A CONCEPTUAL END-USE MODEL FOR RESIDENTIAL WATER DEMAND AND RETURN FLOW

by

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ABSTRACT

A conceptual end use model for residential water demand and return flow is presented in this thesis. The model requires a unique description of a single residential stand in terms of all its end-uses. The end-uses include toilet flushing, bathing and showering, garden watering, leaks, et cetera. Various parameters describe each of the end-uses. The model predicts five components relating to water demand and wastewater flow at a residence: indoor water demand, outdoor water demand, hot water demand, wastewater flow volume and concentration of solutes in the wastewater. Twelve monthly results are calculated, for each of the five components, to provide a typical seasonal pattern as well as an annual value.

The large number of input parameters in an end-use model allows for powerful and detailed analysis. The parameters required to populate the model are discussed and guideline values are presented.

The end-use model is used to conduct a sensitivity analysis of each independent parameter for each of the five individual model components. The elasticity and sensitivity is determined at a base point with respect to each parameter for all five results. A research significance index is also devised to integrate the elasticity and availability of data for each parameter. The result is a prioritised list of the most critical parameters for each of the five components, which are the ones that should receive the focus for future study and data recording.

The parameters are combined to obtain a list of the overall most important parameters in the model for all components combined, and based on a combination of the elasticity-based rank and the sensitivity based rank. The five most important parameters are the household size, toilet flush frequency, toilet flush volume, the washing machine event frequency and the volume of leaks on a stand.

The practical application of the model is illustrated. The researchers first apply the model to mimic a few commonly accepted characteristics of water demand. The effectiveness of some specific water demand management measures are evaluated by adjusting selected model parameters. The measures include xeriscaping, the installation of dual-flush toilets, low-flow showerheads, pool ownership and pool cover use. The model also enables practitioners to obtain an insight into the water use habits of homeowners.

The model forms the basis for further research work in the field. Its relatively simple structure and realistic data requirement encourages its integration into existing commercially available software suites for water and sewer system analysis and -management in the civil engineering industry in South Africa, as well as abroad.

KEYWORDS (Library of Congress Subject Headings)

Water consumption – Mathematical models	Watervoorsiening – Wiskundige modelle
Water consumption – Management	Watervoorsiening – Bestuur
Municipal water supply – Management	Munisipale Watervoorsiening – Bestuur
Water salinization	Waterversouting
Sewage	Rioolwater
Hot water supply	Warmwatervoorsiening

DECLARATION

I hereby declare that this thesis submitted for degree DOCTOR INGENERIAE at the RAU, apart from the help recognised, is my own work and has not been formerly submitted to another university for a degree.

H E Jacobs

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ABBREVIATIONS AND ACRONYMS

AADC	average annual daily concentration of TDS (mg/litre)
AADD	average annual daily demand (litres/stand/day)
AADF	average annual daily flow (litres/stand/day)
AADM	average annual daily mass (mg/stand/day)
ACA	Australian Consumers' Association
AMDC	average monthly daily concentration of TDS (mg/litre)
AMDD	average monthly daily demand (litres/stand/day)
AMDF	average monthly daily flow (litres/stand/day)
AMDM	average monthly daily mass (mg/stand/day)
a	binary flag to indicate whether the end-use is present / applicable (=1) or not (=0)
b	volume parameter (litres/event/quantity)
c	frequency parameter (events/person/day or events/stand/day)
CDF	Cumulative distribution function
CSIRO	Commonwealth Scientific and Industrial Research Organisation (of Australia)
d	quantity parameter (household size)
days	number of days in a month (average 30,44 days per month over the year)
DW	Dishwasher (end-use)
DWAF	Department of Water Affairs and Forestry
e	end-use; refer to Table 3.1 for a list of end-uses pertaining to each model component
EC	Electrical Conductivity (a measure of salinity of water, measured in mS/m)
ET	Evapotranspiration
f	garden irrigation factor, or factor for pool cover use
HSRC	Human Sciences Research Council
IMQS	Infrastructure Management Query Station
IWRAPS	Installation Water Resources Analysis and Planning System
IWR-MAIN	Institute for Water Resources – Municipal and Industrial Needs
IWRP	Integrated Water Resources Planning
IWA	International Water Association
JW	Johannesburg Water
m	month (1 ... 12, or January ... December)
k	the empirical constant of proportionality between p and ET known as the crop factor (and it also represents the empirical constant of proportionality between p and the evaporation from the pool surface in this thesis)
l/c/d	litres per capita per day (i.e. litres per person per day)

l/stand/d	litres per stand per day
mg/l	milligram per litre (pertaining to TDS concentration)
MBA	Masters of Business Administration
MNF	Minimum night flow (used to determine leaks by measuring the wastewater flow)
mS/m	milli-Siemens per meter (pertaining to EC measurement)
r	effective monthly rainfall (mm/month)
p	pan evaporation (mm/month)
P_D	Difference value for price elasticity
PPH	People per household (the unit of measurement for household size)
R	actual, or measured, monthly rainfall (mm/month)
RAU	Rand Afrikaans University (named University of Johannesburg after 2005)
RDP	Reconstruction and Development Programme (poverty relief in South Africa)
REUM	Residential End-Use Model (the model described in this thesis)
RW	Rand Water
s	surface area of vegetation type, or surface area of pool water (m^2)
SA	South Africa
SAWS	South African Weather Service
SWIFT	Sewer Water Interface to Treasury
t	actual mass of soluble substances added to water (mg/event)
u	wastewater return factor (0 for no return and 1 for 100% return of water)
UK	United Kingdom
US (or USA)	United States of America
T	water temperature (°C)
TDS	total dissolved solids (mg/litre)
TOPAZ-SUCO	Technique for Optimal Placement of Activities in Zones – Service Utility COsting
VB	Visual Basic
WDM	Water demand management
WM	Washing machine (end-use)
WRC	Water Research Commission
WRSM90	Water Resources Simulation Model 1990 (Midgley et al, 1994)
WSDP	Water Services Development Plan
WSSM	Water Supply Services Model

and the subscript :

c denotes cold (water)

e denotes end-use (refer to Table 3.1)

h denotes hot (water)

i denotes indoor

m denotes month (1 ... 12, or January ... December)

o denotes outdoor

p denotes potable water

s denotes soluble substance

B denotes blended (“desired”) water temperature for end use e

C denotes cold water supply temperature ≈ ambient temperature

H denotes hot water supply temperature ≈ geyser temperature

w denotes wastewater

LIST OF RELEVANT CONVERSION FACTORS

To Convert FROM	Multiply By	TO Obtain
feet	0.3048	metres
gallons(US)	3.785	litres
gallons(US)/day	3.785	litres/day
gallons(US)/capita/day	3.785	litres/capita/day
inches	25.4	millimetres
inches/hour	25.4	mm/hour
gallons(US)/minute	0.063	litres/second
cubic feet	28.316	litres
square feet	0.093	square metres
gallons(US)/week	0.541	litres/day
gallons(US)/household/day	3.785	litres/dwelling/day
gallons(US)/year	0.003785	kilolitres/year
hundred ft^3 per year	2831.685	kilolitres/year
hundred ft^3 per year	7758.040	litres/day