample are accompanied by actual weight of suspended sediment from those samples filtered in the laboratory for calculation purposes. These values provide an Imhoff cone calibration check. In addition, values of filtered sediment are automatically substituted for estimates on those samples where they are available. Example data for furrow no. 1 in the field data sheet (Figure 2) and example input file (Table 1) were input to FRWSED. The results appear in the first record of the example output (Table 2)

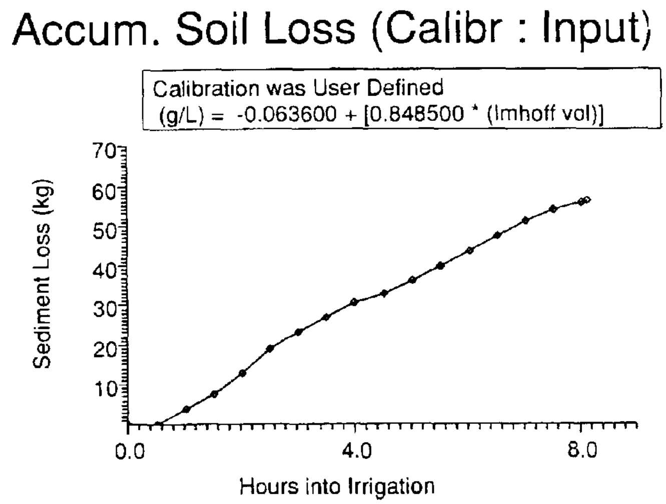
Spreadsheet. Inputs and the field data sheet are as described in above paragraphs. A representation of the spreadsheet screen is presented in Figure 3. The spreadsheet is designed for rapid data entry. All cells except highlighted data input cells are protected to reduce entry error. A macro generates additional forms for each included furrow. Example data for furrow no. 1 in the field data sheet (Figure 2) are used as input into the spreadsheet example shown in Figure 3.

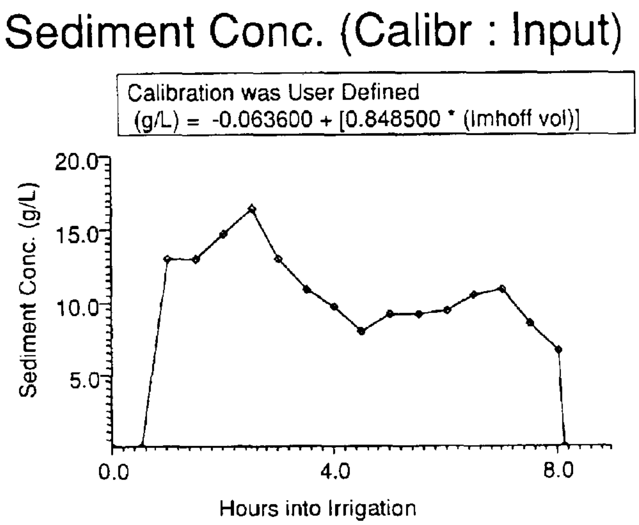
HP-11C (Hand Calculator). The simple HP-llC inputs appear in Table 3. The format in Table 3 is the same as the worksheet that is supplied with this program. The particular data used in the HP-11C example were from a mid-irrigation period obtained from the spreadsheet (bordered in Figure 3).

Program output

FRWSED (Pascal program). FRWSED first prompts the user to input a calibration preference, then branches to routines that either request input calibration coefficients, or request furrow grouping information required to compute calibrations from outflow samples. The Imhoff cone settling volume calibration equation with r^2 and number of







FURROW DATA SUMMARY

DOY	IRG#	IRGTYPE	FRW#	REP	FRWTYPE	TRT
170	1	0	6	1	0	0

	(mm)	(inches)
Total Inflow	56.7	2.23
Total Outflow	26.8	1.06
Total Infilt.	29.8	1.17
	(Kg/Ha)	(in. soil)
Total Soil Loss	2924.7	0.0105
Mean Outflow	(L/min)	11.30
Mean Sed. Conc.	(g/L)	10.90
Advance Time	(min)	32.00

Figure 5. Entire graphic display of FRWSED output for each furrow

pairs regressed is displayed for the grouped data. The screen display (Figure 4) permits rapid visual comparison of up to four calibrations, and provides a handy tool for making rapid manual graphical estimates of sediment concentration from Imhoff cone settling volumes. When calibrations have low correlation coefficients, the graphical output can help determine whether the loss of precision is due to data scatter or deviation from linearity. In the latter case immediate additional insight is gained as to possible curvilinear equation forms that might be suitable for calibration.

The program then asks the user to specify which calibration function will be applied to each of the previously selected furrow groups. Output values are then calculated for all furrows in each group. At this point a program prompt permits the user to request that compiled values for each furrow be displayed (Figure 5) for furrow output. Outflow rate, accumulated sediment loss, and sediment concentration in outflow are plotted as a function of irrigation duration. The graphs are accompanied by a numerical summary of the furrow data.

FRWSED outputs computed-values to a text, or ASCII file (Table 2), which is readily imported into statistical or graphics software. Each data column in the output file is labeled. Furrow identifiers are included to help sort data records, once data are imported into analytical software. Calculated outputs include mean outflow in L min^{-1}, total sediment loss in kg/ha, total inflow in mm, total outflow in mm, total infiltration in mm, mean sediment concentration in g/L, depth of soil loss in mm, infiltration in inches, and furrow advance time in minutes (time required for the water to traverse the dry furrow).

Spreadsheet. Spreadsheet computations are complete once input data have been typed into the appropriate entry fields. Results are displayed in the spreadsheet and can be printed to hard copy (Figure 3). The Quattro-Pro version produces interval and cumulative graphs that plot sediment loss and runoff vs irrigation outflow duration (Figure 6a&b). Calculated output from the spreadsheet (Figure 3) is identical to that of FRWSED (1st record in Table 2). This is because the critical inputs and algorithms for both programs are the same. The spreadsheet also includes an estimate of seasonal soil loss.

HP-11C (Hand calculator). The

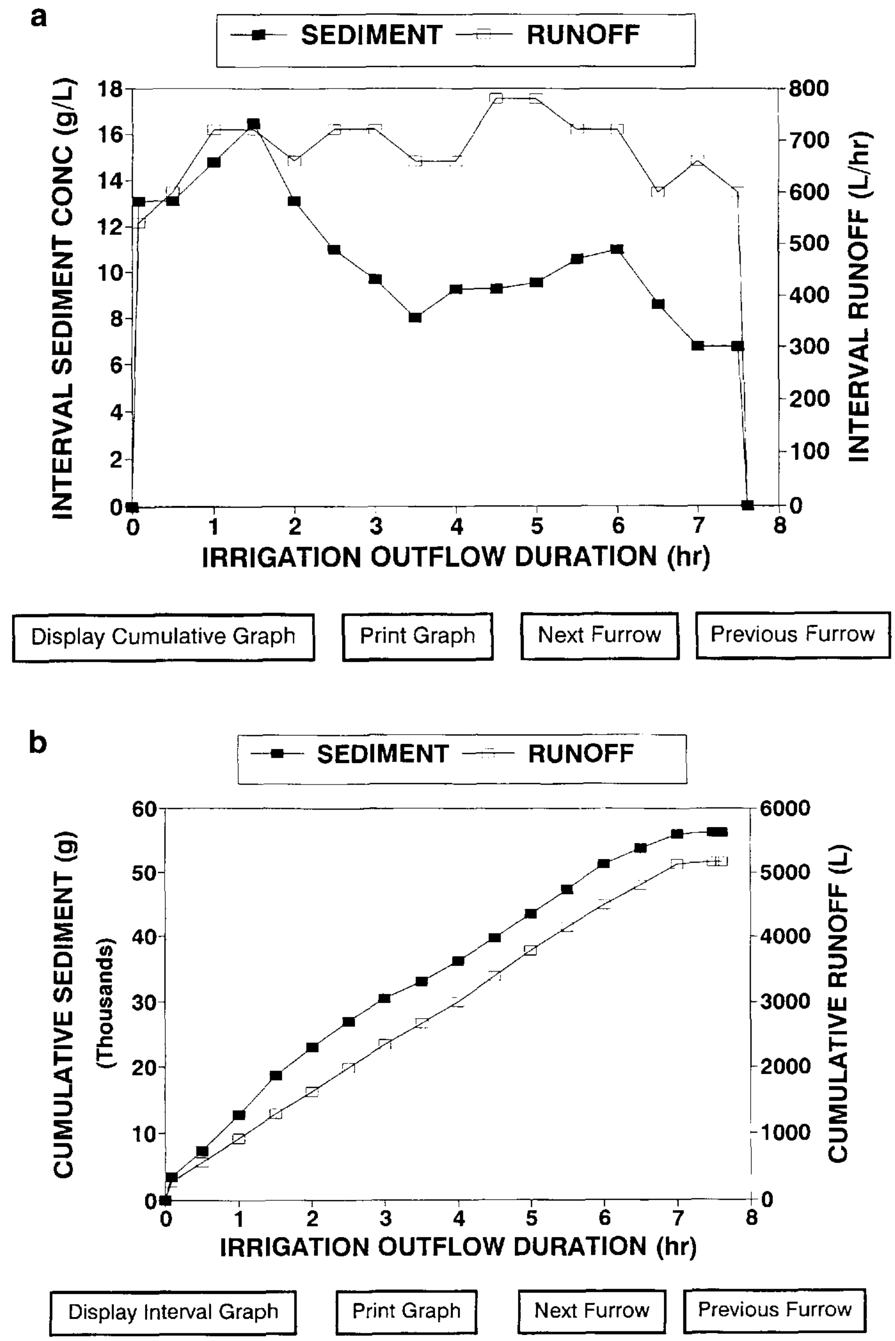


Figure 6a & b. Graphic display of Quattro Pro output for each furrow

HP-11C program output (Table 3) varies somewhat from the FRWSED and spreadsheet outputs. The HP-11C program employs a single observation in its soil loss calculations. FRWSED and the spreadsheet calculate estimates from data gathered over a number of sampling preiods during the irrigation set. Nonetheless, HP-11C estimates are reasonably similar to those produced by the FRWSED and spreadsheet programs, provided caution is used to make the single observation about 4 hours after the runoff period.

Summary

Software that estimates soil loss from furrow-irrigated fields is described. While designed to compute soil loss, the software can be used to monitor any material removed from the field in runoff. Two of the programs are for IBM compatible personal computers, one runs on the HP-11C hand calculator. Each requires one or more interval measurements of furrow inflow and outflow rates, and outflow sediment concentration. The HP-11C program produces rapid coarse diagnostic estimates, while the spreadsheet and Pascal program require more extensive field observations but provide very accurate evaluations. Both PC versions have been used extensively at the USDA-ARS Research Facility in Kimberly and have significantly reduced computational errors and time required for data analysis.

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