Low Water Use Sanitation: The Design, Development and Appraisal of a Low Volume Flush Toilet in Botswana and Lesotho

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The Design, Development and Appraisal of A Low Volume Flush Toilet in Botswana and Lesotho

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ABSTRACT

In 1983 an ODA-funded programme was initiated to consider the feasibility of development of a low water use w.c. design suitable for installation in developing countries, particularly in low cost housing.

The preliminary programme concentrated on modelling the key hydraulic parameters of trap seal depth, trap seal volume and passage width that govern w.c. performance at reduced flush volumes. From this research, a rimless w.c. was developed.

The secondary phase of modelling was concerned with designing the w.c. to be upgradable from pour to cistern flush operation. As the w.c. pan was rimless, a device which was termed a "diverter bar" was designed to allow this flexibility. The final design of the prototype w.c. and diverter bar required a flush volume of only 3-4 litres compared to 9-10 litres for a conventional w.c. to pass the same laboratory tests.

From August 1985 to August 1988, ODA-funded overseas site trials of some 150 of the prototype w.c.'s were undertaken in Lesotho and Botswana. The reduction of flush volume to 4 litres was shown to have no adverse effect on long drainage runs. In Botswana, it was shown that the houses fitted with the prototype 4-litre w.c.'s used a mean of 19 litres per capita per day less than the houses fitted with 10-litre w.c.'s. Expressed in percentage terms, the savings by reducing the flush volume were 23 per cent. The percentage of the total household water used for w.c. flushing was 21 per cent for the houses with 4-litre w.c.'s compared to 40 per cent for the houses fitted with 10-litre w.c.'s. Similar savings were achieved in Lesotho, where trials concentrated on a range of sewage disposal methods. Additional benefits of low volume flush w.c. adoption were identified for on-site sewage disposal and storage, including reduced conservancy tank emptying requirement.

As a result of the programme, further site monitoring in Botswana, site trials in Brazil, in conjunction with IPT Sao Paulo, and China, in conjunction with the Building Research Institutes in Shanghai and Chengdu, are underway.

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INTRODUCTION

Water conservation policies are generally only initiated in times of drought or disaster. Potable water, however, is a vital resource and should be managed and planned accordingly. The flushing of w.c.'s with typically 10-12 litres of water per flush is wasteful of this valuable resource and offers the greatest potential for long term water conservation. Reduced w.c. flush volume is applicable to developed and developing countries alike and must be adequately researched to ensure maintenance of health and sanitation standards. The application of a sanitation system such as the Ventilated Improved Double Pit (VIDP) latrine may be suitable for rural areas, with a relatively low population density, but is generally not suitable for the ever, and rapidly, increasing urban and suburban areas, where sewer connection is more appropriate.

Valuable experience and insights into the hydraulic parameters governing low water use w.c. designs were obtained by the authors during a research project from 1978 to 1981, which successfully developed a 4.5-6 litre flush volume close coupled w.c. for the UK market, funded by the UK Confederation of British Ceramic Sanitaryware Manufacturers (Uujamhan, 1981). In 1983 a five year research project funded by the Overseas Development Administration was initiated at Brunel University, and from 1985 in conjunction with Heriot-Watt University, to design, develop and site appraise a low volume flush w.c., with the co-operation of Twyfords Ltd. (Bocarro 1988). The project was also seen as relevant to the United Nations' International Decade of Water Supply and Sanitation 1981-1990 and close liaison was maintained with other active groups, such as the World Bank's Technology Advisory Group.

Previous experience and discussions with the project sponsor, ODA, followed by a study tour of Africa, established various criteria for the project:

(i) a flush volume of 3-4.5 litres would be realistic;

(ii) a washdown pedestal P-trap w.c. pan flushed by an independent cistern fitted with a drop valve would offer the widest application. The potential to use locally available cisterns and components was essential to ensure availability of spare parts in the future;

(iii) the potential to offer a bucket/pour flush w.c. pan, upgradable to cistern flush, should be considered. The omission of a flushing rim, which could not be cleaned by pour flushing, would then be necessary and an alternative method of flush water distribution developed;

(iv) the necessity for simplicity of design and operation to ensure adequate maintenance of the w.c. This ruled out systems such as vacuum or pressure assisted solids transportation and the use of siphon break valves and diaphragms;

(v) the predominance of single storey housing and buildings in developing countries minimises pressure fluctuations in the drainage system and would allow reduced trap seal depth, subject to sufficient depth to accommodate evaporative loss;

(vi) Gaborone in Botswana and Maseru in Lesotho would offer good potential for site evaluation of the Low Volume Flush Toilet (LVFT) under a wide range of site conditions.

This report therefore presents the research and development necessary to produce an appliance within these guidelines, together with an overview of the site evaluations in Botswana and Lesotho.

LABORATORY DEVELOPMENT OF THE LVFT

A P-trap w.c. configuration was adopted to conform to common practice in developing countries. The modelling of the LVFT was based on a Twyfords B.S. 1213 P-trap w.c. from which both the flushing rim and trap seal back plate had been removed. Plasticine was used to remodel the internal shape of the bowl and trap, and perspex back plates were fitted to vary trap seal depth. A mechanical tipping bucket was developed to provide repeatable and representative pour flushing by bucket. In addition to British Standard 5503 tests, which included the Ball Test, Paper Test and Sawdust Test, a range of discriminatory tests were used and developed to appraise w.c. performance. These tests included:

(i) Multiple Ball Test using fifty 20mm diameter balls of the same specific gravity which could be selected in the range 0.85-1.15. Discharge efficiency was calculated as the percentage of balls discharging successfully.

(ii) Liquid Contamination Test using potassium permanganate to simulate liquid contamination of the w.c. trap. Light absorption, measured by a colorimeter, of a sample of trap water taken after flushing compared to a sample taken before flushing, calculated as a percentage relative residual concentration, gives an important measure of flushing performance.

(iii) Modified Paper Test using 6 pieces of 125 x 125mm newspaper.

(iv) Simulated Faeces Test using three 30mm diameter by 100mm long foamed plastic stools having a saturated specific gravity of 0.98.

(v) Modified Ball Test using the B.S. 5503 ball, but recording the amount of water discharged ahead of the ball relative to the flush volume. This modification produced a useful degree of discrimination.

(vi) Various bowl washing tests, including the American ANSI A112.19.2M (1982) test, which involves drawing a horizontal line round the bowl 25mm below the rim with a water soluble ink pen and measuring the total length of unwashed line after flushing.

(vii) Blotting Paper Test to measure splashing from the bowl during a flush by placing a sheet of blotting paper over the w.c. bowl and either estimating the area of wetted paper or weighing the paper before and after flushing.

(viii) Transport Test using a 14 metre length 110mm UPVC discharge pipe at a gradient of 1/80, connected to the w.c. Transportation performance of a model solid, typically a half length C2 type maternity pad, was monitored by recording its velocity profile along the pipe and fitting a deceleration characteristic equation. Further details of this test method and the test rig are included in Howarth et al, 1980. This test provides the basis for the definition of the required flush volume relative to length and gradient of drain prior to connection of discharge from other sanitary appliances.

Initial development of w.c. trap and bowl shape were undertaken in the pour flush mode, and then later refined with cistern flush. With the omission of the flushing rim, it was necessary to develop an alternative, but equally effective, means of distributing the flush water around the bowl. A device termed a "diverter bar" was developed to fit onto the end of the flush pipe. The diverter bar has two slightly downward angled side slots with the primary function of distributing cleansing water round the bowl and a bottom jet with the primary function of inducing momentum transfer to solids in the trap. The diverter bar is connected to the end of the flush pipe with a sleeve to allow for different sizes of flush pipe.

The design criteria governing low volume flush w.c. performance are shown in Figure 1. Uujamhan's work had identified a non-dimensional group determining w.c. performance (n), which should be as low as possible, involving the parameters:

trap seal volume (S)
flush volume (F)
trap seal depth (h)
and minimum trap passage clearance (w)
as

$$n = \varphi\left(\frac{S}{F}.\frac{h}{w}\right) \qquad (1)$$

Extensive laboratory testing and development of trap dimensions, bowl shape, flush volume and flushing mechanism led to a final w.c. prototype termed the Mark III w.c. and a Mark VI diverter bar which provided the optimum performance. This combination was finally appraised with a plastic cistern produced in South Africa and a modified ceramic Vaal cistern also produced in South Africa. The ceramic cistern was adopted for the site trials in Botswana and Lesotho due to the fire risk caused by candles placed on a plastic cistern and also as no indigenous manufacture

exists in Botswana and Lesotho of sanitary fittings. The plastic and ceramic cistern fitted to the final version of the w.c. bowl were termed the Mark III and 'field' Mark III w.c. respectively. As a comparison, the original Twyfords B.S. 1213 w.c., termed the Mark 0 w.c., was also tested. Typical test results for flush volumes between 3 and 9 litres are shown in Figures 2 and 3.

Figure 2 shows the results of the 0.85 specific gravity multiple ball test. The plastic and ceramic "cisterned" ('field') Mark III w.c.'s performed similarly, and even at 3 litres performed better than the original (Mark 0) Twyfords w.c. flushing with 9 litres. Similar conclusions can be drawn from Figure 3 which presents the results of the liquid contamination test, with a lower residual concentration for the Mark III w.c.'s at 3 litres than the Mark 0 w.c. at 9 litres. The Mark III w.c.'s only required 2 litres to pass the B.S. 5503 paper and ball tests, but required 3.5 litres to pass the B.S. 5503 sawdust test.

The results confirmed Uujamhan's functional relationship, equation (1) above, as represented in Figure 4, for both solid and fluid contamination removal. It is evident from Figure 4 that the value of the dimensionless parameter plotted as the abscissa should be as low as possible, subject to certain physical limitations. At an early stage in the development of the w.c., it was decided to adopt a minimum trap passage width (w) of 63mm in order to meet dietary constraints. Consideration of drain pressure fluctuation and trap seal evaporative loss suggested that trap seal depth (h) could be safely reduced from 50mm to 36mm. These two limitations effectively dictated a minimum trap volume (S) of approximately 0.86 litres. The dimensions of the Mark III w.c., the original Mark 0, B.S. 1213 Twyfords w.c. and the requirements of B.S. 5503 are presented in Figure 5. The value of the dimensionless parameter $(\frac{S}{F}.\frac{h}{w})$ for the Mark 0 w.c. with 9.1 litre flush is 0.143. Substituting the limits suggested above would require a flush volume (F) of 3.4 litres to attain similar w.c. performance.

Results, in the form of solid deceleration characteristics, from the solid transportation tests are shown in Figure 6. These results are presented as solid velocity along the drain, set at a gradient G (defined as vertical drop divided by horizontal distance), at distance L from the w.c. drain connection, plotted as $\sqrt{L/G}$ which has been shown to provide a linear characteristic, Swaffield and Wakelin, 1976. From Figure 6 it is evident that a flush volume of 3 litres should only be adopted for drain lengths of up to 11.25 metres at a gradient of 1/80 prior to inflow connection from other sanitary appliances. Most on-site sewage disposal or storage systems would meet this restriction. For main sewer connected drains a minimum flush volume of 4 litres is required to achieve similar solid transportation performance to the Mark 0 w.c. flushed with 9 litres. These flush volumes were therefore adopted for the various site trial conditions.

SITE TRIALS - BOTSWANA

After completion of the design and development phase of the project, Caradon Twyfords of Stoke on Trent in the UK produced

220 of the Mark III w.c. pans, the principal dimensions of which are shown in Figure 5. An identical number of the Mark VI diverter bars, the principal dimensions of which are shown in Figure 7, were machined from PVC by a local firm in Uxbridge. The overseas appraisal phase of the project, which commenced in August 1985, involved ceramic cisterns. These site trials were concentrated in the capitals of Botswana and Lesotho.

The Botswana programme of prototype w.c. installations was completed by May 1986. The main concentration of installations was in Gaborone where some 95 of the units are installed. The remaining 8 w.c.'s were installed in Gumare.

There were several aspects of the monitoring. First of all, there were monthly inspections of all the project installations in Gaborone. These inspections were used to identify any problems with the w.c.'s and to ensure they were functioning correctly. The inspections helped to solve a problem with the cistern design. Once cured, none of the w.c.'s were leaking water. Also, as a result of this monitoring, early installation faults were cured and eventually the frequency of maintenance was practically negligible.

Three drainage surveys were carried out on an estate of 63 houses fitted with the experimental w.c.'s in Gaborone West. Figure 8 shows a schematic layout of the house plots and the main drainage runs. The surveys were necessary to monitor the effect of reduced flush volumes on long drainage runs. The conclusion of the surveys was that the w.c. flush volume of 4 litres had had no adverse effect on any of the main sewer lines or the house to main sewer connections.

A detailed study was carried out on the same estate to determine the effect of reduced flush volume on household water consumption. Water readings were taken at 14 day intervals from December 1986 to September 1987 and thereafter at 1 month intervals to July 1989. A control sample of 30 houses with 10-litre w.c.'s, but otherwise identical, was selected on an adjacent estate on the other side of the road and immediately south east. The prototype group were found to use a mean of 2.4 kilolitres less per house per month than the control group. In terms of litres per capita per day, water consumption in the prototype group of 69 lcpd compared to 88 lcpd for the control sample, a difference of 19 lcpd. In terms of percentage savings, the prototype houses used 16-30% less water than the control group. Household water consumption, and % water saving with respect to the control group, over the monitoring period December 1986 to July 1989 for the prototype and control groups are shown in Figure 9, and show consistent seasonal correlation of water savings. Figure 9 also illustrates that the water consumption for the prototype and control group housing prior to the installation of the trial w.c.'s in the prototype group was sensibly identical over 12 months from February 1985.

Additional water data were collected to determine the percentage of household water that was used for w.c. flushing. A prototype sample of 30 houses fitted with 4-litre w.c.'s and a control sample of 15 houses fitted with 10-litre w.c.'s were used for the

analysis. The results showed that the prototype group used 21% of household water for w.c. flushing and the control sample used 40%.

This result was used to predict the savings that were possible using a range of flush volumes from 2-13 litres, as shown in Figure 10. From a knowledge of the total water use during any period in both prototype and control group dwellings, and the appropriate percentage used for w.c. flushing, the non-w.c. usage may be determined. The number of w.c. operations for the prototype w.c. is also known from its flush volume, thus the hypothetical w.c. water use with any flush volume may be added to the non-w.c. volume used. Thus a comparison between the control group and the prototype group set to any flush volume may be carried out.

A study of the number of w.c. operations inherent in the control and prototype groups via flush volume setting and w.c. total usage illustrates that the prototype w.c. was normally only flushed once per usage, indicating the efficiency of the design.

This analysis technique could be used for future design calculations and showed that the non-w.c. water use for both the control sample and prototype sample were virtually the same. This result further justified the comparison between the two samples taken of Botswana Housing Corporation low income housing.

A detailed questionnaire was carried out on the same prototype and control samples, primarily to assess user reaction to the low volume flush toilets. From an analysis of basic data from the control and prototype samples, it was apparent that the groups were virtually identical in terms of population structure, age, employment, income and education. This result was a further justification of selecting the two samples for comparison in the water data analysis. The overall reaction to the prototype w.c.'s was positive.

All of the prototype w.c.'s installed in Gaborone were functioning at the end of the monitoring phase reported here in July 1989. However there were some major problems encountered in the one project site outside Gaborone. At a village school in Gumare, Northern Botswana, over half of the eight prototype w.c. installations were reported inoperable in November 1987. Failure was due to broken cistern components, lack of maintenance and intermittent water supply. It is apparent that much more robust cistern components and a user education programme are essential for adoption of water seal toilets in rural schools and institutions.

SITE TRIALS - LESOTHO

The site trials of the prototype w.c.'s in Lesotho had similar objectives. The monitoring of 53 w.c.'s included further water data collection and questionnaires to establish whether there had been any adverse user reaction.

In Maseru, Lesotho, fifty prototype w.c.'s were fitted in a variety of installations. Due to the differing town planning organisation in Gaborone and Maseru it was not possible to locate blocks of dwellings for w.c. installation. Similarly a wide range of disposal methods, from septic tanks, to conservancy tanks, main drainage and converted pit latrines were used. This made a systematic monitoring study, such as that possible in Gaborone West, impossible.

However, two types of monitoring was undertaken:-

1) Water readings taken from the records of the local water utility in Maseru;
2) Frequency of conservancy tank emptying, again taken from the water utility records.

An added complication in Maseru was that the low flush volume w.c.'s were installed over a period from October 1985 to August 1986, thus no clear start date could be identified as in Gaborone. Due to this it was necessary to compare the water use before and after installation in both the prototype and control groups to allow for the natural escalation of water use by the population over this time period.

Table 1 illustrates water meter readings for a small prototype group of 9 w.c.'s. The water data were collected from January 1985 before installation up to March 1987. The correction shown for the control group water use rise varies with the installation date and is based on a set of control group water data over a period from January 1985 to March 1987.

The overall water saving is shown as 37%, however the size of the sample is too small to make this a definitive figure.

House	Mean Water Consump. before install. of LVFT	Mean Water Consump. after install. of LVFT	Month & year of install.	Increase in water consump. in control group	Adj. value for x_2 $= x_2/x_3$	%-Age change in $(x_2-x_1)/x_1$
	x_1	x_2		x_3	x_2	
A	21.87	23.83	9/85	1.42	16.78	23.27
B	6.44	6.46	1/86	1.60	4.04	59.40
C	9.46	9.28	1/86	1.60	5.80	38.69
D	14.08	15.33	1/86	1.60	9.58	31.96
E	5.36	7.74	3/86	1.49	5.19	3.17
F	15.86	12.21	3/86	1.49	8.19	48.36
G	52.77	42.46	6/86	1.41	30.11	42.94
H	22.03	22.15	6/86	1.41	15.71	28.69
I	8.31	4.57	7/86	1.38	3.31	60.17
						~~MEAN x = 37.41~~

Table 1 Water meter reading data analysed for prototype group in Maseru

The increase in control group water usage ratio following prototype w.c. installation varied with installation date. The ratios presented in Table 1 were calculated as follows:-

Let c_i be the control group water usage per month from January 1985, $i = 1$, to March 1987, $i = 27$. The monthly figures were again corrected from the rather variable meter reading dates to yield comparable monthly averaged figures.

Assume that the particular prototype w.c. was installed in March 1986, thus $i = 15$.

The control volume data was manipulated as follows to give the increase ratio, r.

$$r = \frac{\text{Mean } c_i \ (i = 15 \text{ to } i = 27) \text{ water consumption}}{\text{Mean } c_i \ (i = 1 \text{ to } i = 14) \text{ water consumption}}$$

Similarly the water utility conservancy tank emptying data were used to ascertain whether savings were being made by low flush volume w.c. users. Ten installations were used for the prototype group, five existing tanks as a control group. The frequency of emptying was monitored from April 1985 - October 1986. An identical technique to that shown in Table 1 was used to determine the reduction in tank emptying, corrected for the natural escalation in water use in Maseru.

The result of this monitoring was an overall reduction of 0.45 tank emptying visits per month per prototype dwelling, or roughly a 1/3 reduction over the year in total visits. This figure is broadly in line with the water meter readings for the sewered dwellings in Table 1. In Maseru all installed w.c.'s were normally set to 3 litres flush volume, so the greater saving compared to Gaborone was to be expected, however tank emptying is a non exact measure and again the number of dwellings involved was small and, due to the local conditions in Maseru, all the dwellings of both prototype and control group were significantly different to each other.

At the end of the monitoring period, all but two of the w.c.'s were in use. One w.c. was not in use as the cistern inlet-valve had been damaged. In the other case, the w.c. had been connected to a waste pipe which habitually blocked. Investigation attributed the cause to a poorly levelled pipe, which was to be corrected.

The development and installation of a two compartment septic tank and shallow soakage pit accepting discharge only from the 3 litre flush toilet proved successful on six sites. Another successful development involved the upgrading of a VIDP latrine to a two compartment septic tank and soakaway accepting discharge from the 3 litre flush toilet installed in the house. The latrine slab and superstructure were retained in case of future drought. Further monitoring will be required of these developments to establish their long term potential.

A user questionnaire was again used to establish whether there had been any adverse user reaction to the w.c.'s. The majority questioned preferred their new w.c. but the main criticism was that the w.c. was prone to fouling by excreta near the water surface.

In Lesotho, it was shown that the prototype w.c. would also work in its pour-flush mode. For the particular installation only 2 litres were required per flush. The lack of potential pour flush clients proved that people's aspirations are for water mains connected cistern flush toilets and pour flush does not meet those aspirations in Lesotho.

CONCLUSIONS

1. From a study tour in 1983, at the start of a 5 year ODA-funded research project, the need for water conserving w.c. designs was established and Lesotho and Botswana were identified as suitable locations for site trials.

2. Development of a rimless washdown w.c. pan was carried out in conjunction with Twyfords, who produced prototypes and 220 of the final design for the site trials.

3. A device known as a diverter bar was designed to allow the w.c. to be upgraded from pour-flush to cistern-flush operation.

4. An experimental programme showed that the prototype w.c. required a minimum of 3 litres to discharge faeces and urine. However, a minimum of 4 litres was required for satisfactory transport performance.

5. Overseas site trials of some 150 of the prototype w.c.'s were then undertaken in Lesotho and Botswana. This study was a unique evaluation of the transport performance and water saving potential of low volume flush toilets.

6. The programme in Botswana proved that the reduction in flush volume had no adverse effect on long drainage runs. Furthermore, the installation of the prototype w.c.'s had led to substantial water savings of 16-30%. A survey also proved the user acceptability of the design.

7. The programme in Lesotho endorsed all the results of the Botswana study. It was also shown that only 3 litres per flush were sufficient, if sewage disposal was on-site in either a septic tank or conservancy tank with up to 10 metres of interconnecting drain.

8. A cost benefit analysis showed that water conserving designs could be cost effective, especially if water tariffs are set to encourage water conservation.

9. The design and development phase of the project are now complete. The prototype w.c. has been proven to work successfully and it would appear to be cost effective to develop w.c.'s that require 4 litres or less. It is hoped

that this research will encourage w.c. manufacturers to produce such designs. Indeed, a firm in Zimbabwe are now producing a fibreglass design, based on the 3-4 litre flush prototype w.c.

10. The project has been extended with ODA and British Council support in Brazil, where IPT in Sao Paulo has participated in the setting up of further site trials, involving the installation of 30 LVFT at San Carlos. IPT will be involved in monitoring water use and undertaking user surveys.

11. Six LVFT have also been supplied to the People's Republic of China and initial site evaluations will take place in Shanghai and in Chengdu. Under ODA funding initial visits to the Shanghai Research Institute for Building Sciences and the Sichuan Institute for Building Research have been undertaken and detailed discussions held with ceramic manufacturers in China. This extension will hopefully lead to a full manufacturing programme.

REFERENCES

Swaffield, J.A. and Wakelin, R.H.M. — "Observations and analysis of parameters affecting water solid transport in internal drainage systems" The Public Health Engineer, Vol. 4, No. 6, November 1976.

Howarth, G., Swaffield, J.A. and Wakelin, R.H.M. — "Development of a flushability criterion for sanitary products" CIB/W62 meeting, Brunel University, 1980.

Uujamhan, E.J.S. — "Water conservation w.c. design: a study of the design parameters affecting w.c. performance" Ph.D. Thesis, Brunel University, 1981.

Bocarro, R.A. — "Water conserving w.c. design for developing countries" Ph.D. Thesis, Brunel University, 1988.

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Caradon Twyfords provided manufacturing support and produced the LVFT installed in Botswana, Lesotho, Brazil and China.

The overseas site trials would not have been possible without the active support of the Botswana Housing Corporation and the Botswana Ministry of Local Government and Lands and, in Lesotho, the participation of the Urban Sanitation Improvement Team in Maseru. The contribution of all members of these organisations who participated in the reported research is gratefully acknowledged.

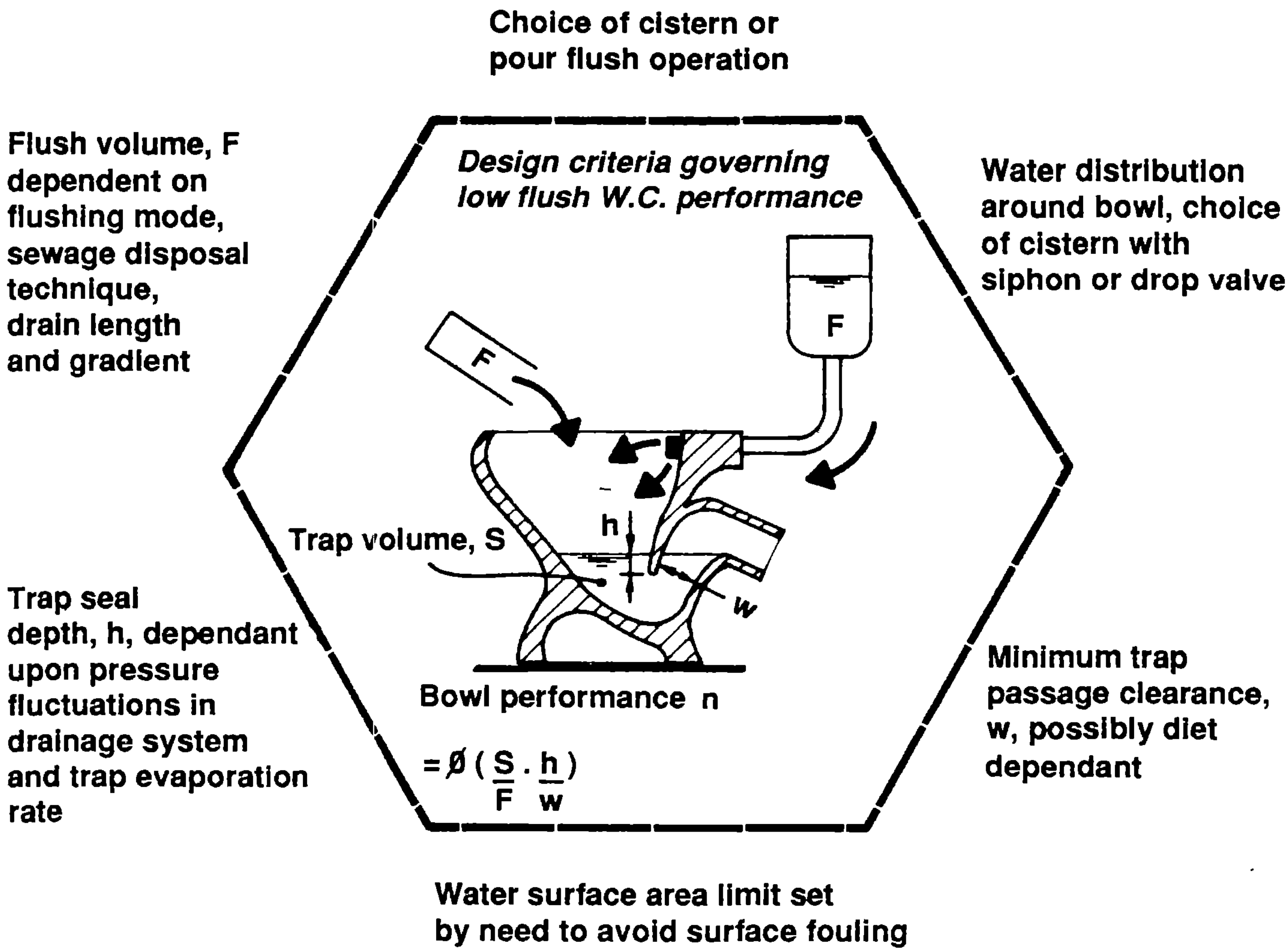


Figure 1
Design Criteria Governing Low Flush Volume W.C. Performance.

Plate 1

Low volume flush W.C. as installed in Gaborone West, Botswana and Maseru, Lesotho. Note design of the diverter bar and the resulting water distribution around the bowl ensuring surface cleaning and efficient discharge.

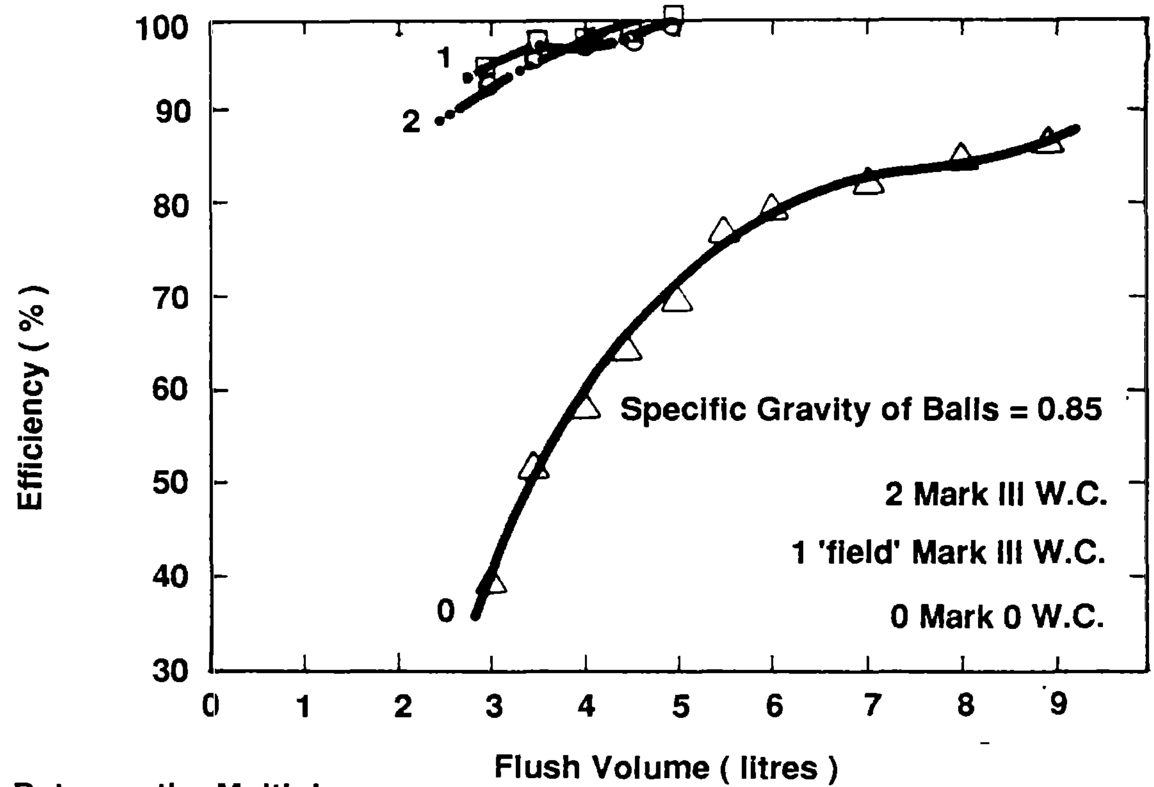


Figure 2
A Comparison Between the Multiple Ball Efficiencies Obtained by the Mark 0, Mark III and 'Field' Mark III W.C.'s.

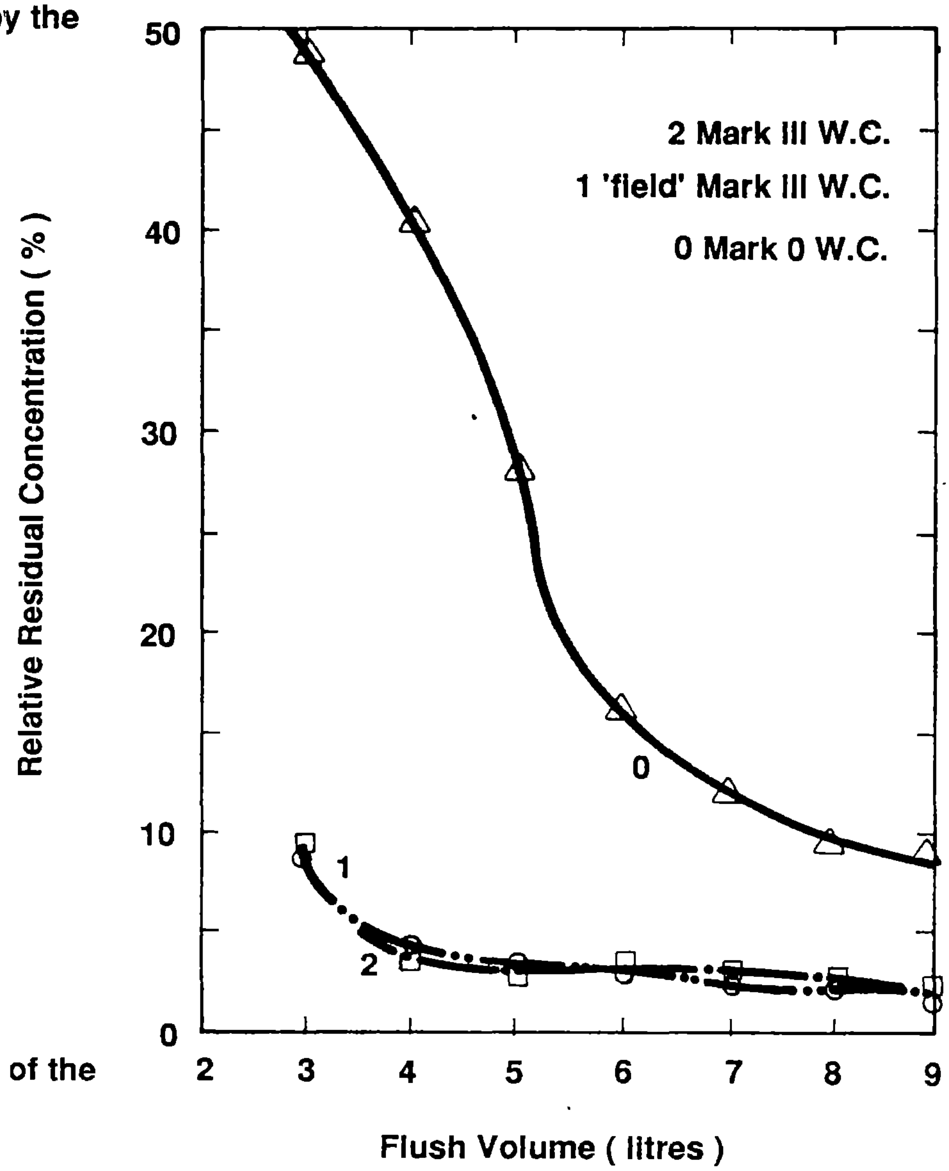


Figure 3
A Comparison Between the Concentration Test Results of the Mark 0, Mark III and 'Field' Mark III W.C.'s.

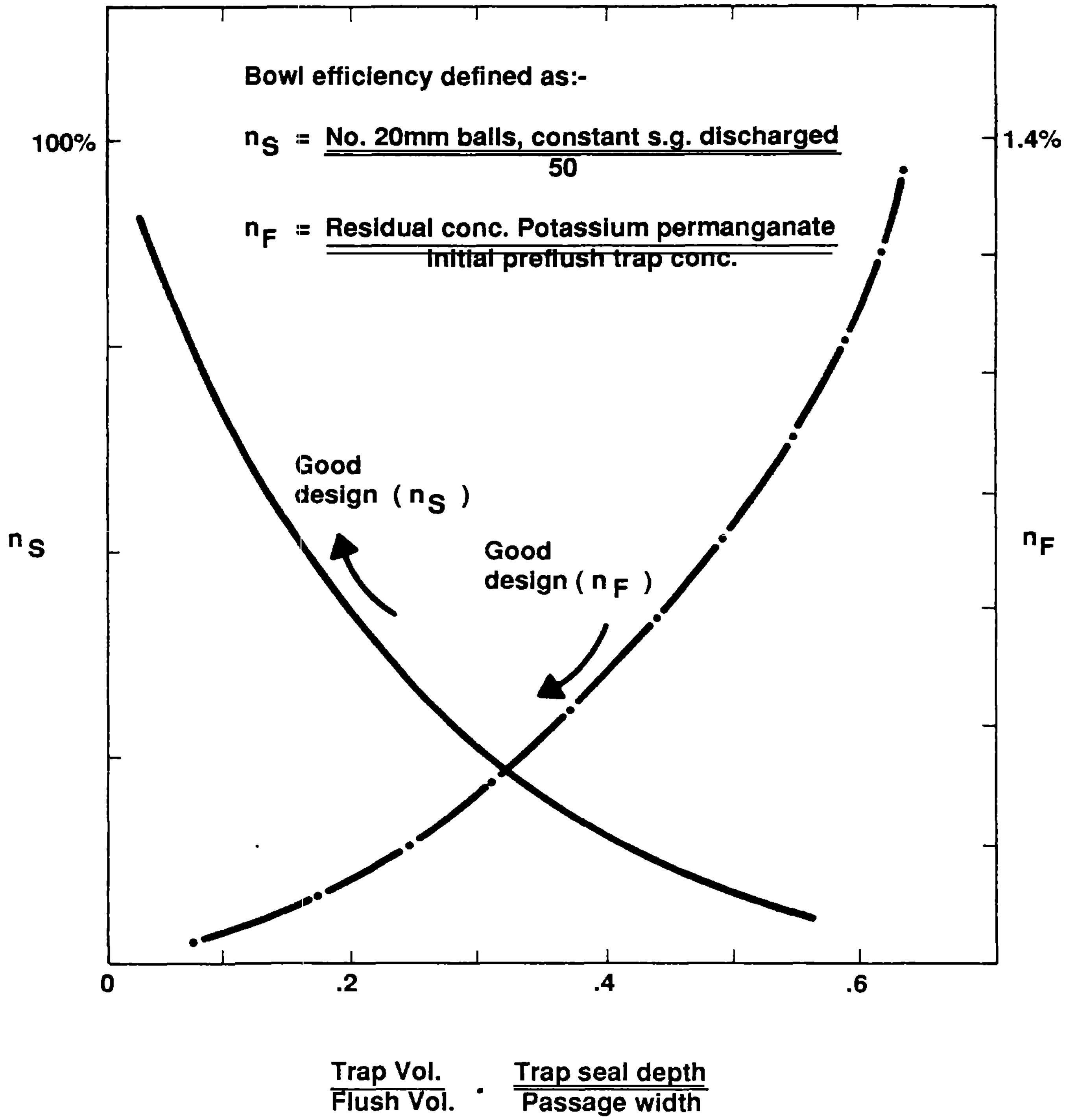
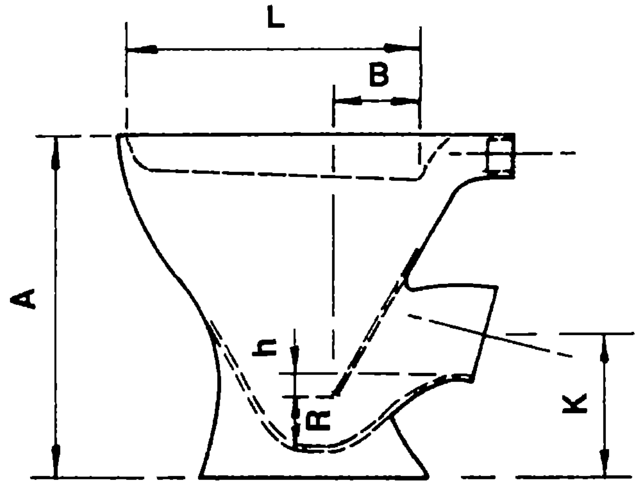
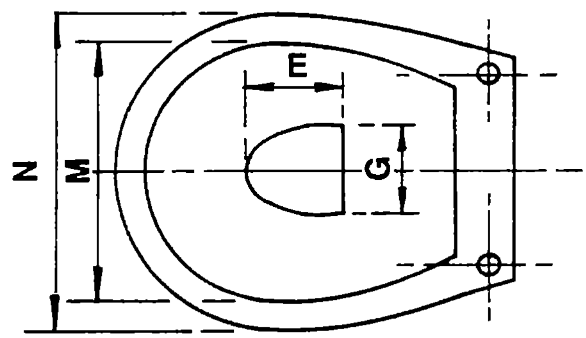


Figure 4
Bowl Performance in Terms of Both Solid and Fluid Contamination Removal.





Description	BS 5503: pt. 2	Twyfords BS 1213 p - trap W.C. pan Mark 0	Mark III W.C.
Depth of water seal h	50 min	56	36
Clearance below tip of plate R	75 min	77	69
Trap seal volume	n /a	1.79 L	0.86 L
Water surface:			
back to front E	150 min	165	118
side to side G	110 min	113	79
Height A	390 + 10	406	390
Distance from tip of back plate to inside face of flush rim B	70 max	30	32
Width of opening M	240 min	260	275
Length of opening L	290 min	320	320
Width of pan N	360 + 10	355	350
Height to centre of W C. outlet K	190	191	190

Figure 5
A Comparison Between the Prototype W.C. and B.S. Designs.

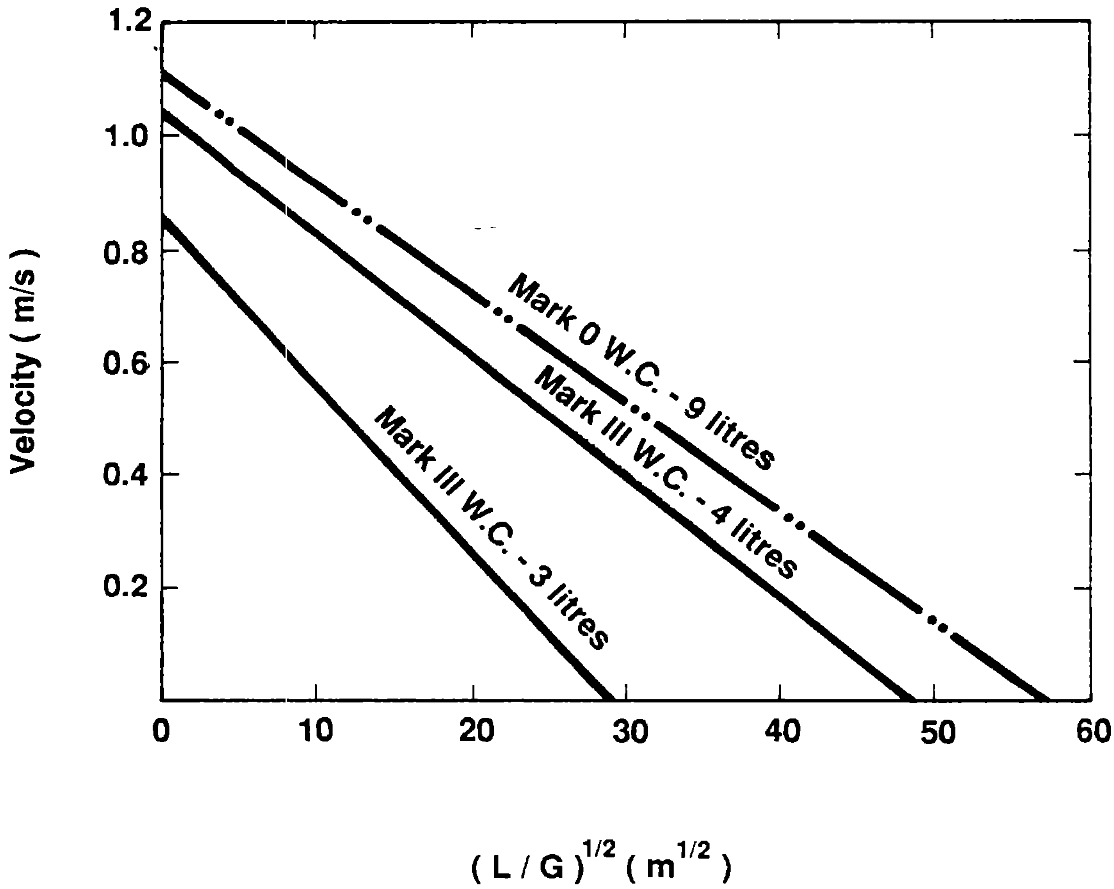


Figure 6
A Comparison Between the Transport Test Results of the Mark 0 and Mark III W.C. (With the Mark VI Diverter Bar).

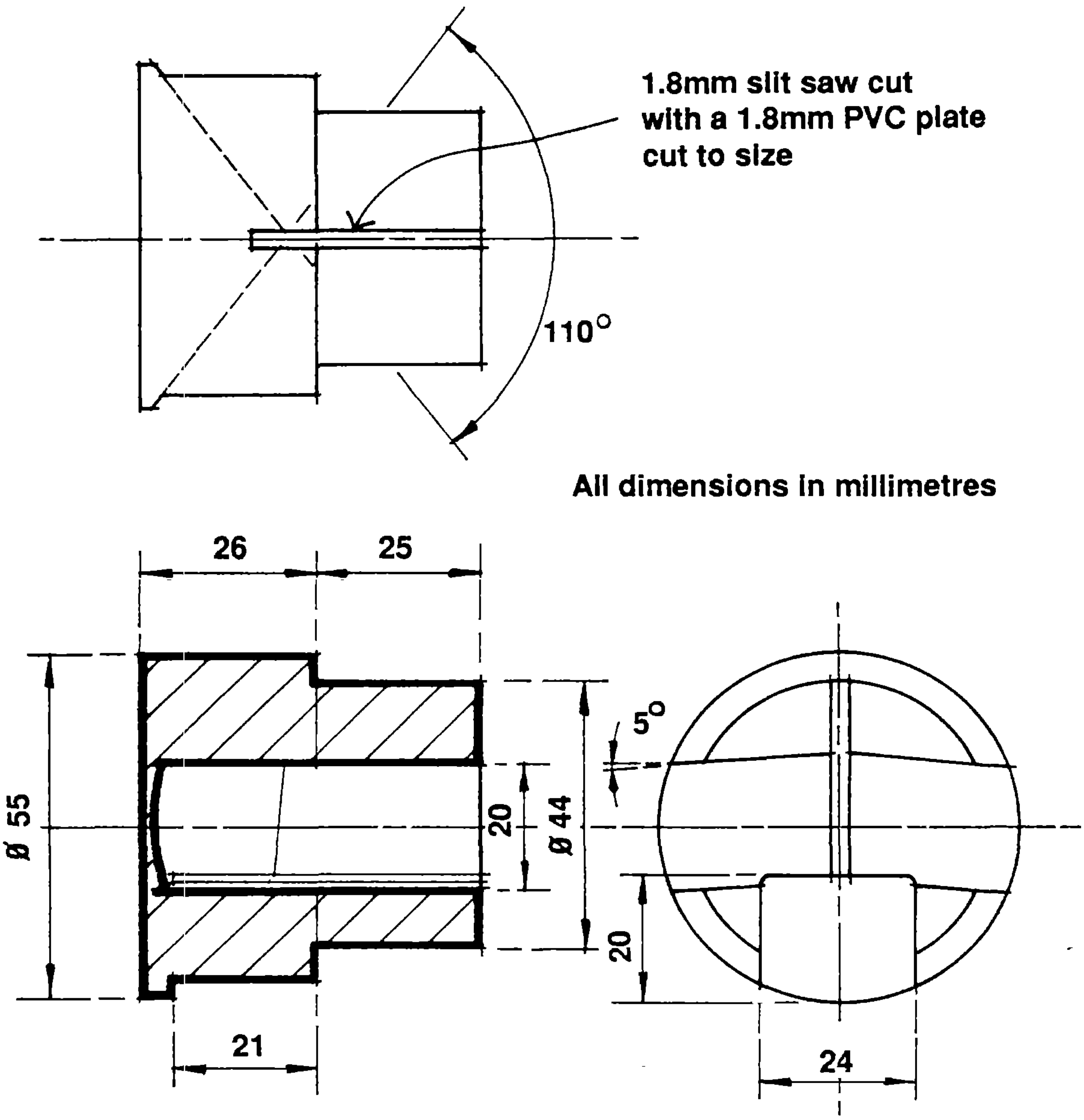


Figure 7
The Mark VI P.V.C. Diverter Bar.

Plate 2
View of the prototype housing group in Gaborone West, Botswana. The 63 house prototype group was located adjacent to the smaller, 30 house, control group.

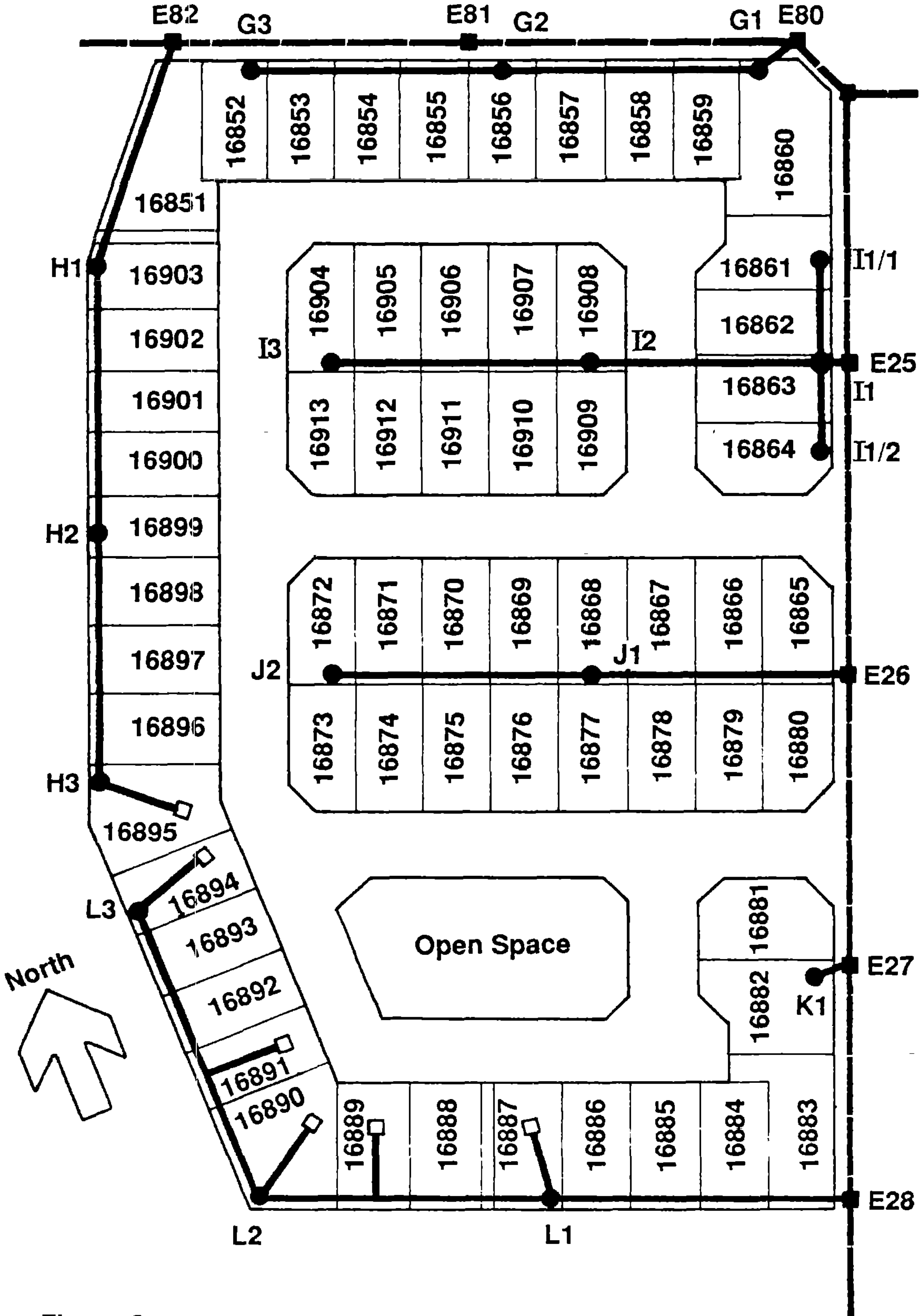
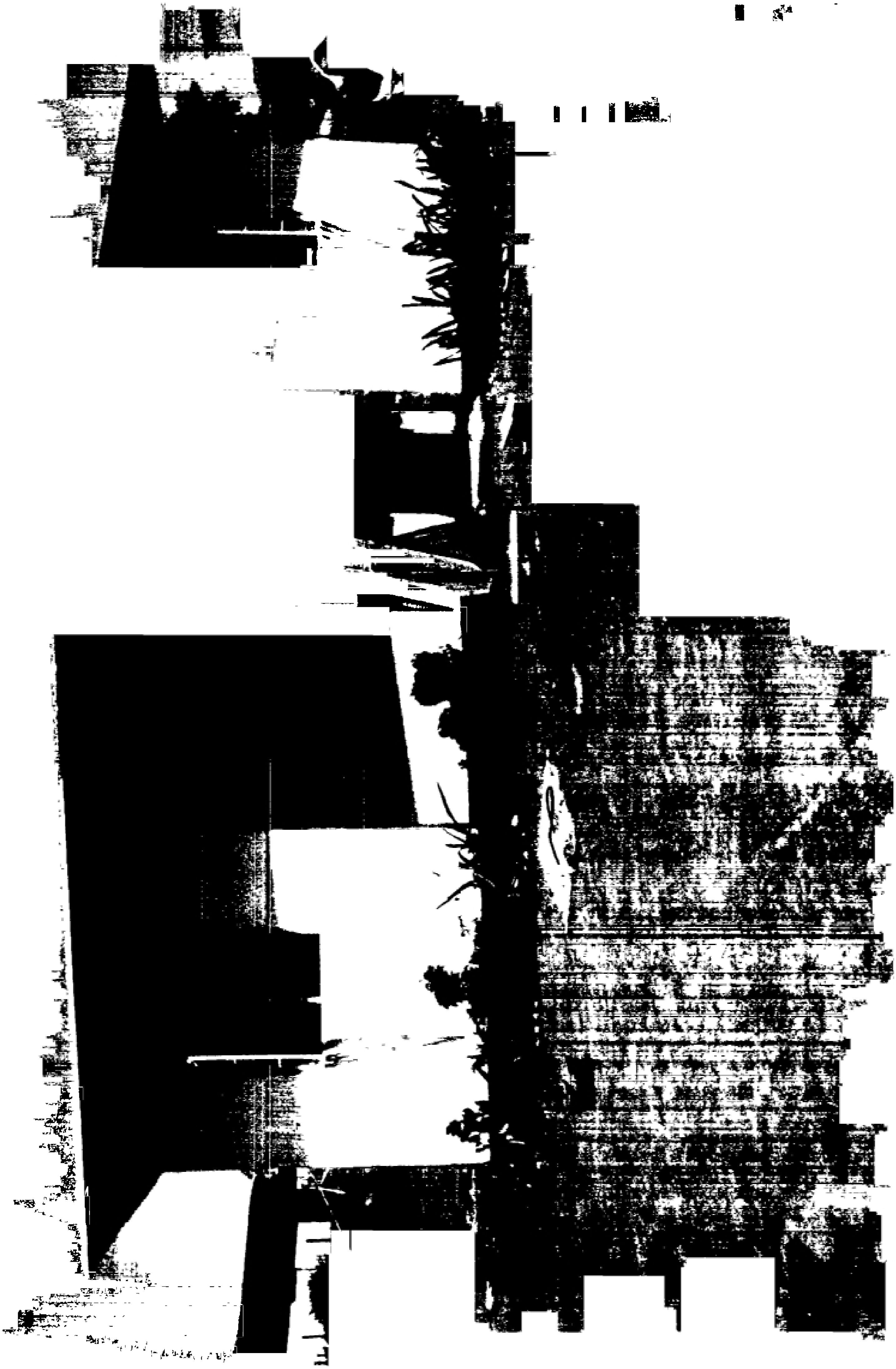


Figure 8
Site Schematic Drawing of the 63 Low Income B.H.C. House Plots in Gaborone West Fitted With the 4 Litre Flush Prototype W.C., and also Showing the Manhole Locations and Main Drainage Runs.

Plate 3
View of a typical single storey low income housing scheme dwelling in Gaborone West. Accommodation comprised living room, 2 bedrooms, shower room and kitchen. Water and drainage were provided but no electricity supply.



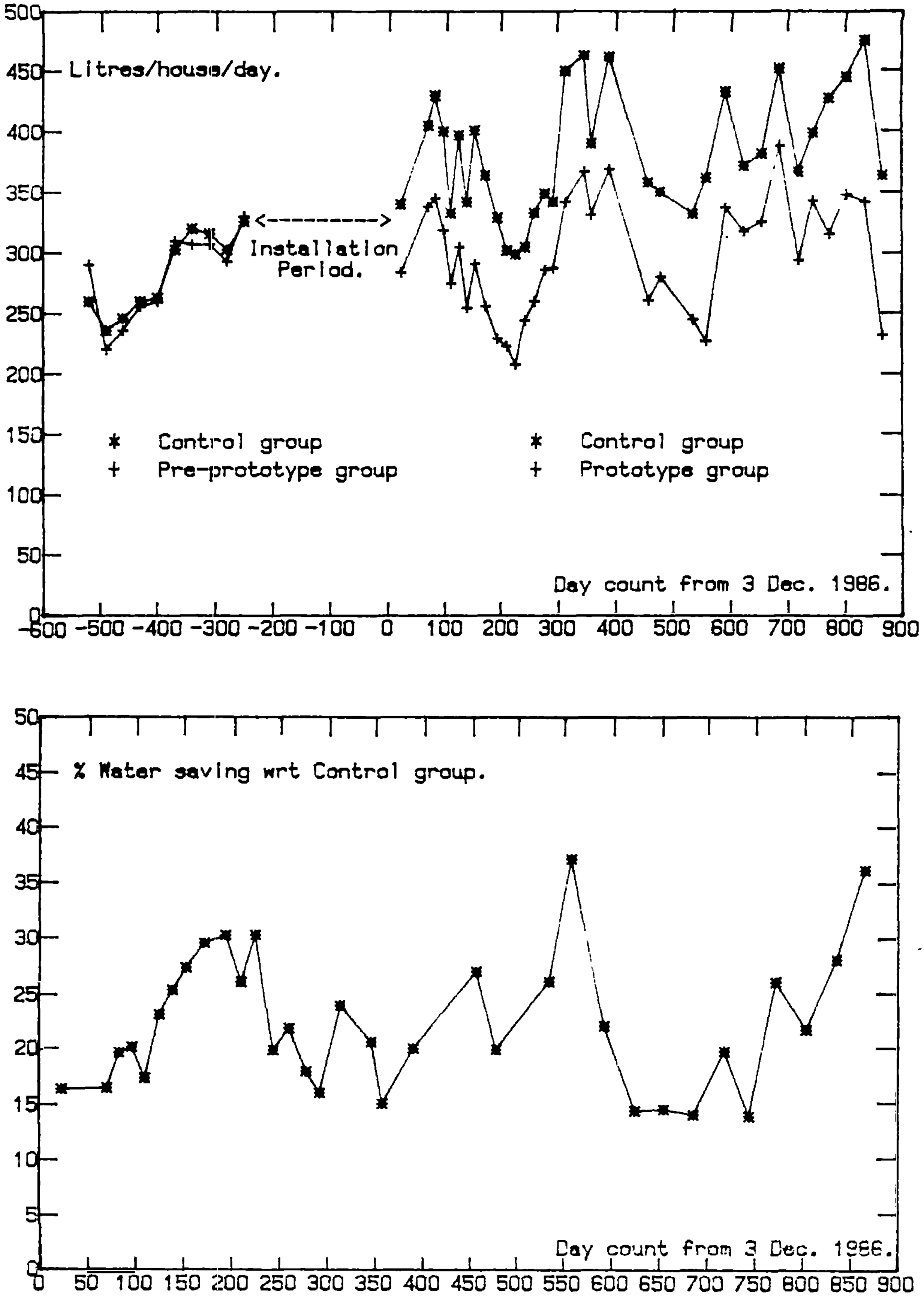


Figure 9
Water Consumption and % Saving Data from the Protoype and Control Group Housing in Gaborone West, Botswana. Note the Comparability of the Sample Groups Prior to the Trial W.C. Installation and the Seasonal Nature of the Results.

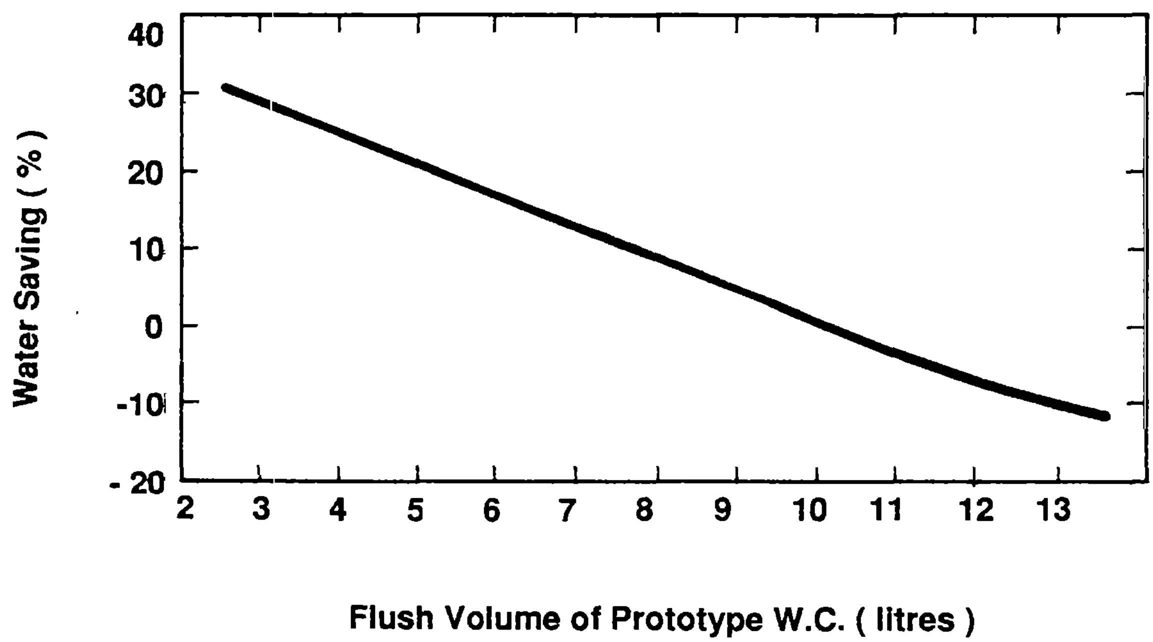


Figure 10
Potential Effect of Changing the Flush Volume of the Prototype W.C.