Water Resources Research Institute
Annual Technical Report
FY 2001

Introduction

Research Program

Development of Novel Dual-Function Media Matrix for Protecting Water Resources from Noxious Organic Wastes - Phase II

Basic Information

Title:	Development of Novel Dual-Function Media Matrix for Protecting Water Resources from Noxious Organic Wastes - Phase II
Project Number:	2001PR2481B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	104B
Congressional District:	N/A
Research Category:	Water Quality
Focus Category:	Groundwater, Hydrology, Solute Transport
Descriptors:	Water Resources, Contaminant Transport, Infiltration, Landfill Materials, Waste Disposal, Sludge, Wastewater Treatment, Depth Filter
Principal Investigators:	Moses N. Bogere, Narinder K. Mehta

Publication

SYNOPSIS

Project Number: Start: 03/01/2001
End: 02/28/2002

Title: Development of Novel Dual-Function Media Matrix for Protecting Water Resources from Noxious Organic Wastes – Phase II

Investigators: Moses N. Bogere and Narinder K. Mehta
Department of Chemical Engineering, UPRM

Focus Categories: WW, WQL, TRT, GW, ST

Congressional District: N/A

Descriptors:

Problem and Research Objectives:

The dual-functionality property of combinations of soil, sand, gravel and natural adsorbent is the major mechanism through which natural media and mother-nature protects environmental resources, including groundwater and arable land, from wastes injected in soils, landfills, caves and depleted wells/aquifers. By this mechanism wastes are immobilized within natural media by adsorption, absorption and encapsulation, and under favorable conditions the immobilized wastes biodegrade in a finite time. However, immobilization and biodegradation in natural media are not optimized to sustain continual injection of wastes without leading to pollution. This is mainly because the important media properties are bound to fail under certain environmental conditions: leakage of the media upon contact with heavy rainfall infiltration, flooding, and rising of the water table. Furthermore, in-situ biodegradation fails also to take place within a finite time if there are insufficient microbes and nutrients to sustain contaminant species reaction pathways. Another problem encountered in the treatment of large volumes of oily wastewater is that it is difficult to separate large amounts of oils & grease from wastewater. This investigation tackled the problem of developing novel cost-effective dual-function (filter) media for separation, immobilization and treatment of wastewaters containing high concentrations of oils & grease and odorous organic particulates.

The overall objective of this work was to develop and to determine the effectiveness of novel dual-function media matrix for the immobilization of odorous wastewater mixtures containing large quantities of oils and grease. The media and immobilized wastes were used to study and to optimize in-situ biodegradation. The wastewater used in this study contains high concentrations of oils and grease, varying between *500* to *10000 mg/L* range, and significant amounts of suspended solids. These wastewaters pose unique challenges since they contain high concentrations of oils, grease and odorous biodegradable solids. The objective of this work was to develop and to determine the effectiveness of novel dual-function media matrix for the immobilization of odorous waste mixtures containing oils and grease. The media and immobilized wastes were used to study and optimize in-situ biodegradation. The investigation used as a model wastewater generated from the tuna industries at Mayaguez. Over a four-month period the average daily concentration of oils and grease was 2000 *mg/L* and 2800 *mg/L* of total suspended solids (TSS). The specific research objectives included: (i) conducting filtration and washing tests with the developed (dual-function) media matrix to immobilize oils & grease and suspended solids; (ii) in-situ biodegradation tests in secondary wastewater treatment; (iii) characterization and optimization of dual-functionality properties through packed bed experiments. The central focus was to develop effective and economical novel dual-function media to immobilize wastes and increase in-situ biodegradation rates through inoculation with oil eating microbes.

Methodology:

The investigation was divided into three major parts: separation of oils & grease and suspended solids from wastewater using dual-function filters; characterization of materials to find the right combination of matrix for immobilization and inoculation; and in-situ biodegradation in secondary treatment. The methodology and procedures are discussed below.

Separation step using dual-function filters: A high-efficiency depth filter was modified to function as a dual-function filter media by inserting immobilizing media matrix into the filter chamber.

The mixtures handled consist of combinations of wastewater, oily phase and odorous organic particulates. The first objective and primary treatment step was to separate the dispersed oily phase and particulates from the multicomponent wastewater mixture. Several materials (walnut, bagassee, corn, sand, and adsorbents) and their combinations were tried (in packed beds first) with the purpose to develop enhanced dual-function media matrix. Enhanced media consists of transport layers (membrane-like septum for high-pressure filtration) and a mass transfer zone (dual-function media matrix). The filtration characteristics and mass transfer rates of the enhanced media combination were then studied by generating a plugging curve for each media.

The study focused on understanding the complex fluid-solid interactions within the transport layers zone and in the media matrix (mass transfer) zone, and performance characteristics under different operating constraints. The penetration depth of oily phase and its effects on septum clogging characteristics, two-phase flow, and particulates and oily phase retention rates, immobilization of wastes and the effect of particle size in the depth (mass transfer) zone were established.

Generally, this part of the study included the following itemized tasks:

1. Sample preparation. Laboratory samples of multiphase mixture samples composed of organic solid, oils & grease, water, clay, polymer and sand were prepared from samples taken from the industrial facility. The candidate samples from industry were stored in sealed drums or containers. Analysis was done on every sample to amount of oils & grease before and after the filtration step The samples were added to the feed tank only when they were needed (*the samples need special handling and disposal*). At a later stage in the investigation the equipment was installed at the plant site.

2. Dual-function filter media preparation and loading. This involved
    - Particle size analysis of media material (a combination of clay, soil, sand, gravel, anthracite, a mixture of polymeric adsorbent and combinations of biosorbents: bagasse and walnut).
    - Immobilization studies dealt with selection of adsorbent and biosorbents based on oils/tar removal efficiency. The removal efficiency of each media was determined. Separate tests in batch mode were conducted to determine the most suitable combination adsorbent for a given oils and grease content in wastewater. These tests were quite cumbersome because raw wastewater samples tested contained 800 to 4000 *mg/L* oils & grease. Saturation tests were conducted on several media combinations in batch mode.
3. Separation experiments on test rig. These tests were carried out first on the high-efficiency dual function bag filter. The oils & grease and solids recovery efficiency was determined for various dual-function filter media.

The separator is a high efficiency (batch mode) filter shell into which the filter bags or cartridge filters are inserted. The filter bag type, see Fig. 1, is constructed of polyethylene materials with different micron size selection. The bags include additional transport layers attached to the bag. The media to trap the oils and odorous substances was inserted into the bag. The particulate solids and immobilized oils retained in the bags were used in further studies on washing, immobilization and biofiltration.

Immobilization, washing, biodegradation and biofiltration tests: The retained solids, sludge and dual-function media in the filter bags were conditioned for further tests. Additional materials were added to simulate injection site conditions but these studies are part of an on-going study. It is planned that the resulting material (solid matrix plus waste) will be added to the depth bed and washing tests will be conducted. The objective of these tests should be to determine the ability of the solid matrix to retain and immobilize oily wastes in light of extenuating conditions. The solid matrix will be optimized through further tests to maximize waste retention in a finite time.

The second objective of this investigation was to treat the remaining oils & grease from primary treatment by inoculating the wastewater with oil-eating microbes, the Biotech 2000 Formula IV. The microbes were established to be effective at biodegrading the oils & grease. The microbes were added to wastewater samples with approximately 25% of the original oils & grease and their effectiveness was established. In this part of study, analytical scheme based on UV absorption was developed to determine dynamically the degradation of oils & grease.

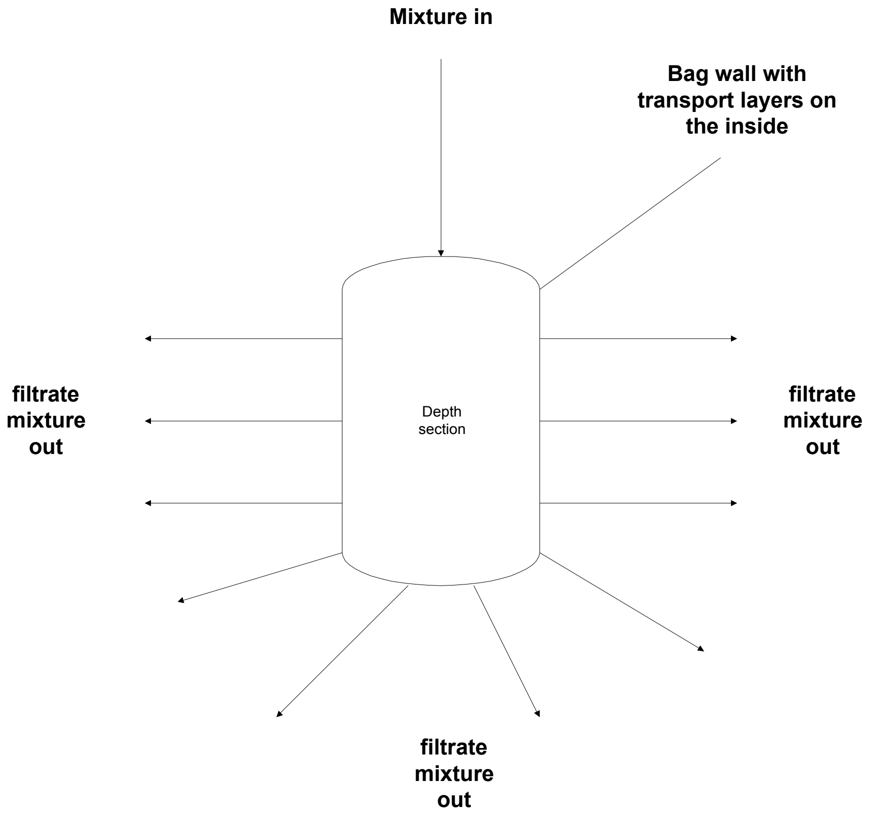


Figure 1 Filter bag

Further tests will be conducted in the future to determine the characteristics of injection site material (with the waste): its waste retention rates during washing and biodegradation rates (also during washing).

Principal Findings and Significance:

Over the previous 12 months the PIs have conducted studies related to Phase I & II of the investigation. The data generated has established that high efficiency depth filters are capable of separating oils/grease, odorous biodegradable solids and other solids from tuna wastewaters. The performance data obtained for various media indicate a significant improvement when 1 to 2 liters of matrix is added to bag filters (the results will appear in a paper to be published soon). And in order to evaluate the performance of the media, percentage removal of each filtration test was used as a basis for evaluating data. On average batch saturation tests and test rig experiments have established that the materials remove about 60 to 90% of oils & grease from raw wastewater, walnut producing the best results (the results will become available from the publication). The results for a combination of them will be published later. It has been established that any conventional separation method usually fails in these circumstances (due to rapid fouling of the media). The results show that dual-functionality of the media once optimized is capable of immobilizing and biodegrading oily wastes/sludge. The key to fast and in-situ biodegradation is to embed a priori oil eating microbes and nutrients into the matrix. Generally this procedure should reduce the amount of sludge that is generated at the wastewater treatment site. The major candidates for dual-function media are walnut shells (bead-sized particles), bagasse and high-efficiency filter media (from Ronningen-Petter, a filter company). Additional tests are being conducted to determine the right media combination.

Publications

List all publications completed during the year as a result of work funded under Section 104 during the current budget period. Also list publications resulting from Section 104 work completed during previous budget periods if they were not included in a previous report.

1. Articles in refereed Scientific Journals

Author (last name, first name)	Bogere, Moses N.
Other authors (first name, last name)	Narinder K. Mehta and Daneira M. Colon
Year	2002 (submitted July 2002)
Title	Towards Effective Dual-Function Media for the Separation and Treatment of Wastewaters containing Oil & Grease
Name of Journal	Separation Science and Technology Journal
Volume (number)	
Page numbers	
Supporting Section 104 Project No.	(to be filled by the Institute office)

Author (last name, first name)	Bogere, Moses N.
Other authors (first name, last name)	Narinder K. Mehta and Daneira M. Colon
Year	2002 (under final preparation for submission)
Title	Plugging Curve Characteristics of Fibrous Media used as Dual-Function Media for removing Oil & Grease and Suspended Solids from Wastewater
Name of Journal	Chemical Eng. Commun.
Volume (number)	
Page numbers	
Supporting Section 104 Project No.	(to be filled by the Institute office)

2. Book Chapters

Author (last name, first name)	
Other authors (first name, last name)	
Year	

Title of Chapter	
Name of Editor(s)	
Title of Book	
Publisher	
City	
State	
Page numbers	
Supporting Section 104 Project No.	(to be filled by the Institute office)

3. Dissertations

Author (last name, first name)	Colon, Daneira
Year	2002 (to defend in August)
Title	Dev of Novel Dual-Function Media for Treatment and Separation of Oil & Grease from Tuna Wastewater
MS or Ph.D. dissertation?	MS
Departament	Civil Engineering
College	Engineering
University	University of Puerto Rico Mayaguez
City	Mayaguez
State	PR
Number of pages	
Supporting Section 104 Project No.	(to be filled by the Institute office)

4. Water Resources and Environmental Research Institute Reports

Author (last name, first name)	
Other authors (first name, last name)	
Year	
Title	
Name of WRERI	Puerto Rico Water Resources and Environmental Research Institute
University	University of Puerto Rico at Mayagüez
City	Mayagüez
State	Puerto Rico
Number of pages	
Supporting Section 104 Project No.	(to be filled by the Institute office)

4. Conference Proceedings

Author (last name, first name)	Colon, Daneira
Other authors (first name, last name)	Narinder K. Mehta and Moses N. Bogere
Year	2001 (February)
Title of Presentation	Effective novel dual-function media for separation and treatment of wastewaters

	containing oils & grease
Name of Editor(s)	Dr. Walter F. Silva-Araya
Title of Proceedings	Sixth Caribbean Islands Water Resources Congress
Publisher	PRWRERI
City	Mayaguez
State	PR
Page numbers	
Supporting Section 104 Project No.	(to be filled by the Institute office)

Bogere, M. N., Mehta, N. K. and Colon, D. M., Effect of Surfactants on Biodegradation Efficiency in the Secondary Treatment of Oily wastewaters, to be submitted to Colloids and Surfaces. A. PhysicoChemical & Engineering Aspects (2002).

5. Other Publications

Author (last name, first name)	
Other authors (first name, last name)	
Year	
Title	
Other information needed to locate publication	
Page numbers (if in publication)	
Number of pages (if monograph)	
Supporting Section 104 Project No.	(to be filled by the Institute office)

TRAINING ACCOMPLISMENTS

List all students participating in Section 104 projects.

Field of study	Academic Level				Total
	Undergraduate	MS	Ph.D.	Post Ph.D.	
Chemistry					
Engineering:					
Agricultural					
Civil	1	1			2
Chemical	1				1
Computer					
Electrical					
Industrial					
Mechanical					
Geology					
Hydrology					
Agronomy					
Biology					
Ecology					
Fisheries, Wildlife, and Forestry					
Computer Science					
Economics					
Geography					
Law					
Resources Planning					
Social Sciences					
Business Administration					
Other (specify)					
Totals	2	1			3*

* additional students (15) have used the experimental setup for undergraduate studies

Basic Information

Title:	
Project Number:	
Start Date:	1/1/2001
End Date:	1/1/2001
Funding Source:	104B
Congressional District:	
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	
Principal Investigators:	

Publication

Well and Interstitial Water Corp Protection Chemicals Study on the Salinas Fan

Basic Information

Title:	Well and Interstitial Water Corp Protection Chemicals Study on the Salinas Fan
Project Number:	2001PR12B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	
Research Category:	Water Quality
Focus Category:	Water Quality, Solute Transport, Toxic Substances
Descriptors:	
Principal Investigators:	Jose Dumas

Publication

Well and Interstitial Water Corp Protection Chemicals Study on the Salinas Fan

Basic Information

Title:	Well and Interstitial Water Corp Protection Chemicals Study on the Salinas Fan
Project Number:	
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	
Research Category:	Water Quality
Focus Category:	Water Quality, Solute Transport, Toxic Substances
Descriptors:	
Principal Investigators:	Jose Dumas

Publication

SYNOPSIS

Start: 04/01/2002
End: 08/01/2002

Title: Well and Interstitial Water Crop Protection Chemicals Study on the Salina Fan Delta Aquifer

Investigators : José A. Dumas-Rodriguez and Rafael Montalvo-Zapata, Crop Protection Department, Agricultural Sciences College, University of Puerto Rico Mayaguez Campus.

Focus Categories: TS, WQL, WL

Congressional District: (N/A)

Statement of the critical water problems:

This project examines the groundwater and interstitial water quality, toxic substances and nonpoint contamination in the Jobos Basin Estuarine Reserve. The Jobos Bay is located between the Salinas and Guayama municipalities in the south coast of Puerto Rico and comprises more than 2,500 acres, including a forest and a mangrove. The Jobos Estuaries Ecosystem has been severely stressed since the late 80's by land and water channels alterations which have changed the water flow patterns of the zone. One of the key issues that needs to be addressed in Puerto Rico and worldwide is the pesticides and phthalate esters movement in soil and groundwater and their effects over sensitive environmental zones, including flora, fish and wildlife.

Non-managed application of pesticides and other compounds that reach non target sites may result in leaving residues where crops will later be planted or where they may reach surface and ground water resources. No intensive research in Puerto Rico related to organic pollution in the Jobos mangrove zone has been carried out. The proposed field and laboratory research will be the first one that will help provide a more comprehensive view of water quality in the zone and will be complementary to another research project related to nitrate levels currently underway in the zone.

Statement of the results or benefits:

The expected benefits of the research proposed will be the development and advancement of new scientific information related to pesticide and organic toxic residues in the groundwater and interstitial water in the Salinas and Guayama municipalities. Agriculture is expected to continue in the zone, and water sampling for the presence of crop protection chemicals is necessary to ensure human health and the protection and conservation of the environment. The project will also provide data risk/benefit for decisions concerning chemical usage. Data for the year 2002-2003 will be analyzed, interpreted and results, findings and conclusions will be submitted for either technical papers on referred journals, oral presentations and posters during the following year. There will be one or two publications associated with the completion of the research.

Methodology:

Sample collection, preservation and handling

All pollutants analysis will be conducted at the Agricultural Experimet Station Pesticide Laboratory. Water samples will be collected at a minimum of 15 wells from agricultural growing areas of the Jobos basin zone, and at a minimum of 15 piezometers and/or springs on the Jobos Reserve. Efforts will be made to have wells and piezometer in the north, west and east zones of Jobos basin zones; near to the Nigua River, parallel to the abandoned stream channel, and in the Esmeralda fault, north to the bedrock hill at Aguirre Sugarmill. A preliminary sampling (screening) will be performed in the selected zone by using immunochemical methods for carbamates, s-triazines, organophosphorus and other pesticide residue analysis, and to delineate properly the water quality and variations within the affected area. A minimum of six wells and six piezometers or springs in the zone will be selected and used to achieve reliable results and findings. The selected sampling wells, piezometers and/or springs will be sited by GPS. Water samples will be taken monthly for one year. Triplicate samples will be collected in one-liter dark brown glass bottle with Teflon lined cap (pre-washed with detergent and hot tap water, rinsed with distilled and de-ionized water, and dried in an oven at 400 °C for 1 h). All water samples will be placed in an ice chest at around 4 °C and transferred to the Central Analytical and Pesticide Laboratories at Rio Piedras, within the same collecting day. Sodium thiosulphate and copper metal (80 mg/L) will be added to remove a residual chorine and sulfur, respectively. The samples will stored at 0 to 4 °C in a refrigerator from the time of collection until extraction that will be within seven days after collection. All water samples will be filtered through a Whatman GB/F filter, followed by a Nylon membrane filter before chemical analysis.

Pesticides and other type of organic compounds analysis:

For carbamate analysis, samples will be filtered through a 0.22um polyvinylidene difluoride filter, followed by direct injection into a High Performance Liquid Chromatograph (HPLC) with a C-18 column coupled to post column derivatization system and a fluorometric detector. The detection will be made by post-column derivatization and fluorescence detection (Foerst, 1987).

Other types of thermally stable compounds will be extracted following the US EPA method 8270 that include 259 semi-volatile organic compounds. A 1-L water sample, containing a surrogate, will be extracted in a continuous extractor, first under acid and then under basic conditions. Analysis will be performed by GC/MS using a DB-5 capillary column and an appropriate computer system.

Ammonium, nitrate, nitrite, pH, conductivity and phosphate

These chemical analysis will be conducted at the Central Analytical Laboratory . Ammonium, nitrate and nitrite will be analyzed using the EPA method 353.2. Phosphate will be analyzed by the EPA method 365.1. The water sample will be preserved at 4 °C with diluted sulfuric acid to pH <2 until the analysis.

Soil microbial biomass C and N

Soil core samples, in triplicate, from 0 to 10 and 10 to 20 cm will be collected from six plot areas selected by using the ground and surface water flow pattern map. These areas were selected due to the high hydraulic conductivity, and besides have the higher potential to be affected by dissolved solids that come from any human activities in the zone. The selected areas were in the north, west and east zones of Jobos basin zones; near to the Rio Nigua, parallel to the abandoned stream channel, and in the Esmeralda fault, north to the bedrock hill at Aguirre Sugar Mill. Soil samples will be placed in plastic bags, transferred to Rio Piedras, and then dried at 40 °C. The 100 g of soil will be re-wetted to 15% moisture to stimulate microbial activity, and then incubated at 25 °C for 5 days. Soil microbial biomass C will be determined by fumigation incubation by exposing 40 g soil samples rewetted and incubated for 5 d to alcohol free $CHCl_3$ vapor for 24 h. The vapors will be evacuated and removed and the soil will be incubated on a 1-L gas tight glass container for 10 days at 25 C. Carbon dioxide evolved will be trapped in 1N KOH and determined by titration with 1N HCL. The quantity of evolved CO2-C will be divided by an efficiency factor of 0.41 to calculate microbial biomass C (Anderson, 1982, Haney, 2000).

Soil microbial biomass N will be determined by analyzing NH4-N concentration of fumigated samples following 10-d incubation period minus initial NH4-N prior fumigation, divided by an efficiency factor of 0.41. The NH4-N will be extracted from 7g soil sample using 28 ml of 2M KCl. Samples will be shaken for 30 min on a reciprocal shaker and filtered, and the extracts will be analyzed for NH4-N using an autoanalizer.

Bulk density, clay organic carbon content determination

Soil bulk density, clay, sand, silt, plus inorganic and organic carbon content will be determined using standard methods reported elsewhere (Blake, 1965). Data collected will be statistically analyzed by using variance method. The plot will be all area in which the soil samples for microbial analysis will be collected. The treatment will be wells and piezometers, and the factors will be the soil type and their physical and chemical characteristics mentioned above.

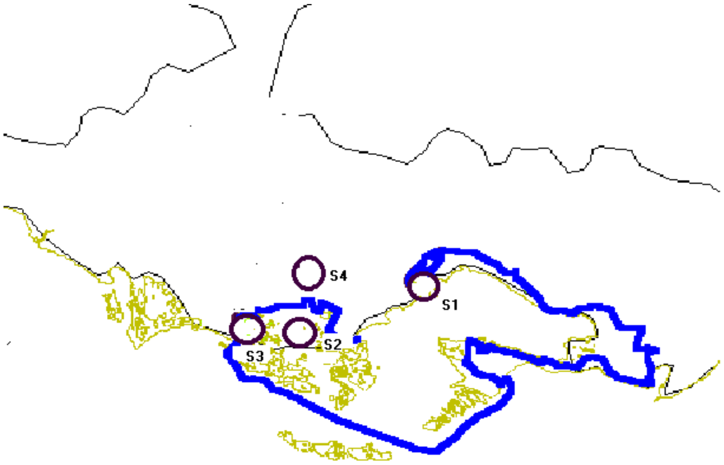
Adsorption studies

Adsorption will be expressed as k-Langmuir values, and the more knowledge k-Freundlich values. A stock solution of 40 ppm in distilled and de-ionized water will be prepared for each selected compound by using each of the soil types collected in the selected plot area mentioned above. Concentrations of 0.5, 1,5,10,20,40 ppm will be prepared by dilution with distilled and de-ionized water. Batch equilibrium sorption isotherms will be obtained for each individual pesticide (Liu, 1997). The laboratory tests will be conducted treating 1g of air dried soil with 10 ml of the selected compound solution in a sealed test tube. The suspensions will be protected from light using aluminum paper, kept at 22 °C, and placed on a shaker for 24 h. Then, they will be centrifuged for 10 min at 2500 rpm and a 5 ml aliquot of the clear supernatant solution will be extracted with three successive 15 ml portions of methylene chloride. The samples will be concentrated, with a smooth flow of high purity nitrogen gas, diluted with hexane to 5 ml, and analyzed using GC-FTD or GC-MS. The adsorption curves for pesticides and k- values will be determined using the Langmuir model.

Data generated will be compared with the bulk density, clay and organic carbon content of the surrounding soils closed to the sampled wells. The significance of the data will be statistically analyzed to find a relationship between these properties

Principal Findings and Significance:

A study has been conducted in the Salinas municipality to determine crop protection chemicals in ground and interstitial waters. Four sampling zones were selected for interstitial water monitoring. The central and west zones (S2, S3 and S4) are under intensely cultivated with bananas, plantains, papaya, sorghum, sunflowers, soybeans and other agricultural commodities upstream. The south central zone (S2) is severally affected by mangrove death, and the southern area is on a salt flat zone (S3) (Figure 1).



EXPLANATION

○ - S1,S2,S3,and S4 -Sampling sectors where piezometers were sunk

▬ - JOBANERR and Aguirre Forest limits

Figure 1. Jobos Bay water-collection sites in the study area and JBNERR and Aguirre Forest boundaries in Salinas Puerto Rico

A total of fourteen wells was selected and twenty two piezometers were sunk. Water samples were collected to determine pH, conductivity, NO3, NO2, NH4, TOC, TC, IC, Zn, Fe, Pb, Cu, and toxic organic compounds and pesticides. The water samples showed a high content of organic compounds, many of them long chain hydrocarbons and alcohols as detected by GC-MS. Some interstitial water samples in the central zone of JBNERR resulted in positive detection of the organochloride insecticides lindane (BHC) and pentachlorophenol (PCP). These insecticides were extensively used in the sugarcane plantations and wood treatment about 40 years ago. Additionally PCP is also a major product of the metabolism of hexachlorobenzene in mammals. Other harmful compounds were detected in some interstitial water samples, such as N-methyformamide, 1,2-benzene dicarboxilic acid, diethyl ester, benzene alcohol, and others. On piezometers located in the S4 sampling area, atrazine was detected at levels below 0.5 g/L. The occurrence of a pesticide in a piezometer depends on the chemical and physical properties of the pesticide, the pesticide use and the characteristics of the water drainage through soil. Until now pesticide traces were found in three of the four monitoring zones selected for this study (S2-Aguirre South, S3-Las Mareas and S4-Aguirre North). All these zones have lower mangrove growing than Aguirre Forest, and this fact probably have a strong impact on pesticide presence in the interstitial.

During the April to August 2002 period, nitrate was detected at levels between 0.11 and 5.00 g/mL only in one piezometer in the Aguirre north zone (S4), which is close to the sorghum growing area. Phosphorus was detected only on the Aguirre Forest sampling zone (S1) at levels between 0.5 and 30 g/mL which pinpoint toward a hot point source of contamination near to this piezometer. Lead, cooper and zinc were detected in some interstitial waters. Lead levels were between 0.11 and 1.54, cooper levels were between 0.03 and 0.11, and zinc levels were between 0.05 and 0.37 g/mL. The pH profile of the piezometers sampling areas showed higher values in interstitial water of the S4 area ranging between 8.0 and 8.4, while the remaining sampling zones had values ranging between 7.3 and 8.0.

Regarding to groundwater analysis the major contaminant found in the monitoring wells in agricultural land was nitrate, but its level has been variable throughout the months, probably due to the variability in rainfall, and fertilizer application. However, detectable phosphorus level were not found in the sampled wells in agricultural lands, suggesting that its presence in piezometers from Aguirre Forest come from others sources. In general lead, cooper and zinc were not detected in the sampled wells. Atrazine, a s-triazine herbicide was detected (below 0.1 g/L) in some monitoring wells.

Laboratory testing are currently done to measure C and N microbial biomass on the four sampling zones to determine differences and their relationship to water quality findings of this research. The main significance of this research is measuring the presence of some important water contaminants in groundwater and their spread through the JBANEER via interstitial water movement. The results, until now, suggest spreading of some contaminants from agricultural lands via interstitial water. Additionally, some contaminants no related to agricultural activities were found in some interstitial water sampling sites.

Publications:

Well and Interstitial Water Crop Protection Chemicals Study on the Salina Fan Delta Aquifer. (Abstract) to be submitted to the SOPCA Annual Technical Meeting on November 15, 2002.

TRAINING ACCOMPLISHMENTS
ACADEMIC LEVEL

FIELD OF STUDY	Undergraduate	Master's Degree	Ph.D. Degree	Post Ph.D.	Total
Chemistry					
Engineering: Agricultural		1			1
Civil					
Environmental					
Chemical	1				1
System (industrial)					
Other*					
Geology					
Hydrology					
Agronomy					
Biology					
Ecology					
Social Sciences					
Computer Science					
Geography					
Law					
Resources Planning					
Other (specify)					

__________2_________ **TOTAL**

* Less than 5 students in any one field of study.

Microbial Source Tracking to Determine the host origin of fecal contamination in two Puerto Rican watersheds

Basic Information

Title:	Microbial Source Tracking to Determine the host origin of fecal contamination in two Puerto Rican watersheds
Project Number:	
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	
Research Category:	Water Quality
Focus Category:	Water Quantity, Waste Water, Non Point Pollution
Descriptors:	
Principal Investigators:	Eduardo Schroder

Publication

SYNOPSIS

Project Number: Start: 03/01/2002
End: 08/31/2003

Title: Microbial Source Tracking to Determine the Host Origin of Fecal Contamination in two Puerto Rican Watersheds

Investigators: Eduardo C Schröder
Department of Agronomy and Soils, UPRM and
Peter G. Hartel
Department of Crop and Soil Sciences
University of Georgia

Focus Categories: NPP, WQL, AG

Congressional District: N/A

Descriptors:

Problem and Research Objectives:

Coliform bacteria, "fecal coliforms" have been used traditionally as indicators of microbiological safety of water. Since they normally inhabit the intestinal track of warm-blooded animals, their presence in soil or water is a good indicator of contamination with pathogens. Therefore, assessing microbial contamination in the water constitutes a fundamental public health issue. Fecal coliform counts are typically used to monitor the microbiological quality of water in Puerto Rico.

One of the most vexing problems in isolating fecal coliforms from water samples is not knowing the host origin of these bacteria. In the past, the only way to identify the host origin of a bacterium was to observe the phenotypic markets (such as colony characteristics and antibiotic resistance). The main problems with using phenotypic markers are their lack of reproducibility and lack of discriminatory power (ability to distinguish two closely related strains). However, it is now possible to identify the host origin of a bacterium based on its DNA. This alternative method, called genotyping, not only has increased reproducibility, but also has increased discriminatory power. The most common of these genotypic methods include chromosomal DNA restriction analysis, plasmid typing, pulsed field gel electrophoresis, various polymerase chain reaction (PCR) method, and ribotyping. As a method for distinguishing a subspecies of a bacterium, ribotyping is considered to have excellent reproducibility, good discriminatory power, excellent ease of interpretation, and good ease of performance.

We will isolate and ribotypes *Escherichia coli* for several reasons, but particularly because is a good indicator of pathogenic bacteria. However, further tests to consider alternative indicator bacteria will be performed. The specific objectives will be to isolate a large number of isolates to ribotypes and track their origin. Initially methods will be tested and samples obtained from the Yaguez River, and in the future, Añasco River will be sampled.

Methodology:

The investigation is divided into three major parts:

A) Sampling of rivers in either base flow or storm flow
B) Using IDEXX Colilert for general survey and to obtain *E. coli* isolates
C) Conduct a targeted survey to determine if sources are persistent or transient, and if persistent, whether point or non point sources can be determined.

Principal Findings and Significance:

We developed a new targeted sampling protocol for microbial source tracking (Fig. 1). This new sampling protocol offers two advantages for microbial source tracking. First, all sampling is completed in one location (the Yaguez River) in one day. This reduces problems with geographic and temporal variability of *E. coli* isolates. Second, it identifies persistent sources of fecal contamination. Not surprisingly many nonpoint sources are subsequently identified as point sources. There is no need to do microbial source tracking on point sources. Therefore, the amount of microbial source tracking needed is minimized (as are the associated costs). This changes the focus of the first year's work from developing an *E. coli* database for Puerto Rico to direct sampling of the Yaguez River, which was designated for the second year of the grant.

At this time, the Yaguez River has been sampled for the general survey during base flow conditions. Counts of *Escherichia coli* ranged from 1.4 x 10^2 to 1.2 x 10^5 CFU per 100 mL. Assuming that this is not a problem of *E. coli* regrowth under subtropical conditions, the data suggest that the Yaguez River is grossly contaminated with fecal material. Two hotspots were identified, one near the mouth of the river, and the other near a textile plant. (The textile plant is not suspected as a source and simply is a location point.) Counts of *E. coli* at both locations exceeded 10^5 CFU per 100 mL.

Because of these high counts, obtaining "local knowledge" about the sources is unnecessary, and, assuming these locations represent persistent sources, and they will be sampled in the next weeks. At least 50 *E. coli* isolates will be obtained from each of the two potential sources and the river itself. Ribotyping with the Qualicon RiboPrinter is expected to commence shortly thereafter.

First data are already analyzed and will be presented at the American Society for Microbiology meeting in May 2003. Additionally two research papers will be submitted for publication to peer review journals.

TRAINING ACCOMPLISMENTS

List all students participating in Section 104 projects.

Field of study	Academic Level				Total
	Undergraduate	MS	Ph.D.	Post Ph.D.	
Chemistry					
Engineering:					
Agricultural					
Civil					
Chemical					
Computer					
Electrical					
Industrial					
Mechanical					
Geology					
Hydrology					
Agronomy	4	1			5
Biology		4			4
Ecology					
Fisheries, Wildlife, and Forestry					
Computer Science					
Economics					
Geography					
Law					
Resources Planning					
Social Sciences					
Business Administration					
Other (specify)					
Totals		5			9

SYNOPSIS-WRRI-Extension Request Report March 2003

Dynamic Simulation of Water Distribution Systems With Instantaneous Demands

Basic Information

Title:	Dynamic Simulation of Water Distribution Systems With Instantaneous Demands
Project Number:	
Start Date:	3/1/1999
End Date:	2/29/2000
Funding Source:	104B
Congressional District:	
Research Category:	Water Quality
Focus Category:	Water Quantity, Water Supply, Models
Descriptors:	
Principal Investigators:	Walter F Silva

Publication

1. Silva-Araya, W., Artiles-Leon, N., and Romero, M., 2002, A Model for Prediction of Instantenaous Water Demand,in Proceedings of HYDROSOFT 2002, Wessex Institute, Montreal, Canada,6 pages.
2. Silva-Araya W. and Artiles-Leon, N., 2002, "DYNAMIC SIMULATION OF WATER DISTRIBUTION SYSTEM WITH INSTANTANEOUS DEMANDS",Puerto Rico Water Resources and Environmental Research Institute, University of Puerto Rico, Mayaguez, Puerto Rico, 84 pages.

DYNAMIC SIMULATION OF WATER DISTRIBUTION SYSTEM WITH INSTANTANEOUS DEMANDS

FINAL REPORT

Submitted to: Puerto Rico Water Resources and
Environmental Research Institute

Prepared by:

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ABSTRACT

A new methodology to model residential water consumption using a micro-scale simulation algorithm was developed. The algorithm combines an unsteady flow model with an instantaneous demand model. The instantaneous demand model was constructed from probability distributions for the simulation time of aperture and the duration of valve openings inside a house. Several households were represented on an experimental setup to verify the ability of the model to respond to the dynamic nature of the instantaneous water use. An excellent prediction of the time-dependent discharge along the distribution pipe was obtained.

Four houses in an economically homogeneous neighborhood were chosen to measure water consumption data. These data were used to develop regression models used in a dynamic hydraulic model to predict the behavior of water consumption along a pipeline.

CHAPTER I

INTRODUCTION

1. Introduction

The steady state flow assumption has been used extensively in the analysis and design of water distribution systems. However, recent studies indicate that the flow in these systems should be analyzed for unsteady flow conditions (Karney & McInnis, 1990).

This study proposes a mathematical model to predict the volume of water consumed in a neighborhood. The model combines an algorithm of statistical simulation to predict the domiciliary demand and an algorithm of hydraulic simulation for dynamic conditions of flow. The algorithm of statistical simulation uses measurements of flow in typical households to develop an instantaneous demand model.

1.1 Project Justification

By the middle of the 23rd century it is expected that 90% of the population live in cities. Presently near two thirds of the fresh water is used for the agriculture, but the proportion of necessary water to supply the cities continues increasing (Sharmir and Howard, 2000). Urban planning, in regions where the population increases day by day with limited water resources, requires precise estimates of the amount of water. The quantity of drinkable water is limited and the demand is intense.

Puerto Rico suffers a crisis in the handling and distribution of drinkable water. Shortage often alters the daily activities of the population. The demand of water increases day by day due to the industrial, commercial and urban development. For this reason, it is urgent to find methods to improve the simulation of water consumption and water system behavior. These new models will be a tool for efficient rehabilitation and improvements of water distribution systems.

The result of this project was a new methodology to simulate the operation of water distribution systems, which includes a regression model in combination with a dynamic flow model, to estimate the volume of water consumption in residential areas.

1.2. Objectives

This project developed a methodology to model the instantaneous behavior of water distribution systems. The methodology consists of two parts: a regression model that simulates the demand of water in homogeneous residential areas and an algorithm that simulates the dynamic behavior of discharges and pressures in the pipeline

1.3. Methodology

This project was carried out in four parts that are described next.

1.3.1. Surveys on Households Occupation

Questionnaires were distributed in an economically homogeneous neighborhood, with the purpose of obtaining information of the occupation of people in the residences at different hours of the day and the different days of the week. This information was used to determine the average number of people that were in the residences every day and at every hour of the seven days of the week.

1.3.2. Experiments in a Laboratory Model

A physical model was built to simulate the behavior of a distribution water line with ten entrances equally spaced. The experimental equipment is described in section 4.1. Closing and opening sequences of valves were simulate to obtain the variability in the consumed volume of water. The outflow, the pressures at the beginning of the pipe and the consumed volume of water were monitored during the experiments. The laboratory experiments helped to prevent possible difficulties in the collection of field data, carried out later on. A program was developed to simulate the consumption of water in the laboratory experiments and the results were compared. The results are discussed in the section 4.9.

1.3.3. Collection of Field Data.

The flow and the pressure were measured continually at the pipeline entrance of several residences in a neighborhood. It was presumed that the patterns of consumption of water are similar in most of the residences. A pressure transducer and a flowmeter were installed in the residences. The data was stored in a datalogger and then transferred to a computer. This provided information of the consumption patterns including duration, frequency and intensity of the demanded water in the residences of the studied area. The obtained data was use to develop a probabilistic model that simulates the instantaneous consumption of water, frequency and duration of the openings. The results are discussed in Chapter 5.

1.3.4. Simulations with Field Data.

A scenario to simulate the behavior of a distribution line, using the data gathered in each house was conceptualized. This is discussed in detail in Section 5.6. The friction factor of the distribution main pipe, the internal diameter of the pipe, the speed of the pressure wave and the initial flow, were estimated theoretically to be able to run the simulations. This is explained with detail in the Section 5.2.

CHAPTER II

FUNDAMENTAL EQUATIONS

3.1. Hydraulic Model

The equations that describe the unsteady flow in pipe systems are conservation of mass and conservation of momentum.

3.1.1. Method of Characteristics

The partial differential equations that describe the unsteady flow in pipe systems are converted into ordinary differential equations by means of the Method of Characteristics. The final equations are known as the equations of compatibility given by (Chaudhry, 1987)

Positive compatibility equation

$$\frac{dQ}{dt} + \frac{gA}{a}\frac{dH}{dt} + \frac{f}{2DA}Q|Q| = 0 \tag{3.1}$$

Negative compatibility equation

$$\frac{dQ}{dt} - \frac{gA}{a}\frac{dH}{dt} + \frac{f}{2DA}Q|Q| = 0 \tag{3.2}$$

where Q is the volumetric flow, t it is the time, g is the gravitacional acceleration , A is the cross sectional area of the pipe, a is the speed of the wave of pressure, H it is the piezometric head, f is the Darcy-Weisbach friction factor and D it is the diameter of the pipe.

These equations are valid along the characteristic lines as shown in Figure 3.1 and their simultaneous solution provides the pressures and the flow at the nodes during unsteady flow conditions. Data for the boundary conditions are necessary to obtain the pressure and discharge at the ends of the pipeline and at those sites where a water demand occurs. The main pipe of the domiciliary connections was modeled as a local demand with constant flow. If water is not used, the demand flow is zero.

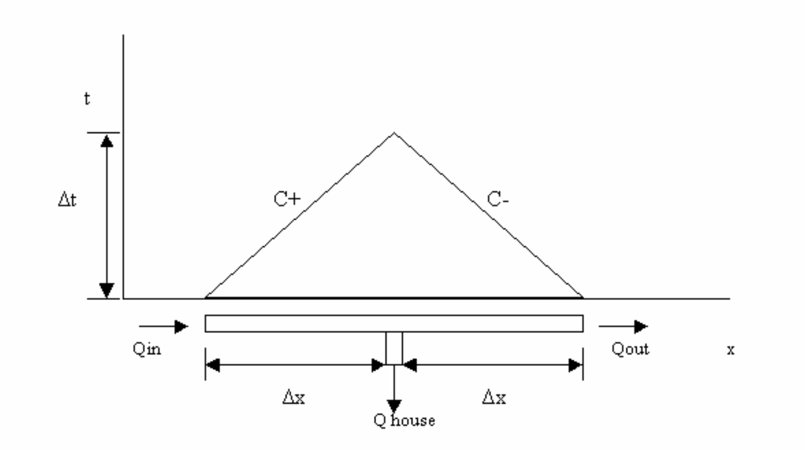


Figure 3.1. Caracteristic lines and demand flow

The equation of conservation of mass is

$$Q_{in} - Q_{out} - Q_{house} = 0 \tag{3.3}$$

where *Qin* is the flow upstream of the junction, *Qout* it is the flow downstream of the junction and *Qhouse* it is the domiciliary demand flow. If the pressure, p, the flows Q*in*, Q*out* and Q*house* are known at time t_0, then, the pressure p, the flows Q*out* and Q*in* could be obtained at time $t_o + \Delta t$ by the simultaneous solution of Equations 3.1, 3.2 and 3.3.

Following the notation given in Figure 3.2, the discretized equations are (Durán and Silva Araya, 1998) .

$$Q_{ib} - Q_{fa} + \frac{gA}{c}(H_b - H_a) + \frac{fQ_{fa}^{2}}{2DA}\Delta t = 0 \tag{3.4}$$

$$Q_{fb} - Q_{ic} - \frac{gA}{c}(H_b - H_c) + \frac{fQ_{ic}^{2}}{2DA}\Delta t = 0 \tag{3.5}$$

$$Q_{ib} = Q_{fb} + q \tag{3.6}$$

where Q_{ib} is the initial lateral flow of entrance before the nodal exit b, Q_{fa} is the exit lateral flow of the node *a*, H_b is the piezometric head of node *b*, H_a is the piezometric head of the node *a*, Q_{fa} is the lateral exit flow of the node *a*, Q_{fb} is the lateral flow of exit of the node *b*, Q_{ic} is the lateral entrance flow before the nodal exit *c* and, *q* is the demand flow of each household.

If the demand flow *q* is known, the unknown variables are the flow before the nodal exit Q_{ib}, the flow after the nodal exit Q_{fb}, and the piezometric head at node H_b at time $t+t_o$.

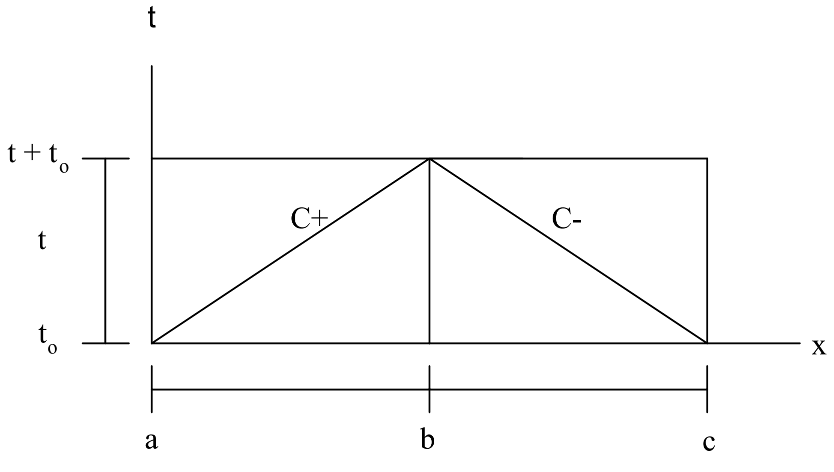


Figure 3.2. Condition for intermediate nodes in the pipe

3.2. Water Demand Model

A residential area is composed by many houses with similar consumption patterns, each one of those which has a number of faucets and other consumption devices The term faucet will be used to indicate any consumption of water. The water demand in a distribution system is modeled as a sequence of discrete events formed by the opening and the closing of faucets.

The consumption patterns in a residence are characterized by three variables namely intensity, duration and frequency. The intensity is the flow of water that enters a house, it was considered constant during the time of use, independently of how many faucets were opened in the house. The frequency refers to the interval of time between two consecutive openings and, the duration is the interval of time that a faucet remains open.

3.3.1. Probabilistic Distributions

The model developed considers that the water consumption is a random variable, therefore, the demand patter was generated by using probabilistic distributions and random data generation techniques. The exponential distribution is frequently used as a model for the distribution of times among the occurrence of successive events. The reason of this is that the exponential distribution is closely related to the process Poisson.

The frequency with which a faucet opens was modeled by the exponential distribution. The basic form of this distribution is shown in the Figure 3.5 (Banks,et. al, 1995).

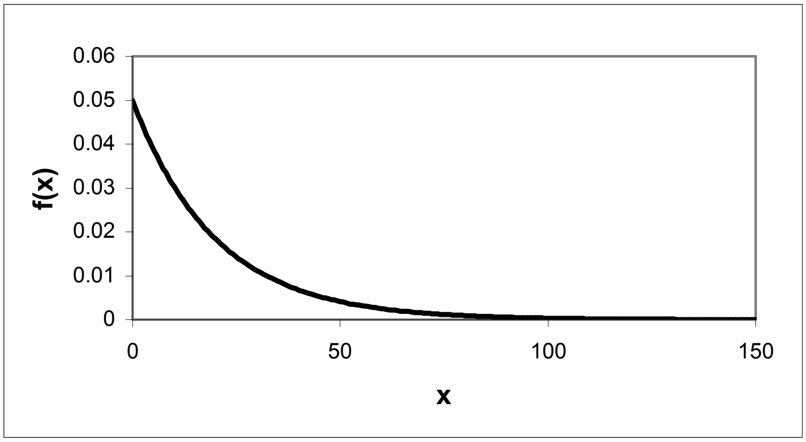


Figure 3.5. Basic form of the Exponential distribution

The model is given by:

$$T = -\frac{1}{\lambda} Ln(R) \tag{3.11}$$

where λ is the number of times that a faucet opens per unit time, T is the time between two consecutives openings of a faucet and R is a random number between 0 and 1. Buchberger and Wu (1995) reported for a normal day an average of 40openings of all the faucets of a house. λ could be computed as

$$\lambda = \frac{\#nu}{3600 * \#faucets} \tag{3.12}$$

where λ is the number of openings per second, *#nu* is number of valve openings per tour and *#fauces* is the number of faucets at a household. The values of λ used in this research are given in Table 3.1.

Tabla 3.1 λ values for different frequencies

# faucets	**Time between apertures (min)**	**#nu/faucet/hour**	**Λ Uses/faucet/hour**	**λ Uses/faucet/s**
1	3	20	20	0.005556
1	6	10	10	0.00278
1	12	5	5	0.00139

This model generates the times between openings of one faucet. The simulation of the opening of each faucet is independent of the other faucets.

The duration of the valve openings was simulated using the Weibull, the Exponential distribution and the Lognormal distribution. The basic form of the Exponential distribution was shown in the Figure 3.5. The basic forms of the Weibull and Lognormal distributions are shown in Figures 3.6 and3.7, respectively.

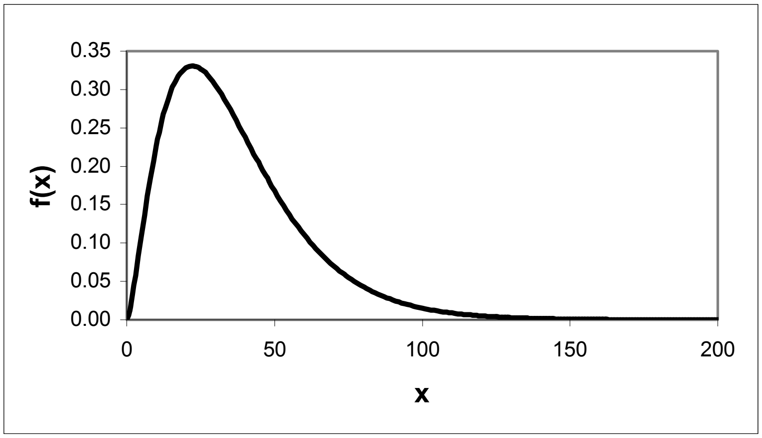


Figure 3.6 Basic form of the Weibull distribution

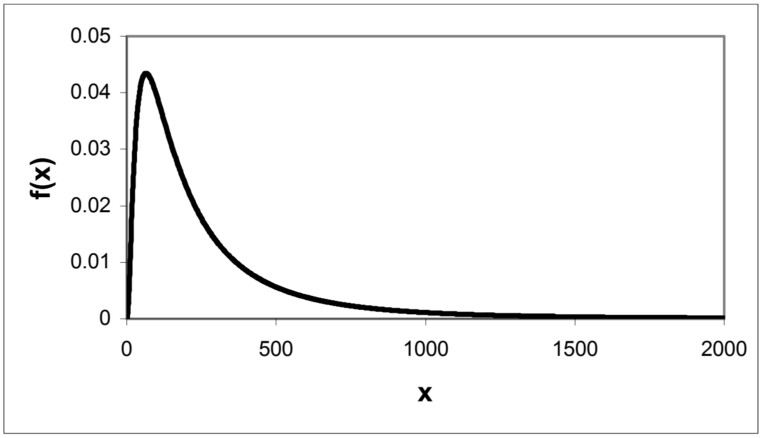


Figure 3.7 Basic form of the Lognormal distribution

The equations for the Weibull distribution are

$$Du = \alpha\left[-Ln\left(1-R\ \right)\ \right]^{1/\beta} \tag{3.13}$$

$$Du = \frac{-1}{\lambda}Ln(R) \tag{3.14}$$

$$Du = e^{z} \tag{3.15}$$

where

$$z = \mu + \sigma\sqrt{(-2Ln(R_1)}\cos(2\pi R_2))\,, \tag{3.16}$$

Du is the duration of the opening, α and β are the parameters of the Weibull distribution, λ is the duration of the opening per unit time, *R, R1*, and *R2* are random numbers between 0 and 1, μ and σ are the parameters of the Lognormal distribution. Opening durations of twenty, forty and one hundred eighty seconds were used in the simulations.

CHAPTER IV

EXPERIMENTAL WORK

4.1. Description of the experimental equipment

The system consists of a centrifugal pump that pumps water from a constant level tank. The pipe has 94.49 meters of longitude and 51 millimeters diameter. Ten household connections were represented by using 5.09 cm (2 in), PVC - SCH 40 pipe connections. The connections are separated 8.2 meters representing a house along the distribution line. Each connection has a flowmeter which was used to measure the demanded volumes of water.

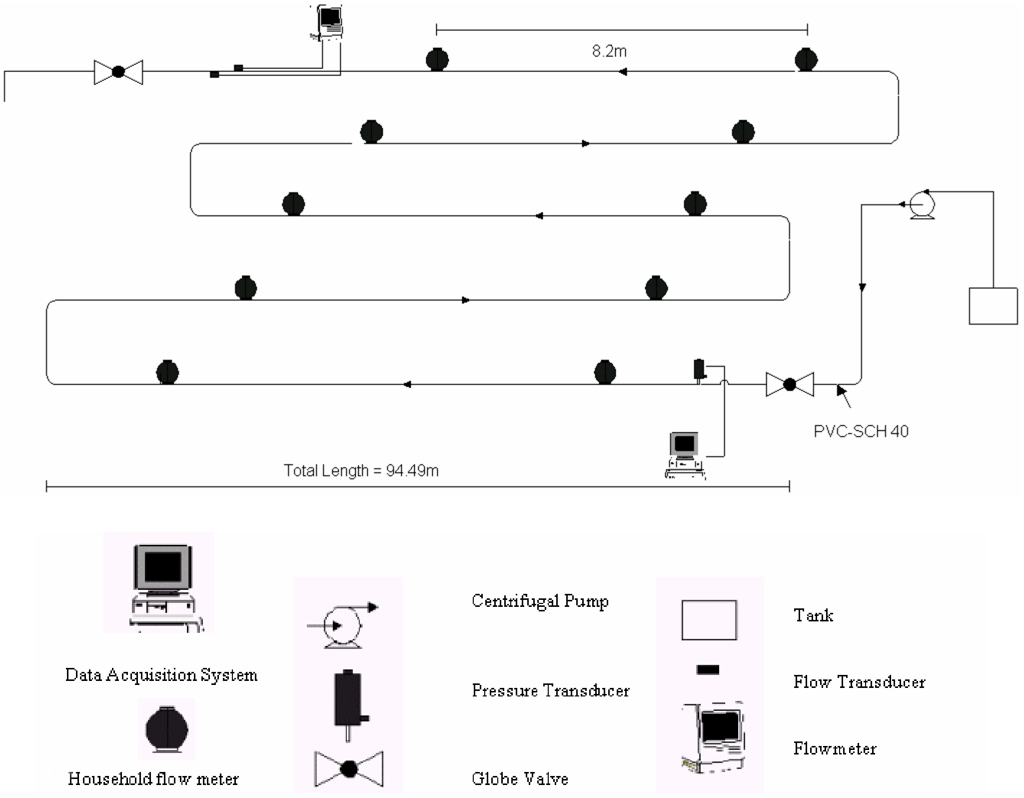


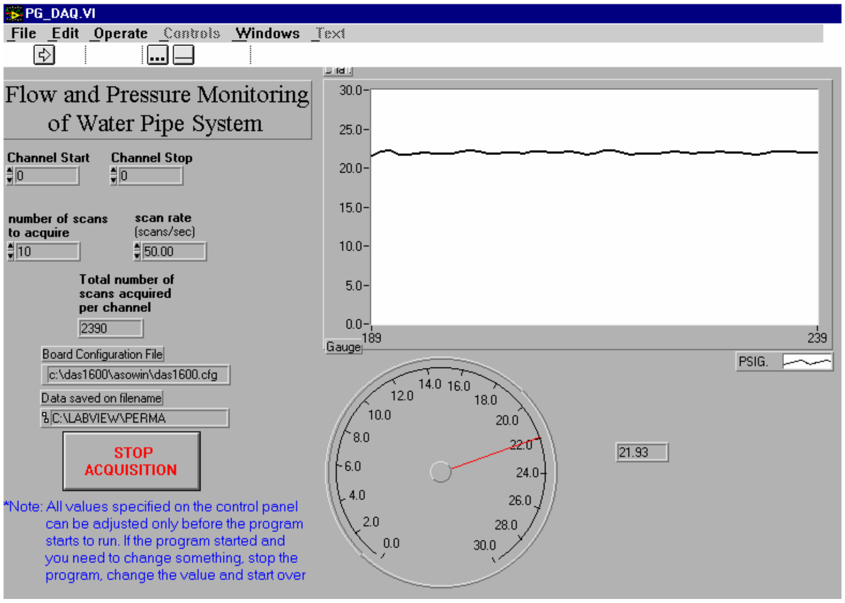
Figure 4.1. Physical model of water distribution system

4.1.1. Pressure transducer

An electronic pressure transducer was installed (Sensotec Pressure Transducer Model TJE with a precision of 0.1%) to record pressure data at the upstream of the pipeline during the experimental runs. The range of the transducer was 0 kPa to 207 kPa.

4.1.1.1 Data Acquisition Program

The data was recorder using a DAS (Collazos, 1999). As shown in Figure 4.3, this program allows the user to specify the sampling frequency. The Channel Start and Channel Stop buttons were not used in this work, since they were not necessary. The scan rate is the number of data per second to take in a simulation. The number of scan to acquire refers to the number of times that the transducer takes samples before displaying an average.



Channel Start: 0
Channel Stop: 0
number of scans to acquire: 10
scan rate (scans/sec): 50.00
Total number of scans acquired per channel: 2390
Board Configuration File: c:\das1600\asowin\das1600.cfg
Data saved on filename: C:\LABVIEW\PERMA
21.93

*Note: All values specified on the control panel can be adjusted only before the program starts to run. If the program started and you need to change something, stop the program, change the value and start over

Figure 4.3 Data acquisition system

4.1.3. Ultrasonic flowmeter

An ultrasonic flowmeter (Controlotron model 1011 Universal Flowmeter 1010 WPI) was installed downstream of the pipe to measure the flow at the exit of the distribution line (Figure 4.4 and 4.5). This flowmeter uses two ultrasonic transducers, shown in Figure 4.6. The flowmeter has 1% intrinsic accuracy and measures flow to a sampling frequency of 0.2 Hz.

Figure 4.4. Ultrasonic flowmeter

Figure 4.5. Ultrasonic flowmeter

Figure 4.6. Flow Transducers

4.1.4. Measurement of water consumption

The volume of water was measured laterally through each faucet at the end of each experiment using the watermeters. The sum of the volumes of water consumed in each meter is the demanded total volume in an experimental run. This represents the real volume used by the population.

4.2. Experimental procedure

The experiment consists of the representation of ten houses. The volume of water that leaves the system laterally was read directly from the meters when the experiments were finished. The sum of the consumed volumes of water is the demand water volume. Dividing the volume among the total time in that a key remains open we obtain the flow average of each faucet.

To simulate the domiciliary demands experimentally a sequence of openings and closing of faucets was generated by the probabilistic distributions described in the Section 3.3. This sequence was repeated during the experiment. An example of the sequence of the openings and closing of valves is shown in Table 4.2. The first column presents the cumulated time, in seconds, the second column represents the number of the valve, and the third and fourth columns represent the closing-opening sequence.

Table 4.2. Valve openings and closing sequence

Time (sec)	**Faucet Number**		**hours**	**Minutes**	**seconds**
1959.00	1	close	0	32	39
1973.14	3	closer	0	32	53
2142.95	3	Open	0	35	43
2170.30	3	closer	0	36	10
2333.43	1	Open	0	38	53
2338.30	1	closer	0	38	58
2424.03	3	Open	0	40	24
2440.80	3	closer	0	40	41
2460.99	2	Open	0	41	1
2476.03	2	closer	0	41	16
2618.30	3	Open	0	43	38
2635.47	3	closer	0	43	55
2828.37	3	Open	0	47	8
2838.37	2	closer	0	47	18
3069.39	2	Open	0	51	9
3083.09	2	close	0	51	23

4.3. Experimental Results

Eleven experiments were run with different sequences of openings and closings of valves in a water distribution line. The exponential distribution was used to generate the times between openings with an average of 3, 6 and 12 minutes. The Weibull, Exponential and Lognormal probabilistic distributions were used to generate the duration of the openings with an average of 20, 40 and 180 seconds. Experiments of 2 and 3 hours duration were performed. Table 4.5 summarizes de experimental runs. The columns 7 and 8 show the volume measured downstream of the distribution line and the volume calculated respectively with the hydraulic model. Column 9 demonstrates that the mathematical model predicts accurately the downstream total volume. The error was calculated by using the following equation

$$\%_{error} = \frac{V_{medido} - V_{calculado}}{V_{medido}} x100 \qquad (4.10)$$

Table 4.5. Summary of Experimental Runs

Exp.	**Average duration of the exp. (hours)**	**Average time between openings (min)**	**Average Duration of the openings (sec)**	**Distribution of the duration of the openings**	**Used keys number**	**Vol. measured (m3)**	**Vol. calculated (m3)**	**error %**
1	3	3	40	Exponencial	9	37.32	37.17	0.42
2	3	6	20	Weibull	5	38.44	38.66	0.54
3	3	3	20	Exponencial	5	39.53	39.32	0.55
4	3	3	20	Weibull	9	39.54	37.15	6.04
5	3	3	40	Weibull	5	37.88	37.45	1.13
6	3	6	40	Exponencial	5	36.56	37.54	3.22
7	3	6	20	Exponencial	9	27.02	27.01	0.04
8	2	6	180	Log Normal	5	26.39	26.42	0.031
9	2	12	180	Log Normal	5	24.30	24.83	2.19
10	2	12	180	Log Normal	9	21.45	21.44	0.06
11	2	6	180	Log Normal	5	24.87	24.89	0.081

It is observed that the biggest error was of 6%, for experiment No. 4, however, the other experiments produced errors smaller than 3.22%. Graphs of the calculated and the measured instantaneous flows are shown in Figures 4.12 to 4.18, corresponding to experiments 1, 2, 3, 4, 7, 8, 9, 10 and 11 respectively. These experiments correspond to different statistical characteristics; therefore, come from different population's behavior.

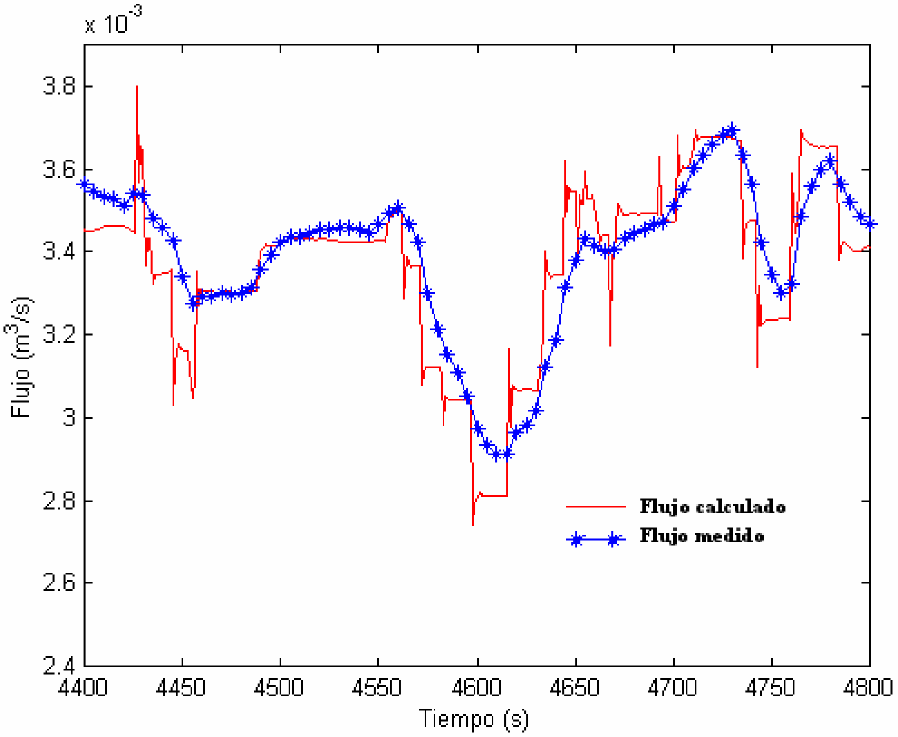


Figure 4.12. Experiment 1

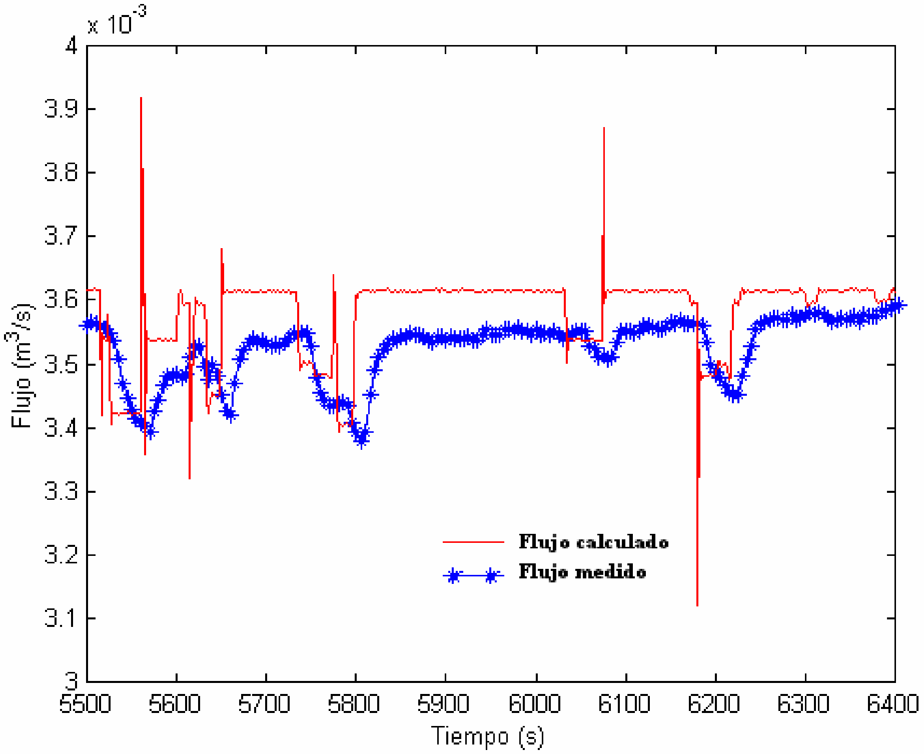


Figure 4.13. Experiment 2

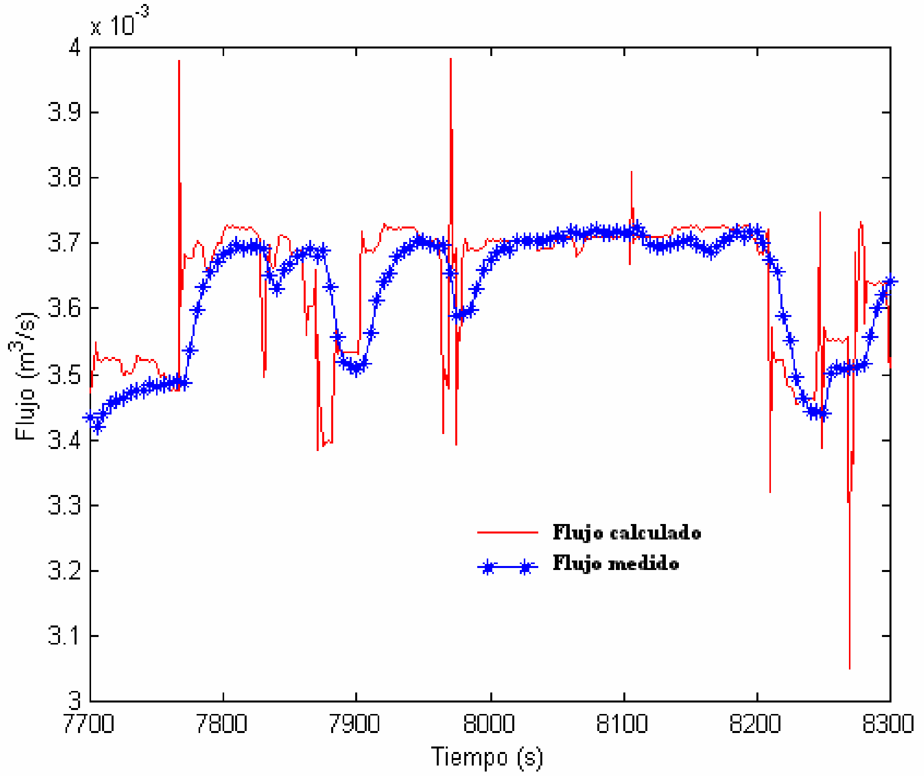


Figure 4.14. Experiment 3

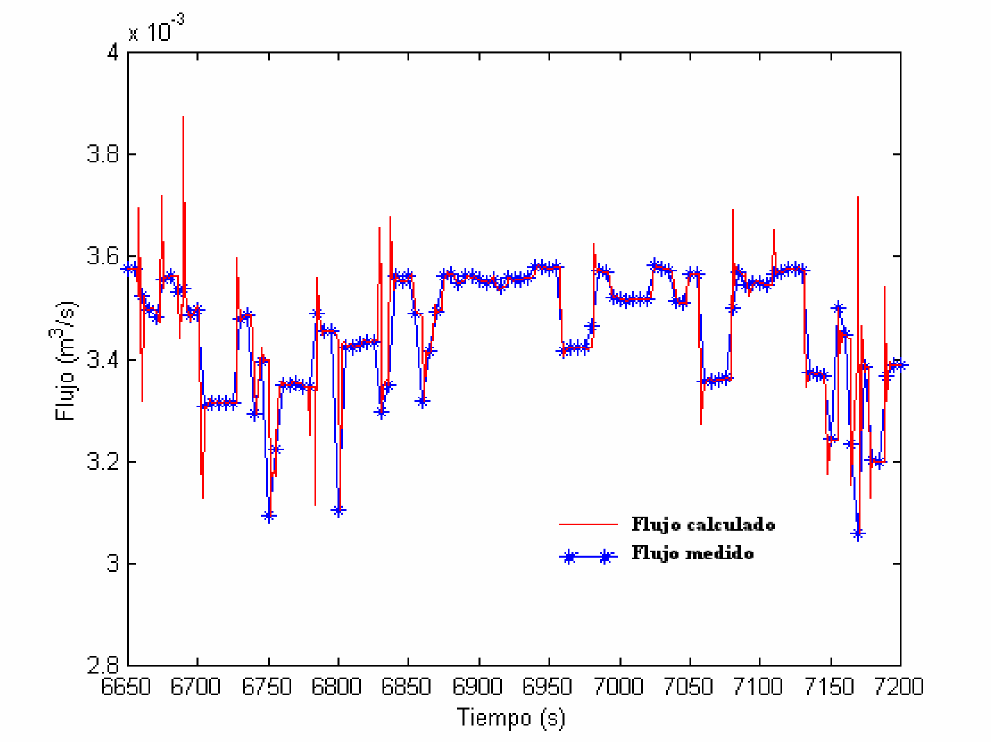


Figure 4.15. Experiment 4

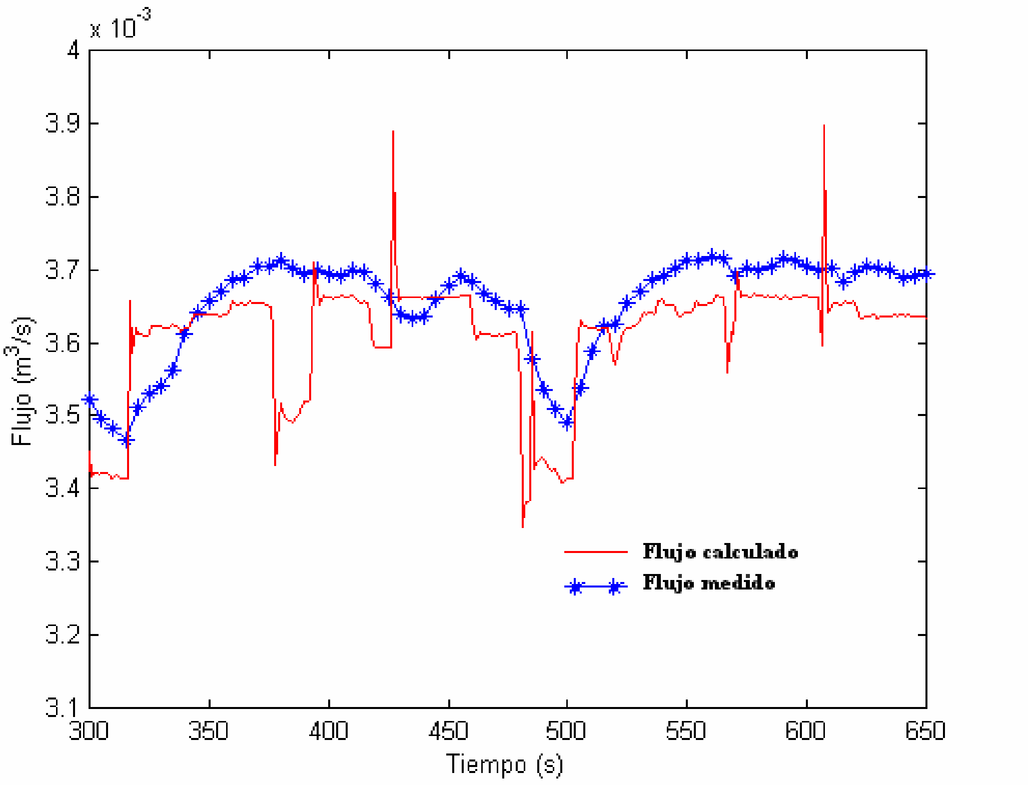


Figure 4.16. Experiment 7

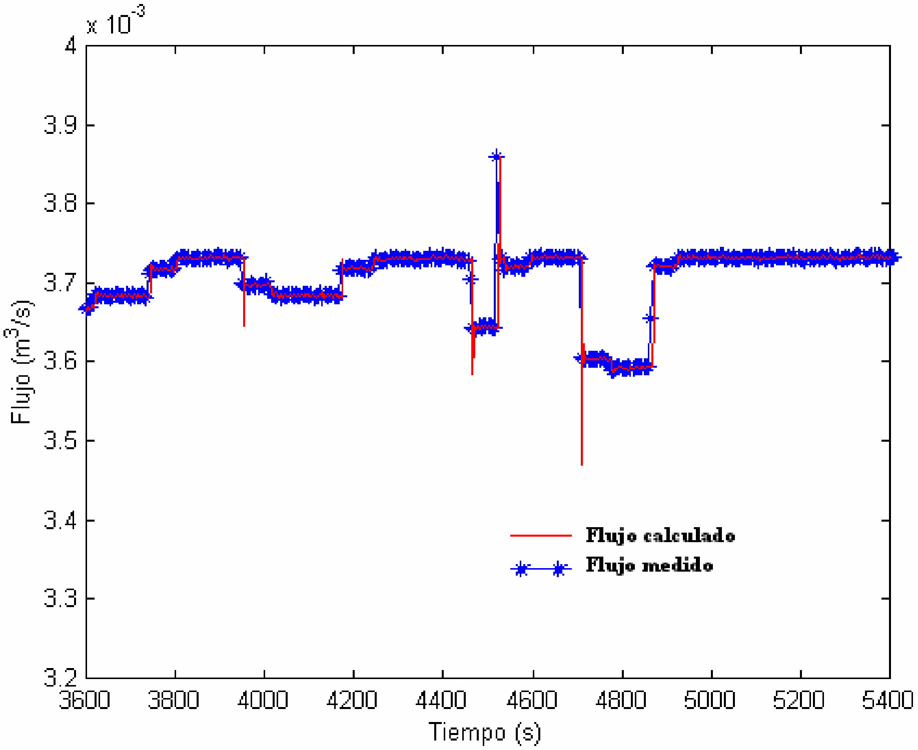


Figure 4.17. Experiment 8

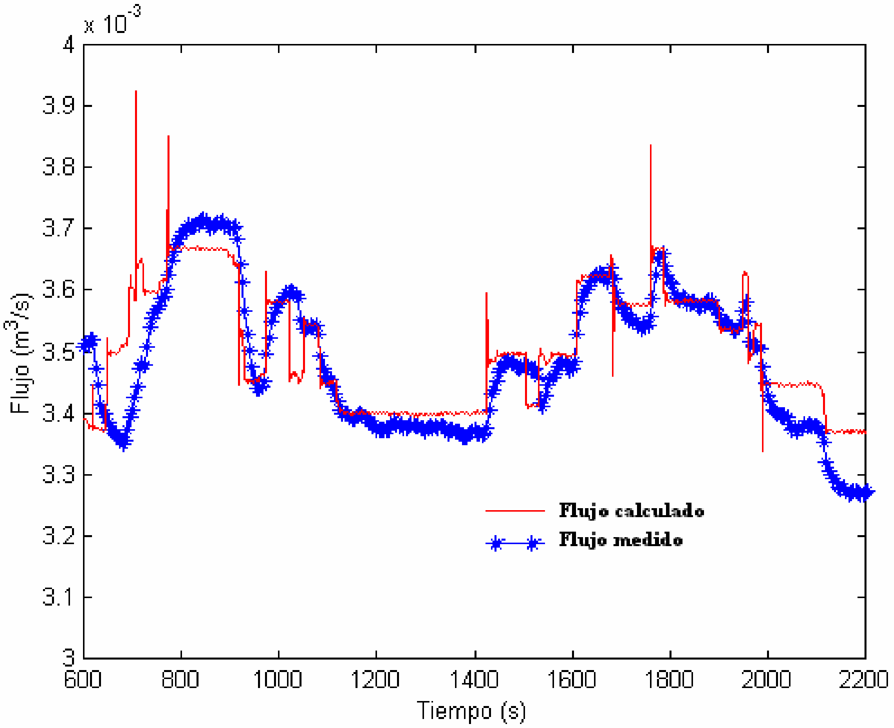


Figure 4.18. Experiment 9

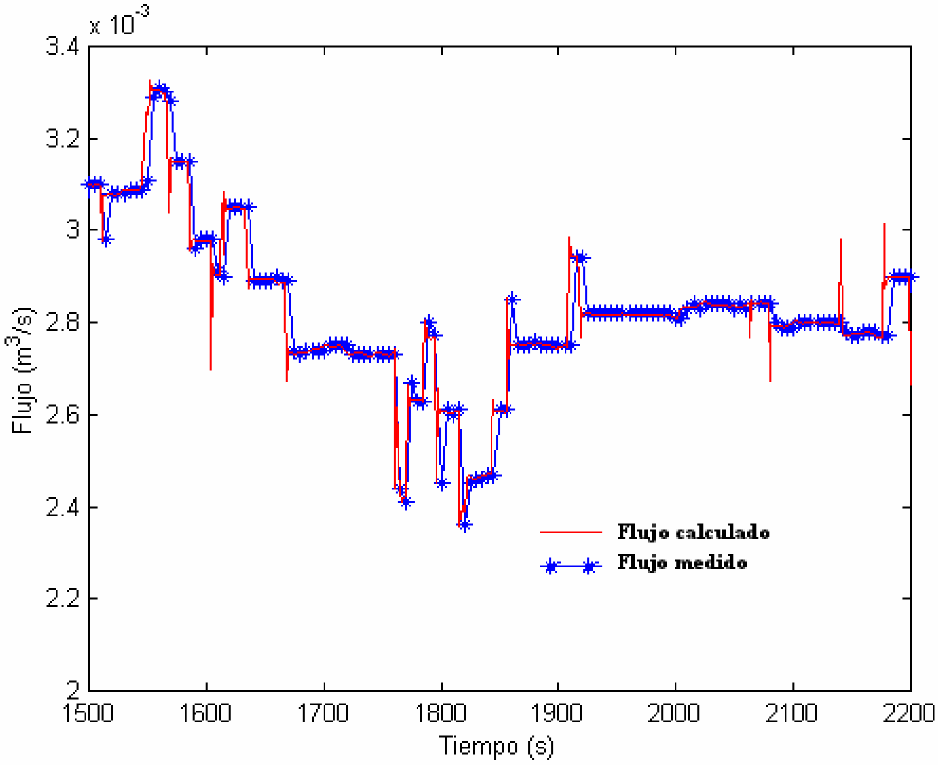


Figure 4.19. Experiment 10

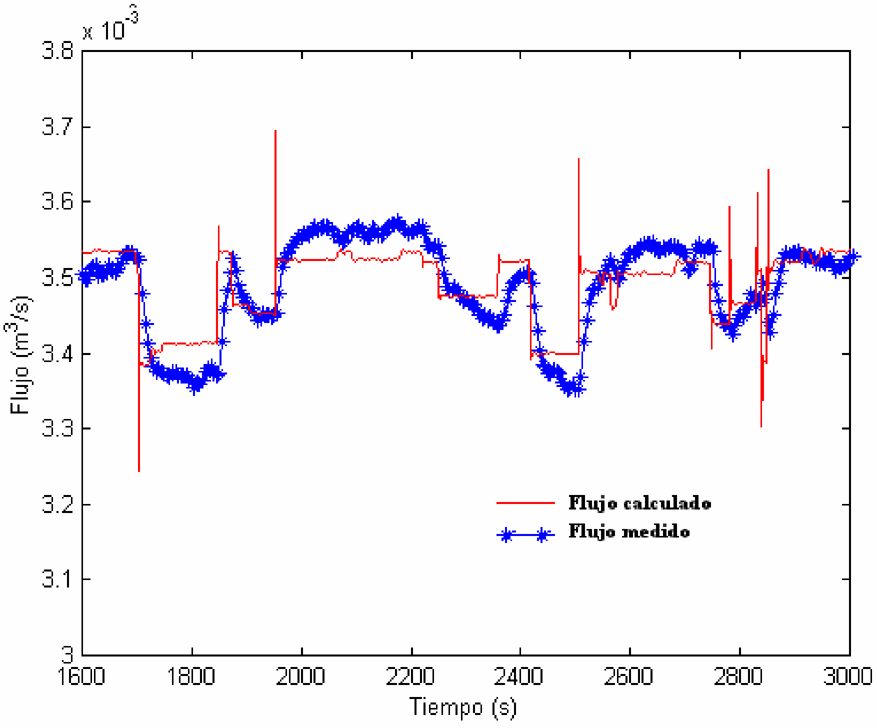


Figure 4.20. Experiment 11

Table 4.5 and Figures 4.12 to 4.20 demonstrate that the hydraulic model predicts the instantaneous volume of water along the distribution line. In the laboratory experiments the maximum error was of 6.0% and the minimum 0.031%. The total demand volume, is similar to the measured water demand volume.

There is a better agreement between the computed and measured water volumes in the experiments with longer durations of openings and longer times between openings. The reason for this is that the behavior is more stable and less dynamic (see Figures 4.17 to 4.20). By having longer opening durations, the flow reaches a more steady condition, as compared with the smaller duration and smaller time between openings. Valve operation effects are less important in the former case. However, even in situations where the conditions are very dynamic, the model reproduces the system response with good accuracy.

The spikes in flow measurements shown in the graphs are due to the fact that the closings and openings in the computer simulations are assumed instantaneous, causing pressure waves of higher magnitude than those occurring in the real system; therefore, the computed instantaneous discharges are higher and lower. Also, the ultrasonic flowmeter takes data every 5 seconds, having the possibility of skipping the exact discharge at the moment of closure or opening of one or more faucets. The results would be a drop in the measured flow during a valve closure or, the opposite during an opening. Some possible error that could also contribute to the differences between measured and computed results are:

1. The human error: people can delay the opening or closing of valves at the moment indicated in the provided sequence. Also, people could omit some closing or opening causing differences in the instantaneous exit flow.
2. The speed with which the people closes the valves or open it depends on each individual person, and this could also affect the final results.
3. The exit flow in each faucet changes with the opening or the closing of other valves in the same distribution line. This effect is important under the laboratory conditions because the pressures of water are relatively small (137 kPa-151 kPa).

CHAPTER V

FIELD MEASUREMENTS

5.1. Field measurements

The instantaneous consumption of water was measured at four houses of a homogeneous urbanization of middle class. It is expected that the consumption patterns are similar. The input data flow, at the beginning of the pipe of each residence, were gathered using the the ultrasonic flowmeter previously used in the laboratory. The data were gathered for one week at each house. The ultrasonic flowmeter and the flow transducers were installed at the entrance pipe segment of the houses (Figure 5.1 and 5.2) to measure the entrance flow to the residence continually in the time. The measures of the flow were taken every 10 seconds to provide information of the water consumption continually in time.

A pressure meter was installed in a valve outside the house (Figures 5.3 and 5.4) to have evidence of the changes in pressure during the day. This meter, model HPR-2109 of the Telog Company, is a hydrant pressure meter with 6.35 cm diameter. It can measure pressures from 0 kPa up to 1379 kPa with an accuracy of 0.3% of the total scale of the instrument. The connection of the pressure meter decreased from 6.35 cm to a connection of 1.91 cm (Figure 5.3 and it Figure 5.4), since it is the common connection in the gardens of the residences. Once installed it was programmed to gather pressure measurements every 10 seconds.

Figure 5.1. Flowmeter and transducers

Figure 5.2. Flow transducers

Figure 5.3 Pressure meter

Figure 5.4.Pressure meter at the household entrance

Conceptualization of the distribution line

A line of of water consumption of fourteen residences was conceptualized, seven residences to each side of the distribution line (Figures 5.5). This model has three boundary conditions, the same as the distribution system installed in the laboratory:

1. The pressure upstream of the pipeline.
2. The flow downstream of the pipeline.
3. The demand flow.

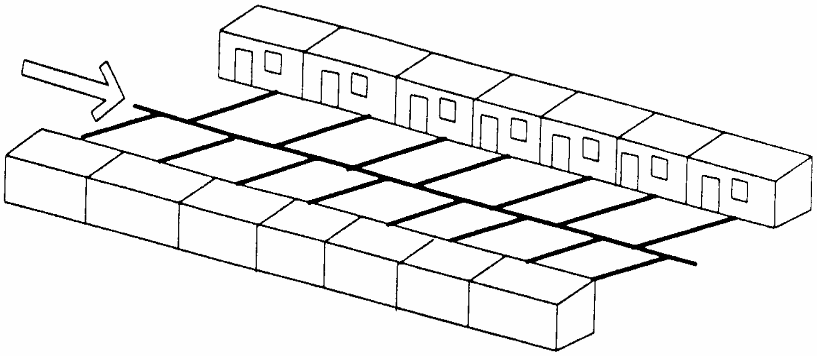


Figure 5.5. Representation of a distribution line (adapted of Durán, 1997)

The necessary input data for the hydraulic model is shown in the Table 5.1.

Table 5.1. Input data used in the simulations

Input data	Units	Values
Friction factor	Nondimensional	0.031
Wave pressure	m/s	500,1000
Length distribution line	m	88.0
gravitational acceleration	m2/s	9.81
Initial flow Qo	m3/s	0.0141
Space between residences	m	12.57
Orifice coefficient	Nondimensional	0.0873

The friction factor was considered for an old cast iron pipe, four inches in diameter. The diameter and the pipe material correspond to the an 18 years old residential. The theoretical wave speed is 543 m/s; however, the simulations were carried out with values of 500 m/s and 1000 m/s, to study the sensitive of the model to changes in the wave speed. The data for the calculation of the wave speed are shown in Table 5.2.

Table 5.2. Parameters used for the calculation of the wave speed

Parameters	**Units**	**Value**
K	Gpa	2.19
ρ	Kg/m^3	999
E	Gpa	125
D	M	0.1016
e	Mm	0.26
μ	Adimensional	0.25
ϕ	Adimensional	366.35
c	m/s	543.61

The pipe length was estimated measuring the length of one of the streets of the neighborhood where the data were gathered. Eight simulations were performed and the results are discussed in the section 5.6.

5.3. Surveys Analysis.

Three hundred and fifty (350) questionnaires were distributed in the economically homogeneous urbanization, where the patterns of consumption of water are similar. This questionnaire asked to the residents on the occupation during the different days and the different hours of the week. Of the total of distributed questionnaires, one hundred thirty-four (154) were returned to the University of Puerto Rico, Mayaguez Campus, representing 39% of the population. The statistical analysis of the questionnaire reveals that the occupation of the residences is different during the week days (Monday thru

Friday) and during the weekends (Saturday and Sunday). Tables 5.3 and 5.4 summarize the results. The average number of people inside the house remains constant from Monday thru Friday; however, there are significant differences during the weekends. Figure 5.6 shows the relationship that exists among the average number of persons inside the house during the hours of the day the different days of the week.

Three occupation periods, from Monday thru Friday, are presented in Table 5.5. The first period goes from 9 am to 5 pm, the second goes from 5 pm at 7 pm and the third from 7 pm to 9 am. The first period corresponds to an average of 1.2 persons with a standard deviation of 1.23. The second period has an average of 2.2 persons with a standard deviation of 1.56. The third period has an average of 2.82 persons with a standard deviation of 1.51.

During Saturdays and Sundays can also be distinguished two periods of homogeneous occupation (Table 5.6). The first period goes from 9 am to 7 pm and the second goes from 7 pm to 9 am. The first period corresponds to an average of 2.36 persons with a standard deviation of 1.82. The second period has an average of 2.84 persons with a standard deviation of 1.54. During on Saturdays and on Sundays the occupation is more homogeneous during the whole day than from Monday to Friday.

Table 5.3. Average and Standard Deviation of Household Occupation

Hour		Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
12am-6am	Aver	2.8897	2.8382	2.8602	2.8455	2.8161	2.875	2.9264
	DE	1.5235	1.5017	1.5063	1.5147	1.5163	1.5749	1.5330
6am-8am	Aver	2.8308	2.8529	2.8455	2.8529	2.8529	2.8676	2.875
	DE	1.6309	1.6217	1.6324	1.6217	1.6353	1.5338	1.5272
8am-10am	Aver	1.1985	1.1764	1.1911	1.1838	1.2205	2.3897	2.5661
	DE	1.1341	1.1410	1.1321	1.1366	1.1527	1.6109	1.6896
10am-12pm	Aver	1.0808	1.0220	1.0661	1.0367	1.0588	2.1764	2.2058
	DE	1.1555	1.1383	1.1559	1.1508	1.1659	1.6324	1.6106
12pm-2pm	Aver	1.1470	1.1544	1.1323	1.1691	1.1470	2.2720	2.3308
	DE	1.1708	1.1730	1.1788	1.1709	1.1771	1.6486	1.6467
2pm-4pm	Aver	1.4348	1.4411	1.4264	1.4632	1.4558	2.2205	2.2352
	DE	1.4074	1.4077	1.4227	1.4137	1.4291	1.5994	1.6919
4pm-6pm	Aver	2.2426	2.2426	2.2426	2.2500	2.2279	2.5	2.5735
	DE	1.5658	1.5610	1.5799	1.5575	1.5727	1.6055	1.6313
6pm-8pm	Aver	2.8235	2.7426	2.7720	2.7426	2.7352	2.7058	2.875
	DE	1.4801	1.4757	1.4451	1.4757	1.4819	1.6289	1.5749
8pm-10pm	Aver	2.9044	2.8088	2.8455	2.8235	2.7500	2.7794	2.8897
	DE	1.4700	1.4882	1.4497	1.4751	1.5141	1.5855	1.5524
10pm-12am	Aver	2.875	2.8235	2.8308	2.8161	2.7573	2.7720	2.8823
	DE	1.5027	1.4901	1.4481	1.4667	1.4681	1.5449	1.4860

Aver= Average
DE= Standard Deviation

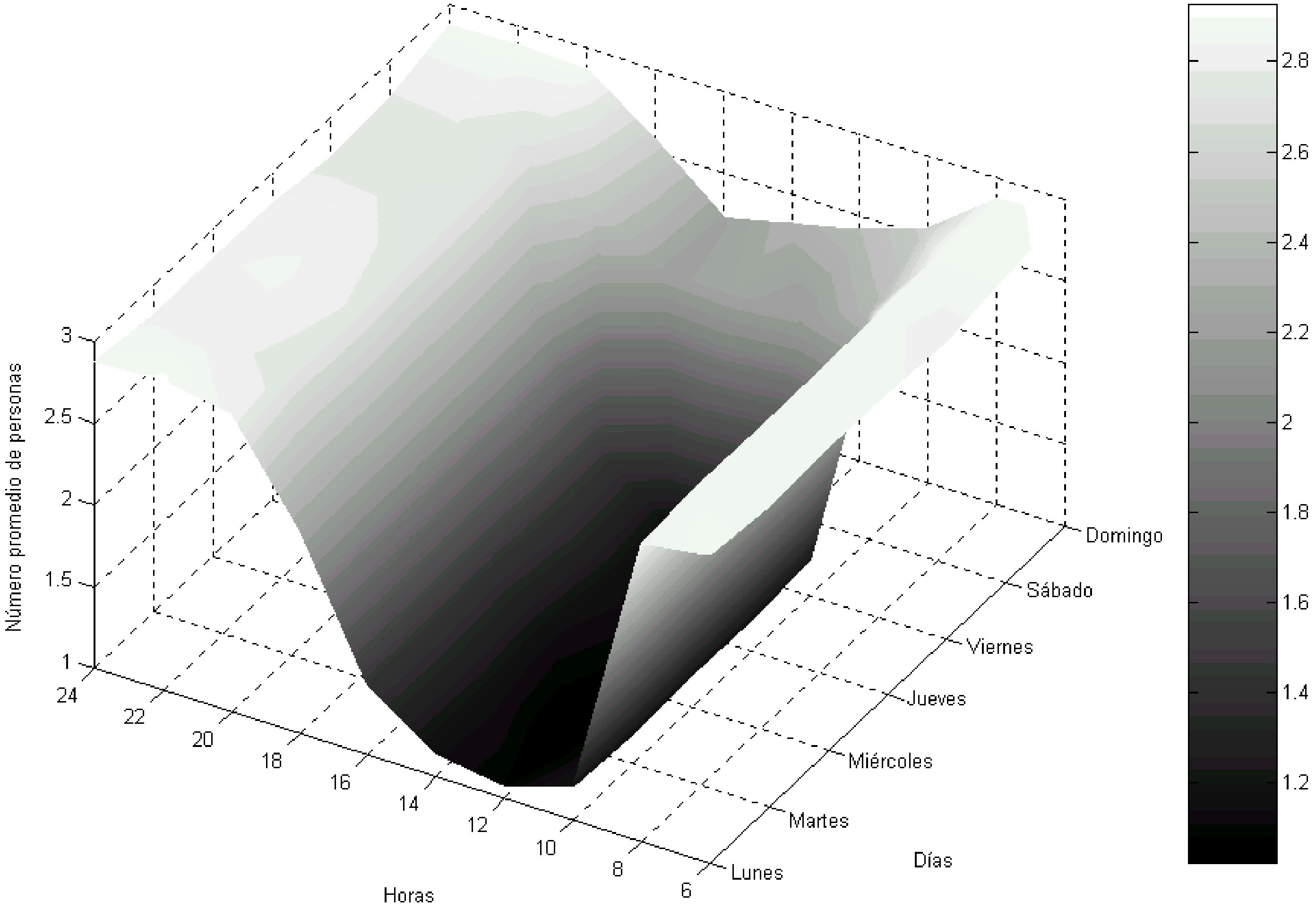


Figure 5.6. Average number of persons in households per tour per day

Table 5.4. Summary of average number of persons in households during the weekdays and weekends

Hour of the day	Number average of people	
	Monday to Friday	Saturdays and Sundays
12am-6am	2.8500	2.9000
6am-8am	2.8470	2.8700
8am-10am	1.1941	2.4800
10am-12pm	1.0529	2.3000
12pm-2pm	1.1500	2.3000
2pm-4pm	1.4441	2.2300
4pm-6pm	2.2411	2.5400
6pm-8pm	2.7632	2.7900
8pm-10pm	2.8264	2.8300
10pm-12am	2.8205	2.8300

Table 5.5. Periods of occupation during the weekdays

Períodos del día	Número promedio de personas	Desviación Estándar
9 am - 5 pm	1.2102	1.2303
5 pm - 7 pm	2.2411	1.5628
7 pm - 9 am	2.8214	1.5100

Table 5.6. Periods of occupation during the weekends

Períodos del día	Número promedio de personas	Desviación Estándar
9 am – 7 pm	2.3683	1.8247
7 pm – 9 am	2.8448	1.5491

5.4. Simulation with Field Data

A total of four houses in an economically homogeneous urbanization were chosen, in which the flow and the entrance pressure were measured. The ultrasonic flowmeter was programmed to gather the data of water consumption every ten seconds. The pressure transducer was also programmed to gather data every ten seconds. The number of people that live in each house is shown in the Table 5.7.

Table 5.7. Person's number in the residences

House	**Persons living in the residences**	
	Adults	**Chidren**
1	4	4
2	3	0
3	2	2
4	3	0

5.5. Analysis of Field Data

The time between openings and the openings duration were obtained from the measured values and used to adjust a regression model that allows the simulating of the behavior of consumption of water in the residences. The regression equations are provided as input data to the computer model to simulate the hydraulic behavior of the system.

From the survey it was found that the occupation pattern is the same from Monday thru Friday, and on Saturdays and Sundays (Table 5.4). The field measurements demonstrate that the consumption average was 0.7625 m^3 of water per day per house during the weekdays and 0.9152 m^3 per day per house during the weekends. The demands of water are larger during the weekends; therefore, the statistical analysis were divided in two periods: the first period from Monday thru Friday and the second period for Saturdays to Sundays.

A total of 4,074 openings were detected, 1,082 belong to the first house, 568 openings belong to the second house, 1,156 belong to the third house and 1,268 openings belong to the fourth house. Total and per house histograms of the time between openings and the duration of the openings are presented in Figures 5.7 to 5.10. The natural logarithm of each value was used to appreciate the class distribution.

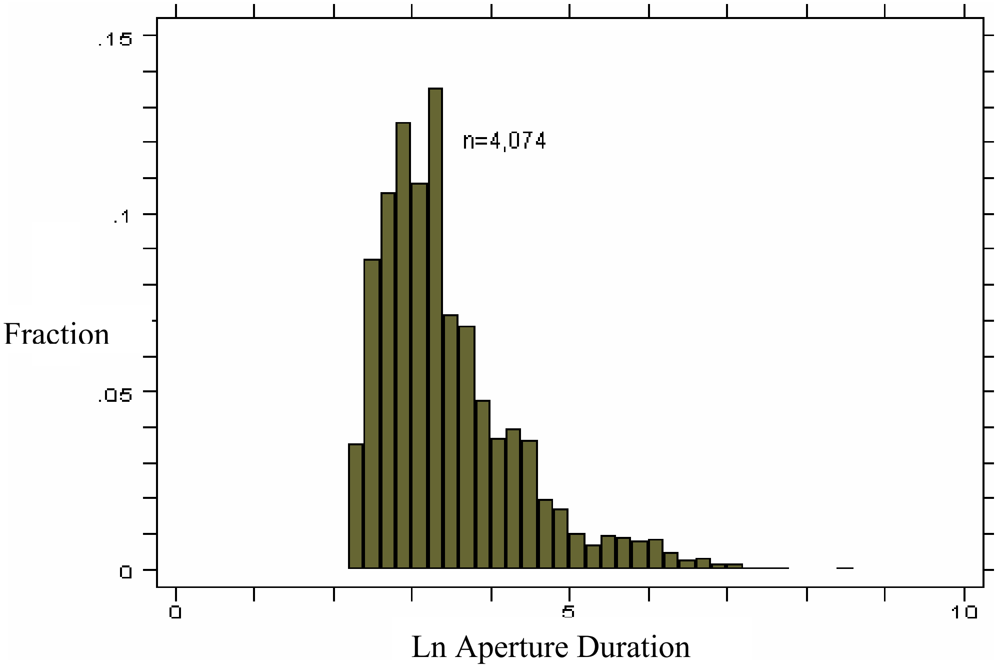


Figure 5.7 Histogram for the duration of openings (all samples)

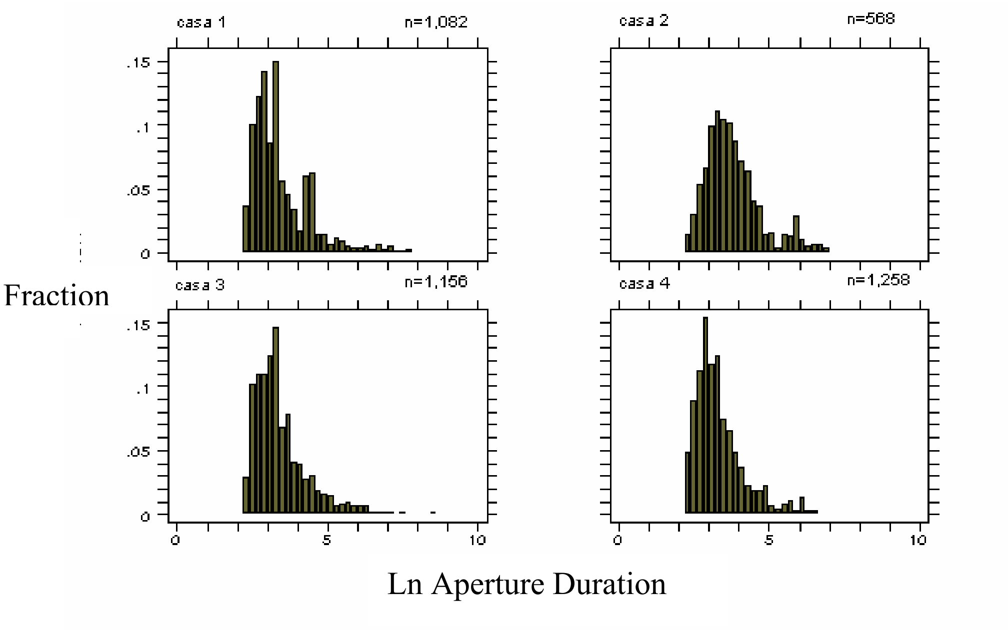


Figure 5.8 Histograms for the duration of the openings per house

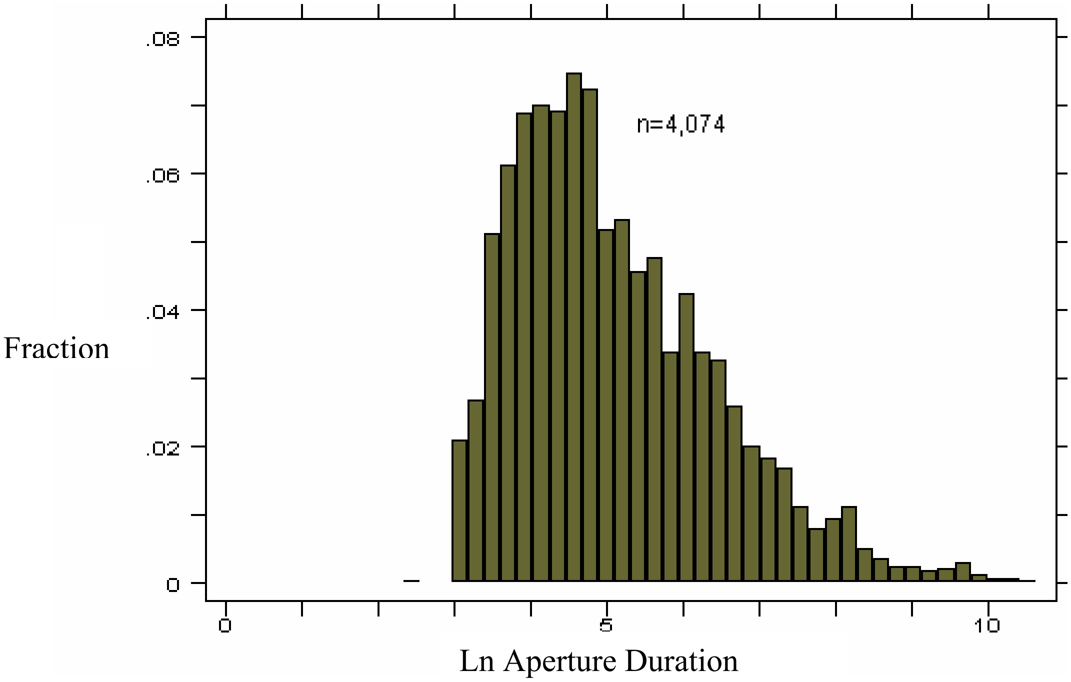
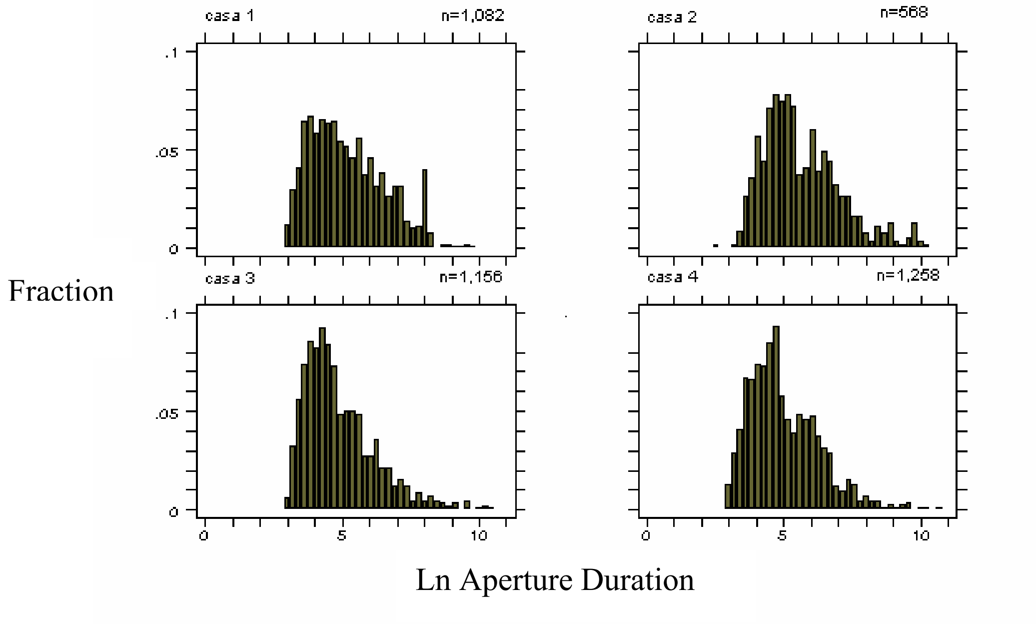


Figure 5.9. Histogram of time between openings (all samples)



Figures 5.10 Histograms for the time between openings per house

The individual histograms show that the four residences follow similar patterns for the times between openings and the duration of consumption of water. Therefore, we can consider that all the data are similar, to obtain a representative regression model of homogeneous residences.

The discoveries were:

1. The hour of the day and the number of persons do not influence significantly the duration of the openings, since these averages stay almost constant, as shown in Figures 5.11, 5.12, 5.13 and 5.14. The average duration of the openings, in natural logarithm, is represented with a curve, while the values of the natural logarithms of the durations are represented with small circles. The same conclusion applies for the weekdays and for the weekends.

2. This conclusion could be extended to the average of the times between openings, represented by a curve, while the values of the natural logarithms of the times between openings are represented with small circles.
3. The times between openings have higher values during the early morning, as shown in Figures 5.15 and 5.17. There are not drastic changes in the averages values of the times between openings after 6:00 am approximately.
4. The number of persons do not influence significantly in the average of the time between openings of weekdays and weekends (Figure 5.16 and 5.18). Therefore, independently of the number of persons in the residence, there are not drastic changes in the value of the average time interval between valves openings.

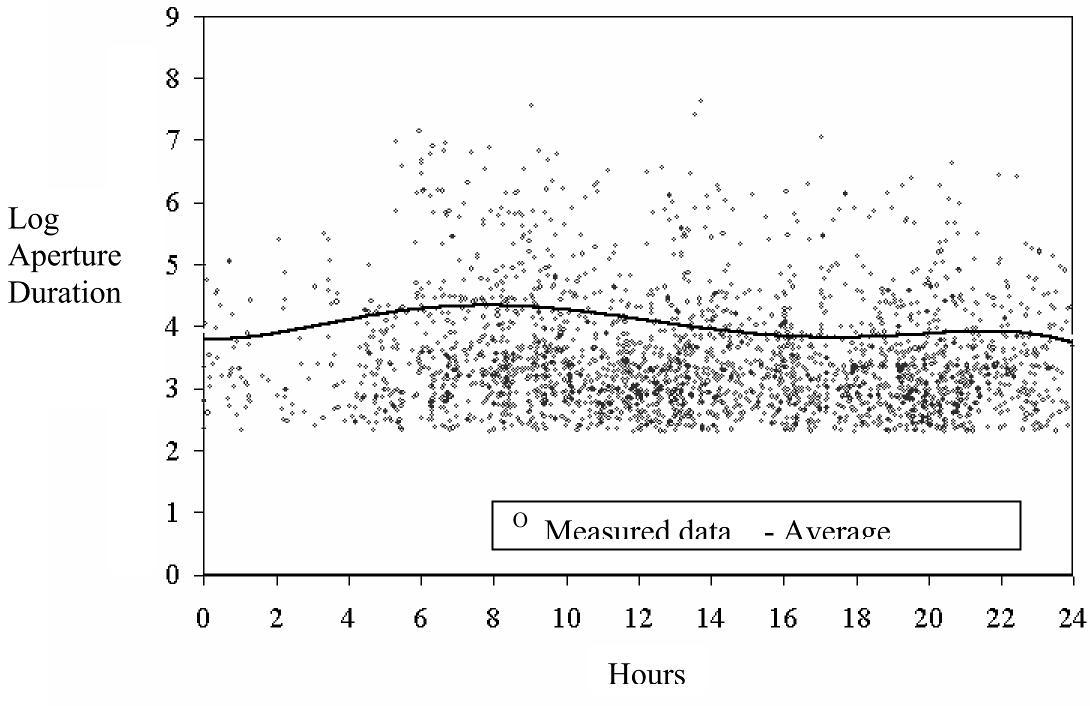
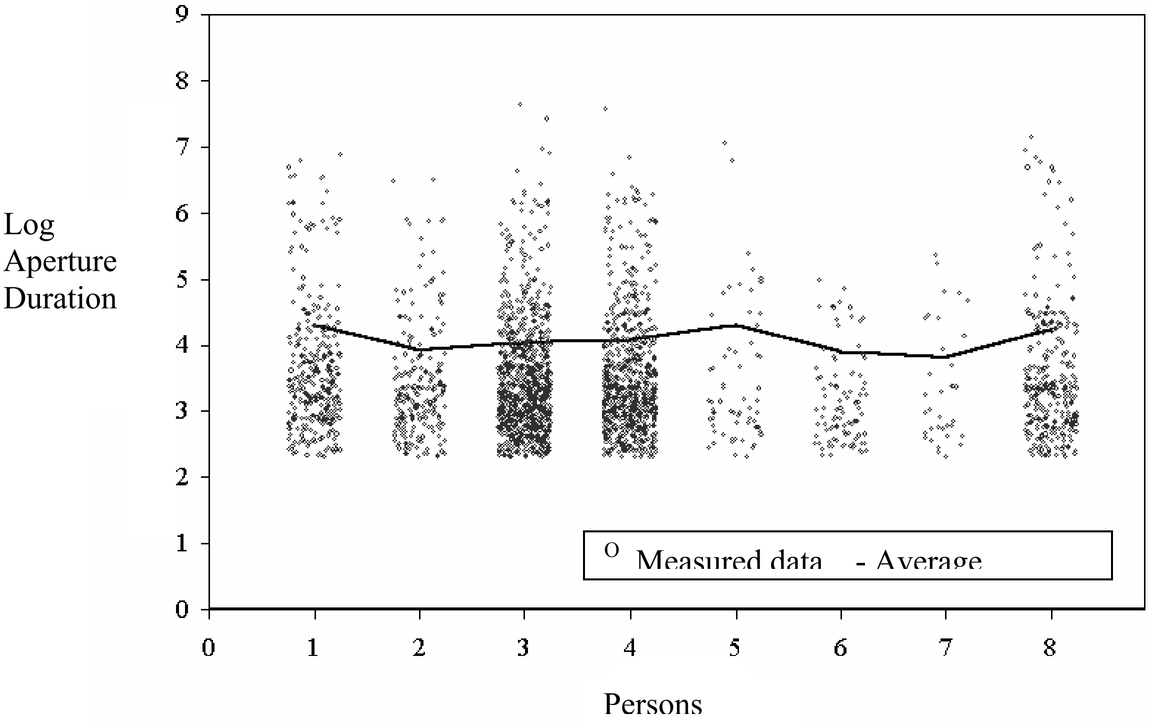


Figure 5.11. Ln (duration of the openings) versus hours of the day - Monday thru Friday



Figures 5.12. Ln (duration of the openings) versus persons-Monday to Friday

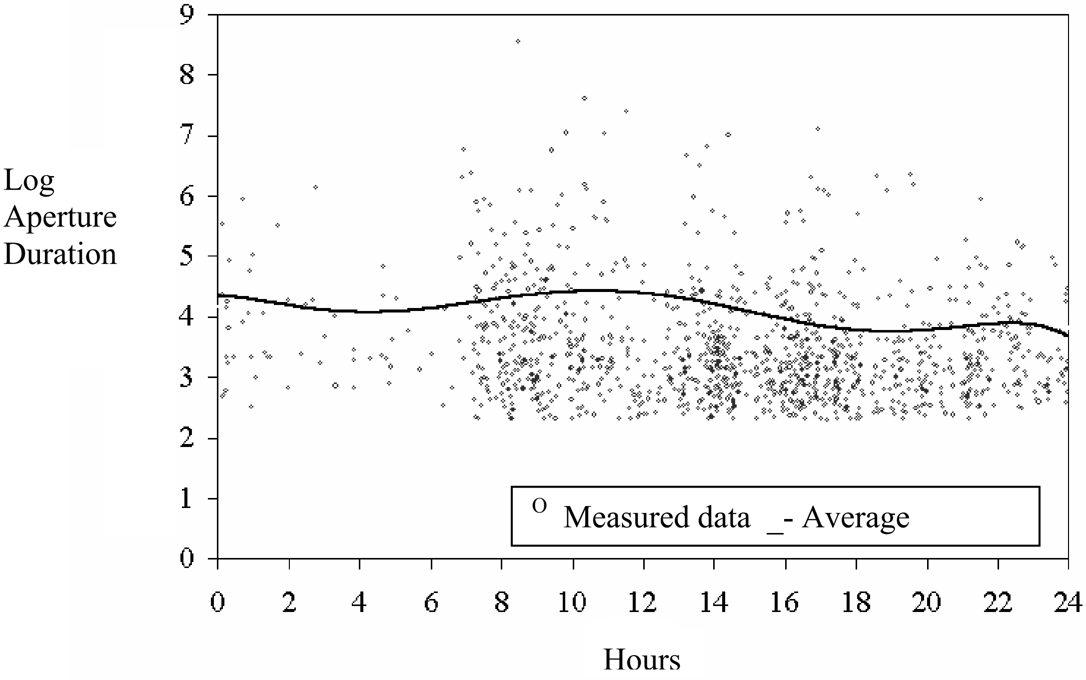


Figure 5.13. Ln (duration of the openings) versus hours -
Saturdays and Sundays

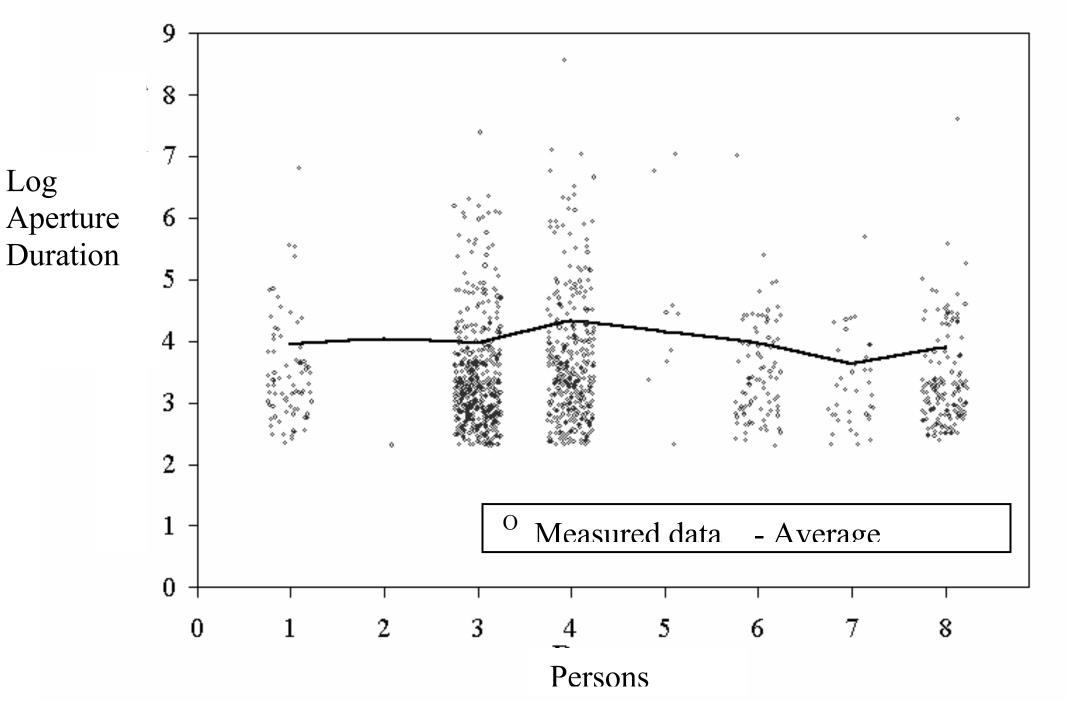
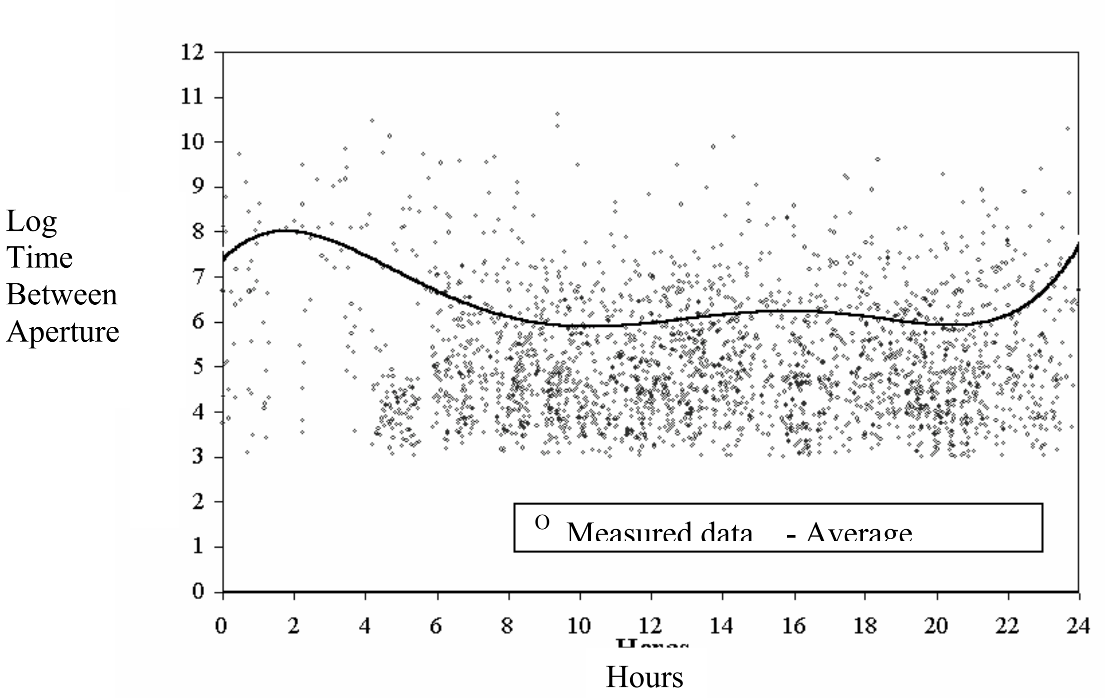


Figure 5.14. Ln (duration of the openings) versus people - Saturdays and Sunday



Figures 5.15. Ln (time among openings) versus hours - Monday to Friday

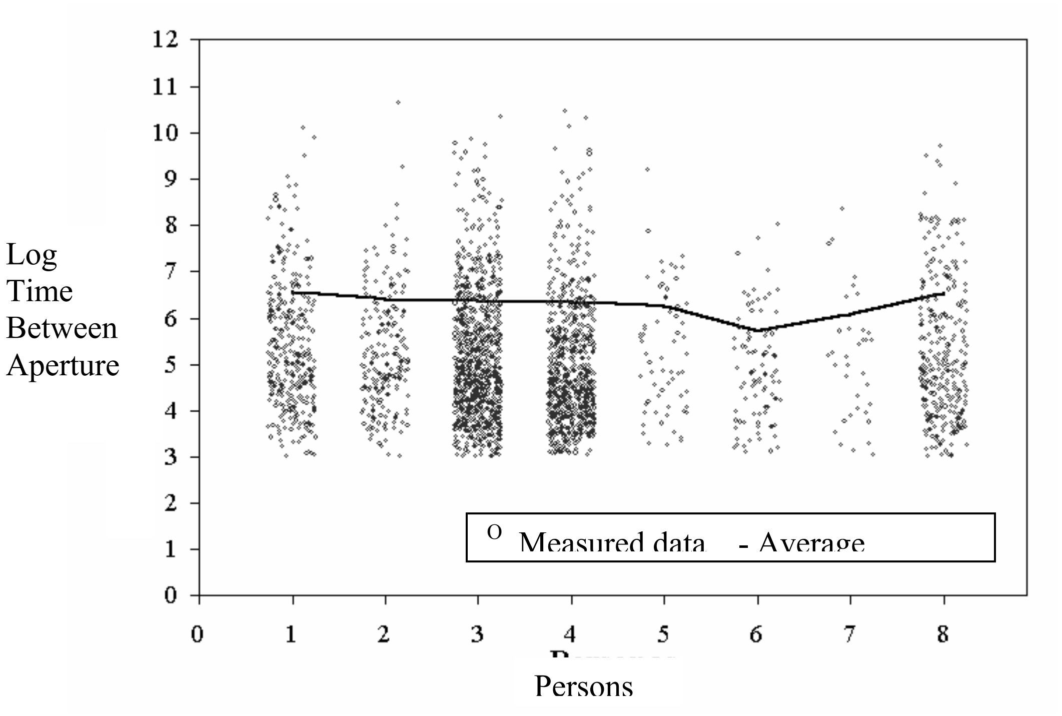


Figure 5.16. Ln (time among openings) versus persons -
Monday to Friday

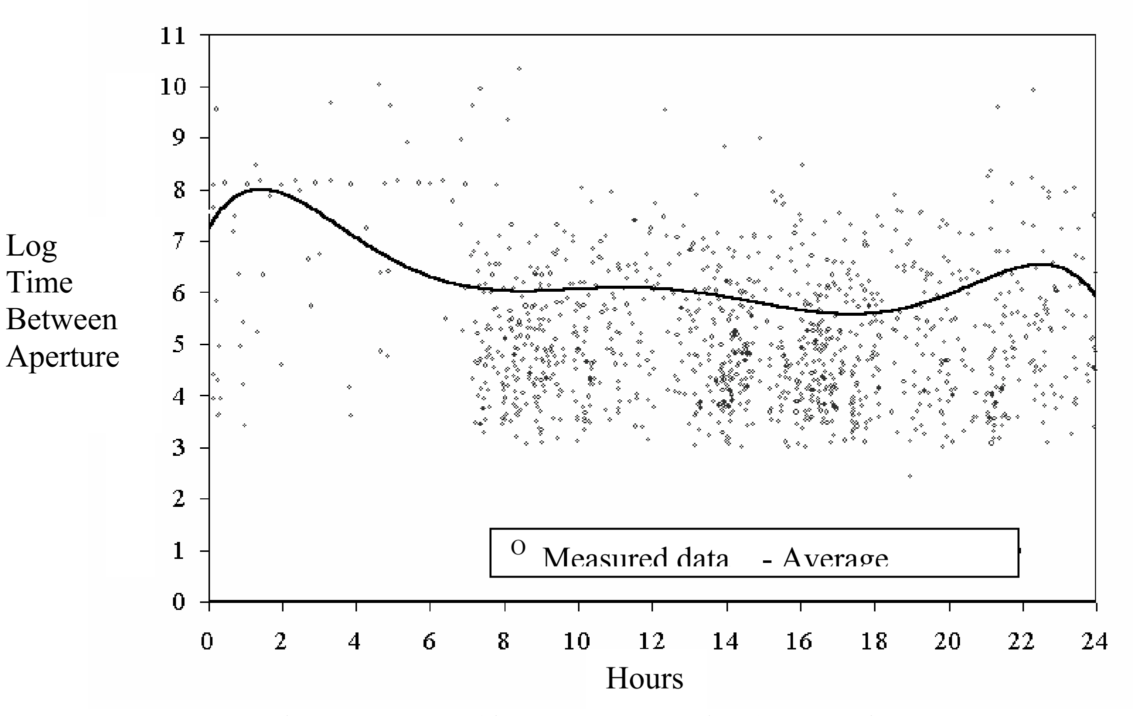


Figure 5.17. Ln (time among openings) versus hours -
Saturdays and Sundays

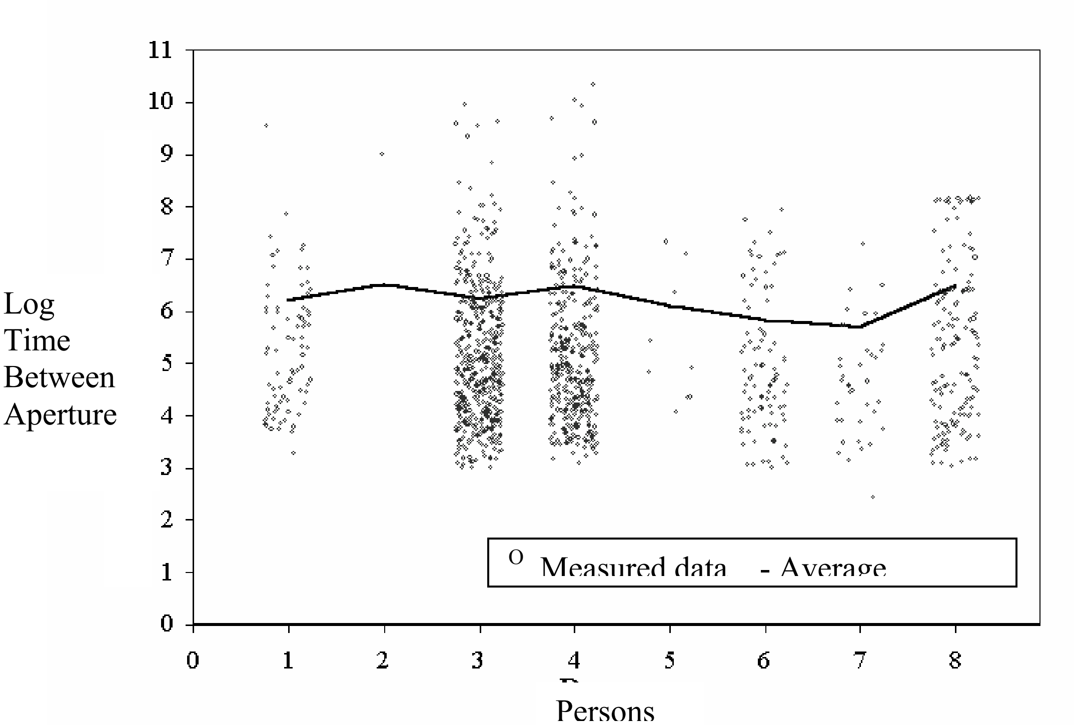


Figure 5.18. Ln (time between openings) versus persons
Saturdays and Sundays

Tables 5.8 present the intervals of the values shown in Figures 5.11, 5.13, 5.15 and 5.17.

Table 5.9 present the intervals of the values shown in Figures 5.12, 5.14, 5.16 and 5.18.

Table 5.8. Intervals of average time between apertures and aperture duration during the hours of the day

Period	**Variable**	**Interval of average of the variable (Ln s)**	**Interval of average of the variable (s)**
Monday through Friday	Time between openings	8.00-6.0	2980.96-403.43
	Duration of the openings	4.42-3.92	83.09-50.40
Saturdays and Sundays	Time between openings	8.10-5.66	3294.47-287.15
	Duration of the openings	4.45-3.82	85.63-45.60

Table 5.9. Interval of average time between openings and duration as function of the number of persons in the house

Period	**Variable**	**Interval of the values average of the variable (Ln s)**	**Interval of the values average of the variable (s)**
Monday through Friday	Time between openings	6.55-5.7	699.24-298.87
	Duration of the openings	4.30-3.81	73.70-45.15
Saturdays and Sundays	Time between openings	6.5-5.7	665.14-298.87
	Duration of the openings	4.34-3.62	76.71-37.34

In this study we conclude that the number of people and the hours of the day do not influence significantly in the time between openings and the opening duration, in the period between the 6:00 am and the 8:00 pm. In the early hours, a great consumption of water is not expected, contrary to what happens in the morning hours, in the hours of the afternoon and at early hours of the night. According to the previous graphs, we can observe that, from approximately 6:00 am up to 8:00 pm there is not a significant variation in the average of the time between openings and the average of the duration. Therefore, the regression models were developed for this period of time, one for weekdays and another for weekends.

5.6 Regression Model

The fundamental supposition of the model is that the variables are normally distributed.

Presuming that the durations of the openings and the times between openings, comes from a Lognormal distribution; the empiric-accumulated probability distribution was obtained for the logarithms of the times between openings and the duration of these for every period (an example is shown in the Figure 5.19). Then, it was possible to obtain the inverse accumulated normal, z, corresponding to each probability accumulated for the duration and the time between openings of every period. Random normal variables coming from a cumulative probability distribution were generated. After obtaining the inverse of the cumulative function, corresponding to each cumulative empiric probability, graphs of the variable of interest versus z were created, (an example is shown in Figure 5.20).

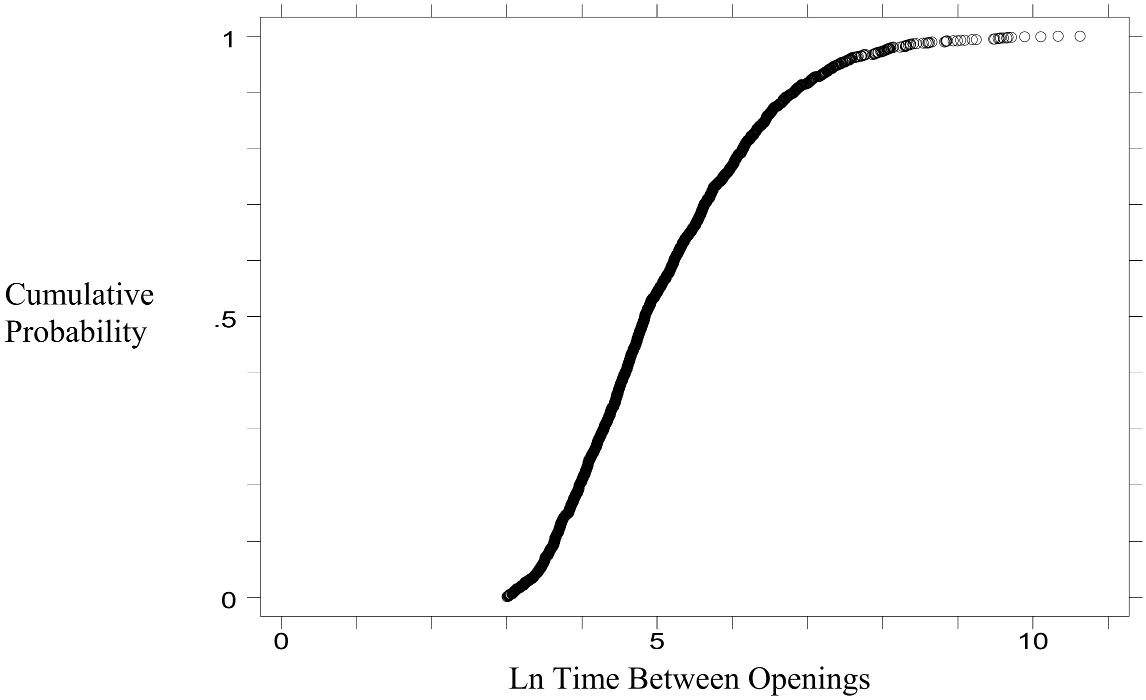


Figure 5.19. Empirical probability versus z Ln (time between openings)

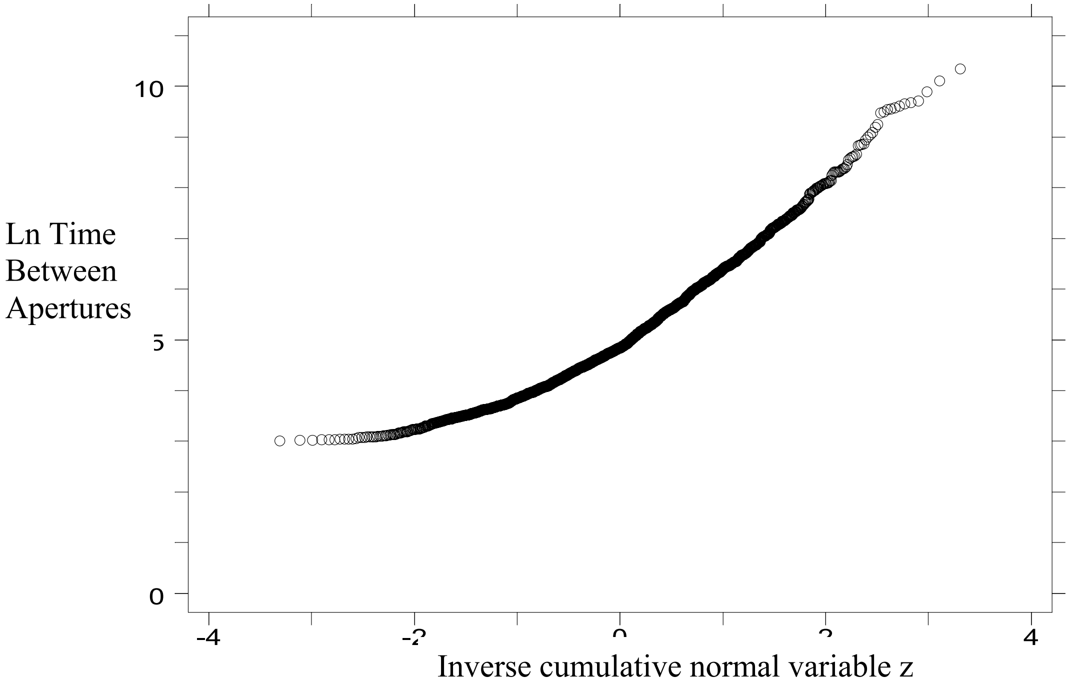


Figure 5.20. Ln (time betweem openings) versus inverse cumulative normal

Regressions were done to fit the variable of interest to the inverse accumulated normal z. The chosen has a coefficient of multiple determination, R2, greater than 0.99. The more R2 comes closer to 1, the more efficient it is the regression of the model in explaining the variation of each variable. R2 measures the efficiency of the regression curves to adjust the measured it dates. This coefficient refers to the logarithmic variable and not to the values of the real times of the duration of the openings and the times between openings. The exponential function returns the logarithmic values of real values of each variable, as shown in the Table 5.10.

Table 5.10 presents the regressions obtained for the times between openings and duration for every period and in the Table 5.11 the coefficients of multiple determination are presented.

Table 5.10 Established formulas for the times between opening and the duration of the openings

Period	Variable	Formulas
Monday through Friday	Time between openings	$e^{(0.1922055Z^2+1.236559Z+4.901783)}$
	Duration of the openings	$e^{(-0.0121303Z^4+0.0207283Z^3+0.2818487Z^2+0.792053Z+3.235046)}$
Saturdays and Sundays	Time between openings	$e^{(0.1740431Z^2+1.19469Z+4.825154)}$
	Duration of the openings	$e^{(0.0292397Z^3+0.2362305Z^2+0.7887201Z+3.225159)}$

Z is a normal random number between 0 and 1

Table 5.11.Coeficientes of multiple regression for every period

Period	Variable	Coefficient of multiple determination (R2)
Monday through Friday	Time between openings	0.9987
	Duration of the openings	0.9943
Saturdays and Sundays	Time between openings	0.9965
	Duration of the openings	0.9960

The comparisons between these regressions and the measured data or real data of the durations of the openings and of the time between openings are shown in the Figure

5.21 to the Figure 5.24. In these graphs the real values are shown in comparison with the predicted values to visualize the prediction capacity of the model.

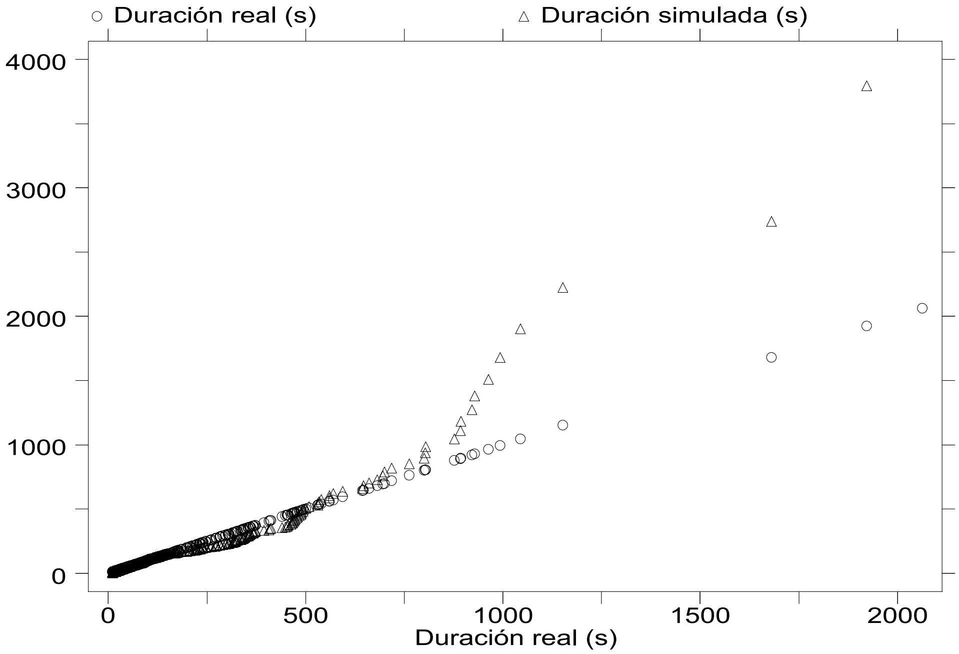


Figure 5.21. Real and predicted data for the duration of the openings-Monday to Friday

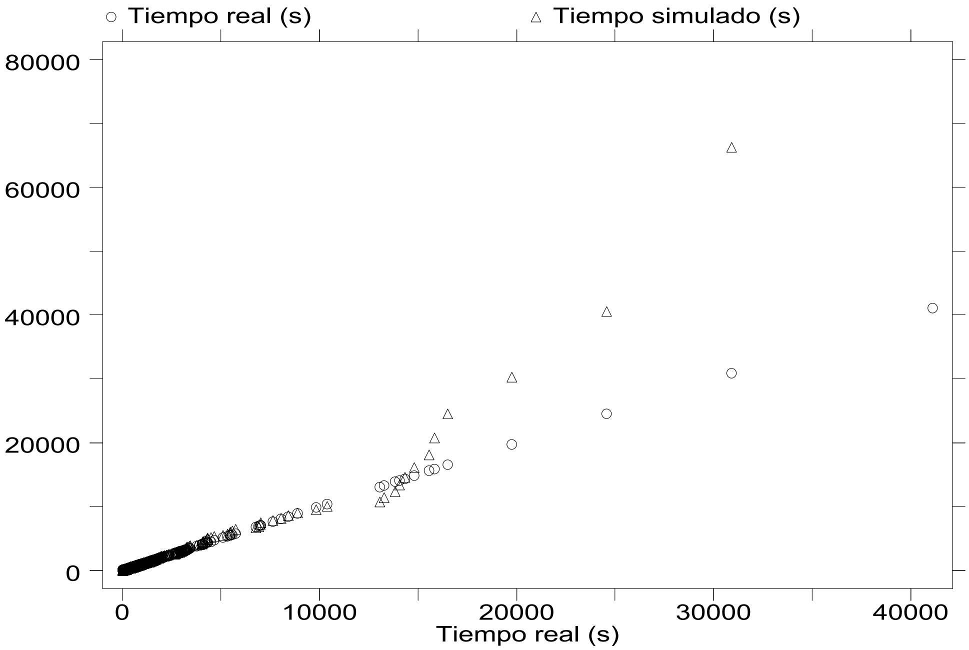


Figure 5.22. Real and predicted data for the times between openings –Monday through Friday

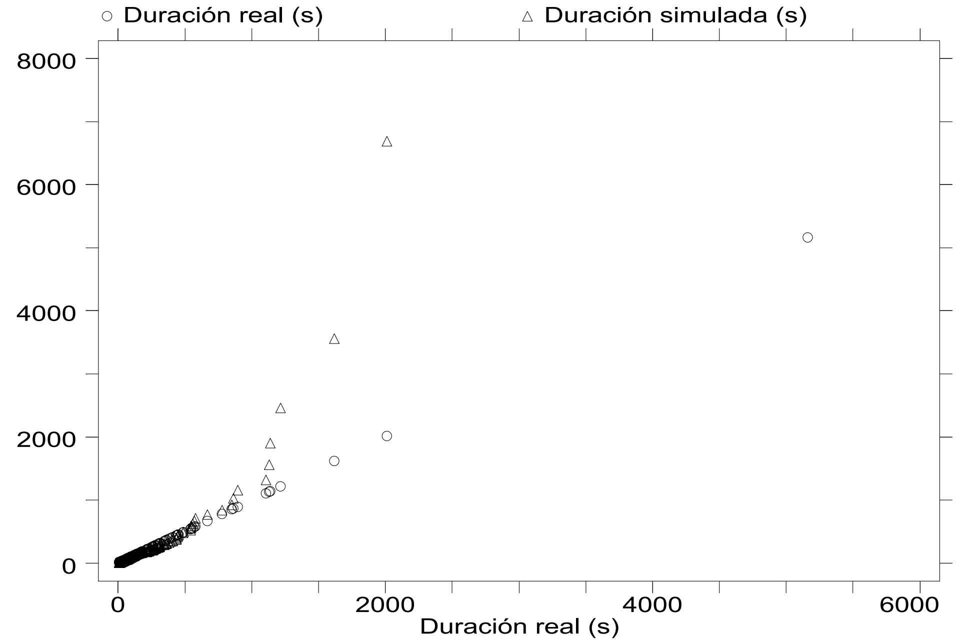


Figure 5.23. Real and predicted data for the duration of the openings-Saturdays and Sundays

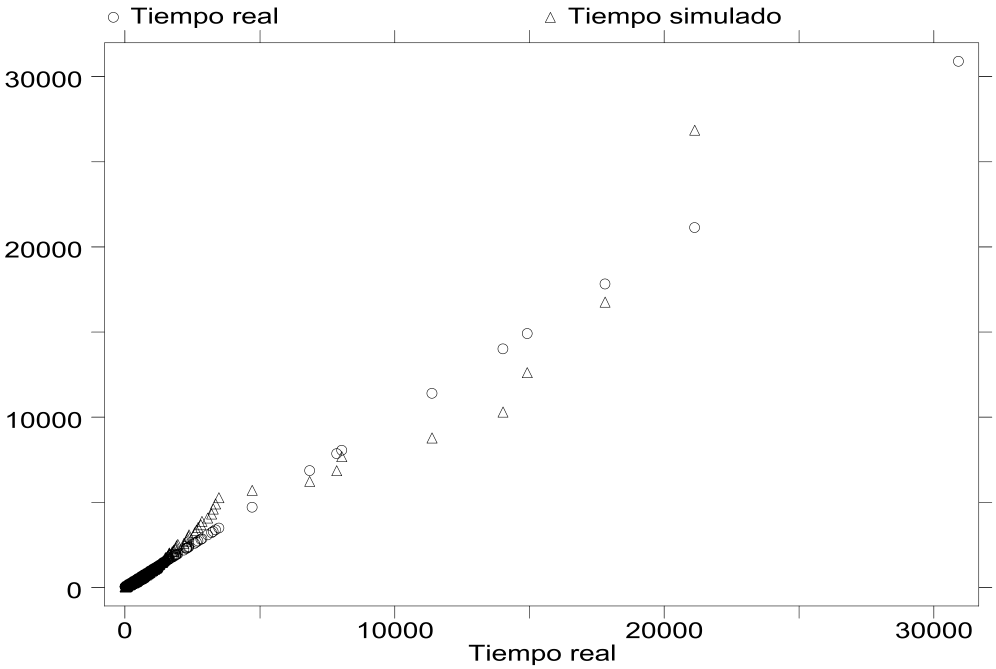


Figure 5.24. Real and predicted data for the times between openings-Saturdays and Sundays

A detailed statistical summary is shown in Tables 5.12 and 5.13) for the measured values and the predicted ones for every period.

Table 5.12. Time between openings for the days of the week and the weekends

Period	**Variable (s)**	**Average (s)**	**Standard deviation (s)**	**Minimum (s)**	**Maximum (s)**
Monday through Friday	Real time	502.45	1782.92	20.14	41111.41
	Predicted time	519.91	2231.23	18.44	66326.48
Saturdays and Sundays	Real time	426.83	1583.58	11.36	30903.96
	Predicted time	405.30	1312.56	16.35	26875.13

Table 5.13. Duration of the openings for the days of the week and the weekends

Period	**Variable (s)**	**Average (s)**	**Standard deviation (s)**	**Minimum (s)**	**Maximum (s)**
Monday through Friday	Real time	60.91	128.74	10.00	2062.74
	Predicted time	62.17	163.72	4.44	3794.92
Saturdays and Sundays	Real time	66.17	211.26	10.00	5161.06
	Predicted time	69.82	276.80	8.84	6689.71

Figures 5.21 to the Figure 5.24 and the Tables 5.12 and 5.13 show that the real and predicted averages of the times between openings are very similar. This also happens with the duration of the openings, the averages of the real durations and the averages of

the predicted times for both periods are similar. Also, the standard deviations of the real and predicted values and the values of the minima for both periods are similar. This demonstrates that the regressions predict the variability of the times between openings and the durations for the real times. However, the regressions don't predict the values of long times well and there are marked differences between the predicted and real times values. But these values of times that are not reproduced satisfactorily by the regressions are very few in comparison with the 2,148 values used to create the regressions. In Figure 5.21 appear eleven real data, which are not reproduced satisfactorily by the probabilistic regressions. The same happens with the values of the long times of opening durations as for the times between openings.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

The purpose of this investigation was to create a probabilistic model of instantaneous water demand in combination with a dynamic hydraulic model.

The most important conclusions are:

1. The hydraulic model in combination with the statistical model predicts with accuracy the real behavior of the distribution line of the laboratory.
2. The model is able to predict the behavior of the distribution line with times between small openings and small durations with good accuracy, likewise as the times between more spaced openings and longer durations.
3. The number of persons and the hours of the day do not influence significantly in the averages of the times between openings and the durations of the openings.
4. No significant difference exists between the values of the times of opening and the duration of the real openings in comparison with the predicted values of the times between openings and the duration of these, generated by the probabilistic regressions.
5. The regressions provide a probabilistic base to simulate the instantaneous demands of in a water distribution system.

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Information Transfer Program

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	3	0	0	0	3
Masters	3	0	0	0	3
Ph.D.	0	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	6	0	0	0	6

Notable Awards and Achievements

Publications from Prior Projects