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LOW FLUSH WCs

INTERNATIONAL DATABASE SEARCH
and
RESEARCH FINDINGS

by

HERIOT-WATT UNIVERSITY

for

THE DRINKING WATER INSPECTORATE

November, 1994

International database search and current research findings: low flush w.c.'s.

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Part 1 - literature search on low flush volume w.c.'s

International database search and current research findings: low flush w.c.'s.

Extent of search.

The BIDS.ISI, BIDS Compendex and UnCover on-line international electronic databases were searched back to 1988. The keywords used are listed in Appendix 1. In addition, a selection of available current research undertaken by the drainage research group headed by Professor J. A. Swaffield has been included, together with recent work reported at the CIBW'62 and Conserve 90 conferences, as Appendix 2.

Summary of findings.

In total, 30 references are included in this search. They cover the following range of subjects:

(i) market force studies,
(ii) technology,
(iii) impact/effect/savings,
(iv) policy,
(v) current research.

Across each of these headings, the general tone of the abstracts is that there are benefits from retrofit programmes and new-build awareness programmes and that, properly marketed, customers will readily perceive these benefits and are prepared to adopt legislative changes. Several large scale pilot schemes have been operated in the past, including rebate driven retrofit projects, with measurable benefits.

Appliance manufacturers are beginning to produce fittings of appropriate design, and code bodies are researching the implications of low water volume usage patterns. Their findings, and those of current researchers, is that the quality of a drainage service is not reduced on reduction of flow volume provided that the system as a whole is properly sized. The design parameters that influence w.c. performance, and measurement techniques that accurately characterise it, show that six litre flush w.c.'s have acceptable levels of performance, judged even by past standards. This is adequately illustrated in the enclosed references, and the material in Appendix 2.

Report format

As discussed, there was insufficient time to permit the individual search papers, many of which are held abroad, to be retrieved and copied for this report. The abstracts have been grouped together into headings, while current research material at our immediate disposal has been included as separate off-prints in Appendix 2, with illustrations where appropriate. You may find that some of the CIB-W62 material is difficult to obtain otherwise.

Part 1 - literature search on low flush volume w.c.'s

market forces/studies

Title: Solving MWRA's supply issues through conservation AU: Kempe_M JN: Resources Planning and Management: Saving a Threatened Resource - In Search of Solutions, Proceedings of the Water Resources Sessions at Water Forum 1992 pp.163-168 PU: ASCE, New York, New York, USA IS: 0-87262-876-0 DT: Conference Paper NA: Massachusetts Water Resources Authority, Boston, Massachussetts, USA CF: 1992 National Conference on Water Resources Planning and Management - Water Forum '92, Baltimore, MD, USA, Aug 2-6 1992 CC17352, ASCE

Abstract: Facing a supply/demand imbalance where demand was exceeding supply by over 10%, MWRA acted to implement a balanced water conservation strategy. The strategy included leak detection and repair, meter rehabilitation, retrofit of residential users with water saving devices, outreach and water audits for commercial/industrial users, public education programs and other efforts. With the program still underway, MWRA water use has dropped by approximately 20% to date, well under safe yield limits. (Author abstract)

Key Words: Water supply, Water conservation, Leak detection, Retrofitting, Water meters, Information dissemination, Massachusetts Water Resource Authority (MWRA), Water supply/demand imbalance

Title: Market Penetration. Myth or reality: local agency persepctive. AU: Nero_WL JN: Management and Regulations for the New Decade Proceedings - AWWA Annual Conference 1991 pp.459-463 PU: American Water Works Assoc, Denver, CO, USA. IS: 0360-814X 0-89867-591-x DT: Conference Paper NA: City of Tampa Water Dep, Tampa, Florida, CF: Proceedings of the 1991 AWWA Annual Conference, Philadelphia, Pennsylvania, 23 - 27 Jun 1991 CC16346, AWWA

Abstract: Local governments throughout the country, have been implementing water conservation programs for nearly twenty years. In that time, not only have water saving technologies improved, but the understanding of water conserving behavior has also improved. Through better and more thorough analyses we now know more about who participates inconservation programs, and why, as well as how much water we can expect to save as a result of these programs. This paper addresses participation and retention rates and their effect on a residential retrofit project in Tampa, Florida.

Key Words: PUBLIC UTILITIES - Conservation, WATER SUPPLY - Conservation, MUNICIPAL ENGINEERING, PENETRATION, PLANNING PROGRAMS

Title: Residential water conservation. Casa del Agua. AU: Karpiscak_MM Foster_KE Schmidt_N JN: Resources Bulletin 1990 Vol.26 No.6 pp.939-948 IS: 0043-1370 DT: Article NA: Univ of Arizona, Tucson, Arizona

Abstract: A single-family residence in Tucson, Arizona, was retrofitted with water-conserving fixtures, rainwater harvesting, and graywater reuse systns The use of municipal water was reduced by 66 percent to 148 gallons per day (gpd) and total household use was reduced by 27 percent to 245 gpd. Graywater reuse averaged approximately 77 gpd or 32 percent of the total household water use. Evaporative cooling required about 15 gpd. Water use for toilet flushing

was only 9 gallons per capita per day (gpcd) or 14 percent of interior water use. (Author abstract) 16 Refs.
Key Words: WATER RESOURCES - Conservation, HOUSES - Water Supply, WATER DISTRIBUTION SYSTEMS, PLUMBING - Fixtures, WATER SUPPLY, WASTEWATER TREATMENT, RESIDENTIAL WATER CONSERVATION, RAINWATER HARVESTING, GRAYWATER REUSE, EVAPORATIVE COOLER WATER USE, DEMONSTRATION PROJECT, WATER CONSERVING FIXTURES

Title: Water use reductions from retrofitting indoor water fixtures. AU: Whitcomb_JB JN: Resources Bulletin 1990 Vol26 No.6 pp.921-926 IS: 0043-1370 DT: Article NA: Brown and Caldwell Consultants, Pleasant Hill, California
Abstract: A water use model was developed to estimate water savings from installation of low-flow showerheads and toilet displacement devices in residential housing. The model measures household water use in per capita terms with adjustments for age of occupants, household income, if occupants responsible for direct paymlletinnvolved with a pilot retrofit program in the Seattle, Washington, area were analyzed. We estimated per capita indoor water use to decline by 6.4 and 2.1 percent from complete installation of low-flow showerheads and toilet displacement devices, respectively. (Author abstract) 4 Refs.
Key Words: WATER SUPPLY - Management, PLUMBING - Retrofitting, MATHEMATICAL MODELS, WATER RESOURCES - Conservation, HOUSING, URBAN PLANNING, INDOOR WATER FIXTURES, WATER USE MODELS, WATER SAVINGS, LOW FLOW SHOWERHEADS, TOILET DISPLACEMENT DEVICES, RESIDENTIAL HOUSING

Title: Low-volume toilet retrofits in low-income public housing projects. AU: Mullarkey_N JN: Management and Regulations for the New Decade Proceedings - AWWA Annual Conference 1991 pp.487-495 PU: American Water Works Assoc, Denver, CO, USA. IS: 0360-814X 0-89867-591-x DT: Conference Paper NA: Lower Colorado River Authority, Austin, Texas, CF: Proceedings of the 1991 AWWA Annual Conference, Philadelphia, Pennsylvania, 23 - 27 Jun 1991 CC16346, AWWA
Abstract: The Lower Colorado River Authority (LCRA) was established by the consisting of the counties which comprise the watershed of the lower Colorado River. The LCRA Act of 1934 establishes LCRA's mission in four areas - water, electric energy, conservation and lands. In water, LCRA is empowered to control floods and control, store, sell, preserve and distribute the waters of the Colorado River and its tributaries. LCRA provides water for irrigation, generation of electric energy, reclamation of arid lands, and municipal drinking water for communities in central Texas.
Key Words: WATER RESOURCES - Conservation, HOUSES - Water Supply, TOILET SYSTEMS, WATER CONSERVATION, PUBLIC HOUSING PROJECTS

Part 1 - literature search on low flush volume w.c.'s

Title: Market penetration of residential retrofits. A statistical perspective. AU: Rodrigo_D Dziegielewski_B JN: Management and Regulations for the New Deca Full Record (excluding keywords) CF: Proceedings of the 1991 AWWA Annual Conference, Philadelphia, Pennsylvania, 23 - 27 Jun 1991 CC16346, AWWA
Abstract: For many water agencies throughout the U.S., water conservation is becoming an important water management strategy. This is especially true in the western part of the country where droughts, dwindling reliable water supplies, and fast growing population are forcing water agencies to consider alternative methods to meet water demands. In particular, one conservation strategy is receiving widespread attention - the residential plumbing fixture retrofit. Residential homes using non-conserving plumbing fixtures, (showerheads and toilets) are retrofited with low-flow showerheads and toilet displacement devices. In some cases a more aggressive retrofit is applied, where the old non-conserving toilet is replaced with a low or ultra-low-flush toilet. In either case, large scale retrofit programs require substantial financial participation on the part of the water agency and can easily cost millions of dollars. 5 Refs.
Key Words: WATER SUPPLY - Conservation, HOUSES - Water Supply, PETROFITS, MARKET PENETRATION, CONSERVING DEVICES

Title: Water use reductions from retrofitting indoor water fixtures. AU: Whitcomb_JB JN: Resources Bulletin 1990 Vol.26 No.6 pp.921-926 IS: 0043-1370 DT: Article NA: Brown and Caldwell Consultants, Pleasant Hill, California
Abstract: A water use model was developed to estimate water savings from installation of low-flow showerheads and toilet displacement devices in residential housing. The model measures household water use in per capita terms with adjustments for age of occupants, household income, if occupants responsible for direct payment of water bill, and type of water fixtures. Detailed data on 308 single family residences involved with a pilot retrofit program in Seattle, Washinton was developed to estimate water savings from installation of low-flow showerheads and toilet displacement devices in residential housing. The model measures household water use in per capita terms with adjustments for age of occupants, household income, if occupy showerheads and toilet displacement devices, respectively. (Author abstract) 4 Refs.
Key Words: WATER SUPPLY - Management, PLUMBING - Retrofitting, MATHEMATICAL MODELS, WATER RESOURCES - Conservation, HOUSING, URBAN PLANNING, INDOOR WATER FIXTURES, WATER USE MODELS, WATER SAVINGS, LOW FLOW SHOWERHEADS, TOILET DISPLACEMENT DEVICES, RESIDENTIAL HOUSING

Title: Bathroom fixtures in today's environment. AU: Suzanski_MJ JN: Construction Specifier 1990 Vol.43 No.8 pp.68-73 IS: 0010-6925 DT: Article
Abstract: The demand for large, beautiful bathrooms has changed the face of the building industry. Once found solely in high-priced residences, products such as whirlpools and solid brass faucets are now frequently specified for both commercial and residential jobs at a variety of prices. New materials for tubs and advanced engineering for faucets have created products that are exceptional in function, as well as luxurious in form. At the same time, water shortages and inadequate sewage treatment capacities in regions across the country have prompted calls -

and legislation - for plumbing products that conserve water. A combination of new technology and new materials for tubs and advanced engineering for faucets and many closet designs has enabled U.S. plumbing product manufacturers to introduce toilets that flush on 1.6 gallons of water, rather than the current 3.5 standard, with little or no compromise in performance. The influx of these new plumbing products, and the range of characteristics they exhibit, raises a number of questions about performance and cost. Profiles of some of the more popular products are presented: whirlpools; materials; low flush toilets; faucets.
Key Words: PLUMBING - Fixtures, PUMPS, JET, WATER SUPPLY - Management, SEWAGE

technology

Title: Low flush plumbing fixtures and wastewater systems AU: Konen_TP, Pongavanam_S, Martin_RB JN: Resources Planning and Management and Urban Water Resources 1993 pp.657-661 PU: ASCE, New York, New York, USA IS: 0-87262-912-0 DT: Conference Paper NA: Stevens Inst of Technology, Hoboken, New Jersey, USA CF: Proceedings of the 20th Anniversary Conference on Water Management in the '90s, Seattle, WA, USA, May 1-5 1993 CC18621, ASCE, American Consulting Engineers Council, American Water Resources Assoc, American Water Works Assoc, Bureau of Reclamation, Pacific Northwest Region, et al

Abstract: The significance of low flush plumbing fixtures on the wastewater collection and treatment system serving a small community has been determined. Among the concerns studied were: functional performance of the fixtures, transport of wastes in building drains and laterals, and the operation of the treatment plant. The results of the laboratory and field measurements show 39 percent reduction in water use with no detrimental impact on the collection system or wastewater treatment. (Author abstract) 2 Refs
Key Words: Wastewater treatment, Plumbing fixtures, Flow measurement, Wastewater collection, Field measurements, Low flush fixture

Title: Conservation. A benefit of good management. AU: DeHart_D JN: Journal of the New England Water Works Association 1991 Vol.105 No.1 pp.43-45 IS: 0028-4939 DT: Article NA: Dept of Public Works, Danvers, Massachussetts

Abstract: In this paper the author outlines the six water saving measures instituted in a small New England water system of 26,000 subscribers. The results of the conservation program are reported and as the author says '...you be the judge, you decide if its worth it,...' (Author abstract)
Key Words: WATER RESOURCES - Conservation, WATER SUPPLY, METERING, LEAK DETECTION, PRICING, PUBLIC EDUCATION, WATER USE

Title: Fixture unit values for the flushometer-tank. AU: Fung_YF Konen_TP JN: Plumbing Engineer 1989 Vol.17 No.4 pp.28-31 IS: 0192-1711 DT: Article NA: Stevens Inst of Technology, Hoboken, New Jersey

Abstract: The objective of this engineering study has been the development of fixture unit

values for the flushometer-tank. The product consists of a sealed reservoir which receives, stores water and pressurizes the entrapped air to line pressure. When flushed, release of the charged water creates siphonic action in the bowl instantly, allowing a substantial reduction of consumption without loss in function. This engineering investigation and study to integrate the flushometer-tank technology with current plumbing practice consisted of the following: 1) adaptation of the graphical Hunter method to a computerized procedure to facilitate ease and consistency in the generation of fixture unit values; 2) verification of the computer program through the generation of the original Hunter fixture unit values; 3) confirmation of the Uniform Plumbing Code, UPC, published values for additional fixtures; and 4) determination of fixture unit values for the flushometer-tank flushing technology products.
Key Words: PLUMBING - Fixtures, COMPUTER SOFTWARE, FLUSHOMETER TANK, GRAPHICAL HUNTER METHOD, UNIFORM PLUMBING CODE, FIXTURE UNIT VALUES

impact/effect/savings

Title: Water and waste water savings achieved by ultra low flush toilets in Santa Monica, California AU: Perkins_C, Munves_S JN: Resources Planning and Management and Urban Water Resources 1993 pp.60-673 PU: ASCE, New York, New York, USA IS: 0-87262-912-0 DT: Conference Paper CF: Proceedings of the 20th Anniversary Conference on Water Management in the '90s, Seattle, WA, USA, May 1-5 1993 CC18621, ASCE, American Consulting Engineers Council, American Water Resources Assoc, American Water Works Assoc, Bureau of Reclamation, Pacific Northwest Region, et al

Abstract: Since its implementation in December 1989, the Bay Saver Residential Fixture Rebate Program has replaced over 30,000 water-wasting toilets and shower heads in Santa Monica with 1.6 gallon per flush ultra low flow toilets and 2.5 gallon per minute shower heads. Upon anticipated completion of the Bay Saver Program in April 1994, the City will have achieved a permanent reduction in water usage and waste water flows of 1.9 million gallons per day (MGD). These 1.9 MGD of reduced water usage and decreased waste water flows represent a 15 percent reduction in Santa Monica's average total daily water demand and a 19 percent reduction in average total daily waste water flows. It is estimated that the projected 1.9 MGD permanent sewage flow reduction will save the City of Santa Monica approximately 9.5 million in avoided sewage treatment capacity purchases alone by the year 2000. (Author abstract)
Key Words: Plumbing fixtures, Sewage treatment, Flow measurement, Low flush toilets, Shower heads, Santa Monica

Title: Demonstrating residential water conservation and reuse in the Sonoran Desert. Casa Del Agua and Desert House. AU: Karpiscak_MM Brittain_RG Gerba_CP Foster_KE JN: Science and Technology 1991 Vol.24 No.9 pp.323-330 IS: 0273-1223 0-08-041837-6 DT: Article, University of Arizona, Tucson, Arizona, CF: Proceedings of the International Symposium on Wastewater Reclamation and Reuse, Costa Brava, Spain, 24 - 26 Sep 1991 CC15364,

Abstract: Single-family homes are being used to demonstrate and research water conserving and reuse techniques and technologies. These facilities can provide real-world data as well as public information and educational programs. The installation of water-conserving fixtures,

rainwater harvesting, and graywater reuse systems and storage can reduce the requirements for potable water by 50 percent. Casa Del Agua and Desert House show that the science of conserving resources can be balanced with the art of designing quality desert dwellings. (Author abstract) 9 Refs.
Key Words: WATER RESOURCES - Conservation, WASTEWATER TREATMENT, EDUCATION

Title: Social acceptability of water conservation in Springfield, Ill AU: Lant_CL JN: Journal of the American Water Works Association 1993 Vol.85 No.8 pp.85-89 IS: 0003-150X DT: Article NA: Southern Illinois Univ - Carbondale, Carbondale, Illinois, USA
Abstract: Water conversation initiatives are more likely to succeed if they are socially acceptable. A survey of 2,700 residential customers of Springfield (Ill) City Water, Light and Power was conducted to assess the acceptability of 12 possible conservation measures and the relationship between demographic and attitudinal factors and overall acceptance of conservation. Lawn watering restrictions, education, home water-saver killinois, USA
Abstract: Water conversation initiatives are more likely to succeed if they are socially acceptable. A survey of 2,700 residential customers of Springfield (Ill) City Water, Light and Power was conducted to assess the acceptability of 12 possible conservation measures and the relationship between demographic and attitudinal factors and overall acceptance of conservation. Lawn watering restrictions, education, home water-saver kits, low-flush toilet rebates, and a low-flow fixtures ordinance for new construction were most acceptable.

policy

Title: Energy policy Act: assessing its impact on utilities AU: Vickers_A JN: Journal of the American Water Works Association 1993 Vol.85 No.8 pp.56-62 IS: 0003-150X DT: Article NA: Amy Vickers and associate Inc., Boston, Massachussetts, USA
Abstract: With passage of the federal Energy Policy Act in 1992, the United States will have uniform water efficiency standards for nearly all toilets, urinals, showerheads, and faucets manufactured after January 1994. The reduced water demand and wastewater volumes will influence policy and planning decisions of utilities. With passage of the federal Energy Policy Act in 1992, in the United States, all toilet and sanitary manufacturers will be required after 1994 to provide a minimum 10-year leak-free guarantee on all toilets produced. Use of treatment chemicals, utility demand for energy, and related energy combustion emissions are all expected to decrease with reduced water consumption. 12 Refs.
Key Words: Energy policy, Public policy, Energy management, Water conservation, Laws and legislation, Energy policy act, Impact on utilities, United States

Title: Water audit encourages residents to reduce consumption AU: Nelson_JO JN: Journal of the American Water Works Association 1992 Vol.84 No.10 pp.59-64 IS: 0003-150X DT: Article NA: North Marin Water District, Novato, California, USA
Abstract: The North Marin (Calif.) Water District (NMWD) conducted a free home water audit for randomly selected customers from single-family detached homes. All were in the upper

Appendix 1 - keyword search logic employed for part 1 search

	low flush	and	w.c.	and	water saving		
	low flush	and	water closet	and	water saving		
	low flush	and	toilet	and	water saving		
	low flush	and	water conserving	or	water saving		
	low flush	and	w.c.	and	water conserving		
	low flush	and	water closet	and	water conserving		
	low flush	and	toilet	and	water conserving		
	low flush	and	w.c.	or	water saving		
	low flush	and	water closet	or	toilet		
	low flush	and	water saving	or	device		
	low flush	and	water saving	or	fixture		
	low flush	and	retrofit	or	rebate		
	toilet	and	water conserving	or	water saving		
	w.c.	and	water conserving	or	water saving		
	water closet	and	water conserving	or	water saving		

Appendix 2.

Item 1, Appendix 2.

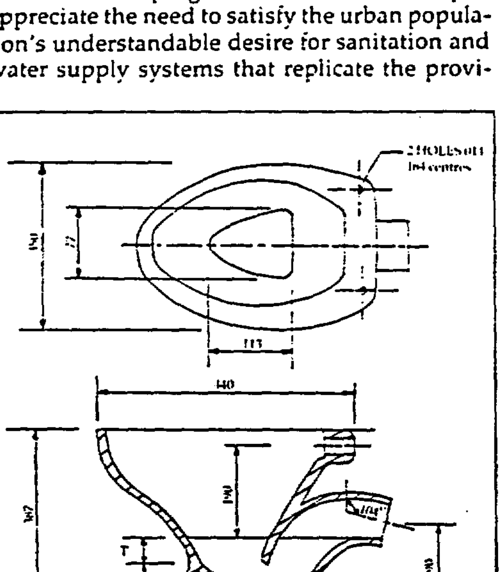
'Low water use sanitation - the design and site evaluation of a 3 litre flush volume w.c.', Professor J. A. Swaffield, Dr. R. H. M. Wakelin, pp351, Developing World Water, Grosvenor Press International, 1988

LOW WATER USE SANITATION — THE DESIGN AND SITE EVALUATION OF A THREE-LITRE FLUSH VOLUME WC

by Professor J A Swaffield and Dr R H M Wakelin

WATER conservation within the boundaries of domestic sanitation provision and usage should not be viewed as simply an end in itself, but rather as a means of redistribution of an available resource. In this context it has applications to both developed and developing countries. In the developed world it has long been understood that for low-water-use domestic appliances to be successful, they must be designed and manufactured to high levels and must present no operational difficulties to the user. For example, in the context of wc design, reduced flush volume must not lead to any undue pan fouling or subsequent drain blockage and maintenance costs.

In the developing countries it is necessary to appreciate the need to satisfy the urban population's understandable desire for sanitation and water supply systems that replicate the provision for the higher income groups. Thus, while the application of 'appropriate technology', such as the Double Ventilated Improved Pit Latrine in rural areas suffering a water shortage, is correct, the application of similar solutions in urban areas to conserve water may conflict with the aspirations of the inhabitants.



KEY W.C. DESIGN PARAMETERS

DETAIL	BS 5503	MARK III
Trap seal volume (litres)	1.8 measured	0.86
Trap seal depth T (mm)	52 minimum	35.5—36.5
Min. passage size M (mm)	75 minimum	63
Water surface (mm)	150 X 100	113 X 77

Figure 1: Final prototype design of the wc. Not to scale, all dimensions in mm.

The UK Overseas Development Administration-funded low volume flush wc design project at Brunel and Heriot-Watt Universities in the 1983 to 1988 period was set up to meet this need for water conservation in urban areas while, at the same time, satisfying the user demand for 'proper' sanitation appliances.

The project involved the development of a wc capable of flushing successfully at three to four litres of water usage and of being used either as a pour flush or a cistern flush wc. During the period from 1974 to 1983 the authors, as co-founders of the Drainage Research Group at Brunel University, have been involved in the analysis of building drainage networks, particularly the effect of reduced flush volume on solid transport, and the development of improved test methods that would allow the design of low volume flush wc bowls.

From 1978 to 1981, a project to develop a 4½ litre flush volume close coupled wc for the UK market, utilising a siphon cistern and a 50mm trap seal depth, was undertaken on behalf of the UK Confederation of British Ceramic Sanitaryware Manufacturers. This project led to the manufacture of trial wcs and site evaluation at Brunel University and allowed the development of discriminatory test methods for both solid and fluid contamination removal from the wc bowl. It indicated clearly the fundamental hydraulic linkages existing between flush volume, trap seal depth, trap volume and wc passage dimensions. It was found that reducing both the trap seal depth and the trap volume was the key to satisfactory operation at much reduced flush volumes.

In 1983 the authors obtained ODA funding for a developmental and site evaluation programme, the latter to take place in Botswana and Lesotho, aimed at the production of a three- to four-litre flush volume wc. The technique utilised was to start with a Twyfords British Standard nine-litre flush volume wc and to

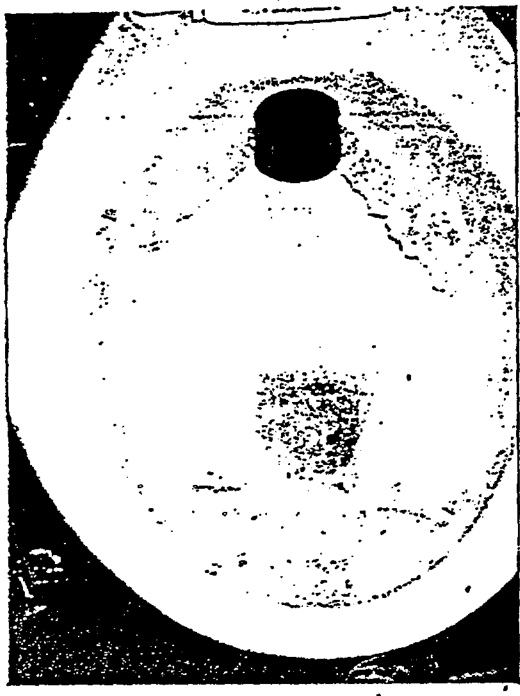
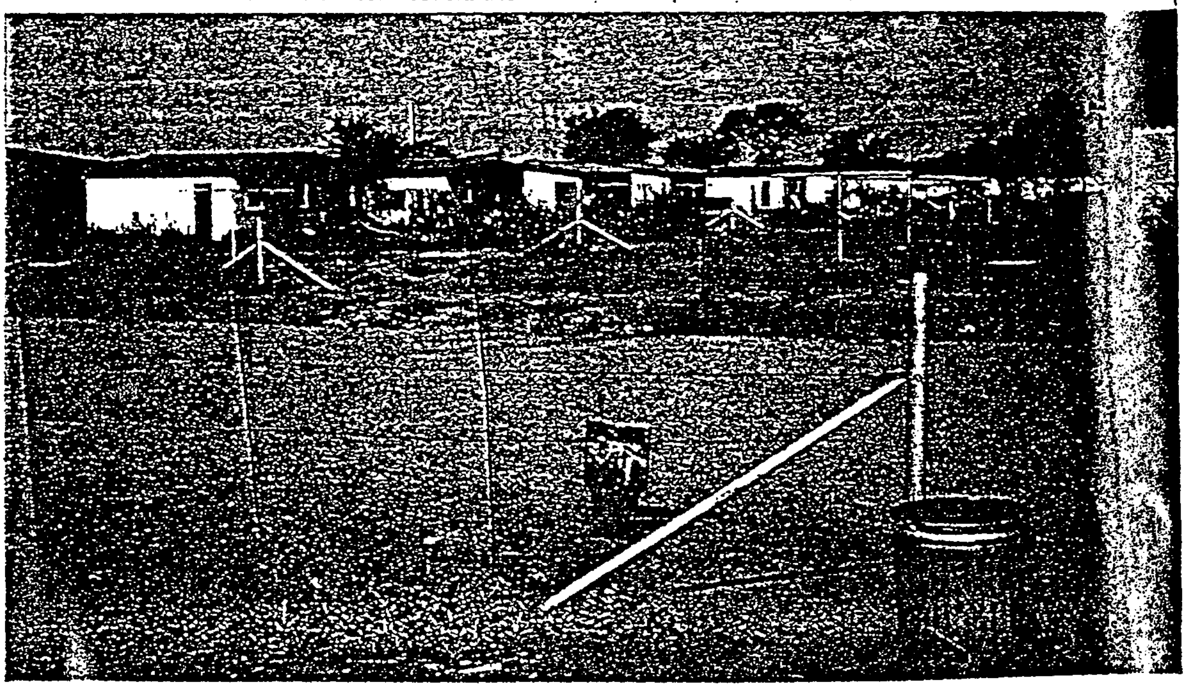


Figure 2: The Low Volume Flush Toilet showing the 3.0 litre flush distribution provided by the spreader bar.

remove both the flushing rim and the trap seal back plate. By remodelling the internal contours of the bowl and also by varying the trap water volume and the trap seal depth, an optimum combination was achieved, as shown in Figure 1. The removal of the flushing rim was dictated by the need to provide a pour flush option and led to the development of a flushing 'spreader bar' at the rear of the bowl. Water flows from the cistern through the flush pipe and into the rear of the bowl and is then distributed around the bowl by three jets formed at the spreader bar device that terminate the flush pipe. Two side jets distribute the flow around the sides of the bowl while the third provides a vertical flow downwards to the bowl water surface, thereby providing an impetus for the discharge of solids. Figure 2 illustrates the bowl in operation.

The final bowl design was passed to Twyfords in Stoke-on-Trent who produced a trial batch for delivery to Southern Africa. Preliminary evaluation of possible trial sites had led to the choice of Gaborone (Botswana) and Maseru (Lesotho), two site trial areas which were quite different. The Gaborone low income housing provided by the Botswana Housing Corporation were laid out in orderly estates equipped with well maintained mains sewerage systems, Figure 3. Each house was provided with a water supply and drainage, but no electricity connection. In addition to 89 wcs installed under these conditions in Gaborone, 10 were installed in private houses and in the offices of the BHC Architects Department, and six in a school in Northern Botswana. Installation was completed by August 1986 and water usage measurements were initiated on a 14-day cycle. In Gaborone the majority of the BHC houses were retrofitted with the test wc so that water usage data prior to the installation date was available. This allowed the identification of an adjacent control group of

Figure 3: A view of the Gaborone West Trial Site in Botswana, where Low Volume Flush Toilets were retrofitted in place of 10-11 litre flush wcs.



30 dwellings that had shown statistically similar water usage in the preceding year. Water usage measurements in the modified dwellings and in the control group now show statistically significant water savings and shifts in the associated frequency distribution. In the period November, 1986 to July, 1987 water savings of around 20 per cent have been recorded in the trial sites when compared to the control group.

In Maseru 55 wcs were installed between October, 1985 and July, 1986 in a wide variety of housing served by a range of sewerage collection systems, varying from mains sewers to conservancy tanks, septic tanks and modified double pit latrines. The housing policy in Maseru made it rather more difficult to determine accurately the water savings being achieved. However, for the cases involving conservancy tanks, a reduction in tanker visits of a third has been noted over the year since installation was completed.

While the low volume flush wc would not meet British Standards specifications in terms of water seal depth, it is important to view such specifications in the context of their objectives. For example, the 50mm water seal depth is linked to the suction pressures commonly found in the vertical stacks in multi-storey buildings and, as such an application was not planned for the developed wc, this specification is irrelevant.

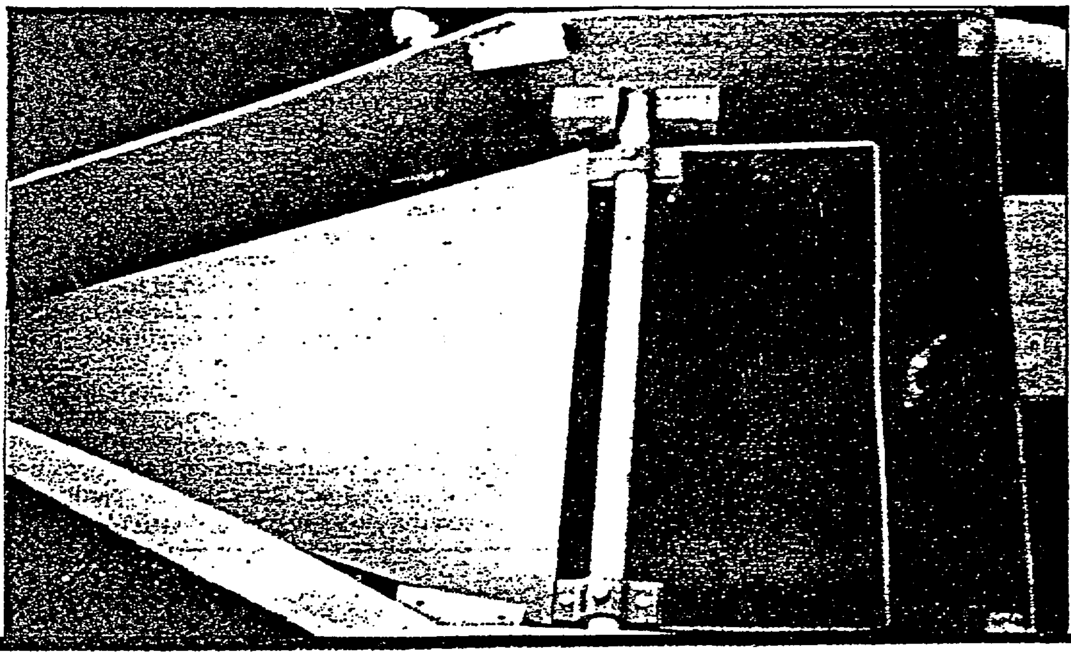
In both Botswana and Lesotho, the wc has performed well at the low flush volume, no consistent adverse comments have been noted from regular visits to users by the research worker on site, and the water savings have been shown to be worthwhile.

One of the main research concerns in the programme was that the sewers served might become blocked due to the reduced flush volumes failing to provide self-cleansing conditions. This has not been found to be the case. However, a parallel exercise involving the trial of tipping tank designs was also initiated as part of this programme. A tipping tank is a pivoted collection tank filled from the dwelling's sink or shower waste which, due to its shape, will automatically empty its contents by tipping when the stored fluid centre of gravity moves above and ahead of the pivot location. Figure 4 illustrates such a device installed in Botswana. The tipping tank was designed to hold some 20 litres of water that could be discharged as a steep fronted wave at irregular intervals, thus providing a surge that clears out any deposited solids from a considerable pipe length.

Laboratory and theoretical studies showed that the placement of a series of tipping tanks could be predicted to maintain self-cleansing in a sewer network. While the tanks were not found to be strictly necessary in the Botswana and Lesotho evaluations, they would be invaluable linked to shallow gradient drain networks that also featured the use of water conservancy appliances.

The site trials described in Botswana and Lesotho have been successful and it is now hoped to extend the project through joint British Council and ODA support to Brazil, where IPT in Sao Paulo will participate in further site trials. The concept of reduced flush volume wcs has been shown to be a practical proposition: manufacture and use of such wc bowls is the next objective. □

Figure 4: The Tipping Tank installed in Botswana showing the tipping tank pivoted within the outer tank and counterbalanced to provide a 20 litre surge.



ITEM 2.

Item 2, Appendix 2.

'The Engineered Design of Building Drainage Systems', J. A. Swaffield, L. S. Galowin, ch. 1.5, pp11-15, Ashgate Publishing, 1992

THE ENGINEERED DESIGN OF BUILDING DRAINAGE SYSTEMS

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summation of the individual appliance discharge unit values. Research developed a code relationship linking discharge units to actual flow rates and thus, by utilising the steady free surface flow equations, depths of flow were calculated for various pipe gradients and diameters. These calculations become the basis for the design guide tables now commonly available in the UK, USA and Europe that indicate to the designer the loading at which pipe gradient should be increased or diameters altered. Clearly this approach was essential as a simplistic summation of flow rates from all the connected appliances would yield an unrealistically high system flow and hence lead to grossly oversized drains. As will be shown later oversizing does not represent any factor of safety as it leads to shallow flows with a much enhanced probability of solid deposition and maintenance problems.

However the discharge unit, or fixture unit, method is basically flawed once it is transformed into a system flow rate. This transformation automatically implies a quasi-steady flow governed by the traditional free surface flow equations, namely Chézy and Manning, suitably modified to allow for the circular cross section of the partially filled pipes. This is not the appropriate description for network flow as in fact it is, at least in the upper reaches of the system, ie within the true building drainage system, markedly unsteady as the flow reacts to the random discharge of the appliances connected to the network. The value of Hunter's research within the continuing development of drainage design is that it clearly illustrated the need to consider statistically the user patterns most likely for a particular system. These combinations of appliance operation may then be utilised as the input data for an unsteady flow model of the network that will simulate, and provide data on, the actual variations in flow depth and rate at any point in the network at any instant, taking into account the effects of junctions, solids in transport and possible backflow conditions - conditions which are all found within actual systems.

Hunter's work will be returned to later, however its importance over the past 50 years cannot be underestimated, both as the basis for the design of current drainage networks and also as an example of the influence of research upon the development of drainage design methods.

1.5 Water conservation and its effect on w.c. design

Water conservation is both an economic necessity and an engineering challenge. It is by no means a new phenomenon or criteria within drainage design; Billington and Roberts (1982) quote the controversy raised in 1900 when the London Water Company reduced flush volumes from 40 to 9 litres. Similar concerns were raised, British Bathroom Council (1988), when a reduction from 9 to 6 litres for the UK was proposed. In Europe, and particularly in Scandinavia, 6 litres has been the norm for decades. Additionally Swedish manufacturers have developed highly successful 3 litre w.c.'s, initially only for use in 'weekend' homes, linked to septic tanks by 75mm drains set at a 1/25 slope. More recently these units have become acceptable within urban applications due to a realisation that it is perhaps the total flow from the building that matters rather than the individual w.c. flush volume.

Water conservation is a necessary and achievable objective. In the UK Webster and Lillywhite (1979) demonstrated that up to 40% of domestic water use was accounted for by w.c. flushing. The w.c. is the one appliance where meaningful savings could be made by a careful synthesis of hydraulic and design methodologies.

As commercial organisations the ceramic manufacturers naturally do not publish the techniques they employ to determine w.c. shape and performance. However, in the UK an industry funded research programme is available for scrutiny and some of its results, linking the hydraulic bowl parameters to performance may be of interest.

Figure 1.7, Swaffield and Wakelin (1990), illustrates the choices present in the design of a w.c. Figure 1.8 illustrates the effect of the values allocated to the governing variables (flush volume, F; trap volume, S; trap seal depth, h; and minimum passage width, w) on the test performance of a w.c., evaluated by use of the multiple ball discharge method, to give a prediction of solid discharge performance and a potassium permanganate solution removal test, designed to simulate the removal of fluid waste. (It should be noted that the results for the potassium permanganate test were obtained by means of a before and after light absorption test on a sample of trap water, rather than by visual comparison to a range of prepared solutions). It is clear from the curves in Figure 1.8 that values of the non dimensional variable Sh/Fw in the region of 0.1 yield acceptable values of both solid and liquid waste removal, for example a typical w.c. having a 6 litre flush volume, 50mm trap seal and a 66mm passage width, requiring a Sh/Fw value of 0.13 would require the trap volume to be reduced to 0.95 litres, somewhat less than normally found in current higher flush volume w.c.'s. These figures also indicate a move to wash down rather than siphonic w.c.'s, a move that might be unacceptable in some societies.

However research of a fundamental nature has indicated a design direction that could lead to the considerable savings in water consumption. It is noticeable that while Scandinavian manufacturers do not publish their design

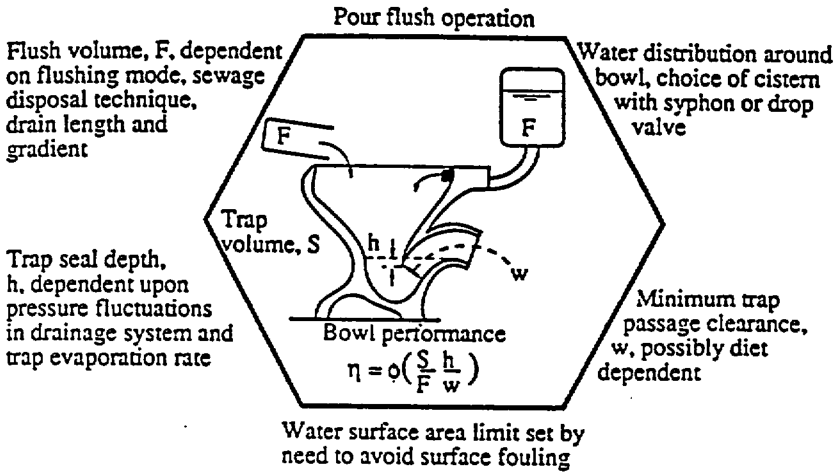

Figure 1.7 Design criteria governing low flush volume w.c. performance

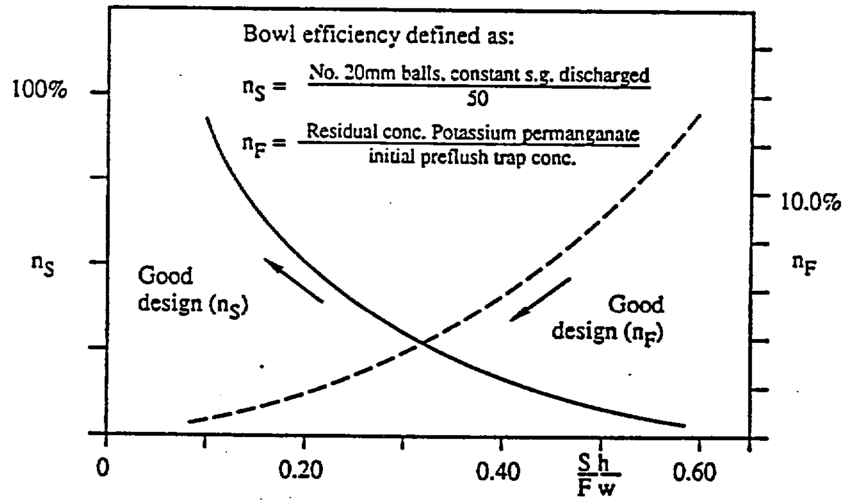

Figure 1.8 Bowl performance for solid and fluid contamination removal

methodologies, the successful low flush volume w.c.'s produced in Sweden all display design parameters clearly in line with the predictions of this research.

1.5.1 Water conservation and solid transport

One of the great myths surrounding low flush volume w.c. introduction is that all the flushed solids will be deposited in the drain and that the system will fail. Experience in Sweden and in a site trial in Phoenix, Arizona, Anderson and Seigrist (1986), utilising Ifo low flush bowls, disprove this. Similarly a 4 year site trial in Botswana of a 4 litre flush volume w.c., developed as part of a UK Overseas Development Administration project, Swaffield and Wakelin (1990), generated no drain blockage problems within a drainage network, Figure 1.9, laid to British Standard Institution guidelines, while the water savings, Figure 1.10, were considerable when compared to the use of locally available Vaal Potteries 10 litre w.c.'s. The source of this mythology may be traced to a lack of understanding of the mechanisms of solid transport; these will be outlined in detail in Chapter 10. Generally solids move through a system by a continuous process of deposition and re-acceleration caused by the arrival of later appliance discharges, not exclusively w.c.'s. Thus an assessment of solid transport performance must include the system as a whole.

W.c. testing has in the past concentrated upon its ability to discharge waste or successfully remove liquid contamination. The need to introduce solid transport as a further test was recognised in the US by ANSI, the current test is based on the ability of a w.c. to ensure the transport of 50 17mm diameter balls 16m along a pipe set at a slope of 1/50 (0.02 or 1/4 inch per foot). This test may be traced back to a similar procedure reported by Billington and Roberts (1982). In 1900 the Sanitary Institute in London initiated a test programme for w.c.'s involving some eighteen hundred tests of a 9 litre w.c. that left 5% of the test balls in the trap and 21% along a 50ft length of pipe. (The pipe diameter may be safely assumed to have been 4 inches or 100 mm.)

The influence of research on drainage design is again clear in the importance now being attached to solid transport, both in the acceptance tests mentioned above and also in the use of multi media solid testing as reported by Galowin and Swaffield (1991) as a means of simulating the heavier loads likely to be found in commercial building applications of low flush volume w.c.'s.

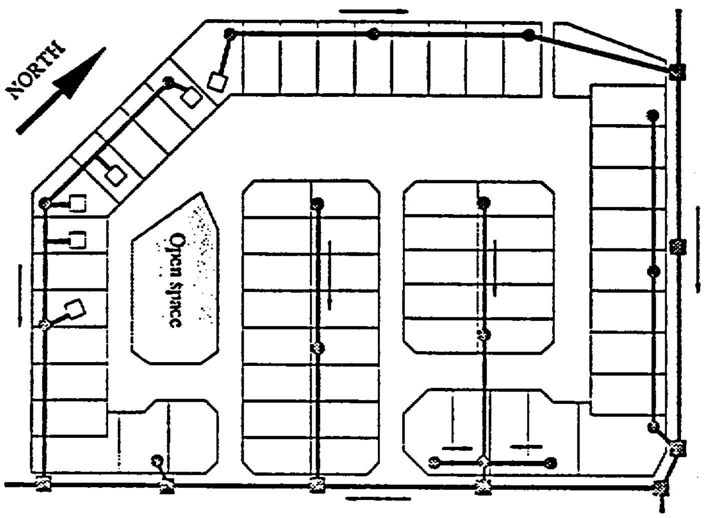

Figure 1.9 Layout of 63 low income Botswana Housing Corporation house plots, Gaborone West, fitted with 4 litre flush w.c.'s. Note 100mm diameter drains set at 1/90

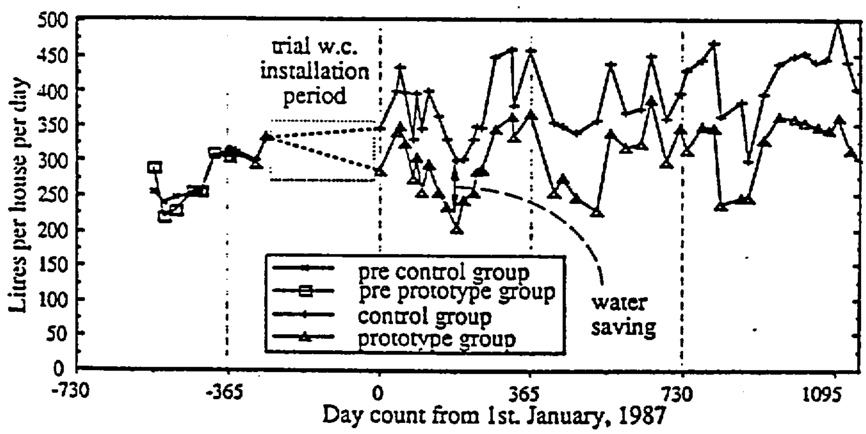

Figure 1.10 Comparison of prototype 4 litre flush w.c. housing group water consumption to a control group over a 3yr period. Also note pre-installation water consumption sensibly identical for both groups.

ITEM 3.

Appendix 2.

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'Water Efficient Plumbing Fixtures Through Standards and Test Methods', L. S. Galowin, J. A. Swaffield, pp 179-183, Conserv 90, The National Conference and Exposition Offering Water Supply Solutions for the 1990's, Arizona, August 1990

WATER EFFICIENT PLUMBING FIXTURES THROUGH STANDARDS AND TEST METHODS

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1. CURRENT ISSUES

New reduced flow rates and volumetric limits on water consumption for plumbing fixtures and appliances for water saving plumbing products are proposed in national legislation introduced in the U.S. Congress. Major concern exists for the ability of low volume fixture flows from water conserving plumbing fixtures and devices discharged into the drainage system for the functions of waste removal, transport and clearing the drains.

Measurments in low flow studies of water closet solid waste transport in drainlines and various loads of laboratory type simulants show discharged fixture wastes can be conveyed through the drainage piping. Test measurements have verified that computational methods for solution of the equations for various drainage loading conditions for partially filled drain flows accurately determine the transient hydraulic events.* Traditional references do not provide solutions for time dependent pipe hydraulics and waste transport problems. Computer modeling calculations and test data show the "carry out" of waste solids from the building to the sewer occurs in a series of successive carries and not necessarily from a single fixture flow.

2. ACCEPTANCE OF LOW FLOW DEVICES

Performance of fixtures to effectively perform the required functions relies upon plumbing standards, however the drainage system usually is not of concern in standards. Drain design practice has relied on model plumbing code (Hunter drainage fixture units) tabulations for sizing, pipe pitch, diameter, and wall pipe roughness. Plumbing codes and local regulatory jurisdictions reference standards. The ANSI A112.19.6 draft hydraulic standard includes a drainline waste transport test and a performance test for hydraulic assist water closets.

What has happened with the introduction of ultra low flow fixtures to raise questions about the performance of drainage systems to carry out their

* Partially from a manuscript by the investigators, "Engineered Design Methods for Building Drainage Systems" for Gower Technical Press.

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intended functions? Why have the reduced flows raised so many concerns and challenges about drainline loadings and real or hypothesized problems of stoppages, or blockages? The Hunter method for pipe sizing design does not predict local flow conditions because it was not intended for determination of hydraulic drainline phenomena. Details of time dependent local hydraulic conditions in drains and the drainline transport of waste materials have not previously been a primary concern of plumbing analysis. Only the time varying predictive computer based numerical method (Swaffield, Galowin, et al) accurately determines the hydraulic conditions in transient partially filled pipe flow.

3. SOLID WASTE TRANSPORT IN DRAINS

Transport of wastes by waste water flow in drain piping is based upon a 2 ft/sec sweeping velocity (from gravel-like materials). Human fecal waste, water soaked paper and sanitary products have specific gravity values close to water. The forces that act on waste material masses have been modeled for computation by investigators as hydraulic head, wall pipe friction due to normal buoyancy/weight component, and weight component due to pipe pitch.

Solid waste transport experiments and theoretical research have developed an understanding of the conditions previously unknown. Test results for transport of solid waste in drains were obtained with: simulants of capped water filled plastic cylinders; plastic balls and plastic pellets; water filled deformable plastic sheath cylinders (water closet bulk test material for ANSI A112.19.2-82); instrumented drain measurements of live loads of fecal and other wastes; tampons and sanitary napkins in a laboratory rig.

3.1 <u>Simulant Solids Deposited on the Pipe Walls</u> - Steady waste water partially filled pipe flow tests show the solids move at steady velocities along the drain. Comparisons of the solids steady transport velocities with the steady water velocity, (Chezy-Manning equation - partially filled pipe flow) generally indicate solids move at lesser velocities than the water, i.e., solids are not "swept" along at the average velocity of the water. Low volume water closet surge tests showed simulant solids, initially deposited at rest on the pipe wall, accelerate to a peak velocity followed by decreasing velocity trajectory.

3.2 <u>Live Load Waste Discharges from Water Closets</u> - The normal live loading of feces, tissues, sanitary products and other materials in the water closet waste stream, from male and female restrooms, were measured by Bokor with laboratory sensor instrumentation and automated data recording system in newly installed instrumented transparent drain pipes. Measurements in both the laboratory drain test rig and in the instrumented rest room facilities validated the capability to model the actual waste performance characteristics in laboratory experiments with simulants, and also to verify mathematical computations. Wastes that were deposited on the pipe wall from a single flush were carried from the drain in the next flush.

4. UNSTEADY DRAIN FLOW

The flow mechanisms in building drainage networks differs from those in sewer flows. The effects of wave attenuation upon the various fixture and appliance discharges largely determine the flow conditions responsible for solid transport. In the drainage system the solids may be treated as discrete masses subject to forces due to local unsteady flow conditions.

4.1 <u>Discrete Waste Solid Transport Simulation</u> - Requirements for reusable simulation waste solids for drain loads tests have been investigated internationally. Agreement has been shown between observed and calculated solid velocities for a range of flow rates, pipe diameters, pipe gradients, solid mass, length and diameter values. Those confirm that solid diameter was the main determinant of transport in partially filled drains and solid length was not the primary factor. Modeling of the moving boundary equation for the leakage flow dependence of waste water about the solid, as a function of the approach flow specific energy, has been shown to be reliable.

4.2 <u>Multiple Solid Transport</u> - Multiple solid body transport in the drain as a function of time show "accordion-like" mode of lead and trailing bodies, alternately speeding up and slowing down in opposition to each other. The theoretical model for "live loads" transport in drains agrees with tests; that further confirms the theoretical capability to reproduce experimental results. Interactions that couple the time varying water depths, (i.e., buoyancy and hydraulic head forces vary with thinning and increasing water depths between the solids in transit) are inherent to the hydraulic events.

4.3 <u>Drain Pipe Network - Waste Solid Transport in Steps</u> - Demonstrated application of the drainage system computer model to multiple pipe networks include horizontal branch drains, non-stationary hydraulic jumps at fittings and junctions and vertical stack flows in multistory buildings. Multiple drain loadings, with solids at the network entry points, showed solid body transport velocity and travel distance occur "stepwise". Reverse flow conditions at junctions, with changes from supercritical to subcritical flows, applies to determination of the motion and temporary stops of the solid bodies at those locations. All input solids experienced intermittent pipe wall depositions, being moved on by <u>subsequent inflow surges</u>.

4.4 <u>Discrete Solid Transport in Various Diameter Drain Pipes</u> - Reduced consumption water closet installations in conservation retrofit programs have raised concern for the capability of flushing waste solids through the drainage pipe networks where large pipe diameters exist. The Swedish Building Research Institute (SBRI) reported on a sewer system study with lowered volume water closet installations at the CIB W62 meeting in Gavle, Sweden (September, 1989). The investigation includes study of the hydraulic conditions in existing installed large pipe diameter sewers (current practice results in oversized pipes). Pipe sizing design criteria for sewer conveyance and development of drain loadings for "pseudo-steady flow" from random event discharges from installed plumbing fixtures and devices are to be developed.

Laboratory tests were run with a diameter step change from a short water closet drain pipe connection of 110 mm (4.4 in) to 225 mm (9 in) sewer pipe. Transport carry distances were determined with a weighted offset center of gravity ball waste simulant. Distances traversed vary as a function of the number of flushes and with gains from additional steady flow rates. Without additive streams repeated flushes contribute very small incremental benefits to solid motion; for a water closet flush of 6 l (1.6 gal) the simulant undergoes limited stepwise transport increments for up to 5 flushes. Large diameter pipe transport capability is significantly reduced in the absence of other waste water streams added to the water closet discharge.

The computer based model was applied to investigate the effect of pipe slope and diameter on the transport of solid waste for repeated 6 l and 9 l water closet discharge profiles. Transport distances are traversed in "stop/go" occurrences in larger pipes. When the solid has travelled sufficiently far downstream, for attenuation of the repeated inflow surges to result in a pseudo-constant flow rate, steadier motion results. Decreasing pipe diameters were determined to enhance the transport performance. Experiments and computed waste solid transport results show larger diameter pipes have deteriorated transport capability with repeated single water closet flush.

5. TEST REQUIREMENTS FOR STANDARDS

5.1 Basis for a Drainline Carry Test - A New Requirement - From the ANSI/ASME A112.19.2 and 19.6 Working Group review of simulant transport data from water closets of 14 l (3.5 gallons) and low consumption types of about 6 l (1.6 gal) the average carry distance requirement of 40 feet was selected as the acceptable performance parameter. The (draft standard) test rig for the drainline carry test requires a 60 ft length pitched pipe at a slope of 2 percent (1/4 inch per foot) with a connected turning elbow to the water closet. The test uses 100 plastic balls per load and is repeated three times; the test procedure, measurements, and average carry distance calculation is given.

5.2 Test Results for Ultra-low Flush Water Closets - Tests of ten 6 l (1.6 gal) or less ultra-low flush water closets, currently available in the U.S., were made for evaluation of drainline carry requirements in the draft standard. All water closets satisfy the minimum carry distance of 40 ft; three units demonstrated clearance of the 60 ft drain. All met the requirement that the average number of balls discharged from the water closet shall exceed 75.

6. CONTROLLED WATER CLOSET DISCHARGES

Retrofit measures with a partial flush cycle mechanism, or dams, retain part of the total water volume in the tank; removal of wastes from the bowl depends upon the ability of the reduced water flow to carry the waste materials over the weir. The normal functions, accepted in the plumbing industry for original equipment, are usually not tested for add-on devices to installed fixtures, e.g., adequate rim wash, sufficient dilution contaminant concentration levels, and adequate trap seal replenishment. Devices for water conservation retrofits have claimed the ability to save water and that they "work", but no hydraulic performance data is offered. Acceptance of such devices in water conservation retrofits has not taken into account potentials of performance degradation or criteria for sanitary requirements. Legal aspects from potential adversary positions, that may develop due to the inadequacy of sanitary services and potential health risks, do not seem to have concerned local jurisdictional officials to control and permit proper procedures for introduction of those devices in order to retain minimal health and safety requirements..

A basis for testing two-step flush mechanisms for essential performance parameters applicable for standards considerations was prepared at NIST by F. Winter. Testing criteria were developed for requirements for siphonic action, retention of the trap seal, adequate removal of the liquid wastes from the bowl, adequate cleansing of the inner surfaces of the bowl, adequate removal of paper wastes from the bowl, and satisfactory mechanical operation of the mechanism. Reduced performance criteria were proposed with caution about degradation, particularly in the event of successive flushes, at the lowered volume flush with those devices. The report can guide developments by water conservation practitioners and planners. Hydraulic performance data for reduced flush devices (not only water savings) should be made available on labels or information sheets in packages for retrofit installations.

7. PERFORMANCE TESTS FOR ALTERNATIVE PLUMBING FIXTURES

7.1 Hydro/Electrical/Assist Water Closets - Provisions for alternative testing media for evaluation of hybrid types of water closets that differ from conventional gravity driven water closets were adopted by the A112.6 Working Group. A performance test method permits the following: allows a manufacturer or testing laboratory to provide alternative test materials, within appropriate requirements for physical test similitude to the prescribed test materials already specified in the standard, that requires controlled satisfactory comparisons between the substitute materials with the specified test media, and demonstrates conventional performance evaluation at comparable levels with the criteria which are included in the standard with the prescribed test media.

8. COMMENTARY

The current considerations and thrust toward national plumbing legislation indicates broad interests in expanding water conservation through standards. Already, states and local governments have accelerated the acceptance of low-flow devices by changes in their regulations anticipating the ANSI standards approvals. This review demonstrates the necessity of research to prepare information required in considering formulation of standards. Establishment of an "intensity of discharge load/usage" predictive method to evaluate the extent of beneficial auxiliary flows into the drain is needed for existing larger plumbing drain capacities in water conservation retrofit actions. A predictive procedure could follow Hunter's probabilistic methods (or other probability models) for simultaneous event fixture discharges/usages.

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ITEM 4.

Appendix 2.

Item 4, Appendix 2.

'Critical Review of Research and Long-term Experience with Minimum Flow Toilet Fixtures', Damann L. Anderson, R. L. Siegrist, pp 189-193, Conserv 90, The National Conference and Exposition Offering Water Supply Solutions for the 1990's, Arizona, August 1990

Critical Review of Research and Long-term Experience with Minimum Flow Toilet Fixtures

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Water-using activities within residential dwellings throughout the United States contribute to a yearly per capita consumption of potable water that exceeds 18,000 gallons. One third or more of this results from toilet flushing alone. When combined with toilet usage in non-residential establishments, the average American uses about 9,000 gallons of water per year for flushing a mere 130 gallons of body waste down the toilet. To reduce this level of water use and the concomitant wastewater flow, numerous water saving approaches have been proposed and studied including non-water carriage toilets, grey water recycling, and alternative low-consumption toilet fixtures. This presentation reviews the authors' experiences and research into the performance of alternative and ultra-low-volume or low consumption toilet fixtures (fixtures using less than 6 liters or 1.6 gallons per flush).

University of Wisconsin Studies

Field studies were first conducted at the University of Wisconsin in the late 1970's to document the performance of alternative toilet systems in residences, under funding from the U.S. Department of Interior, Office of Water Research and Technology (OWRT), and the State of Wisconsin (Siegrist, Boyle, and Anderson; 1981). This research focused on a field evaluation of several low consumption and minimum flow toilet systems as well as the use of recycled grey water for flushing of conventional toilet fixtures in single family homes.

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The toilet fixtures studied utilized water volumes of 0.4 to 1.6 gallons per flush (gpf), 72 to 92 percent less than the 5 gallons per flush of conventional fixtures. Nine toilet fixtures of four different types were installed in five homes and monitored for periods ranging from 57 to 702 days. Toilets evaluated included the Microphor (0.5 gpf), Monogram (0.4 gpf), and two models of the Ifö Cascade (0.8, 1.6 gpf).

Results of the study showed interior daily water use reductions of 26 to 45 percent for the low consumption fixtures as compared to a 5 gallon/flush toilet. Although the mean daily interior water use was reduced substantially, peak daily and hourly interior use was not reduced nearly as much. Peak day water use reductions with the low consumption fixtures were 9 to 23 percent while peak hour reductions were only 0 to 12 percent.

The operation and maintenance requirements of the low consumption fixtures were relatively minor, but somewhat more than for conventional fixtures in the case of the Microphor and Monogram units. Power use was required for the Microphor and Monogram units and was measured at 0.0016 and 0.0008 kilowatt hours/use, respectively. User reaction was positive to all of the fixtures based on questionnaires and interviews with the home owners.

In addition to the low consumption toilets, two grey water recycle systems were installed and monitored in two homes for a total period of 559 days. The recycle system evaluated was a commercially available unit which employed the processes of sedimentation, pressure filtration and chlorine disinfection and was housed in a small, self-contained unit. The treated grey water was then plumbed back to conventional toilet fixtures for flushing.

Results of the recycle system evaluation showed interior water use reductions of 28 and 31 percent in the two homes studied when compared to the use of potable water for flushing a five gallon per flush toilet. In one home, a favorable grey water balance was maintained and no additional potable make-up water was required. At the second residence approximately 0.6 gallons per capita per day (gpcd) of potable make-up water was needed to meet the flushing demand. As in the low consumption toilet evaluation, this phase of study found the recycle systems impacted the peak day and hour water use reductions much less than the mean day reductions.

The operation and maintenance requirements for the recycle systems were significantly greater than for a conventional toilet fixture. In fact, user reaction to the recycle systems was somewhat negative because of the need for routine maintenance such as residual chlorine monitoring, filter washing and replacement, and storage tank sludge removal. In the final analysis, it appeared that the low consumption toilet fixtures provided similar water use reductions with far greater user acceptance than the grey water recycle systems.

More details of the University of Wisconsin studies are available in Siegrist, Boyle, and Anderson (1981).

Phoenix Study

A study was undertaken in 1985 to evaluate the performance of low consumption toilet fixtures under field conditions in Phoenix, Arizona. Two residential subdivisions developed by John F. Long Homes, Inc. were compared, one utilizing conventional toilet fixtures ($\geq$ 3.5 gpf) and one using low consumption fixtures (0.8 gpf) exclusively. The objectives of the study were to compare the ULV toilets with conventional toilets in terms of water savings, sewer transport, wastewater composition, and user acceptance.

Based on a questionnaire survey of households, homes in the two subdivisions were similar with the exception of the toilet fixtures. The survey also revealed that user acceptance of the conventional fixtures and the low consumption fixtures were similar. Data from the low consumption subdivision indicated that these fixtures may require slightly more cleaning than normal. Data from the conventional subdivision indicated multiple flushing was required to clear the bowl of waste materials more often than the low consumption toilets. Also, the frequency of toilet clogging was reported to be much less by the home owners using low consumption toilets. Fifteen percent of the low consumption respondents reported cases of toilet clogging while 64 percent of the conventional subdivision respondents reported the same. Responses from both subdivisions and City of Phoenix sewer maintenance personnel indicated no abnormal incidence of house sewer blockage or clogging in either subdivision.

Water use by household was compared using data from the months of December and January, 1984 and January, 1985. December and January data were used because these months represented the period of least exterior water use. Based on this data, average monthly water use by homes monitored in the low consumption subdivision ranged from 19 to 28 percent less than homes in the conventional subdivision over the same months. These results agree with the range that would be predicted based on the 80 percent reduction in toilet flush volume provided by the low consumption toilets and normal residential water use.

Wastewater composition and flow in the two subdivisions was monitored over a period of five days during the study. These results were highly variable, but showed that wastewater composition in the low consumption subdivision was within the range of characteristics typical of municipal wastewater (Metcalf and Eddy, 1979) despite the reduced flow.

Wastewater flow monitoring data, while highly variable, indicated that the frequency and magnitude of peak wastewater flow conditions were similar in the two subdivisions. It appeared that peak flows in sewers serving homes with low consumption toilet fixtures may therefore provide similar cleansing velocities to remove accumulated sediment. This result agreed with the University of Wisconsin studies which showed less impact from low consumption fixtures on peak flows than on average daily flows.

A review of City of Phoenix manhole inspection and sewer cleaning records was also made during the study. These records indicated no problems with waste transport or sewer blockages in either of the subdivisions monitored. Inspection of manholes in the study areas during this study also indicated similar sewer sediment conditions within both subdivisions.

In summary, the results of the Phoenix Study showed significant reductions in water use and wastewater flow from the use of low consumption toilets. User acceptance of the fixtures was equal to or better than that of the conventional toilets. Waste flushing and transport through the household plumbing system, building sewers, and sewer mains were as satisfactory with low consumption fixtures as with conventional fixtures. More specific details of the Phoenix Study can be found in Anderson and Siegrist (1989).

Summary and Conclusions

The level of usage of low consumption toilets has increased dramatically during the 1980's and an increasing number of local and state jurisdictions are requiring their use in new construction and retrofit applications. There remains however, a continuing debate surrounding many performance related issues (e.g. flushing efficiency, waste carriage and treatment effects, water savings) and long-term user acceptance. Often the debate is fueled by tradition and personal preference rather than a good understanding of the available state-of-knowledge regarding these low consumption fixtures.

The experiences of the authors with low consumption toilet fixtures over the last 10 years indicates that these fixtures could be used in residential areas in the United States without adverse effects on user service levels or water and wastewater utility systems. These experiences include not only the comprehensive studies discussed here, but experience in personal residences, and several years experience living in Scandinavia where low consumption fixtures are the norm. In addition, numerous other studies have documented the satisfactory performance of low consumption fixtures (Baker, 1980; Cole and Sharpe, 1981; Siegrist, 1983; HUD, 1984; Sharpe et.al., 1984; and Hampton and Jones, 1985).

While the performance of low consumption toilet fixtures in residential settings has been documented, their performance in the wide variety of commercial settings has not received as much attention. The increasing number of fixtures being installed across the country without reported problems suggests satisfactory performance for these uses as well, but this should be documented. Other remaining research needs lie in the area of building water supply and drainage design. Current design practices do not adequately take into consideration the reduced flows of low consumption fixtures and it is the authors' opinion that building plumbing systems are currently not optimally sized as a result.

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Appendix 2.

ITEM 5.

Item 5, Appendix 2.

'Low Consumption Plumbing Products: An Approach to Standardization', P. J. Higgins, pp 195-199, Conserv 90, The National Conference and Exposition Offering Water Supply Solutions for the 1990's, Arizona, August 1990

ITEM 6.

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Item 6, Appendix 2.

'Wht Toilets? A History of the Low Consumption Toilet and its Introduction into the U.S. Market', W. L. Corpening, pp201-202, Conserv 90, The National Conference and Exposition Offering Water Supply Solutions for the 1990's, Arizona, August 1990 were widely accepted throughout Sweden and, within a short time, were the only products used in both residential and commercial installations throughout Scandanavia.

Water conservation has become a steadily increasing issue, pushed along by the severe drought in California in the late seventies and continuing concerns over the costs of new supply and management of existing supplies where new construction continues at a rapid pace. The rising cost of waste treatment facilities has also been a contributing factor to the interest in reduction of water use and sewer flows. As it became apparent that it was possible to significantly reduce the amount of water used in the home by simply changing the toilets, more cities started writing low consumption ordinances, instituting rebate programs and promoting water efficiency.

Since the introduction of this Swedish technology into the United States in 1981, the total market for ultra low flush toilets has grown from approximately 5,000 units in the first year to an estimated 2.5 million units in 1990. And the Swedes weren't the only ones to come up with appropriate technology to meet the demand. American manufacturers have been working on the development of this low consumption technology for years, taking the average flush volume from five or seven gallons down to three-and-a-half in the late 70s and now meeting the demand for the 1.6 gallon flush toilet.

Toilets on the market include a range of model types and technologies. Some manufacturers' products accomplish the reduced flow with the gravity flush and others utilize the boosted or air-assisted design. There are a number of options regarding design, from the typical round bowl residential toilet to the high fashion designer types and bowls designed for both commercial and institutional applications.

Low consumption toilets are being manufactured in Mexico, South America, Asia, Europe, Australia, and Indonesia as well as in the United States. The Swedes have toilets that use only 0.8 gallons (3 liters) of water per flush and the Japanese have toilets that accomplish two tasks by incorporating a faucet on top of the tank in order to use the same water twice--the potable water used for washing the hands becomes the tank water for the next toilet flush. There are toilets that utilize vacuum to evacuate waste with only two quarts, and toilets that use one cup of water and some foam to accomplish the task.

When Thomas Crapper first worked on the development of the water closet in England to help stop the tremendous waste of water, he started an evolutionary process that continues today. The need to save water and reduce wastewater has never been more apparent than it is now as we move into the 1990s and beyond. The low consumption toilet is here to stay and has become an integral part of many water management plans and programs throughout the country.

Orange Track

Municipal Water Supply and Conservation

WHY TOILETS?--A HISTORY OF THE LOW CONSUMPTION TOILET AND ITS INTRODUCTION INTO THE U.S. MARKET

Wendy L. Corpening

W.L. Corpening & Associates

When Thomas Crapper worked on the development of the first low consumption toilet in England nearly 100 years ago, he probably didn't envision the enormous impact his technological achievements would have on water conservation strategies as we near the year 2000.

I use the term low consumption for this first "water closet," as it was called, because the main reason for its development was to help curb the tremendous water waste that occurred with the prevailing sanitary fixtures of the time. The high tank, gravity flush toilet was a significant improvement over the fixtures that allowed the user to simply "pull the plug" to flush away waste--more often than not, the plug wasn't put back and water ran continuously even when fixtures weren't being used.

So from the first Crapper/flapper valve technology to the wide range of ultra low flush toilets available today, there has been a continuing evolution to provide sanitary, high quality plumbing fixtures that can be utilized for water savings and effluent reduction.

After Tom Crapper's work on the water closet, several changes occurred that were not in the best interests of saving water in the bathroom, including the design of fixtures that used up to seven gallons of water to flush. It's ludicrous to think that it would take seven gallons of water to flush approximately one pint of human waste into a sewer system.

Then, in 1973, a Swedish manufacturer of plumbing fixtures designed a toilet that used only 1.6 gallons (6 liters) of water and utilized both gravity and velocity to accomplish the task of carrying the waste into the sewer lines. The design was simple, straightforward and could exhibit up to 80 percent savings over the standard toilets in place in the United States at the time. These new low consumption or ultra low flush toilets

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LOW CONSUMPTION PLUMBING PRODUCTS: AN APPROACH TO STANDARDIZATION

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(e) Paper test - a defined bulk amount of interfold paper is added to the bowl and a single flush must clear the load.

(f) Drainline carry - the ball media is again added to the bowl. The average carry distance of the balls must be 40 feet in a 4" drain which is sloped at 1/4" to the foot. Independent tests of nine random-sample gravity type and flushometer tank 1.6 gallon per flush water closets resulted in a minimum carry of 51 feet. This test does not suggest that these fixtures will function in all drainline configurations, but it does show relative performance of products against one another. The drainline requirements were selected as the worst piping scenario which would exist downstream from a water closet. Piping of a smaller diameter (3" for example) or pipe slopes less than 1/4" per foot (1/8" per foot) will achieve a better carry of the waste load as the depth of water in the pipe or the slower velocity of the discharge helps to convey wastes further.

(g) Splash test - probes are placed within the bowl and water is not permitted to rise to a specified level.

(h) Spray test - the seat surface is examined for visual droplet deposits.

Urinals

In addition to water consumption evaluation, urinals are required to perform accordingly:

(a) Dye test - similar to the water closet requirements, water exchange and dilution is critical in urinals.

(b) Ink line test - a superior wall washing is critical for a sanitary condition in urinals. This test evaluates such washing characteristics of the fixture.

Showerheads

Showerheads are presently evaluated for flow rate maximums of 3.0 gpm in pressures from 20 to 80 psi. If the flow restrictor is not installed within the showerhead or if the restrictor is removable with a force of 8 lbs. or less, the flow rate analysis is tested without the restrictor.

Lavatory and sink fixture fittings (faucets) - Lavatory and sink faucets are tested from 20-80 psi. Flow rates cannot exceed (presently) 3.0 gpm.

All of the above mentioned products and their related packaging is now required to be marked with the flow rate or water consumption and with the reference designation of the standard to which it performs. This identification is important to the fixture and fixture fitting purchaser, installer, and inspector.

We hope that this report will give you, the Conserv 90 participant, a better understanding of the importance of standardization of product for the purposes of saving water and, as important to maintain integrity of public health, sanitation and safety.

Table 1
Water Consumption in Plumbing Products

Product Description	Average Water Consumption 1980's	1990's
Water Closet	3.5 gpf	1.6 gpf
Urinal	2.0 gpf	1.0-1.5 gpf
Showerheads	3.0 gpm	2.5 gpm
Lavatory faucet	3.0 gpm	2.0-2.5 gpm
Sink faucet	3.0 gpm	2.5 gpm

gpf = gallons per flush
gpm = gallons per minute

LOW CONSUMPTION PLUMBING PRODUCTS: AN APPROACH TO STANDARDIZATION

To quote the classics: "These are the best of times, these are the worst of times." No better assessment can be made of the water crisis in our nation. These are the best of times with personal and professional growth in our nation, but the worst of times with respect to energy and water use by the American consumer and business. But we can make today the turning point in our future with a dedication to conservation and wise water management.

Ever since plumbing has been "brought indoors" water has been used as an expendable commodity, with little attention or care from the average citizen as to its proper use. Water closets are frequently used as waste baskets; urinals as glorified ashtrays; showers as tropical waterfalls, and faucets as "musical accompaniment" while shaving or brushing our teeth.

Water conservation must take two approaches in order to be effective. First, there must be an active, conscious effort by the consumer to save water. This effort requires little pain to the lifestyle, but will achieve great measure in accomplishing the goal of saving water for future generations.

The second approach, that of passive conservation, is best achieved with the design, installation and maintenance of low consumption plumbing products.

Plumbing products within the building have undergone major "surgery" in the last ten years. We have witnessed firsthand the legislative demand for more water conserving products. Maximum consumption values, as dictated by law, were once seen as an encroachment on the manufacturing agenda. However, extensive effort is now being applied to maximize product efficiency with minimal water use. See Table 1 for an example of this change which incidently, has occurred, for the most part, in the past three years. Table 1 reflects the typical proposed values of legislation for the future. These numbers may vary slightly from state to state.

For these numbers to be truly requisite beneficial however, product performance must be an integral of the regulatory demand. It is one thing to legislate a maximum water consumption requirement for a series of products, but it is of equal or greater importance to demand product performance with water conservation. What good is conservation when products perform so poorly that the consumer attempts to modify the product's design to be more satisfied with its performance?

This is the critical goal of product standardization. A coalition of consumers, producers, and general interest members voluntarily participate to establish minimum performance standards for plumbing products such as those products identified in Table 1. This coalition is dedicated to the purpose of establishment of criteria to demonstrate a products "ability" to operate properly; and to withstand pressure and temperature extremes, chemical exposure, physical abuse and other "assaults" during its normal working life.

In addition to the performance tests, standards for plumbing products also include requirements for packaging and labeling so that water consumption values may be readily and quickly identified.

A close scrutiny of the plumbing fixture and fixture fitting standards as published by the American Society of Mechanical Engineers (and ratified by the American National Standards Institute) gives us some insight into the importance of performance tests for plumbing products.

Water Closets

It should first be noted that the water consumption analysis of this fixture is only one of many tests which the water closet must pass. Let's look at the test criteria for these fixtures:

(a) Ball test - 100 3/4" polypropylene balls are placed in the bowl. The density of the balls cause them to sink into the well. At least 75 balls must clear the bowl with the initial flush. (The ASME A112.19.2 and .6 Working Groups are examining the possibility of increasing this minimum performance requirement to higher levels for public use fixtures.) This media has proven to be a very effective material for demonstrating bowl performance with a simulated waste load.

(b) Granule test - 2500 polyethene granules are placed in the bowl. After flushing once not more than 125 pellets may remain in the bowl. The granules both sink and float, thereby simulating typical waste characteristics.

(c) Dye test - blue dye is added to the bowl and representative samples are diluted in various concentrations. The dilution ratio after a single flush must be at least 100 to 1. It is very important for the bowl to exchange the water after each flush and this test reflects that evaluation.

(d) Ink line test - an ink line is scribed on the dry bowl surface below the flushing rim. After a single flush, no more than a 2" line (total length) can remain and no line segment can exceed 1/2".

ITEM 7.

Appendix 2.

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'The Use of Financial Incentives to Encourage Implementation of Water Conservation Programs', M. D. Moynahan, E. J, Thornhill, R. W. Brown, pp 355-359, Conserv 90, The National Conference and Exposition Offering Water Supply Solutions for the 1990's, Arizona, August 1990

THE USE OF FINANCIAL INCENTIVES TO ENCOURAGE IMPLEMENTATION OF WATER CONSERVATION PROGRAMS

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Los Angeles, California

Metropolitan Water District of Southern California (Metropolitan) imports water for use in Southern California and provides about one-half of the supplies used in the region. Metropolitan was created in 1928 by a vote of the citizens of the region to finance, construct, and operate the Colorado River Aqueduct. Metropolitan is also the largest customer of the State Water Project, which conveys surface water over more than 400 miles to meet water demands of residents, businesses, and farms throughout the State.

Metropolitan is a public agency and supplies water directly to 27 member agencies, including 14 cities, 12 municipal water districts, and one county water authority. These member agencies, in turn, provide water to over 300 cities.

In Metropolitan's service are for each of the last several years, natural population growth and net in-migration added roughly 400,000 new residents annually. This represents an increase in water demands during each year that exceeds the total water demands of cities the size of Miami, Cincinnati, Pittsburgh, or St. Louis. Growth in water demands, of course, is not limited to urban Southern California. Population in Northern California and the Central Valley continues to grow at

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a rapid rate, the economic growth in those regions is accompanied by increasing water demands. Significant amounts of water are also being demanded in efforts to preserve the environment and support freshwater recreation and tourism activities.

Against this backdrop of intensifying competition for water resources, the reliable water supplies available to Southern California have dwindled. Metropolitan lost over one-half of its reliable Colorado River supply as a result of the 1963 Arizona vs. California decision by the United States Supreme Court. The California State Water Project (SWP), designed in part to offset this loss, remains incomplete. The City of Los Angeles will lose a significant portion of its annual water supply through court action intended to preserve the Mono Lake environment. The local groundwater resources, historically the backbone of regional water supplies, are now threatened because of varying degrees of groundwater contamination.

Metropolitan's projections show that given the conditions as described above, the Southern California region will be experiencing a water shortage of 500,000 acre-feet per year by the year 2000, and over 1,000,000 acre-feet per year by 2010.

The two principal ways Metropolitan can offset these projected shortfalls is through demand reduction or conservation programs, and supply augmentation programs. This paper describes a key water demand reduction program that Metropolitan is using to encourage water conservation.

In many cases, the benefits of conservation on the local level are not sufficient to offset total project costs, which would include direct program costs such as new staffing and hardware, as well as administrative overhead, loss of revenue by retail water purveyors, and other factors.

Recognizing this in September 1988, Metropolitan established the Conservation Credits Program (Credits Program) which uses economic incentives to encourage the development of water conservation projects by its member agencies and other water retailers in Southern California. Under the Credits Program, Metropolitan will pay a "conservation credit" to participating agencies that adopt conservation programs with verifiable water savings. Currently, Metropolitan will pay the lessor of one-half the cost of a project or an amount per acre-foot (AF) of imported water saved based on the avoided cost of SWP aqueduct pumping subject to a minimum of $75 per AF. The avoided cost of pumping in the SWP aqueduct is currently at the rate of $106/AF.

Metropolitan intends to encourage a variety of water conservation practices with the Credits Program. For example, a joint effort with the City of Pasadena will result in the retrofit of residential bathroom devices, replacing high-flow showerheads with low-flow showerheads and installing toilet dams to reduce water usage in the bathroom, where 65 percent of residential indoor use occurs. Similar programs have been approved for the cities of Los Angeles and San Diego.

A $2.4 million project was recently undertaken jointly with the City of Santa Monica to replace existing toilets, which may use between 3.5 and 7 gallons per flush, with new technology ultra-low-flush toilets, which require only 1.6 gallons per flush. Participating households in Santa Monica will receive a $100 rebate for each bathroom retrofitted. Nonparticipating households will pay a Conservation Incentive Fee of $1.00 per single-family bathroom and $0.65 per multi-family bathroom per month to help finance the program.

Other proposals under the Credits Program would reduce water use by large-scale turf irrigation systems, implement major leak detection and repair programs, conduct residential and commercial water audits to teach water savings techniques, and develop other conservation approaches.

Projects are selected using the following criteria:

1. Anticipated Effectiveness
   A key criteria is the anticipated effectiveness of the proposed program. For example, a measure with a hardware change will, in general, be more effective than one which requires a behavioral change.

2. Verifiable Results
   The results in water savings must be verifiable. In order to encourage the implementation of projects, Metropolitan will use reasonable estimates of potential water savings. The final verification of results will be Metropolitan's responsibility with close cooperation from the participating agency.

3. Economics
   The economics of the project must be sound for both the region as a whole and for Metropolitan. Each project is subject to an economic analysis just like other Metropolitan water supply augmentation programs.

4. Financial Need
   A member agency or sub-agency must show that Metropolitan's participation is needed in order for the program to be financially feasible.

5. Innovation

Metropolitan is looking for innovative water conservation measures and encourages the implementation of new ideas.

As shown in Table 1, Metropolitan to date is participating in eight Credits Programs with total project costs of $8.2 million and Metropolitan's share $3 million.

Reduced demands through water conservation has become an increasingly important component of long-range planning in Metropolitan. Due to limited reliable data, estimates of the effectiveness for conservation vary widely and as a consequence are subject to considerable uncertainty. In order to determine the effectiveness of each type of water conservation measure, Metropolitan is conducting comprehensive independent evaluations for each of the eight projects now in various stages of completion. Results of these studies are expected to be available within the next twelve to eighteen months.

The Credits Program is the cornerstone of Metropolitan's conservation activities. Through the use of financial incentives, Metropolitan aspires to maximize the potential for water savings.

APPROVED CONSERVATION CREDITS PROGRAMS — TABLE 1

AGENCY	TYPE OF PROGRAM	ESTIMATED WATER SAVINGS (AF)		TOTAL PROJECT COST	MWD CREDITS	CONSULTING COST
		Annual	Total	$$$	$$$	$$$
Pasadena	Residential In/Outdoor Survey	450	2,250	272,000	33,900 (12.5)	19,000
Irvine Ranch Water District	Residential Retrofit/Survey	135	675	270,000	135,000 (50%)	120,000
Pasadena	Residential Kit Retrofit	1,000	5,000	802,000	375,000 (46.8%)	100,000
Santa Monica	Toilet/Retrofit	935	7,900	2,362,000	600,000 (25.0%)	110,000
San Diego	Residential Kit Retrofit	1,400	7,000	1,075,000	525,000 (43.6%)	74,000
San Diego CWA	Large Turf Audit	1,000	5,000	285,000	142,500 (50%)	60,000
Los Angeles	Toilet/Retrofit	250	2,500	900,000	185,250 (21%)	50,000
Los Angeles	Residential Kit Retrofit	2560	12,800	2,200,000	1,100,000 (50%)	140,000
	TOTAL COST	7730	43,125	8,166,000	3,096,650	673,000

ITEM 8.

Appendix 2.

Item 8, Appendix 2.

'Close Coupled Washdown w.c. Design, the Case For a 6 Litre Flush Volume', J. A. Swaffield, R. H. M. Wakelin, Drainage Research Group, Dept of Building Technology, Brunel University, U.K., 1982.

CLOSE COUPLED WASHDOWN W.C. DESIGN. THE CASE FOR A SIX LITRE FLUSH VOLUME.

by

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Close coupled washdown W.C. design, the case for a six litre flush volume.

by

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SUMMARY

The case for reduced flush volume operation of w.c.'s is presented in the context of national water usage. The parameters governing efficient close coupled washdown w.c. operation at reduced flush volumes are identified. Six litres is shown to be a realistic minimum flush volume, within the limitations of cistern and siphon operation. Modifications to the design of trap shape and trap volume of close coupled washdown w.c.'s are shown to be capable of providing satisfactory w.c. performance at a 6.0 litre flush volume.

February, 1982.

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List of Figures and Tables:

1. The need for water conservation w.c. design

Water conservation may seem to have little justification if it is viewed as an isolated design objective. However, it is necessary to consider the effects of water conservation in the wider economic context. Whilst some water uses, such as industrial processes or agriculture, incur little expenditure in treatment either on supply or disposal, this is not the case for domestic usage, where both water treatment and sewage disposal costs have to be met. Additionally, the upward trends in life style expectations and improvements in sanitary conditions inevitably lead to increasing demands for domestic quality water supply, these demands in turn leading to increased capital expenditure on supply and disposal systems.

Against these economic considerations, water conservation may be seen as both a viable and worthwhile design exercise. Walker (1) outlined the major problems facing the water supply industry and identified water wastage through leakage, or apparent wastage through faulty recordings, as accounting for some 20% of daily national consumption. Obviously detailed design of appliances and processes to reduce water usage cannot readily be seen to compete with this figure, however the water authorities are currently engaged in efforts to reduce the unaccounted loss figures and the situation may be expected to improve (1), so that a detailed study of water usage, such as that presented by Webster (2), remains helpful.

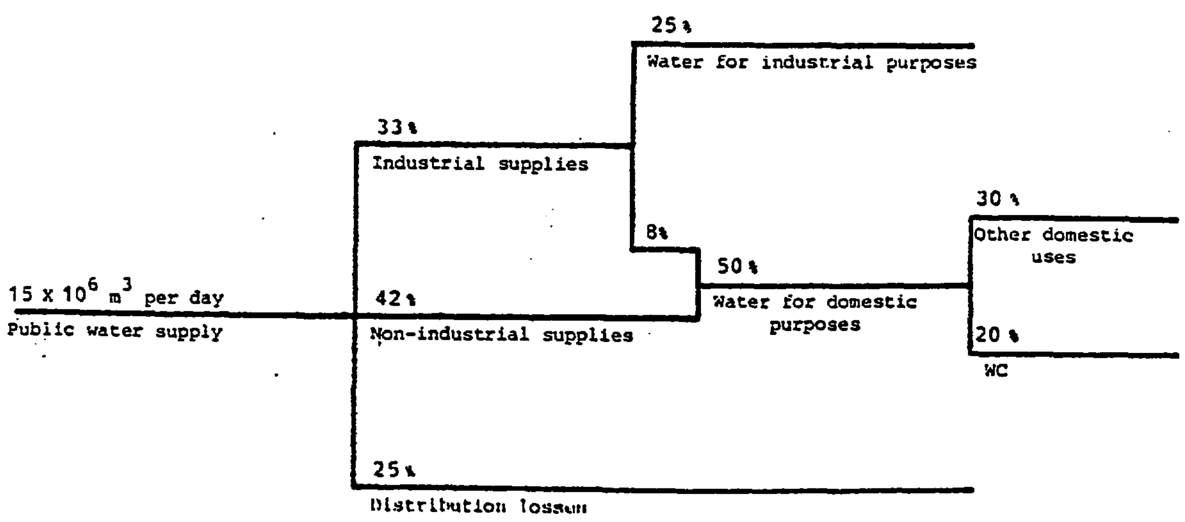

Figure 1. Estimated use of public water supply {after Webster (2)}.

Webster's estimated use of public water supply, including a 25% distribution loss, presented in Figure 1, shows that of the national usage of water, 20% is utilised for w.c. flushing. A trivial calculation based on a reduction from 9 litres per flush to 6 litres per flush for each w.c. indicates a possible saving of approximately 7%, or 1×10^6 m^3 per day. However, this conclusion is totally dependant on the ability of either existing or new w.c. designs to provide a satisfactory performance at the reduced volume of flush. Naturally, unsatisfactory performance, leading to repeated flushes, is totally counterproductive as it would inevitably lead to increased usage. It is therefore imperative that a detailed assessment of w.c. performance at low flush volumes be undertaken prior to introducing the appropriate legislation.

Preliminary work in this area, reported by Swaffield and Marriott (3) in 1978, indicated a relationship between flush volume and trap volume. However, this work was limited in that it was a totally university based project with no industrial involvement in modelling, the results being based on two available washdown pans. However, this work led to close contacts between Brunel and the industry through CBCSM and to a joint 3 year research programme dedicated to an investigation of the w.c. design parameters governing successful performance at reduced flush volumes.

The research programme, carried out by the Drainage Research Group at Brunel University was intended primarily to investigate the possibility of reduced flush volume operation for close coupled washdown w.c. designs. The project was undertaken in a number of phases, as outlined below, however the research programme was organic in that its course responded to both the research findings and to detailed discussions between CBCSM and the Brunel team. Overall, the programme may be seen as having been comprised of the following phases:

(i) Development of improved quantitative test methods to measure the performance of close coupled washdown w.c.'s at reduced flush volumes.

(ii) Determination of the acceptability or otherwise of the use of reduced flush volumes with existing close coupled washdown w.c. designs.

(iii) Systematic study of the effect of design parameters, such as seal depth, water surface area, trap volume, trap passage dimensions, etc.

(iv) Synthesis of the results of the research into a modified close coupled washdown w.c. design that would be based on an existing w.c. and subjected to both laboratory and installed site testing.

The main results of this research programme and the basis for the decisions taken during the programme are presented in this report.

2. Quantitative tests developed to study w.c. performance

The first phase in the programme was the development of quantitative tests capable of discriminating between the effects of the various w.c. design parameters. These tests in themselves represent a new approach to the subject area, as previously the majority of tests methods available were qualitative, or of the "go - no go" variety. While these tests were primarily developed for the close coupled washdown w.c. test programme, they have a significantly wider application.

In order to obtain a better understanding of the mechanism of w.c. operation, and the importance of individual design parameters, it was necessary to vary the applied flush volume beyond the limits of either legislation or design desirability.

The developed tests are set out below:

(i) Flow Rate

This test involves the measurement of time dependant water flow rate out of the cistern, and both into the w.c. bowl, and subsequently out of the bowl, by monitoring the depth changes in the cistern and a w.c. discharge collection tank with pressure transducers. Flush volumes of 9.0, 7.5, 6.0 and 4.5 litres were used, an average of 10 flushes being taken. The volume build-up rate within the w.c. bowl was also monitored by a float driven linear displacement transducer.

(ii) British Standard Ball

The 43mm diameter, 1.07-1.08 specific gravity British Standard (w.c.) Ball was introduced into the w.c. bowl. Using flush volumes of 9.0, 7.5, 6.0 and 4.5 litres, the volume of water ahead of the ball as it was discharged from the w.c., and both the volume and waterhead in the w.c. bowl above seal water level on ball discharge, were measured. A mean value of twenty flushes was taken for each flush volume.

(iii) Single Density Multiple Ball

In this test fifty 20mm diameter plastic spherical balls of known specific gravity were placed in the w.c. pan. Using flush volumes of 9.0, 7.5, 6.0 and 4.5 litres, the number of balls discharged from the w.c. was noted. Nine sets of different specific gravity balls (0.236-1.235) were used for each of the flush volumes, results being averaged over 10 flushes.

(iv) Multiple ball test utilising French Ball specific gravity

Unlike the multiple ball test, the French Ball (S.G. = 0.84) test was carried out using 30 balls - efficiency again being defined by a ratio of the discharged number of balls to the total number for ten flushes.

(v) The Powder (Sawdust) Test

The internal surface area of the w.c. bowl between the lower edge of the rim and water seal surface were treated with sawdust, and the ability of the water to reach or clean all parts of the bowl was then estimated.

(vi) Concentration

In this test, a known concentration and quantity of potassium permanganate solution was added to the seal water - ensuring a thorough mix and maintenance of usual seal water level. Using flush volumes of 9.0, 7.5, 6.0 and 4.5 litres, a sample of the seal water was taken before and after each flush for colorimetric/concentration analysis, results being averaged over five flushes.

(vii) Rim Resistance

This test involved varying the flow of water into the w.c. bowl from 10 litres/minute to 200 litres/minute (0.17-3.3 litres/sec.). This enabled the rim plus inlet resistance to be measured by the change in supply back pressure reading as the flow rate was varied.

(viii) The Paper Test

Four different grades of paper were used in this test:

(i) 'Hard' plain, single Izal sheets of size 125mm x 125mm, 50.3 secs absorbency and 4.2 grams/12 sheets

(ii) 'Hard' rolled, single Izal sheets of size 115mm x 136mm, 53.9 secs absorbency and 4.2 grams/12 sheets

(iii) Winfield 'soft' ply double tissue of size 125mm x 125mm, 50.8 secs absorbency and 6.5 grams/12 double ply sheets

(iv) Andrex 2 'soft' ply luxury tissue of size 139mm x 112mm, 12.3 secs absorbency and 6.4 grams/12 double ply sheets

For each flush, 12 separate sheets of paper were loosely crumpled and placed individually into the w.c. pan and flushed within 20 seconds of the start of the operation. Flush volumes of 9.0, 7.5, 6.0 and 4.5 litres were used and the operation was carried out five times for each flush volume.

(ix) Sponge Test

Ten 63mm x 19mm x 19mm synthetic sponges with all the air removed were placed into the w.c. pan and flushed.

3. Suitability of existing close coupled washdown w.c. designs for reduced flush volume operation

Detailed reporting of the test results would be inappropriate and therefore only sample results are presented in Figures 2 to 4. However, some trends revealed by the test programme may be clearly identified.

(i) as expected there was a deterioration in performance in all the tests as the flush volumes were reduced from 9 litres.

(ii) high cistern discharge rates, even at reduced flush volume, resulted in improved multiple ball discharge efficiency, at all multiple ball specific gravities. This was due to the increased momentum transfer to the solids in the w.c. bowl.

(iii) high cistern discharge rates did not improve the residual concentration test results, designed to simulate urine removal, due to the increased mixing in the bowl caused by the higher kinetic energy of the cistern discharge.

(iv) a marked deterioration, of the order of 2 to 4 times, in residual concentration was noticeable between 6.0 litres and 4.5 litres total flush volumes.

(v) trap seal volume was seen to correlate with improved performance, i.e. reducing trap volume improved the multiple ball and residual concentration results.

(vi) surface cleaning, within the limits of the sawdust test, was not found to be a problem.

(vii) paper removal below 6 litres total flush volume was considered to present difficulties with the existing designs of close coupled washdown w.c. tested.

Based on the results obtained in this initial phase of the research, it was decided to continue with a systematic appraisal of the effects of individual trap design parameters on close coupled washdown w.c. performance, with the aim of producing a close coupled washdown w.c. design capable of improved, or at least comparable performance at reduced flush volume relative to existing close coupled washdown w.c.'s at 9.0 litre flush volumes.

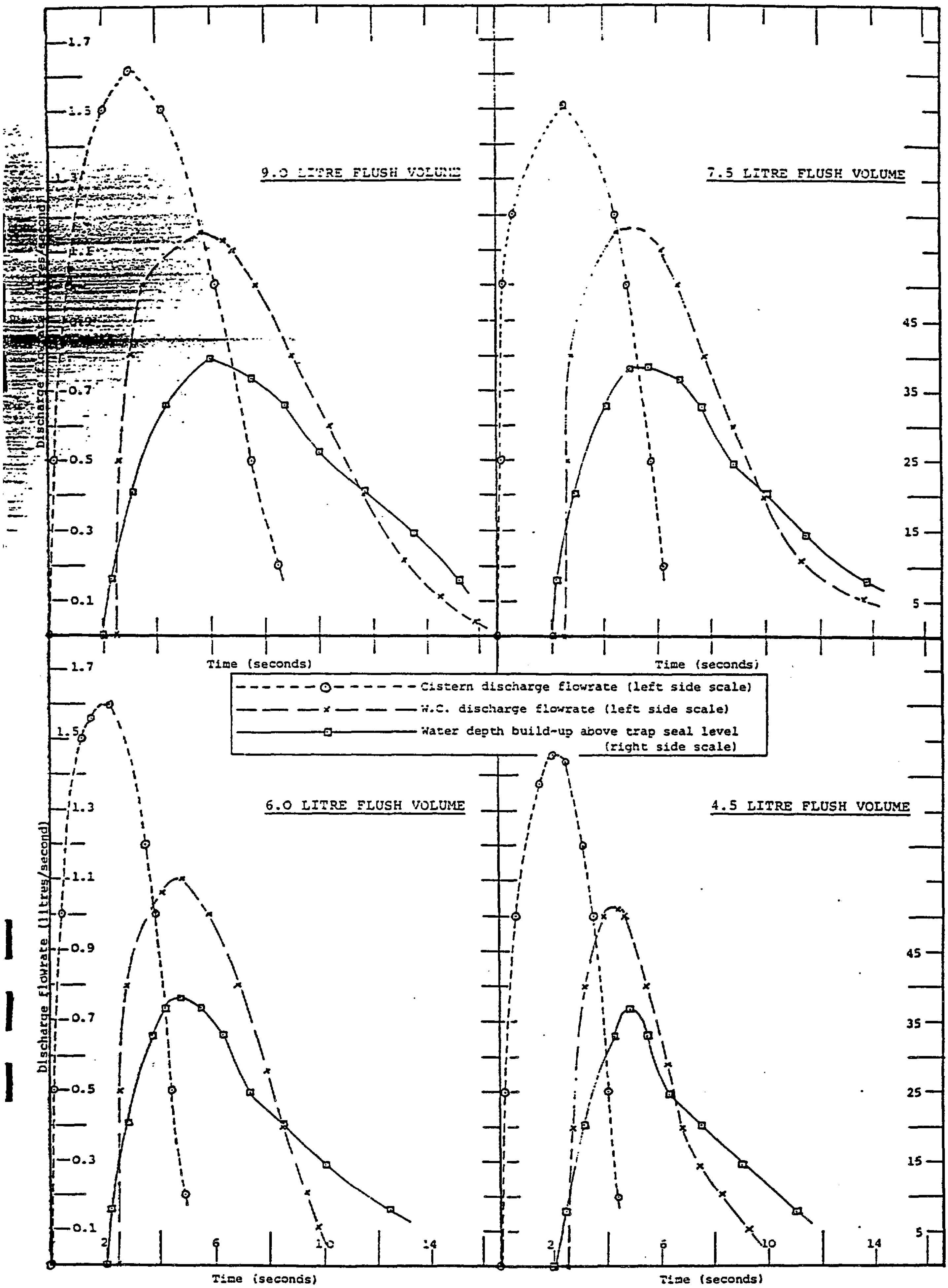

Figure 2. Sample results of cistern discharge flowrate, W.C. discharge flowrate

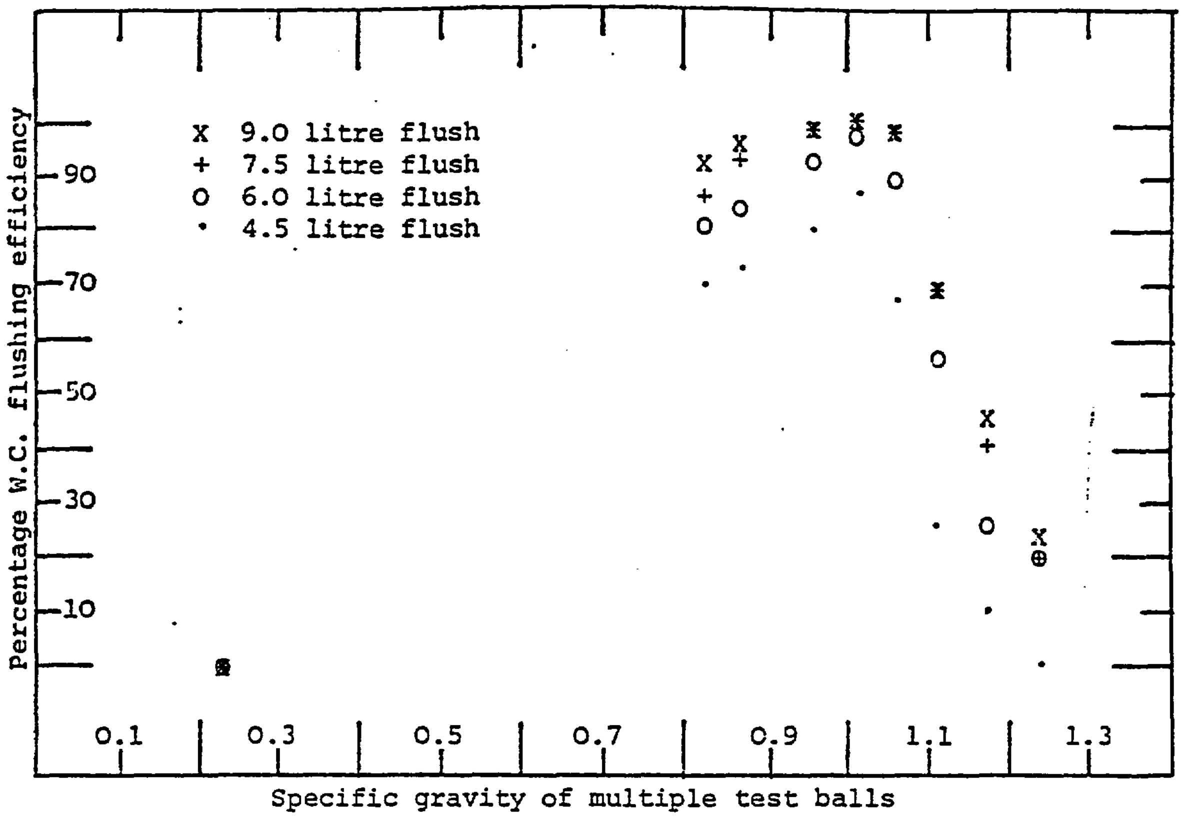

Figure 3. Sample results of W.C. flushing efficiency plotted against specific gravity of multiple test balls for flush volumes of 9.0, 7.5, 6.0 and 4.5 litres.

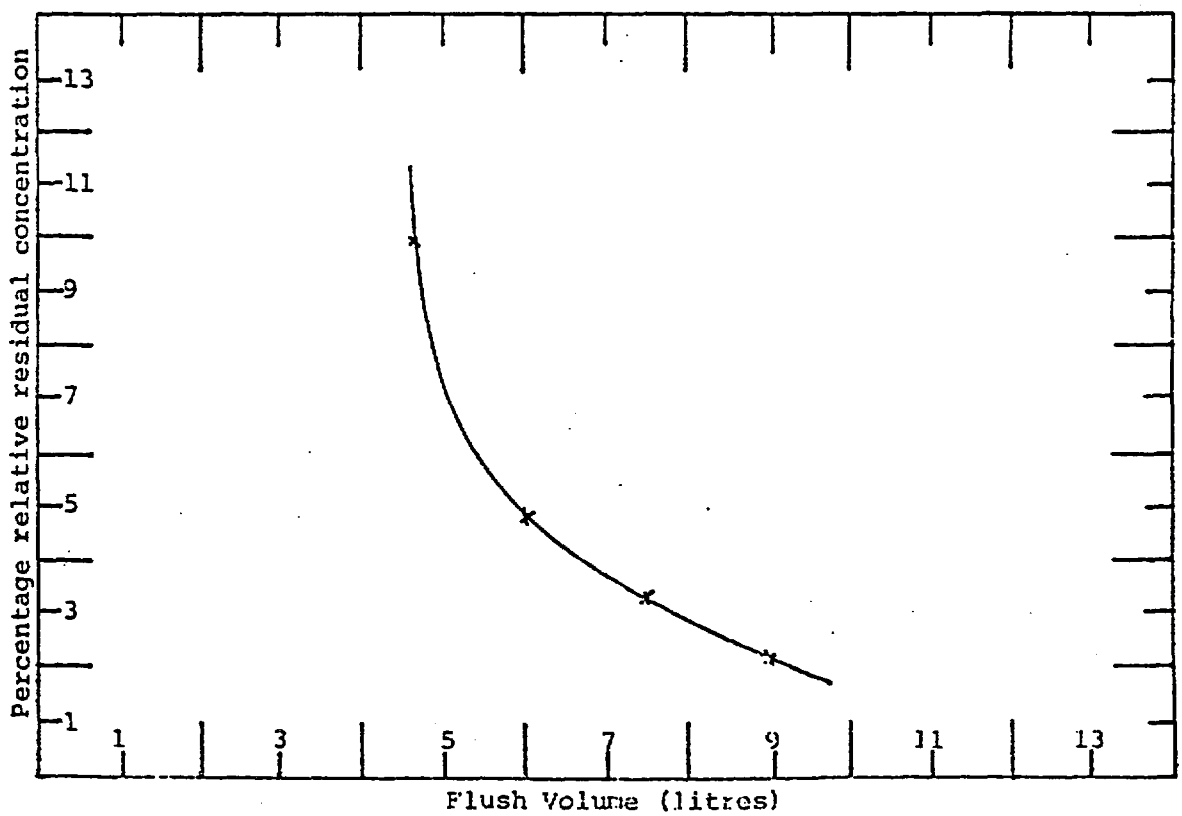

Figure 4. Sample reults of percentage residual concentration plotted against flush volume.

4. Influence of individual design parameters on close coupled washdown w.c. performance

Figure 5 illustrates, in a schematic fashion, the hydraulic and legislative constraints within which close coupled washdown w.c. design may be undertaken. In order to establish the influence of the individual parameters indicated on the final performance, it was necessary to both cross the barriers represented by these constraints and to overcome the limitation imposed on inflow rates by siphon operation with a mechanical pumped inflow system capable of maximum flowrate and duration control. Figure 6 illustrates the facility designed for this purpose. The full range of quantitative tests described previously were utilised with this test installation and systematic w.c. parameter changes were achieved for trap seal depth, trap volume, and discharge passage dimensions.

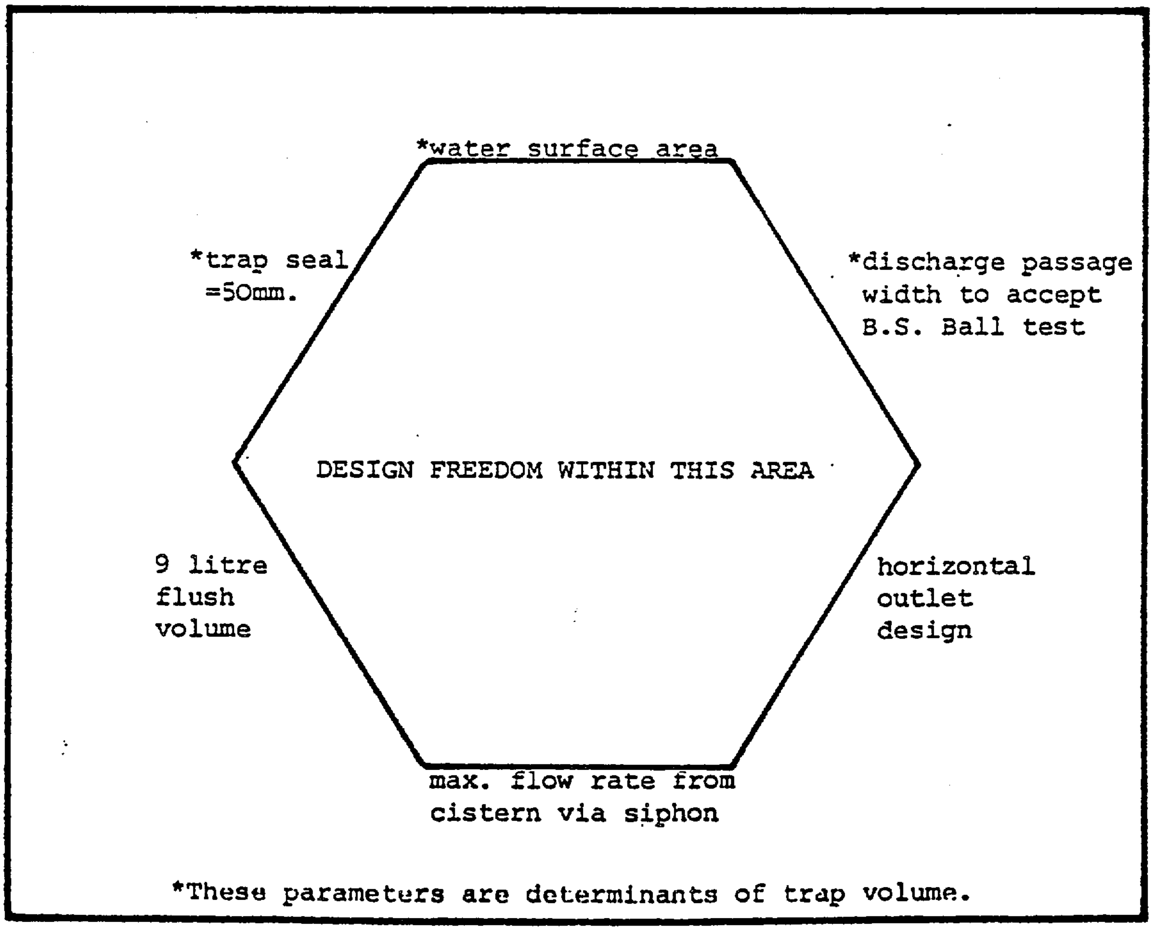

Figure 5. Schematic representation of the hydraulic and legislative constraints defining close coupled washdown W.C. design.

The horizontal outlet design was retained in all tests as the research was confined to a consideration of the hydraulic design of the appliance without imposing criteria onto the aesthetic freedom of the designer.

Similarly, the initial testing of available close coupled washdown w.c.'s had shown that the area of design displaying the maximum potential for improvement was the trap volume and passage shapes below the water line. For this reason no work was undertaken on rim or cistern and siphon design, however this area remains as a possible future topic.

An existing close coupled washdown w.c. with an initially large trap volume was chosen as the basis for the tests. The back plate, Figure 7, was removed prior to firing and replaced by a perspex plate so that trap seal depth could be varied. Similarly, the effect of reducing total trap volume, by restricting the water surface area and passage dimensions was studied by rebuilding the internal shape of the trap with surface coated plaster of paris.

The series of tests undertaken with the modified w.c. trap and water seal dimensions highlighted a number of conclusions:

(i) the flow rate to the w.c. bowl should be in the range 1.5 ℓ/s to 2.5 ℓ/s, however no advantage was measurable above this range.

(ii) the discharge rate from the w.c., which is a function of the resistance of the trap passages, should be above 1.0 ℓ/s.

(iii) reducing trap volume is undoubtedly the key consideration in improving the hydraulic efficiency of close coupled washdown w.c.'s without impairing aesthetic design freedom.

(iv) the tests, which included trap seal values less than 50mm and a range of passage dimensions, indicated that a relationship existed linking both residual concentration efficiency and multiple ball discharge efficiency to the design parameters of trap volume, total flush volume. seal depth and maximum seal passage dimension. In both cases an expression of the form

$$\eta = \phi \left[\frac{\text{Seal volume}}{\text{Flush volume}} \times \frac{\text{Seal depth}}{\text{Seal passage}} \right]$$

was developed.

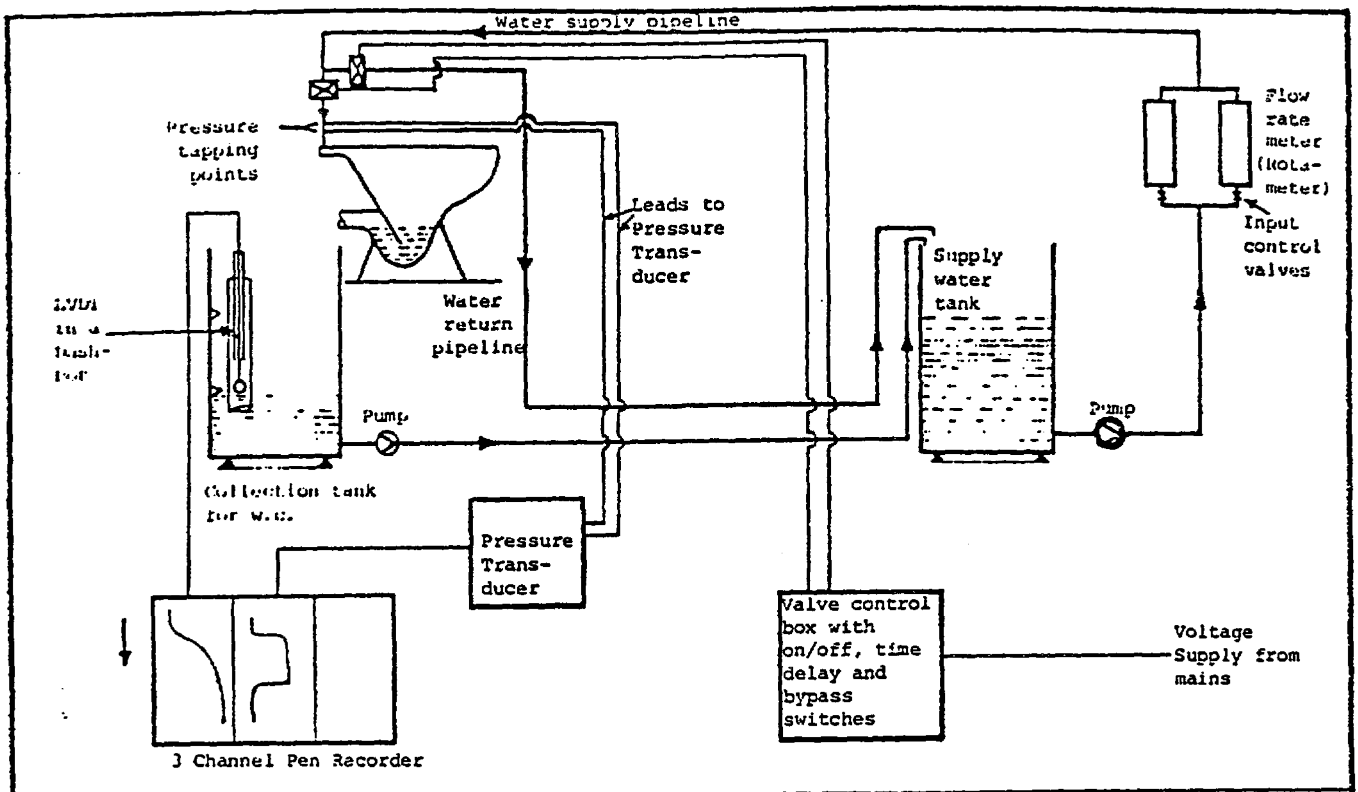

Figure 6. Schematic (NTS) layout of the mechanical equivalent cistern instrumentation.

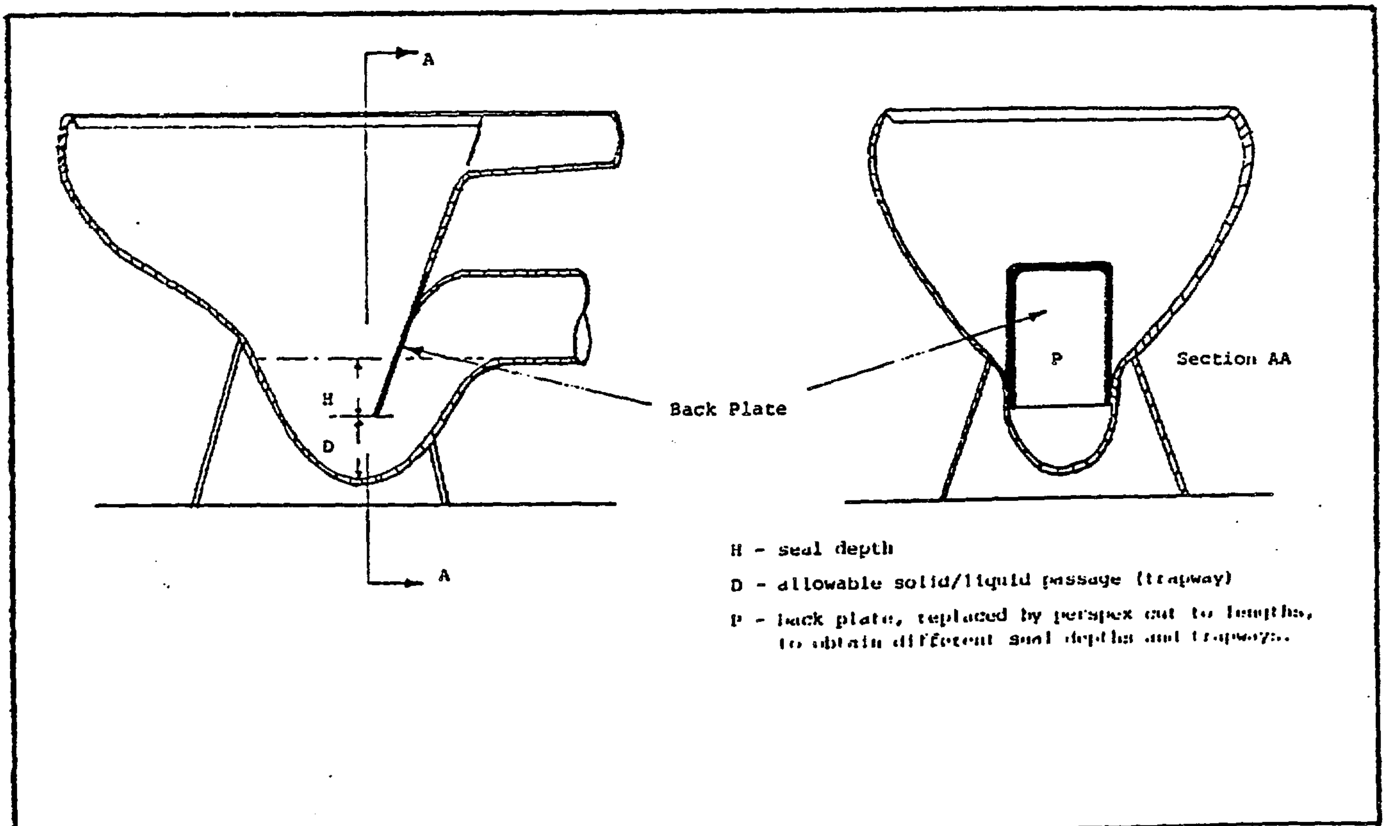

Figure 7. Schematic (NTS) of experimental W.C. with back plate removed and showing the (usual) seal depth and maximum or allowable seal passage (D).

In parallel with the controlled inflow tests, siphon operated cistern results were also obtained at each trap volume and seal depth modification stage. These results are shown in Figures 8 and 9 and confirm the form of the relationship developed with the mechanically controlled flow facility.

Following discussion of the practicality of the reduced trap volume w.c. design for limited production, three models were produced, namely Mk I, II and III. The Mk I close coupled w.c., based on an existing design, failed at the firing stage and the mould was corrected to form the Mk II. The Mk III was a similar reduced trap volume, close coupled, washdown w.c. based on another manufacturer's existing model. Both Mk II and Mk III models complied with the 50mm trap seal depth requirement, Figure 7, however while the trap passage was adequate to allow the B.S. ball test to be complied with, geometry inevitably dictated that the water surface areas of both models were less than those recommended at present.

5. Laboratory and site testing of trap volume modified close coupled washdown w.c.'s

Table 1 compares the performance test results for the Mk II and III w.c.'s and their respective parent w.c.'s. The trap modifications were sufficient to yield comparable, and often improved, laboratory results at a 6.0 litre flush volume relative to a 9.0 litre flush volume for the parent w.c. While the performance tests have concentrated on the efficiency of w.c. evacuation, transport of solids in the downstream drainage system is also important. Considerable work at Brunel has been devoted to developing suitable test criteria for solid transport, (4), much of it supported by the Association of Sanitary Protection Manufacturers. Both the Mk II and Mk III w.c.'s at 6.0 litre flush volumes were found to provide satisfactory transport capability to a range of sanitary products, of saturated mass in the range 60 to 200 gms. It was concluded therefore, that the transport performance exhibited by the modified w.c.'s at a 6.0 litre flush volume were satisfactory.

Site testing was undertaken at Brunel, where the Mk II and III modified close coupled washdown w.c.'s were installed in toilet facilities serving the library, administration offices, student accommodation, academic staff offices and lecture theatres. Monitoring of the site testing was undertaken by a variety of methods including:

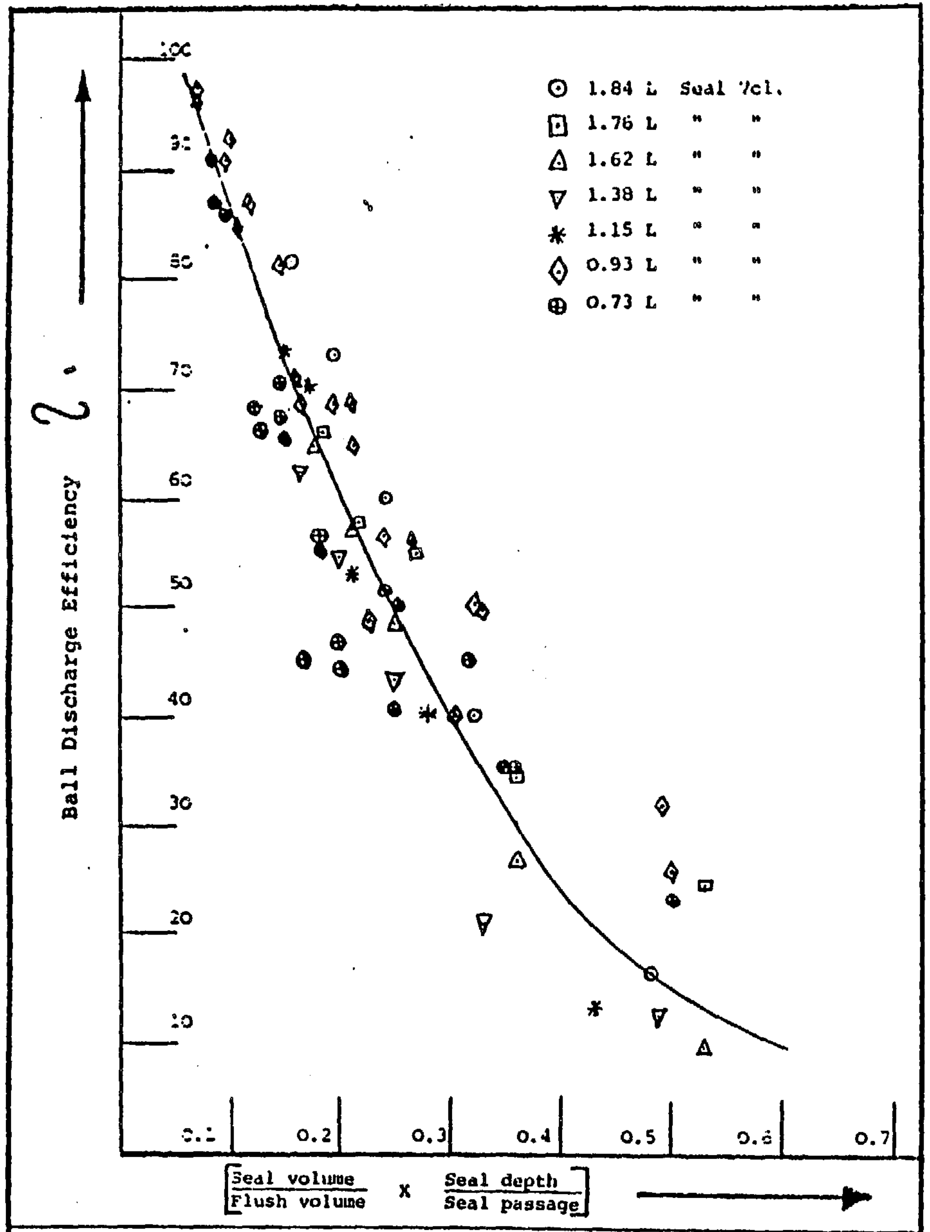

Figure 8. Graph of Ball (SG=0.867) Discharge Efficiency plotted against the dimensionless grouping representing the trap design parameters.

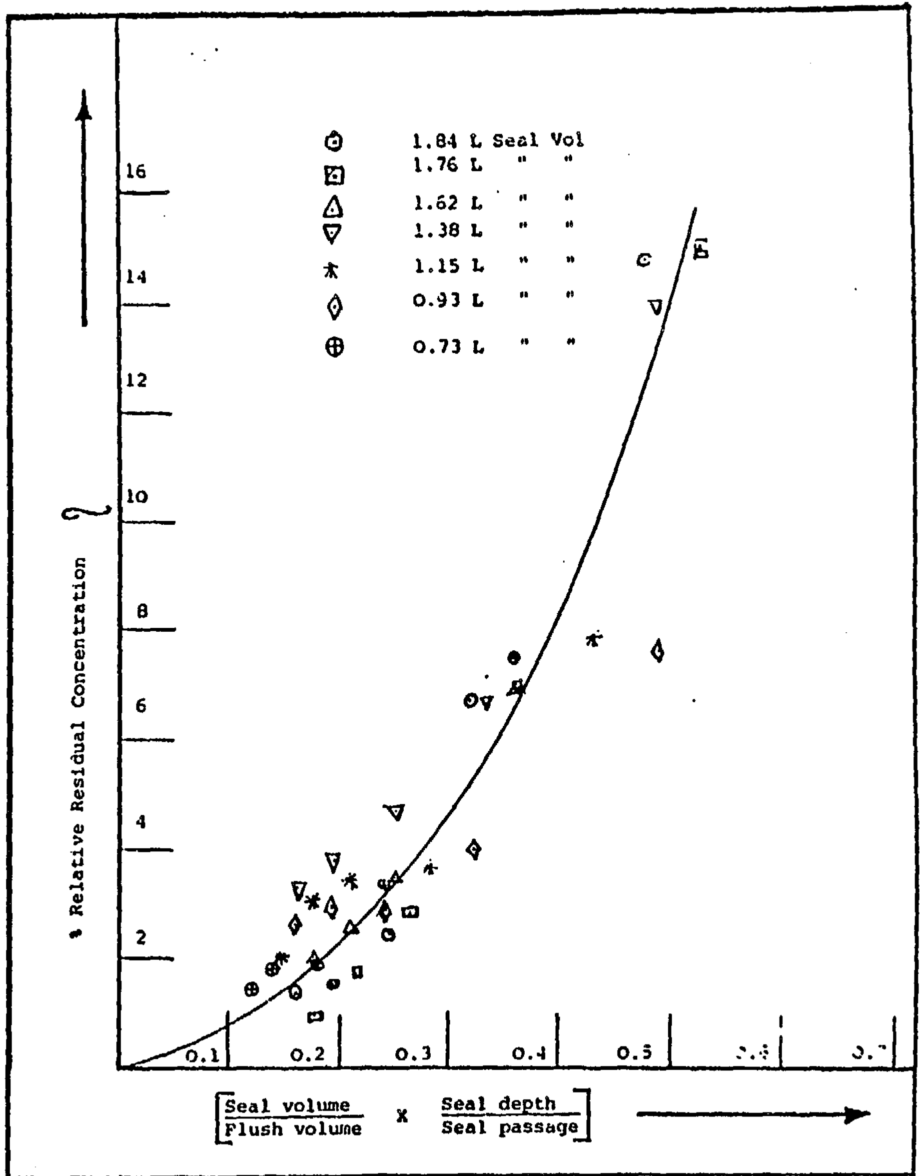

Figure 9. Graph of Percentage Relative Residual Concentration plotted against the dimensionless grouping representing the trap design parameters.

TEST	Mk II		Mk III	
	Parent W.C. at 9.0 litres	Modified W.C. at 6.0 litres	Parent W.C. at 9.0 litres	Modified W.C. at 6.0 litres
B.S. Ball (43mm diameter)	Pass	Pass	Pass	Pass
B.S. Paper (Andrex double ply tissue)	Pass	Pass	Pass	Pass
B.S. Sawdust	Pass	Pass	Pass	Pass
Multiple ball 0.867 specific gravity	81.2%	83%	95.4%	91%
Multiple ball 1.17 specific gravity	100%	100%	45.8%	100%
Residual concentration (potassium permanganate)	1.44%	1.32%	2.24%	1.97%
DESIGN PARAMETERS				
Outlet	horizontal	horizontal	horizontal	horizontal
Trap seal depth	50mm	50mm	50mm	50mm
Trap sump volume	1.90 litres	1.17 litres	2.05 litres	1.31 litres
Trap passage dimension		64mm		60mm
Water surface		83 X 146 mm		100 X 130 mm

Table 1. Comparison of Mk II and Mk III modified close coupled washdown W.C.'s to their respective parent models.

(i) Daily checks on pan surface fouling, or paper or solids left in the pan after flushing.

(ii) Weekly checks of manholes along the drains serving the modified w.c.'s.

(iii) Weekly checks of cleaning and drain maintenance records.

(iv) Total flush volume for each w.c. was calibrated and set to the desired 6.0 litre level in each installation. Counters both in the w.c. cistern, and concealed in the cubicle doors allowed the number of flushes per user as well as the total water volume used to be recorded.

(v) A questionnaire designed to determine user acceptance was devised and completed by a wide range of users, including students, staff, visitors, etc., in an interview type situation.

The results of these tests were that the modified w.c.'s caused no adverse user reaction, the number of flushes per user was recorded as close enough to unity to indicate no user tendency to consistently re-flush, the study of cleaning and drain maintenance reports indicated no problems of pan fouling or drain deposition.

The overall impression of the site tests therefore must be that the modified low trap volume close coupled washdown w.c. operated satisfactorily in a wide spectrum of user applications.

6. Conclusion

The need to conserve water may be supported both on design and economic grounds. The work reported was specifically designed to highlight those parameters in the design of a close coupled washdown w.c. that could most readily be modified to yield satisfactory w.c. performance at reduced flush volumes. Through close collaboration, good relations and many discussions between the Brunel Drainage Research Group and CBCSM, it was possible to arrive at design solutions that achieved the hydraulic improvements necessary without impairing the designer's aesthetic freedom.

In particular, the work has shown that trap volume modification may be utilised to achieve satisfactory close coupled washdown w.c. performance at a 6.0 litre flush volume without modification to existing rim, cistern or siphon designs. This volume also corresponds, from the residual concentration tests, to a lower limit as below this volume the residual concentration in the trap water rises significantly.

These conclusions are supported by extensive laboratory testing and by monitoring performance in a wide range of installed site conditions on the Brunel University campus.

7. References

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ITEM 9.

Appendix 2.

Item 9, Appendix 2.

'Assessment of w.c. Performance Using Computer-Based Prediction Techniques', J. A. McDougall, J. A. Swaffield, CIB-W'62 Conferance, Brighton, U.K., 26-29th September, 1994

Assessment of w.c. performance using computer-based prediction techniques.

by

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SUMMARY.

The water flows encountered within a building drainage network as a result of appliance discharge are inherently unsteady, the local flow at any point in the network being dependent upon both the usage pattern of the appliances and the attenuation imposed upon any discharge due to its progress through the network. Such wave attenuation depends upon both the physical parameters of the network, such as pipe slope, diameter, roughness and junction design, and on the form of the actual discharge itself. High amplitude, short duration flows attenuate more rapidly than those featuring longer duration times or more gradual changes in flowrate. The interaction of such discharge profiles on combination at junctions introduces a further time dependent component into any design load calculation. The transport of waste solids within such flows is therefore a complex process, dependent on all the afore mentioned parameters as well as individual solid mass and size.

While the flow conditions within building drainage systems may appear at first sight to be complex, they belong to a well understood category of unsteady flows within the wider field of fluid mechanics. The necessary solution techniques have been available for some time, awaiting the advent of reliable, fast computing. This paper presents an extension to the method of characteristics model of unsteady partially filled pipeflows to allow the transport of waste solids in attenuating and combining appliance discharge flows within complex building drainage networks to be simulated. In particular the simulation addresses the interaction between the appliance discharge profile and the design of the drainage network, thus allowing the suitability of any particular wc design to be evaluated at the system design stage. This process may also be seen as a means of determining the required wc discharge performance to yield a particular solid transport performance in a particular network, and is therefore of direct relevance to appliance manufacturers and drainage system designers. It will be shown that wc performance may be characterised by a single coefficient dependent upon both appliance and network, emphasising the interactive nature of the design problem.

Assessment of w.c. performance using computer-based prediction techniques

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1. INTRODUCTION

1.1 Background

The water flows encountered within a building drainage network as a result of appliance discharge are inherently unsteady, the local flow at any point in the network being dependent upon both the usage pattern of the appliances and the attenuation imposed upon any discharge due to its progress through the network. Such wave attenuation depends upon both the physical parameters of the network, such as pipe slope, diameter, roughness and junction design, and on the form of the actual discharge itself. High amplitude, short duration flows attenuate more rapidly than those featuring longer duration times or more gradual changes in flowrate. The interaction of such discharge profiles on combination at junctions introduces a further time dependent component into any design load calculation. The transport of waste solids within such flows is therefore a complex process, dependent on all the afore mentioned parameters as well as individual solid mass and size.

While the flow conditions within building drainage systems may appear at first sight to be complex, they belong to a well understood category of unsteady flows within the wider field of fluid mechanics. The necessary solution techniques have been available for some time, awaiting the advent of reliable, fast computing. The research required to allow the development of drainage simulation models has been regularly reported to CIBW62 meetings and has been summarised by Swaffield and Galowin (1992). Such simulations allow the local flow conditions in a drainage network to be predicted, dependent upon the usage pattern of the connected appliances, the form of individual appliance discharge profiles and the design of the drainage network. The transport of solids within such attenuating appliance discharge, and as affected by combining flows at junctions, may be simulated providing a suitable model of the relationship between solid velocity and the velocity of the surrounding flow can be established. This paper extends the model introduced by McDougall and Swaffield (1993) and illustrates its application as an aid for both system designers and wc manufacturers.

The design and selection of w.c.s has, to date, been empirical and experience-based. The manufacturer has to rely on laboratory tests to determine the effectiveness of a particular design of w.c., in many cases such tests are merely conformance to standard rather than performance evaluations; while the architect/engineer choosing a w.c. for a particular system installation is limited to making comparisons based on appearance, cost or manufacturer's reputation. Meanwhile, the design of the drainage system to which the w.c. will be connected has historically been based on the Fixture Unit method, which is statistically based, the statistical basis relying on data gathered under steady-flow conditions. No account is taken of the varying nature of the flows found in building drainage systems, nor of the lengths of the pipes to which the w.c.s are to be connected. None of these techniques allow an evaluation of the effectiveness of a particular wc for a particular drainage network operating under set design conditions, such as a requirement to introduce water conservation measures or to meet set maintenance targets.

This paper will illustrate the benefits of a simulation approach to the design of drainage networks and the selection of appliances. As such the simulation techniques presented will be of relevance to both designers and manufacturers and for the first time will introduce the concept of appliance rating to meet a particular set of design requirements.

1.2 Development of the Solid Velocity Model

A computer-based solid velocity model has now been developed, based on laboratory measurements carried out at Heriot-Watt University. The model, which is an addition to the pre-existing simulation designed to predict flow velocities and flow depths throughout a building drainage network, is that reported at the CIB/W62 1993 Seminar (McDougall & Swaffield) as partly complete.

The combined model is capable of predicting flow velocities, flow depths, and solid velocities throughout any building drainage network based on known flow rates, and includes a facility to take account of simulated defects. To allow the model to work in all possible defective system situations, it has been necessary to extend it so that it will work for pipes with positive or negative slope in conjunction with flows in either the positive or negative direction.

At present, the solid velocity part of the model is based specifically on American National Bureau of Standards (NBS) solids 80mm long and 38mm diameter with an S.G. of 1.05, and this is the solid assumed to be used throughout this paper. However, work is now being carried out at Heriot-Watt University to enable the model to be generalised so that it will be capable of predicting velocities for solids of any diameter and S.G. Length of the solid is being ignored as it has been determined that it is not one of the major factors affecting solid velocity (Bokor, 1982).

Figure 1 gives a graphical illustration of how the model is used to calculate solid velocities in a 100mm diameter coated cast iron pipe set to a slope of 1:100 (0.01). The flow velocity has also been shown for comparison.

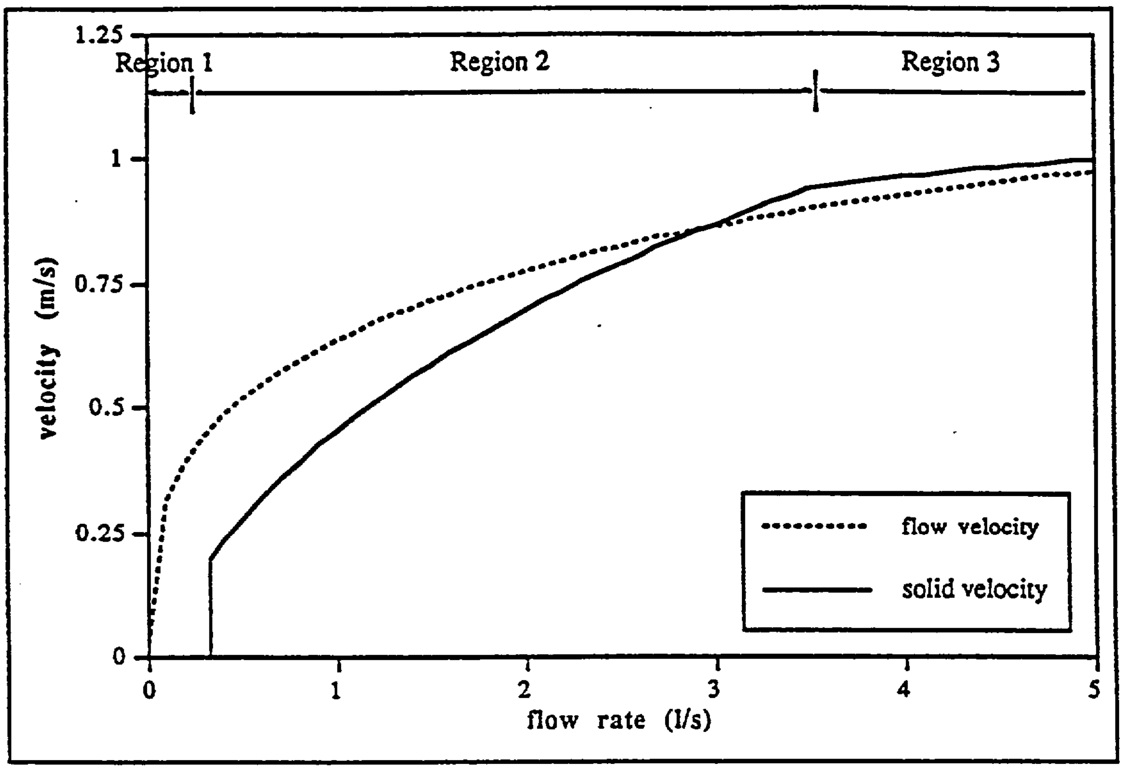

Figure 1 An illustration of the solid velocity model for 100mm diameter coated cast iron pipe at a slope of 1:100 (0.01)

Whether a given solid is in motion or static is determined on the basis of flow depth. Where the depth is below a certain level, determined by the diameter and slope of the pipe, the friction between the solid and the pipe wall exceeds the sum of the forces trying to move the solid and the solid is therefore static. This corresponds to flow region 1 in figure 1.

If it has been determined by the above test that the solid is in motion, the solid velocity is calculated based on the theoretical average flow velocity at the point in the flow occupied by the solid. There are two different flow regions to be considered here; region 2 where the solid is in motion but retains some contact with the pipe wall, and region 3 where the solid has lifted off entirely. In flow region 2, friction occurs between the solid and pipe wall, so the solid velocity is likely to be less than the average flow velocity, but will tend towards and eventually slightly exceed the flow velocity as the flow rate increases. In flow region 3, there is no longer significant friction between the solid and the pipe wall; the solid velocity is likely to be slightly in excess of the average flow velocity, because it is travelling in that part of the flow cross-section furthest from the pipe walls.

The model automatically takes account of which of the three fore-mentioned flow regions the solid is in at any one time and calculates the solid velocity accordingly.

Laboratory observation and measurement have shown that the acceleration and deceleration rates of the solid are not necessarily the same as those of the surrounding flow due to inertia effects. While the tendency will be for the velocity of the solid to move towards that dictated by the immediately surrounding flow conditions, such change may be more gradual than the rate of change of the flow velocity. This limitation on the rate of change of velocity of the solid occurs because the weight of the solid will tend to oppose changes in its velocity. Therefore, limiting factors for acceleration and deceleration have been incorporated into the model based on laboratory measurement, to prevent possible unnaturally high acceleration or deceleration of the modelled solid giving rise to misleading answers.

2. METHODS OF ASSESSING W.C. PERFORMANCE

In this Section, various possible methods of assessing w.c. performance are presented and discussed. Actual comparisons between the performances of different w.c.s using these methods are then presented in Sections 3 and 4.

To assess w.c. performance using numerical solid transport prediction techniques, it is necessary to make some assumption as to when a solid is likely to leave the w.c. bowl and enter the pipe. It is possible to assume simplistically that the solid enters the pipe at, say, the start or the mid-point of the flush, and determine its predicted travel distance on that basis.

However, in practice, solids will enter the pipe at various times throughout the duration of the flush. Therefore, what is required is a method of averaging the predicted travel distances resulting from various insertion times throughout the flush so that a weighted average figure will represent the average distance a solid will travel for a given w.c./pipe combination.

2.1 Using Statistical Averaging Methods

One possible way of representing solid entry times is to use a statistical distribution curve. The chi-square family of curves is similar in use to the Poisson distribution curve. However, unlike the Poisson curve that is centred on a specific point, it consists of a whole family of curves each with differing degrees of skew, dependent on the number of degrees of freedom present. These curves, whilst being intended for entirely different uses to that proposed here, are suitable for the purpose, and can be used to represent the distribution of entry times, the average occurring at any desired point during the flush profile.

Chi-square tables can be found in any statistical text-book. In this application, it is firstly necessary to calculate the degree of skew inherent in each of the curves represented in the tables. To quantify the degree of skew, a "skew factor" has been used. The curves are each divided into ten equal bands, and the skew factor calculated for each using the term

$$\sum_{i=1}^{i=10}(iy_i)\Big/20$$

where y_i is the proportion of the area below the curve in band i to the total area below the curve, as shown in figure 2. These calculations produce a table of chi-square curves, each of which has a weighting value for each of the ten bands and a skew factor. The value of the skew factor will always be greater than 0 and less than 1, a skew factor of 0.5 representing a

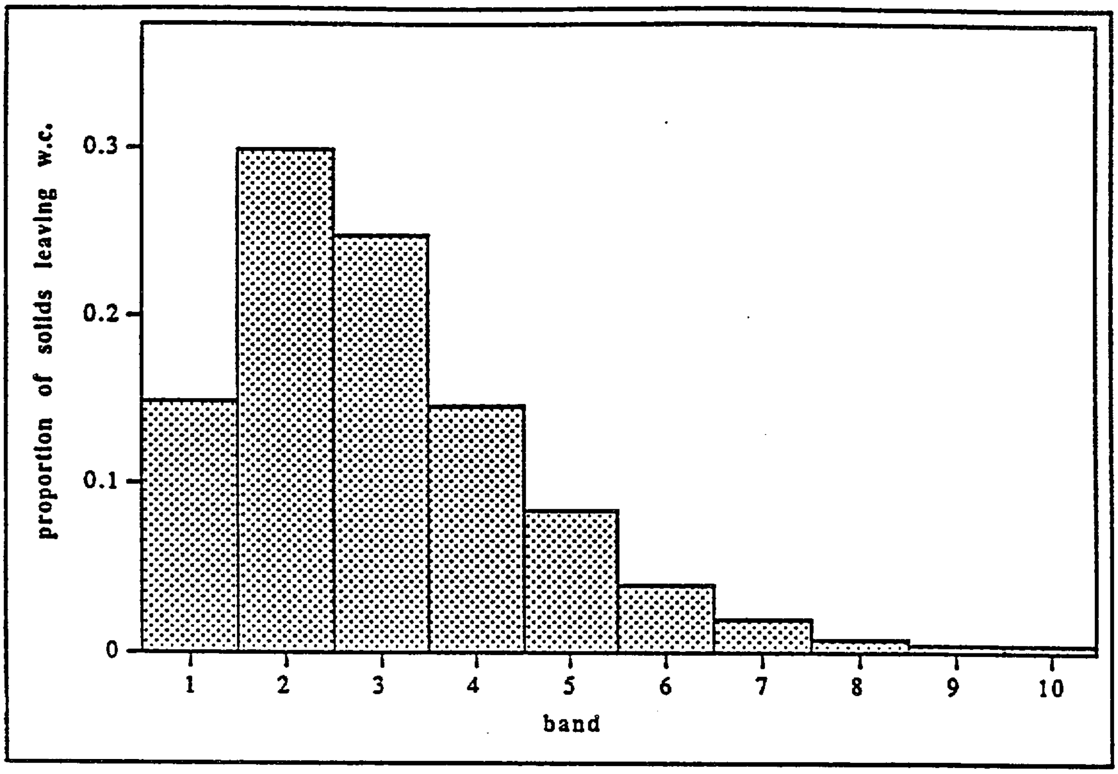

Figure 2 Chi-square distribution chart for skew factor = 0.25

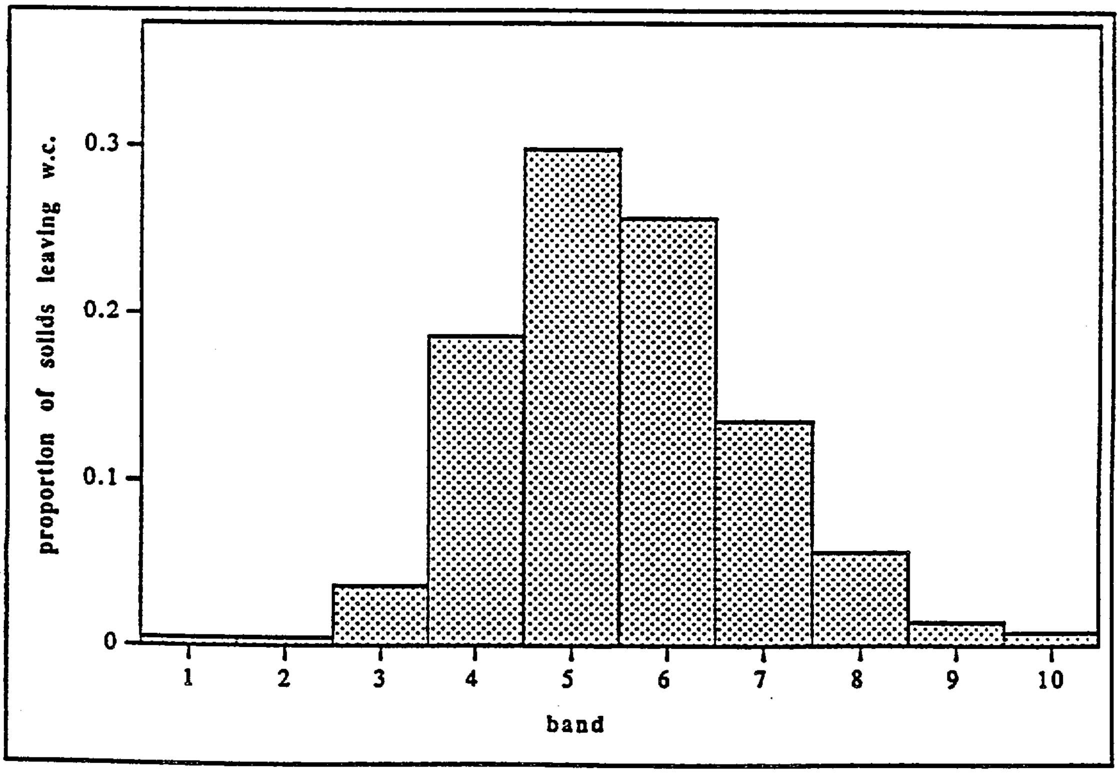

Figure 3 Chi-square distribution chart for skew factor = 0.5

centred curve (i.e., zero skew) whilst values below 0.5 are forward-skewed and those above 0.5 rearward-skewed.

The flush profile is similarly split into ten equal bands, on the basis of flush volume rather than time. For each of these bands, it is firstly necessary to calculate the time that represents the mid-point of that band. Secondly, the skew factor inherent in the flush is calculated, by dividing the time taken for the first half of the total flush volume to enter the pipe by the total flush duration. Thirdly, the weightings for each of the ten bands are interpolated from the table derived as described above, on the basis of the skew factor. The solid deposition distance relative to each insertion time is then determined using the solid velocity model, and the overall weighted average calculated.

Calculations of flush ratings were done initially using distribution curves with skew factors of 0.25 and 0.5, the distribution charts of which are shown in figures 2 and 3. The problem here, however, lies in deciding which of these, if either, more accurately represents the actual flush pattern.

2.2 Using Flush Profile Biasing

An alternative way of determining a likely distribution pattern is to assume that solids will enter the drain for the full duration of the flush, the proportion of solids entering during any one period being in proportion to the percentage of the total flush volume leaving the w.c. during that period. As with the chi-square weighting methods, the widths of the bands are determined on the basis of equal flush volume, not time.

Once the bandwidths have been determined, calculation proceeds in the same way as described in Sub-section 2.1.

This method was chosen as most closely representing the various possible solid insertion times, as it gives a single figure that will characterise the performance of a w.c. within a given situation, the figure being biased to reflect the effect of skewed distributions. While the method is not likely to represent exactly the spread of actual insertion times, it is likely to give a bias to the results which will take into account all factors inherent in the flush profile of the w.c. being tested.

2.3 Solid Transport on Second and Subsequent Flushes

The method outlined under Sub-section 2.2 produces a single figure that represents the average distance a solid is expected to travel on its first flush. Thereafter, to determine how far the solid is likely to travel, it is necessary to calculate how much further the solid will be moved by each subsequent flush.

This is possible using the same computer model as is used to calculate the travel distance for the initial flush, with the starting distance for second and subsequent runs being the finishing distance for the previous run. By using the output from one run as the input for the next on an

iterative basis, it is possible to perform this operation automatically, thereby calculating either the maximum travel distance for that solid in that situation, or, alternatively, how many flushes are required to move the solid a given distance.
The process is shown diagrammatically in figure 4, where x-final (the total travel distance following a flush) is plotted against x-initial (the total travel distance prior to that flush). The steps required to calculate the number of flushes to clear 30 metres is shown.

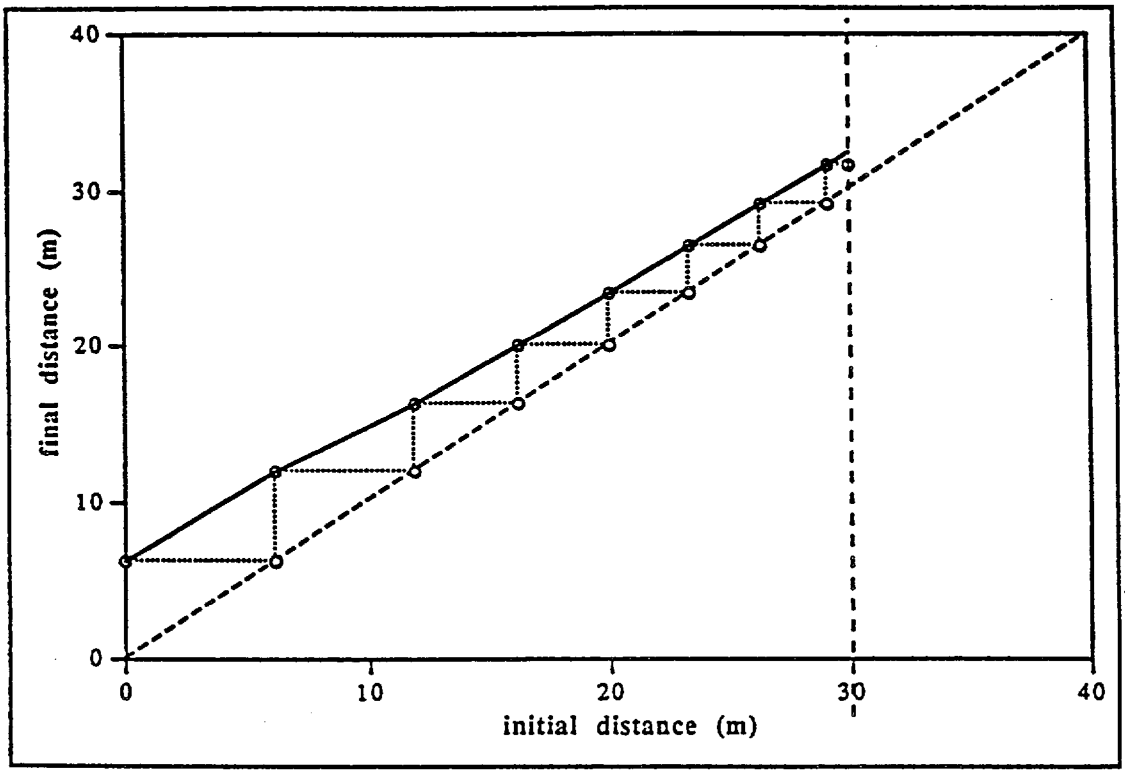

Figure 4 Final flush distance plotted against initial flush distance

The calculations described above could not have been carried out by hand; a computer program is necessary for this purpose. This program is capable of running multiple set-ups in batch mode, combining any number of different w.c. flush profiles with any number of different pipe diameters, materials and slopes, and any desired baseflow.

3 SOME SAMPLE COMPARISONS OF W.C. PERFORMANCE

The comparisons between the performances of the various w.c.s described in this Section have been done using flush profile biasing, as discussed in the previous Section, for the first flush. The travel distance thus calculated for the first flush has then been used as the basis for multiple-flush evaluations. In practice there would continue to be a spread of travel distances, although this will decrease further along the drain.

All tests have been done assuming the w.c. is connected to a long, straight coated cast iron pipe at a slope of 0.015 with a baseflow of 0.1 litres/second, the only variation being in the diameter of the pipe being used.

3.1 The Effects of Variations in Flush Volume

Figure 5 shows the flush profiles for six w.c.s, which have been numbered, for convenience, from 1 to 6.

Figure 6 shows the results obtained using w.c.s 1, 2 and 3, with flush volumes of 11.2, 12.6 and 13.25 litres respectively, each connected to a 100mm diameter pipe. The graph shows that, to move a solid beyond 100 metres down the pipe requires 19, 13 and 12 flushes respectively.

Compare the previous figure with figure 7, which shows the results obtained using w.c.s 4, 5 and 6, with flush volumes of 3.6, 5.94 and 6.84 litres respectively, each connected to a 75mm diameter pipe. This time, the graph shows that, to move a solid beyond 100 metres down the pipe requires 28, 7 and 7 flushes respectively.

This gives a clear demonstration of the effect of water conservation measures on solid transport. The 3.6 litre w.c. does not perform as well as the larger w.c.s in this situation. However, leaving this w.c. aside for the moment, the results obtained for the other two low flush volume w.c.s show that increased solid transport performance is possible while using considerably less water per flush, simply by decreasing the diameter of the pipe. It is possible to optimise further the performance of these w.c.s, up to a point, by increasing the slope of the pipe where site conditions allow, and this is where the 3.6 litre w.c. is likely to work best, i.e., with 75mm diameter pipes at slopes of 0.02 or greater.

3.2 The Effects of Variations in Flush Duration, Skew Factor and Peak Flow Rate

Figure 8 shows the flush profiles of five w.c.s, each having the same flush volume but differing in flush duration, skew factor or peak flow rate from each other. Note that the flush profile for w.c. 5, which was included in figure 5, has been repeated here for clarity. Skew factors, where not shown, are equal to 0.5. All tests in this Sub-section have been done assuming a 75mm diameter pipe. For the moment, we are interested in w.c.s 5 and 5a to 5c; w.c. 5d will be discussed in the next Sub-section.

Duration - Figure 9 shows a comparison of the results for two w.c.s having identical flush volumes, skew factors and peak flow rates, but with different flush durations. The w.c. with the increased flush duration performed very slightly better in this test (by about 2%), but the two sets of results are very similar.

Peak Flow Rate - Figure 10 shows a comparison of the results for two w.c.s having identical flush volumes, flush durations and skew factors, but with different peak flow rates. The w.c. with the higher peak flow rate performs considerably better on the first flush (by

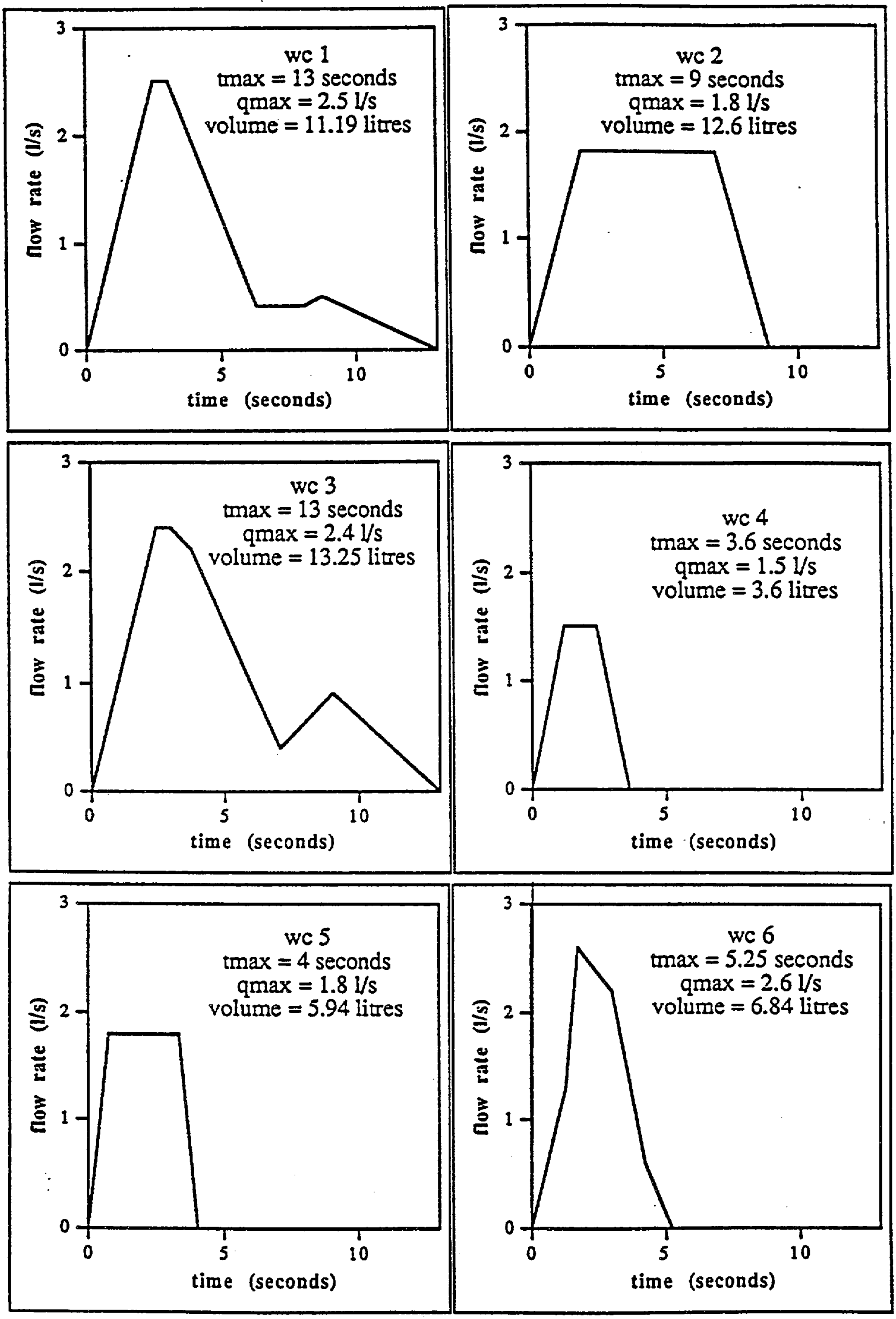

Figure 5 Flush profiles for w.c.s 1 to 6

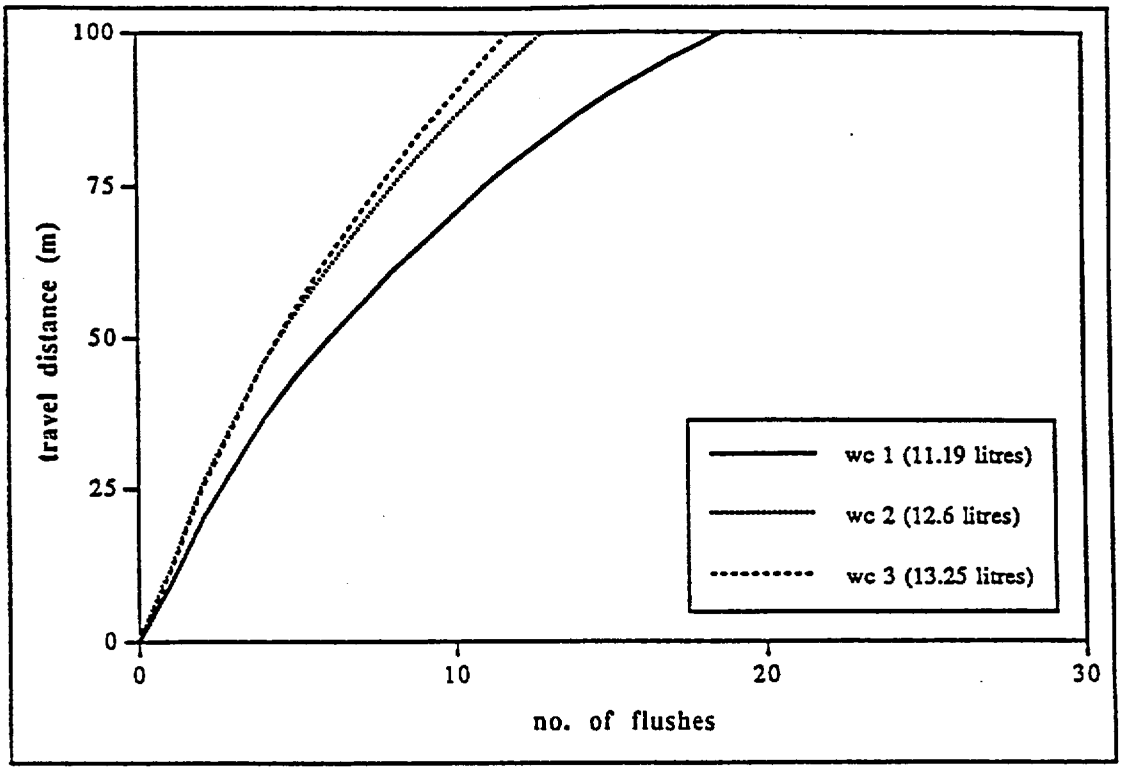

Figure 6 Comparison of results for w.c.s 1, 2 and 3

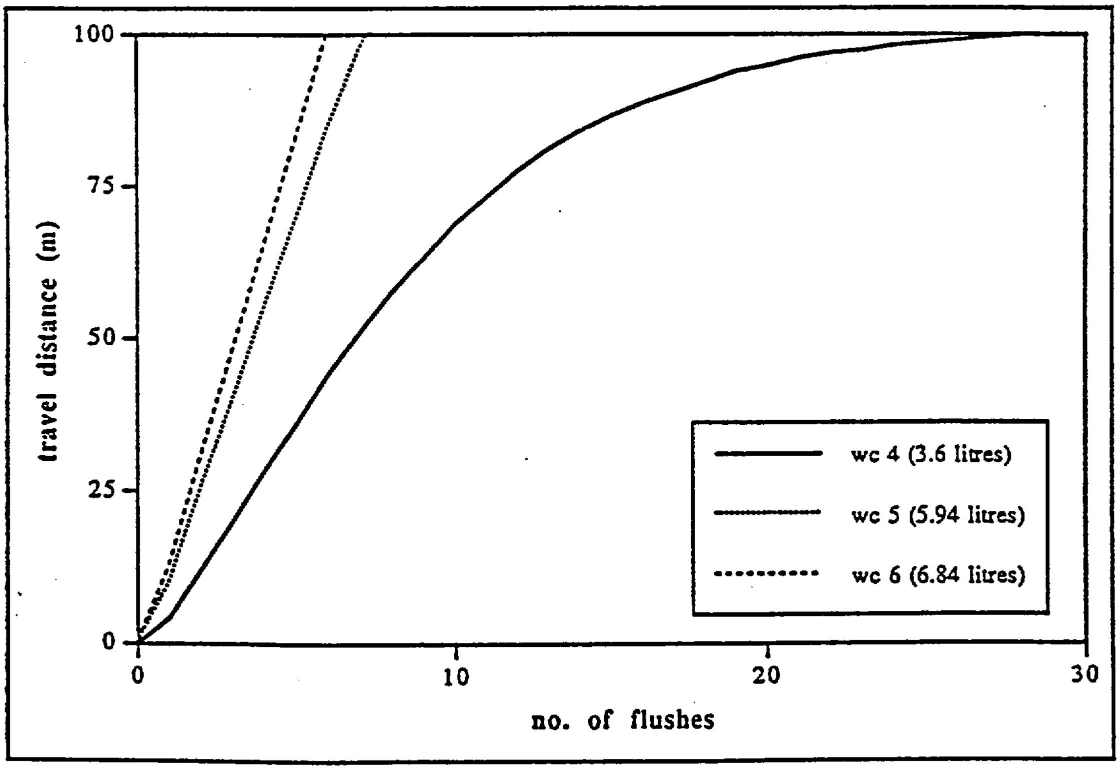

Figure 7 Comparison of results for w.c.s 4, 5 and 6

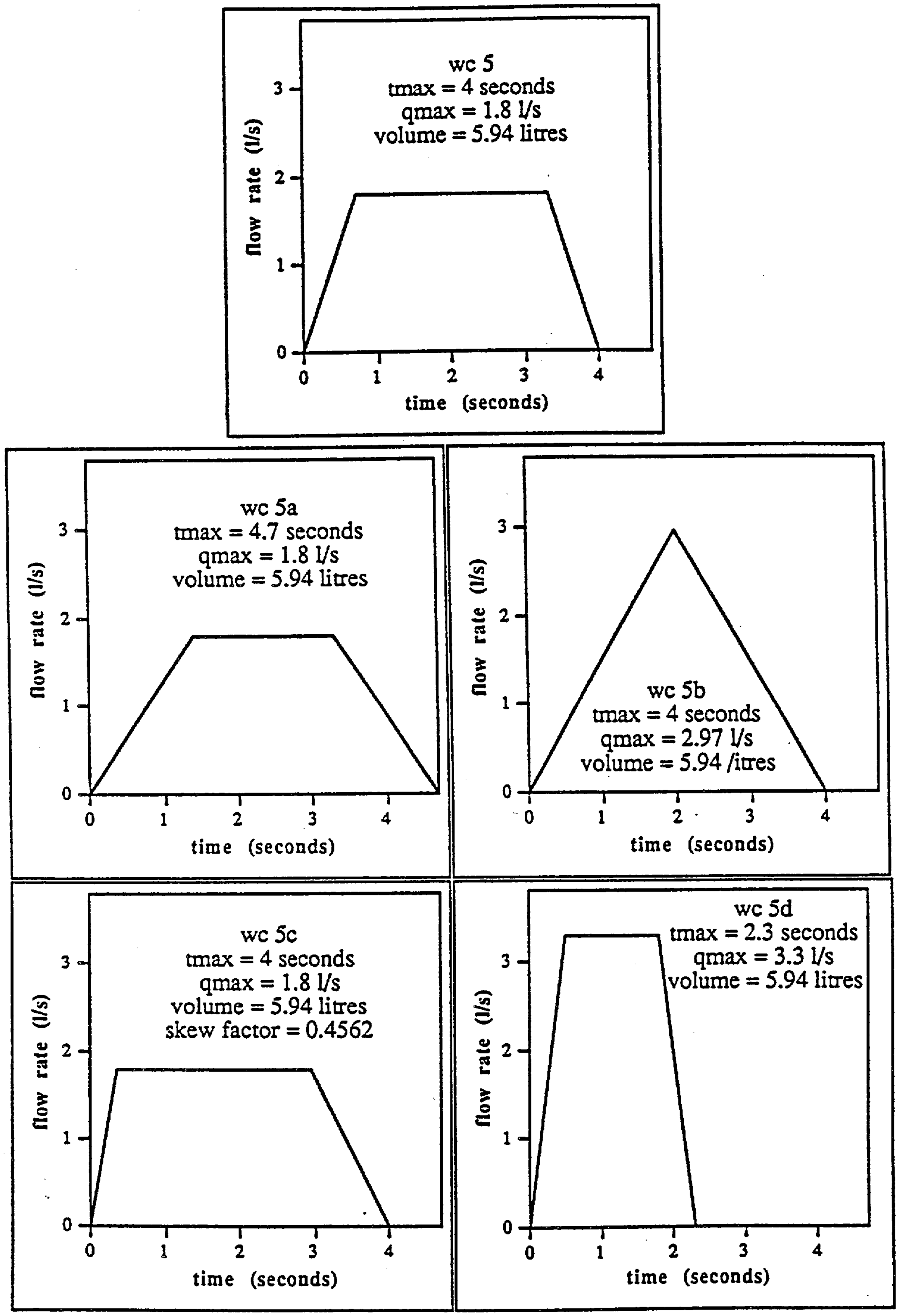

Figure 8 Flush profiles for wcs 5 and 5a to 5d

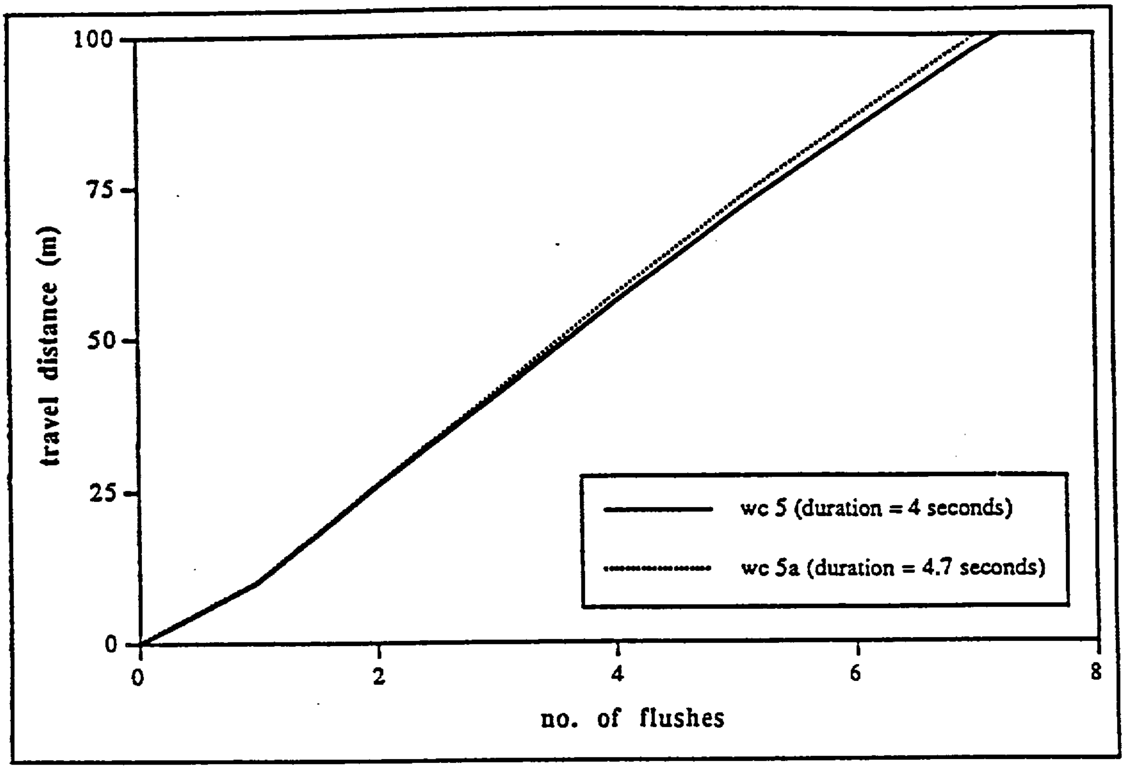

Figure 9 Comparison of results for w.c.s 5 and 5a, showing the effect of changing the flush duration

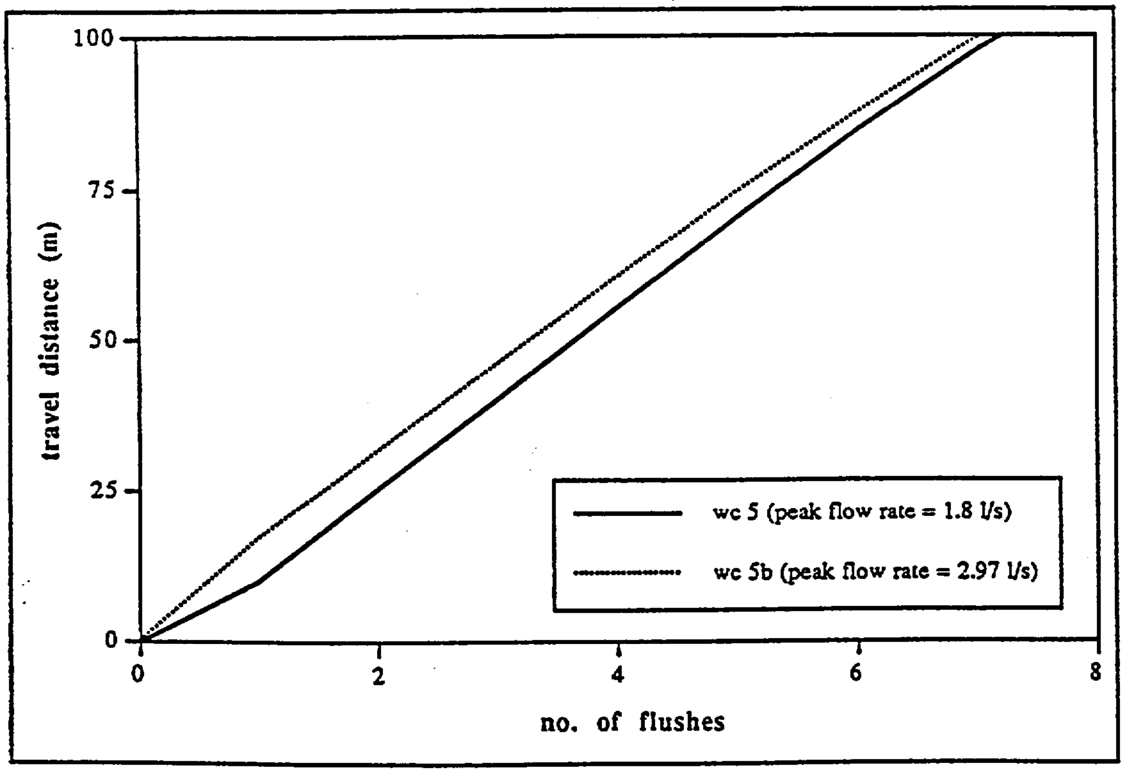

Figure 10 Comparison of results for w.c.s 5 and 5b, showing the effect of changing the peak flow rate

about 70%). However, the two sets of results are coming closer as the total distance approaches the limit of 100 metres.

Skew Factor - Figure 11 shows a comparison of the results for two w.c.s having identical flush volumes, flush durations and peak flow rates, but with different skew factors. The w.c. with the forward-skewed flush profile performed very slightly worse in this test (by about 1.4%), but the two sets of results are very similar.

The above comparisons show that it is possible to determine whether a change in one of the factors representing a flush profile is likely to improve or worsen the performance of the w.c. in a given situation. It should not, however, be assumed that a change in one of the factors in a given direction will always affect performance in the same direction - every case would have to be individually investigated.

3.3 The Effects of a Combined Variation in Peak Flow Rate and Flush Duration

Referring again to Figure 8, w.c.s 5 and 5d each have the same flush volume and skew factor, but different peak flow rates and flush durations. Effectively, w.c. 5 has a gravity cistern while w.c. 5d has a pressure cistern.

Figure 12 shows a comparison of the results for these two w.c.s each connected to a 75mm diameter pipe. The first flush carries the solid 9.92 metres and 22.24 metres, respectively, down the pipe, whilst to carry the solid beyond 100 metres down the pipe requires 8 and 9 flushes respectively. The pressure cistern (w.c. 5d) is clearly seen to carry the solid a considerably greater distance on the first flush than the gravity cistern (w.c. 5). The situation is reversed, however, for pipe lengths in excess of about 45 metres.

Thus, this example has clearly demonstrated that a w.c. which has been shown to perform well in a given situation is not necessarily the best w.c. for all situations.

4. APPLICATIONS OF W.C. PERFORMANCE ASSESSMENT

It has been shown that it is now possible to summarise w.c. performance in a single figure for a given situation, whether that figure be distance travelled following a single flush, the number of flushes required to travel a given distance or the maximum travel distance beyond which a solid will not be affected by further flushes. Therefore, it is possible to make direct comparisons between a range of w.c.s to assess which is likely to perform best in a given situation. Alternatively, where a w.c. has already been chosen, it would be possible to run a variety of situations to determine which pipe diameter / slope / material combination would give the best performance.

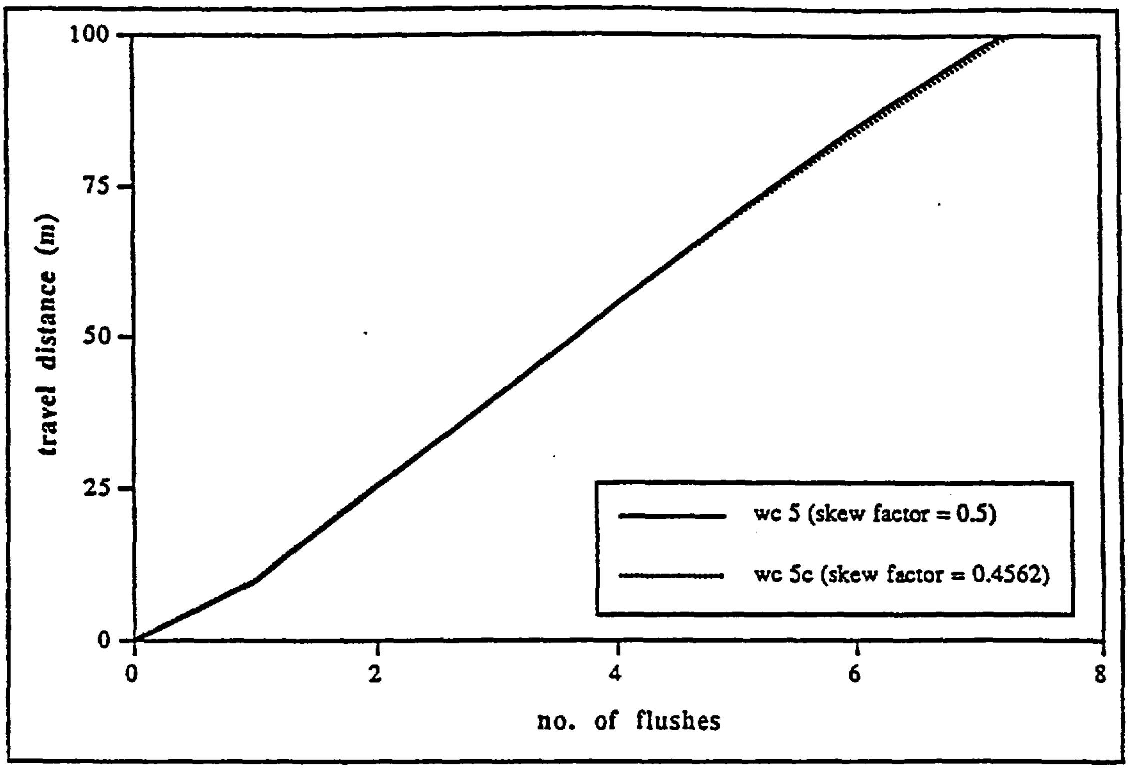

Figure 11 Comparison of results for w.c.s 5 and 5c, showing the effect of changing the skew factor

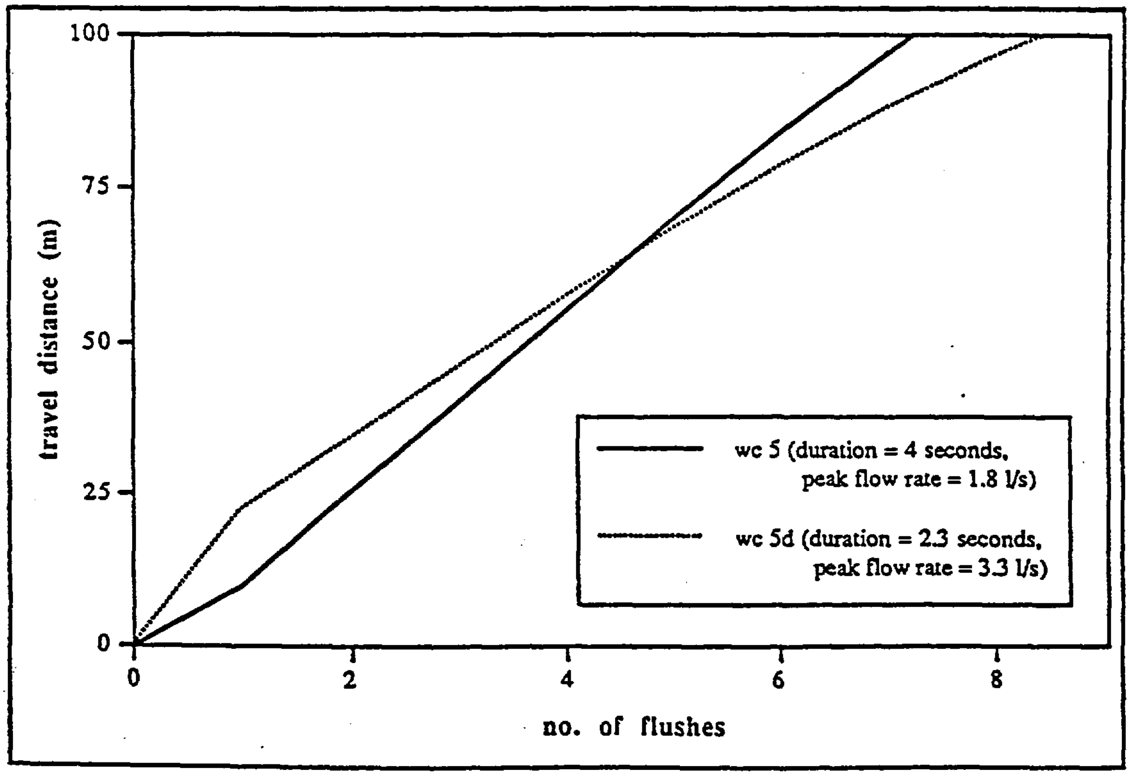

Figure 12 Comparison of results for w.c.s 5 and 5d, showing the combined effect of changing the peak flow rate and the flush duration

Whilst the examples presented here have only shown results based on a single w.c. flushing into a single long pipe, this has been done for the sake of simplicity. The techniques already developed would allow evaluation of w.c.s in complete building drainage networks, with one or more w.c.s flushing at various times and, as required, sink, wash-basin, shower and bath flushes added.

As an example of the various possible methods of comparison presented in this paper, Table 1 below shows results on a 100mm diameter pipe for w.c.s 1 to 3 using all the methods previously discussed. As can be seen, the w.c. with the greatest flush volume (w.c. 3) performs best on the first flush if it is assumed that the solid will be inserted at the start of the flush. However, all three of the methods of evaluation which employ some kind of weighted average show that w.c. 2, with a lesser flush volume than w.c. 3, performs best overall on the first flush. Finally, the last column shows that w.c. 2's advantage on the first flush, and therefore in short pipes, is not in evidence in long pipes.

W.c.	Flush volume (litres)	<---- Distance travelled on first flush (metres) ----> Insertion at time zero	Chi-square biased (skew=0.25)	Chi-square biased (skew=0.50)	Flush profile biased	Flushes to move solid 100m
1	11.19	14.93	12.72	10.54	9.40	19
2	12.6	17.82	15.92	12.24	11.42	13
3	13.25	17.95	15.20	12.01	10.54	12

Table 1 A comparison of various methods of evaluating w.c. flush performance

It will be clear from the examples given in this paper that it is possible to use the techniques presented as a design tool for w.c. manufacturers, as the effects of variations in flush profile could be rapidly and accurately predicted for any particular drainage network, or for any target network that a future code committee might decide was representative of the range of conditions likely to be met in practice. The use of such simulations would also allow the interactive performance of the appliance and the network to be evaluated for any user defined appliance usage profile, thus allowing the implications of such design constraints as water conservation and maintenance regimes, based on probable solid deposition patterns, to be investigated. This is not intended to suggest that numerical methods should be used as a replacement for laboratory testing, rather the opposite as it would become even more important for manufacturers to be able to provide reliable appliance discharge profiles as a basis for the evaluation of the suitability of their product within any proposed drainage network. Thus the use of simulation packages in parallel with appliance design would be a preliminary indicator to the w.c. designer prior to final product manufacture. Such a technique would remove many of the uncertainties currently surrounding appliance choice, as well as providing the manufacturer with a reliable measure of the product's capabilities in service.

5. FINAL REMARKS

This paper has outlined the application of numerical simulation techniques to the design of both drainage systems and appliances. In doing so the paper has drawn on the output of a concerted and planned research programme, whose objective was to introduce soundly based fluid mechanics analysis techniques to the design of building drainage systems. The applications described in this paper must be seen as concurrent with the design and analysis simulations for vent systems presented by the other members of the research group at Heriot-Watt University. Taken together, these proposals offer a new approach to the design and evaluation of building drainage networks that emphasises an user defined appliance usage profile as the basic data required to drive the simulation, a departure from the probability based approach previously employed in system design. It must be stressed that the current probability/steady flow design limits approach cannot by its very nature address the problems solved by this paper and the accompanying vent system simulation, Swaffield, Campbell and Jack (1994). Equally it must be stressed that the limitations of the current design methodology was fully recognised by Hunter (1940) when he wrote

> '..*hence the conventional pipe formulae apply to the irregular and intermittent flows that occur in plumbing systems only during that time (usually very short) and in that section of pipe in which the variable factors involved (velocity or volume rate of flow or hydraulic gradient and hydraulic radius) are constant*',

although this caveat may have been overlooked in its application over the past 50 years.

The current programme of research will continue with further laboratory measurement and analysis of solid velocities using solids with different S.G.s and diameters. It is expected that, on completion of this work, the solid velocity model already completed can be extended to take account of variations solid diameter and S.G. In addition, the site surveys carried out to date to determine the extent of defects in installed building drainage systems will be extended to give a large database of defects. It will then be possible to apply the information contained in this database to the computer-based model, to allow prediction of flow depths, flow velocities and solid velocities throughout defective (i.e., realistic) building drainage networks. Completion of this work will allow the methods discussed in this paper to be applied to any drainage network with or without defects.

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Appendix 2.

ITEM 10.

Item 10, Appendix 2.

'Low Flush Volume Water Closets, Mixed Media Testing, Waste Transport and Drainage Sizing', J. A. Swaffield, L. S. Galowin, R. Yingling, CIB-W'62 Conferance, Brighton, U.K., 26-29th September, 1994

CIB-W62 Paper

LOW FLUSH VOLUME WATER CLOSETS, MIXED MEDIA TESTING, WASTE TRANSPORT AND DRAINAGE SIZING

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To be presented in Brighton, England, by Prof. John A. Swaffield, Dr. Lawrence S. Galowin

26 - 29 September 1994

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SUMMARY

Low flush volume water closets and other water conservation fixtures are of major interest because of national regulations for water conservation under the Energy Policy Act of 1992. Parameters necessary to understand performance with linkage to laboratory test methods in plumbing standards for fixture evaluations and apply to design for drainage pipe sizing requirements were examined . Theoretical and experimental investigations of the hydraulic conditions in drains were undertaken to demonstrate methods for analysis and testing of water closet performance with transport of waste solids in drains.

Currently, interest in plumbing standards for water closets is toward several classifications for usage based on intended classification of buildings. New test requirements with different levels of performance will be required. Mixed media for such testing now appears to be under favorable consideration with specification of different loads for testing evaluations.

Numerical solutions from a computer model for unsteady partially filled pipe flow in drains with transport of solids discharged from water closets were applied in this study. Discrete solid waste simulants in gravity and pressurized tank types of low flush volume water closets were modeled and drainline transport distances determined for diameter and pitch variables.

Test results are reported for two loadings of mixed media simulant waste loadings, categorized for residential and commercial simulations, in evaluations of water closet discharges and transport of solids in drainlines for two different diameters and slopes. Eighteen low flush volume water closets of gravity and pressurized (flushometer) tank types were tested following a prescribed protocol for water closet performance capabilities for clearing the bowl and transport distance. Test data comparisons showed that model representations can confidently be applied in guiding standards writers for test methods development and for engineering analysis by designers for pipe sizing purposes.

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MIXED MEDIA TESTING, WASTE TRANSPORT AND DRAINAGE SIZING

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INTRODUCTION

The United States Energy Policy Act of 1992, Public Law 102-146 regulates flow rates or consumption by volume for many plumbing products. Reference to ASME plumbing standards is made for test methods and performance requirements in laboratory test evaluations. Plumbing and water authorities have great concern about solids deposition in the drain that may cause blockages with reduced flows.

Replacement of plastic balls as standard test media with more complex mix of simulants has gained interest. To improve testing more appropriate simulation materials of normally discharged wastes from water closets are required to evaluate i) discharge of solids from the bowl, and ii) transport distance of solids along the length of the drain. Finding a useful mixed media for testing has become an urgent topic.

Currently, test requirements with 6 liter water consumption can be met by product manufacturers. At least two types of water closets are commercially available; those are gravity and pressurized (flushometer) tank types. However, growing concern for differences in performance, and need for design information, i.e., drainage fixture units differences, recognizes that all low flush volume water closets with low flush volumes do not provide the same performance.

STANDARDS ISSUES

The current hydraulic standard ASME A112 19.6 [1] requires loadings of plastic balls and that 75 percent of the test plastic balls clear the bowl and that average carry distance of 40 feet (about 12 meters) is achieved in a 4 inch (100mm) diameter drain at 2 percent slope. At the initial time of acceptance of that test it represented an achievement of linking, for the first time, drainline conditions to the fixture performance. The requirement of a transport test has been vindicated as necessary for providing a rational basis for acceptance installations by water conservation authorities in replacement programs with low flush volume water closets. No distinction for acceptable performance separates higher from marginal levels of performance; only a minimum requirement is set for pass/fail criteria.

Commercially available 6 liter water closets operation is of either gravity or pressurized tank types. Selected tests [2, 3, 4] suggest that differentiation of the usage also becomes an additional necessity. There is a growing call for improvements in the standard since performance differences can result. Interest in standards revisions that leads to categories for different purposes with distinct levels of performance requirements has extended to considerations for plumbing code drainage fixture units changes based upon usage and possibly the type of water closet.

Usage classifications are (broadly) suggested for i) single family residences, ii) apartments and light commercial buildings, iii) commercial, light industrial, and public buildings, iv) heavy industrial and special events facilities (arenas, public convention halls and airport facilities). Those distinctions attempt to account for differences in maintenance, non-personal commitment, and intense or abusive use with unusual waste loads not customarily experienced. Congested utilization due to time scheduled intermissions and recesses contribute to heavy traffic into the restroom facilities that may cause unusual loadings and high frequency usages. For different levels of service establishment of new test requirements are therefore needed in standard laboratory testing measurements with new appropriate criteria for pass/fail.

Determination of properties and loadings with new waste simulant materials, other than plastic balls, is recognized as an important change for laboratory testing. What materials and quantities should constitute loadings remains subject to discussion rather than a product of informed plumbing research. Identification needs to be made for selection of the constituent materials, defining properties, and particularly loading sample sizes (numbers, mass, volume, availability, reusability, retention of prescribed characteristics, etc.) and formulation of acceptable performance criteria. Mixed media should have characteristics that allow for some compression and interactions in passage through the trap, enough resiliency to restore to its shape and have dimensional similarities to real waste loads. Materials should have specific gravity and total mass volume at representative values of fecal materials. Additional characterization would entail paper, or paper-like materials. For laboratory testing there are requirements for stability and reusability from repetitive use and the assurance that reproducible data can be obtained.

MODELING WATER CLOSET DISCHARGES

The simulation and prediction of hydraulic conditions in partially filled drains requires modeling of the hydraulics coupled with solid waste transport. Computer based numerical method of solution by the method of characteristics for the governing time dependent equations developed for mathematical analysis with applications to calculations for drain pipe conditions in building drainage systems is contained in "The Engineered Design of Building Drainage Systems" [5]. The lead authors showed attenuation of the surge from water closets and the location of solids in the discharge profile governs waste transport in acceptance installations by water conservation authorities in replacement programs with low flush volume water closets. No distinction for acceptable performance separates higher from marginal levels of performance; only a minimum requirement is set for pass/fail criteria.

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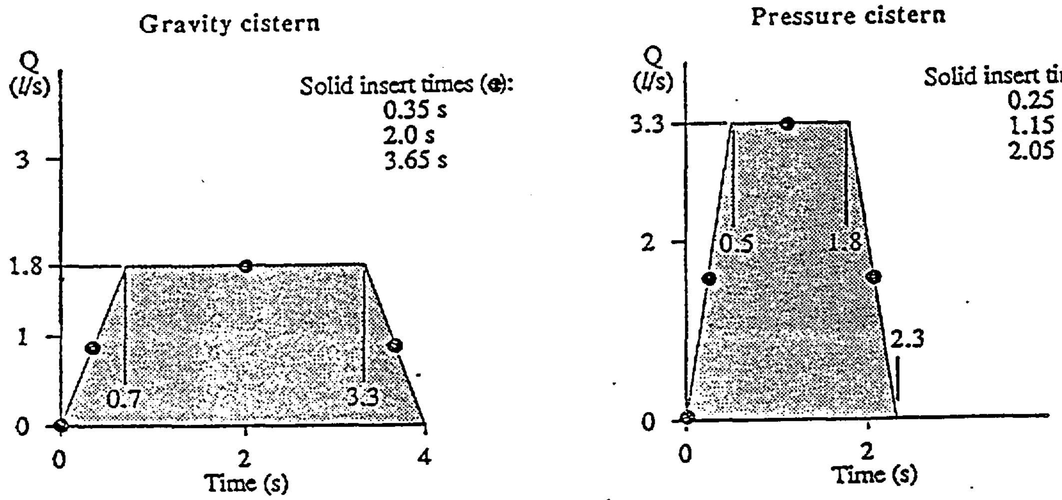
The shape and peak flow rate of discharge profiles are significant for the capability of removing solid wastes from the bowl and entry/transport along the drain. Location of solids in the discharge profile governs delivery into the drain and the resulting transport distance. The carry distance from a single surge has been shown to be limited and dependent upon pipe pitch, diameter, and roughness.

Water closet discharge profiles for low flush volume water closet types considered in this study are shown in the sketch. The inflow rate vs time curve generates a wave that propagates along the length of the drain. Friction reduces the difference between the flow velocities within the wave and the overall effect will be to attenuate the wave, lowering the peak flow rate and depth as the wave moves through the drainlines, with a consequent reduction in solids transport.



w.c. Discharge characteristics

In this study three waste solids were considered in the discharge profile; they were midway along the rising, steady, and falling portions of the assumed discharge profiles. In the calculations the times noted on the figure were used to introduce, in turn, the first,

CALCULATION MODEL	
Pipe diameter, in (mm)	Pitch or Slope (%)
3 (75)	0.01, 0.02
4 (100)	0.01, 0.02
6 (150)	0.01, 0.02

partially filled drainage pipe systems [5, 6, 7, 8]. Comparisons of computer model analyses and experimental results with measured unsteady flows have been in good agreement.

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MODELING SIMULATIONS

In this study three waste solids were considered in the discharge profile; they were midway along the rising, steady, and falling portions of the assumed discharge profiles. In the calculations the times noted on the figure were used to introduce, in turn, the first,

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Pipe diameter, in (mm)	Pitch or Slope (%)
3 (75)	0.01, 0.02
4 (100)	0.01, 0.02
6 (150)	0.01, 0.02

second, and third solid. The profiles are representative of the two types of 6 liter low flush volume water closets. Discharge through a turning elbow to a straight pitched pipe drain 20 meters in length with a smooth wall (standard test requirement) was assumed. The solid transport was determined for the conditions listed.

Results for the transport distance for the three solids for the gravity and pressure tank types are presented as distance against time in figures 1 and 2. The time varying sections of the curves attain constant values that represent the maximum distance from one flush action of the water closet; the solids stopped within the pipes. The maximum distances are listed below and shown in figure 3. Greater transport distances for the pressurized tank as compared to the gravity type are shown. That results from higher energy content associated with the peak flow rates (other test data comparisons follow descriptions of the testing of twenty water closets discussed in the latter part of the report). Results for a diameter of 150 mm show no sensitivity to the pitch effects for both types of water closets.

SOLIDS TRANSPORT DISTANCES (m), [ft]						
GRAVITY TYPE						
	SLOPE 0.01			SLOPE 0.02		
	Pipe Diameter			Pipe Diameter		
Solid #	75 (mm)	100 (mm)	150 (mm)	75 (mm)	100 (mm)	150 (mm)
1	9.1	5.4	1.3	16.7	9.7	1.3
2	8.5	4.9	1.1	15.8	9	1
3	7.2	3.5	0.7	13.8	7	0.7
Avg.	(8.3)	(4.6)	(1.03)	(15.43)	(8.9)	(1.0)
	[27.3]	[15.2]	[3.4]	[50.9]	[29.37]	[3.3]
PRESSURIZED TANK						
1	9.7	7	6.9	19.2	12.1	7.4
2	9.3	6.6	6.3	18.5	11.5	6.7
3	8.1	5.2	4.8	17	10.1	5.2
Avg.	(9.03)	(6.3)	(6)	(18.2)	(11.2)	(6.4)
	[29.8]	[20.7]	[19.8]	[60.2]	[37.1]	[21.2]

The differences between the average transport distances for slopes of 0.02 and 0.01 are important for design information. For considerations leading to standard test methods the size of the test facility may influence first consideration for the smaller slope. To improve distinguishing differences in performance from the average transport a greater pipe pitch is necessary.

The transport distance of solids in the drain depends on the location of the solid(s) in the discharge profile. Solids in the earlier part of the profile are carried further along the drain; those that are in the tail of the profile have reduced carry distances. Delays attributable to the exit passage through the bowl and trap are not included in the model.

In the (following) test data delays of solids in the water closet were found mostly due to the mode of flow pattern in the bowl and the trapway unable to accommodate the solids, prior to entry into the drain; that appears to depend upon the individual design and results in widely varying transport distances. Also, it was found that for some water closets all solids were not discharged in the first flush and even in the second flush.

DESCRIPTION OF TEST PROGRAM

The Washington Suburban Sanitary Commission laboratory test facility was built at the Burnt Mills Depot, Maryland, the layout is shown in figure 4. The test stand provides four water closet locations with drain pipe connections for solids discharge and waste transport testing. A fifth station provided a vertical outflow location for measurement of flush volume of each water closet prior to transport testing. The angled platform and the dimensions of the test room required turning fittings in the piping drain direction (simulations of more realistic installations of building drains) that may only effect transport distance but not of the number of solids discharged from the bowl. The drains of transparent PVC were 3 and 4 inch diameters (75 and 100 mm) at pipe pitch (slope) of 1 and 2 percent (1/8 inch and 1/4 inch per foot). A 4 inch diameter cast iron pipe at 1 percent slope also was provided for a limited number of tests. An additional branch flow tee fitting, 20 feet from the platform was set into each drain to introduce a steady 2.2 gpm branch flow (for simulation of other discharged fixtures) into each drain for determining interacting flow effects on main drain waste transport.

Water closets were mounted in turn at each of the four drain connection stations so that all drainline conditions were measured for each water closet. All test runs were duplicated, five times for the light loads and a sixth test with flow entry at the branch fitting; for heavy loads the tests were run three times, without branch flows. Each test set (run) consisted of two flush sequences, one with a waste load in the bowl and the second flush without added solids in the bowl after complete bowl refill and water flow cessation, and if any solids remained from the initial flush they were retained for the second flush. Data was recorded after each flush operation. With branch sideflow only one test run of two flushes was conducted. Additionally, selected water closets were tested with discharges into a 4 inch diameter, one percent slope, cast iron drain with a milled slot in the crown to permit test measurements with "rough wall new condition" pipe for a "worst case acceptable drain" (current code allows cast iron pipe of that size). Consequently, each water closet was operated at least thirty six times with loads for the first flush and thirty six times for the second flush (no added load), so that for the twenty water closets tested in four transparent drains and selective added tests, over 1400 tests were conducted.

Measurement tapes were mounted on the crown of all drains from which transport distances were measured. Controls, pressure gauges, flowmeters were installed for setting and maintaining test conditions and for recording test events. Drain lengths were approximately 100 feet, but the maximum test length for transport was 80 feet because the exit manifold collector for recovery of the solids had potential impact on pipe end conditions. Details of the test developments, samples tried, trial testing leading to the test protocol and discussion of the different conditions evaluated are presented in the Washington Suburban Sanitary Commission report [9].

Considerations for light (residential) loads and heavy (commercial) loads were based on trials with several candidate materials. The observed extent of "filling the well" was examined for the two different quantities of test materials finally accepted. The adopted heavy load stood above the water level in the bowl (with normally filled condition) for some water closets. Fully soaked synthetic sponges floated and fully soaked natural sponges sank to the base of the bowl; towelettes tended to be nearly neutral and were added after the sponges into the test loading. After solids came to rest, with some partially submerged, the test proceeded. Test protocols for the loading procedure and conducting tests were written in order to minimize error and bias to assure a common approach in conducting the tests.

The data for the sample materials and average mixed load parameters are shown in the following table. The natural sponge solids at the base of the bowl were the earliest solids discharged and generally had the greatest transport distance. In some tests all solids were not cleared from the bowl; those were mostly synthetic sponges that floated, an indication that lighter solids had greater difficulty to clear the bowl.

SOLID WASTE SIMULANT TEST LOADS								
Simulant			Light (Residential) Load			Heavy (Commercial) Load		
Material	Size	Sp. Gr.	Qty.	Displ,	Wt.	Qty.	Displ,	Wt.
Syn.Sponge	1"x1"x1"	.83	8	131 ml	109 g	12	197 ml	164 g
Natl.Sponge	1"x1"x1"	1.04	12	197 ml	238 g	14	229 ml	238 g
Towelettes	6.5"x 6.2"	.75	0	-	-	4	30 ml	23 g
Total			20	328 ml	346 g	30	456 ml	425 g
Avg. Specific Gravity			0.96			0.93		

TEST RESULTS

Test data forms are shown for a pressurized and gravity water closet used for recording the tests. Test conditions are identified by the notation for first and second flush. Note that a zero entry indicates solids did not leave the water closet. For branch flow tests flow was set on before the flush, at 2.2 gals/min; the data are listed in the last columns of the forms. An example of distributions of individual solid distances for another pressure tank type water closet with both loads is shown in figure 5. Note the definite tailing off of the latter solids that must have been in the last part of the discharge profile.

Individual test run averages were calculated for each group of test solids in first and second flush tests, then a combined average formed. The average of all the test runs for each water closet with each category of loads was determined and are illustrated in figure 3. The agreement of data and predicted results are favorable and demonstrate the utility of planning test programs in order to anticipate the measured parameters in magnitude and trends. No adjustments were made for any testing/observation conditions when solids blocked the trapway entrance and prevented discharge from the bowl into the drain; such data was incorporated into the test summary. The spot size water surface in the bowl was determined (approximately) to evaluate effects of that water closet parameter.

The computer based model calculations indicated that position of the solids in the discharge profiles would show different distances of waste transport along the length of the drain and dependency upon pipe diameters. The water closets for both loadings yielded different distances for gravity and pressurized tank types that varied with pipe pitch and diameter which were in accord with the model predictions.

Seven water closets were tested with a light load for discharges into the cast iron drain with 4" diameter pipe at 1/8 in/ft (0.10) including one water saver type of 3.5 gal flush. Those tests also consisted of five test runs of sequenced first load flush and second flush (with any residual solids) and no branch flow.

DATA PRESENTATIONS

The figures 6, 7, 8, 9, present the average transport distance test results for light and heavy loads for both diameters and pipe slopes. The first flush is separated from the second flush and permits comparisons between each water closet for each condition. Cast iron pipe test (4 inch diameter, 1% slope) data is included on figure 8 for comparison with the smooth wall plastic pipes. Decreased performance is attributable to the rough wall pipe condition. Overall conditions for transport distance is in descending order: 3 inch at 2%, 4 inch at 2%, 3 inch at 1%, and 4 inch at 1%. Designers should recognize this information in their engineering procedures. Limited performance correlation of water closets appears for effects of the light and heavy loads ranking order.

A summary of the tests with heavy loads is presented in figure 10 for two flush sequences and no branch flows. In almost all cases pipe slope of 2%, with 3 inch and 4 inch diameters, provide the greatest distances. The variability between performance of each water closet is clear from the different values of transport distances. The differences found in the tests must be attributed to the difficulty or ease of extraction of solids in the leading part of the discharge profiles.

Figure 11 indicates effects of added branch flows on transport distance in a 3 inch diameter, 1% slope drain with a light load and two flushes. Added flow extends carry distances of solids but the greatest transport effect was observed to occur from the second flush. Additional transport shown here has been assumed as a fact, but that assumption has not previously had test measurement confirmation.

Performance differences appear in comparisons of light and heavy load simulations and confirmed in the testing. Classifications for categories of use does appear to be feasible and explicit from these measurements based on both the number of solids discharged and transport distance. Significant differences between the 20 water closets were evident, most likely due to design concepts integrated into the products.

Figure 12 indicates the number of solids discharged in rank order for the first flush and as indicated for both loading conditions and are listed (unordered) in the following table. Water spot areas (from a normal to the surface projection) are indicated on the figures. No correlation appears with water spot size for the light load. However for heavy loads the peak number(s) discharged are associated with larger water spot areas. The smallest spot areas do not have the lowest solids out of the water closets.

FIRST FLUSH AVERAGE NUMBER SOLIDS OUT (AVERAGE)
No Branch Flow, Into PVC Drains

WC #	3" D. @ 2%		4" D. @ 2%		3" D. @ 1%		4" D. @ 2%	
	Light Load	Heavy Load	Light Load	Heavy Load	Light Load	Heavy Load	Light Load	Heavy Load
1	10	9.3	15.4	8.8	13	9	14.2	8.2
2	20	30	20	26.7	19.8	30	20	29.7
3	20	30	20	29.7	20	30	19.8	29.3
4	20	20.3	20	19	20	30	20	18.3
5	20	18.7	20	16.3	20	13	20	24.3
6	20	29.7	20	29	20	30	20	30
7	20	24.7	20	11.7	20	24.7	20	15
8	20	22.7	20	22.3	20	21.3	20	29
9	19.1	14.7	20	26	19.8	16.7	19	22
10	20	30	20	30	20	30	20	30
11	19.8	3.3	15.2	14.7	19.6	19.3	19.8	19
12	20	30	20	30	20	26	20	30
13	12.4	18.3	18.6	20	18.2	24.7	19	20.3
14	20	16.3	20	30	20	18.3	20	30
15	20	13	20	16.7	20	7.7	20	17.1
16	20	30	20	30	20	29.3	20	30
17	20	19.3	20	20.3	20	23.3	20	30
18	20	22.3	20	14.7	20	22.7	20	26.7
19	19.6	17.3	17.2	19.3	19.2	20	19.8	18.3
20	20	16	19.6	24.7	19.4	19.3	19	25

The following table indicates the total number of solids not discharged for both loading

WATER CLOSET SUMMARY FOR TOTAL NUMBER OF SOLIDS NOT DISCHARGED[1]								
100 Total Solids for Light Loads in 5 Paired Flush Sequence Test Runs[2] 90 Total Solids for Heavy Loads in 3 Paired Flush Sequence Test Runs[3]								
WC #	3" Diameter 2% Slope		4" Diameter 2% Slope		3" Diameter 1% Slope		4" Diameter 1% Slope	
1								
2								
3								
4								
5						14		8
6		1						
7		6		29		15		31
8		19		2		3		
9		29		11		11		21
10								
11		67	19	35		8		34
12								
13	36	28	1	30		13		36
14								
15		43		15		51		30
16						1		
17		32		20		20		
18		20		43		8		
19		12		17		13		27
20		29		21		28		19

[1] No branch flow tests in summary.

[2] Represents 10 flushes. A fresh load followed by another flush without added solids in each pair of tests with initial solids load of 20 items.

[3] Represents 6 flushes. A fresh load followed by another flush without added solids in each pair of tests with initial solids load of 30 items.

conditions. Water closets are capable of removing all solids with the light loads with two flushes except for two cases. With heavy loads there are differences; some water closets are not able to discharge all the solids, even with a second flush. Distinctive performance differences can be demonstrated with this test loading and be applicable to development of a rating method.

In figure 13 a summary of all tests for transport distances is presented with the first flush, averaged for all water closets for each diameter and pitch for the pressurized tank, gravity tank and the 3.5 gallon flush volume. The cast iron pipe with the 3.5 gallon flush water closet was assumed as the target acceptance value for the required carry distance since current code practice permits such installations (without reports of failures due to blockages and wall deposits). The only 6 liter water closets able to meet that equivalent condition is with a 3 inch diameter pipe at 2% slope and that may be acceptable practice for installations.

In a number of tests the total heavy load solids were not completely discharged and even with a second flush some water closets could not empty the bowl. Both loadings represented a challenge to some water closets in performance testing, for others good repeatability in multiple tests was found (repeated 5 runs for light loads and 3 runs for heavy loads). Water closets that displayed poor performance with the sample materials had various numbers of solids discharged and inconsistent measured transport distances. Consistency for numbers discharged and transport distance in the drain was displayed by better performing water closets. However, no one-to-one correlation between performance with light and heavy loads was found from comparisons of data for both conditions, i.e., a good performance with a light load did not demonstrate good performance with a heavy load. That appears to demonstrate that the mixed media loading can be applied to obtain distinct differences from the two test loading conditions for application to differences in usage classifications.

COMPARISONS OF TESTS WITH ANALYTICAL MODEL

Test data and theoretical determinations of transport performance for each low flush volume water closet are listed below and shown in figures 3, 14, 15 for comparisons of waste transport capability. Considerable variations about the average are seen from one water closet to another. Agreement in the average distances for pipe diameter and pitch effects are confirmed between the computed and test measurements. Solids transport in the drain from water closets depend upon the surge wave generated and then upon the attenuation of the wave in the drain. The water closet discharge profiles are modified by the waste solid loads and delays in exiting the fixture; the trapway/bowl interactions with light and heavy loads are not necessarily the same and the consequence of different performance results. Drainline distance limits with low flush volume fixtures are important specification qualifications so that pipe size diameter and pipe pitch parameters must be accounted for in proper design. The analytical tool for carrying out the correct engineering design procedures is available from the computer analysis.

AVERAGE DISTANCE FOR SOLIDS TRANSPORT							
PRESSURIZED TANK WC 3" D., s=.02 Test Data		GRAVITY TANK WC 3" D., s=.02 Test Data		COMPUTER MODEL 3" D, s=.02 Distance (ft)			
WC #	Distance (ft)	WC #	Distance (ft)	Pressurized		Gravity	
4	24	1	23	Avg.		Avg.	
6	44	5	39	60.2		50.9	
8	23	7	32	Transport Distance for Each Solid (ft)			
10	55	9	26				
12	37	11	30	#	Dist.	#	Dist.
14	39	13	18	1	63.4	1	55.1
16	46	15	41	2	61.1	2	52.1
		17	75	3	56.1	3	45.5
		18	40				
		19	50				
		20	24				
	Avg. = 38 ft		Avg. = 30 ft				

AVERAGE DISTANCE FOR SOLIDS TRANSPORT							
PRESSURIZED TANK WC 4" D., s=.02 Test Data		GRAVITY TANK WC 4" D., s=.02 Test Data		COMPUTER MODEL 4" D, s=.02 Distance (ft)			
WC #	Distance (ft)	WC #	Distance (ft)	Pressurized		Gravity	
4	18	1	17	Avg.		Avg.	
6	33	5	27	37.1		29.4	
8	17	7	19	Transport Distance for Each Solid (ft)			
10	39	9	23				
12	29	11	18	#	Dist.	#	Dist.
14	31	13	22	1	39.9	1	32
16	46	15	37	2	38	2	29.7
		17	56	3	33.3	3	23.1
		18	48				
		19	23				
		20	21				
	Avg. = 30 ft		Avg. = 28 ft				

CLASSIFICATION FOR CATEGORIES OF USAGE

The different loads represent two variable mixed media material groups that appear to satisfy the need for discrimination of performance of water closets. There is little evidence for setting the quantities of mass and volume that best represent light and/or heavy usage. Therefore, it seems to be important that the test loadings have distinct characteristics that indicate clear differences in testing, with discrimination capability from one fixture to another. The test data and observations showed better performing water closets, in repeated test runs, gave comparable results without much difference from one run to another. Lesser performance fixtures were characterized by wider swings of the data when tests were repeated, an undesirable lack of fixture consistency that test media should be able to distinguish as shown by these tests. The test materials were able to be reused and yield repeatability; no efforts were made to establish lifetimes.

The water closet test data clearly separated the performance capabilities so that confidence in establishing a criteria for rank order strategy can be a realistic consideration. A combination of "scoring' assessment should account for: a) removal of solids from the bowl, and b) transport distances by a ranking order or distance (measured in the drain) with a weighting rule for determining a mean value, or an average value. The testing demonstrates the essential part of planning necessary progress toward a better standard.

CONCLUSIONS

Mixed media test loads for residential (light) loads and commercial (heavy) loads were arranged from preliminary laboratory evaluations to apply to testing of low flush volume water closets. In a new test facility test measurements were obtained for extraction of solids from water closets and solid waste transport distances in drainlines.

Testing of low flush volume water closets with two different mixed media representing residential and commercial loads demonstrated that gravity and pressurized tank types provided different levels of performance and demonstrated other parametric information.

- The capability of extracting solids from the fixture into a drain line was shown to be approximately the same for all water closets with the residential loading.
- For the commercial loading there were smaller numbers of solids out of the bowl; greater extraction capability was determined for the pressurized tank type water closets. Some water closets could not clear the bowl with a second water (only) flush. Waste solids transport distances for the pipe sizes and pitches tested indicated partially greater values for pressurized tank types, but not consistently for all models.
- For the residential loading the waste transport distances were only partially greater with the pressurized tank types. For commercial loadings transport distances were mainly greater for pressurized tank types. All water closets had separate overall performance levels identified.

Therefore, the mixed media can be considered to have shown a discriminating capacity for separate category ratings based upon combined performance for extraction and distance.

Model analysis comparisons with test results validated the predictive proficiency for determining transport and pipe sizing effects and applicability to plumbing drain problems.

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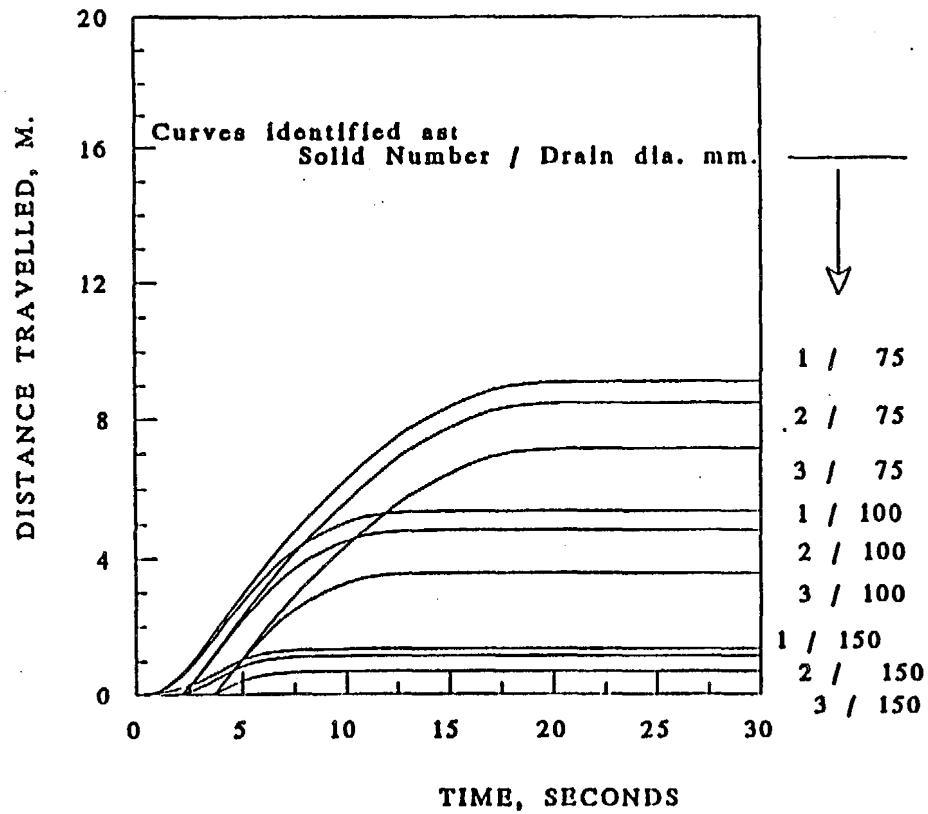
EFFECT OF DRAIN DIAMETER, 75, 100 OR 150 MM, ON SOLID TRANSPORT FOLLOWING DISCHARGE OF A 6 LITRE GRAVITY CISTERN WC TO A 20 M LONG HORIZONTAL DRAIN AT 0.01 SLOPE



EFFECT OF DRAIN DIAMETER, 75, 100 OR 150 MM, ON SOLID TRANSPORT FOLLOWING DISCHARGE OF A 6 LITRE PRESSURE CISTERN WC TO A 20 M LONG DRAIN AT 0.01 SLOPE.

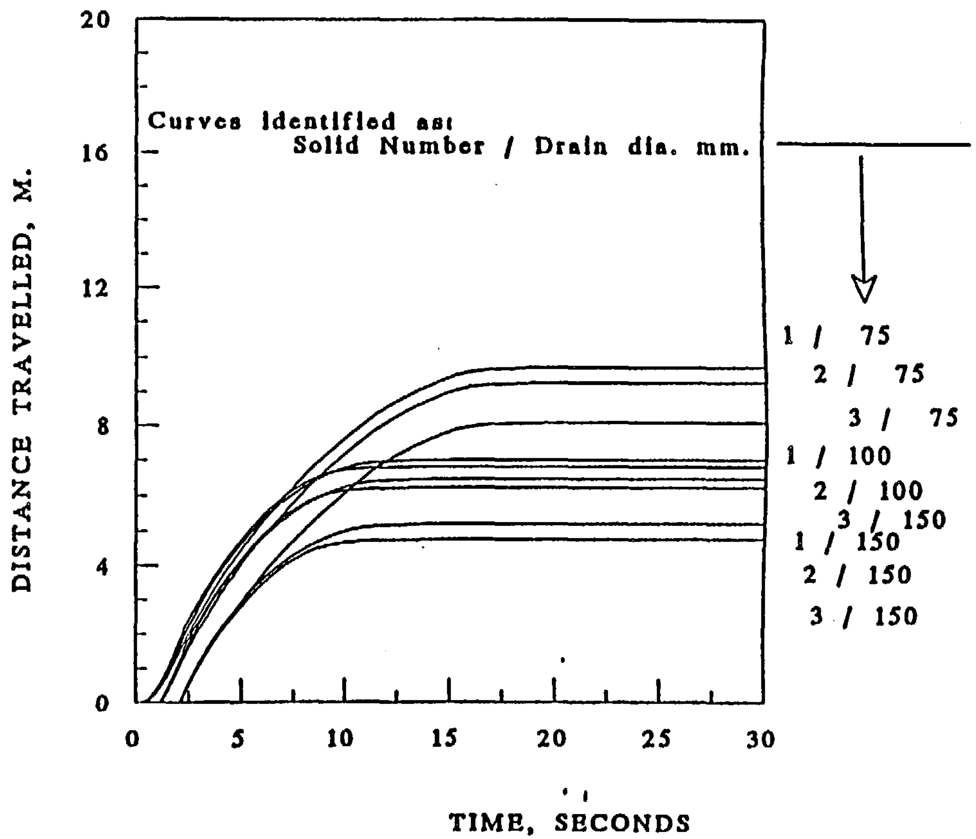


Figure 1

EFFECT OF DRAIN DIAMETER, 75, 100 OR 150 MM, ON SOLID TRANSPORT FOLLOWING DISCHARGE OF A 6 LITRE GRAVITY CISTERN WC TO A HORIZONTAL DRAIN AT 0.02 SLOPE.

EFFECT OF DRAIN DIAMETER, 75, 100 OR 150 MM, ON SOLID TRANSPORT FOLLOWING DISCHARGE OF A 6 LITRE PRESSURE CISTERN WC TO A 20 M LONG HORIZONTAL DRAIN AT 0.02 SLOPE

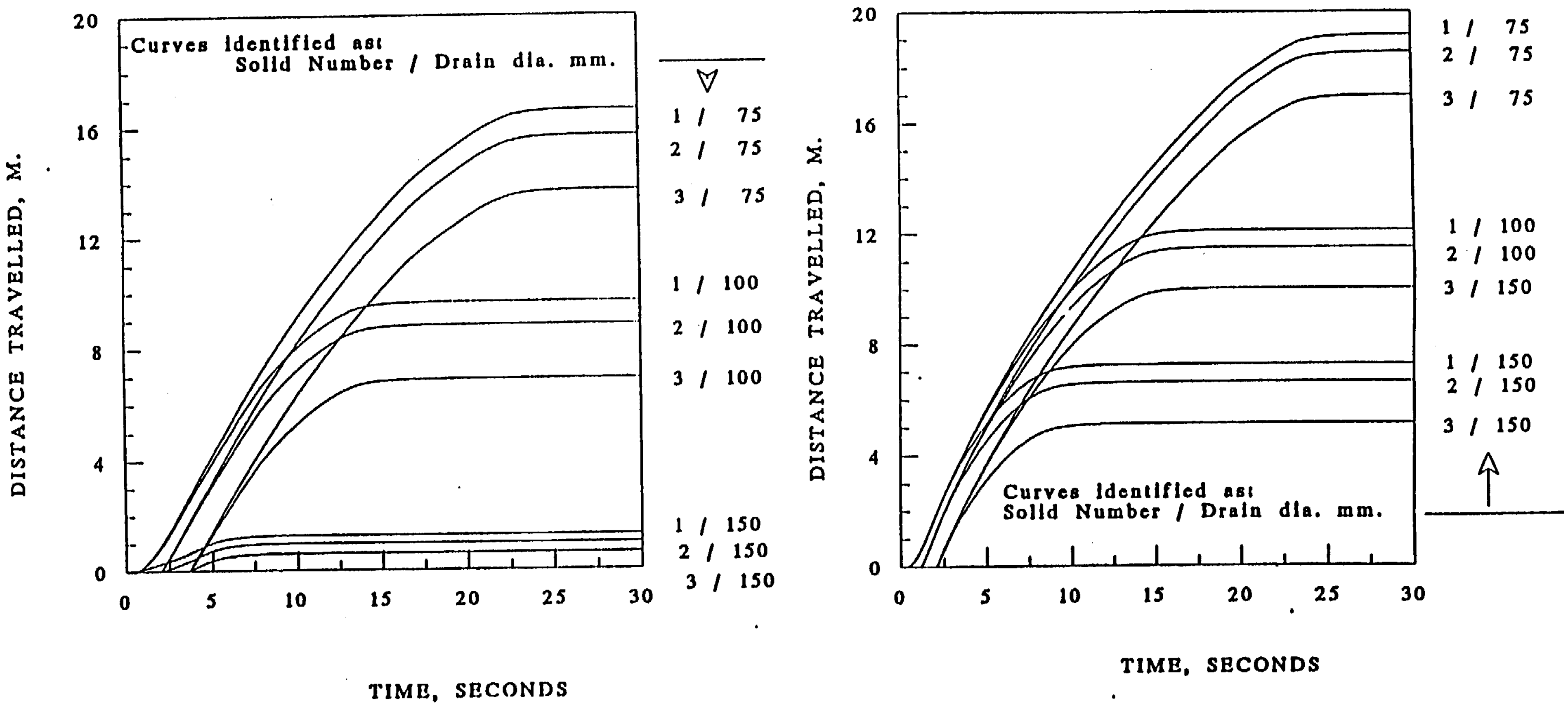


Figure 2

SOLID WASTE TRANSPORT DISTANCES

PIPE DIAMETERS AND PITCHES; THEORETICAL AND EXPERIMENTAL

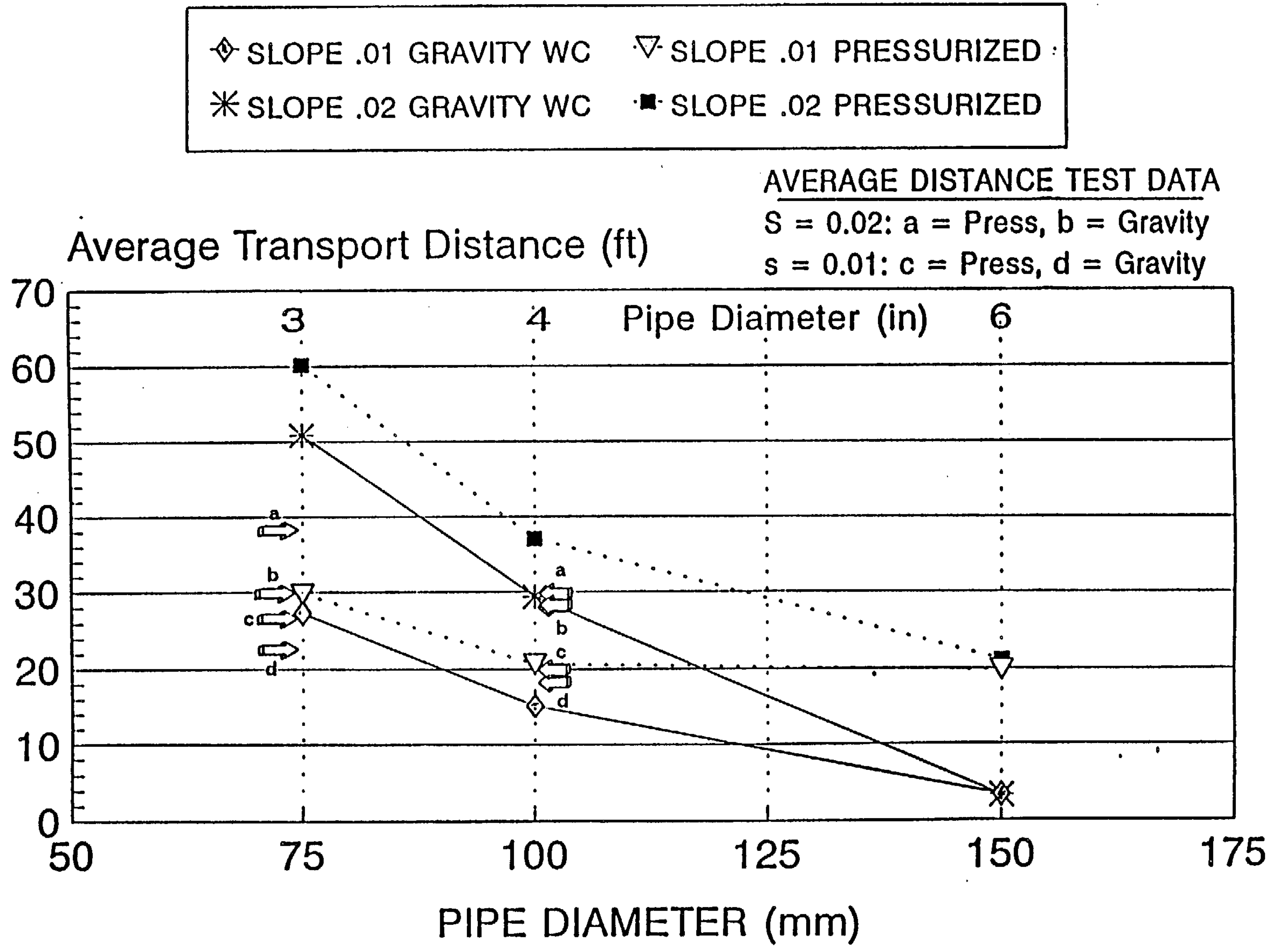
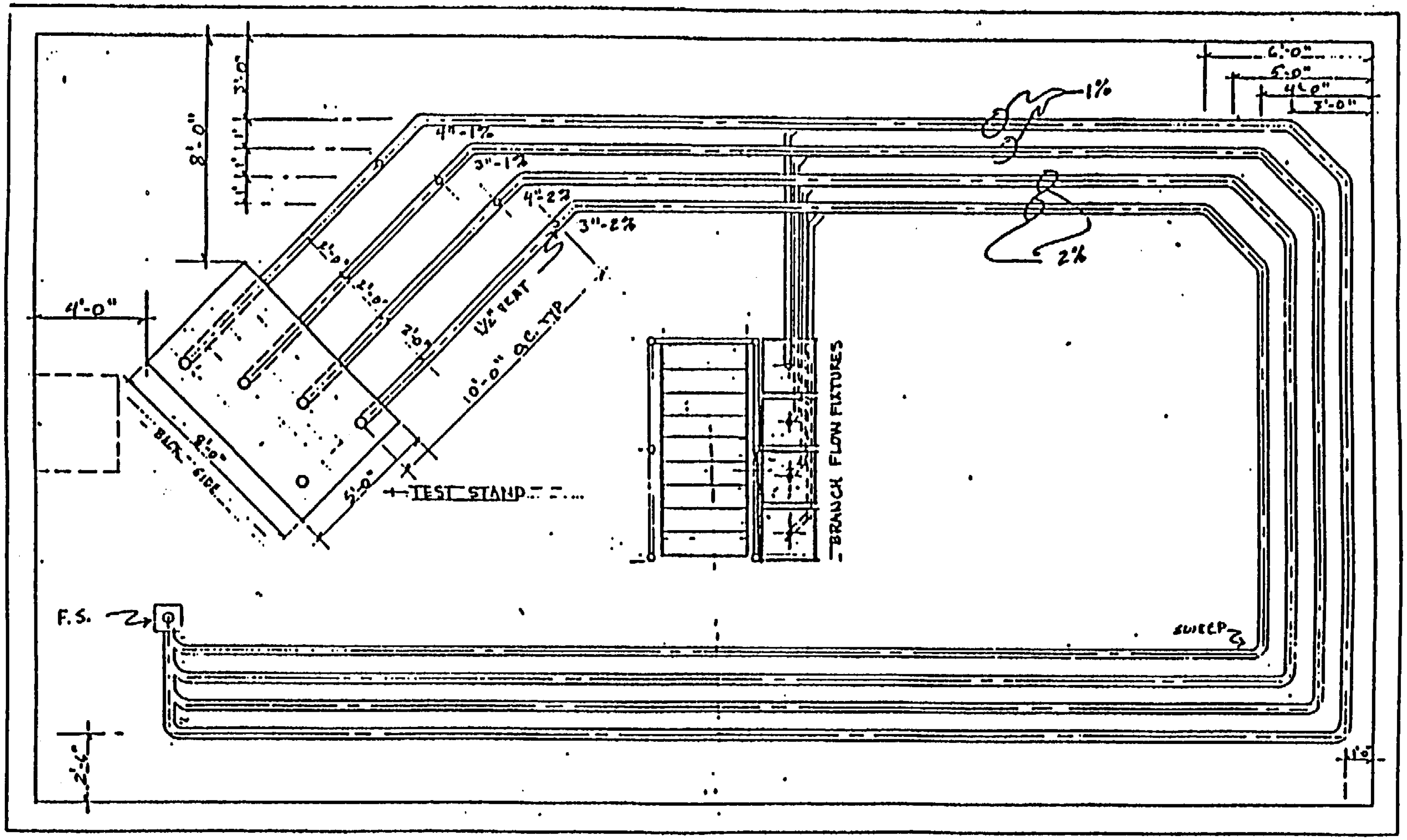


Figure 3



1/4" = 1'=0"
FLOOR PLAN

Floor Plan Layout of WSSC Water Closet
Drainline Transport Testing Laboratory

Figure 4

W.C. MIXED MEDIA DRAIN LINE TRANSPORT TEST

(Residential & Non-Public Commercial)

WASHINGTON SUBURBAN SANITARY COMMISSION

Tester Mohr Date 3-6-92 Supply Press.(psi) 62 Drain Dia.(in.) 3 ___ 4 X Pitch 1% X 2% ___ W.C. # 16

Water Consumption as Tested: Flush #1 ____ gal. Flush #2 ____ gal. Average Gal. 1.625 Branch Flow: 220 gpm

TRANSPORT DISTANCE OF TEST MEDIA (FEET)* (WITHOUT BRANCH FLOW) — RUN #1 to RUN #5; (WITH BRANCH FLOW) — RUN #6

MEDIA ITEM	RUN #1				RUN #2				RUN #3				RUN #4				RUN #5				RUN #6			
	First Flush		Second Flush		First Flush		Second Flush		First Flush		Second Flush		First Flush		Second Flush		First Flush		Second Flush		First Flush		Second Flush	
	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N
1	31.2		49.6		29.0		42.4		27.8		41.0		34.0		46.3		24.1		34.2		23.3		42.4	
2	24.0		48.4		28.0		42.3		25.1		40.9		28.7		44		22.6		34.0		22.9		42.3	
3	19.1		48.3		26.2		41.4		25.0		40.9		26.2		37.7		22.5		34.0		21.2		42.2	
4	19.0		48.2		25.8		41.3		21.4		40.7		24.4		37.6		17.8		33.9		17.8		42.1	
5	18.9		48.1		24.4		41.2		21.3		40.6		18.2		37.5		10.7		33.9		17.7		42.0	
6	18.8		48.1		24.2		41.1		18.0		40.5		17.7		37.4		20.6		33.8		17.5		42.0	
7	18.5		48.0		23.6		41.0		17.9		40.4		17.6		37.3		17.6		33.8		17.0		41.9	
8	16.5		47.9		20.9		40.9		17.4		40.3		17.5		37.2		10.7		33.6		16.8		41.9	
1		39.5		67.4		80		80		37.1		68.1		80		80		51.5		65.7		80		80
2		39.4		67.3		80		80		37.0		68.1		38.2		71.5		25.5		34.9		33.9		42.9
3		38.2		66.0		49.4		80		36.9		68.0		38.1		71.4		25.4		34.8		33.8		42.8
4		35.3		53.6		35.4		61.8		36.8		67.9		38.0		71.4		25.3		34.7		33.7		42.7
5		35.2		53.6		35.4		61.7		36.7		67.8		37.9		71.3		25.2		34.6		33.6		42.7
6		35.1		53.5		35.3		61.7		36.7		67.8		37.9		71.2		25.1		34.5		33.5		42.6
7		35.1		53.5		34.0		61.6		36.6		67.2		37.8		71.2		25.0		34.4		33.4		42.5
8		35.0		53.4		34.0		61.5		36.5		67.7		37.8		71.1		24.9		34.3		33.3		42.5
9		34.9		53.3		33.9		59.2		36.4		67.6		37.7		71.1		24.0		34.2		33.2		42.4
10		34.8		53.2		33.1		59.1		36.3		67.5		37.3		71.0		23.9		34.1		33.1		42.3
11		34.8		53.2		33.1		59.0		34.9		67.4		37.3		70.9		22.7		34.1		23.6		42.2
12		34.7		53.1		33.0		59.0		34.8		51.3		37.2		70.9		17.2		33.7		17.6		42.1
Tot.	166	432	386.4	681.1	202.1	516.6	331.6	784.6	173.9	436.7	325.2	796.9	184.3	495.2	315	863	159.2	316.3	271.2	444.0	154.2	332.1	336.8	547.7
Ave.	20.15	36	48.32	56.75	25.26	43.05	41.45	65.38	21.73	36.39	40.65	66.40	23.03	41.26	39.37	71.91	19.9	26.35	33.9	37.0	19.27	27.67	42.1	45.64
Ave.	40.45				43.78				41.29				43.89				29.28				33.67			
Ave.	39.73																				33.67			

S=Synthetic Sponge (8) N=Natural Sponge (12) *Media not clearing bowl recorded as zero (0) feet

W.C. MIXED MEDIA DRAIN LINE TRANSPORT TEST

(Public Commercial)

Tester Mohr Date 3-9-92 W.C.# 16

Supply Pressure (psi) 62 Drain Dia.(in.) 3 ___ 4 X Pitch 1% X 2% ___

Water Consumption as Tested: Flush#1 ___ gal. Flush#2 ___ gal. Average Gal. 1.625

TRANSPORT DISTANCE OF TEST MEDIA (FEET)*
(WITHOUT BRANCH FLOW)

MEDIA ITEM	RUN#1						RUN#2						RUN#3					
	First Flush			Second Flush			First Flush			Second Flush			First Flush			Second Flush		
	S	N	T	S	N	T	S	N	T	S	N	T	S	N	T	S	N	T
1	23.3			28.7			22.0			40.6			23.0			30.4		
2	19.8			28.6			15.1			40.0			22.7			30.4		
3	18.9			28.4			13.3			39.7			19.5			30.2		
4	18.4			28.3			12.6			39.6			18.6			30.1		
5	18.3			28.2			12.5			39.5			18.3			30.0		
6	16.1			28.2			12.3			39.4			18.2			29.9		
7	16.0			28.1			12.0			39.3			16.3			29.9		
8	15.9			28.0			11.3			39.2			15.6			29.8		
9	14.0			27.9			11.6			29.2			15.5			29.7		
10	12.5			27.7			11.2			39.1			12.0			29.7		
11	12.4			27.7			11.1			39.0			11.9			29.6		
12	12.3			26.6			10.9			38.5			11.8			29.6		
1		25.2			29.2			27.5			40.9			24.3			31.1	
2		25.1			29.1			26.2			40.8			24.3			31.0	
3		24.0			29.1			22.1			40.7			24.2			31.0	
4		23.9			29.1			21.3			40.5			24.1			30.9	
5		23.2			29.0			17.1			40.2			24.0			30.8	
6		21.9			29.0			16.0			40.1			23.9			30.8	
7		20.8			28.7			15.2			40.1			23.6			30.8	
8		19.2			28.5			15.0			39.9			23.6			30.8	
9		18.6			28.3			13.2			39.7			23.1			30.6	
10		18.5			28.1			12.4			39.4			22.9			30.5	
11		15.8			28.0			11.3			39.1			21.0			30.2	
12		14.3			28.0			11.0			39.0			19.4			30.2	
13		14.2			27.8			10.8			38.9			16.2			30.0	
14		14.1			27.7			10.7			38.8			15.7			29.8	
1			22.1			28.9			21.7			40.6			23.9			30.7
2			21.8			28.9			17.6			40.4			23.6			30.7
3			19.5			28.6			17.5			40.4			23.4			30.7
4			19.3			28.5			13.3			39.8			21.1			30.3
Tot.	197.9	278.8	82.7	336.4	399.6	114.9	156.4	229.8	70.1	473.4	558.1	161.2	203.6	310.3	92	359.3	428.5	122.4
Ave.	16.49	19.91	20.67	28.03	28.54	28.72	13.03	16.41	17.52	39.45	39.86	40.3	16.96	22.16	23	29.94	30.60	30.6
Ave.	23.72						27.76						25.54					
Ave.	25.67																	

S=Synthetic Sponge (12) N=Natural Sponge (14) T=Towelette (4) *Media not clearing bowl recorded as zero (0) feet

WASHINGTON SUBURBAN SANITARY COMMISSION

W.C. MIXED MEDIA DRAIN LINE TRANSPORT TEST

WASHINGTON SUBURBAN SANITARY COMMISSION

(Residential & Non-Public Commercial)

Tester *Mohr* Date: 3-6-92 Supply Press.(psi) 62 Drain Dia.(in.) 3 X 4 ___ Pitch 1% X 2% ___ W.C. # 17

Water Consumption as Tested: Flush #1 ___ gal. Flush #2 ___ gal. Average Gal. 1.78 Branch Flow: 2.20 gpm

TRANSPORT DISTANCE OF TEST MEDIA (FEET)* (WITHOUT BRANCH FLOW) — RUN #1 to RUN #5; (WITH BRANCH FLOW) — RUN #6

MEDIA ITEM	RUN #1 First Flush S	RUN #1 First Flush N	RUN #1 Second Flush S	RUN #1 Second Flush N	RUN #2 First Flush S	RUN #2 First Flush N	RUN #2 Second Flush S	RUN #2 Second Flush N	RUN #3 First Flush S	RUN #3 First Flush N	RUN #3 Second Flush S	RUN #3 Second Flush N	RUN #4 First Flush S	RUN #4 First Flush N	RUN #4 Second Flush S	RUN #4 Second Flush N	RUN #5 First Flush S	RUN #5 First Flush N	RUN #5 Second Flush S	RUN #5 Second Flush N	RUN #6 First Flush S	RUN #6 First Flush N	RUN #6 Second Flush S	RUN #6 Second Flush N
1	57.5		80		62.2		80		57.0		80		33.7		48.4		35.9		53.7		56.2		80	
2	52.0		80		[illegible]		80		56.5		80		33.6		48.3		35.8		53.6		56.2		80	
3	[illegible]		80		62.0		80		44.0		72.9		33.5		48.2		35.8		53.5		56.1		80	
4	[illegible]		80		58.2		80		44.5		62.5		33.4		48.2		35.7		52.5		56.1		80	
5	[illegible]		[illegible]		58.2		80		44.4		62.4		33.4		48.1		35.7		52.4		56.0		[illegible]	
6	[illegible]		[illegible]		58.1		80		44.3		62.3		33.3		48.1		35.6		53.4		56.0		80	
7	56.6		[illegible]		58.0		80		44.2		62.2		33.2		48.0		35.6		53.3		55.9		80	
8	56.5		[illegible]		52.9		80		44.1		62.1		33.1		48.0		35.5		53.3		55.9		80	
1		80		[illegible]		72.6		80		62.9		80		54.2		56.6		43.6		80		[illegible]		80
2		51.7		[illegible]		62.8		80		62.8		80		53.5		56.6		36.9		54.5		[illegible]		80
3		51.6		[illegible]		62.7		80		62.5		80		34.5		49.1		[illegible]		54.4		56.7		80
4		52.5		[illegible]		62.6		80		62.4		80		34.4		48.9		[illegible]		54.3		56.6		80
5		[illegible]		[illegible]		62.5		80		57.0		80		34.3		48.9		36.6		54.2		56.5		80
6		[illegible]		[illegible]		62.4		80		56.9		80		34.2		48.8		36.5		54.2		[illegible]		80
7		[illegible]		[illegible]		62.4		80		56.8		80		34.1		48.7		36.4		54.1		[illegible]		80
8		[illegible]		[illegible]		62.3		80		[illegible]		80		34.0		48.6		36.3		54.0		56.4		80
9		[illegible]		[illegible]		62.3		80		56.7		80		33.9		48.5		36.2		53.9		[illegible]		80
10		52.2		[illegible]		62.2		80		56.6		80		33.8		48.5		36.2		53.9		[illegible]		80
11		51.2		[illegible]		62.2		80		56.6		80		33.7		48.4		36.1		53.8		[illegible]		80
12		51.1		80		60.1		80		53.6		80		33.6		48.3		36.0		53.8		[illegible]		80
Tot.	451.1	711.2	640	960	476.7	757.1	640	960	379.6	704.6	544.4	960	267.2	418.2	385.3	599.9	285.6	444.2	427.7	675.1	448.4	701.4	640	960
Ave.	56.86	59.16	80	80	59.58	63.09	80	80	47.45	58.71	68.05	80	33.4	37.25	48.16	49.99	35.7	37.02	53.46	56.25	56.05	58.45	80	80
Ave.	61.03				70.66				63.55				42.22				45.60				68.62			
Ave.	58.21																				68.62			

S=Synthetic Sponge (8) N=Natural Sponge (12) *Media not clearing bowl recorded as zero (0) feet

W.C. MIXED MEDIA DRAIN LINE TRANSPORT TEST

(Public Commercial)

Tester Mohr Date 3-9-92 W.C.# 17

Supply Pressure (psi) 62 Drain Dia.(in.) 3 X 4 ___ Pitch 1% X 2% ___

Water Consumption as Tested: Flush#1 ____gal. Flush#2 ____gal. Average Gal. 1.72

TRANSPORT DISTANCE OF TEST MEDIA (FEET)*
(WITHOUT BRANCH FLOW)

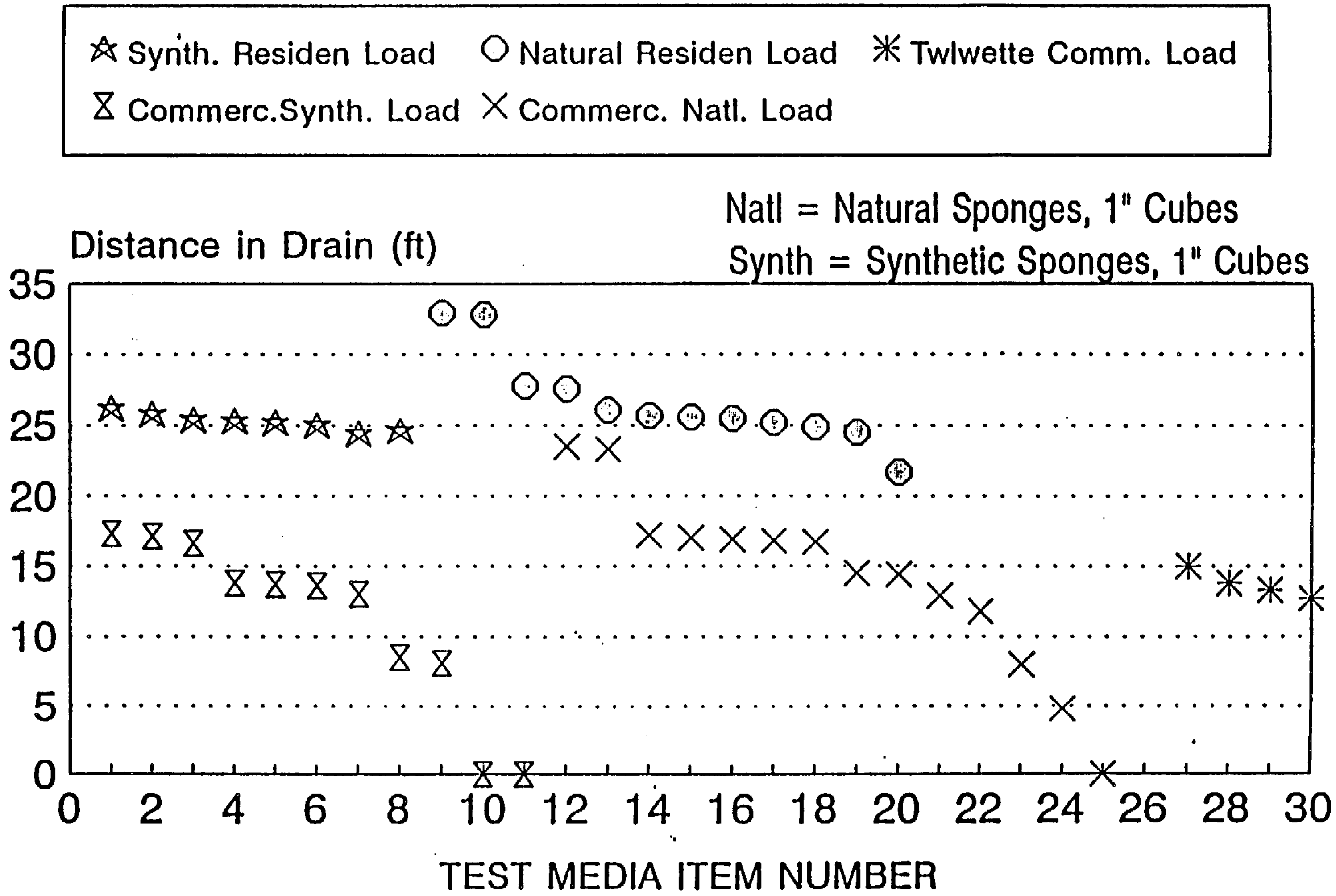
MEDIA ITEM	RUN#1						RUN#2						RUN#3					
	First Flush			Second Flush			First Flush			Second Flush			First Flush			Second Flush		
	S	N	T	S	N	T	S	N	T	S	N	T	S	N	T	S	N	T
1	23.2			26.9			28.5			28.5			32.7			35.8		
2	23.7			26.8			28.4			28.4			32.7			35.7		
3	23.6			26.8			28.3			28.3			32.5			35.6		
4	20.3			26.6			28.2			28.2			32.4			35.5		
5	2.2			26.4			28.1			28.1			32.4			35.5		
6	0			0			28.0			28.0			32.3			35.4		
7	0			0			23.4			23.4			32.2			35.4		
8	0			0			23.4			23.4			32.0			35.3		
9	0			0			4.0			4.0			31.8			35.1		
10	0			0			0			0			31.5			34.9		
11	0			0			0			0			32.1			34.8		
12	0			0			0			0			19.3			34.5		
1		24.3			27.6			32.1			30.1			34.2			36.5	
2		24.2			27.5			30.0			30.0			33.3			36.3	
3		24.1			27.4			29.3			29.3			33.2			36.1	
4		24.0			27.3			29.3			29.3			33.1			36.1	
5		23.9			27.2			29.1			29.1			33.0			36.1	
6		23.8			27.2			29.0			29.0			32.9			36.0	
7		23.5			27.1			29.0			29.0			32.9			35.9	
8		23.5			27.0			28.9			28.9			32.7			35.9	
9		23.4			27.0			28.8			28.8			32.6			35.6	
10		20.4			26.7			27.7			28.7			32.2			35.4	
11		20.4			26.6			28.6			28.6			31.9			35.3	
12		13.0			26.5			27.4			28.4			31.9			35.2	
13		0			0			24.2			24.2			31.7			35.0	
14		0			0			24.1			24.1			31.6			35.0	
1			0			0			0			0			22.0			34.7
2			0			0			0			0			20.6			34.7
3			0			0			0			0			19.5			34.7
4			0			0			0			0			19.0			34.3
Tot.	93.6	268.5	0	133.5	325.2	0	220.3	397.5	0	222.2	397.5	0	371.8	457.2	81.1	423.5	500.2	138.4
Ave.	7.8	19.17	0	11.12	23.22	0	18.35	28.39	0	18.35	28.39	0	32.98	32.65	20.27	35.29	35.72	34.6
Ave.	10.21						15.58						31.58					
Ave.	19.12																	

S=Synthetic Sponge (12) N=Natural Sponge (14) T=Towelette (4) *Media not clearing bowl recorded as zero (0) feet

SND (II UH/2.0 13 7 0

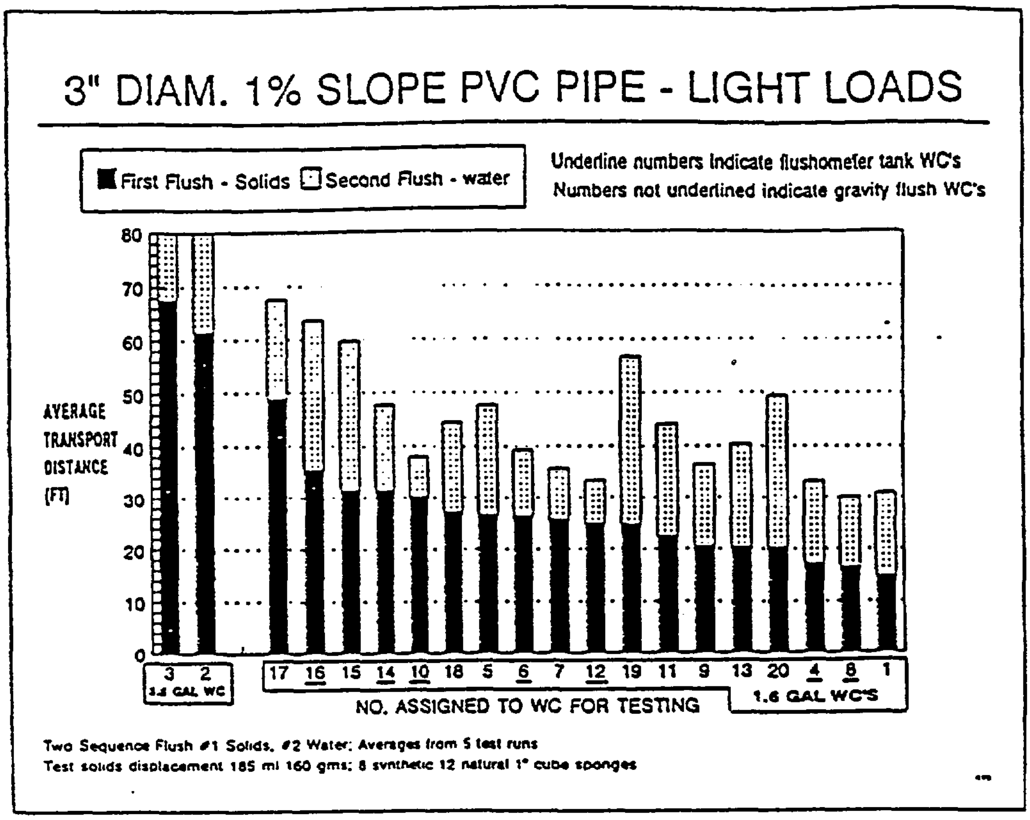
WASHINGTON SUBURBAN SANITARY COMMISSION

MIXED MEDIA DRAINLINE TRANSPORT TEST
3" DIAMETER, 2% SLOPE DRAIN
RUN NO. 1; RESIDENTIAL AND COMMERCIAL LOADS

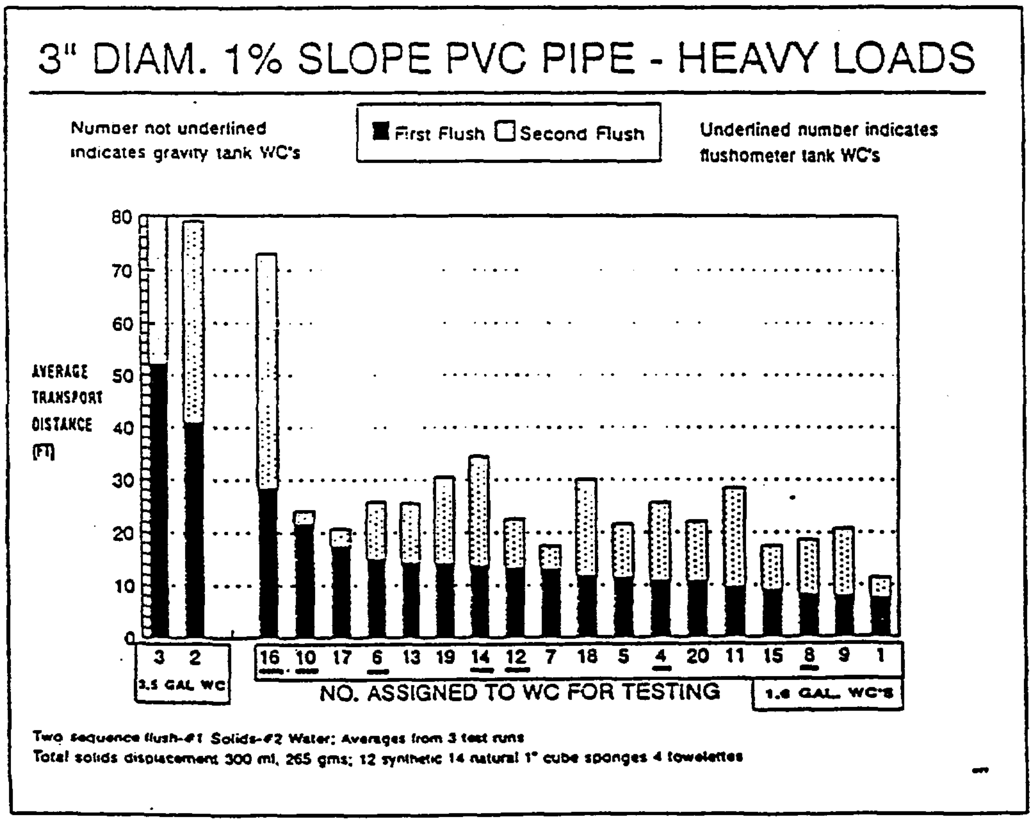


Residential Load = 8 Synthetic and 12 Natural Sponges, 1" Cubes
Commercial Load = 12 Synthetic, 14 Natural Sponges, 1" Cubes and 4 Towelettes

Figure 5

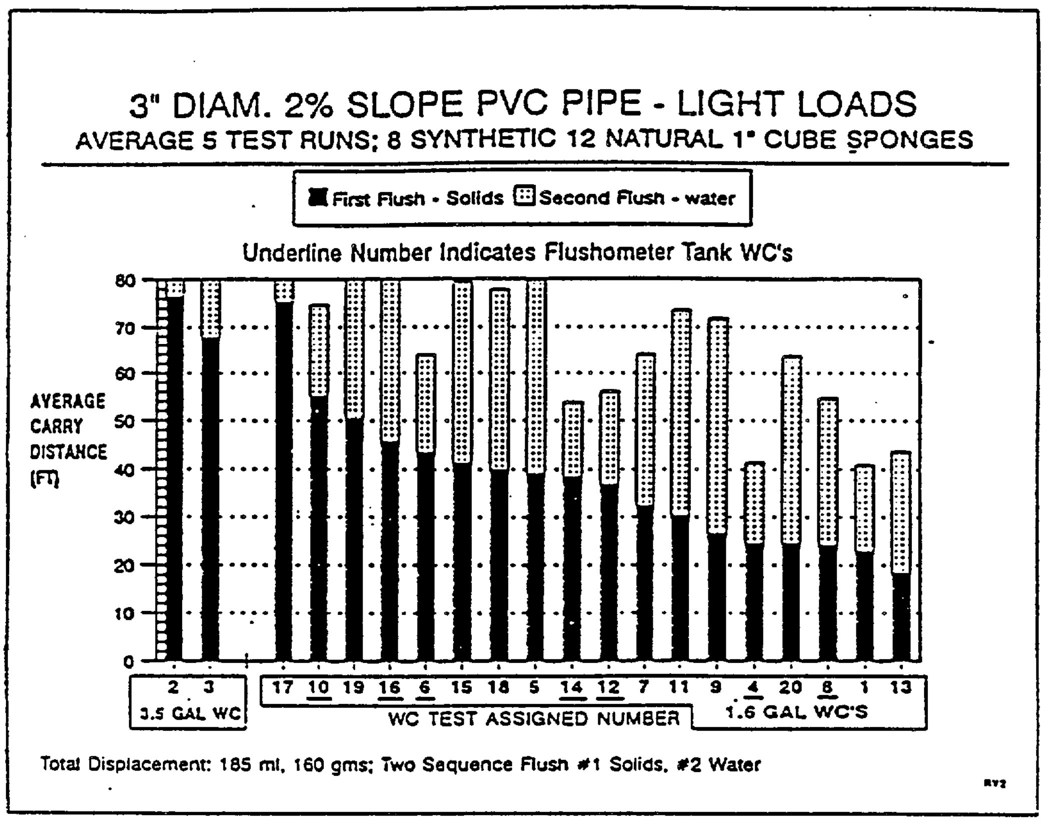


3" DIAM. 1% SLOPE PVC PIPE - LIGHT LOADS
First Flush - Solids
Second Flush - water
Underline numbers indicate flushometer tank WC's
Numbers not underlined indicate gravity flush WC's
AVERAGE TRANSPORT DISTANCE (FT)
80
70
60
50
40
30
20
10
0
3 2
3.5 GAL WC
17 16 15 14 10 18 5 6 7 12 19 11 9 13 20 4 8 1
NO. ASSIGNED TO WC FOR TESTING
1.6 GAL WC'S
Two Sequence Flush #1 Solids, #2 Water; Averages from 5 test runs
Test solids displacement 185 ml 160 gms; 8 synthetic 12 natural 1" cube sponges

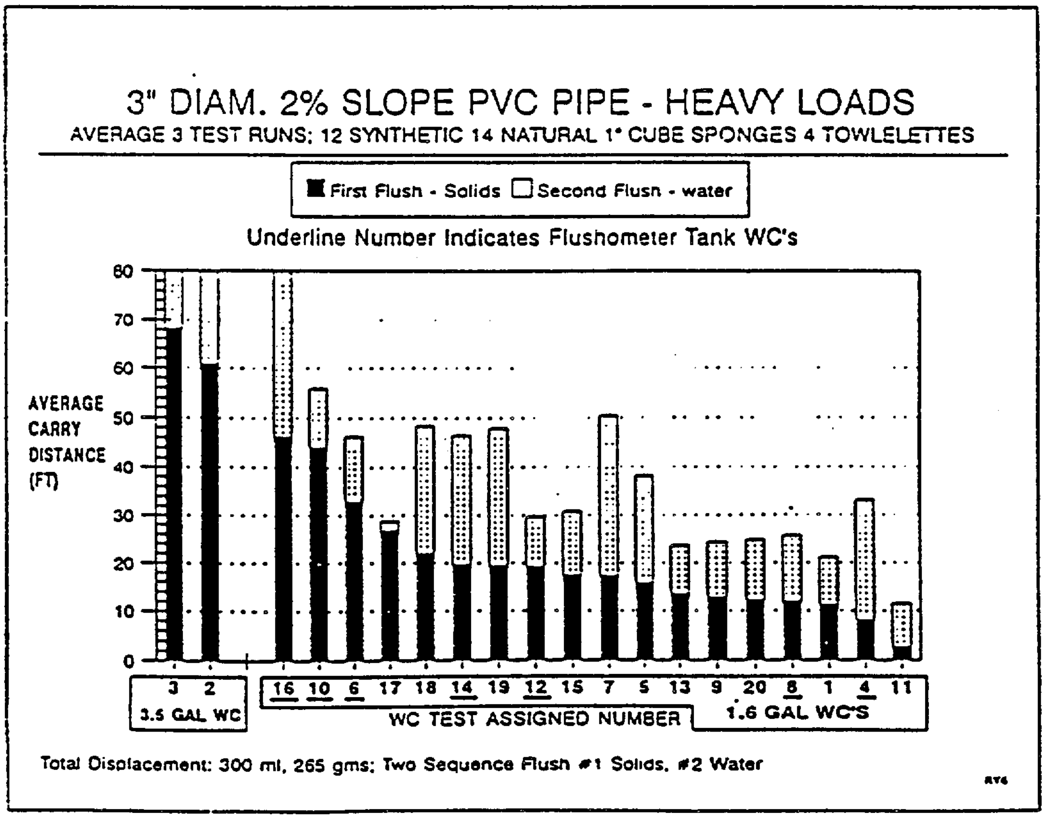


3" DIAM. 1% SLOPE PVC PIPE - HEAVY LOADS
Number not underlined indicates gravity tank WC's
First Flush
Second Flush
Underlined number indicates flushometer tank WC's
AVERAGE TRANSPORT DISTANCE (FT)
80
70
60
50
40
30
20
10
0
3 2
3.5 GAL WC
16 10 17 6 13 19 14 12 7 18 5 4 20 11 15 8 9 1
NO. ASSIGNED TO WC FOR TESTING
1.6 GAL. WC'S
Two sequence flush-#1 Solids-#2 Water; Averages from 3 test runs
Total solids displacement 300 ml, 265 gms; 12 synthetic 14 natural 1" cube sponges 4 towelettes

Figure 6

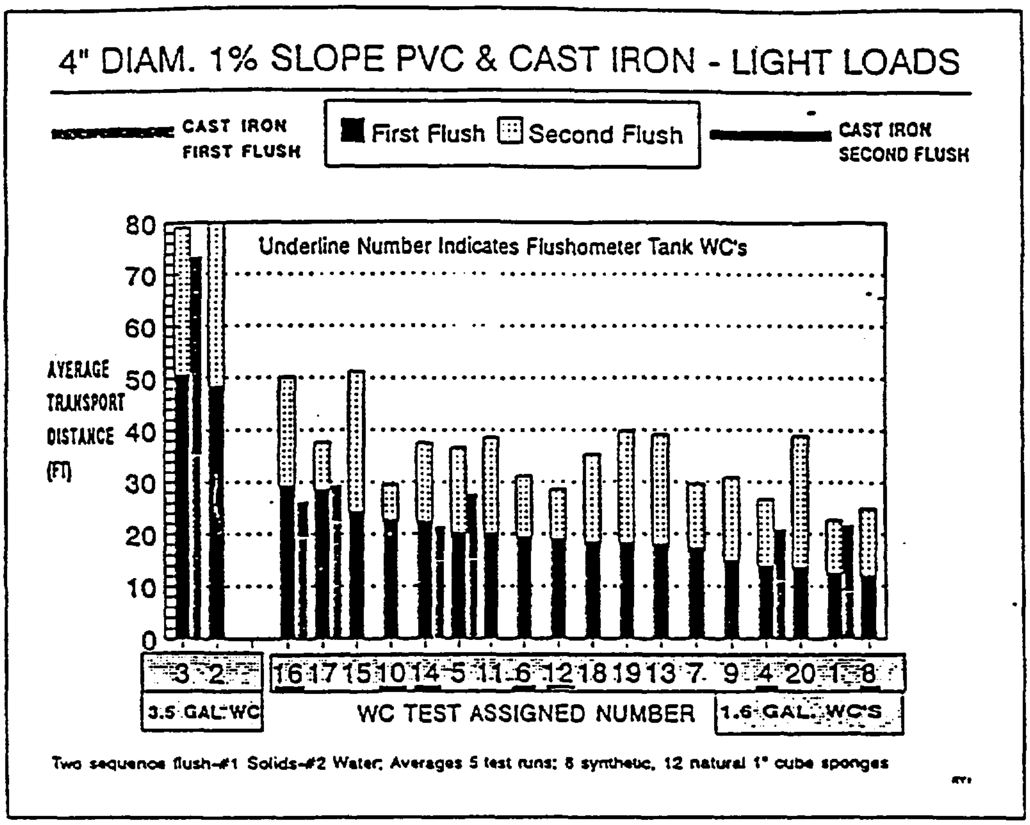


3" DIAM. 2% SLOPE PVC PIPE - LIGHT LOADS
AVERAGE 5 TEST RUNS; 8 SYNTHETIC 12 NATURAL 1" CUBE SPONGES
First Flush - Solids
Second Flush - water
Underline Number Indicates Flushometer Tank WC's
AVERAGE CARRY DISTANCE (FT)
80
70
60
50
40
30
20
10
0
2 3
3.5 GAL WC
17 10 19 16 6 15 18 5 14 12 7 11 9 4 20 8 1 13
WC TEST ASSIGNED NUMBER
1.6 GAL WC'S
Total Displacement: 185 ml, 160 gms; Two Sequence Flush #1 Solids, #2 Water

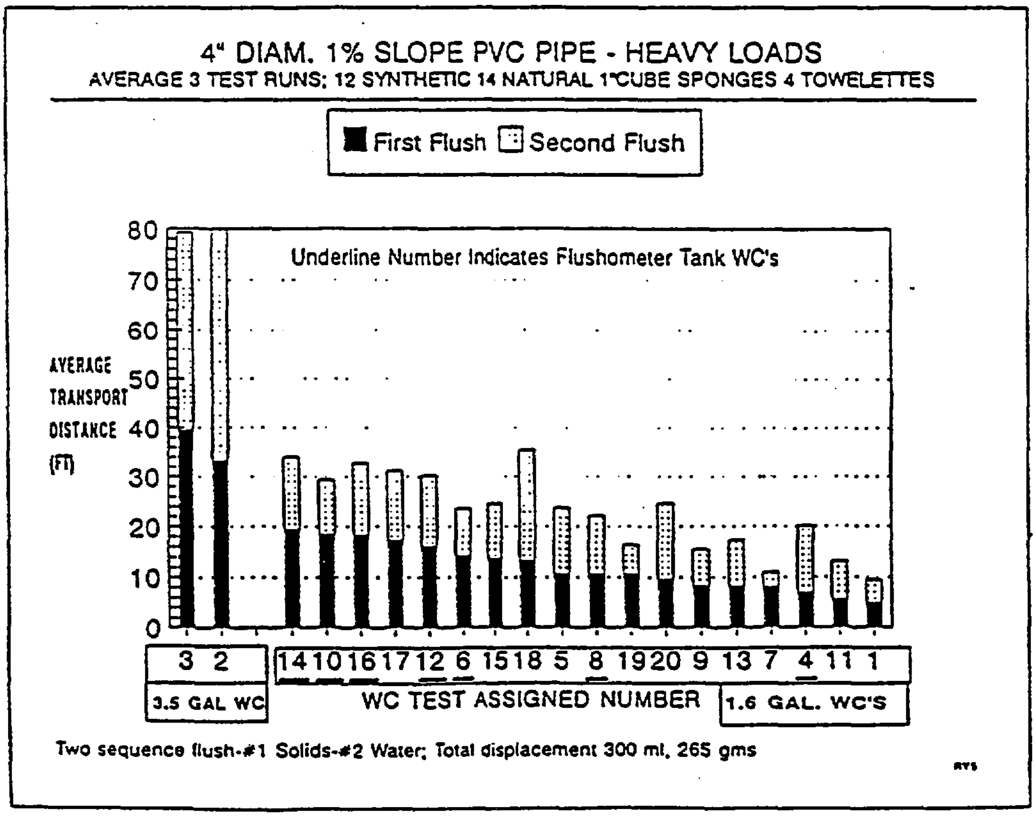


3" DIAM. 2% SLOPE PVC PIPE - HEAVY LOADS
AVERAGE 3 TEST RUNS; 12 SYNTHETIC 14 NATURAL 1" CUBE SPONGES 4 TOWLELETTES
First Flush - Solids
Second Flush - water
Underline Number Indicates Flushometer Tank WC's
AVERAGE CARRY DISTANCE (FT)
80
70
60
50
40
30
20
10
0
3 2
3.5 GAL WC
16 10 6 17 18 14 19 12 15 7 5 13 9 20 8 1 4 11
WC TEST ASSIGNED NUMBER
1.6 GAL WC'S
Total Displacement: 300 ml, 265 gms; Two Sequence Flush #1 Solids, #2 Water

Figure 7

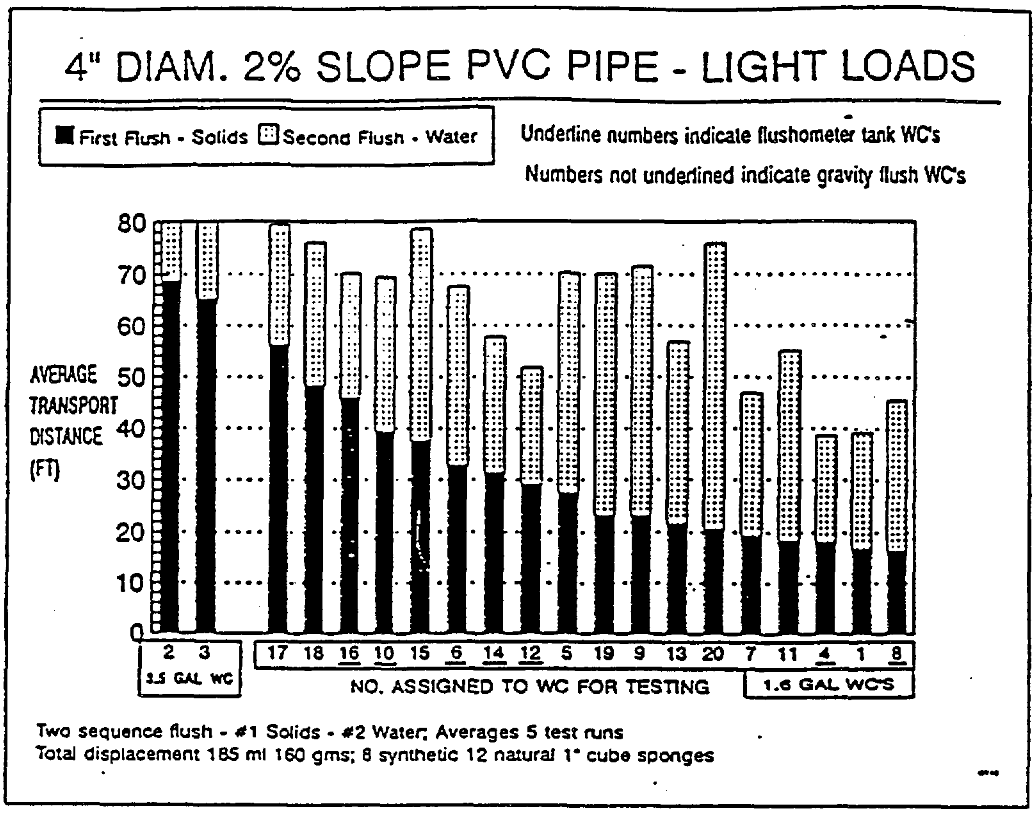


4" DIAM. 1% SLOPE PVC & CAST IRON - LIGHT LOADS
CAST IRON FIRST FLUSH
First Flush
Second Flush
CAST IRON SECOND FLUSH
Underline Number Indicates Flushometer Tank WC's
AVERAGE TRANSPORT DISTANCE (FT)
80
70
60
50
40
30
20
10
0
3 2
16 17 15 10 14 5 11 6 12 18 19 13 7 9 4 20 1 8
3.5 GAL WC
WC TEST ASSIGNED NUMBER
1.6 GAL. WC'S
Two sequence flush-#1 Solids-#2 Water; Averages 5 test runs; 8 synthetic, 12 natural 1" cube sponges



4" DIAM. 1% SLOPE PVC PIPE - HEAVY LOADS
AVERAGE 3 TEST RUNS; 12 SYNTHETIC 14 NATURAL 1"CUBE SPONGES 4 TOWELETTES
First Flush
Second Flush
Underline Number Indicates Flushometer Tank WC's
AVERAGE TRANSPORT DISTANCE (FT)
80
70
60
50
40
30
20
10
0
3 2
14 10 16 17 12 6 15 18 5 8 19 20 9 13 7 4 11 1
3.5 GAL WC
WC TEST ASSIGNED NUMBER
1.6 GAL. WC'S
Two sequence flush-#1 Solids-#2 Water; Total displacement 300 ml, 265 gms

Figure 8


4" DIAM. 2% SLOPE PVC PIPE - LIGHT LOADS
First Flush - Solids
Second Flush - Water
Underline numbers indicate flushometer tank WC's
Numbers not underlined indicate gravity flush WC's
AVERAGE TRANSPORT DISTANCE (FT)
80
70
60
50
40
30
20
10
0
2 3
3.5 GAL WC
17 18 16 10 15 6 14 12 5 19 9 13 20 7 11 4 1 8
NO. ASSIGNED TO WC FOR TESTING
1.6 GAL WC'S
Two sequence flush - #1 Solids - #2 Water; Averages 5 test runs
Total displacement 185 ml 160 gms; 8 synthetic 12 natural 1" cube sponges

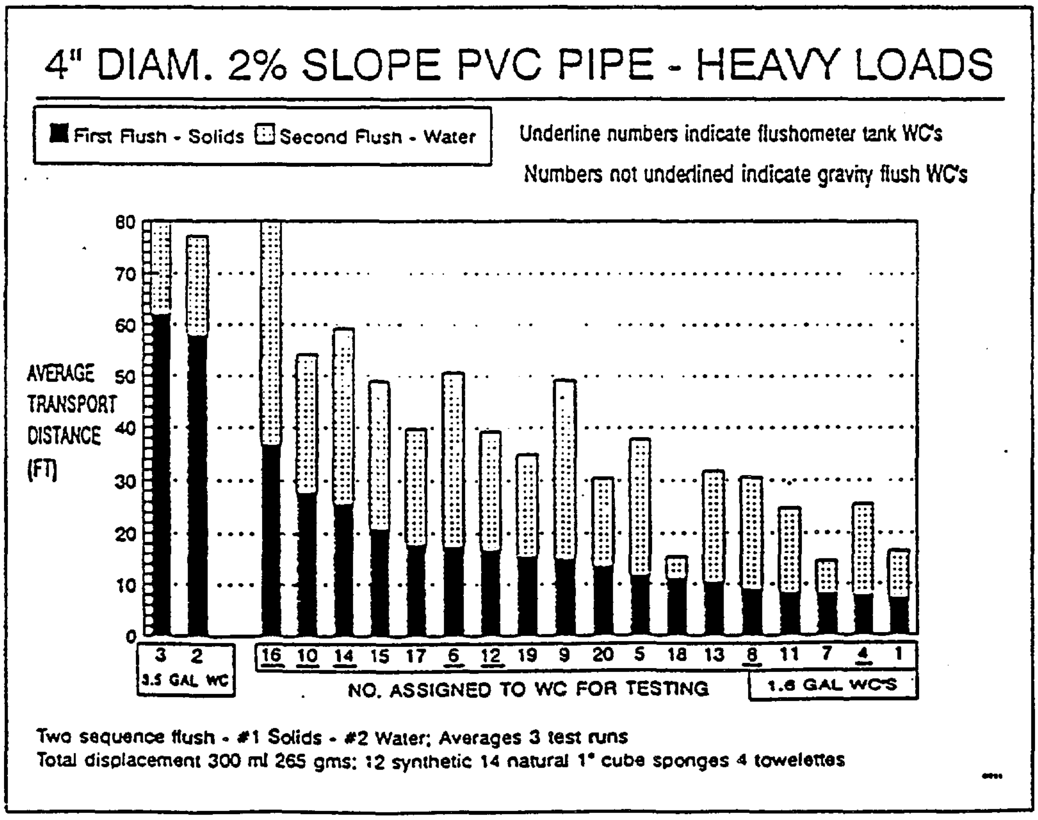
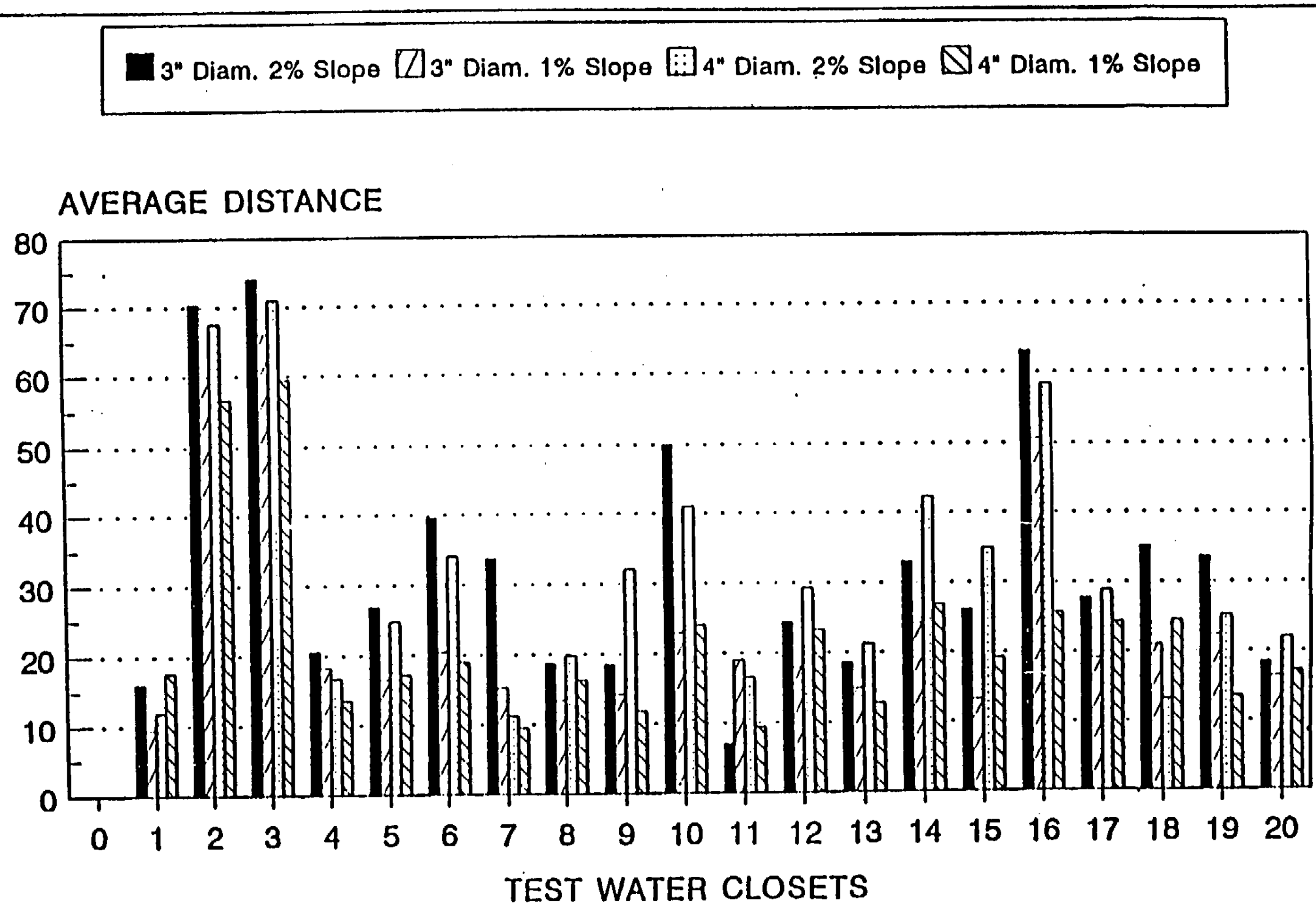

4" DIAM. 2% SLOPE PVC PIPE - HEAVY LOADS
First Flush - Solids
Second Flush - Water
Underline numbers indicate flushometer tank WC's
Numbers not underlined indicate gravity flush WC's
AVERAGE TRANSPORT DISTANCE (FT)
80
70
60
50
40
30
20
10
0
3 2
3.5 GAL WC
16 10 14 15 17 6 12 19 9 20 5 18 13 8 11 7 4 1
NO. ASSIGNED TO WC FOR TESTING
1.6 GAL WC'S
Two sequence flush - #1 Solids - #2 Water; Averages 3 test runs
Total displacement 300 ml 265 gms; 12 synthetic 14 natural 1" cube sponges 4 towelettes

Figure 9

MIXED MEDIA DRAIN LINE TRANSPORT, HEAVY LOAD

AVERAGE DISTANCE, PVC DRAIN, TWO FLUSH SEQUENCE, NO BRANCH FLOW
12 SYNTHETIC, 14 NATURAL 1" CUBES, & 4 TOWELLETTES

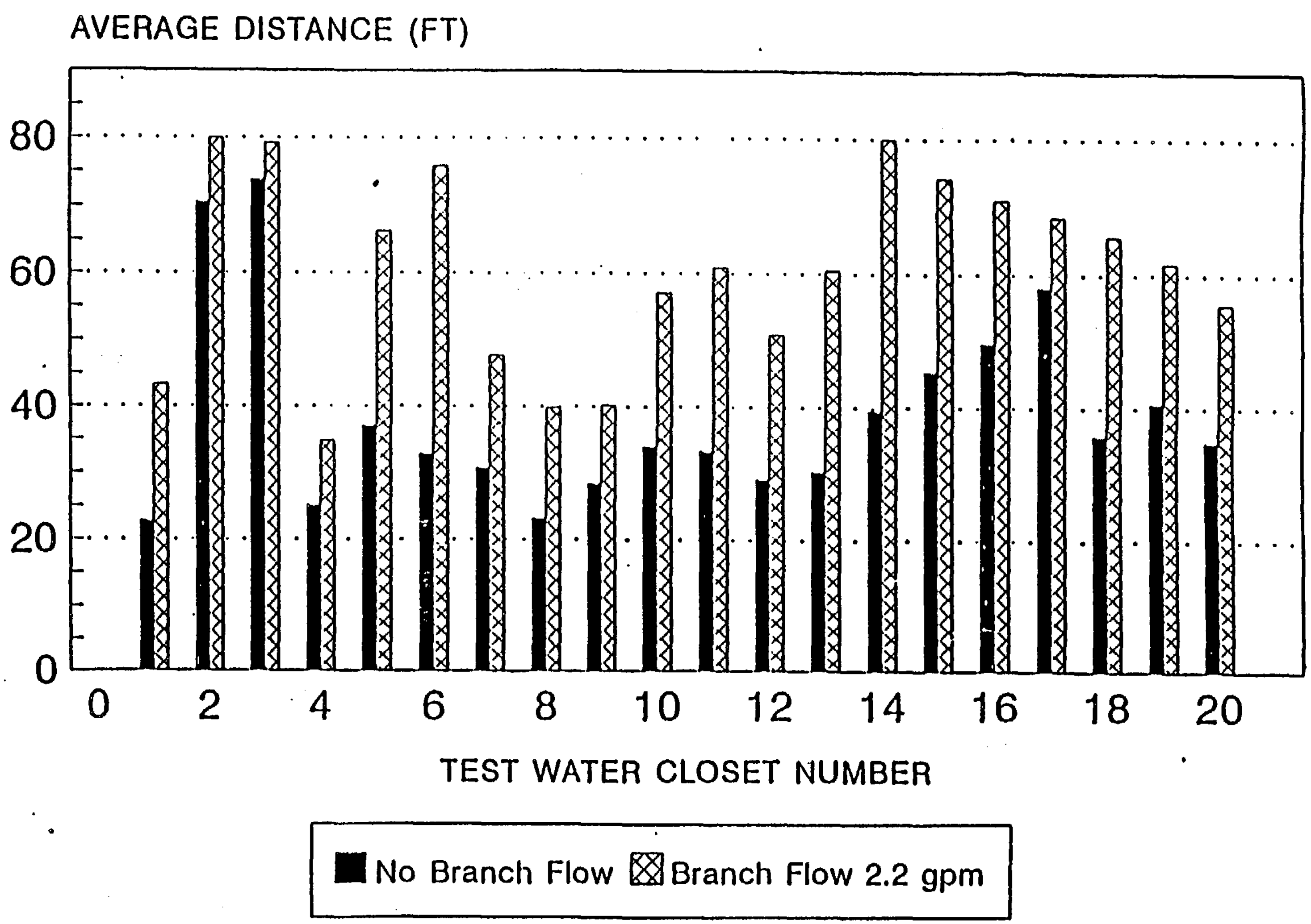


LOW FLUSH VOLUME WC'S #1, #4-20; WATER SAVER #2,3
2 FLUSH FOLLOW-ON DATA, AVERAGE OF 3 RUNS
ELONGATED BOWLS # 1, 8, 10, 12, 14; FLUSHOMETER TANKS # 4, 6, 10, 12, 14, 16

Figure 10

MIXED MEDIA DRAIN LINE TRANSPORT

AVERAGE DISTANCE FOR 1% SLOPE, TWO FLUSH SEQUENCE

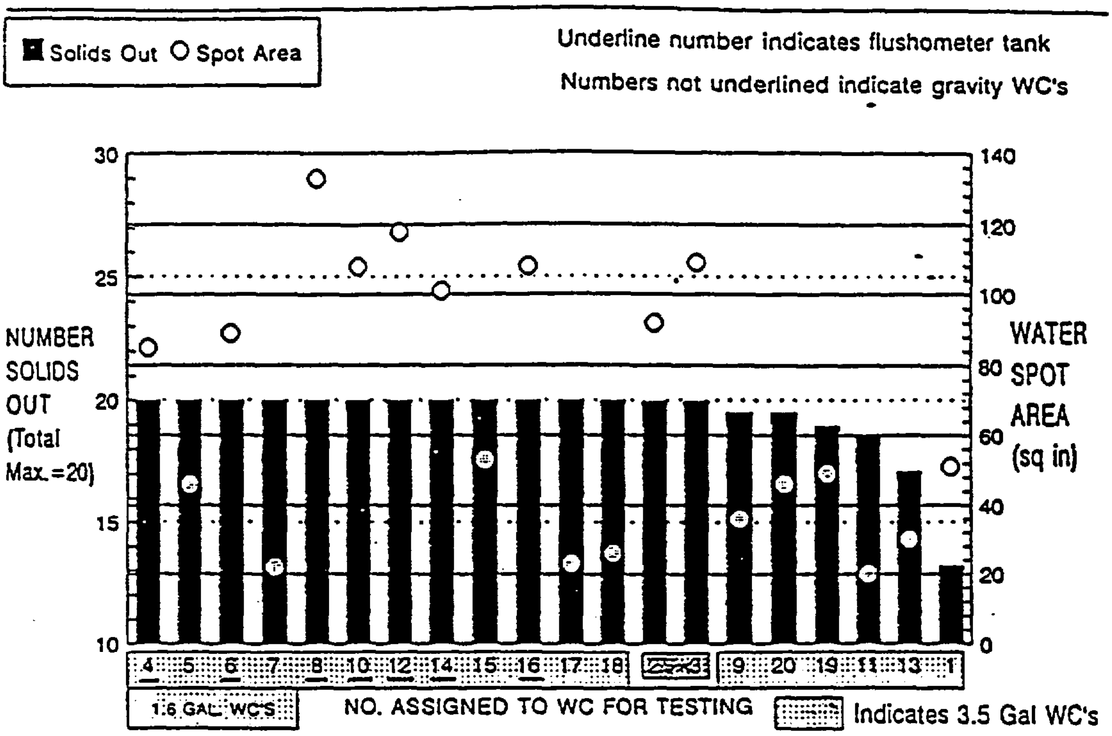


LOW FLUSH VOLUME WC'S #1, #4-20; WATER SAVER #2,3
3" DIAMETER, 1% PITCH, PVC PIPE, #2 FLUSH FOLLOW-ON
8 SYNTHETIC, 12 NATURAL 1" SPONGE CUBES

Figure 11

SOLIDS DISCHARGED FROM WC'S - LIGHT LOADS, RANK ORDER

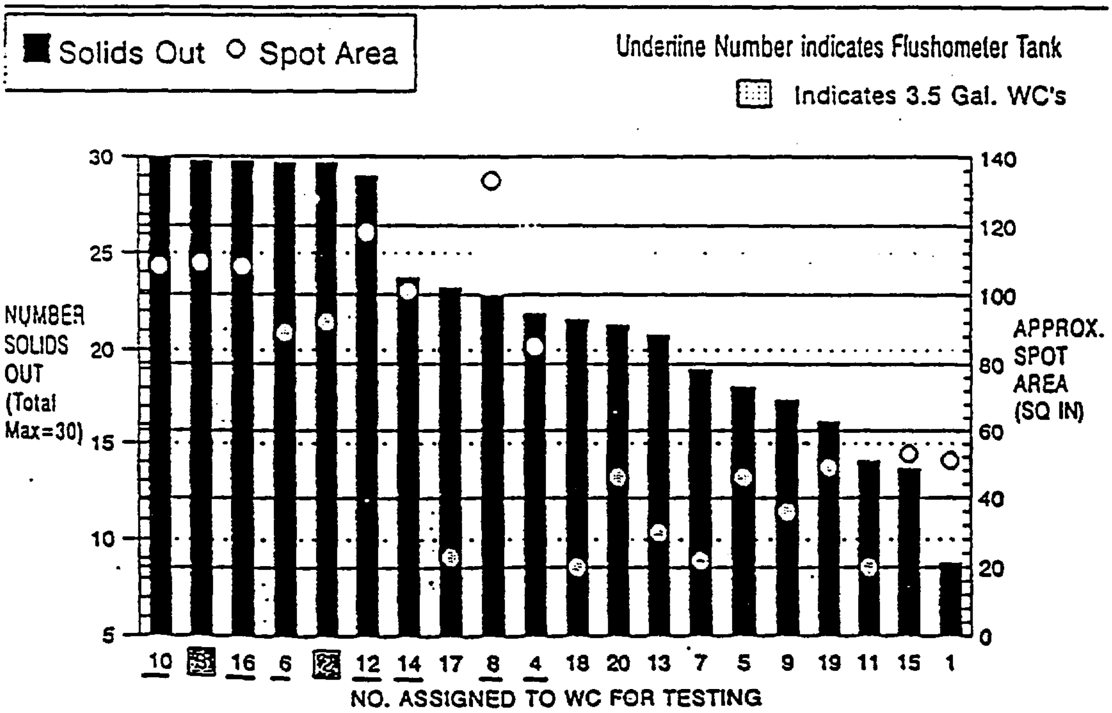
FIRST FLUSH ONLY; AVERAGES FROM 20 TEST RUNS



Total solids displacement 185 ml 160 gms; Test loads 8 synthetic, 12 natural 1" cube sponges

SOLIDS DISCHARGED FROM WC'S - HEAVY LOADS, RANK ORDER

FIRST FLUSH ONLY; AVERAGE FROM 12 TEST RUNS



Test Load 12 Synthetic, 14 Natural 1" Cube Sponges, 4 Towelettes; Displacement 300 ml, 265 gms

Figure 12

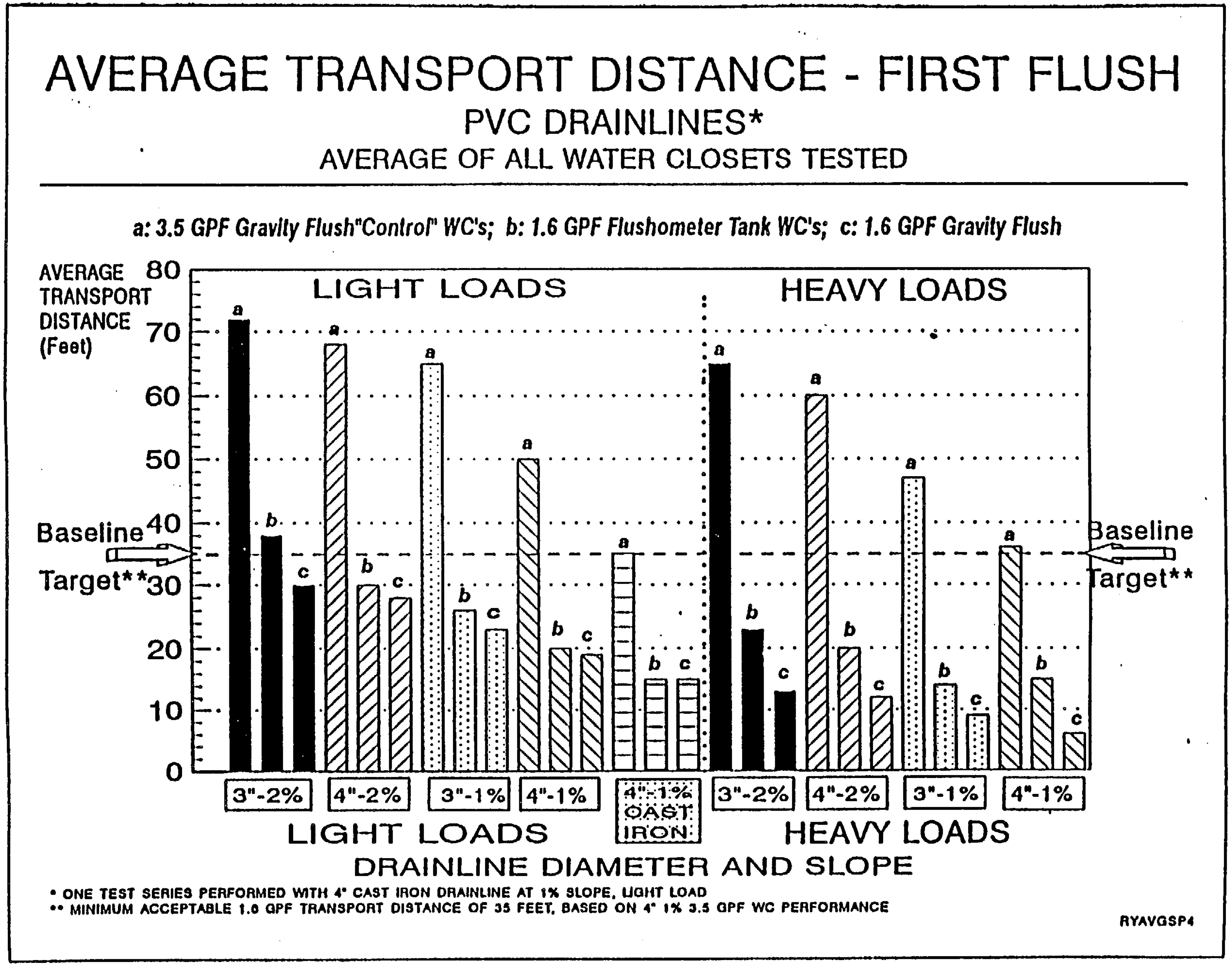

AVERAGE TRANSPORT DISTANCE - FIRST FLUSH
PVC DRAINLINES*
AVERAGE OF ALL WATER CLOSETS TESTED
a: 3.5 GPF Gravity Flush"Control" WC's; b: 1.6 GPF Flushometer Tank WC's; c: 1.6 GPF Gravity Flush
AVERAGE TRANSPORT DISTANCE (Feet)
0
10
20
30
40
50
60
70
80
Baseline
Target**
LIGHT LOADS
HEAVY LOADS
a
b
c
3"-2%
4"-2%
3"-1%
4"-1%
4"-1% CAST IRON
DRAINLINE DIAMETER AND SLOPE
* ONE TEST SERIES PERFORMED WITH 4" CAST IRON DRAINLINE AT 1% SLOPE, LIGHT LOAD
** MINIMUM ACCEPTABLE 1.6 GPF TRANSPORT DISTANCE OF 35 FEET, BASED ON 4" 1% 3.5 GPF WC PERFORMANCE
RYAVGSP4

Figure 13

TEST DATA, TWO DIAMETERS, 2 PERCENT SLOPE

PRESSURIZED TANK WATER CLOSETS

TRANSPORT DISTANCE LIGHT (RESIDENTIAL) LOADS

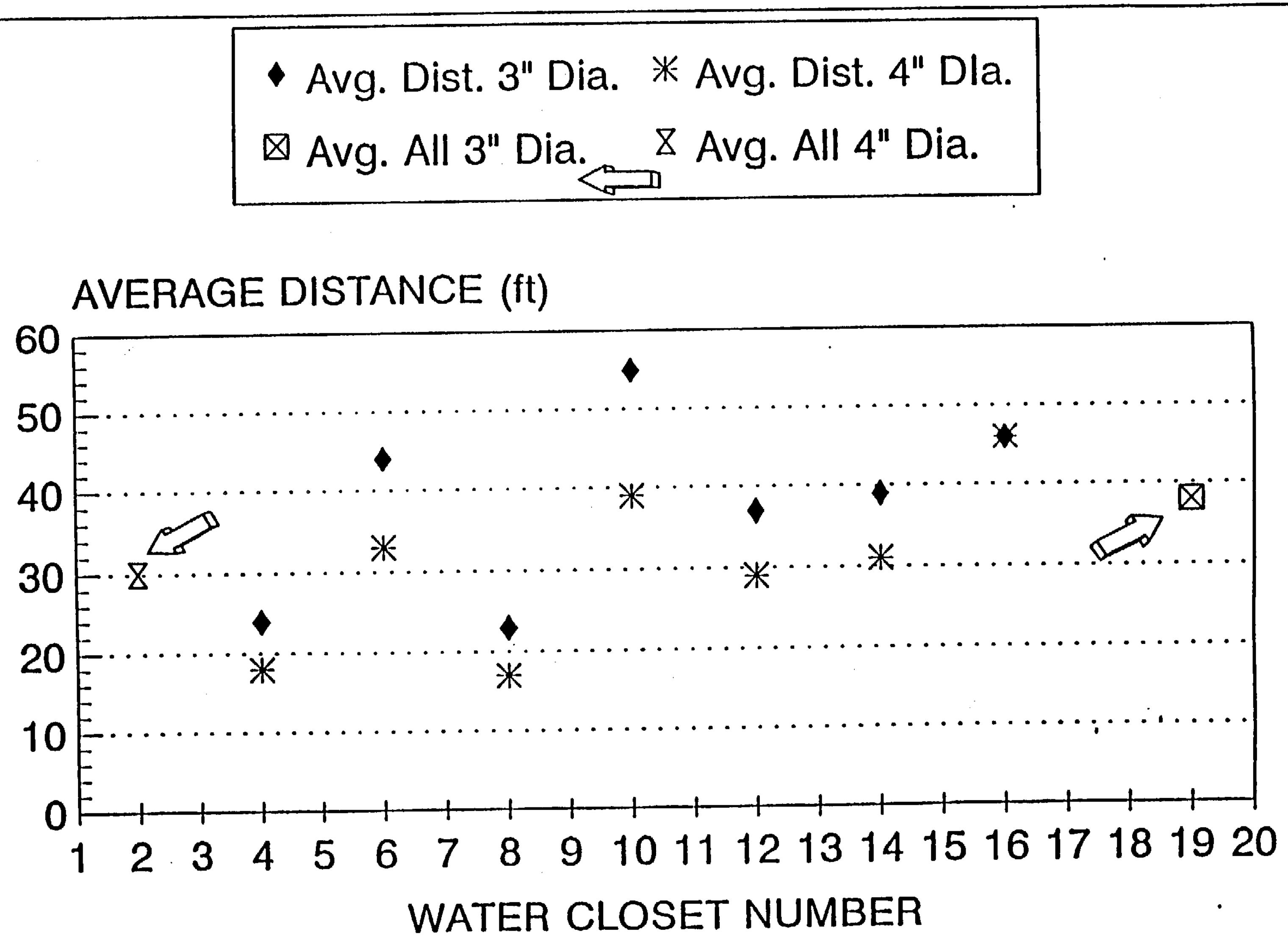
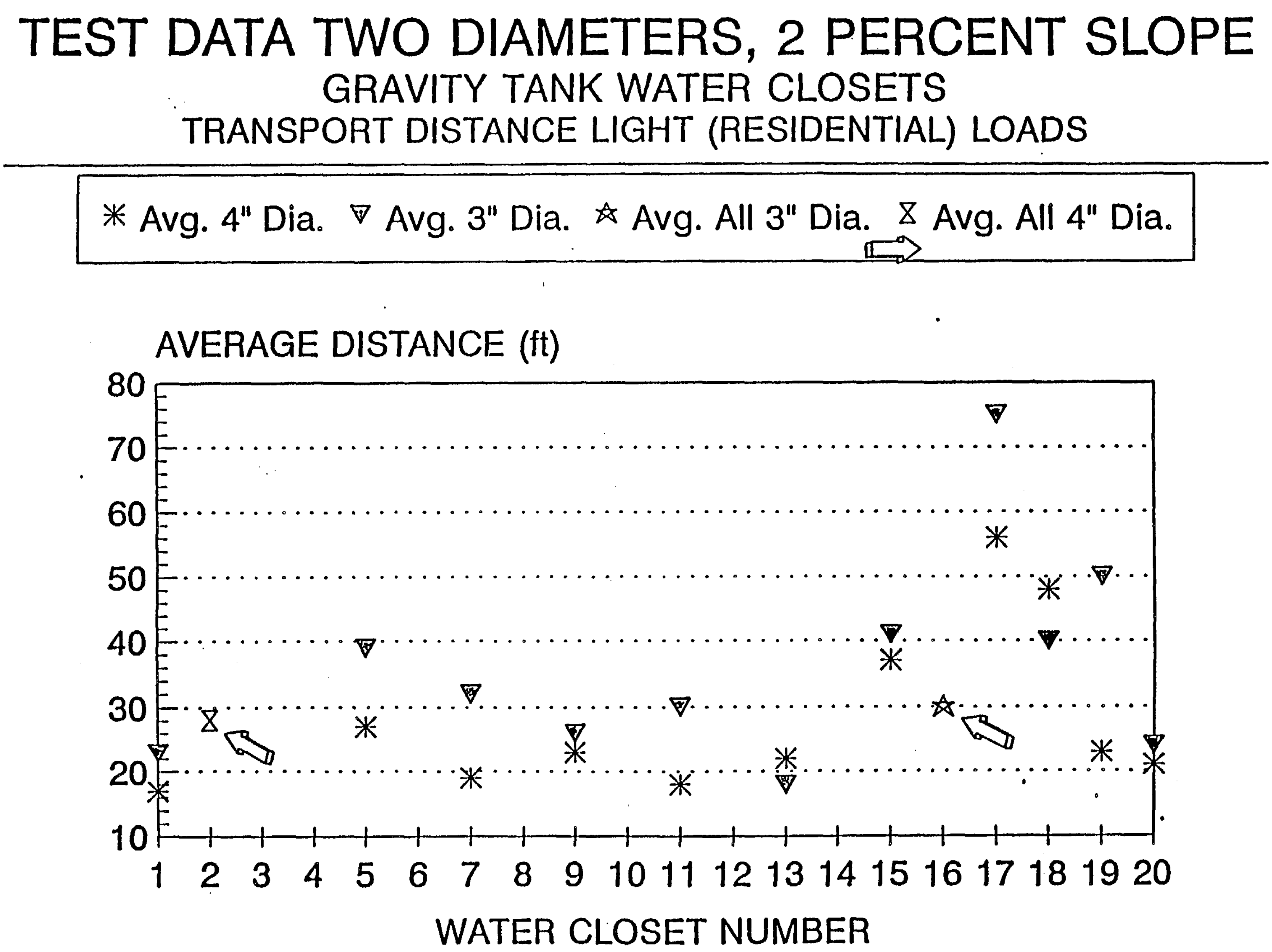


Figure 14



TEST DATA TWO DIAMETERS, 2 PERCENT SLOPE
GRAVITY TANK WATER CLOSETS
TRANSPORT DISTANCE LIGHT (RESIDENTIAL) LOADS
Avg. 4" Dia.
Avg. 3" Dia.
Avg. All 3" Dia.
Avg. All 4" Dia.
AVERAGE DISTANCE (ft)
80
70
60
50
40
30
20
10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
WATER CLOSET NUMBER

Figure 15

Appendix 2.

ITEM 11.

Item 11, Appendix 2.

'Water Closet Characteristics and Performance - A Synthesis', J. A. Swaffield, CIB-W'62 Conferance, Porto, Portugal, 20-23rd September, 1993

WATER CLOSET CHARACTERISTICS AND PERFORMANCE
- A SYNTHESIS -

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WATER CLOSET CHARACTERISTICS AND PERFORMANCE - A SYNTHESIS.

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Abstract

This paper presents an overview of the research on the design of w.c. performance for water conservation over the past 20 years. In doing so it concentrates upon the evolution of low flush volume w.c.s as a means of reducing urban water consumption. The paper investigates the relationship between waste transport within building drainage systems and w.c. discharge volume, utilising both experimental and computer modelling research to demonstrate the implicit interactions that exist in this field. The paper will draw upon previously published work, much of it presented to CIBW62 seminars, in order to put in perspective the current debate as to the acceptable w.c. discharge volume and its relationship to drainage systems design and maintenance.
Keywords: Water conservation, W.c. design, Drainage systems, Solid transport, Standards tests.

1. INTRODUCTION

The Industrial Revolution and the mass migration to the cities led to major public health problems. In the UK Chadwick's report of 1842 eventually led to a major expansion of sewer provision in London and elsewhere in the UK. Other major cities followed, including Paris, 1848, Boston, 1857, Berlin, 1875 and Tokyo, 1887.

Modern water supply and sanitation may be seen as 'post-Chadwick'. The urban sprawl resulting from the Industrial Revolution, first apparent in the UK but soon found throughout Europe, generated both the problems and the reformist movements concerned with the health and housing of the urban working classes. By the end of the 19th century water supply and sanitation techniques and designs would be generally recognisable against modern practice. In particular the importance of odour ingress prevention to the dwelling by the use of appliance water trap seals was understood and a basic w.c. was in use.

The development of the w.c. had awaited the provision of a distributed water supply and drainage system within buildings. The first recognisable w.c. was designed by Sir John Harrington, an Elizabethan eccentric, and included a cistern, bowl, flush pipe and seat. Between the 17th and 19th centuries many 'experimental' w.c. types were developed, however the first recognisably modern w.c. was the Jennings closet, utilising a siphon to flush from a water storage cistern. During the 1880s the art of plumbing, the subject having taken its name from the wide spread use of lead for piping, was eloquently described by Hellyer (1891) in a series of commentaries on good practice. During this period many of the still existing ceramic manufacturers came into existence, including Twyfords in the UK and Gustavsberg in Sweden.

By 1880 w.c. flush volumes were already a concern, as indeed they remain over 100 years later. London's Water Company protested at flush volumes of up to 40 litres being used by some new w.c. designs and by 1900 9 litres, or 2 Imperial gallons, was established as the UK norm, Billington and Roberts (1982). (This decision appears to have been arbitrary with no surviving evidence as to the deciding factors.) In the USA public preference led to siphonic rather than wash down w.c. designs, with flush volumes as high as 36 litres serving into the 1980s. In Europe, particularly Germany, wash out bowls became popular, with flush volumes similar to the UK norms.

By the 1980s most of the developed countries had realised that the water consumption attributable to the w.c. was unrealistic and not necessary. New designs, many originating in Sweden, coupled to the effects of water shortages and droughts have led to 4 to 6 litres becoming the likely norm for future w.c. water usage.

2. WATER CONSERVATION AND ITS EFFECT ON W.C. DESIGN

Water conservation is both an economic necessity and an engineering challenge. It is by no means a new phenomenon or criteria within drainage design; Billington and Roberts (1982) quote the controversy raised in 1900 when the London Water Company reduced flush volumes from 40 to 9 litres. Similar concerns were raised, British Bathroom Council (1988), when a reduction from 9 to 6 litres for the UK was proposed. In Europe, and particularly in Scandinavia, 6 litres has been the norm for decades. Additionally Swedish manufacturers have developed highly successful 3 litre w.c.'s, initially only for use in 'weekend' homes, linked to septic tanks by 75mm drains set at a 1/25 slope. More recently these units have become acceptable within urban applications due to a realisation that it is perhaps the total flow from the building that matters rather than the individual w.c. flush volume.

Water conservation is a necessary and achievable objective. In the UK Webster and Lillywhite (1979) demonstrated that up to 40% of domestic water use was accounted for by w.c. flushing. The w.c. is the one appliance where meaningful savings could be made by a careful synthesis of hydraulic and design methodologies.

As commercial organisations the ceramic manufacturers naturally do not publish the techniques they employ to determine w.c. shape and performance. However, in the UK an industry funded research programme is available for scrutiny and some of its results, linking the hydraulic bowl parameters to performance may be of interest.

Figure 1, Swaffield and Wakelin (1990), illustrates the choices present in the design of a w.c., while Figure 2 illustrates the effect of the values allocated to the governing variables (flush volume, F; trap volume, S; trap seal depth, h; and minimum passage width, w) on the test performance of a w.c., evaluated by use of the multiple ball discharge

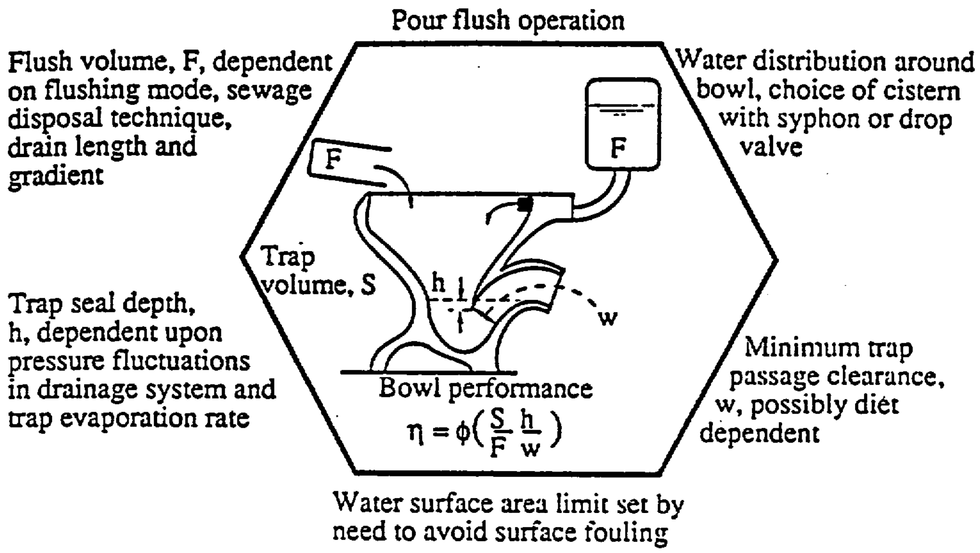

Figure 1 Design criteria governing low flush volume w.c. performance

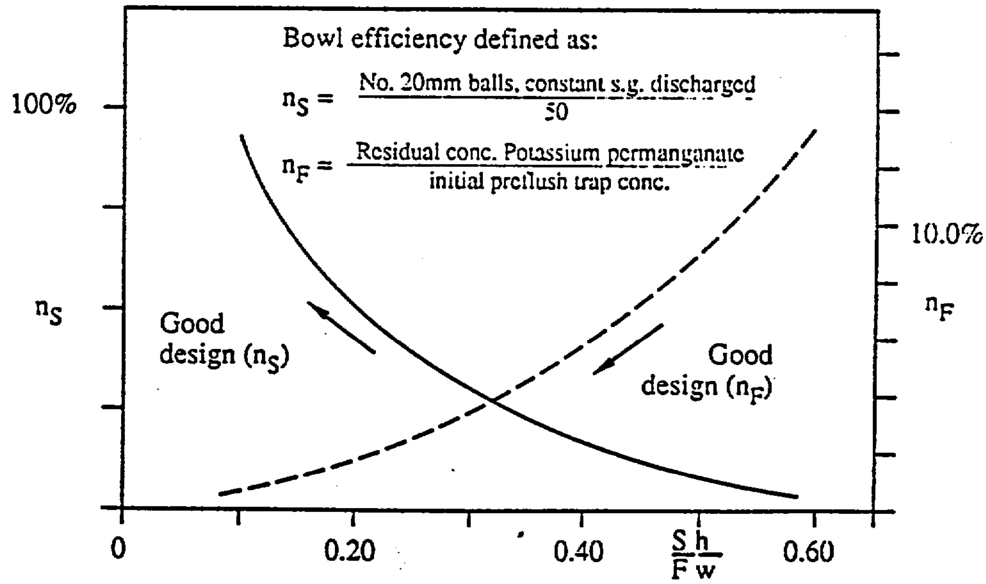

Figure 2 Bowl performance for solid and fluid contamination removal

method, to give a prediction of solid discharge performance and a potassium permanganate solution removal test, designed to simulate the removal of fluid waste. (It should be noted that the results for the potassium permanganate test were obtained by means of a before and after light absorption test on a sample of trap water, rather than by visual comparison to a range of prepared solutions). It is clear from the curves in Figure 2 that values of the non-dimensional variable Sh/Fw in the region of 0.1 yield acceptable values of both solid and liquid waste removal, thus a typical w.c. having a 6 litre flush volume, 50mm trap seal and a 66mm passage width, ie a Sh/Fw value of 0.13 would require the trap volume to be reduced to 0.95 litres, somewhat less than normally found in current higher flush volume w.c.'s. These figures also indicate a move to wash down rather than siphonic w.c.'s, a move that might be unacceptable in some societies.

However this research indicated a design direction that could lead to the considerable savings in water consumption. It is noticeable that while manufacturers do not publish their design methodologies, the successful low flush volume w.c.'s produced in Sweden all display design parameters clearly in line with the predictions of this research.

3. W.C. ACCEPTANCE TESTS

Standards organisations have been involved in the development of w.c. acceptance tests for many decades. Tests have developed which proport to guarantee a minimum level of acceptability for w.c. operation in normal usage. The main areas of concern are

1. Removal of waste solids.
2. Removal of fluid wastes.
3. Bowl cleansing.
4. Trap seal retention on w.c. discharge.
5. W.c. discharge as a contribution to drain loading.

Clearly the subject area indicates that simulants are necessary to model practice. In the case of solid removal the British Standards Institution single ball test is perhaps the oldest, utilising a 43mm diameter ball of specific gravity 1.08. Similarly the multiple ball test (100 or 50 of 20mm diameter) has been utilised, essentially a French standard. In the late 1970s Fakazell simulant was developed in Germany as a test medium, Knoblauch (1979), and in the United States tests were developed in the mid 1980's utilising mixed media - sponges of various dimensions, water filled latex sheets and non-woven fabrics, Konen and Kannan (1991). Various sponge tests were also prevalent, together with tests designed to assess the removal of toilet tissue, including specifications for crumpling procedures and soak time.

In the UK the Association of Sanitary Protection Manufacturers instituted a flushability test that pioneered the linkage between w.c. clearance and drain transport, Howarth et al (1980).

Generally these tests were of the pass only variety and offered no developmental data that could be used in the design of future w.c.'s to provide water conservation through reduced flush volumes. The multiple ball test, developed from the original French standard, did offer the possibility of design data as the number of balls discharged could be linked to flush volume and other w.c. design parameters.

The removal of fluid contamination from w.c. bowls, particularly urine removal, with no solid or toilet tissue paper present in the bowl, was the subject of basic pass standards in many national acceptance codes. Normally a dye test would be utilised and a visual comparison made at the end of the test against a range of pre-prepared samples. This is the basis for the current U.S. test as developed by Stevens Institute. Again this is a test method that does not offer any developmental data. A natural extension of this test involves the use of a photometric technique to assess the residual concentration left in the bowl after flushing. The technique involves adding a known quantity of Potassium Permanganate to the w.c. trap seal water and taking a sample after fully mixing. A further sample is taken at the end of the w.c. flush. Light absorption measurements for both samples yield a comparative residual concentration following flushing. This test modification allows quantitative data to be gathered that can determine the effect of reduced flush volume operation on any existing w.c. and could be utilised in the assessment of dual flush water saving devices.

While the solid removal tests are basically not amenable to any form of mathematical modelling, the removal of fluid contamination may be represented by a reference to the measurable inflow profile to the bowl, recorded by measurement of the cistern water level, and the w.c. discharge profile. Numerical application of the contamination decay equation over small time steps within the flush duration then yields reasonable agreement between measured and predicted residual concentration values, Figures 3 and 4, Uujamhan (1981), provided that a sustainable model of the contamination mixing and discharge is developed.

The initial BSI testing for bowl cleansing utilised the so called sawdust test where the area of bowl surface left covered with sawdust at the end of a flush was measured and compared to a specified minimum. More recent US tests have utilised a fibre tip marking pen to introduce a line grid on the bowl surface. The length of line left unwashed away at the end of the test may be compared to a specified minimum. These tests are not amenable to modelling and would have to be part of any w.c. development testing programme. The water surface area minimums included in national codes are designed to aid the achievement of satisfactory bowl cleansing by reducing the likelihood of surface fouling. Tests by BRE in the UK in the 1980's considered various alternative media to represent surface fouling but these results were not published.

Splash tests are concerned with the possibility of water droplets reaching seat level. These tests were developed utilising blotting paper sheets to cover the seat level and would have to be part of any w.c. development process.

Due to the normal 75mm or 100mm drain connections to w.c. discharge spigots, there is unlikely to be a self siphonage problem. Induced siphonage may occur and limits are set in the standards that control the negative pressures in the drainage network to retain trap seal at a minimum level. Normally 50mm is utilised as a trap seal depth, however this value could be varied depending upon the w.c. application. Clearly commercial considerations would become important if non-standard trap seal depths were to be considered.

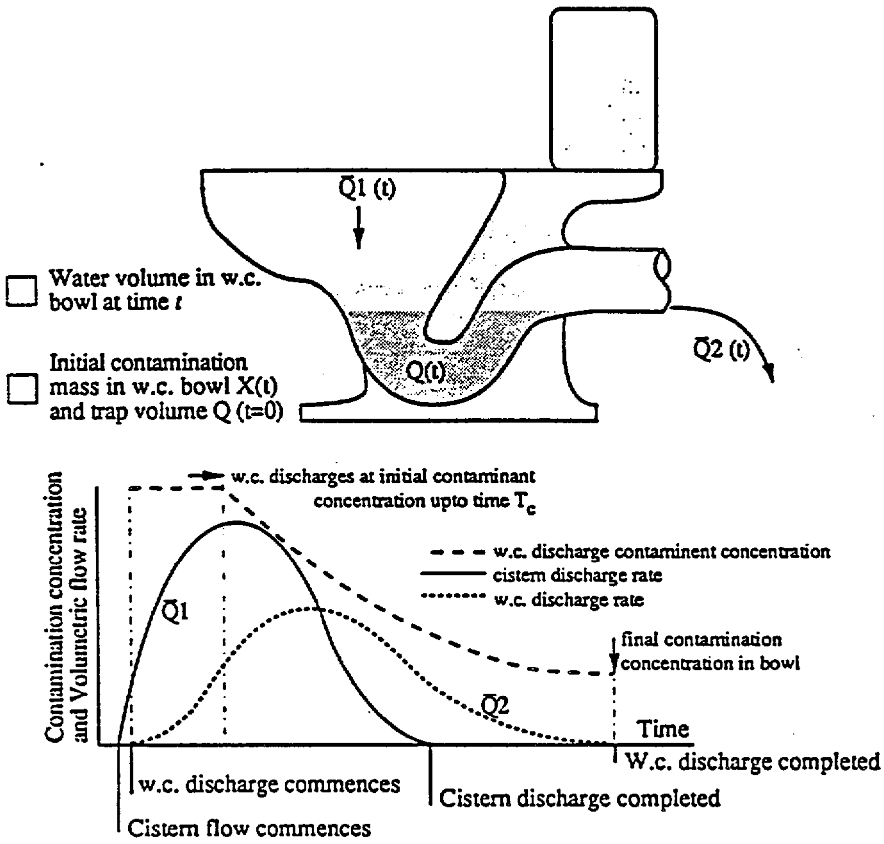

Figure 3 Schematic diagram of w.c. bowl mixing and contamination discharge

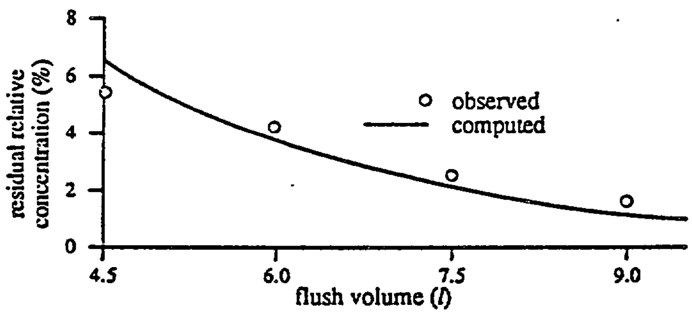

Figure 4 Measured potassium permanganate ($KMnO_4$) contamination concentration in the trap after the flush compared to laboratory measurements, T_c value set to 2 seconds in mixing model:

$t<T_c,\ c_{discharge} = c_{t=0}$

$$t>T_c,\ c_t = \frac{\text{Mass contaminant in bowl}}{\text{Bowl trap water volume}}$$

$$\therefore c_t = \frac{c_{t-dt}\,(Q(t-dt)-Q2(t)dt)}{Q(t-dt)+(Q1(t)-Q2(t))dt}$$

4. W.C. DISCHARGE PROFILES AS A BASIS FOR DRAIN LOADING

Traditional methods of drain loading calculations have developed from the original work of Hunter (1940) in the fixture unit/discharge unit design method. In order to assign a value to each w.c. type it was necessary to develop a test to record the w.c. discharge profile, in particular its duration and peak flow. A wide range of methods have been utilised, falling into two main categories, namely a mass versus time record and a volume discharge versus time record.

Pink (1973) presented a form of the mass versus time record that illustrates the fundamental problem with this mode of measurement may be a necessity to "take out" the momentum of the discharge flow. This inevitably damps the peak flows recorded.

Uujamhan (1981) utilised the volume versus time methodology, however the major problem here is that "waves" on the surface of the collection tank introduced "noise" into the readings.

A very recent development at Heriot-Watt University is illustrated in Figure 5 where the volume versus time advantages are maximised by the introduction of a system of depth measurement at a range of locations over the surface of the collection tank. The rates of change of the water surface height in the collection tank is measured by means of a pressure transducer recording the average air pressure in the vertical tubes distributed across the surface of the tank. Figure 6 illustrates a comparison of the results based on 1 to 12 monitoring points. This technique removed the problems associated with the earlier test methods and would allow the utilisation of improved models of drain loading and w.c. fluid contamination removal.

Traditionally the w.c. discharge profile has been recorded without solids in the flush, however the presence of solids in the bowl modifies the flush profile. The mass versus time techniques mentioned cannot handle this. However the volume versus time technique above can cope with this as shown in Figure 6. If the design of networks in the future is to be undertaken utilising improved mathematical models that incorporate appliance discharge profiles and user patterns, rather than depending upon a quasi-steady flow based on the fixture unit method, then these modified discharge profiles become important.

5. WATER CONSERVATION AND SOLID TRANSPORT

One of the great myths surrounding low flush volume w.c. introduction is that all the flushed solids will be deposited in the drain and that the system will fail. Experience in Sweden and in a site trial in Phoenix, Arizona, Anderson and Seigrist (1986), utilising Ifo low flush bowls, disprove this. Similarly a 4 year site trial in Botswana of a 4 litre flush volume w.c., developed as part of a UK Overseas Development Administration project, Swaffield and Wakelin (1990), generated no drain blockage problems within a drainage network, Figure 7, laid to British Standard Institution guidelines, while the water savings, Figure 8, were considerable when compared to the use of locally available Vaal Potteries 10 litre w.c.'s. The source of this mythology may be traced to a lack of understanding of the mechanisms of solid transport, Swaffield and Galowin (1992). Generally solids move through a system by a continuous process

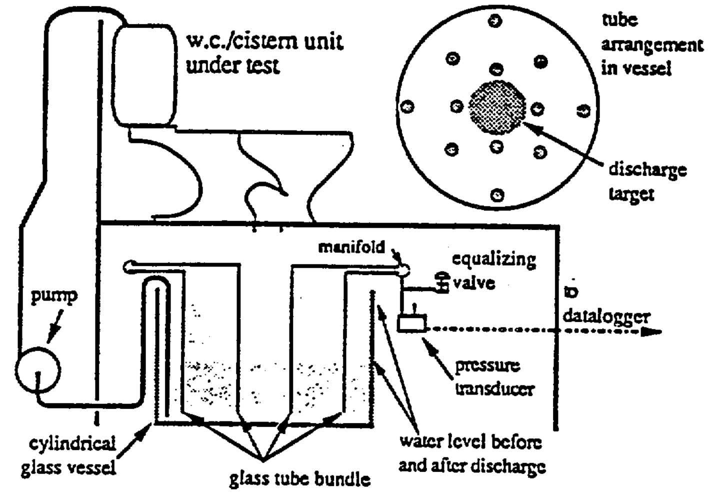

Figure 5 Schematic diagram of device for measuring the flush characteristics of a w.c./cistern unit, by averaging air pressure increase in 12 glass tubes submerged in a tank of known dimensions

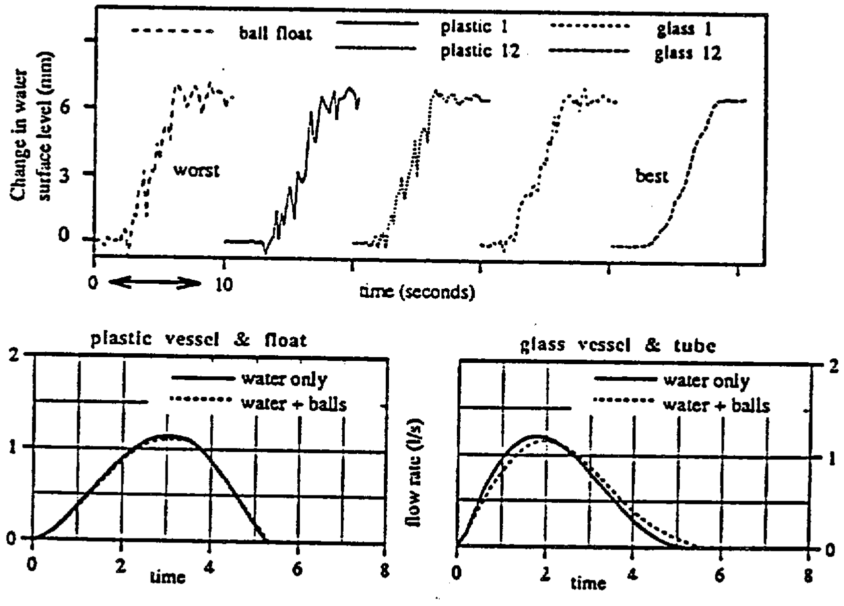

Figure 6 Comparison between data collection techniques (top), and the discrimination possible from the best and worst techniques in a carried load test (bottom). Note that the flexibility of the plastic collection tanks's walls accentuate surface waves and invalidate the discharge profile generated from the depth change data as:

$$\frac{dVol}{dt} = A\frac{dh}{dt}$$

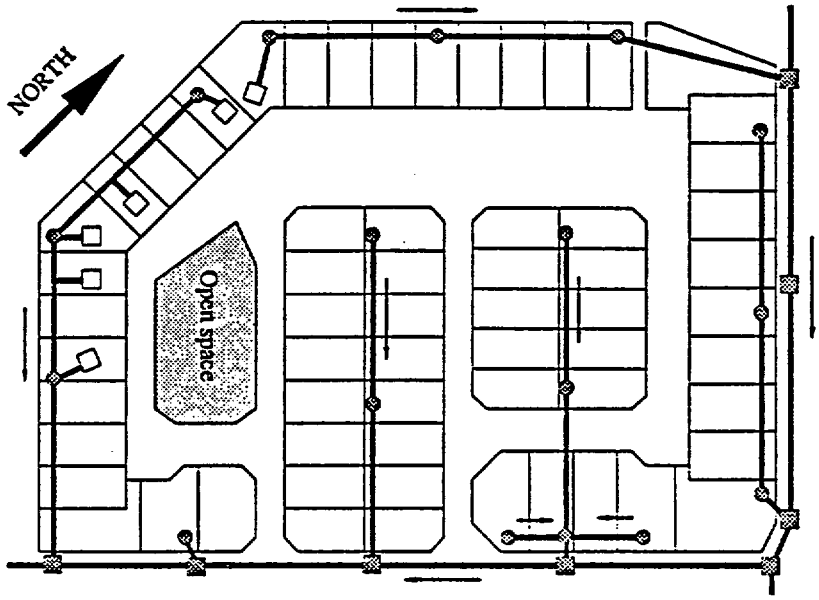

Figure 7 Layout of 63 low income Botswana Housing Corporation house plots, Gaborone West, fitted with 4 litre flush w.c.'s. Note 100mm diameter drains set at 1/90

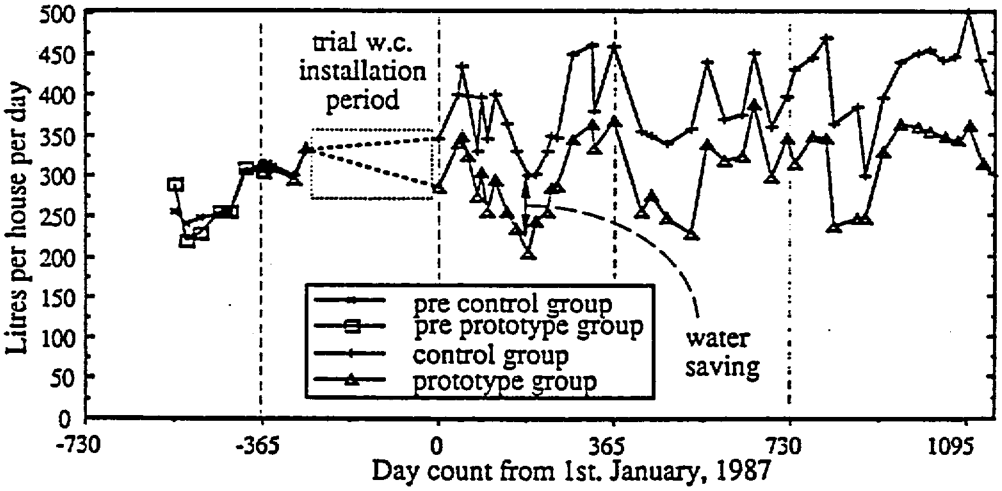

Figure 8 Comparison of prototype 4 litre flush w.c. housing group water consumption to a control group over a 3yr period. Also note pre-installation water consumption sensibly identical for both groups.

of deposition and re-acceleration caused by the arrival of later appliance discharges, not exclusively w.c.'s. Thus an assessment of solid transport performance must include the system as a whole.

W.c. testing has in the past concentrated upon its ability to discharge waste or successfully remove liquid contamination. The need to introduce solid transport as a further test was recognised in the US by ANSI; the current test is based on the ability of a w.c. to ensure the transport of 50 20mm diameter balls 16m along a pipe set at a slope of 1/50 (0.02 or 1/4 inch per foot). This test may be traced back to a similar procedure reported by Billington and Roberts (1982). In 1900 the Sanitary Institute in London initiated a test programme for w.c.'s involving some eighteen hundred tests of a 9 litre w.c. that left 5% of the test balls in the trap and 21% along a 50ft length of pipe. (The pipe diameter may be assumed to have been 4 inches or 100 mm.)

Building drainage networks are required to carry away both waste water and waste solids. As the flow mechanisms within building drainage systems leads to intermittent partially filled pipe flows, the satisfactory transport of waste solids becomes an important factor in the assessment of a drainage design. This also affects any water conserving proposals, either for w.c. design or for other appliances discharging to the system, such as low flow showers. It is important to differentiate the treatment of waste solid transport in building drainage networks from sewer flows. In the building drainage system the solids may still be treated as discrete, subject to a system of forces including hydrostatic, mass, buoyancy and frictional components.

The transport of waste solids within gravity-driven building drainage systems is, to a large extent, dependent on the maintenance of sufficient wastewater flow depth in the pitched drain pipes. The prediction of waste solid transport in partially-filled pitched pipes requires development of the inter-relationships between the controlling transport parameters; eg time-dependent wastewater flow rates and depth, the dimensions of the solids, the pipe diameter, pitch and internal surface conditions, which affects the friction between the solids and pipe wall. The reduction of the water volume discharged from fixtures, such as w.c.'s with reduced flush volumes, or decreased flow rates, can result in lower pipe sweeping velocities or reduced solid carrying capability in conventional sized drain piping. Alternatively, in new building design, the use of smaller diameter drain pipes, which maintain satisfactory solid movement with smaller quantities of water, may be feasible.

The available theory and experimental test data indicate that transport with flows, established either from actual water closets or laboratory experiments with a controlled discharge tank, in pitched drains cause the bodies initially at rest, or introduced with small velocities, to undergo an early acceleration followed by a gradual deceleration. Observations of the phenomena show that following the surge peak the depth of the water in the pipe decreases and the solid velocity decreases or the body may be deposited within the pitched drain pipe. The attenuation of the input surge wave along the length of the drain results in a decreased depth of water and an increase in the time interval for passage of the surge wave, which reduces the transport effectiveness in long drains. The prediction and measurement of attenuation is therefore of significance in the evaluation of the effects of reduced water consumption.

In the UK interest in solid transport in building drains was probably initiated by the problems encountered in the operation of the long, shallow gradient building drainage systems installed in many of the large hospitals built in the 1960s. Additionally, the growing concern with water conservation gave added impetus to the study of this topic, which is now actively being pursued at a number of centres in the UK, Europe and the USA.

The earliest systematic work on solid transport may be traced to Wyly (1964) working at the National Bureau of Standards, Washington, while in the UK Webster and Lillywhite (1979) refer to work conducted in the early 1970s. However, this work, and the contribution of Tsukagoshi and Matsuo (1975), was not primarily concerned with solid transport performance and as such did not introduce the experimental and instrumentation techniques necessary to monitor solid velocity variations along the pipe system.

A systematic study of the transport of waste solids was initiated in the UK in 1974 at Brunel University, as reported by Swaffield et al. (1975, 1977, 1978, 1980), Wakelin (1978) and Bokor (1982). This study developed the necessary instrumentation techniques and established the mechanisms of solid transport in both the laboratory and in installed hospital drainage systems.

In parallel to this research a wide range of work was also undertaken by other laboratories. In particular, at the National Bureau of Standards, Galowin initiated fundamental investigations of the force system acting on moving solids in partially filled pipe flow, while both the Danish and Swedish Building Research Institutes, Neilsen (1979), Olsson (1980), and Japanese researchers have contributed papers to CIBW62 meetings.

During 1981-83 work was under way at IPT, Sao Paulo, concerned with monitoring waste transport from a pour flush toilet installation, via a 20m drain to a cesspit, while BRE in the UK undertook studies based on observations carried out during trials of low flush volume w.c.'s installed in a London office building, Webster and Davidson (1982).

Work directed at a better understanding of the mechanisms of solid transport has continued up to the present. Lilja (1989) considered the effects of pipe diameter and joining flows while Swaffield and Galowin (1992) developed a series of unsteady flow models utilising the numerical method of characteristics to predict local flow conditions and hence solid carrying capacity. Work at Stevens Institute concentrated on assessing w.c. flush volume reduction and the effect of multiple flushing on solid transport leading to the demonstration that a w.c. with a particular flush volume linked to a particular drainage network with no other flows present has a maximum travel range, Kannan (1992). The prediction of this 'range' by numerical means for a single solid had been demonstrated earlier, Figure 9, Swaffield (1991), for a range of single drains of various diameters and slopes. The cyclic effects of multiple flushing demonstrated experimentally by Kannan were also predictable, Figure 10, Swaffield and Galowin (1992[1])

Taken together this body of work presents a firm base on which to develop an experimental model that will adequately predict the likely transport of solids discharged from low cistern flush or pour flush w.c. designs, and will also provide a basis for a wider study of solid transport and deposition.

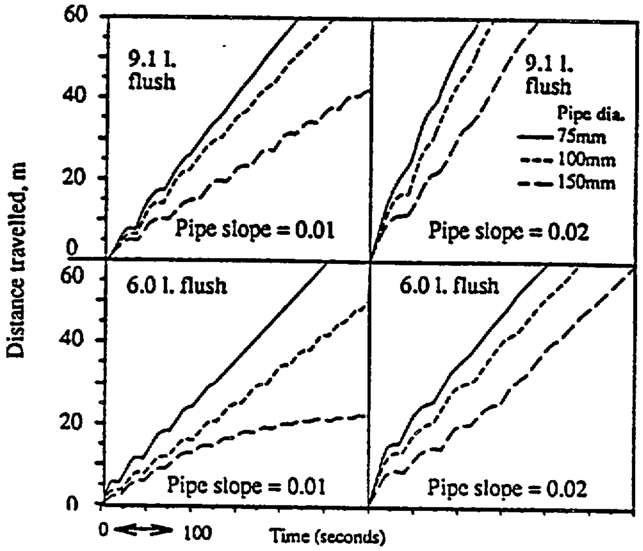

Figure 9 Single solid transport as a result of repeated 9.0*l* or 6.0*l* w.c. discharges at 10 second intervals

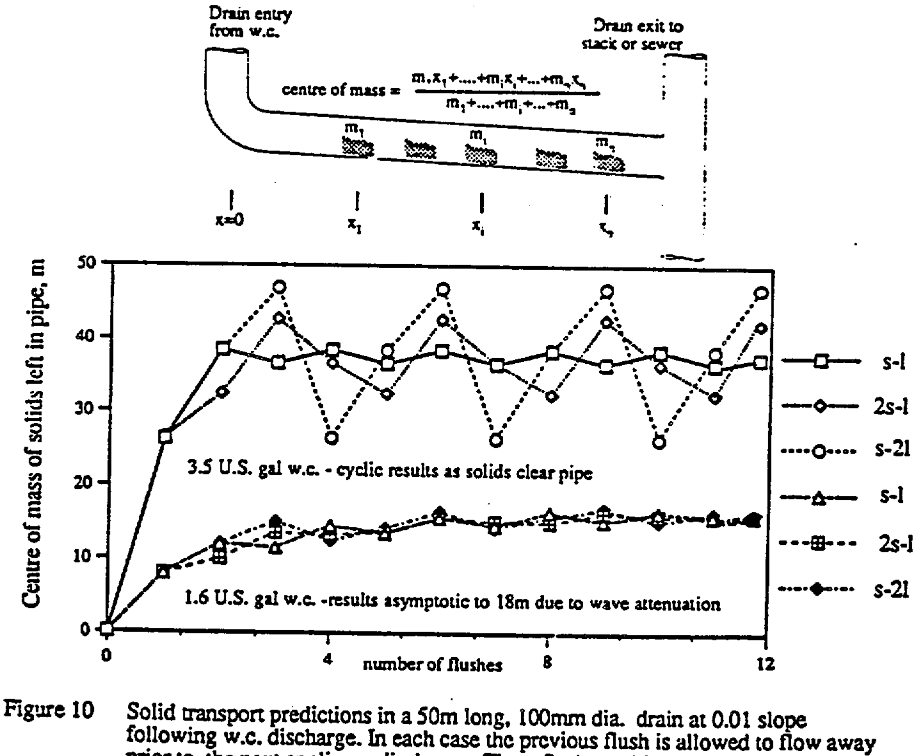

Figure 10 Solid transport predictions in a 50m long, 100mm dia. drain at 0.01 slope following w.c. discharge. In each case the previous flush is allowed to flow away prior to the next appliance discharge. Three flush combinations are illustrated, i.e. solid-liquid, 2solid-1liquid, 1solid-2liquid.

6. SOLID TRANSPORT AS A CRITERIA FOR W.C. - SYSTEM DESIGN

The implication of w.c. design on solid transport in drainage systems was largely ignored until the water conservation proposals of the 1980s. Flushability criteria for sanitary products had been developed, Howarth et al. (1980), however these were concerned with the disposal of the product and while the test specification dictated a successful travel of 10m in a 100mm diameter drain at 1/80 following discharge from a 9 litre flush volume w.c., the test method was not accepted by the w.c. manufacturers.

The first w.c./solid transport test criteria accepted was the ANSI Standard A112.19.6 in the US, applicable to w.c. designs down to 6 litre flush volume. Considerable concern exists for the performance of water conserving fixtures and devices as related to their sufficiency for providing waste transport and clearing drains. Design considerations and plumbing code information have seriously lagged behind the development of newly introduced manufactured products for plumbing installations. However the revision of standards has been under way for some time in the USA, reflecting the need for potable water conservation as part of a national recognition of the importance of water resource management.

ANSI Standard A112.19.2-82, the 1990 revision consists of two standards, A112.19.2 and 19.6 for hydraulic tests, was primarily oriented toward the 3.5 USgallon flush water closet with tests for hydraulic performance. The test methods, however, are appropriate to the ultra-low volume w.c. since the functions and test media are mostly the same and performance is required to be essentially the same. A new test for drainline carry was included in a revision of the standard to determine the capability of a water closet surge to carry the test medium a minimum distance along the drain. All the hydraulic test methods have been assembled in a new document under a new standard, ANSI A112.19.6, for hydraulic test methods.

The development of test material and requirements for water conserving water closet performance tests in ANSI Standard A112.19.2M included bulk deformable sheath water-filled solids, plastic balls, and plastic pellet test materials. Subsequent difficulties and limited longevity in the use of the bulk sheath water-filled vinyl cylinders was experienced; these are not now specified in updating the new standard for hydraulic test methods (ANSI A112.19.6). Test methods in the standard have been expanded to include a toilet tissue test and a drainline carry test utilising plastic balls.

In the test rig installation for the drainline carry test of the standard, a 60 ft long, 4-in diameter pipe pitched at ¼-in per ft was attached by a turning elbow to the water closet. The test uses 100 plastic balls, each of 20 mm diameter, in each load and is repeated three consecutive times. A 40 ft average carry distance is required for the water closet drainline carry. A detailed test procedure describes how to conduct the test and evaluate the measurements from the calculation for the average carry distance. Test results for several water closets from the drainline carry test are presented in Figure 11. Those results are from recent tests for 12 3.5 USgallon flush water closets, 12 1.6 USgallon flush water closets and 2 pressurised 1.6 USgallon flush water closets. All the closets tested were observed to achieve the 40 ft carry distance requirement. Other tests were undertaken to determine the effect

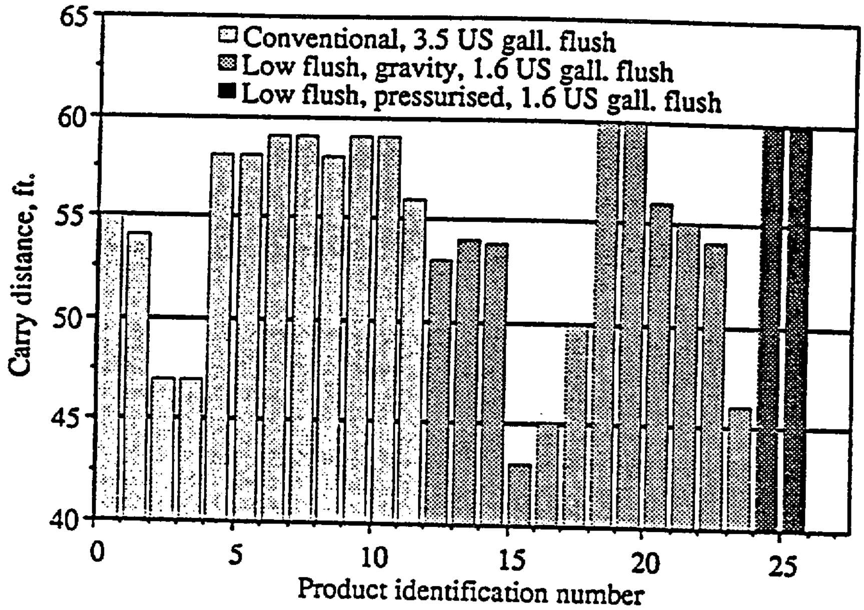

Figure 11 Ball carry test (ANSI/ASME)

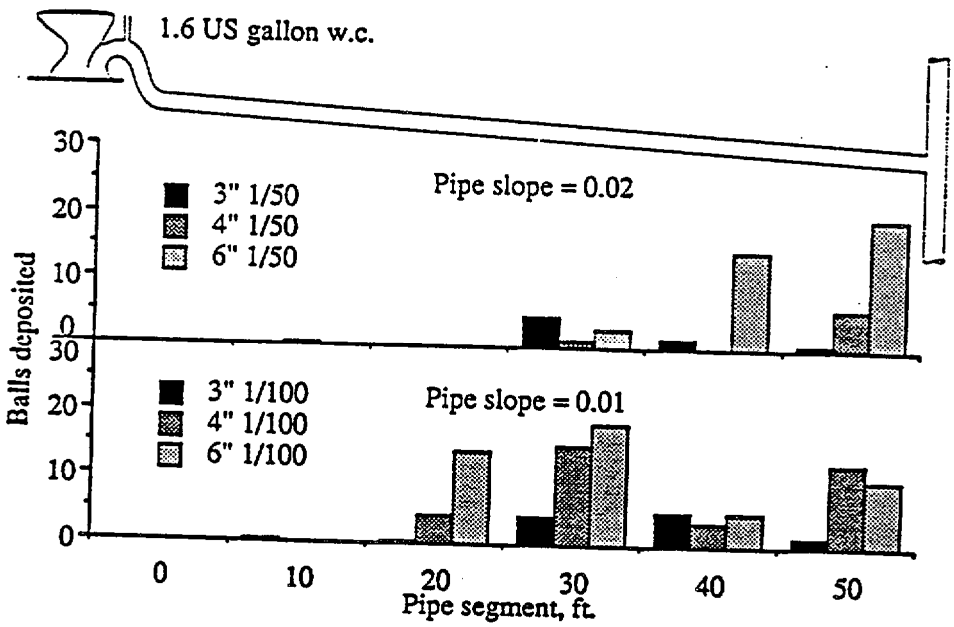

Figure 12 Ball deposition tests for various pipe diameters and slopes, 20mm plastic balls used. Note performance improves with decreasing pipe diameter and steepening slope

of larger bulk media in passing through the trap and transport along the drain.

Critique of the plastic balls for water closet evaluations has been based on the fact that the faecal matter has not been simulated in the performance test. However, it must be recognised that test evaluation techniques require that a reliably reproducible, reusable, test material be available for utilisation in any laboratory.

The ANSI ball test represents the first attempt at linking w.c. acceptance criteria to solid transport. The test could be developed to yield information as to the effect of pipe slope and diameter on transport efficiency, Figure 12 illustrates the results obtained in 75, 100 and 150mm drains following the flushing test defined by ANSI. The choice of a suitable test medium is difficult, particularly as this is a somewhat taboo area in any case, and the problem is naturally complicated by the natural randomness of the input and by anecdotal opinions. A combination of the ball test together with the sanitary product flushability criteria defined by Howarth et al. (1980) may well prove to be the best available.

7. CONCLUSIONS

This paper has attempted to present an overview of the research on w.c. design, identifying the parameters that determine satisfactory performance against the dual objectives of solid and fluid contamination removal. Inevitably this has led to the identification of the w.c. as merely part of a system, rather than an isolated appliance whose design can be considered in isolation from its interaction with the building drainage network. The introduction of water conservation highlights the need for a systems based approach to both appliance and drainage network design as the ability of the w.c. to guarantee solid waste transport, at least as far as the first junction carrying flow from other system applainces, becomes essential.

Advances in drainage design methodology derived from the availability of modern computing facilities linked to mathematical modelling of the unsteady drainage flow allows this approach to be followed and developed. The greatest need is therefore for appliance manufacturers, drainage designers and code specifiers to recognise the advantages inherent in these methodologies.

This paper has also illustrated the w.c. design parameters that determine good performance. The confirmation of the systematic laboratory identification of these governing parameters in field tests should give confidence in their use in future w.c. design. While it would be simplistic to expect that the design of applainces for competitive sale could be governed totally by such relationships, the application of the research discussed could avoid excessive water consumption by poorly designed w.c.'s that either fail to guarantee solid transport or require multiple flushing to clear the bowl.

Finally the reserch summarized has identified the need to establish standards acceptance tests that reflect the role of the w.c. as a constituent part of a system, rather than an isolated applaince. It is clear that further work will be necessary to establish these test requirements and CIBW62 has a role in this.

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ITEM 12.

Appendix 2.

Item 12, Appendix 2.

'Reduction in Domestic Water Consumption Through the use of Low Volume Flush Toilets', Adilson Lourenco Rocha, CIB-W'62 Conferance, Porto, Portugal, 20-23rd September, 1993

REDUCTION IN DOMESTIC WATER CONSUMPTION THROUGH THE USE OF LOW VOLUME FLUSH TOILET

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Abstract
The use of low volume flush toilet (LVFT) is a subject of research in a number of countries. There are expressive advantages on the use of these toilets, highlighted by the reduction in the overall demand for water. This gives the water public services opportunity to supply a greater number of people, and by the reduction in sewer volume, permits the use of more economical alternative systems of waste water treatment and disposal. In Brazil the theme has being carried on at IPT where, among other activities on the subject, the Institute has been working with manufactures on LVFT development. The present work treats a real case where LVFT were employed. Two Brazilian manufactured toilet types along with a foreign one obtained thanks to a cooperative technical agreement between IPT and Heriot-Watt University, Edinburgh, Scotland, were used. The research concluded that the use of this type of toilet permitted an economy of 3 L per capita in the water volume daily utilized for toilet flushing.
Keywords: Water Conservation, WC, Low Volume Appliances, Low Volume Flush Toilets

1 INTRODUCTION

Water, like energy, is a limited resource. The petroleum crisis of 1973 awoke the world to the need to conserve energy. Likewise the drought of 1976/77 that occurred in parts of northern hemisphere stirred discussions about what had seemed and inexhaustible resource: the water. Not that studies on the conservation of either energy or water were nonexistent before, but from these dates the problems became definitely integrated into the universe of human preoccupations in the last years of this millennium.

When we speak here of a lack of water we are not saying that rivers and seas will dry up. The problem consists in the significantly higher costs for the implantation of new water supply systems when the water consumption overtakes the local water service capacity. The normal solution is to take water from sources more and more distant or by more costly processes what imply in a increase of energy consumption.

In the domain of building services, solutions are constrained by water conservation to reduce the consumption in the different water usage points in the building. Obviously, these solutions must preserve the good system performance and assure users satisfaction on their requirements. There is a large number of possible technical alternatives which have been discussed in publications over the last 20 years (IPT, 1986).

The economy gained by the reduction in the volume of discharge in toilets is considered potentially promising for two main reasons. Firstly, this appliance alone has been considered to be responsible for about 40 % of total water domestic consumption (Fowell, 1979). Secondly, it presents consumption that can be considered independent of users "taste" offering the possibility to work in its rationalization, in opposition to showers, taps, etc,. The volume of water used in the discharge basically must be sufficient to remove liquid and solid waste from the toilet itself and also from the building drainage pipelines, assuring the waste transportation to a disposal site, that can be the public sewer network.

The research was carried on firstly through the development of an appropriate methodology to evaluate the toilet system (flush tank or valve, toilet bowl and the sanitary branch). Secondly it was studied the toilet system functioning in order to reduce the water consumption, being settled at this phase the directive parameters for the bowl design itself. Finally work was done actually developing a low volume flush toilet.

The industrial development of these bowls along with flush tanks was undertaken by manufactures and the evaluation of the product was made by IPT in terms of laboratory behaviour (Rocha, 1986). However its behave in actual use took some time to be perfcrmed. Only in 1990 were all the pre-requisite conditions fulfilled to begin a research project aimed at monitoring the water consumption of LVFT[1] installed in a housing estate. This project, named "Projeto São Carlos", is the subject of this paper (IPT, 1993).

2 DESCRIPTION OF THE PROJECT

2.1 Locale chosen and toilets used

From the mid 1980s contacts were made with the agencies concerned with planning and financing housing for low income families in order to identify a housing estate in São Paulo, or a nearby town, suitable for the installation of LVFT. It was chosen an estate with 150 houses planned to be constructed in São Carlos, located 220 km from São Paulo,

[1] In Brazil LVFT is called "bacia VDR", i.e,"bacia de volume de descarga reduzido".

through a governmental housing agency.

The estate called "São Carlos Participação" was designed to house employees of "Escola de Engenharia de São Carlos da Universidade de São Paulo" (Engineering School of São Carlos, University of São Paulo). The majority of the houses (110 in total) have 2 bedrooms and a built area of about 46 m^2. From the others 40 houses, all of them with 1 bedroom, 20 have a built area of about 31 m^2 and the rest about 37 m^2.

IPT accompanied the estate construction from the beginning. During this period arrangements were made with toilet bowl and flush tank manufacturers in order to obtain the necessary products. The types, makes and quantities of toilet bowls and flush tanks installed in the houses are presented in Table 1. It is important to do some comments about these products:

a) the bowls and flush tanks were supplied free of charge by the manufacturers;

b) the Twyfords LVFT bowls comes from UK as an item of the cooperative agreement signed between IPT and Heriot-Watt University, Edinburgh, Scotland;

c) the normal bowls and flush tanks, used for control purpose, were acquired by the construction company using normal purchasing procedures without any orientation from IPT;

d) the flush tank make Astra used for control purpose had a discharge volume of 10 L when adjusted to the maximum possible operational level.

Type		LVFT flush tank	Normal flush tank (control)	Total
	Make	Cipla	Astra	
LVFT bowl	Celite	45	-	45
	Deca	45	-	45
	Twyfords	30	-	30
Normal toilet bowl (control)	Celite	-	30	30
Total		120	30	150

Table 1 - Number of houses where each type/make of toilet bowl and flush tank were installed

2.2 Project objectives and planned activities

The basic objective of the research project was to compare de water consumption in houses installed with LVFT with those installed with normal toilets, and to evaluate over a length of time the LVFT performance.

To make possible to compare the water consumption it was planned:

a) the measurement of the *house water consumption*, total, considering all the sanitary appliances, obtained through the periodic reading of the water meter installed in the meter chamber at the house entry;

b) the measurement of the *toilet water consumption*, individually, obtained through the periodic reading of the water meter installed immediately upstream the flush tank entry.

To make possible to compute the *per capita water consumption*, both from the whole house and from the toilet, it was done a periodic control of the dwelling resident number.

The water meters installed at the flush tank were donated to IPT by a Brazilian water meter manufacturer. It is a 1.5 m^3/h nominal flow-rate meter. The water meters installed at the house entrance were installed by the municipal water service department.

The LVFT behaviour control was carried through the entire research duration, mainly during the periodic visit for water meter reading.

2.3 Conducted measurements

Water meter reading were monthly done during 12 months from June/91 to May/92, in 95 houses of the estate, i.e., 63 % of the total houses. The reasons for not reading 55 houses are the following:

a) not occupied houses by the residents;

b) houses where the entry water meter was not installed due any reason and the flush tank had been substituted by flush valve;

c) houses where the residents do not accepted to participate of the research.

Research measurement data constitute an important source from which it was possible to extract valuable information. The results and conclusions here presented are based in measurements over 61 houses, according to 2nd, 3rd and 4th columns of Table 2 (houses with flush tank where reading was validated). From these 61 measurements, 13 houses had only reading on the flush tank water meter because the entry water meter had not been installed yet. In another 6 houses only the entry water meter reading was considered because the resident had installed flush valve substituting flush tank.

3 RESULTS

This work aims basically to show that the consequence of LVFT use was an effective reduction on water consumption when compared with normal toilet. Two numerical indicators will be utilized for this objective: the house per capita water consumption and the toilet per capita water consumption. Employing per capita indicators was necessary to neutralize the random influence of number of residents variable from direct reading of water meters. To neutralize the not exactly periodic water meter monthly reading, it was adopted the daily average water consumption for each of measured months.

Type of toilet bowl	Houses where the reading was done and considered valid				Houses where the reading was done and not considered valid	Houses where the reading was not done	Total
	Houses with flush tank			Houses with flush valve			
	Reading at the house entry and at toilet	Reading only at the house entry	Reading only at toilet				
LVFT (Celite)	10	1	7	3	7	17	45
LVFT (Deca)	15	3	2	5	4	16	45
LVFT (Twyfords)	12	0	4	2	8	4	30
Control	5	2	0	1	4	18	30
Total	42	6	13	11	23	55	150

Table 2 - Number of houses where water meter readings were or nor done and were or not considered valid

3.1 House consumption

Figure 1 shows graphically the variation of the per capita average daily consumption of the houses during the 12 month period of measurements. Houses are differentiated according to type and make of toilets installed. It can be observed in Figure 1 that all 4 curves have practically the same behaviour. It is not possible to extract from these curves any, even remote, information showing water economy due to the use of any of the four groups type/make of

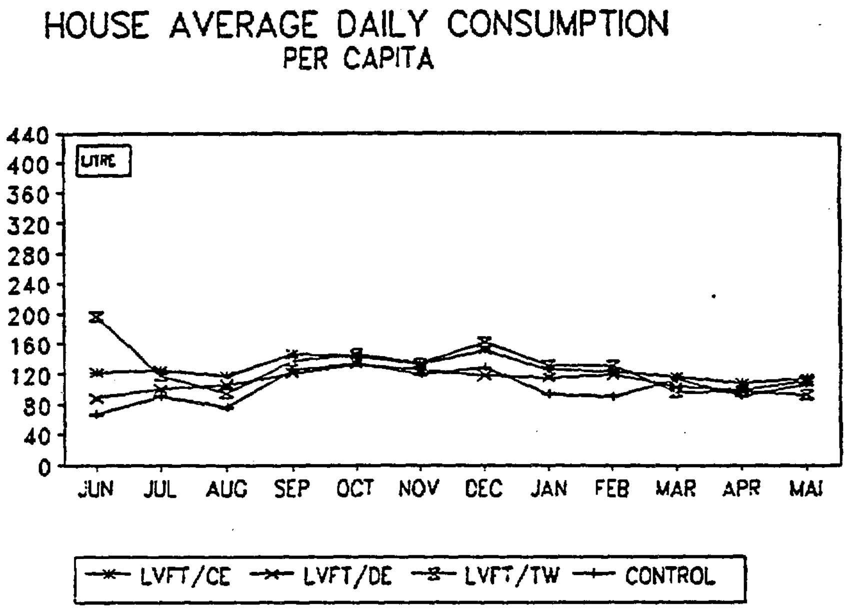

Figure 1

toilets. This fact is explained by the nature of the indicator since the per capita average daily consumption includes the water consumption of all types of water use at house. Thus, the total volume of water used in the shower, lavatory, laundry, kitchen sink, kitchen filter and garden tap reach an amount much higher than the volume used only in the toilet. This phenomenon implies that the total water consumption of different houses had similar behaviour independent of the group type/make of toilet installed. This result also leads to speculate on the real participation of the toilet on the total house consumption that would not be around the 38% previously assessed (Rocha, 1984). If that figure was true an effective reduction on the toilet would imply in a detectable change in the house consumption.

The per capita average daily consumption was computed from monthly readings of the 48 house entry water meters resulting in 120 L valid both for houses with LVFT or normal toilets, indistinctly. This value is compatible with the daily average per capita of the residential figure of 141 L in São Paulo and 30 municipalities of São Paulo metropolitan area (Boaventura, 1986).

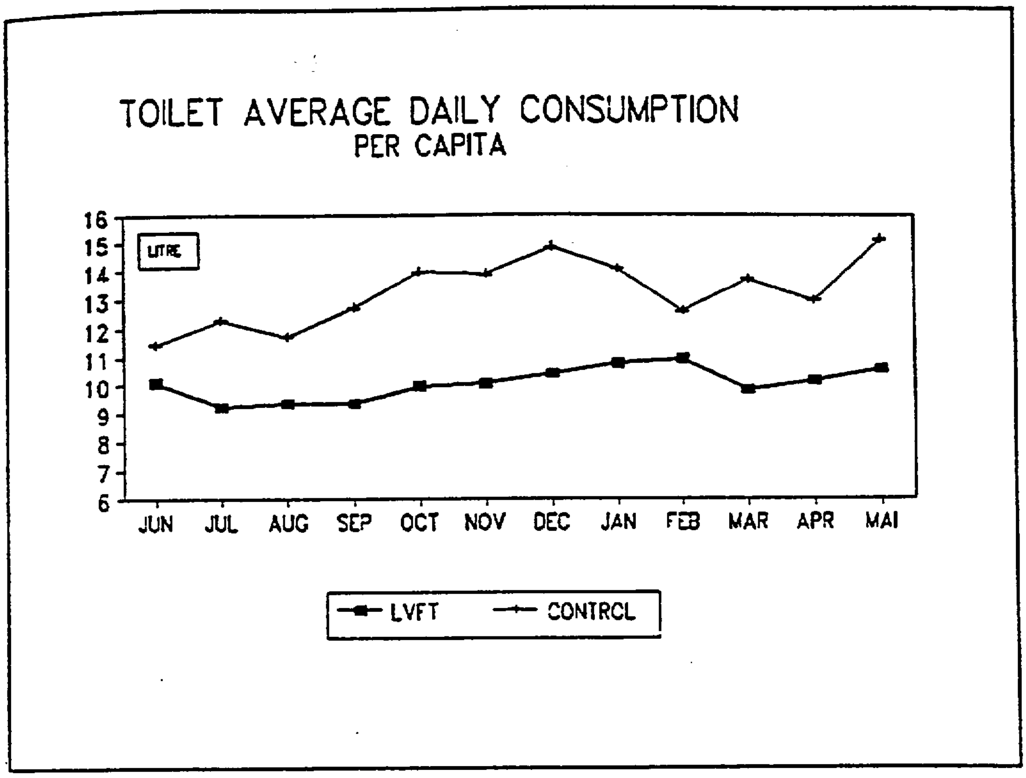

Figure 2

3.2 Toilet consumption

Figure 2 shows graphically the variation of the toilet per capita average daily consumption during the 12 month period of measurements, according the type of toilet: LVFT or normal (control). It is evident the lower consumption of LVFT toilets. From data obtained from monthly reading in 55 flush tank water meters it was computed the per capita average daily consumption of 10 L for LVFT, and 14 L for normal toilets.

Figure 3 shows graphically the same monthly variation of consumption differentiating between LVFT makes. The per capita average daily consumption computed for each make resulted in the same value of 10 L.

3.3 Toilet consumption ratio

The toilet consumption ratio is computed dividing the water volume used in the toilet by the total water volume utilized in the house (including the toilet). Figure 4 shows graphically its variation during the 12 month period of measurements, detaching the LVFT from normal toilet (control) ratio. The LVFT average consumption ratio was 10% while the

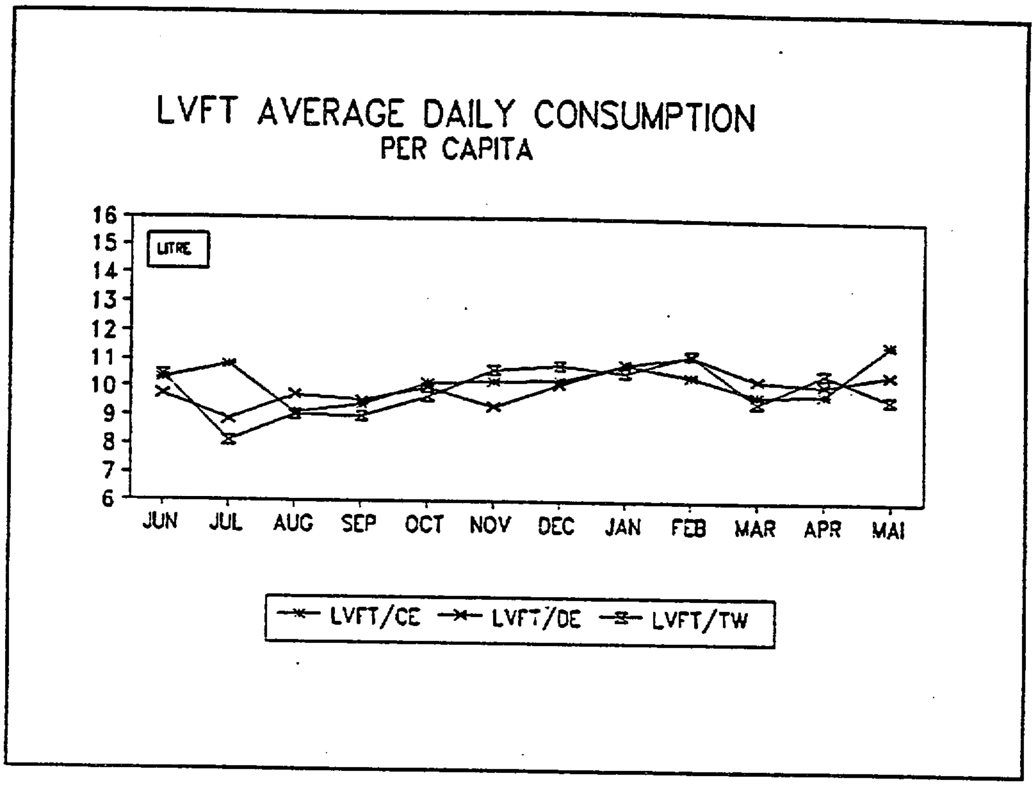

Figure 3

corresponding figure for normal toilets was 16%.

4 CONCLUSIONS AND COMMENTARIES

The employment of LVFT leads to an effective reduction in the water volume used on the toilet flushing. A daily average reduction of 4 L per capita was observed. In terms of comparison with the per capita average daily consumption of the normal toilet used for control (14 L), the LVFT corresponding figure was 29% lower. Referring to the global per capita consumption of 120 L computed for all the houses independently of the toilet type installed, the LVFT represented about 3% of reduction.

Bearing in mind that the LVFT flushing volume is 5 L and considering that its per capita average daily consumption was 10 L, it can be concluded that its average number of flushing actions was 2.0. For the normal toilet the flushing volume is 10 L and the per capita average daily consumption was 14 L, resulting a per capita average number of 1.4 flushing actions. This higher value for the LVFT seems to show that they had to be flushed more times by users for its proper cleaning, i.e, the LVFT would had presenting functioning

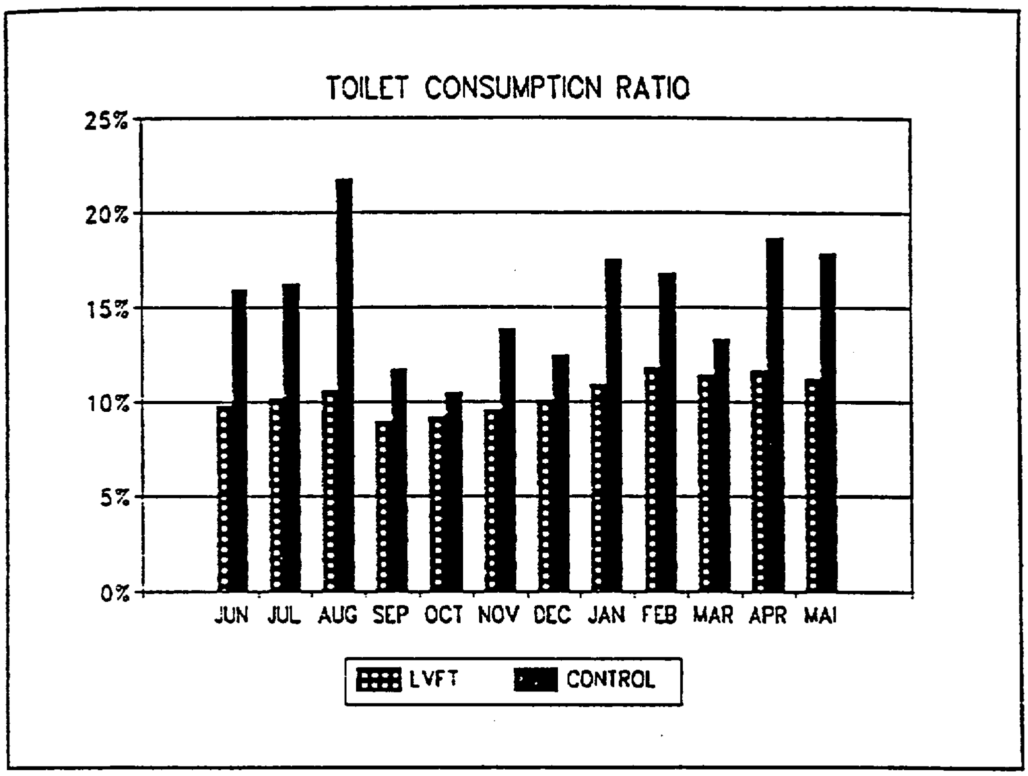

Figure 4

problems. This picture suggests a design revision of the employed LVFT, trying to identify the reasons that lead users to flush it more times.

The global ratio of water consumption in the toilets (16% if all toilets are included - LVFT and normal) actually is much lower than the figure initially expected (about 38%). It shall be stressed that this was the first time that this measurement was carried on in Brazil. However the found water consumption ratio value must not be extended for others types of buildings even residential ones. The validity of the found consumption ratio can be applied only to dwellings of the same type of those subject of this research and with the same economic and social-cultural profile.

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ITEM 13.

Appendix 2.

Item 13, Appendix 2.

'Water closet discharge profiles - impacts on drainage system design', Adilson Lourenco Rocha, CIB-W'62 Conferance, Porto, Portugal, 20-23rd September, 1993

CIB-W62 Paper

Water closet discharge profiles - impacts on drainage system design.

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To be presented in Brighton, England by Prof Swaffield and Dr Galowin

Water closet discharge profiles - impacts on drainage system design.

by

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SUMMARY

The design of drainage systems that take into account waste solid transport has been shown to be dependent upon the discharge profile produced by water closets at the entry to the drain. For low flush volume water closets there is a special need to apply an accurate description of the time distribution of the surge and the time dependency of the hydraulic conditions and waste transport in the drainage system. The determination of the time varying sequences of loadings on the drainage system from appliance discharge into either vertical stacks or horizontal collection systems is essential in order to evaluate the downstream hydraulic conditions, in particular the flow depth and rate, and the associated solid transport velocity variations.

The study presented in this paper applied an unsteady free surface flow numerical simulation based on the method of characteristics to solve the differential equations defining the drain flow conditions. The application of such a simulation is the only means available to model the local hydraulic conditions in the drain following user defined appliance discharge. The study investigated the time dependent flow conditions caused by staggered and simultaneous discharge of four wcs on four floors to a vertical stack and collection drain and compared these to the flow conditions in a horizontal collection drain network accepting staggered or simultaneous discharges from four similar wc types mounted at the end of a series of horizontal branches. The study illustrates the inherently differing flow conditions that apply in each of these cases and the dependency of the resulting solid transport on both system design and appliance specification.

The paper concludes that the availability of dependable simulation techniques offers drainage designers and code specifiers the opportunity to both improve system design and evaluate the implications of water conservation and wc performance on overall system efficiency.

Water closet discharge profiles - impacts on drainage system design.

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INTRODUCTION - UNSTEADY FLOW MODELLING IN BUILDING DRAINAGE SYSTEMS.

Water flow within a building drainage network may be described as unsteady due to both the variation of outflow at each appliance during its discharge, the random usage of the appliances connected to the network and the modifications to the appliance discharge during passage through the network.

Current design methods have incorporated the usage pattern of system appliances by the introduction of probability of use functions, the Fixture Unit Method, Hunter (1940). However the design guidance offered is conservative and assumes steady flow rates related to a summation of the network fixture units. For horizontal branches it has been shown, Swaffield and Galowin (1992), that the increases in diameter and slope recommended correspond to steady flow depths reaching 50% of the pipe diameter.

In parallel to the US / UK design guidelines outlined above, all other developed national codes have their own particular methodologies and limiting values. As these are entirely based upon the translation of steady state empirical data into 'safe' design guidelines, it is extremely difficult to compare their relative merits or suitability to meet changing norms and usage patterns within building drainage.

The introduction of water conservation and the increased installation of water using appliances set up design requirements not necessarily covered by the steady state empirical data utilised to generate these current design guides. Rapid changes in the water consumption of appliances, together with water conservation considerations and future metering and costing strategies imply that improved modelling methods are required to ensure that systems are not over designed for their likely loadings. In building drainage system design, overdesign cannot be regarded as a safety factor as increases in pipe diameter at any given flow rate automatically lead to an enhanced likelihood of solid deposition and maintenance costs.

The harmonisation of European design standards in the immediate future also presents a need for an alternative analysis and design evaluation methodology to allow direct comparison of national codes and the derivation of improved design guides based upon the need to meet system performance requirements.

The term 'unsteady' has an accepted definition that at any chosen location in the pipe network the flowrate and depth will vary with time. This is clearly true for a building drainage system fed by a random selection of appliance discharges.

An appliance discharge to the head of a drain may be described by an inflow vs time curve. This generates a wave that propagates down the drain towards its termination at a vertical stack or at a junction with other branches, which may naturally be carrying their own discharges. Within such discharge waves the deeper zones tend to move faster than the shallower, effectively redistributing the water mass in the wave forward, steepening the leading edge and spreading the tail of the wave. Friction obviously reduces the difference between the flow velocities along the wave, so that not all waves 'break'. The overall effect will be to attenuate the wave, lowering the peak flow depth as the wave moves through the network, with a consequent reduction in both flow depth and peak flow rate, and an increase in flow duration at any location. None of these effects can be predicted by the current design methods and this provided the impetus for the development of the methodology and numerical modelling described.

The degree of attenuation experienced by any appliance discharge is dependent upon pipe diameter, roughness, slope, the shape of the initial flow vs time profile and the baseflow over which it must pass. The driving force for attenuation is the difference in depth and velocity within the wave itself; as these differences decrease due to attenuation, so does the attenuation decrease. Far downstream the wave becomes 'almost' a steady flow, as the summation of many such attenuated waves within the sewer leads to conditions that may be approximated by the equations governing steady free surface flows.

THE MODELLING OF UNSTEADY FLOW CONDITIONS

The water flow and entrained airflows within drainage systems belong to a family of unsteady flows that may be described by the full equations of continuity and momentum, whose solution was first investigated by d'Alembert in the 1750's. The momentum equation may be stated, for either free surface flows or entrained airflows, Swaffield and Galowin (1992) as

$$V \frac{\partial V}{\partial x} + \frac{\partial V}{\partial t} + \frac{1}{\rho} \frac{\partial p}{\partial x} - g \sin \alpha + \frac{f\, V|V|}{2m} = 0$$

where p - pressure, V - mean flow velocity, ρ - fluid density

The modulus of the velocity, |V|, is introduced so that the friction force opposes the direction of the flow at any given time. (The velocity is defined as positive in the positive x direction).

Similarly the continuity equation becomes

$$\frac{\partial V}{\partial x} + \frac{1}{\rho} \frac{d\rho}{dt} + \frac{1}{A} \frac{dA}{dt} = 0$$

where	$\partial V/\partial x$	accounts for the change between inflow and outflow,
	$1/\rho\ d\rho/dt$	accounts for the liquid compressibility, and
	$1/A\ dA/dt$	accounts for the radial change in conduit size.

This equation is general in application as no assumptions have been made as to fluid properties, conduit cross sectional shape or the presence of a free surface.

FREE SURFACE WAVE PROPAGATION IN UNSTEADY FLOWS.

In this case, for the equation of motion, the fluid pressure may be replaced by flow depth, h, as p=ρgh and the frictional resistance may be expressed via the friction slope, S, defined from the Chezy equation yielding an expression

$$V \frac{\partial V}{\partial x} + \frac{\partial V}{\partial t} + g \frac{\partial h}{\partial x} + g\ (S - S_0) = 0$$

where S_0 is the channel slope, positive if inclined downwards.

The equation of continuity may also be simplified as in this case there is no fluid compressibility effect but the cross sectional shape of the filled channel will change with flow depth, thus

$$A \frac{\partial V}{\partial x} + T \frac{\partial h}{\partial t} + VT \frac{\partial h}{\partial x} = 0$$

where T is the free surface width.

The unsteady flow equations of motion and continuity this flow case are examples of quasi-linear hyperbolic partial differential equations and as such may be solved by numerical techniques.

In order to solve these equations numerically they must first be transformed into total differential equations, via the method of characteristics, resulting in expressions for free surface flow

$$\frac{dV}{dt} \pm \frac{g}{c}\frac{dh}{dt} + g(S - S_o) = 0$$

provided that

$$\frac{dx}{dt} = V \pm c$$

where the term $(gA/T)^{1/2}$ is the wave propagation velocity, reducing to $(gh)^{1/2}$ for the special case of the rectangular channel

As the methodology depends upon the inflow profiles of discharging appliances, it follows that this technique also offers the opportunity to deal with the appliance usage pattern explicitly, rather than by depending upon some probability of use function that might well be inappropriate for the particular building or user condition being considered.

It should be noted that the finite difference expressions only exist provided that the dx/dt relationships are adhered to, this is known as the Courant Criterion and links simulation time step to distance increments or inter node pipe lengths. It will be seen that the Courant Criterion depends upon flow velocity and wave speed; it is useful to note that for free surface flows these are comparable, commonly <5m/s, These dx/dt equations define lines drawn in the x - t plane known as characteristics. These characteristics may be thought of as the mode of communication of information from one location in the flow at the current time to another location one time step in the future.

At the boundaries to any system only one characteristic can exist and it is necessary to represent the boundary by some developed equation linking flow depth, or air pressure to flow rate and/or time. It is the ability to develop such boundary conditions that endows the method of characteristics with its particular suitability as a simulation technique for unsteady flow in building drainage and vent systems.

Any network may be subdivided into two categories of unsteady flow modelling, namely the transmission of transients along a partially filled pipe and the effect of any imposed condition at pipe boundary. Boundary conditions include w.c. discharge to a drain; pipe junctions, including displaced hydraulic jumps; entry to vertical stacks; the transformation of the stack annular flow back into free surface flow at entry to the lowest level collection drain or solid transport within a pipe network.

The development of these boundary conditions requires both an empirical, laboratory based input, as well as a study of the mathematics required to transfer the observed boundary effects into a set of relationships compatible with the method of characteristics model. A fuller description of the model mathematics and the validation undertaken may be found in Swaffield and Galowin (1992) and Swaffield and Boldy (1993).

INCLUSION OF SOLID TRANSPORT WITHIN A METHOD OF CHARACTERISTICS UNSTEADY FLOW MODEL - THE SOLID VELOCITY / FLOW VELOCITY DECREMENT APPROACH

The introduction of a moving solid into the method of characteristics model requires a suitable boundary condition to be developed that links solid velocity to the flow depths and velocities both immediately upstream and downstream of the solid location. Observations of actual drainage system operation, Bokor (1982), indicated that for a large proportion of discharged solids ie. paper towels, toilet paper, some faecal material, the solid velocity may be approximated by a relationship involving local flow depth and velocity. This model would retain all the advantages of the method of characteristics prediction of wave attenuation effects but would in all probability slightly underestimate solid transport distance.

The local velocity of the solid may be calculated from the local flow depth and velocity calculated by the full method of characteristics solution, McDougal and Swaffield (1993, 1994). This model is limited in the region of final deposition as the flow depth upstream of the solid is likely to increase considerably as the solid velocity goes to zero, however as the velocities predicted will be low the error on deposition position will be small. The model can deal with multiple solids that close up or merge by introducing a change in the form of the relationship to conform to some larger merged solid. Despite its limitation this model presents the designer with a rapid methodology for identifying both possible solid deposition, and design solutions by adjusting pipe slope, diameter or appliance choice.

APPLICATION OF THE SIMULATION TO THE PREDICTION OF FLOW CONDITIONS IN BOTH A VERTICAL AND HORIZONTAL DRAINAGE NETWORK.

Figure 1 is a summary of the drainage system layouts compared, namely a vertical stack and a horizontal collection system. The overall lengths of the systems are identical. Two different 6 litre wc types are considered, a 'gravity' cistern and a 'pressure' cistern model, peak outflows 1.8 and 3.3 litre/second respectively. Simultaneous and random discharges for the 4 wc's shown were considered. Three solids are discharged from each, timed midway along the rising, steady and falling portions of the assumed discharge profiles. The slopes of all pipes in any one network are assumed constant, ie if the collection drain is at 0.01 then all the branches etc are also at 0.01.

One point of special note in Figure 1 is the presence of the 'comparative point' taken as entry to the horizontal drain downstream of the final wc branch and the base of the vertical stack. Solid transport will be compared relative to this point and this will explain the NEGATIVE solid location shown on later figures, ie solids discharged from wc1 effectively start at -22m relative to this point.

Figures 1a, 1b and 2a, 2b compare the accumulated flow entering the collection drain at the base of the stack or downstream of the last wc horizontal branch. Points to note are ..

1. the pressure tank discharges give a higher maximum at the base of the stack for both simultaneous and random discharge, 4.6 compared to 3.6 litres/second.

2. there is evidence of fewer peaks in the random discharge accumulated flow than in the simultaneous case, but this is not a major factor as the secondary peaks are quite low, ie. not more than 1 litre/second maximum.

3. although not illustrated, changing the slope of the wc connection, 2m long, on each upper floor had little or no effect on the accumulated flow at the base of the stack.

Figures 3a and 3b compare the accumulated flow to the collection drain downstream of the last wc branch for the 8 cases considered. Points to note are ...

1. In all cases the simultaneous discharge condition results in a series of maximum flowrates at entry to the collection drain, the first and largest representing the discharge from the last wc, wc4 on Figure 1. Subsequent peaks corresponding to wc3,wc2 and wc1 in that order demonstrate the increased attenuation expected with greater travel distance and the separation of the peaks also corresponds to the relative lengths of the pipes traversed to reach this point, 2, 6, 14 and 22 m for wc4, 3, 2 and 1 respectively.

2. In all cases the random discharge case gave a higher peak flowrate and fewer subsequent lower peaks as the discharge from wc1, having the furthest to travel. arrives at the entry to the collection drain to reinforce the later discharge from wc4, the discharge with the shortest travel distance.

3. The effect of pipe slope is more important here and in all cases results in higher peak flows but in the same number of subsequent peaks. There is also evidence that the wave velocity is higher with increased slope as subsequent peak flow values at entry to the collection drain happen earlier as the slope is changed from 0.01 to 0.02.

Figures 4a,b to 7a,b present the flow depths and local flowrates along the collection drain at the base of the vertical stack for the 8 cases considered. Points to note are ...

1. In every case there is evidence of a steepening of the wavefront due to the energy of the flow at the base of the stack, Swaffield and Galowin (1992). Results are presented for the 0.01 slope case only, the steepening would have been more marked for 0.02 and would also have persisted further along the collection drain.

2. The differential wave speed depending on flow depth is clearly responsible for the smoothing of the rather jagged flow profile at the base of the stack into the flow profile 15 m further down the collection drain.

Figures 8a,b to 11a,b present flow depths and flowrates along the collection drain downstream of the last wc branch in the horizontal system, and are therefore comparable to Figures 4 to 7. Points to note are ...

1. All cases show continuous attenuation.

2. The smoothing out of the flow peaks over the 15 m length of the drain is more marked.

3. The entry depth is the depth appropriate to the downstream side of a 45 degree junction, ie the local flow critical depth, and therefore is pretty close to the exact opposite of the 'energy' flow case at the base of the stack. This should have a detrimental effect on solid transport performance.

4. While all the cases show attenuation, the attenuation in the pressure cistern case is more marked and illustrates the dependence of wave attenuation on appliance discharge profile as well as the system parameters of slope, roughness and diameter.

5. The peak flow is greater for the random discharge cases compared to the simultaneous cases as the discharge from wc1 has time to arrive.

Figures 12a,b and 13a,b compare the solid transport performance in the collection drains for both the vertical stack and horizontal systems. Note the negative distances on these figures, these refer to solids discharge into the horizontal system that have to travel from 22 to 2 m to reach the entry to the collection drain, the point of comparison identified in Figure 1. For these figures only transport predictions for solid no. 2, ie the solid discharged at the mid point of the wc discharge profile plateau has been presented. Points to be noted ...

1. The solid start time for the collection drain at the base of the vertical stack depends on the time taken to fall, this varies for each floor, hence the four lines starting at 0 m and leaving the system at 15 m.

2. The four solids discharged into the horizontal branches typically travel about 10 - 12 m, and hence none leaves the system on the first flush with pipe slopes of 0.01.

3. For the vertical stack system the effect of increasing the collection drain slope to 0.02 would only speed the solids out of the system and these results are not presented.

4. For the vertical stack system all solids leave the system at all slopes and this is true for all three solids from each wc. However it will be seen that the random discharge of either the gravity or pressure wc's resulted in a 'poorer' solid transport performance.

5. For the horizontal system the effect of random vs. simultaneous discharge is mixed. From the figures presented for the wc1 solid, with the farthest to travel, random discharge improved travel distance as it benefitted from flow reinforcement as it passed the branch junctions downstream. For the simultaneous case, this did not occur for the solids from wc1 and wc2, however solids from wc3 and more markedly wc4, benefitted from simultaneous discharge as the later arrival of the surge from upstream gave added impetus to these solids, by then within the collection drain.

6. The same comments apply in general to both the gravity and pressure wc's. However the advantage of random discharge is even more marked in the case of the solid from wc1.

Figures 14a,b and 15a,b compare the effect of pipe slope on the transport in the horizontal system collection drain. In every case transport is improved by increasing pipe slope, in one case the wc4 solid following simultaneous discharge of the four wc's exits the system, having travelled 17 m along the wc4 branch and the collection drain.

Figure 16 demonstrates that for repeated simultaneous discharge of the four gravity cistern wc's, at 60 second intervals, that three flush sequences are need to clear the mid profile solids from the horizontal system. The curves illustrate that the solids become deposited while waiting for the next flush to move them on.

CONCLUSIONS

The application of the method of characteristics based simulation presented in this paper has illustrated the flexibility of such numerical techniques. By choosing an application where the predictions would inevitably confirm the expectations of experienced system designers it is hoped that other system performance predictions will also be seen as accurately representing the unsteady flow conditions that prevail within building drainage systems in response to system operation.

The study has also illustrated the dependence of local flow conditions upon both the appliance discharge profile and the design of the system itself. The simulation therefore offers advantages to system designers and appliance manufacturers. For the first time simulation of the type illustrated allow the designer to specify the required performance of the appliance or the manufacturer to demonstrate ahead of system installation that a particular appliance can meet the system specification. This has obvious advantages in dealing with such changes in drainage performance criteria as water conservation.

The use of simulations, as illustrated in this paper, also allows the designer to consider user regimes not previously addressed via steady flow/probability models. For example the effects of random or simultaneous discharge may be investigated, as can flows in little used networks.

This paper should be seen as part of an ongoing research programme, fully reported to past CIBW62 meetings from 1981 onwards, aimed at the introduction of computer based analysis and simulation techniques to the design of building drainage networks. The overall objective of the programme was to emphasise that the unsteady flow conditions generated within building drainage networks belong to a well understood family of flow regimes within the wider field of fluid mechanics and that the future design of drainage networks, and the specification of design codes across national boundaries, could be improved and enhanced by the adoption of such computer based simulation techniques.

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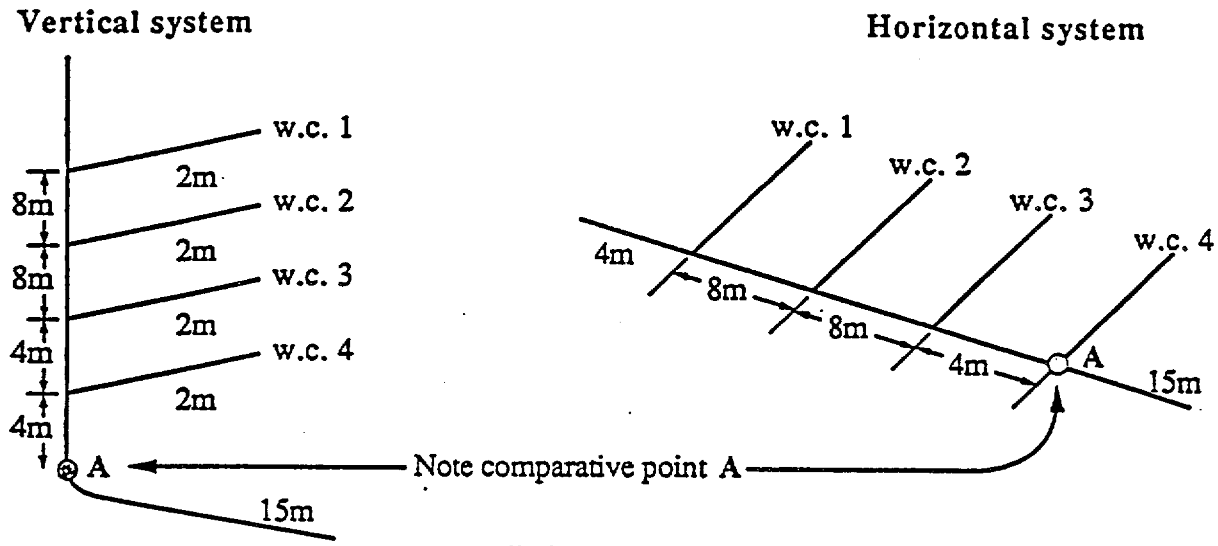
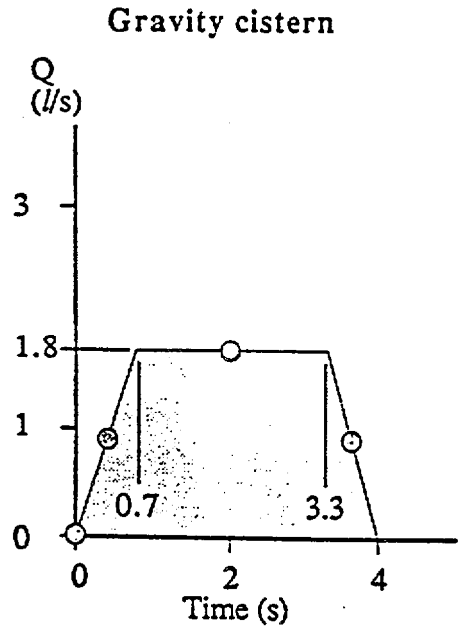
Figure 1. Test specification

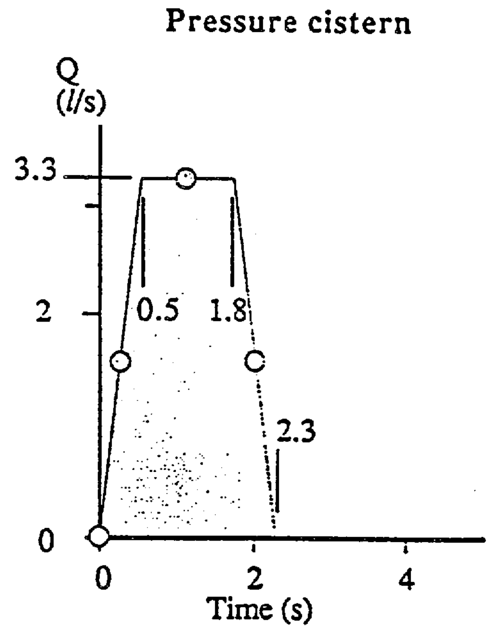


All pipe slopes: 0.01 or 0.02
All pipe diameters: 100mm

w.c. Discharge characteristics



Solid insert times (⊙):
0.35 s
2.0 s
3.65 s



Solid insert times (○):
0.25 s
1.15 s
2.05 s

Discharge sequence:	1 Simultaneous	–	0 secs
	2 Random	w.c. 1	0 secs
		w.c. 2	4 secs
		w.c. 3	6 secs
		w.c. 4	9 secs

Figure 1a. Comparison of the accumulated flow at the base of the stack following simultaneous and random gravity cistern wc discharge on four floors. All 'horizontal' drains 100mm diameter and 0.01 slope.

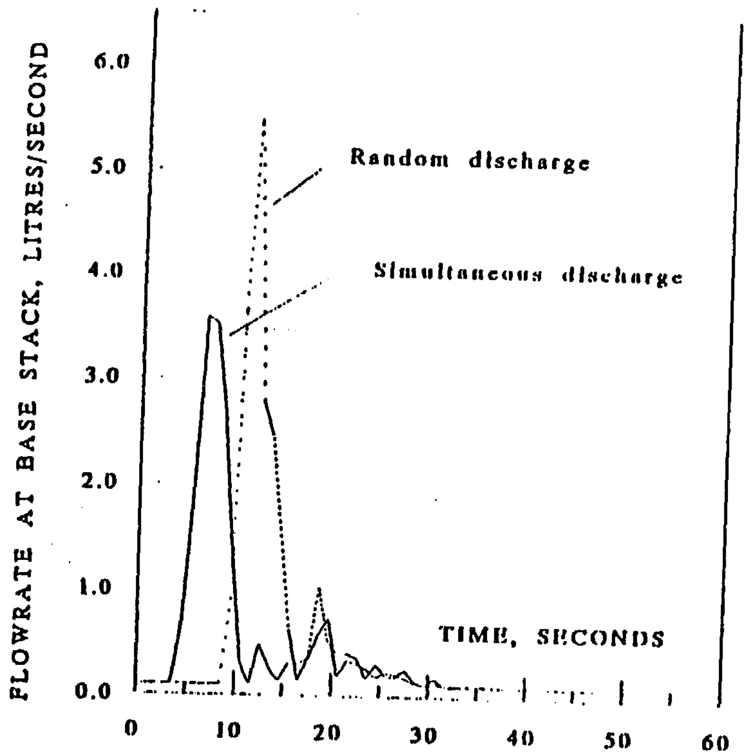


Figure 1b. Comparison of the accumulated flow at the base of the stack following simultaneous and random pressure cistern wc discharge on four floors. All 'horizontal' drains 100mm diameter and 0.01 slope.

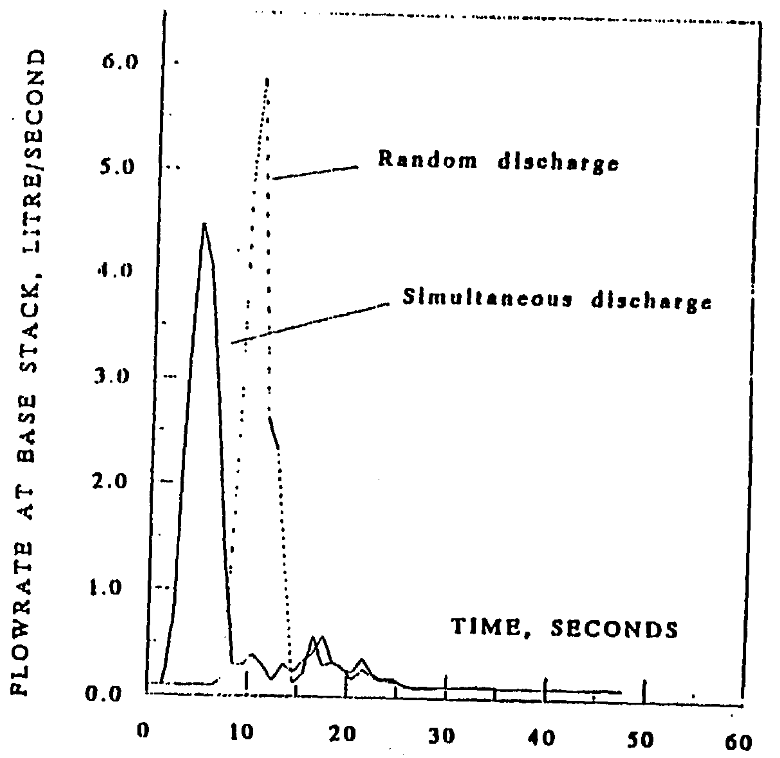


Figure 2a. Comparison of the accumulated flow at entry to the collection drain in a horizontal system following simultaneous and random discharge of four gravity cistern wcs. All drains 100mm diameter and 0.01 slope.

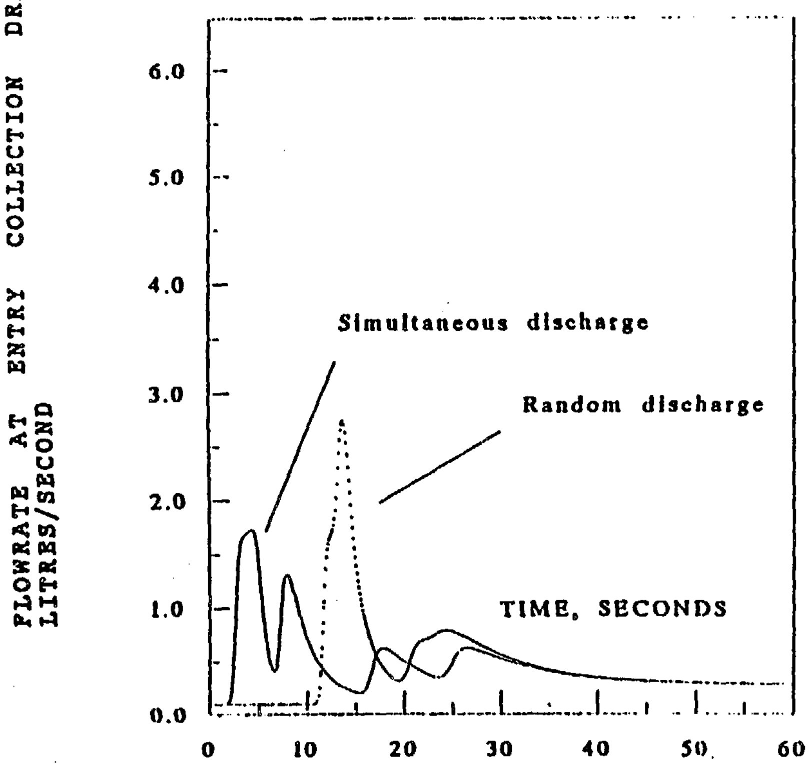


Figure 2b. Comparison of the accumulated flow at entry to the collection drain in a horizontal system following simultaneous an random discharge of four pressure cistern wcs. All drains 100mm diameter and 0.01 slope.

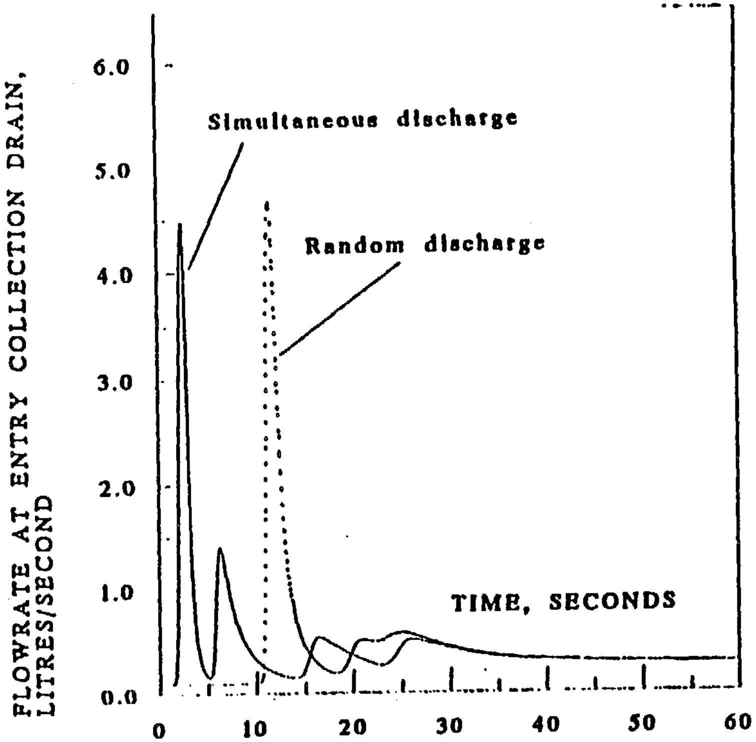


Figure 3a. Comparison of the accumulated flow at entry to the collection drain in a horizontal system following the simultaneous and random discharge of four gravity cisterm wcs. All drains 100mm diameter and either 0.01 or 0.02 slope.

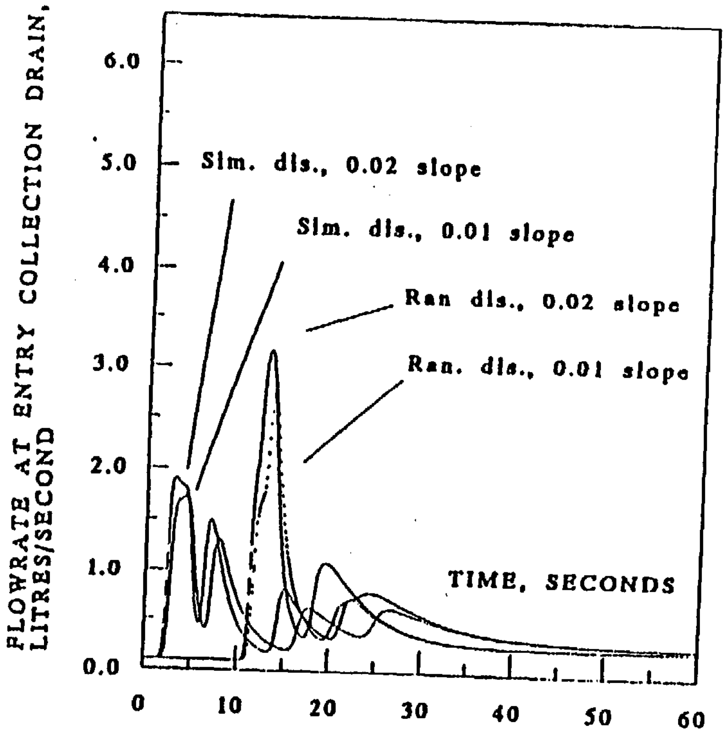


Figure 3b. Comparison of the accumulated flow at entry to the collection drain in a horizontal system following the simultaneous and random discharge of four pressure cistern wcs. All drains 100mm diameter and either 0.01 or 0.02 slope.

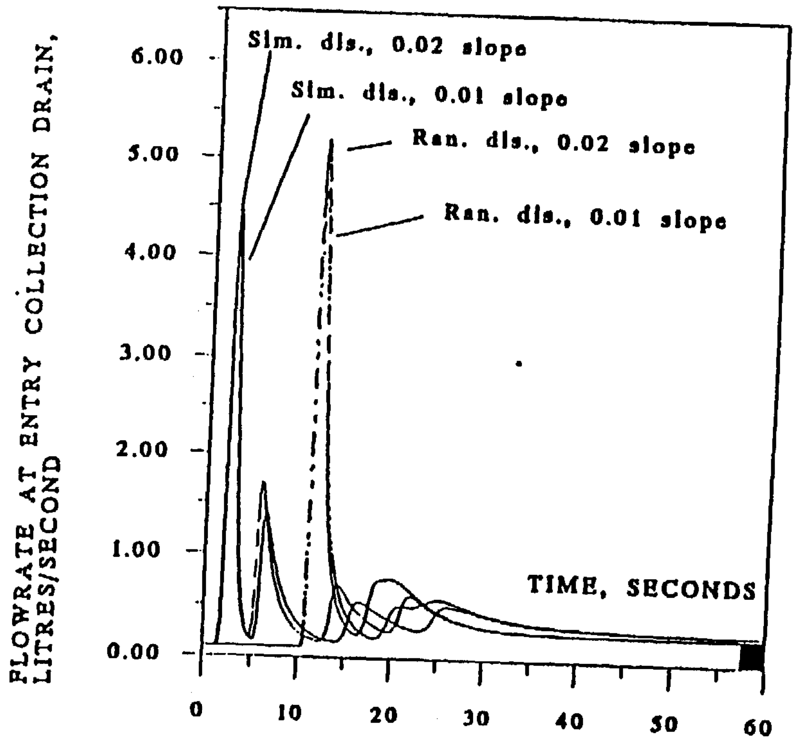


Figure 4a. Flow depth along the collection drain at base of vertical stack, 100mm diameter, 0.01 slope, following simultaneous discharge four pressure cistern wcs on upper floors.

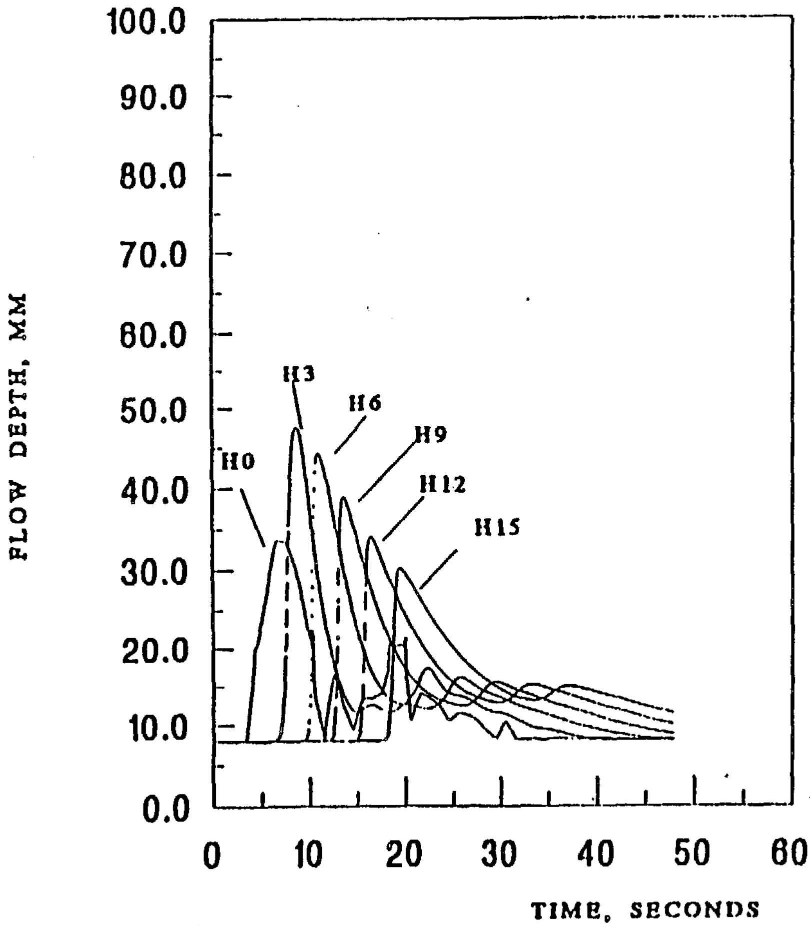


Figure 4b. Flow attenuation along the collection drain at base vertical stack, 100mm diameter, 0.01 slope, following simultaneous discharge of four gravity cistern wcs on upper floors.

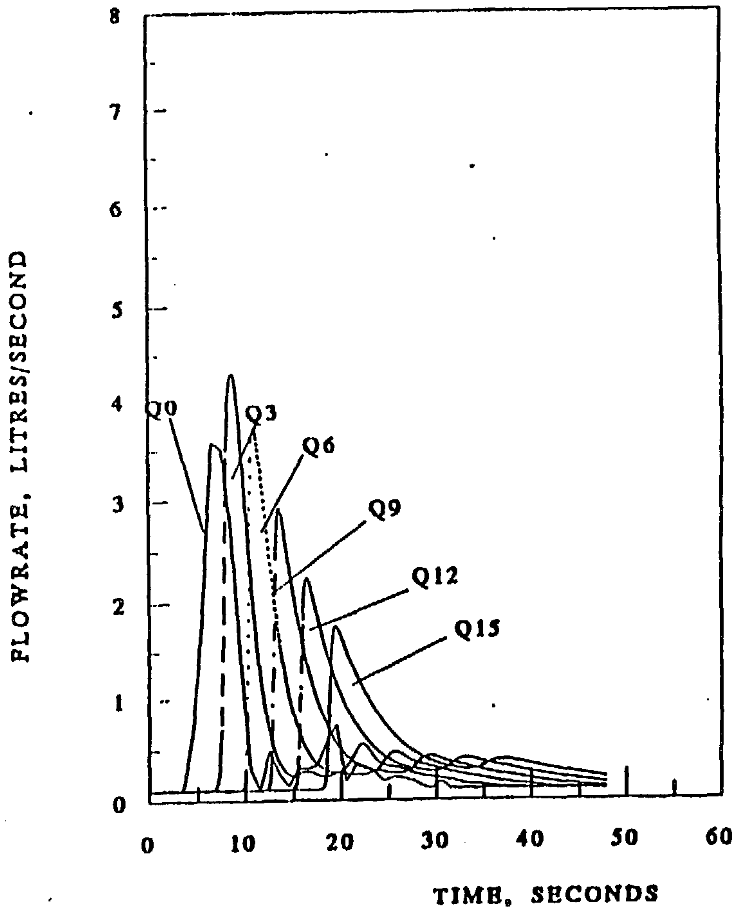


Figure 5a. Flow depth along the collection drain at the base of the vertical stack, 100mm diameter, 0.01 slope, following random discharge of four pressure cistern wcs on upper floors.

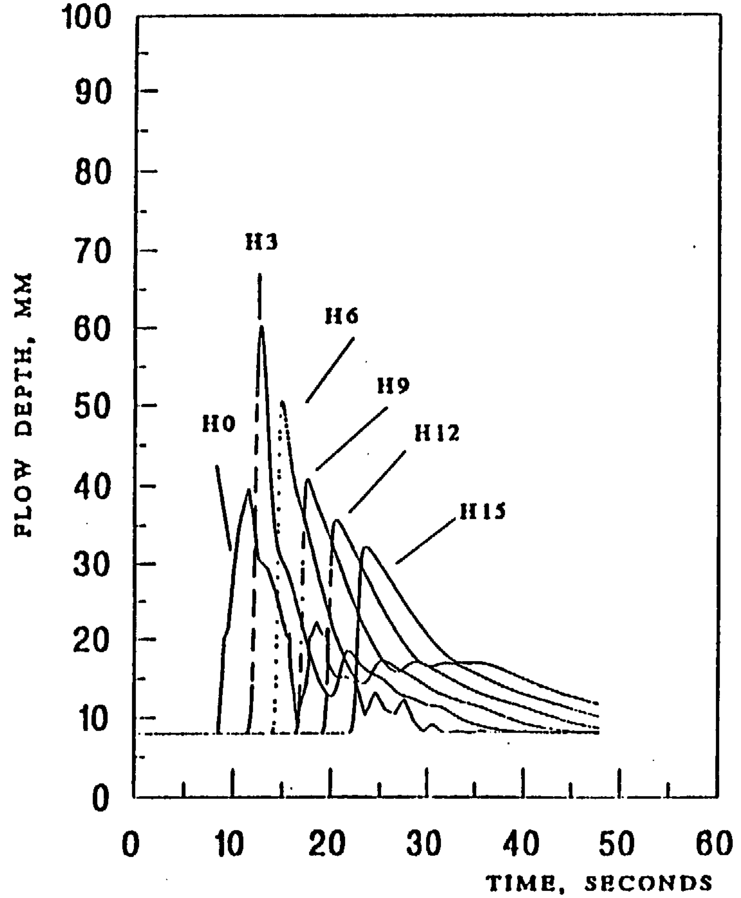


Figure 5b. Flow attenuation along the collection drain at the base of the vertical stack, 100mm diameter, 0.01 slope, following the random discharge of four gravity cistern wcs on upper floors.

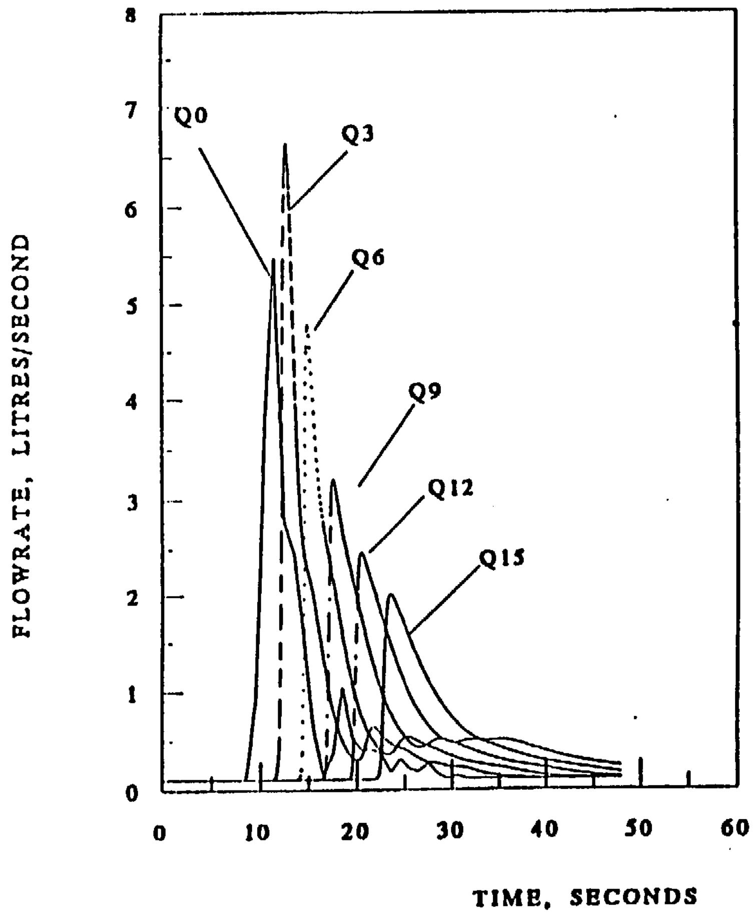


Figure 6a. Flow depth along the collection drain at the base of the vertical stack, 100mm diameter, 0.01 slope, following the discharge of four pressure cistern wcs on upper floors.

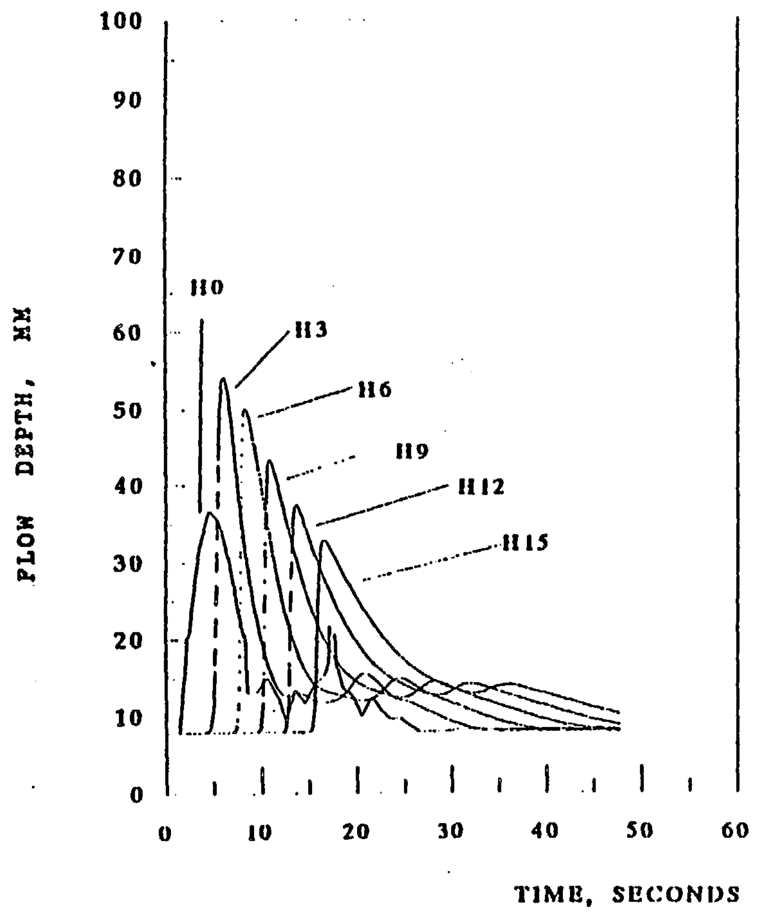


Figure 6b. Flow attenuation along the collection drain at the base of the vertical stack, 100mm diameter, 0.01 slope, following the simultaneous discharge of four pressure cistern wcs on upper floors..

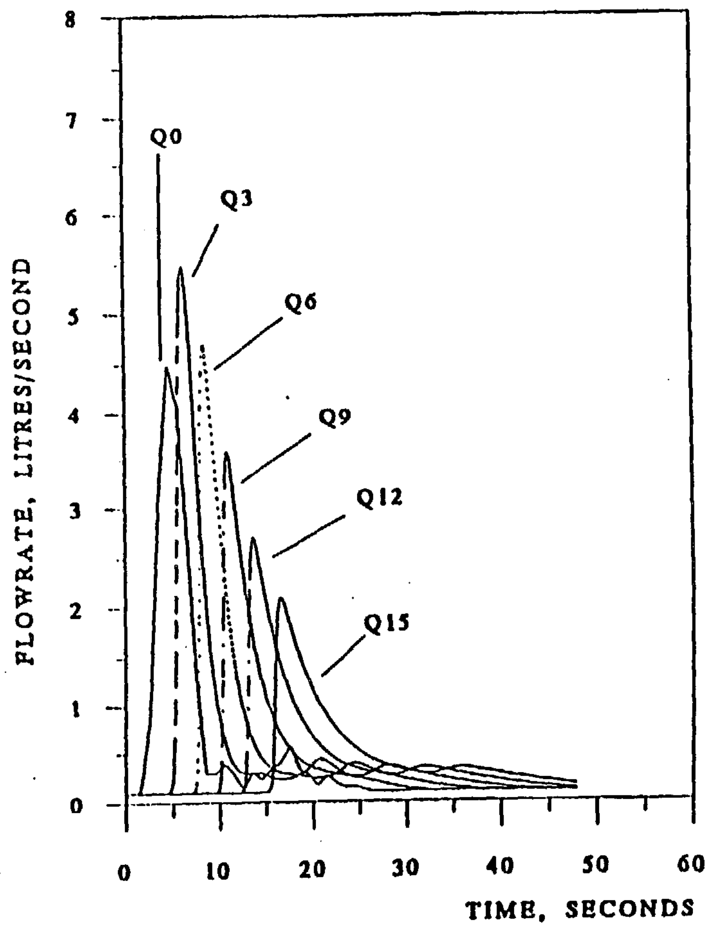


Figure 7a. Flow depth along the collection drain at the base of the vertical stack, 100mm diameter, 0.01 slope, following the random discharge of four pressure cistern wcs on upper floors.

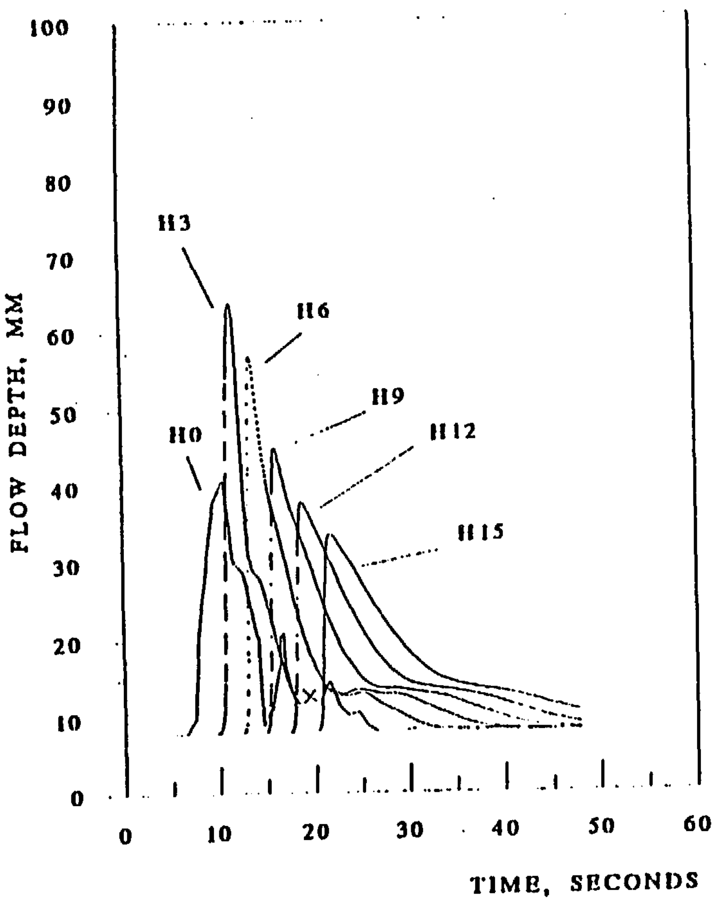


Figure 7b. Flow attenuation along the collection drain at the base of the vertical stack, 100mm diameter, 0.01 slope, following the random discharge of four pressure cistern wcs on upper floors.

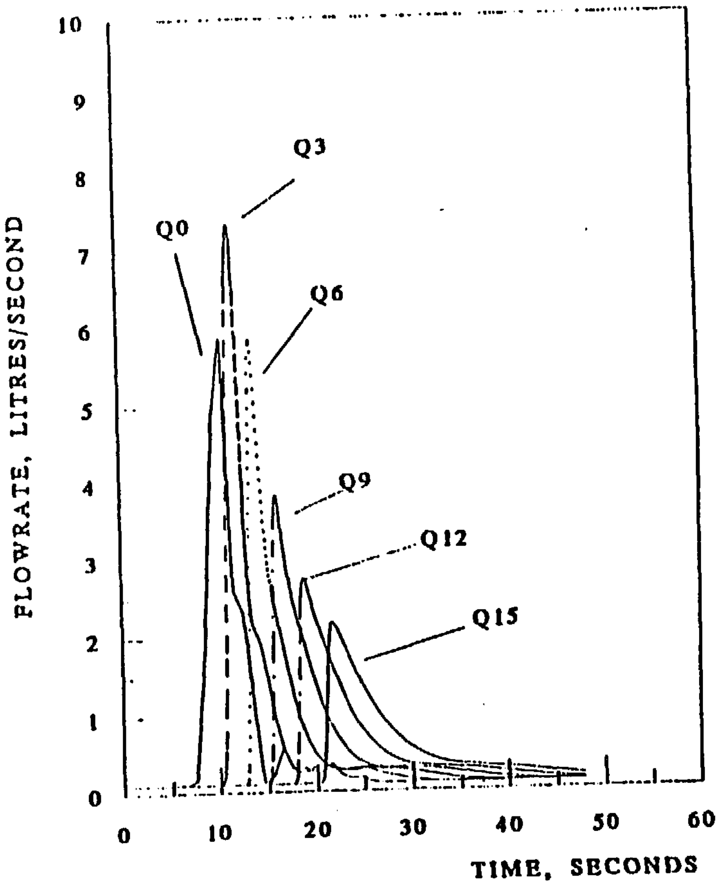


Figure 8a. Flow depth along the collection drain, 15m long, 100mm diameter, 0.01 slope in a horizontal system following the simultaneous discharge of four gravity cistern wcs (WcH1-4)

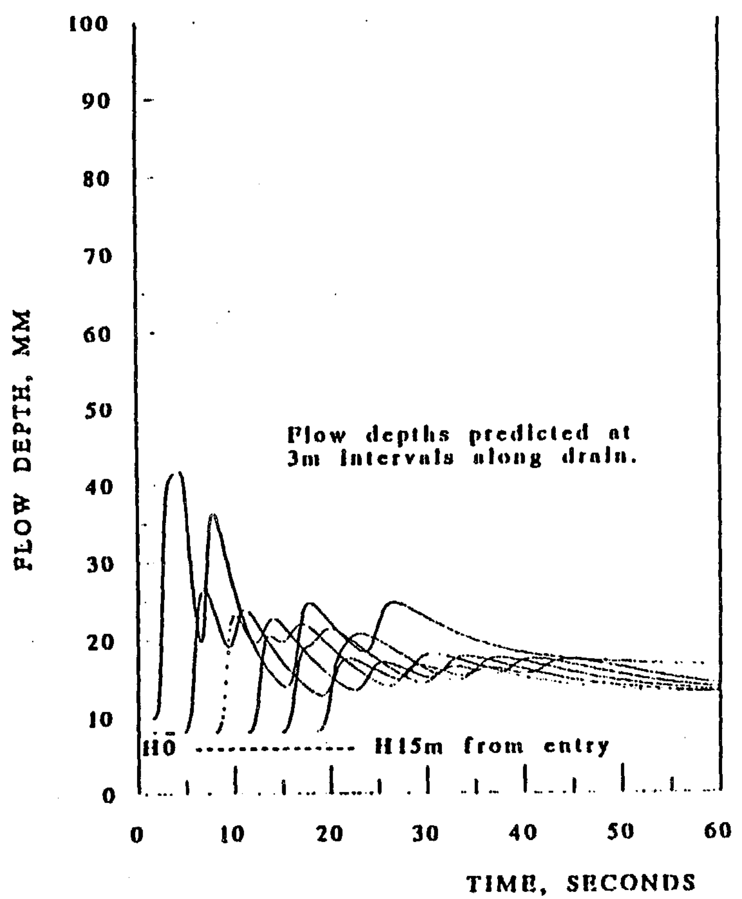


Figure 8b. Flow attenuation along the collection drain, 15m long, 100mm diameter, 0.01 slope in a horizontal system following the simultaneous discharge of four gravity cistern wcs (WcH1-4)

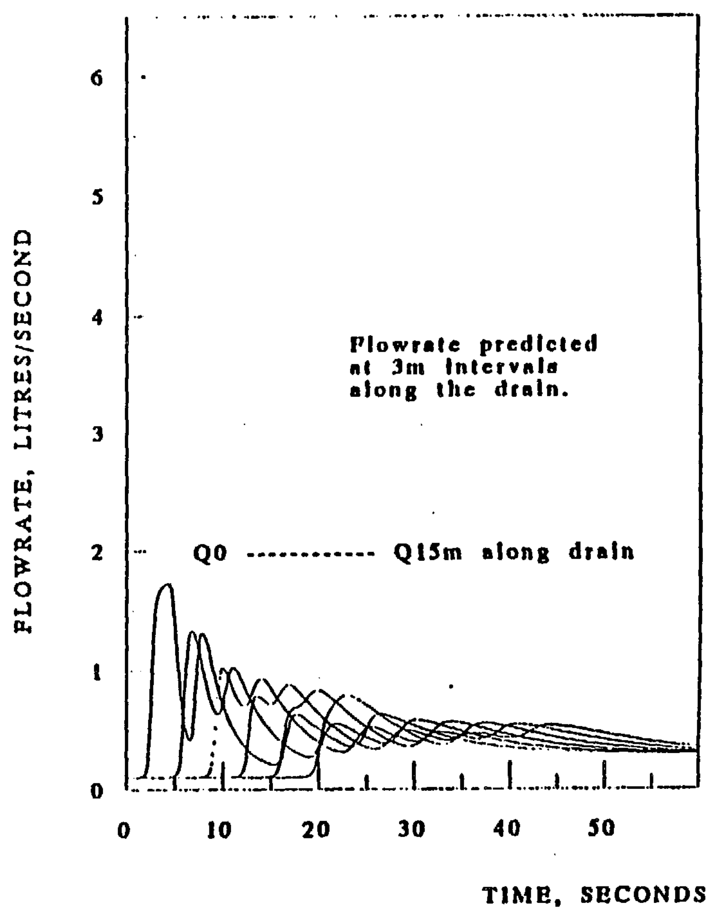


Figure 9a. Flow depth along the collection drain, 15m long, 100mm diameter, 0.01 slope in a horizontal system following the random discharge of four gravity cistern wcs (WcH1-4)

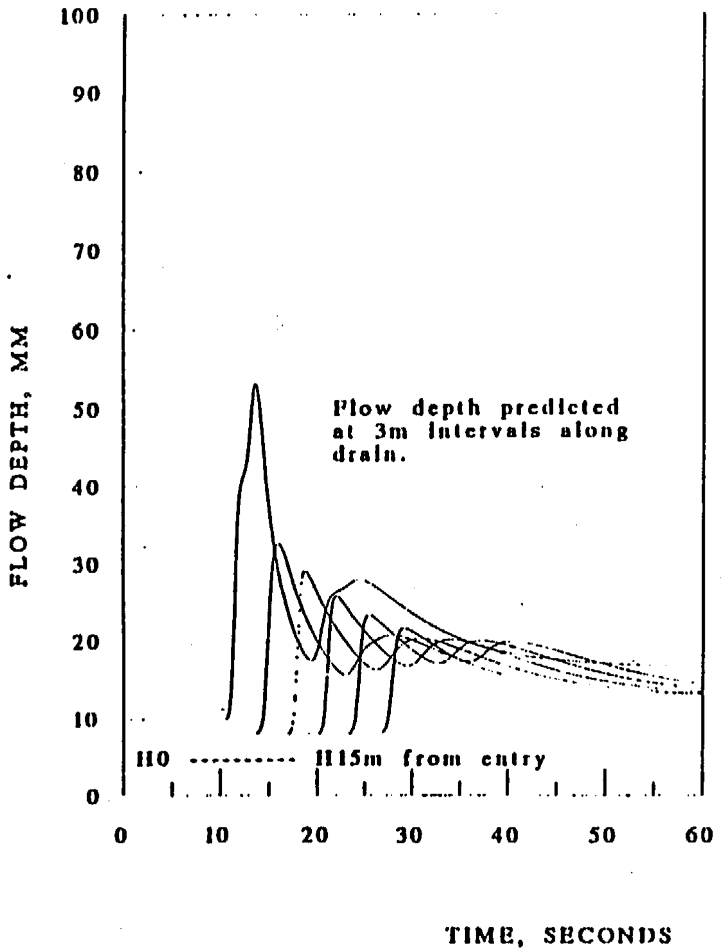


Figure 9b. Flow attenuation along the collection drain, 15m long, 100mm diameter, 0.01 slope in a horizontal system following the random discharge of four gravity cistern wcs (WcH1-4)

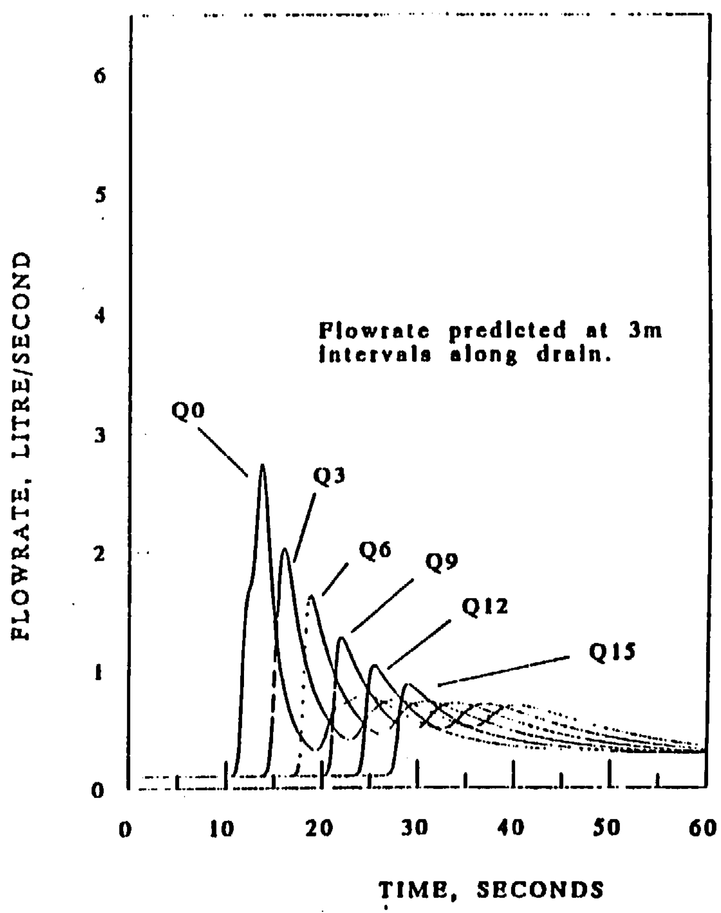


Figure 10a. Flow depth along the collection drain, 15m long, 100mm diameter, 0.01 slope in a horizontal system following the simultaneous discharge of four pressure cistern wcs (WcH1-4)

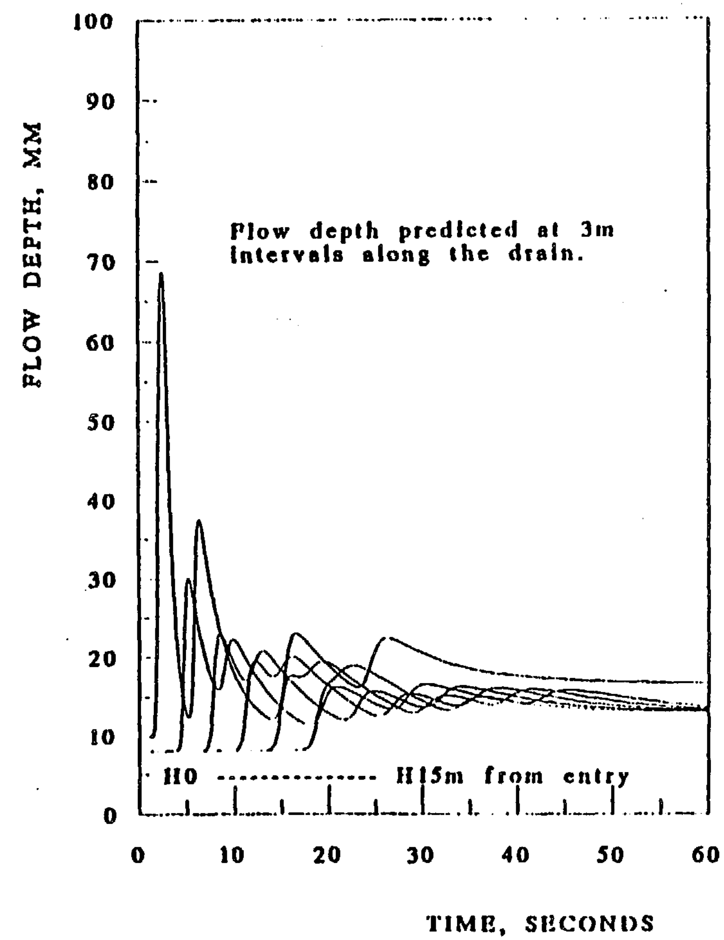


Figure 10b. Flow attenuation along the collection drain, 15m long, 100mm diameter, 0.01 slope in a horizontal system following the simultaneous discharge of four pressure cistern wcs (WcH1-4)

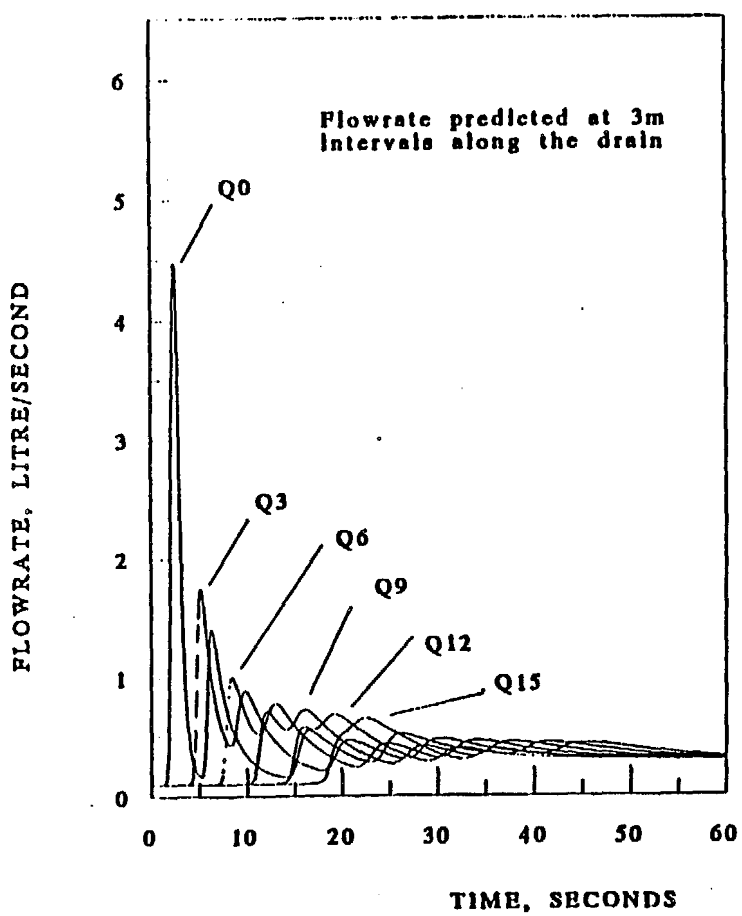


Figure 11a. Flow depth along the collection drain, 15m long, 100mm diameter, 0.01 slope in a horizontal system following the random discharge of four pressure cistern wcs (WcH1-4)

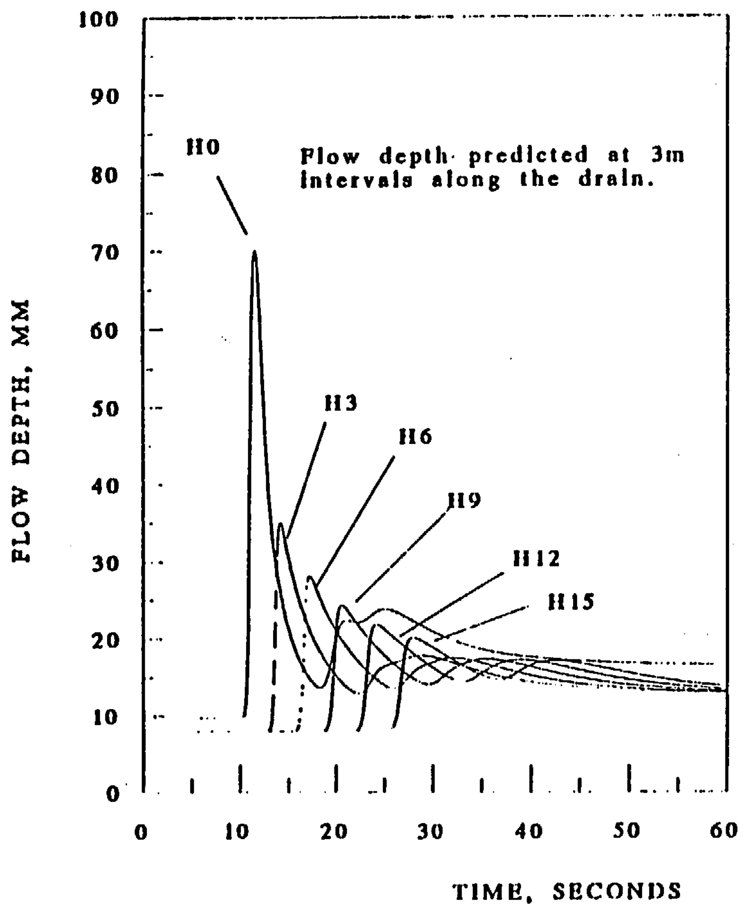


Figure 11b. Flow attenuation along the collection drain, 15m long, 100mm diameter, 0.01 slope in a horizontal system following the random discharge of four pressure cistern wcs (WcH1-4)

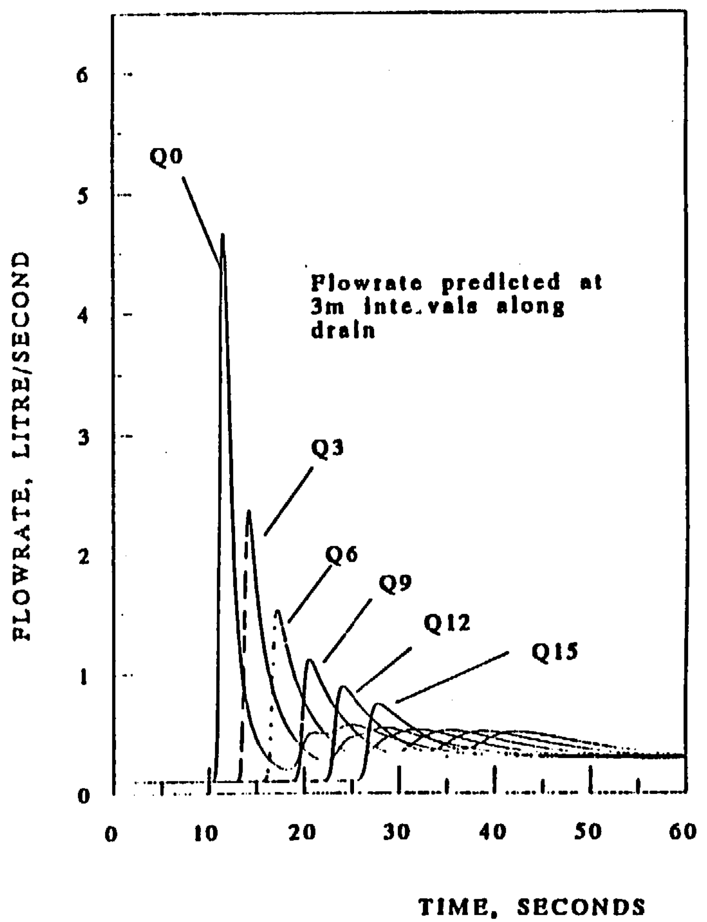


Figure 12a. Solid transport following simultaneous discharge of four gravity cistern wcs arranged vertically (WcV1-4) on four upper floors, or horizontally (WcH1-4) on branches connected to a collection drain, 15m long, 100mm diameter, 0.01 slope.

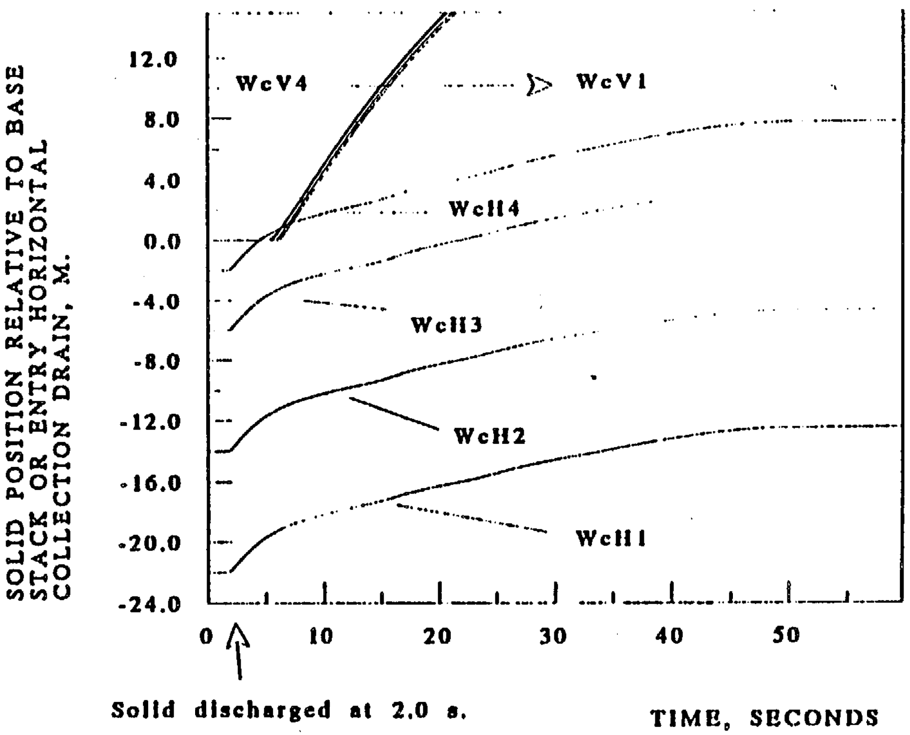


Figure 12b. Solid transport following random discharge of four gravity cistern wcs arranged vertically (WcV1-4) on four upper floors, or horizontally (WcH1-4) on branches connected to a collection drain, 15m long, 100mm diameter, 0.01 slope.

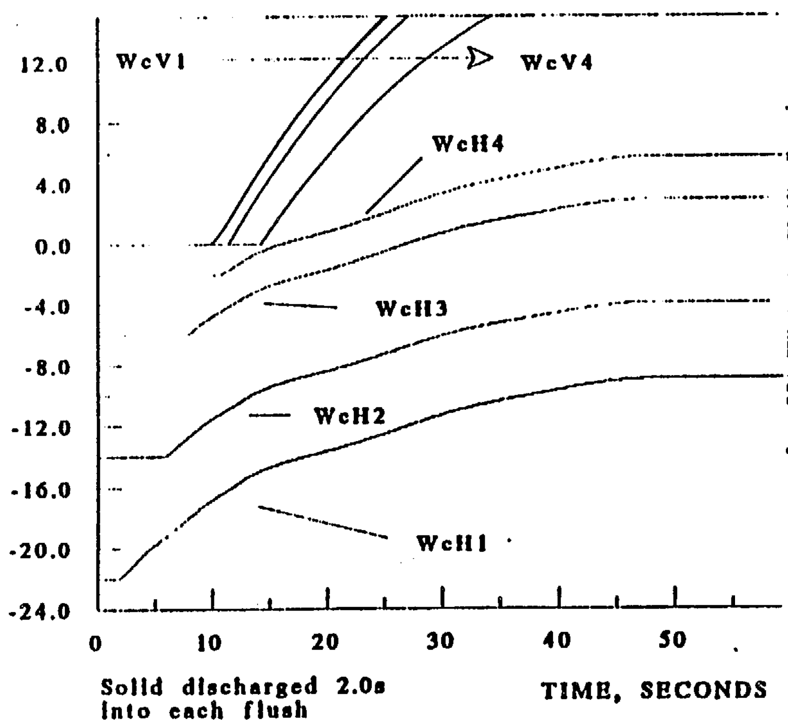
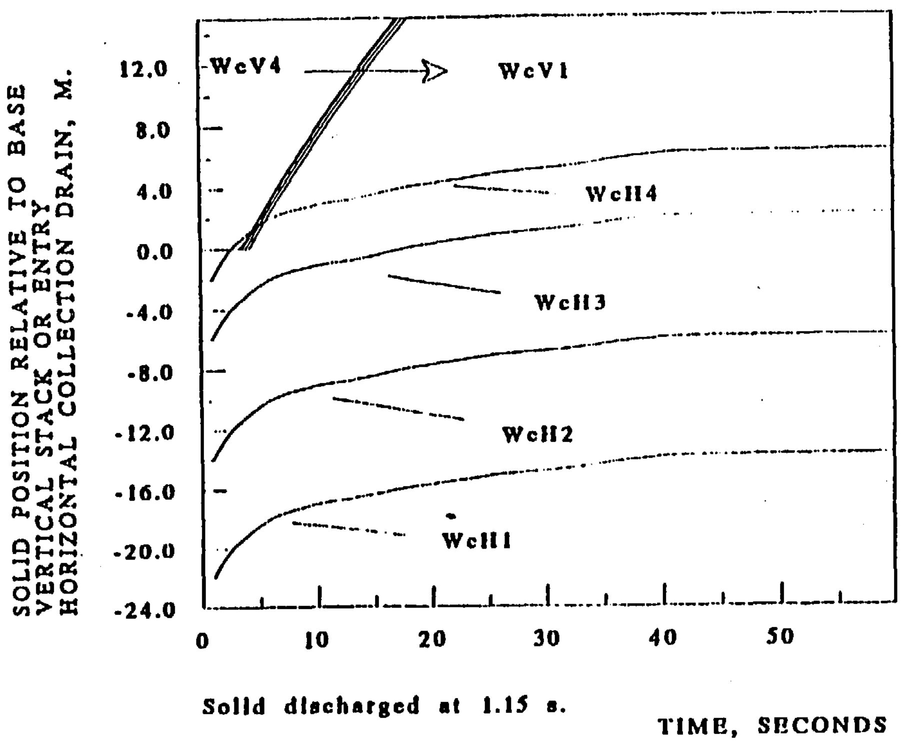
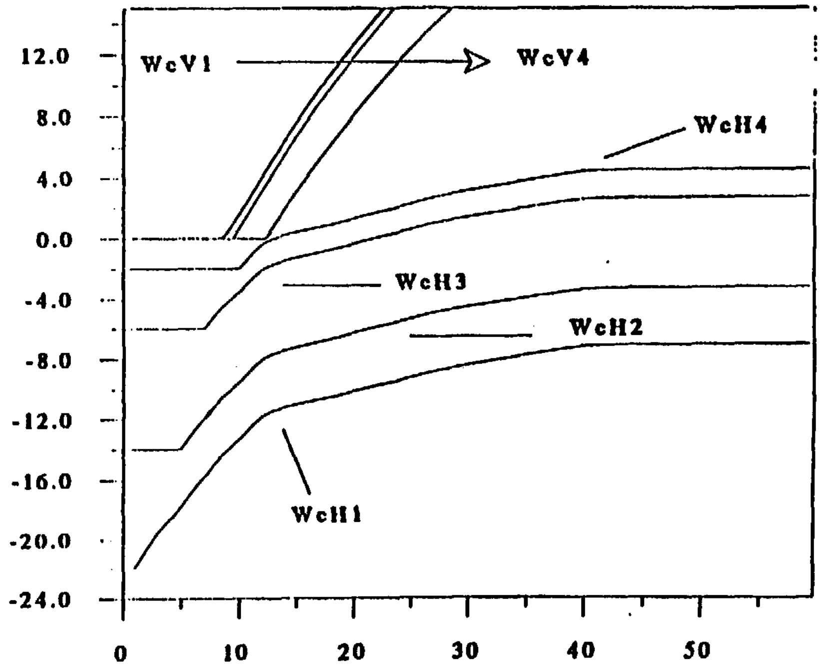


Figure 13a. Solid transport following the simultaneous discharge of four pressure cistern wcs arranged vertically (WcV1-4) on four upper floors, or horizontally (WcH1-4) on branches connected to a collection drain, 15m long, 100mm diameter, 0.01 slope.



Solid discharged at 1.15 s.

Figure 13b. Solid transport following random discharge of four pressure cistern wcs arranged vertically (WcV1-4) on four upper floors, or horizontally (WcH1-4) on branches connected to a collection drain, 15m long, 100mm diameter, 0.01 slope.



Solid discharged 1.15 s into each flush.

Figure 14a. Effect of pipe slope, 0.01 or 0.02, on solid transport following the simultaneous discharge of four gravity cistern wcs (WcH1-4) connected to a horizontal collection drain, 15m long, 100mm diameter. Solid discharged 2.0s into flush.

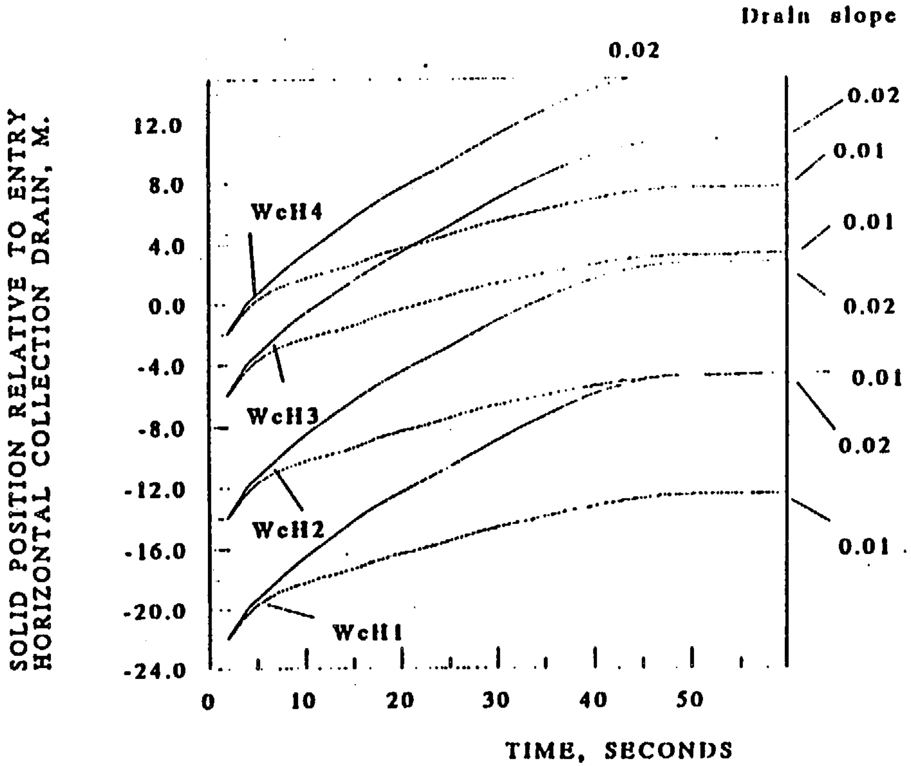


Figure 14b. Effect of pipe slope, 0.01 or 0.02, on solid transport following random discharge of four gravity cistern wcs (WcH1-4) connected to a horizontal collection drain, 15m long, 100mm diameter. Solids discharged 2.0s into each flush.

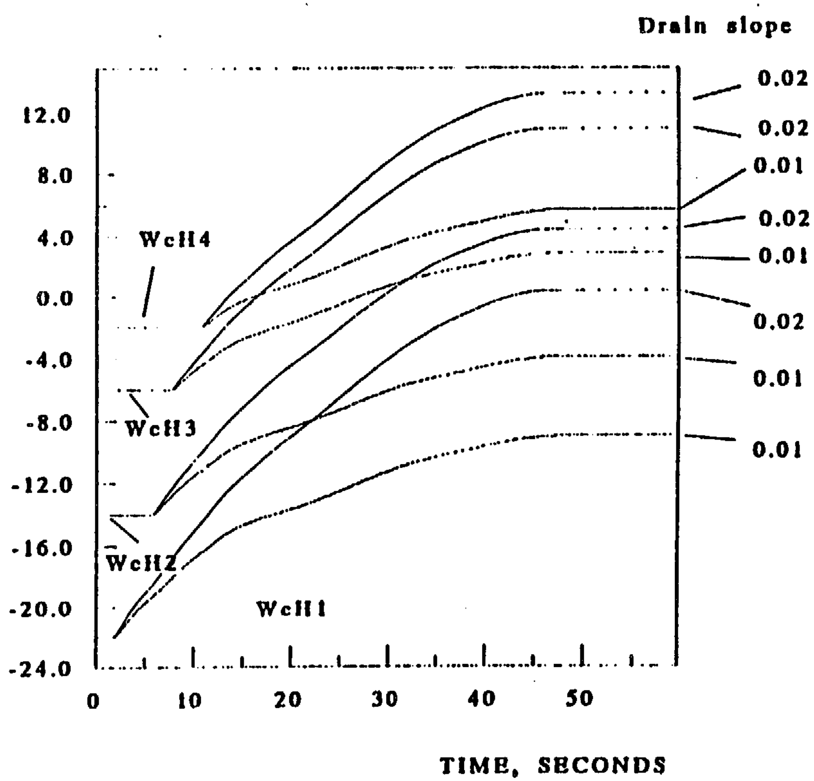
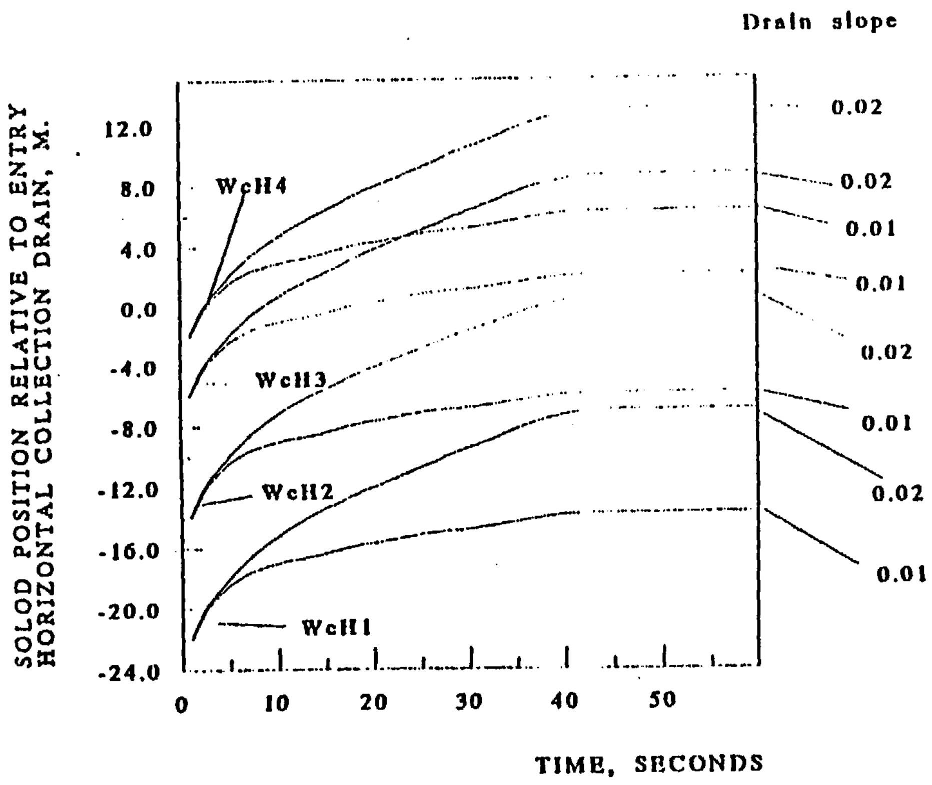


Figure 15a. Effect of pipe slope, 0.01 or 0.02, on solid transport following the simultaneous discharge of four pressure cistern wcs (WcH1-4) connected to a horizontal collection drain, 15m long, 100mm diameter. Solid discharged 1.15s into flush.

Figure 15b. Effect of pipe slope, 0.01 or 0.02, on solid transport following random discharge of four pressure cistern wcs (WcH1-4) connected to a horizontal collection drain, 15m long, 100mm diameter. Solids discharged 1.15s into each flush.



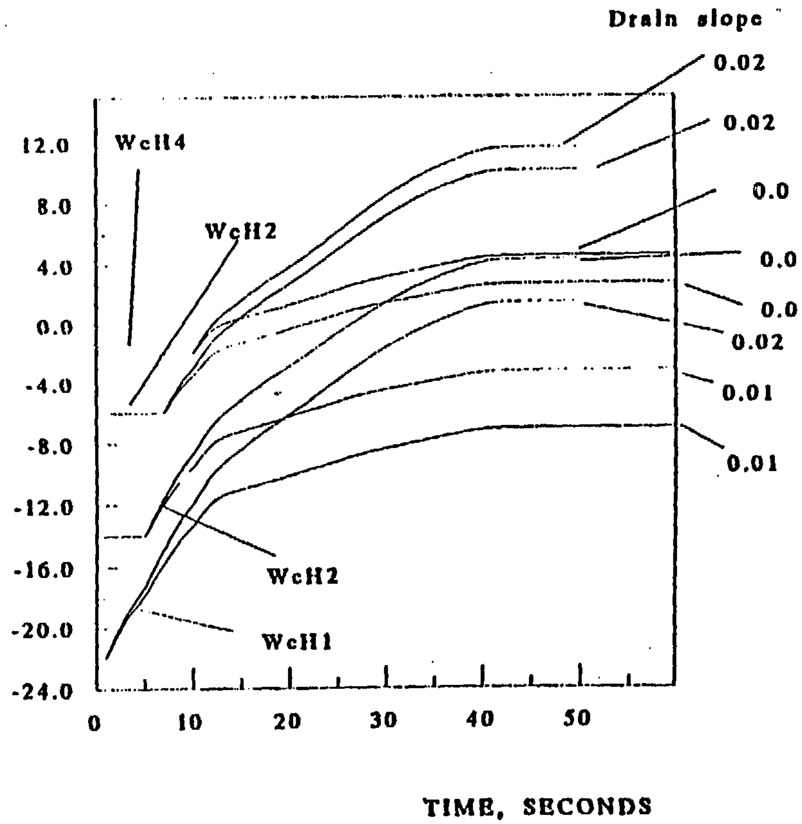
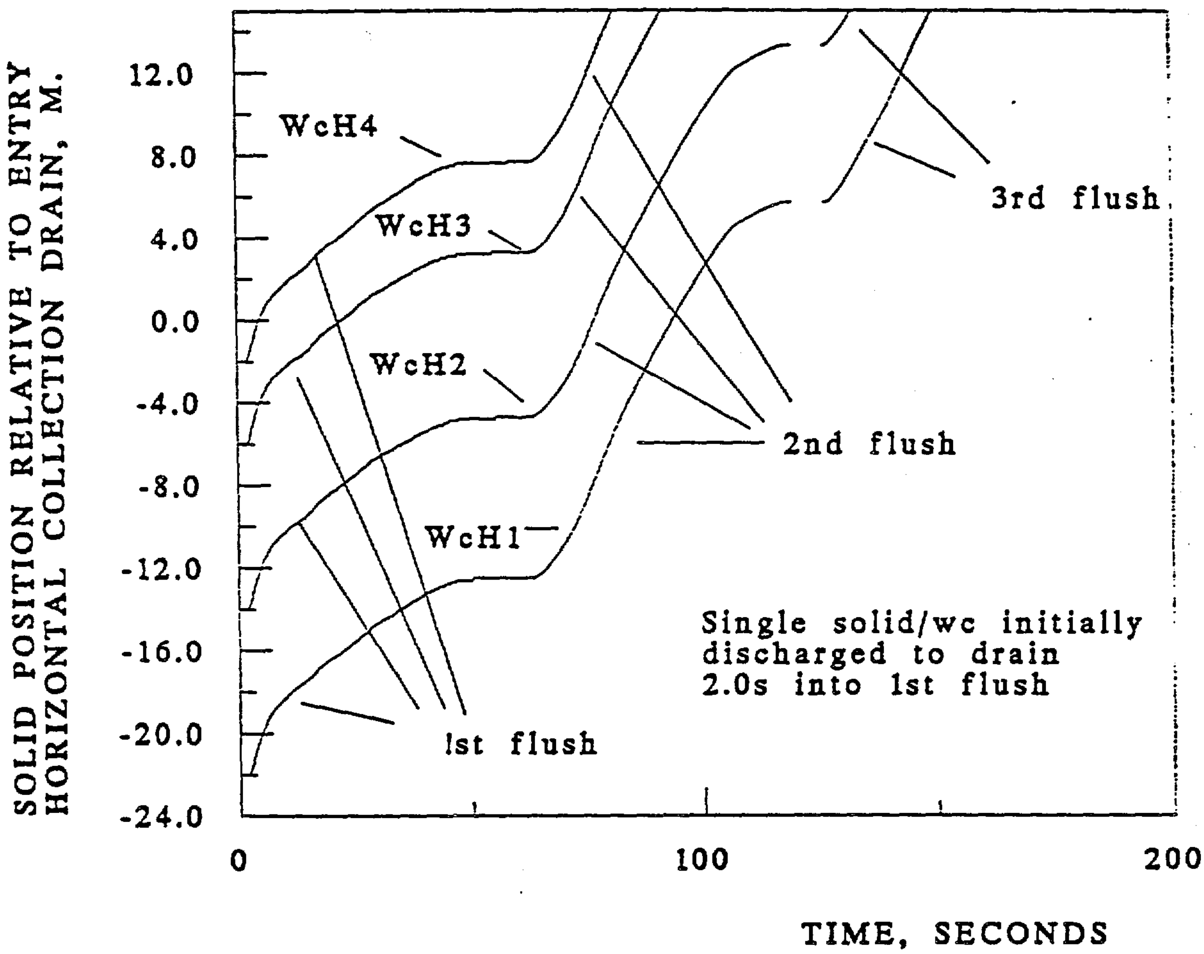


Figure 16. Effect on solid deposition in the horizontal drain network of repeated wc operation. Four gravity cistern wcs (WcH1-4) flushed simultaneously and at 60s intervals. All drains 100mm diameter, 0.01 slope. All solids ejected by 3rd flush.



ITEM
14.

SURVEY OF PURCHASER OPINIONS
ABOUT
ULTRA-LOW-FLUSH TOILETS

(LOS ANGELES,
CALIFORNIA)

SURVEY OF PURCHASER OPINIONS ABOUT ULTRA-LOW-FLUSH TOILETS

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Like many other agencies, the Los Angeles Department of Water and Power (Department) began its Ultra-Low-Flush (ULF) Toilet Rebate Program with concerns about the customers' acceptance of these ULF toilets. How do customers like their new ULF toilet compared to the old toilet that was replaced? Do some brands or models work better than others? In developing the list of approved toilets should some be excluded because of inferior quality or performance?

To answer these questions and assure Department management that continued expenditure of several million dollars was providing the anticipated customer satisfaction, the Department contracted with the Wirthlin Group to obtain purchaser opinions about their ULF toilets.

This paper summarizes the report done by Wirthlin titled "A SURVEY OF PURCHASER OPINIONS ABOUT ULTRA-LOW-FLUSH TOILETS". Copies of the report can be obtained by writing the Department. The report summarized the purchasers opinions regarding ULF toilets in general as well as rating responses of the performance of twelve specific ULF toilet models that generated enough responses for statistical validation.

EXECUTIVE SUMMARY

The survey was mailed to nearly 23,000 Department customers who received rebates for ULF toilet installations. Nearly 9,000 responses were received back with 1,625 coming from multi-family dwellings and 7,315 from private residences. The responses represented over 31,000 ULF toilet installations. The mailing list came from early participants in the rebate program so most respondents had use of their new toilets for over one year.

Besides overall satisfaction with ULF toilets, purchasers rated their toilets in the frequency of the following activities: double flushing, cleaning, use of a plunger to unclog, mechanical problems, and the need for a plumber to unclog. These responses were rated with respect to more often, less often, or the same as the old toilet that was replaced.

Generally, ULF toilet purchasers are well satisfied with their new toilets. Almost 75 percent said they would "very likely" purchase ULF toilets in the future as compared with only 7 percent who would "very likely" purchase conventional toilets in the future. Also, overall satisfaction ratings for the new ULF toilets were high. Considering the aggregate ratings across all brands, using a ten-point scale where "10" means "very satisfied" and a "1" means "very dissatisfied", more than half the respondents gave their new ULF toilet a 9 or a 10. The mean rating is a very positive 7.8.

As can be expected, what purchasers liked best about ULF toilets is that they save water, even though they generally require double flushing somewhat more often than conventional toilets. Also the survey found that the issue of double flushing exerted the greatest influence on satisfaction as compared to the other factors tested, such as frequency of clogging etc. In other words, the toilet brands which required the least double flushing tend to receive the highest purchaser satisfaction ratings.

Based on the survey results, the most satisfactory (highest rated) models are the American Standard New Cadet 2172, the Kilgore Quantum 150-1 (both pressure assisted models) and the Toto Kiki USA 703/704 (gravity model). The American Standard and the Kilgore models out scored the other models in virtually all categories.

DETAILED FINDINGS

OVERALL SATISFACTION

Purchasers were asked their overall satisfaction with their ULF toilets. Figure 1 shows the results of this question. With a mean rating of 7.8, this indicates a very high satisfaction level with ULF toilets. Also over two-thirds of the respondents rated their toilets into one of the three highest categories, either a 10 (36%), a 9 (17%) or an 8 (16%).

Purchasers were also asked their likelihood to purchase a ULF toilet in the future. With a 1 indicating 'very likely to purchase a ULF' and a 4 indicating 'very likely to purchase a conventional toilet', a mean rating of 1.4 indicates a strong likelihood of purchasing ULF toilets. Figure 2 summarizes the results.

Figure 3 shows the overall levels of satisfaction with the various specific ULF toilet models. The toilets receiving the highest ratings are the American Standard New Cadet Aquameter 2172, the Kilgore Quantum 150-1 and the Toto Kiki USA 703/704. The toilets receiving the lowest are the Eljer Preserver 091-4800 and the Norris 516/516C.

TOILET PERFORMANCE IN TERMS OF SPECIFIC FACTORS

ULF toilets were surveyed on the frequency with which the purchaser performed several performance related activities on their new ULF toilet versus the old toilet that was replaced. The activities surveyed were double flushing, use of a plunger, cleaning, mechanical problems, and use of a professional plumber to unclog the sewer lines. The frequency of these actions were rated 'less often', 'the same as', or 'more often' than the old toilet replaced. Percentages for each response were then calculated. Finally an index for each performance characteristic was then derived by subtracting the percentage of respondents reporting that a specific problem occurred 'more often now' (in reference to ULF toilets) from the percentage reporting 'less often now'. For example, with regard to double flushing, 21% of the total sample reported that they double flush 'less often now' while 34% reported they double flush 'more often now'. This results in a double flushing index of -13%. Therefore a positive index indicates a positive ULF response with a negative index indicating negative response.

Figures 4 through 8 illustrate the survey results for the performance indices for the responses to the frequencies of double flushing, mechanical problems, use of a plunger, cleaning, and need for a plumber. The ULF toilets significantly out rated their conventional toilet counterparts in the areas of mechanical problems and the need for plumbers as indicated by the very high positive indices. However, the conventional toilets rated better than ULF toilets on double flushing frequency. Performances were very similar in the categories of cleaning and use of a plunger.

Finally, two open ended questions were asked regarding what the purchasers liked and disliked about their new ULF toilets. As expected the feature liked best was 'uses less water' while the biggest dislike noted was 'flushing action'.

CONCLUSIONS

The survey provided very valuable information to the Department about our customers' perception of their ULF toilets' performances. The results were overwhelmingly positive indicating a high level of satisfaction. The more frequency of double flushing is a concern, however, relatively high ratings of the ULF toilets among purchasers who double flush more often now indicate that this 'negative' performance characteristic was not significant enough to be dissatisfied with the ULF toilet or to dissuade customers from future ULF purchases. The survey was also valuable in developing the current list of approved ULF toilets that qualify for the Department's rebate.

FIGURE 1
OVERALL SATISFACTION RATINGS
TOTAL RESPONDENTS = 8940

Rating	1	2	3	4	5	6	7	8	9	10
Respondents	516	216	213	224	472	346	600	1393	1515	3256
Percentages	6	2	2	3	5	4	7	16	17	36

FIGURE 2
LIKELIHOOD OF PURCHASING A
ULF TOILET IN THE FUTURE

	very likely to purchase ULF 1	2	3	very likely to purchase conv. 4
Respondents	6712	1027	416	603
Percentages	75	11	5	7

FIGURE 3
95% CONFIDENCE LEVEL AROUND MEAN RATINGS OF ULF TOILET MODELS

Total (mean 7.8)	7.8 xx 7.9
A.S. New Cadet 2172 (mean 8.5)	8.3 xxxx 8.7
Kilgore Quantum 150-1 (mean 8.3)	8.0 xxxx 8.6
Toto Kiki USA 703/704 (mean 8.3)	8.1 xxxx 8.6
Kohler Wellworth 3421 (mean 8.1)	8.0 xx 8.2
Kohler Wellworth 3420 (mean 8.0)	7.8 xxx 8.2
Western Pottery 822L/C Aris (mean 8.0)	7.7 xxxxx 8.3
Kilgore Allegro 130-16 (mean 7.6)	7.6 xx 7.8
A.S. Plebe Aquameter 2139 (mean 7.6)	7.6 xx 7.8
Universal-Rundle Atlas 4090 (mean 7.6)	7.3 xxxxx 7.9
Titon Phoenix Flush Lite ** (mean 7.5)	7.3 xxx 7.7
Eijer Perserver 091-4800 (mean 7.3)	6.9 xxxxx 7.7
Norris 516/516C (mean 6.7)	6.4 xxxxxx 7.0

* Was the Microphor LF 16R at the time of the study

** Was the Lamosa Sahara at the time of the study

FIGURE 4
FREQUENCY OF DOUBLE FLUSHING
Index = Less now - More now

	Less Now	Same	More Now	INDEX
Total	21%	30%	34%	- 13
A.S. New Cadet	44 %	30%	16%	+ 28
Kilgore Quantum 150-1	40	33	15	+ 25
Toto Kiki USA 703/704 *	19	36	26	- 7
Western Pot. 822L/C Aris	19	34	30	- 11
Kilgore Allegro 130-16	20	33	31	- 11
Titon Flush Lite **	16	38	29	- 13
Kohler Wellworth 3420	21	31	38	- 17
A.S. Plebe Aqua. 2139	19	30	36	- 17
Univ. Rundle Atlas 4090	17	30	34	- 17
Kohler Wellworth 3421	21	31	39	- 18
Eljer Preserver 091-4800	15	28	43	- 28
Norris 516/516C	13	20	57	- 44

* Was the Microphor LF16R at the time of the study

** Was the Lamosa Sahara at the time of the study

FIGURE 5
FREQUENCY OF MECHANICAL PROBLEMS
Index = Less now - More now

	Less Now	Same	More Now	INDEX
Total	38%	42%	6%	+ 32
Kilgore Quantum 150-1	58%	28%	4%	+ 54
A.S. New Cadet	51	32	5	+ 46
Kohler Wellworth 3421	46	41	4	+ 42
Kohler Wellworth 3420	44	42	3	+ 41
Toto Kiki USA 703/704 *	37	41	6	+ 31
Univ. Rundle Atlas 4090	37	41	8	+ 29
Eljer Preserver 091-4800	33	47	6	+ 27
Kilgore Allegro 130-16	35	41	9	+ 26
A.S. Plebe Aqua. 2139	35	41	10	+ 25
Norris 516/516C	30	54	7	+ 23
Western Pot. 822L/C Aris	29	45	8	+ 21
Titon Flush Lite **	25	48	10	+ 15

* Was the Microphor LF16R at the time of the study

** Was the Lamosa Sahara at the time of the study

FIGURE 6
FREQUENCY OF USE OF PLUNGER
Index = Less now - More now

	Less Now	Same	More Now	INDEX
Total	21%	48%	21%	0
A.S. New Cadet	44 %	43%	3%	+ 41
Kilgore Quantum 150-1	40	49	6	+ 34
Toto Kiki USA 703/704 *	21	53	10	+ 11
Eljer Preserver 091-4800	20	51	17	+ 3
Western Pot. 822L/C Aris	16	49	15	+ 1
Univ. Rundle Atlas 4090	18	50	20	- 2
Kohler Wellworth 3420	19	50	23	- 4
Kohler Wellworth 3421	20	50	25	- 5
A.S. Plebe Aqua. 2139	18	47	24	- 6
Titon Flush Lite **	16	45	23	- 7
Kilgore Allegro 130-16	18	41	27	- 9
Norris 516/516C	13	34	45	- 32

* Was the Microphor LF16R at the time of the study
** Was the Lamosa Sahara at the time of the study

FIGURE 7
FREQUENCY OF CLEANING
Index = Less now - More now

	Less Now	Same	More Now	INDEX
Total	8%	70%	12%	- 4
A.S. New Cadet	17 %	69%	6%	+ 11
Kilgore Quantum 150-1	10	75	6	+ 4
Western Pot. 822L/C Aris	6	67	7	- 1
Titon Flush Lite **	8	62	10	- 2
Toto Kiki USA 703/704 *	6	67	9	- 3
Kohler Wellworth 3421	8	72	11	- 3
Kohler Wellworth 3420	6	76	10	- 4
Kilgore Allegro 130-16	8	63	14	- 6
A.S. Plebe Aqua. 2139	7	65	15	- 8
Univ. Rundle Atlas 4090	7	61	16	- 9
Norris 516/516C	5	71	17	- 12
Eljer Preserver 091-4800	4	58	22	- 18

* Was the Microphor LF16R at the time of the study
** Was the Lamosa Sahara at the time of the study

FIGURE 8
FREQUENCY OF NEED FOR A PLUMBER
Index = Less now - More now

	Less Now	Same	More Now	INDEX
Total	41%	47%	7%	+34
A.S. New Cadet	50 %	45%	3%	+47
Kilgore Quantum 150-1	47	45	3	+44
Eljer Preserver 091-4800	47	46	6	+41
Toto Kiki USA 703/704 *	44	45	6	+6
Univ. Rundle Atlas 4090	45	42	7	+38
Kohler Wellworth 3420	42	49	7	+35
Kohler Wellworth 3421	40	49	7	+33
Western Pot. 822L/C Aris	40	47	7	+33
A.S. Plebe Aqua. 2139	40	45	9	+31
Kilgore Allegro 130-16	40	44	11	+29
Titon Flush Lite **	37	49	9	+28
Norris 516/516C	35	51	10	+25

* Was the Microphor LF16R at the time of the study

** Was the Lamosa Sahara at the time of the study

ITEM 15.

PROCEEDINGS:

CONSERV 93

LAS VEGAS,
NEVADA

15.

PROCEEDINGS OF

CONSERV 93

THE NEW WATER AGENDA

Sessions 4B-1 through 7C-3

December 12–16, 1993

Las Vegas, Nevada

Conference Sponsors:

American Society of Civil Engineers • American Water Resources Association

American Water Works Association

FOREWORD

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RBM:ns
(E342202)

ACKNOWLEDGEMENTS

Special thanks go to the following people without whome the San Simeon Story wouldn't have occured or been able to be told:

Dave Crimmel (formerly of the Holiday Inn); Doug Thompson (Western Regional Manager for Water Control International); Mike Hanchett (General Manager of the Cavalier Inn); Harley Walters (Chief Maintenance Engineer, Cavalier Inn); John Wallace (Consulting Engineer and General Manager of San Simeon's Waste-water treatment facility); Walt Blankenship (Chairman of the Board, San Simeon Community Services District); Elizabeth O'Leary (Secretary, San Simeon Community Services District); Ron Head (Supervisor, SSCS Waste Treatment Plant); and, John Mickelson and Greg Ray (President and Vice President respectively of Visual Inspection Services).

RBM:ns
May, 1992
(E342201)

SAN SIMEON STORY

BACKGROUND & HISTORY

San Simeon, California is a small town located about half way between Los Angeles and San Fransisco on the Pacific coast (Exhibit "A"). It is visited annually by tens of thousands of tourists who come to see the Hearst Castle and enjoy the spectacular views.

Initially settled in 1769 by Spanish padres, the first formal mission was established in 1797. In 1836, the Spanish governor secularized the mission when he took possession of it and the surrounding area -- dividing the land into three great ranches -- Piedras Blancas, Santa Rosa and San Simeon.

By 1852, beside the massive ranching activity, San Simeon was also the center of a fairly large whaling business. The village included forty-five buildings and twenty-two families who were employed at the whaling station.

In the 1860's, a great drought hit the area causing the loss of grazing livestock and forcing ranchers to sell their land. As a result, new settlers moved into the area -- the Swiss bringing their dairy's; the New Englander's their orchards. In 1865, Senator George Hearst purchased 45,000 acres including all of San Simeon Rancho.

With the decline of whaling, the village of San Simeon essentially disappeared by 1878, except for a hotel. Other than service by a stage line from Cambria, the only access to the area was by boat.

In 1919, William Randolph Hearst began construction of the Hearst Castle -- 165 rooms and 127 acres of gardens located on a hilltop overlooking the area. The Castle was not completed until 1947, 28 years later (Exhibit "B").

Up to the beginning to WWII, the economic life of the area was dominated by William Randolph Hearst, his ranch hands and construction workers he employed. The only exception to the "one man ownership" of the area was a government lighthouse (built in 1874) and a general store.

Tourism didn't start until 1951, when, following the death of Hearst, a plot of land southeast of the general store was given by the estate to be used as a day park. In 1957, the County of San Luis Obispo built a pleasure pier extending from the ocean boundary of the park. In 1958, the Hearst Corporation gave the castle to the State, thereby setting it aside as a State Historical Monument -- which is now visited by millions of tourists each year. In 1971, the State of California took over the operation of the park.

SAN SIMEON TODAY

As the Hearst Castle emerged as a tourist attraction, visitor support facilities in the Village of San Simeon followed (Exhibit "C"). Today, the village consists of a post office; 222 condos, apartments and residences; ten motels with 700 rooms; and a number of restaurants and tourist shops. While the permanent population is only about 250 people, on a typical weekend there are also about 2,000 tourists. Because the village (which is governed by the SSCS) is small, communications are easy. As one person told me, "...everyone knows what his neighbors (competitors) are doing."

San Simeon, which is incorporated, has operated since 1961 as a California State Special District under the name "San Simeon Community Services District" ("SSCS"). It has its own water supply and waste treatment systems that were (mostly) constructed in that year[1].

- Water is obtained from wells located near the village and about 250 yards from the shoreline (Exhibit "D"). These wells are fed by underground aquifers that depend heavily on mountain runoff.

---

[1]The basic water and sewer system was constructed in 1961; added to in 1971; and again (sewer only) in 1987.

- The waste treatment plant is located on the shore (Exhibit "F") and is supplied by gravity-flow through 8,100 lineal feet of sewer pipe.

All structures located within the village (including 1,198 water closets) are connected to both the water and sewer systems.

The now famous western drought began to be serious in 1986. As it continued, its effects on San Simeon's water supplies grew more severe as well levels, which had been dropping, started reaching critical levels. In addition, waste water treatment plant demand was reaching 100% of capacity during the peak season. San Simeon was facing the dual crisis of insufficient water supply and sewer disposal capacity.

To combat this crisis, the SSCS instituted, in 1986, a moratorium on new system hook-ups; a public awareness program on water conservation; and "voluntary" water rationing[2]. However, as matters continued to worsen, in December, 1988, they banned all outside watering (eg. lawn irrigation) and in April, 1989, with the well levels becoming "critical" (salt water began seeping into the fresh water), the city fathers finalized their action plan.

Alternatives under consideration during the preceding months were:

- New, supplemental water sources -- determined as not viable in the near term. Design and construction would take several years;

- Additional waste treatment capacity -- determined as viable. Design and construction would take more than a year;

- Additional rationing such as mandating the closure of 10% of all motel rooms -- deemed as self defeating since it

---

[2]This resulted in only minor reductions being obtained from voluntary conservation; retrofit to low-flow showers; etc.

would cut directly into the economic core of the community;

- Replacement of all toilets with low consumption type (<1.6 GPF) -- deemed as the most viable, near term solution that would only compliment the longer term alternatives.

Since SSCS knew that the toilet was the largest consumer of water within any structure, they decided to take a unique step of replacing *every* toilet in the town.

While other communities had mandated that all new installations be low consumption (eg. <1.6 GPF), San Simeon was the first community in the nation to require the replacement of existing WC's, as well.

On the surface, the San Simeon ordinance looked risky. However, the City Fathers felt confortable with their decision because of the earlier water closet conversion experience obtained at the 102 room Holiday Inn[3].

The Holiday Inn

During most of the 1980's, an engineer named Steve Crimmel was head of maintenance at the Holiday Inn. When he was first employed, all the toilets in the structure were 5-1/2 GPF type. However, because the drought of the 1970's had also made Crimmel an avid conservationist, it upset him to see water being *wasted* by the 5-1/2 GPF "gas guzzlers". As a result, he convinced his management to convert the structure to the, then, state of the art water closet -- 3-1/2 GPF (gravity activated) units. This conversion was completed in 1983.

While this Holiday Inn conversion resulted in reduced water consumption[4], because of the smaller diameter trapways in the 3-1/2 GPF toilets, a significant increase of in-room

---

[3]Now a "Motel 6" franchise. (See exhibit "N"; appendix A-1 & A-2).
[4]Specific data is not available.

clogs resulted -- typically averaging one per day[5]. Thus, in the fall of 1986, having read trade journal stories and ads (Exhibits "G" & "H") about the new flushometer-tank flushing technology's superior extraction and drainline carry capability (Exhibits "I" & "J"), Crimmel accepted Water Control International's ("WCI") promotional offer and purchased and installed a Flushmate® activated water closet[6] for evaluation.

> A flushometer-tank uses the pressure of the supply system to boost the energy stored in its accumulator tank (Exhibits "K" & "L"). Since a flushometer-tank's discharge velocity is significantly higher than a gravity tank, it requires less water to obtain the same extraction and drainline carry effectiveness.

Several months of evaluation[7] resulted in Crimmel proposing, again, that the entire Holiday Inn be converted -- resulting in the purchase and installation of 101 Mansfield[8] Quantum toilets (Exhibit "M").

During the first full year following the retrofit (12 months ending January, 1988) the performance of the Mansfield units resulted in:

- Consumption (per occupied-room/day) reduced by 23% -- from 148 to 115 gallons, exclusive of restaurant and laundry (Exhibit "N"); and, more importantly,

- Stoppages (for the entire motel) were reduced by better than 95% (from one a day to approximately one per month).

---

[5]Conversation with Crimmion on 3/17/92.
[6]WCI only manufactures the Flushmate flushometer-tank that it sells to WCI licensees who incorporate it into special hydraulically designed water closets. WCI was offering Mansfield Quantum for $25.00 each (limit one/customer) to demonstrate the efficacy of its technology.
[7]During the same period, Crimmion also tested several <u>gravity-fed</u> 1.6 gpf WC's that he found to be unsatisfactory because of clogging and cleanliness problems.
[8]A WCI licensee plumbing fixture manufacturer.

SSCS Decision To Buy Flushmate Units

Since the SSCS were determined to minimize their risk, they decided to purchase what "...they knew would work". Accordingly, purchase orders were placed with area plumbing wholesalers for a total of 1,198 Flushmate activated water closets divided between American-Standard's Cadet™ Aquameter™ (Exhibit "O"), Briggs Industries Turboflush™ (Exhibit "P") and Mansfield Plumbing Products' Quantum™. The conversion of San Simeon's toilets, which took six (6) months, was completed in December, 1989.

Results

While San Simeon believed that if it could obtain a 20% overall reduction in water usage, its well levels would stabilize or possibly begin to rise again, the results of the water closet conversion program far exceeded their fondest hopes:

- total community water consumption was reduced by 39% -- almost twice what they had hoped for (Exhibits "Q","R" & "S");
- in-room stoppages were almost completely eliminated (as confirmed by virtually every motel maintenance engineer in the district);
- Salt water incursion was stopped. Well head levels began increasing;
- The economic vitality of the community was preserved. By not having to shut 10% of the available rental rooms, they retained more than $500,000 of revenue per year[9] (Exhibit "T").

[9] Exhibit "T".

Water usage for the 12 months *preceding* the conversion (June, 1989) compared with the 12 months *following* its completion 'December, 1991) was:

Segment	12 Months Ending* 6/89	12/91	% Change
Residential	8,129.3	5,235.3	(35.6%)
Commercial	935.0	169.8	(81.8%)
Restaurant	3,832.8	3,310.6	(13.6%)
Lodging	26,647.5	15,924.9	(40.2%)
Irrigation	820.6	2.2	(99.7%)
Totals	40,365.1	24,643.6	(39.0%)

*Data in 1,000's of gallons.

Besides these immediate results, longer term benefits obtained were:

1. The need to expand the waste treatment plant was able to be pushed back for (at least) seven (7) years -- saving more than $750,000 (capital deferment of $500,000 and an annual savings of approximately $37,500 in debt service or $262,500 over the seven years).

2. A gain in the operating efficiency of the water treatment plant because of the higher solid-to-liquid ratio and the discharge of a higher quality effluent;

3. Deferral of the <u>immediate need</u> for additional water supplies which meant a significant economic savings to the tax payers -- instead of San Simeon having to expend somewhere between $600,000 and $3,500,000 (cost range of the six alternative plans evaluated), they now have the option to tie on to adjoining facilities at a fraction of that cost.

Effect of Reduced Flow on the Sewer lines

A major concern was what effect would the reduced flow resulting from the new toilets have on waste transfer to the treatment plant? Would blockages occur in the sewer system? To answer these questions, in March, 1992, San Simeon hired Video Inspection Specialists ("VIS") of Fresno, California to both clean and inspect (via use of a video camera) the lines[10] (Exhibit "V"). All that VIS removed amounted to only *less than 1/2 truckload -- more than two years after installation of the low consumption WC's*.

> According to John Mickelson, President of VIS, the debris removed consisted entirely of stones and dirt. He said "... there was virtually no human waste or other WC discharge in the lines." Gregory Ray, Vice President of VIS, added that they found no surprises whatsoever -- even at the beginning of the system (furthest from the treatment plant) where any carry problem would be most likely to manifest itself.

Water Closet Ballcock Leakage

Assuming that the toilets constitute no more than 40% of total water consumption in any residential community and considering that the theoretical savings/flush anticipated was 58%, suggests that (by converting all toilets to 1.5 GPF) the community-wide consumption reduction to be obtained would not exceed 20%. Thus, since the conversion actually obtained a 39% community-wide reduction, one has to ask the question, "How is it possible?"

> The answer appears to lie in the fact that prior to the conversion, the ballcocks and flappers in the gravity activated water closets were leaking excessively!
>
> Further, the data seems to suggest that these flushing devices begin leaking (imperceptibly) after about three

[10] First inspection since construction of system.

years of operation -- and as they age further, the leakage rate continues to increase.

To clarify the above, monthly water consumption records were obtained from the Holiday Inn[11] (July, 1986 thru June, 1988) and the Cavalier Inn (January, 1988 thru March, 1992) (Exhibits "W" & "X"). These two motel's account for slightly more than 25% of the total motel rooms in San Simeon and 17% of all SSCS units. This data was then used to:

a. Calculate the difference between theoretical and actual consumption; and then,

b. Reduce "a" (above) into consumption per flush (since only the water closets were changed).

Because no data is available as to how many times, on average, each water closet in a motel is flushed, an arbitrary assumption of 10 flushes/WC/day was deemed reasonable (eight by the renter; two by the maids). Laundry consumption per occupied-room and occupancy rates were assumed to be the same for all motels as that experienced by the Cavalier Inn.

Result of this analysis shows (Exhibit "Y") the following:

1. The Holiday Inn, with relatively new 3-1/2 GPF units (less than 3 years old at the time covered by the data) had only a 2% leakage factor prior to conversion to flushometer-tank activated WC's; whereas,

2. The Cavalier Inn (with much older 3-1/2 GPF WC's) was experiencing 64% leakage; and,

3. All San Simeon motels (as a group) were experiencing a leakage rate of approximately 44% of all water consumed/year.

[11] New owners (Motel 6) unwilling to supply consumption and occupancy data after date of their acquisition.

Conclusions

The San Simeon Story clearly shows that:

1. Flushometer-tank activated toilets really work -- both in their ability to stop clogs and leaks as well as carry waste through a sewer system designed for higher volume discharge WC's.

2. It is economically viable to convert old, high consumption toilets even if each owner was made to pay. Had that been done in San Simeon, the cost of each toilet would have been recaptured in less than two years in reduced water and sewer charges. Each Flushmate activated WC reduced the average SSCS water bill by $101.63/year (Exhibit "Z").

3. The conversion also saved each taxpayer thousands of dollars and avoided a real crisis that would have severely damaged the economic base of the community[12].

RBM:ns
(d342281)

[12] As one motel maintenance engineer stated, "The new toilets literally saved my job. Without water everything would have closed and I would have lost my job".

SYNOPSIS
SAN SIMEON STORY
By
R. Bruce Martin
W/C Technology Corporation

San Simeon, California, is a small town located on the Pacific coast about half way between Los Angeles and San Fransisco. Its economy is based almost entirely on tourism -- sheltering, feeding and serving visitors to the nearby Hearst Castle. The town consists of approximately 250 permanent residents, twelve motels (approximately 700 rooms) and 1,198 water closets.

By the end of 1987, combination of the now famous Western drought and record tourist usage had reduced their fresh water supplies to the point that salt water was intruding into their wells. Additionally, peak summer tourist demand exceeded their wastewater treatment capacity. San Simeon's basic existence was threatened. Voluntary rationing[1] begun in 1986, had failed. Water consumption had to be dramatically reduced since new (additional) supplies of fresh water and waste treatment would take years to obtain. Thus, faced with having to close (not rent) motel rooms to curb water usage -- which would cut directly into their economic base, the Village leaders decided instead on a radical alternate plan -- replacement all toilets with Flushmate® activated Low Consumption (eg. less than 1.6 GPF) types as manufactured by American Standard, Briggs and Mansfield.

The retrofit of all San Simeon's 1,198 toilets[2], was completed in December, 1989, and resulted in:

- total community water consumption reduced[3] by 39%;
- in-room bowl stoppages reduced by 95%;
- salt water intrusion into the fresh water wells eliminated; and,
- economic vitality of the community preserved.
- waste treatment plant expansion deferred for (at least) seven (7) years; operating efficiency improved; higher quality effluent discharge; and,
- opportunity to connect to a new fresh water system being constructed by an adjacent community instead of building new -- saving millions of dollars.

Conclusions

- Flushmate® flushometer-tank activated low consumption WC's work reliably;
- Have no operating problem on sewer system designed for high volume (5-1/2 GPF) toilets[4];
- Effectively eliminate imperceptible ballcock leakage[5];
- Virtually eliminate in-room bowl stoppages[6]; and,
- Lowered operating costs by more than $100 annually per toilet[7].

The full report detailing this remarkable story is available upon request.

RBM:ns
(H602271)

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[1] Including replacement of all showerheads in the village (page #3).
[2] Combination of American Standard Cadet® Aquameter™; Briggs Turboflush™ and Mansfield Quantum.
[3] Consumption/flush accounted for 20%; elimination of ballcock leakage for 19% (Exhibit "Z").
[4] Inspection in March, 1992, of all 8,100 feet of system by Video Inspection Specialists, Inc. (Page #6).
[5] Difference between actual and theoretical usage (Exhibit "Y").
[6] Survey of all San Simeon motel maintenance engineers.
[7] Dollar value of actual savings per toilet (Exhibit "Z").

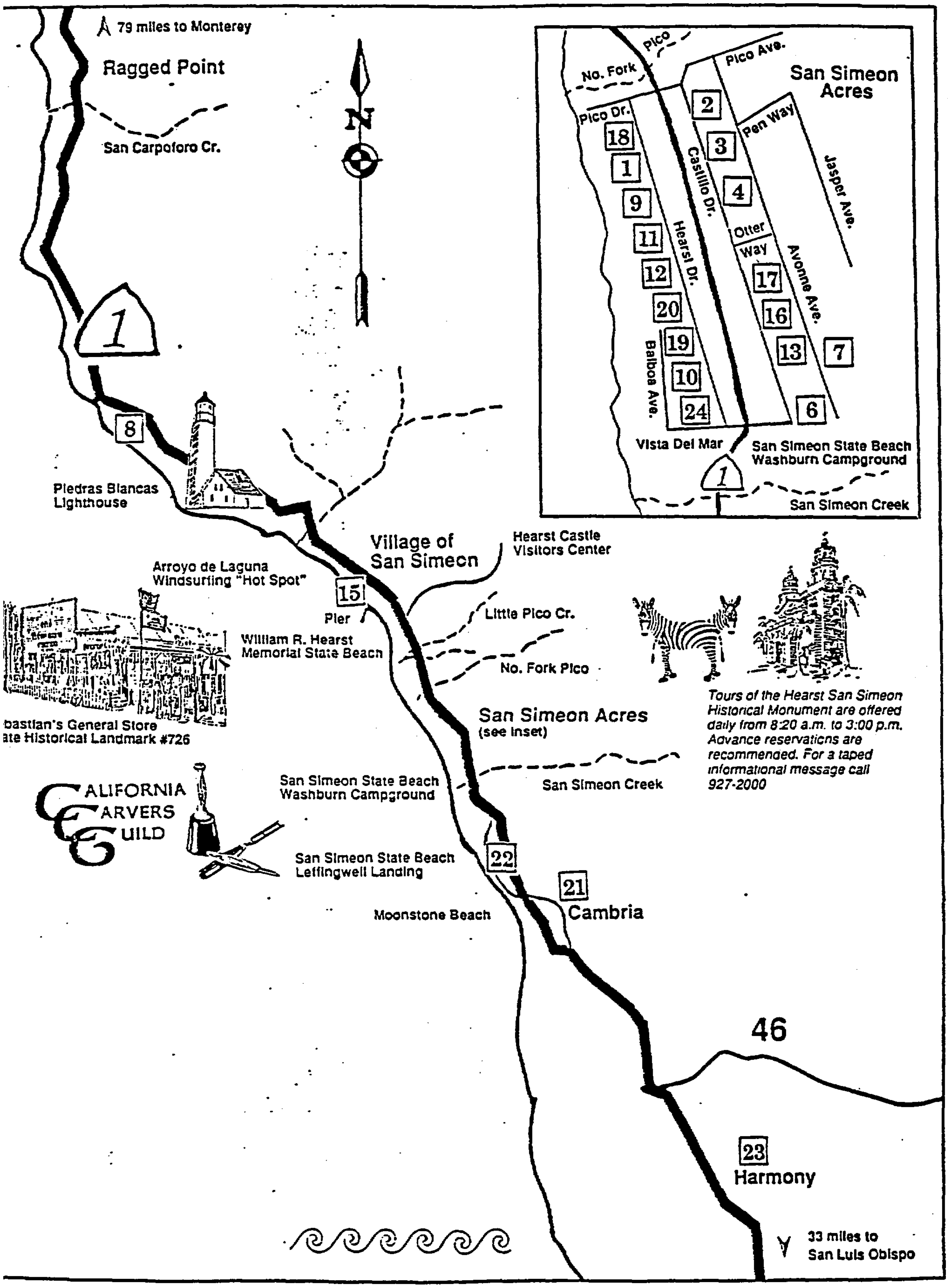
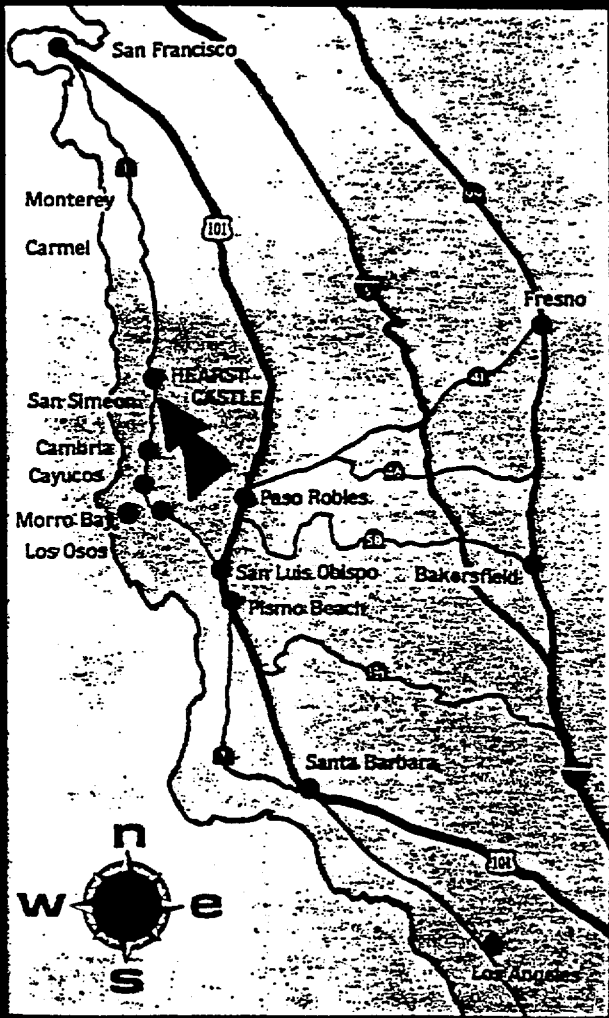

79 miles to Monterey
Ragged Point
San Carpoforo Cr.
N
San Simeon Acres
Pico
No. Fork
Pico Ave.
Pico Dr.
Pen Way
Casillio Dr.
Jasper Ave.
Hearst Dr.
Otter Way
Avonne Ave.
Balboa Ave.
Vista Del Mar
San Simeon State Beach Washburn Campground
San Simeon Creek
2
3
4
18
1
9
11
12
20
17
16
19
13
7
10
24
6
1
8
Piedras Blancas Lighthouse
Village of San Simeon
Hearst Castle Visitors Center
Arroyo de Laguna Windsurfing "Hot Spot"
15
Pier
Little Pico Cr.
William R. Hearst Memorial State Beach
No. Fork Pico
bastian's General Store
ate Historical Landmark #726
San Simeon Acres (see inset)
Tours of the Hearst San Simeon Historical Monument are offered daily from 8:20 a.m. to 3:00 p.m. Advance reservations are recommended. For a taped informational message call 927-2000
California Carvers Guild
San Simeon State Beach Washburn Campground
San Simeon Creek
San Simeon State Beach Leffingwell Landing
22
21
Cambria
Moonstone Beach
46
23
Harmony
33 miles to San Luis Obispo

EXHIBIT "A"



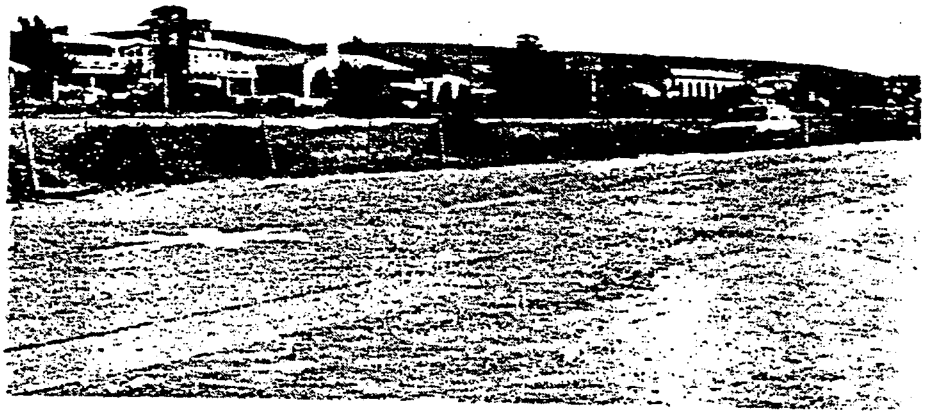
WTP

9070 Castillo Drive San Simeon, CA 93452
805-927-8691

Toll Free Reservations
Nationwide: (800) 854-3380
California: (800) 432 7045
Telex: 683-324
Represented by World Travel Planners

EXHIBIT "B"

EXHIBIT "C"



View of San Simeon's Motel "Strip"

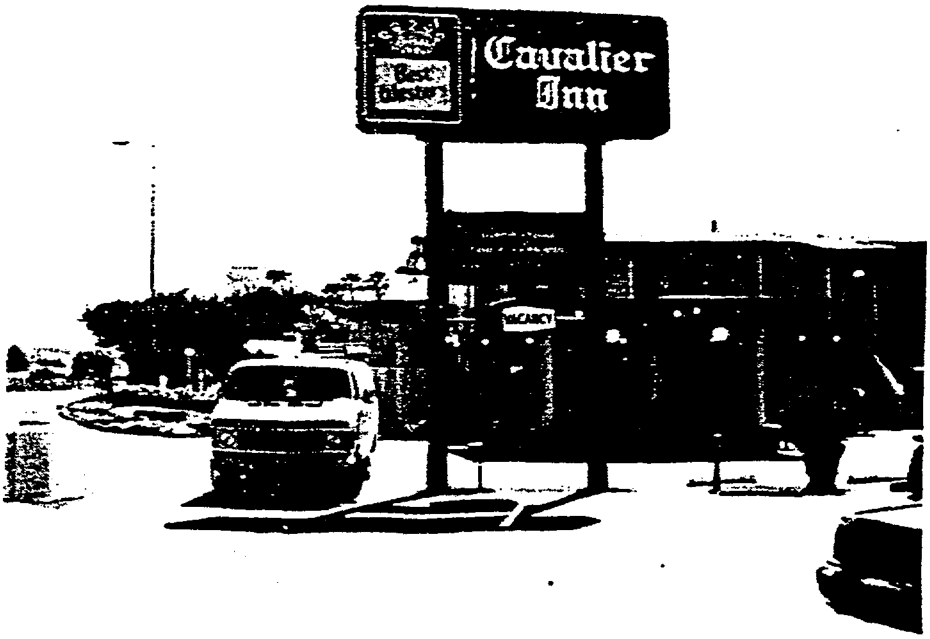
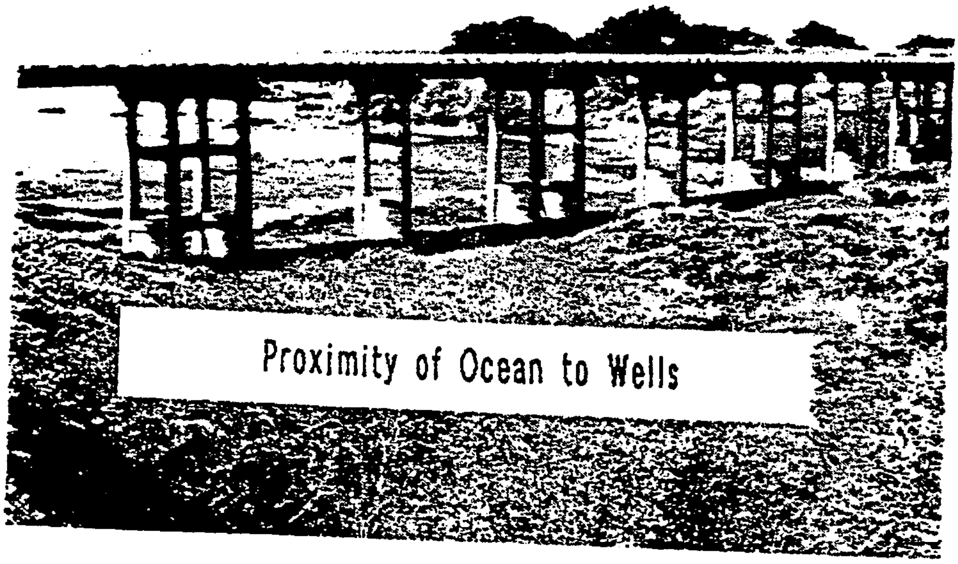
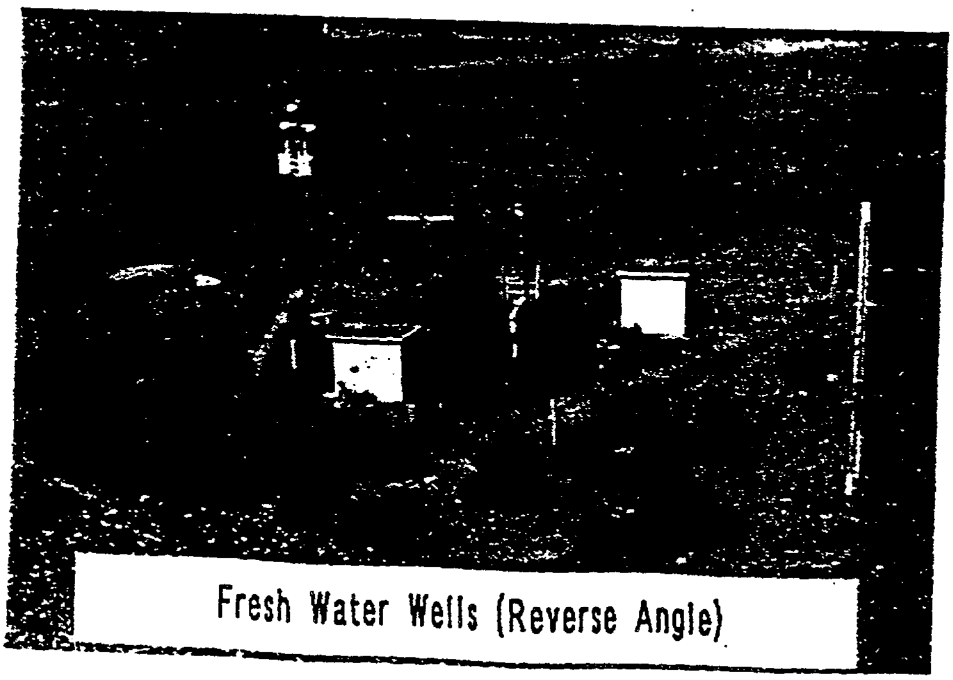


EXHIBIT "D"

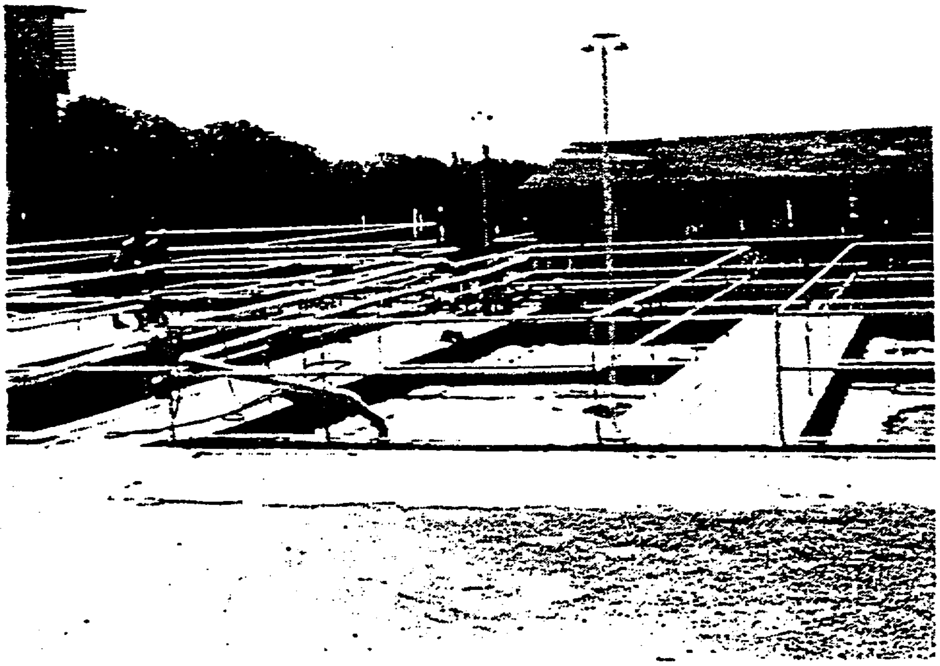


Proximity of Ocean to Wells



Fresh Water Wells (Reverse Angle)

EXHIBIT "E"



San Simeon Waste Treatment Plant

EXHIBIT "F"

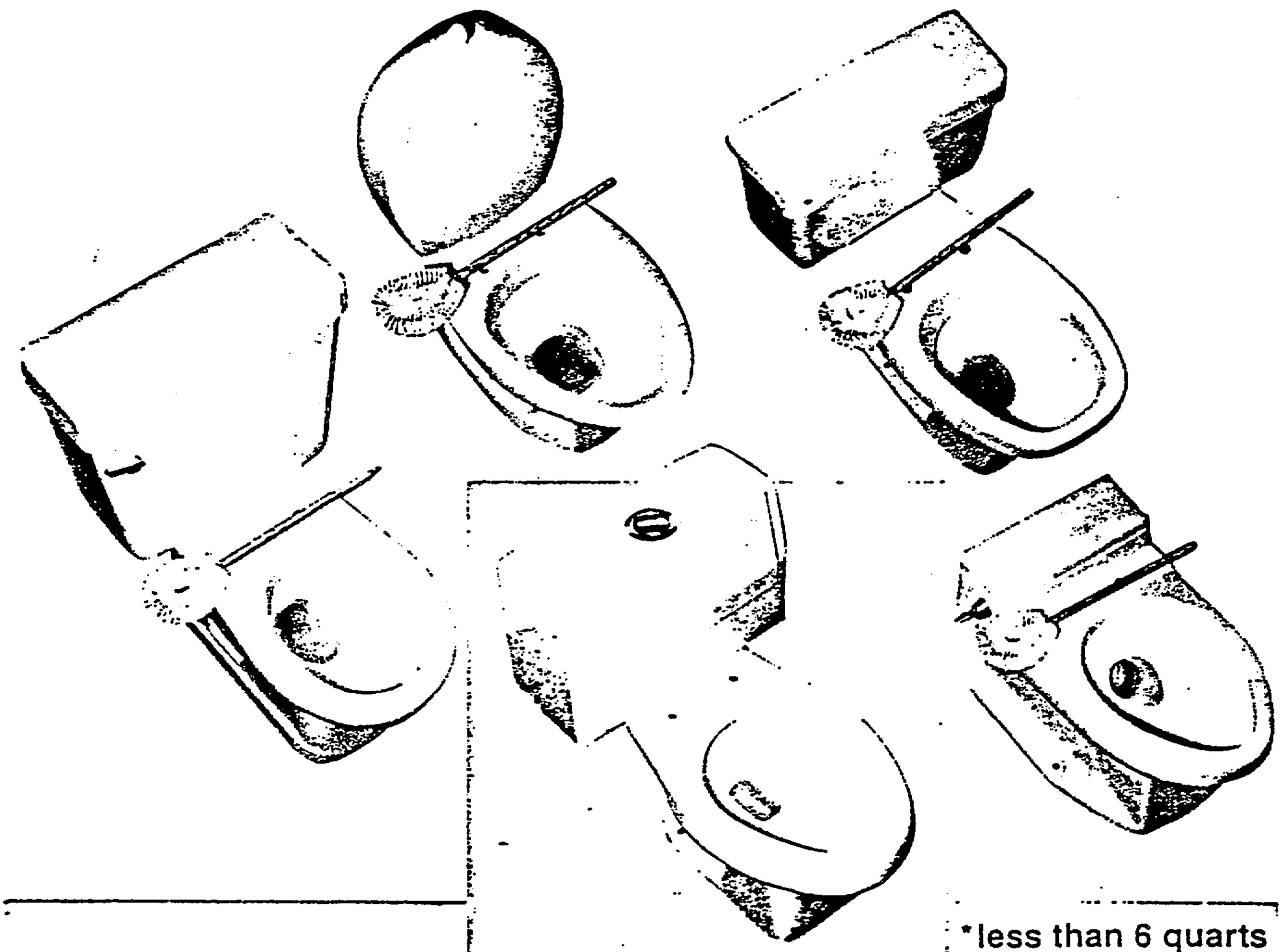
General Store & Post Office

Example of Public Awareness Promotion

Exhibit "H"

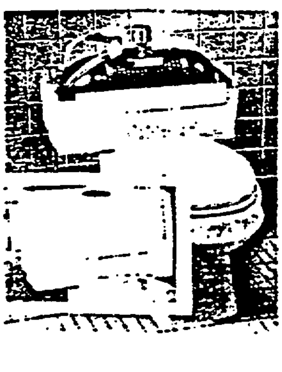
ALL TOILETS ARE NOT [illegible] EQUAL

Only Flushometer/tanks Offer Low Consumption* and Full-Sized Water Seal Surfaces



*less than 6 quarts per flush

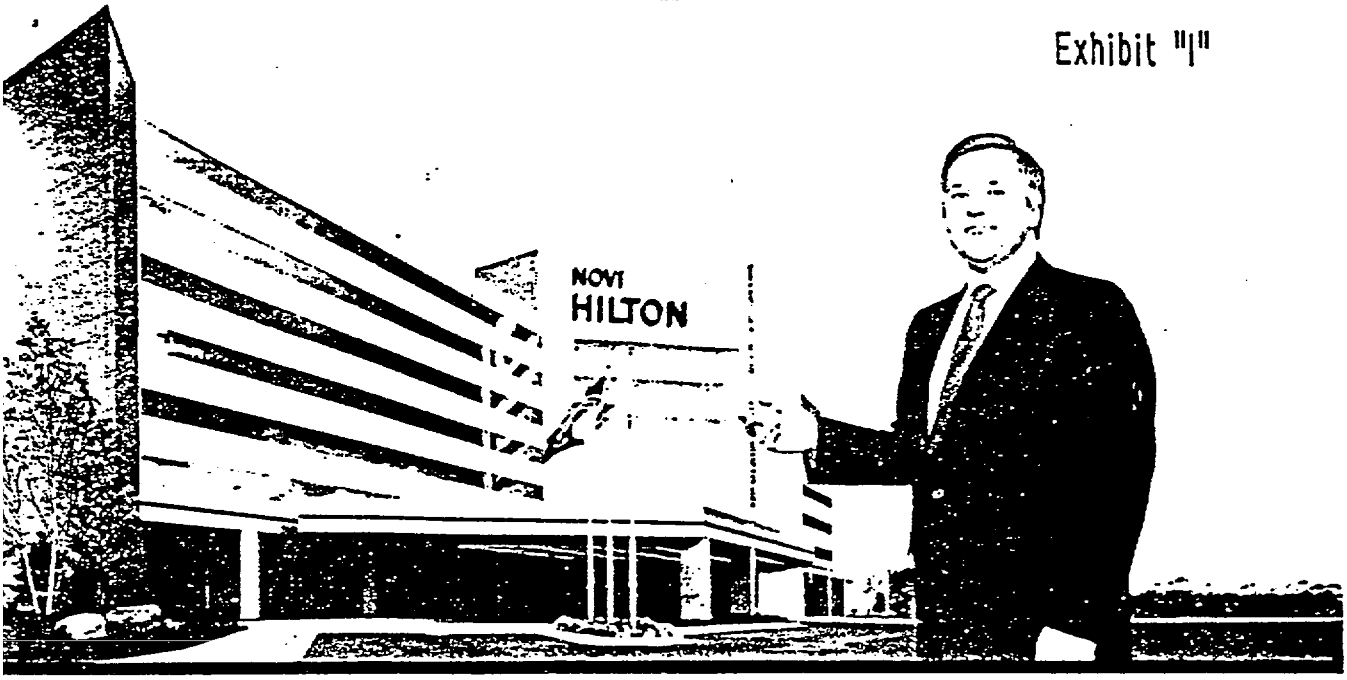
Sloan's Flushmate® Operating System toilets outperform all others. Now available from leading plumbing fixture manufacturers.



WATER CONTROL INTERNATIONAL, INC.
A SLOAN VALVE COMPANY

2820-224 West Maple Road • Troy. Michigan 48084
(800) 533-3460 (313)643-0530

Exhibit "I"



SLOAN'S FLUSHMATE® OPER[illegible]
SAVES $124. PER OCCUPIED [illegible]AR.

"... in addition, maintenance is virtually nil!"

G.E. SEIBERT, C.H.A.
General Manager, Novi Hilton; Novi, Michigan

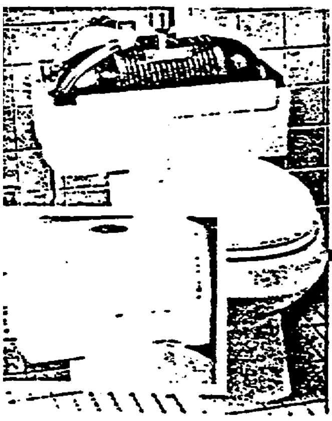
Cut Cost. Increase profit. Use less than 6 quarts of water per flush. It's possible when all guest rooms have Flushmate® Operating System (flushometer/tank) activated toilets. If you need another way to increase profit, find out how much old fashioned, gravity-fed toilets actually cost to operate. How much of your money do they flush down the drain?

At the 240 room Novi Hilton, toilet consumption has been only 77 gallons per occupied room per day. This is 68% less than neighboring hotels where gravity-fed, "watersaver" toilets are used. Actually, the flushometer/tanks have more than paid their way since the beginning of construction. $1,000 per toilet was saved through tap fee reductions and economical pipe system design. With construction soon to start on a new wing, you can bet all 140 new rooms will have toilets that use the Flushmate Operating System.

FLUSHOMETER/TANK ACTIVATED TOILETS DON'T SHAKE, RATTLE OR RUN

A patented, pressurized valve seal eliminates most maintenance department plumbing headaches—those imperceptible leaks you can hear but not find, those annoying mechanical failures common to ballcocks and flappers. By all measurements, flushometer/tank activated toilets have superior performance characteristics.

Incredible? It's fact! These toilets perform better than any other made today. All toilets are not created equal.



AVAILABLE FROM LEADING
PLUMBING FIXTURE MANUFACTURERS.

WATER CONTROL INTERNATIONAL, INC.
A SLOAN VALVE COMPANY
2820-224 West Maple Road • Troy, Michigan 48084
(800) 533-3460 (313) 643-0530

Exhibit "J"

ALL TOILETS ARE NOT CREATED EQUAL

especially when inefficient toilets drain hotel profits . . .

The Quality Inns of Farmington Hills (160 rooms) and Livonia, Michigan (125 rooms) are almost twins. Standard design includes on-site laundry, an indoor pool, whirlpools.

Because occupancy rates were the same last year, water usage per occupied room per day should also have been the same. IT WASN'T! Farmington Hills' was 95 gallons. Livonia's consumption was 173—88% HIGHER.

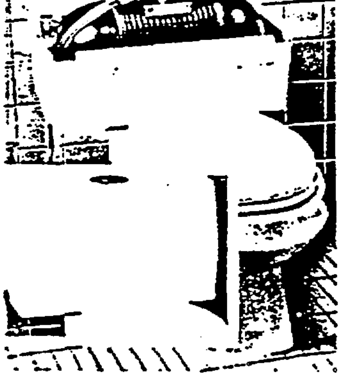
WATER USAGE PER OCCUPIED ROOM	
Livonia	179 gal/day
Farmington Hills	95 gal/day
Livonia Difference	84 gal/day MORE

WHY?

New concept Flushmate® (flushometer/tank) activated toilets are installed in Farmington Hills. By using less than six quarts of water per flush, the owners of the Farmington Hills Quality Inn put water to work for them.

Do you want to save money by putting water to work for you?

Call us.

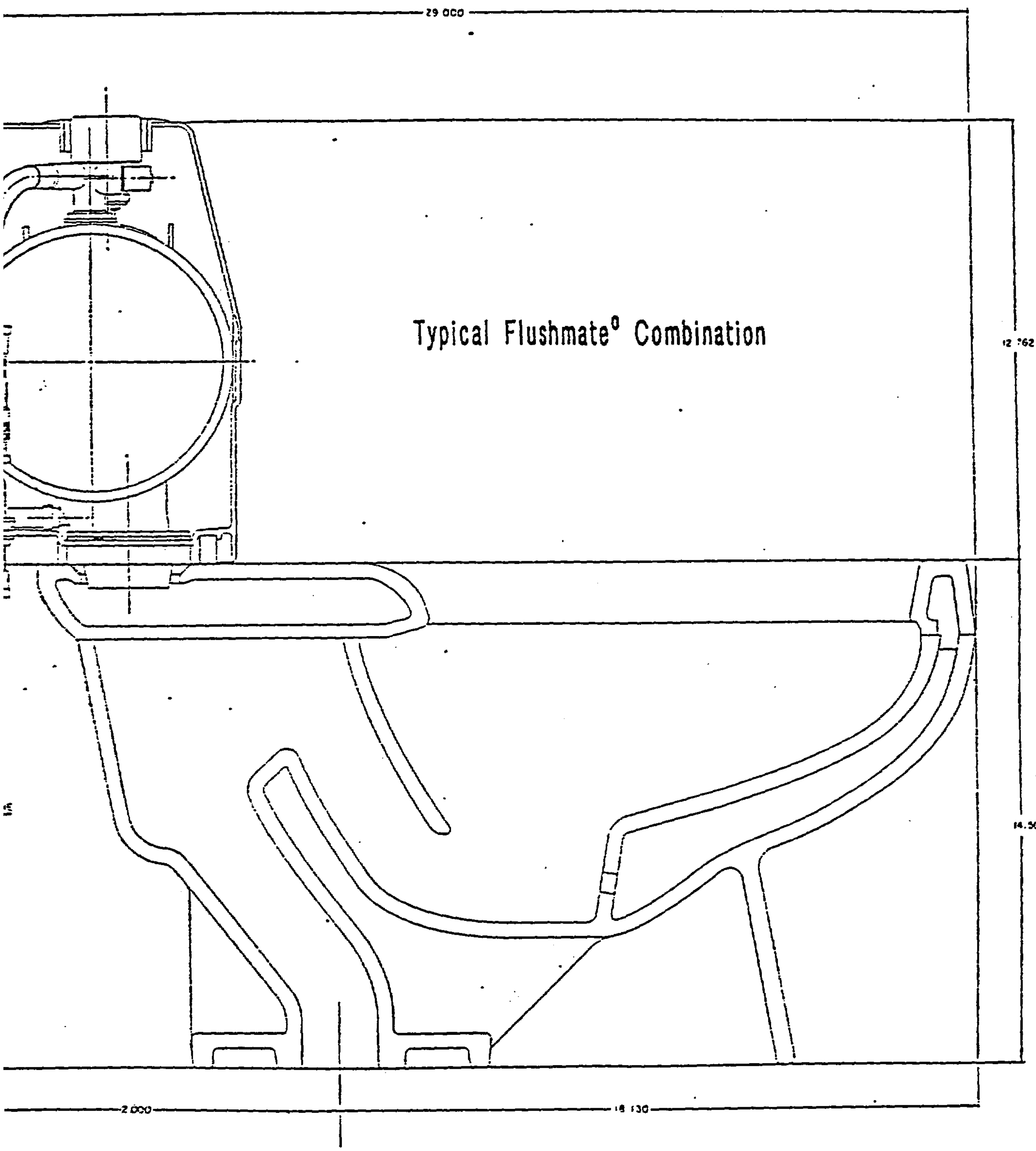


TOILETS WITH SLOAN'S FLUSHMATE® (FLUSHOMETER/TANK OPERATING SYSTEM) OUTPERFORM ALL OTHERS. NOW AVAILABLE FROM LEADING PLUMBING FIXTURE MANUFACTURERS.

WATER CONTROL INTERNATIONAL, INC.
A SLOAN VALVE COMPANY

2820-224 West Maple Road • Troy, Michigan 48084
(800) 533-3460 (313) 643-0530
Fax: (313) 643-8066

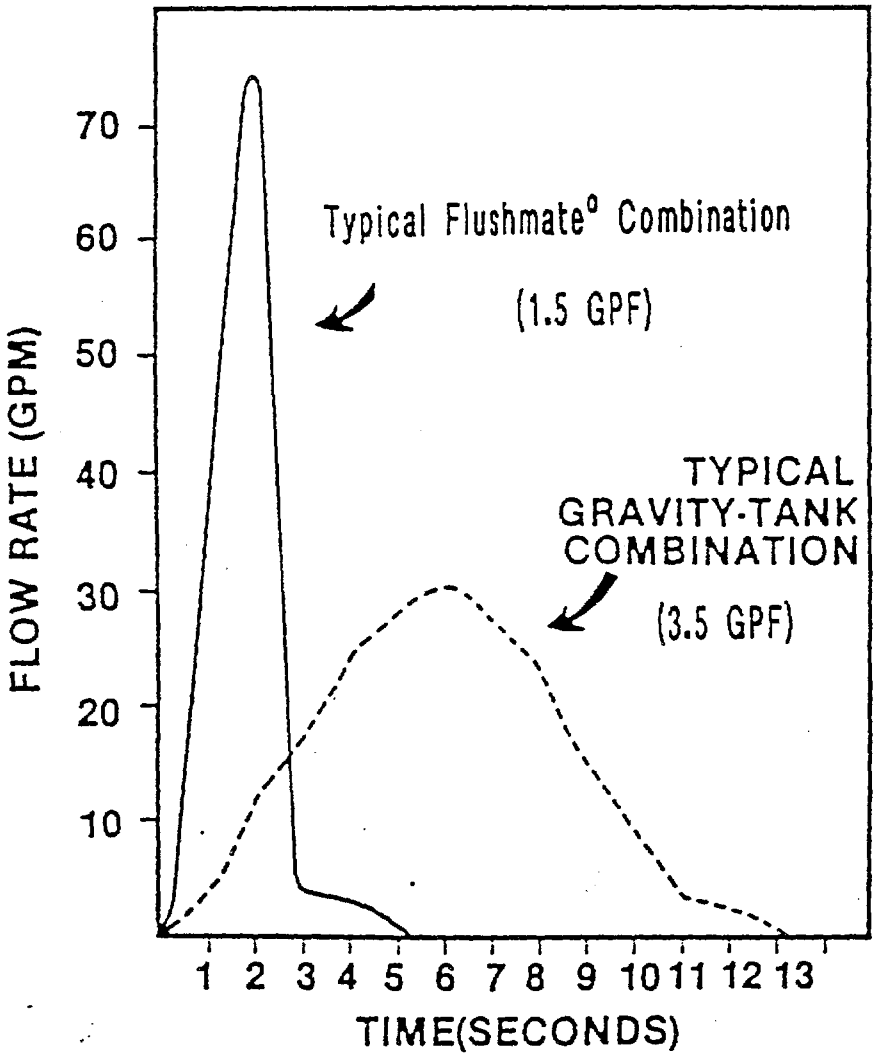
Exhibit "K"



CASHSAVER DX-1400
COMBINATION

Exhibit "L"

COMPARISON OF DISCHARGE CURVES



QUANTUM

MANSFIELD

Exhibit "M"

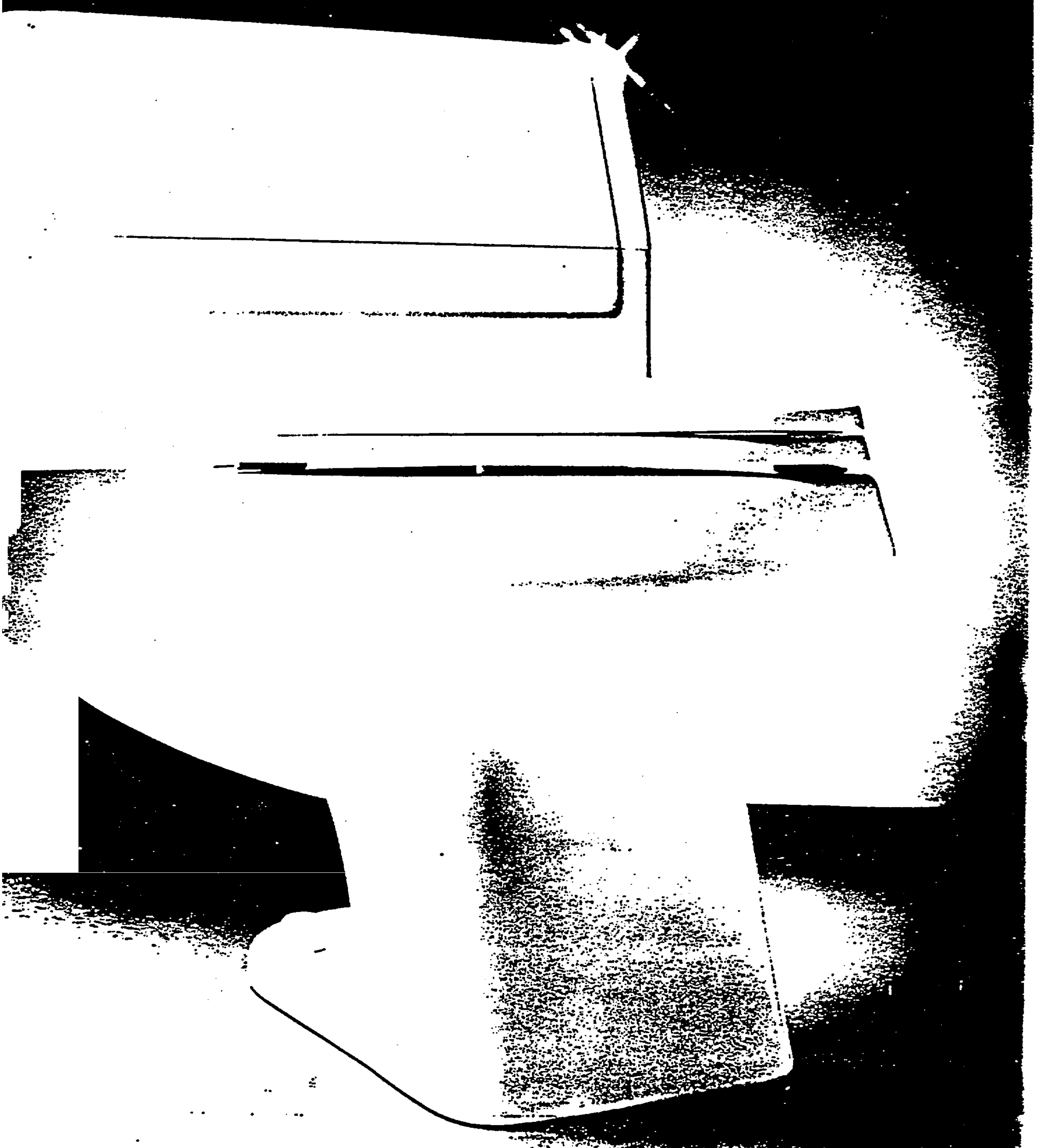
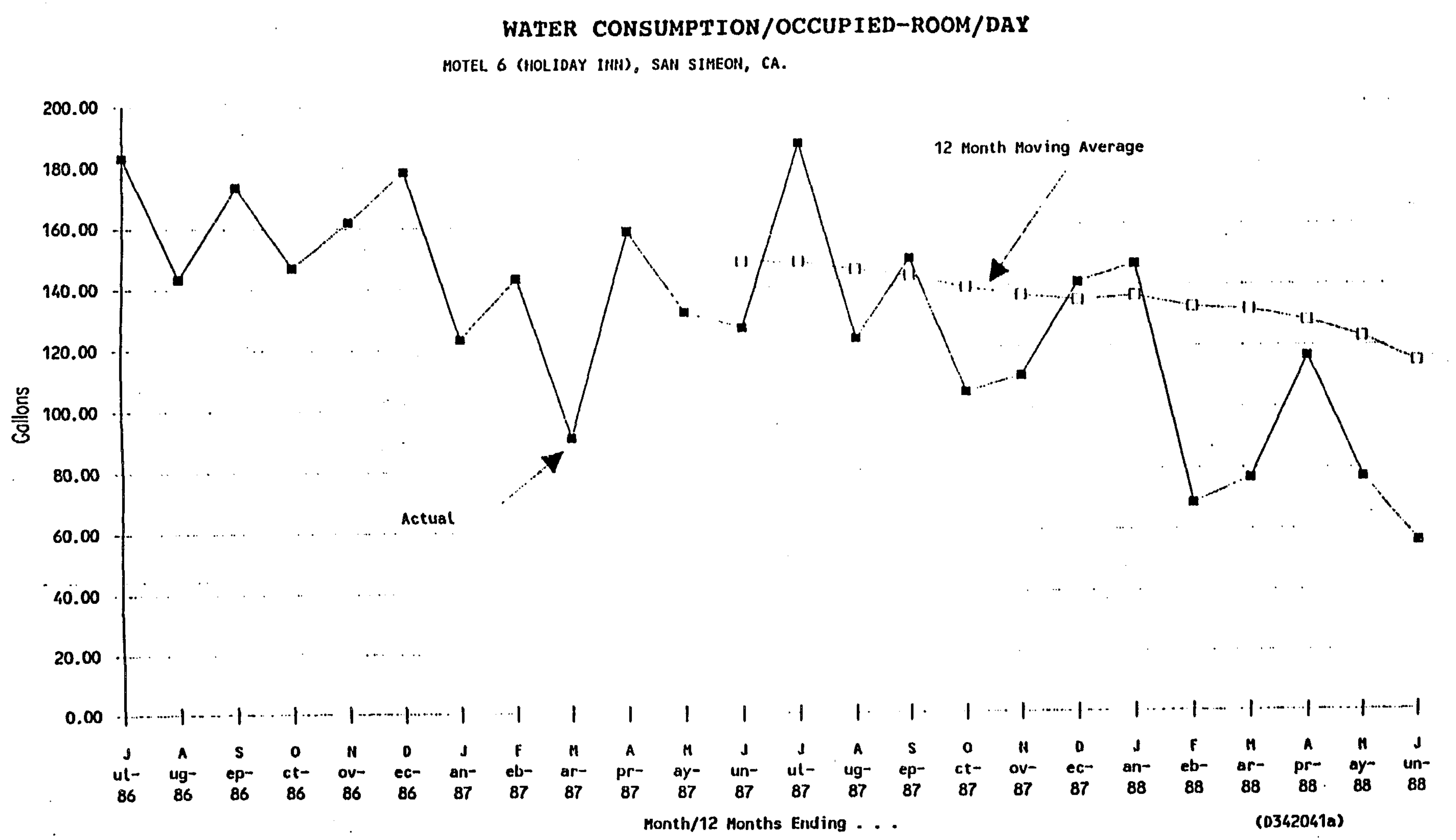


Exhibit "N"



WATER CONSUMPTION/OCCUPIED-ROOM/DAY
MOTEL 6 (HOLIDAY INN), SAN SIMEON, CA.
Gallons
200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
12 Month Moving Average
Actual
Jul-86 Aug-86 Sep-86 Oct-86 Nov-86 Dec-86 Jan-87 Feb-87 Mar-87 Apr-87 May-87 Jun-87 Jul-87 Aug-87 Sep-87 Oct-87 Nov-87 Dec-87 Jan-88 Feb-88 Mar-88 Apr-88 May-88 Jun-88
Month/12 Months Ending . . .
(D342041a)

EXHIBIT "O"

New Cadet™ Aquameter Series Features:

- Contemporary, streamlined design
- Strong 1.6 gallon direct-fed siphon jet flush action, pressure assisted close-coupled flushometer tank
- Full size 12"x10" water surface in bowl area
- Available in Round, Elongated and 18" high Elderly models
- Available in 9 colors: White, Dresden Blue, Orchid, Fawn Beige, Bone, Shell, Heather, Silver and Black to complement American Standard bath fixtures
- Conforms to ANSI Standards

American-Standard Cadet

AQUAMETER PRESSURE-ASSISTED

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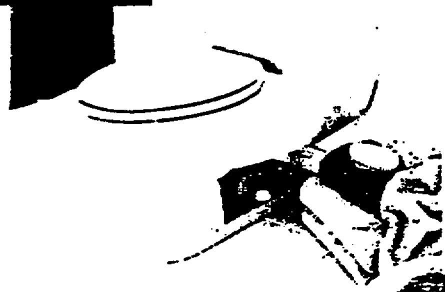
EXHIBIT "P"

Briggs Industries

PRESSURE ACTIVATED TOILETS

Briggs now offers a way to cut your water consumption dramatically and still have a sparkling bowl. Introducing the entire line of Low Consumption toilets from Briggs.



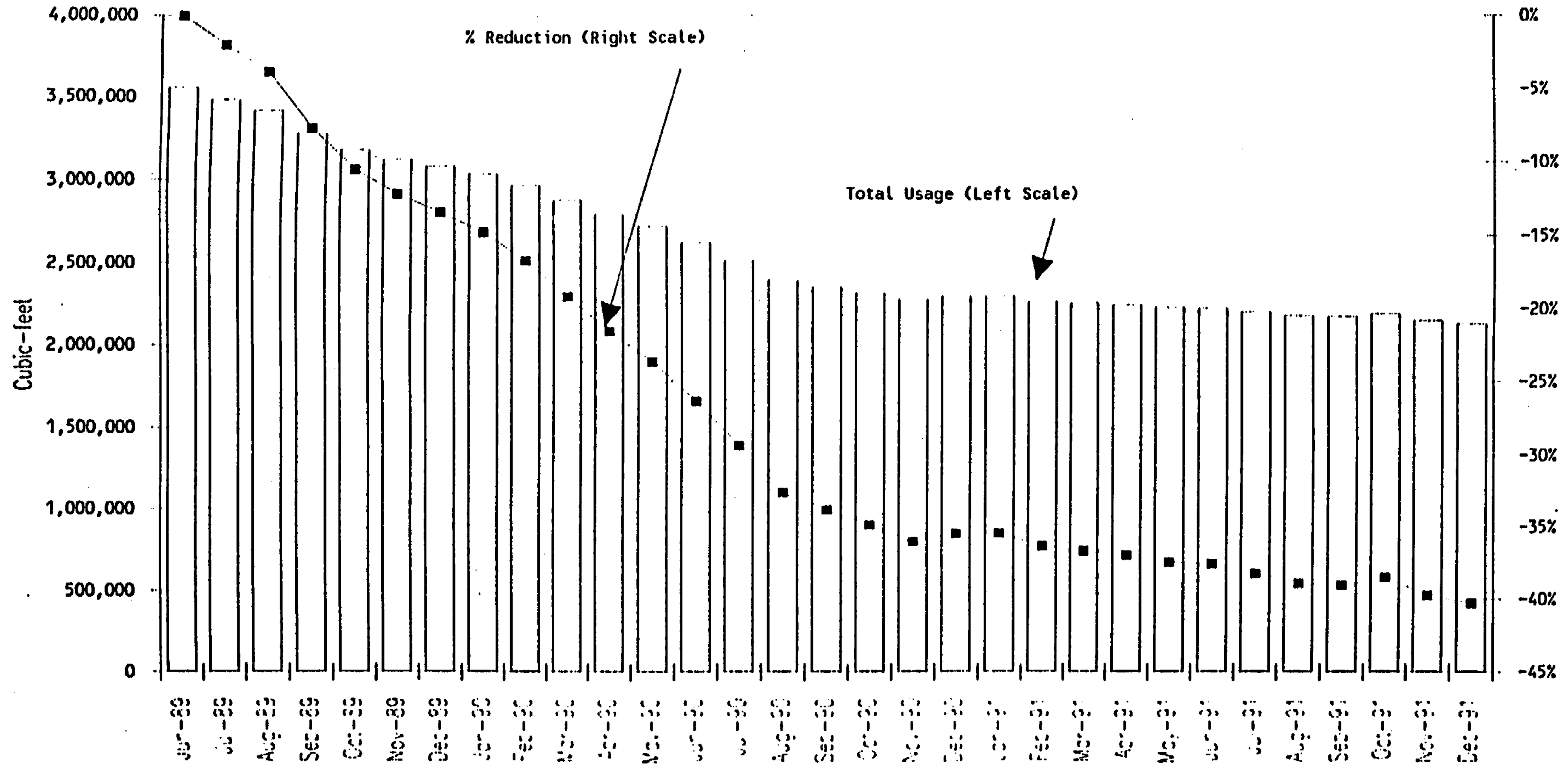
Model 6090 Turboflush™ One-Piece

Model 4700 Turboflush™ Elongated

Exhibit "Q"

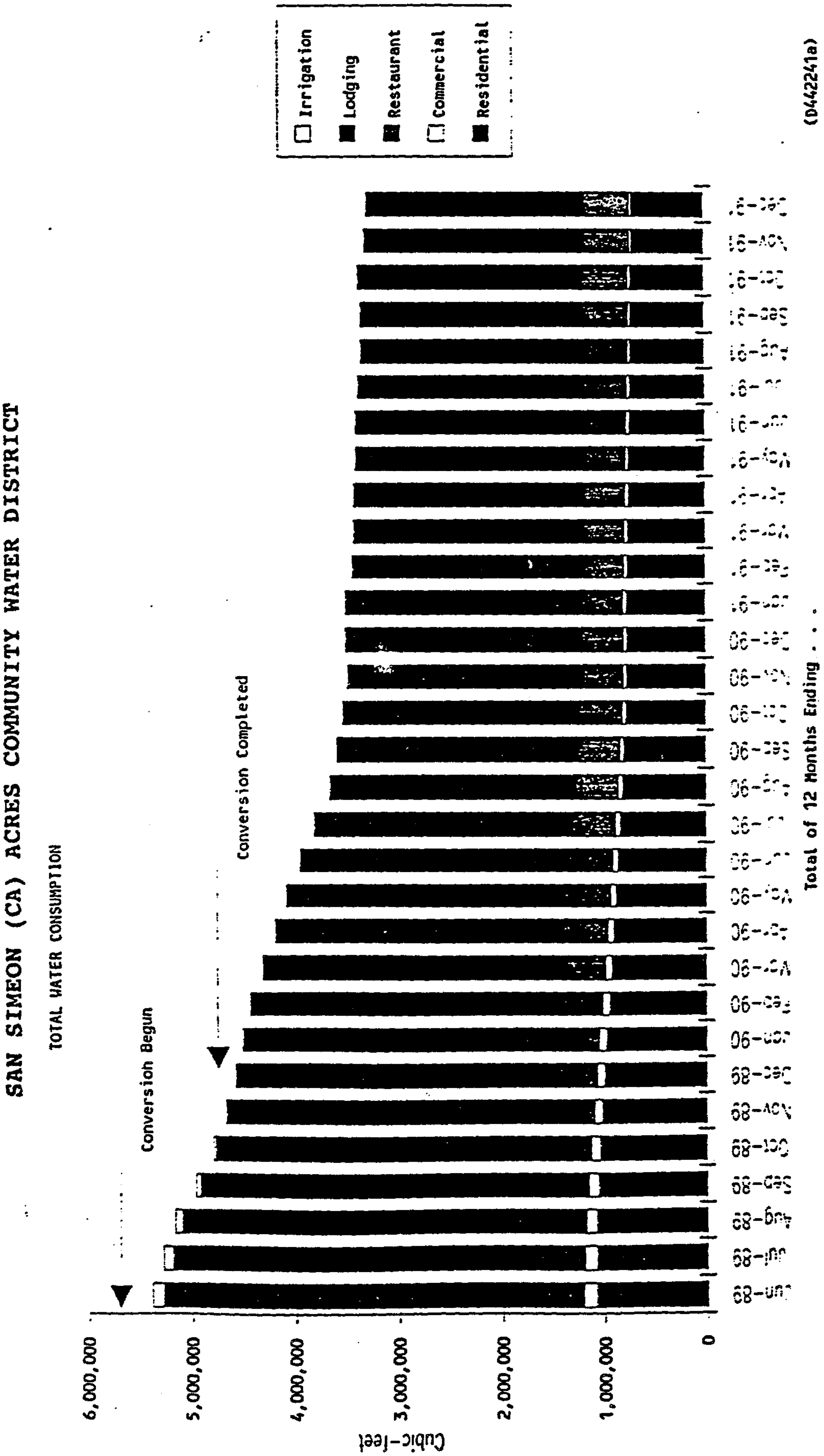
SAN SIMEON ACRES COMMUNITY WATER DISTRICT

Total Consumption - ALL Motels Only (Exclusive of Restaurants)



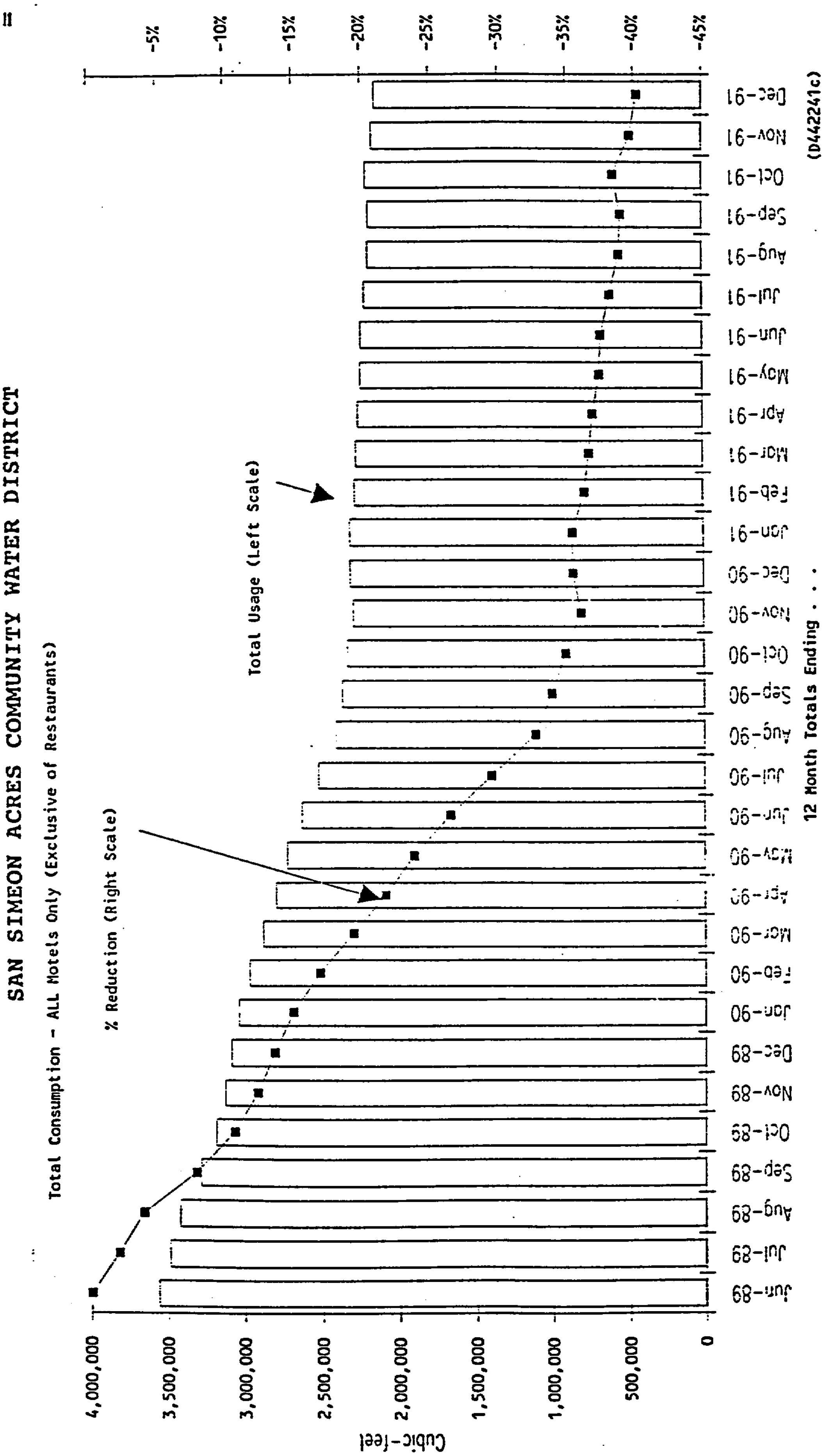
(D442241c)

Exhibit "R"



SAN SIMEON (CA) ACRES COMMUNITY WATER DISTRICT
TOTAL WATER CONSUMPTION
Irrigation
Lodging
Restaurant
Commercial
Residential
(D442241a)
Conversion Begun
Conversion Completed
Total of 12 Months Ending . . .
Cubic-feet
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0

xhibit "S"



SAN SIMEON ACRES COMMUNITY WATER DISTRICT
Total Consumption - ALL Motels Only (Exclusive of Restaurants)
% Reduction (Right Scale)
Total Usage (Left Scale)
12 Month Totals Ending . . .
(D442241c)
Cubic-feet
4,000,000
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
-5%
-10%
-15%
-20%
-25%
-30%
-35%
-40%
-45%
Jun-89
Jul-89
Aug-89
Sep-89
Oct-89
Nov-89
Dec-89
Jan-90
Feb-90
Mar-90
Apr-90
May-90
Jun-90
Jul-90
Aug-90
Sep-90
Oct-90
Nov-90
Dec-90
Jan-91
Feb-91
Mar-91
Apr-91
May-91
Jun-91
Jul-91
Aug-91
Sep-91
Oct-91
Nov-91
Dec-91

Exhibit "T"

ESTIMATED ECONOMIC IMPACT OF 10% ROOM CLOSING OF
700 Rooms (D442231)
All Motels

Month	Rooms Availabl	#Rented	% Occ.	# Closed	Value (@$90/Day)
Jan-88	21,700	13,454	62%	0	$0
Feb-88	20,300	15,225	75%	0	$0
Mar-88	21,700	18,445	85%	0	$0
Apr-88	21,000	19,950	95%	0	$0
May-88	21,700	19,747	91%	0	$0
Jun-88	21,000	20,580	98%	0	$0
Jul-88	21,700	21,700	100%	0	$0
Aug-88	21,700	21,700	100%	0	$0
Sep-88	21,000	21,000	100%	0	$0
Oct-88	21,700	21,049	97%	0	$0
Nov-88	21,000	15,960	76%	0	$0
Dec-88	21,700	12,586	58%	0	$0
	256,203	221,398	86%	NA	NA
Jan-89	21,700	13,888	64%	0	$0
Feb-89	19,600	14,308	73%	0	$0
Mar-89	21,700	17,577	81%	0	$0
Apr-89	21,000	18,900	90%	0	$0
May-89	21,700	19,964	92%	0	$0
Jun-89	21,000	20,790	99%	0	$0
Jul-89 a	21,700	21,700	100%	0	$0
Aug-89	21,700	21,700	100%	0	$0
Sep-89	21,000	20,580	98%	0	$0
Oct-89	21,700	19,096	88%	0	$0
Nov-89	21,000	13,650	65%	0	$0
Dec-89 b	21,700	12,152	56%	0	$0
c	255,503	214,307	84%	0	$0
Jan-90	21,700	12,586	58%	0	$0
Feb-90	19,600	14,308	73%	0	$0
Mar-90	21,700	16,709	77%	0	$0
Apr-90	21,000	17,640	84%	0	$0
May-90	21,700	18,011	83%	0	$0
Jun-90	21,000	19,320	92%	420	$37,800
Jul-90	21,700	21,483	99%	1,953	$175,772
Aug-90	21,700	21,700	100%	2,170	$195,302
Sep-90	21,000	20,160	96%	1,260	$113,401
Oct-90	21,700	19,964	92%	434	$39,060
Nov-90	21,000	14,700	70%	0	$0
Dec-90	21,700	12,152	56%	0	$0
	255,503	208,735	82%	6,237	$561,336

ESTIMATED ECONOMIC IMPACT OF 10% ROOM CLOSING OF
700 Rooms (D442231)
All Motels

Month	Rooms Availabl	Rooms #Rented	% Occ.	# Closed	Value (@$90/Day)
Jan-91	21,700	12,152	56%	0	$0
Feb-91	19,600	11,564	59%	0	$0
Mar-91	21,700	15,190	70%	0	$0
Apr-91	21,000	15,330	73%	0	$0
May-91	21,700	17,794	82%	0	$0
Jun-91	21,000	17,430	83%	0	$0
Jul-91	21,700	18,879	87%	0	$0
Aug-91	21,700	21,049	97%	1,519	$136,712
Sep-91	21,000	21,000	100%	2,100	$189,002
Oct-91	21,700	20,832	96%	1,302	$117,181
Nov-91	21,000	18,900	90%	0	$0
Dec-91	21,700	15,624	72%	0	$0
	255,503	205,746	81%	4,921	$442,895
Jan-92	21,700	13,020	60%	0	$0
Feb-92	20,300	12,586	62%	0	$0
Mar-92	21,700	15,407	71%	0	$0
Totals				11,158	$1,004,231

Exhibit "U"

COMPARISON OF CONSUMPTION
San Simeon Community Water District
(D442241)

Type	Year Ended 6/89 CF	Year Ended 6/89 % Tot.	Year Ended 12/91 CF	Year Ended 12/91 % Tot.	% Cng. (30 Mos.)
Residential	1,086.80	20.14%	699.90	21.24%	-35.60%
Commercial	125.00	2.32%	22.70	0.69%	-81.84%
Restaurant	512.40	9.50%	442.60	13.43%	-13.62%
Lodging	3,562.50	66.02%	2,129.10	64.62%	-40.24%
Irrigation	109.70	2.03%	0.30	0.01%	-99.73%
Totals	5,396.40	100.00%	3,294.60	100.00%	-38.95%

EXHIBIT "V"

Video Inspection Service Sewer Monitor

Walter Blankenship (SSCS Board Chairman)
& Other Community Leaders
Viewing Sewer Inspection

Exhibit "W"

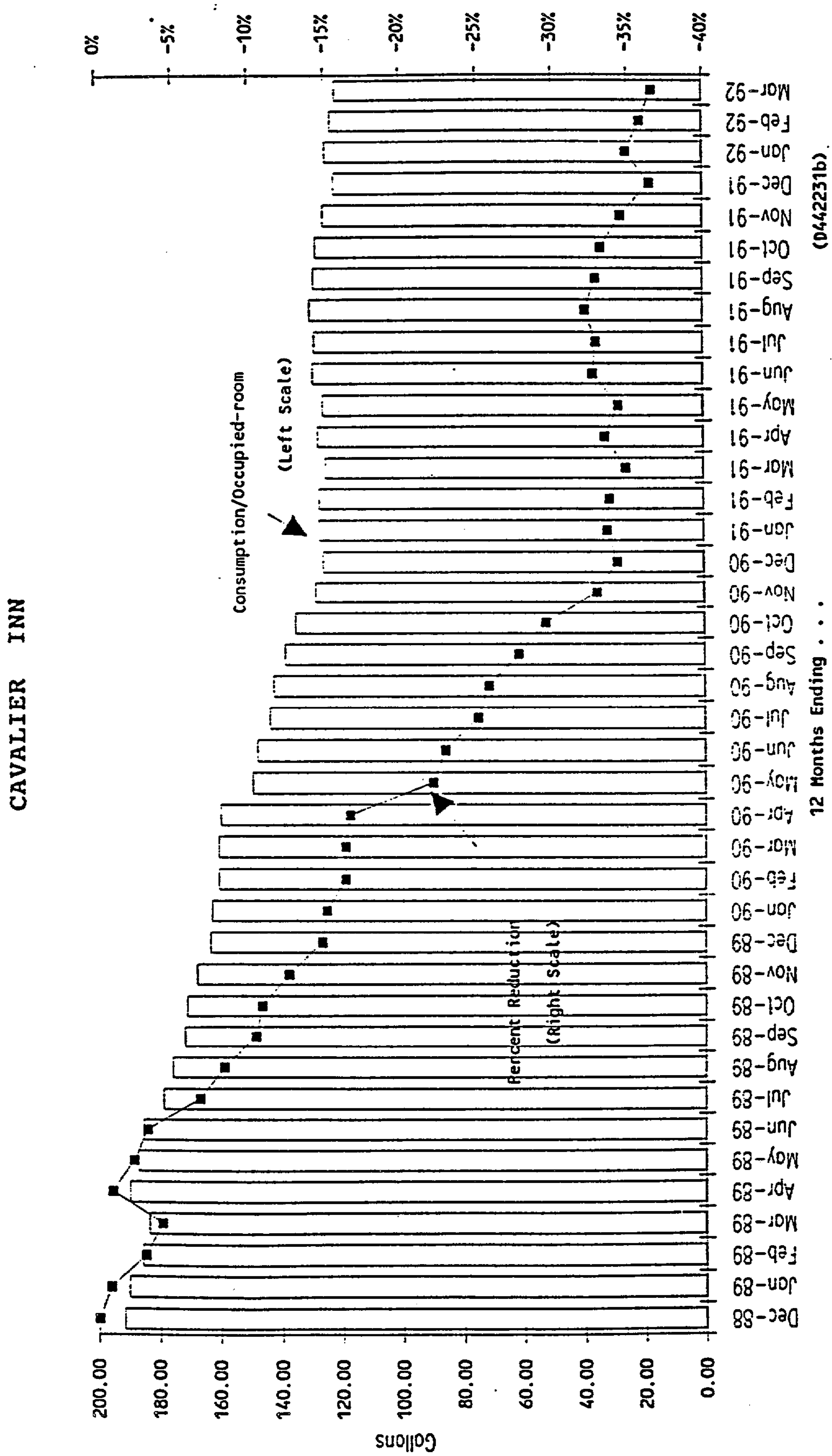

CAVALIER INN
0%
-5%
-10%
-15%
-20%
-25%
-30%
-35%
-40%
Consumption/Occupied-room
(Left Scale)
Percent Reduction
(Right Scale)
Dec-88
Jan-89
Feb-89
Mar-89
Apr-89
May-89
Jun-89
Jul-89
Aug-89
Sep-89
Oct-89
Nov-89
Dec-89
Jan-90
Feb-90
Mar-90
Apr-90
May-90
Jun-90
Jul-90
Aug-90
Sep-90
Oct-90
Nov-90
Dec-90
Jan-91
Feb-91
Mar-91
Apr-91
May-91
Jun-91
Jul-91
Aug-91
Sep-91
Oct-91
Nov-91
Dec-91
Jan-92
Feb-92
Mar-92
12 Months Ending . . .
(D442231b)
200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Gallons

Exhibit "X"

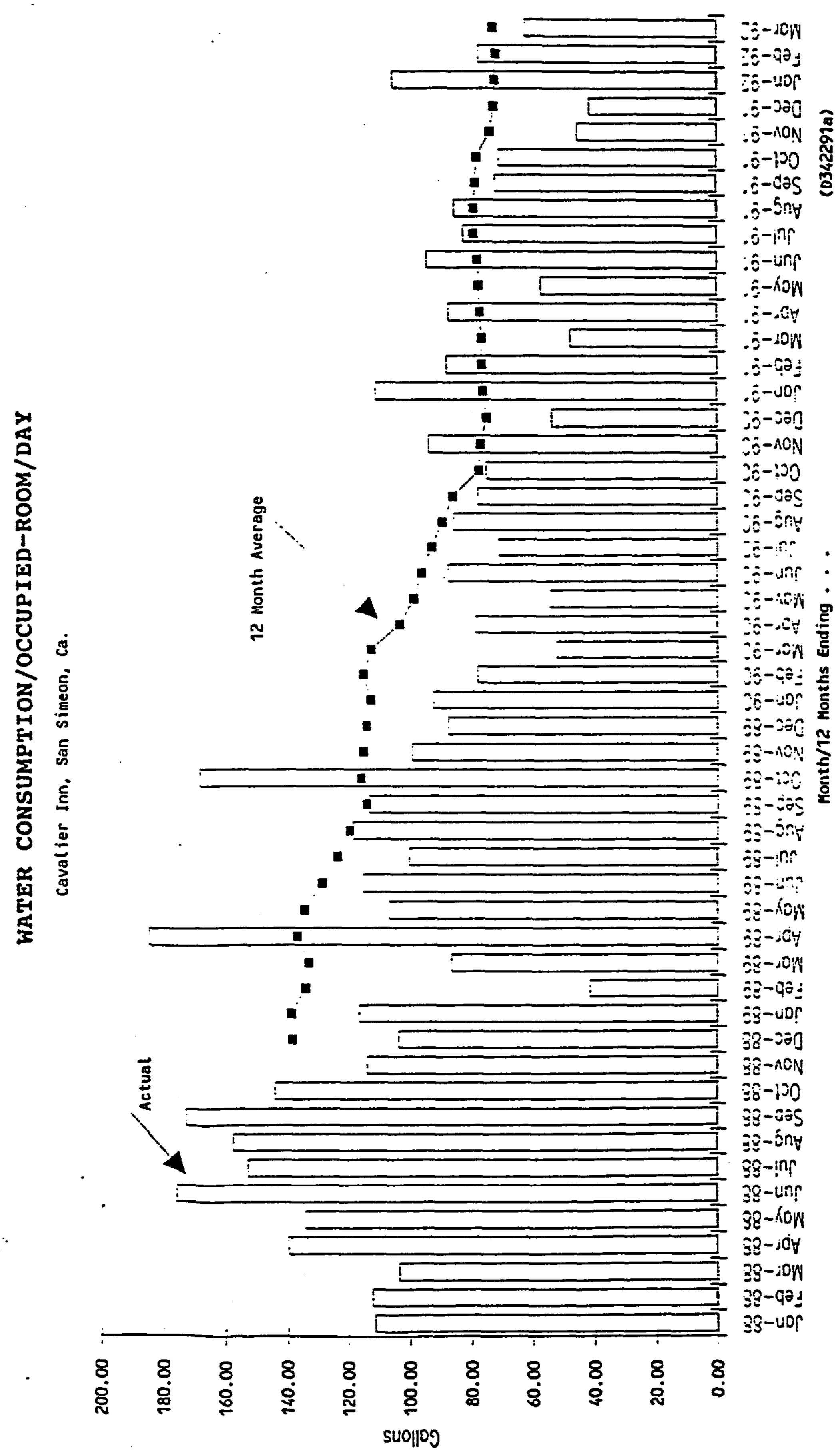

WATER CONSUMPTION/OCCUPIED-ROOM/DAY
Cavalier Inn, San Simeon, Ca.
12 Month Average
Actual
Gallons
200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Month/12 Months Ending . . .
(D342291a)

Exhibit "Y"

Analysis of Water Closet Efficiency

San Simeon Motels

(D342242c)	Holiday Inn	Cavalier Inn	All Motels
Basic Data & Assumptions			
Total # WC's	102	90	770
Avg. Flushes/Occ-Room/Day	10	10	10
# Days/Year	365	365	365
Total flushes/Yr./WC	3,650	3,650	3,650
Total Flushes/Yr. (All WC's)	372,300	328,500	2,810,500
Rated Consumption/Flush			
3.5 GPF - Gravity	3.50	3.50	3.50
1.5 GPF - Pressurized	1.50	1.50	1.50
Savings/flush	2.00	2.00	2.00
Theoretical WC Consumption			
Gravity Units	1,303,050	1,149,750	9,836,750
Pressurized Units	558,450	492,750	4,215,750
Theoretical Savings	744,600	657,000	5,621,000
Actual Room Consumption (Gal)*			
Year-ended 6/89**	3,203,225	3,407,278	15,661,352
Year-ended 12/91**	2,443,383	1,605,742	5,578,262
Annual Savings Obtained	759,842	1,801,536	10,083,089
Amount Attributible to Leaks	15,242	1,144,536	4,462,089
Avg. Actual WC Usage/Flush***			
3.5 GPF (Gravity) - Flushing	3.50	3.50	3.50
- Leakage	0.04	3.48	1.59
	3.54	6.98	5.09
1.5 GPF (Pressurized) - Flushing	1.50	1.50	1.50
- Leakage	0.00	0.00	0.00
	1.50	1.50	1.50
Pressurized Savings/Flush	2.04	5.48	3.59
Distribution of Savings			
WC Flushing	98%	36%	56%
WC Leaks Bewteen Flushing	2%	64%	44%
	100%	100%	100%

* Excluding Laundry & Restaurant Usage.
Laundry assumed to be 50 gals./Occupied-room.
Occupancy assumed to same as Cavalier Inn for same intervals.

** Holiday Inn data for 12 Months Ending 1/87 & 1/89, Respectively.

***Theoretical Usage + Leakage/# flushes.

Exhibit "Z"

ıation of Conversion Return-on-Investment
San Simeon Community
2273)

ɟory	Year-Ending 6/30/89	Year-Ending 12/31/91	Savings Amount	Savings Percent
ır & Sewer Cost /1000 Gal.	$8.17	$8.17	$0.00	0.00%
Vater Closets	1.198	1.198	0	0.00%
Usage (Gal)	40,365,581	24,644,453	15,721,127	-38.95%
Irrigation (Gal)	820,706	2,461	818,245	-99.70%
Consumption (Gal)	39,544,875	24,641,992	14,902,883	-37.69%
Vater Closet (Gal)	33,009	20,569	12,440	-37.69%
ıal Cost of Water & Sewer	$323,081.63	$201,325.08	$121,756.55	-37.69%
ıal Cost/Water Closet	$269.68	$168.05	$101.63	-37.69%
lled Cost/WC			$180.00	
ıal % Return-on-Investment			56%	

Appendix 3 - keyword search logic employed for part 2 search

unvented heating	and	expansion vessel	and	expansion valve	and	water loss	
unvented heating	or	expansion vessel	and	expansion valve	and	water loss	
unvented heating	and	expansion vessel	or	expansion valve	and	water loss	
unvented heating	or	expansion vessel	or	expansion valve	and	water loss	
unvented heating	and	expansion vessel	and	expansion valve	or	water loss	
unvented heating	or	expansion vessel	and	expansion valve	or	water loss	
unvented heating	and	expansion vessel	or	expansion valve	or	water loss	
unvented heating	or	expansion vessel	or	expansion valve	or	water loss	
unvented heating	or	expansion vessel	or	expansion valve	and	water saving	
unvented hot water	and	expansion vessel	and	expansion valve	and	water loss	
unvented hot water	or	expansion vessel	and	expansion valve	and	water loss	
unvented hot water	and	expansion vessel	or	expansion valve	and	water loss	
unvented hot water	or	expansion vessel	or	expansion valve	and	water loss	
unvented hot water	and	expansion vessel	and	expansion valve	or	water loss	
unvented hot water	or	expansion vessel	and	expansion valve	or	water loss	
unvented hot water	and	expansion vessel	or	expansion valve	or	water loss	
unvented hot water	or	expansion vessel	or	expansion valve	or	water loss	
unvented hot water	or	expansion vessel	or	expansion valve	and	water saving	
unvented heating	and	expansion vessel	and	maintenance	and	water loss	
unvented heating	or	expansion vessel	and	maintenance	and	water loss	
unvented heating	or	expansion valve	and	maintenance	and	water loss	
unvented heating	and	expansion vessel	and	maintenance	and	water saving	
unvented heating	and	expansion vessel	and	pressure relief	and	water loss	
unvented heating	or	expansion vessel	and	pressure relief	and	water loss	
unvented heating	or	expansion valve	and	pressure relief	and	water loss	
unvented heating	or	expansion valve	and	pressure relief	or	water loss	
unvented heating	and	expansion vessel	and	pressure relief	and	water saving	
unvented heating	and	maintenance	and	pressure relief	and	water loss	
unvented heating	or	maintenance	and	pressure relief	and	water loss	
unvented heating	or	maintenance	and	pressure relief	and	water loss	
unvented heating	and	maintenance	and	pressure relief	and	water saving	