SUBSURFACE DRAINAGE SYSTEM PERFORMANCE IN EGYPTIAN OLD LAND

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ABSTRACT

A field study was conducted at Mashtul Pilot Area MPA (260 feddans' 1 feddan = 4200 m^2) situated at north Zagazig to evaluate the performance of the long term constructed subsurface drainage system. The evaluation of grades, alignment and clogging of drain lines can give an indication of the system performance and efficiency. Three drainage units served by the same collector were selected. Four 30 m interval PVC lateral pipes were installed at different depths. The results revealed that, the collector drain slopes were either steep or flat while the overall slope of the collector drain was considered steep for about 45.50% of the sections and flat for the rest. On the other hand, some sections showed an inverse slope which can cause a decrease in the discharge rate. The regularity was classified as good for about 82% of the sections and moderate for the rest. The slope of the lateral drains was correct for 41.7% of those under study (12 lateral drains), steep for 16.60%, and flat for the rest, and the regularity was classified as poor except lateral number 71 which had moderate regularity in the first approach while, in the second approach 41.67% had moderate regularity and poor for the rest. Also the deviation of the drain pipes from the straight line was generally larger than pipe diameter. Consequently, air entrapment and sedimentation resulted. The results also indicated that, the average height of sedimentation inside lateral drains was 12.70 mm (618.30 gm/m drain length) while for collector drains, sediment was in 22.88% of pipe diameter. The average reduction in discharge capacity due to sedimentation for laterals and collectors upstream and downstream parts were 17.17%, 32.80% and 17.60% respectively. Also using Manning, Visser and Wesseling equations leads to different safety factors.

INTRODUCTION

Clogging of drains with sediment is a major factor affecting the performance of the subsurface drainage systems in areas with unstable soils. Therefore, coarser

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envelope materials made from polypropylene (PP) with pore size index (O_{90}) of about 350 microns can be recommended to protect drain tubes in calcareous soils of the Western Delta of Egypt (Omara et al. 1995). Sedimentation may also occur due to other factors such as the opening of the drain pipes, grade of the drain line, insufficient slope or water velocity inside drain pipes to remove all deposits, and also using improper type of drain envelope (DRI, 1985). Moreover, Le Grice, and Armstrong (1981) found that 91% of the examined drain pipes had slot width between 1.0 and 1.5 mm, while no slots were larger than 1.5mm. The maximum gap width between clay pipes varied greatly with 20% smaller than 1.0mm and nearly 57% greater than 2.0 mm. Also, Amer (1969) studied the relationship between sedimentation and slope of drain pipes in the Nile Delta. He found that the silt and clay deposits are found through all tile lines with different depths. The depth of deposits ranges from 10 mm (Slope 0.20-0.30%) to 40 mm (Slope 0.06%), as the slope increases silt deposits decrease. He reported that the greater depth of deposit in each tile line was found to be near the outlet (15-20m outlet). He also found that the greater part of material carried into tile lines was silt, which represents 40 to 69% of total sediments, and the rest is clay. Also, DRI (1983) reported that the silting problem is widespread in the tile drainage projects in Egypt. This problem is mainly observed with the cement pipes rather than the PVC pipes, and about 40% of the investigated laterals were completely blocked, while 40% were partially blocked. This was attributed to bad alignment, dislocation and the absence of the gravel envelope. Dierickx (1984), mentioned that the clogging of concrete laterals is more serious than of corrugated PVC laterals. This is mainly due to damaged pipes, too wide gaps, dislocated pipes, bad alignment and the absence of the gravel envelope.

Cleaning of subsurface drainage systems in Egypt was done in the past by using bamboo rods and a brush pulled though the pipes. This technique has been mostly replaced by high and medium pressure flushing machines. Routine flushing is limited to collector pipes only as most laterals lack access tubes. The cleaning of laterals through risers at the cross connectors has been tried at pilot projects. However, with good construction, flushing should not be frequently needed (Abdel Dayem, 1990). On the other hand, Van Zeijts and Zijlstra (1990) mentioned that a subsurface drainage system will function properly if it satisfies certain conditions such as no breaks or blockage in the drain lines. They also found that 6% of the newly laid drains in the Netherlands could not function properly because pipes were crushed, cracked, dented, squeezed flat, or twisted, or because connector sockets had snapped off. The main objective of this study is to evaluate the performance of the subsurface drainage system in one of the pilot areas constructed 18 years ago.

EXPERIMENTAL AREA

The study was conducted at Mashtul Pilot Area (MPA) which is located east of the Bahr Saft area, about 7 km north Zagazig. Three drainage units were chosen from Mashtul Pilot Area, namely units 7, 8 and 9 (Fig. 1). Each unit was provided with four PVC laterals. The spacing between laterals is 30 m, and has different drain depths with lateral length of 300 m. The construction of the subsurface drainage system started in December 1979 and was completed by the end of April 1980. Collector I was chosen (served 125.71 feddans) (1 feddan = 4200 m^2) throughout the course of this study. There are five sub-collectors discharging their drainage water into collector I. The design discharge rate for collectors and sub-collector in MPA was 2 mm/day. The collector drain pipes are concrete with a standard length of 0.75m and vary in diameter from 150 mm at the upstream end up to 350 mm at the outlet. Manholes were made out of prefabricated concrete units with 1 m diameter and standard length of 1 m. The design slope of laterals is 10 cm/100 m according to the Egyptian Public Authority for Drainage Projects (EPADP) standards.

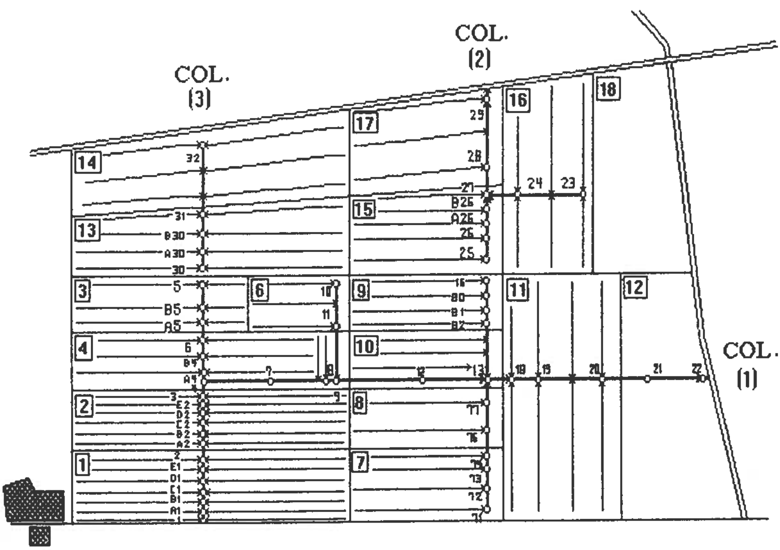

Fig. 1. Layout of Subsurface Drainage System at MPA and Drainage Units

The discharge of laterals was measured using a bucket or a cup with a known volume and a stopwatch. The time needed to fill the bucket or the cup was recorded. The volume of water discharged at the recorded time was calculated, knowing the area served by laterals under study. Moreover, the collector discharge measurements were carried out from a short rectangular steel flume which was fixed at the outlet of the collector drain. The water level in the manholes was measured daily from a fixed point using measuring tape, and the values were converted into Mean Sea Elevation. At the beginning of the study period, the backfill over the lateral pipe under study was excavated until the pipe was exposed at one point. The excavations were made at the middle of the lateral length. Part of the lateral drainpipe was cut carefully and replaced by a new one. The height of sediment (in mm) inside the drainpipe was measured. Samples from deposits inside the drainpipe were collected in each location for particle size distribution analysis using the pipette method, and for dry weight determination in grams per meter length. The soil texture is homogenous along the soil profile and the average clay, silt and sand percentages are 50, 30 and 20 % respectively. Spot levels were taken along the collector and lateral drains of units 7, 8 and 9 to evaluate the quality of construction according to the method suggested by Oosterbaan and Herrendoff (1982) as follows: The actual slope for each section has been defined as the weighted average of the actual slope according to the following equation:

$$Sa = \left(\frac{1}{n}\right) * \sum\left(\frac{H_i}{L_i}\right) \qquad (1)$$

in which, S_a= Actual slope (m/m), H_i = difference in level between pipe at L= 0 and $L = L_i$ (m). L_i = distance from downstream manhole (m) and n = number of levels in this section.

A parameter (U) is introduced to test the relation between the actual slope and the design one according to the following equation:

$$U = 1 - \left(\frac{S_a}{S_d}\right) \qquad (2)$$

in which U = parameter qualifying the pipe slope, according to:
$U < -0.2$ steep, $-0.2 < U < 0.2$ correct, and $U > 0.2$ flat.

Furthermore, the deviation (d_i) from the actual slope has been calculated using the following formula:

$$d_i = H_i - S_a * L_i \qquad (3)$$

in which, d_i is absolute deviation in point (i)

The deviation between the design and actual level of the drainpipe at each point is calculated according to the following equation:

$$d_i = H_d - H_a \qquad (4)$$

The regularity (r) of the drainpipe is defined as:

$$r = d_{mean} + 2 * SD \qquad (5)$$

in which, d_{mean} is the mean value of deviation (d_i), SD is standard deviation of (di) and r is a parameter qualifying the regularity according to: r < D/2 good, D/2 < r < D moderate and r > D poor in which D is the internal diameter of the drainpipe (m). A simple mathematical analyses was used to calculate the reduction in drainpipe area as a result of the sedimentation height inside the pipes. The equations deduced according to the method described by the Oosterbaan and Herrendoff (1982) analysis read:

$$\theta = 2\cos^{-1}(1 - \frac{H}{50}) \qquad (6)$$

$$A = \frac{\theta}{3.6} - (\frac{50 \sin\theta}{\pi}) \qquad (7)$$

where: θ is the center angle of sediment width, H is the sediment height (% of pipe diameter) and A is the reduction in area (% of maximum), and π = 3.1416. The reduction in discharge capacity was calculated according to Cavelaars (1985). A simple mathematical analyses was used to calculate the gap space between concrete collector drain pipes. This mathematical analysis considers the slope and diameter of pipes through calculation. The equation deduced according to this analysis reads:

$$G = 2D \sin [0.5 \tan^{-1} (i)] \qquad (8)$$

Where: G= gap space (cm), D = pipe diameter (cm) and i = slope.

The safety factor can be calculated using the following equation:

$$SF = (1 - Ac/Am) \times 100 \qquad (9)$$

where: SF = safety factor (%), Ac = actual command area (fed.), Am = computed maximum drainable area (fed.).

RESULTS

Quality of Construction of Drain Pipes

The evaluation of grades and alignment gives an indication of the system performance and the problems associated with misalignment such as overpressure, accumulation of sediment, reduction in discharge capacity and maintenance. The quality of construction of the drain pipes can be classified by comparing the design and the actual slope. The actual slope is an indication of the accuracy of the sight line set out by the surveyor and used by the operator to keep the trench box of the pipe laying machine on grade. The regularity is an indication of the accuracy of the operator and his capability to keep the trench box within certain limits of the sight line.

Collector Drain:

Figure 2 shows the longitudinal section of the collector drain, and the calculations for determining the qualification of the collector drain alignment are summarized in Table 1. The analysis of the collector drain slopes leads to the following results:

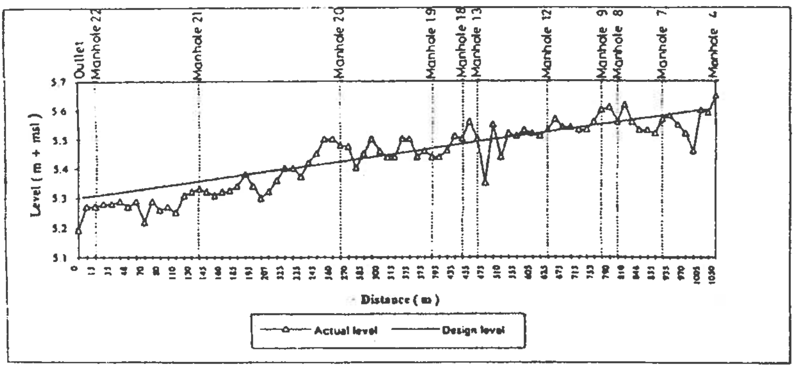

Figure 2. Longitudinal Section of the Collector System

- All sections of the drainpipe were laid at a slope, which is either steep or flat.
- The overall slope of the downstream section (between manhole 22 and 13) is steep and the upstream section (between manhole 13 and 4) is flat. However, some intermediate sections have the opposite qualification. The overall slope of the collector drain is considered steep.
- The slope of the collector sections is steep for about 45.5% of the sections and flat for the rest.
- The short section between the outlet of the collector drain and the first manhole drops sharply to the level in the open drain irrespective of the design slope.
- The section between manhole 18 and 13 is too steep. It referred to the wet condition of the soil during the construction of the pipes because the section crosses an irrigation canal and a row of trees.
- Some sections have an inverse slope, which can create problems due to the decrease in water flow.

- According to the first approach (Table 1). the regularity is classified as good for about 81.8% of the sections and moderate for the rest. The regularity of the downstream section, upstream section, and the overall collector drain has been qualified as good.
- According to the second approach, the regularity is classified as good in all except section (13-12) which has poor regularity. The downstream section is classified as good but the upstream section is poor. The overall collector drain is classified as moderate.

Table 1. Analysis of Collector Drain Alignment

Section between Manholes	Slope X 10^{-4} (m/m)		Qualification	Regularity (r) m		Regularity Qualification	
	S_d	S_a		1st	2nd	1st	2nd
outlet-22	3	40	steep	0.143	0.136	good	good
22-21	3	2.087	flat	0.089	0.053	good	good
21-20	3	2.337	flat	0.122	0.139	good	good
20-19	3	-7.599	flat	0.136	0.091	good	good
19-18	3	6.133	steep	0.102	0.048	good	good
18-13	3	20	steep	0.158	0.073	moderate	good
13-12	3	-13.603	flat	0.112	0.308	good	poor
12-9	3	3.752	steep	0.088	0.047	good	good
9-8	3	-2.222	flat	0.114	0.054	good	good
8-7	3	6.278	steep	0.08	0.113	good	good
7-4	3	-1.745	flat	0.125	0.121	moderate	good
22-13	3	4.645	steep	0.122	0.102	good	good
13-4	3	-3.085	flat	0.115	0.293	good	poor
22-4	3	4.291	steep	0.117	0.137	good	moderate

Lateral Drain:

The same analysis has been carried out for lateral drains as for the collector drain. The analysis started at 30 meters from the outlet because the lateral drain drops sharply to the level in the manhole or sub-collector. Figure 3 shows the longitudinal sections of the lateral drains for units 7,8 and 9. The calculations for determining the qualification of the lateral drains alignment are summarized in Table 2. From the results of this analysis the following conclusions can be drawn: The slope of the lateral drains is correct for about 41.7% of the lateral drains under study, steep for about 16.7% and flat for the rest. In the first approach, the regularity is classified as poor except in lateral 71 which has moderate regularity, while in the second approach the regularity is moderate for about 41.7% and poor for the rest. The deviation of the drain pipes from the straight line is generally larger than the pipe diameter. This quality of installation causes air entrapment and sedimentation resulting in pressure buildup.

Table 2. Analysis of Lateral Drain Alignment

Unit No.	Lateral No.	Slope X 10^{-4} (m/m)		Qualification.	Regularity r (m)		Regularity Qualification.	
		S_d	S_a		1st	2nd	1st	2nd
	71	10	8.67	correct	0.057	0.105	moderate	poor
	72	10	1.33	flat	0.295	0.052	poor	moderate
7	73	10	10.64	correct	0.094	0.055	poor	moderate
	74	10	3.31	flat	0.117	0.235	poor	poor
	75	10	9.33	correct	0.11	0.052	poor	moderate
	76	10	9.95	correct	0.106	0.088	poor	poor
8	77	10	12.97	steep	0.138	0.103	poor	poor
	78	10	0.42	flat	0.431	0.048	poor	moderate
	79	10	14.11	steep	0.252	0.067	poor	moderate
	80	10	8.45	correct	0.232	0.12	poor	poor
9	81	10	6.8	flat	0.206	0.113	poor	poor
	82	10	7.37	flat	0.214	0.081	poor	poor

S_d:Design slope, S_a:Actual slope, r: regularity, 1st: first approach, 2nd: second approach

Clogging of Subsurface Drainage System

Clogging of drains with sediments is an important problem in the design and maintenance of subsurface drainage systems.

Lateral Drain Pipes:

The particle-size distribution of the sediments inside lateral drain pipes under study are presented in Table 3. The texture of the sediments was clay in all samples. The minimum percentage of clay was 50% which was found in laterals 76 and 77, and the maximum was 53.1% detected in lateral 73. The average was 51.5% with a standard deviation of 1.26. The maximum height of sediment was 18 mm and the amount of dry weight was 953.4 gm per meter of pipe length in lateral 73. The minimum height was 9 mm with a minimum dry weight of 390 gm per meter of pipe length. The average height of sediment was 12.7 mm. with a standard deviation of 3.6 and the average dry weight was 618.3 gm per meter length.

Collector Drain Pipes:

The section between manholes 21-20 was blocked at the beginning of the measurement season. Some tree roots were found around the nozzle of the flushing machine. During the summer season, farmers were plugging the collector and sub-

Table 3. Sediments Inside Lateral Drain Pipes

Particle size distribution	Lat. 72	Lat. 73	Lat. 76	Lat. 77	Lat. 81	Lat. 82
Clay %	51.8	53.1	50	50	52.2	52
Silt %	31.7	32.3	32.2	32.2	26.3	30
Sand %	16.5	14.3	17.8	17.8	21.5	18
Texture	clay	clay	clay	clay	clay	clay
Dry weight (g/m)	665.2	953.4	527	425.8	390	748.3
Height of sediment (mm)	14	18	11	9	9	15
Sediment height (%)	19.44	25	15.28	12.5	12.5	20.83
Reduction in area (%)	13.67	19.55	9.66	7.21	7.21	15.09
Reduction in capacity (%)	19.5	26.5	14	11	11	21

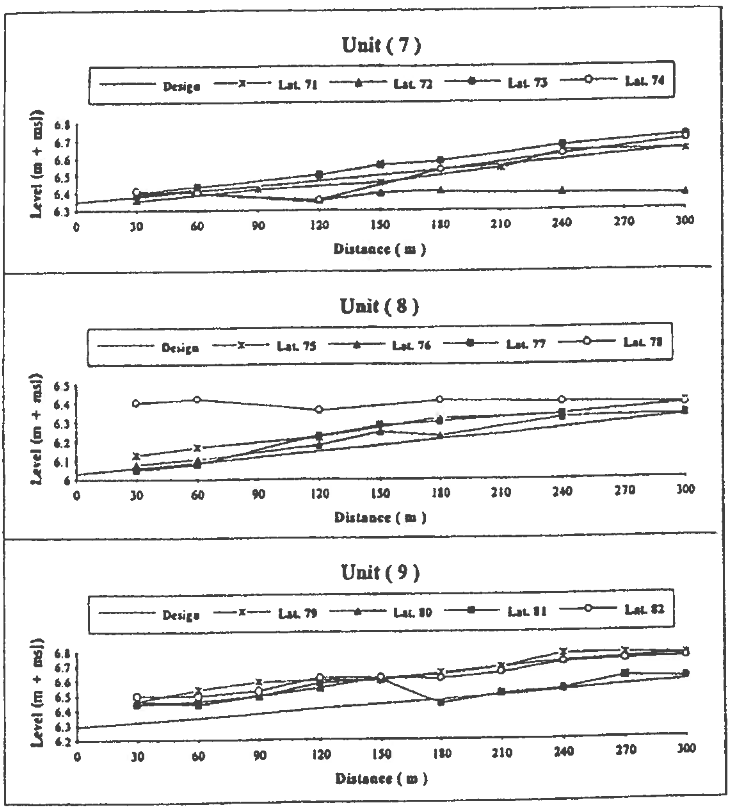

Figure 3. Longitudinal Sections of the PVC Lateral Drains

collectors D and E, Fig. 1. The amount of sediments in the manholes after the summer season was computed. The height of sediments are shown in Table 4. The maximum was 42% of pipe diameter at manhole 7 and the minimum was 5% at manhole 18. The average of the upstream section was 28.6%, but for the downstream section was 17.2%. The average sedimentation height along the whole collector length was 22.9% of pipe diameter.

Table 4. Sediment Inside Collector Drain Pipes at Manholes

anhole (No.)	22	21	20	19	18	13	12	9	8	7
Inside diameter (cm)	30	30	30	30	30	25	25	25	25	25
Sediment height (cm)	2.8	5	9.5	7	1.5	4	8.7	7	5.5	10.5
Sediment height (%)	9.33	16.67	31.67	23.33	5	16	34.8	28	22	42
Reduction in area (%)	4.7	10.96	27.19	17.73	1.87	10.33	30.95	22	16	39
Reduction in capacity (%)	7	16	37.5	24	3.5	15	42.5	31	22	52.5

Source of Sediment

Lateral Drain:

The soil in the area under study was cohesive with high clay content. It was quite stable and does not require envelope material because the stability increases with increasing the clay content (the cohesive forces exceed the hydrodynamic forces). The amount of sediments found inside the lateral drain pipes are related to unusual construction circumstances associated with the installation of drains. A common method of installing subsurface drains in Egypt is to excavate a trench, lay the drain and then backfill the trench with excavated soil. When water begins to flow, particles are carried toward the drain where they will either enter the drain or form a bridge and initiate the compaction process resulting in a stable soil above the perforation. In the case where drain openings are much larger than soil particles, sediment would continuously flow. However, the drain constitutes a confined volume which when filled can not admit more soil. The backfill should be properly compacted before irrigation water is applied to the field especially the top part of the trench. The lower part (the soil just covering the pipe) should not be compacted as it is important that this soil retains a good permeability. DRI (1987a & b) reported the results of pre-drainage investigations in MPA during the year 1978. The ground water salinity is highest in the central and south-eastern part, with a maximum value of 14.5 dS/m. The average groundwater salinity was 8.2 dS/m. The dominant salts are NaCl, $CaSO_4$ and $MgSO_4$. In the western part of the area, however, more Na_2CO_3 and Na HCO_3 occurred which indicated the possibility of an alkalinity hazard at that time. Verhoeven (1979) reported that a high salt concentration in the soil solution compresses the layer of adsorbed cations and hence physical qualities of the soil are good. After a leaching of the excess salts, the clay particles of a sodium soil disperse and fine particles may be washed down to the subsoil where they form an impervious layer. From the above, the source of sediment inside lateral drain pipes is related also to alkalinity which reduces stability after the leaching of the excess salts by drain pipes. DRI (1982) reported that some lateral drains in MPA were constructed under wet installation conditions due to irrigated fields. The wet conditions, which lower stability, can be considered as one of the sources of sedimentation in the drain pipes and will affect drain line performance.

Collector Drain:

Most of the sedimentation originated from abuse by farmers such as plugging of collectors during the rice season and surface drainage into manholes. They block the collector by primitive means to prevent excessive water losses from rice fields, which might lead to pollution of the collector. Farmers' disposal of excess surface water, by cutting holes in the superstructure of the manhole at about the level of the ground surface, usually carries substantial amounts of soil into the manhole. Also, they dump rubbish in the manholes. In addition, some manholes are partly damaged by tractors at the times of tillage, leveling and transporting of crops. In some pre-cast manholes parts of the edges are damaged which allow the irrigation water to flow carrying sediments. Bad grades with ups and downs and inverse slopes also lead to accumulation of sediment. A sudden change in the slope produces a wide gap on one side of the pipes which permits the soil backfill to enter the drain. Under certain conditions, tree roots may enter drain pipes through the gaps and subsequently grow profusely inside the pipe over considerable distances. In extreme cases the roots may fill up the entire cross-section of the pipe. These roots can be like a sieve to catch suspended materials and rubbish and accumulate sediment, and thus seriously obstruct the flow of the drain water.

Effect of Sediment on Discharge Capacity

The reduction in discharge capacity was calculated according to Cavelaars (1985). The reduction in the area curve was calculated from equations 7 and 8 but the reduction in discharge capacity curve was drawn according to Cavelaars (1985). If the percentage of sediment height reaches 40%, it means a reduction in area of 37.4% of maximum but the reduction in discharge capacity is 50% of maximum. The percentage reduction in the area and discharge capacity inside the lateral and collector drain pipes are presented in Tables 3 and 4. The maximum reduction in lateral area was 19.6% which lead to 26.5% reduction in capacity but in the collector the maximum reduction in the area was 39.9% which means 3.5% reduction in the capacity. The minimum reductions in capacity were 11% for the laterals and 3.5% for the collector. The average reduction in capacity for laterals and both the upstream and downstream parts of the collector were 17.2%, 32.8% and 17.6% respectively and the corresponding standard deviations were 6.22, 15.06 and 13.7 respectively.

Actual Safety Factor of The Collector System

A safety factor is important in the design of drainpipe diameter to compensate for a reduction in hydraulic capacity due to sedimentation or slight misalignment. The safety factors for a certain collector section have been calculated by comparing the actual command area of each section with the maximum drainable area using equation (9). The calculated safety factors of the main flow equations for drain pipes are presented in Table 5. The calculation is based on the original design slope and pipe diameters and it is assumed that the pipes have only a transporting function. The safety factors are not the same for all sections, because the required diameter, as calculated using the Manning equation, is always rounded off to the nearest commercially available pipe size. The recommended safety factor by Ven (1983) for Visser and Wesseling equations was 25% for pipe diameter 0.25-0.5 meter. For the same diameter, while Cavelaars (1985) recommended a safety factor of 40% for the Manning equation. Comparison between the recommended safety factors and the calculated ones by using Visser, Wesseling and Manning equations are shown in Table 5 and leads to the following conclusions:

- The use of the Manning equation results in the lowest actual safety factor, ranging from 20% to 42% compared to the recommended value of 40%.
- The use of the Visser equation results in the highest actual safety factors, ranging from 40% to 56% compared to the recommended value of 25%.
- The use of the Wesseling equation results in intermediate actual safety factors, ranging from 34% to 51%, compared to the recommended value 25%.

Table 5. Calculations of Safety Factor (SF) for the Main Flow Equations

Section between manholes	22-20	20-19	19-13	13-9	9-8	8-4
Pipe diameter (m)	0.3	0.3	0.3	0.25	0.25	0.25
Design slop (cm./100m)	3		3	3	3	3
Command area (fed)	125.71	112..62	99..52	62..38	57..62	56..67
Max. drainable Area (fed.)						
Visser	209.4	209.4	209.4	128.65	128.65	128.65
Wesseling	189.25	189.25	189.25	115.38	115.38	115.38
Manning	158.02	158.02	158.02	97.17	97.17	97.17
Factor of safety (%) using:						
Visser	39.97	46.22	52.47	51.51	55.21	55.95
Wesseling	33.57	40.49	47.41	45.94	50.06	50.88
Manning	20.45	28.73	37.02	35.8	40.7	41.68

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations can be drawn:

- The actual slope for lateral or collector drains did not coincide with the design one. The slope of the lateral drains is correct for only 42% of the lateral drains under study. All sections of collector pipe drain were laid at a slope which was either steep or flat. The regularity is classified as poor for most laterals while it was good for most sections of the collector
- The average percentage of sedimentation inside drain pipes was 17.6% of lateral pipe diameter. Consequently, this reduced the area of the lateral drainpipe by 11.8% and the discharge by 15.2%. The average percentage of sediments reached 23% of the collector pipe diameter. The average weight of wet sediments inside the manhole reached 78.8 kg. This is attributed to surface drainage or the misuse of the system by the farmers. The mobile flushing unit under high pressure was successful in cleaning drain tubes
- Regular maintenance for the subsurface drainage system is needed
- More attention should be given to the grade control and regularity of construction

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