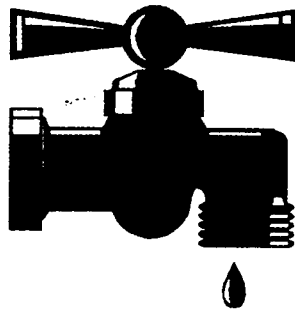


Research Report



The Significance of Rainwater on Sewer Flow

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Econ 6416

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EXECUTIVE SUMMARY

- The City of ██████ outsources its sewer treatment by purchasing reserved capacity at the Iron Bridge Regional Water Pollution Control Facility. Recently, ██████ has incurred penalties for sending wastewater flows in excess of its reserved capacity. The sanitary sewer system is a closed system, but increases in sewer flow appear to coincide with higher levels of rain. This analysis seeks to identify if rainwater is a significant factor in sewer flow.
- Data in the initial model includes: sewer flow in thousands of gallons; inches of rain per month; average monthly temperature; number of residential and commercial customers; number of residential and commercial meters; and, residential and commercial consumption in thousands of gallons (excluding irrigation). It covers the time period from August, 1995 through January, 1998, a total of thirty observations.
- When moving from model A to the final model C, and as a result of multicollinearity, residential meters and customers were eliminated as variables. The LM test indicates the model does not suffer from serial correlation. A review of the t-statistics combined with the Wald test reduced the independent variables to commercial consumption, residential consumption and rainfall. In model C, the F-statistic p-value is less than .05, therefore there is a relationship between the independent variable and dependent variables. The adjusted R-squared indicates that 94 percent of the variation in sewer flow is explained by the independent variables. The p-values of the independent variables are less than .05, indicating they are all significant. The signs of the coefficients are all appropriately positive.
- The final model confirms the infiltration of rainwater into the sewage collection system.
- To address the problem the City has two choices. First, the City may undertake a costly capital improvements program to eliminate leaks in the transmission system. Identification of all the sources of intrusion may not be possible or economically feasible. The second option is to purchase more capacity at Iron Bridge to eliminate the penalty charges. Although this option appears to be the more economical and practical, the cost to the environment and the capital costs involved in adding additional capacity to the plant may be prohibitive.

INTRODUCTION

The City of [REDACTED] (City) provides sewer service to its residents by purchasing reserved capacity at two sewage treatment plants operated by other municipalities. [REDACTED] transmits its wastewater to the Iron Bridge Regional Water Pollution Control Facility (Iron Bridge) operated by the City of Orlando, which currently costs one dollar per thousand gallons up to the amount of reserved capacity. The City is assessed a penalty of approximately \$4,000 (one month's operation and maintenance charges) for flows that exceed reserved capacity for five days in a given month.

During the last 30 months the City has exceeded its capacity and incurred penalties eight times. The months in which capacity was exceeded were months that had significant rainfall. Rainwater should not increase the flow through the sanitary sewer system because it is a closed system. At this time the City has no definitive test to determine if excess flows are caused by rainwater, additional customers and/or increased consumption. This analysis will determine if rainwater is a significant factor in the number of gallons per month of wastewater flow transmitted to Iron Bridge.

DATA

The unit of observation is the City of [REDACTED] and its wastewater transmissions. The time period covered is from August, 1995 through January, 1998. The dependent variable is the wastewater flow in thousands gallons sent to the treatment plant as measured by the Iron Bridge master meter. The initial independent variables are:

- Inches of rain per month
- Average monthly temperature
- Total number of residential customers
- Total number of commercial customers
- Total number of residential meters
- Total number of commercial meters
- Residential consumption in thousands of gallons (excluding irrigation)
- Commercial consumption in thousands of gallons (excluding irrigation)

The inches of rain per month and average monthly temperature were obtained from the Southeast Regional Climate Center of the National Weather Service. Data regarding number of customers, meters and consumption were obtained from the City of [REDACTED] records. The sewer flow data was obtained from Iron Bridge. See appendix E for the list of specific reports.

REGRESSION ESTIMATIONS

INITIAL MODEL: MODEL A

Variable	Coefficient	t-Statistic	p-Value
Rainfall	149.198	4.044	0.001
Residential Consumption	1.127	2.275	0.034
Commercial Consumption	0.636	6.139	0.000
Residential Meters	26.696	1.065	0.299
Commercial Meters	-0.208	-0.001	0.999
Residential Customers	-103.990	-1.318	0.202
Commercial Customers	-156.040	-0.447	0.660
Average Temperature	42.272	1.899	0.072
Constant	225350.800	1.439	0.165

R-squared .956
 Adjusted R-squared .940
 F-statistic 57.695
 Prob (F-statistic) .000

FINAL MODEL: MODEL C

Variable	Coefficient	t-Statistic	p-Value
Rainfall	157.201	4.684	0.000
Residential Consumption	1.236	2.580	0.016
Commercial Consumption	0.723	7.593	0.000
Constant	3400.857	2.661	0.013

R-squared .946
 Adjusted R-squared .940
 F-statistic 151.055
 Prob (F-statistic) .000

In Model A the F-statistic probability is less than .05, therefore there is a relationship between the independent and dependent variables. The adjusted R-squared of .94 indicates that 94 percent of variation of sewer flow is explained by the independent variables. Ignoring the intercept, the probability of the t-statistics for rainfall, residential consumption, and commercial consumption are significant with values of less than .05. Number of residential and commercial customers, number of residential and commercial meters, and average temperature have probabilities in excess of .05, which more than likely indicate they are not significant. Contrary to logical assumptions, commercial meters, residential

customers and commercial customers all have negative estimated coefficients. An increase in any of these variables should increase sewer flow.

In Model C, the F-statistic probability remains less than .05, and the adjusted R-squared is still .94. The probabilities of the independent variables are less than .05, indicating they are all significant. The signs of the coefficients are all appropriately positive.

Model Estimation Sequence

(1) Correct Functional Form. To check for correct functional form, each variable was plotted against the dependent variable. These graphs along with the residual plot, located in appendix D, appear to negate any nonlinear relationships. Both the F-statistic and adjusted R-squared are high. These factors, combined with the fact that the sewer system is a closed system and there are limited other potential variables, reduces the possibility that variables have been omitted.

(2) Multicollinearity. The correlation matrix is located in appendix C. The number of residential customers and number of residential meters are highly correlated, a rho of .98 and high t-statistic p-values support a drop decision. Even though the p-values of the t-statistic are high, the correlation between number of commercial customers and number of commercial meters is moderate resulting in a keep decision. The moderate rho value of residential consumption and commercial consumption along with the low t-statistic p-value signals a keep decision.

(3) Serial Correlation. The result of dropping the collinear variables is model B located in appendix B. The LM test for higher order serial correlation, the results of which are located in appendix F, produced a (T-p)R-squared of 11.71. The F-statistic was less than the chi-square statistic of 21.0 at a .05 level of significance with $p=12$.

(4) Correction. Based on the above, no serial correlation is indicated in model B.

(5) Irrelevant Variables. In model B the p-values for the t-statistics for commercial meters, commercial customers and average temperature are greater than .05, which strongly suggests they are not individually significant. The Wald test of joint significance was conducted to determine if the variables are significant as a group. Model B is the unrestricted model and model C is the restricted model. The F-statistic for the Wald test is less than the critical value of 3.03 at a .05

level of significance corroborating that there is no relationship among the independent variables of commercial meters, commercial customers and average temperature. See appendix F for Wald test values.

FINAL MODEL EVALUATION

Model C estimates each inch of rain increases sewer flow by 157,000 gallons. For every thousand gallons of residential water consumed, sewer flow increases by 1,240 gallons, while a thousand gallons of commercial water increases sewer flow by 720 gallons. It appears that residential customers' sewage flow is augmented by items other than water.

The model confirms the infiltration of rainwater into the sewage collection system. In every model that was estimated, the p-value for rainwater remained significant. Clearly, rainwater intrusion seriously impacts the costs the City of [REDACTED] incurs for the treatment of effluent.

SUMMARY

The infiltration of rainwater translates into a cost of \$157 per inch. Over the course of an average year the National Weather Service's statistics for Central Florida indicate a normal rainfall of 53.5 inches. The City can expect to pay \$8,400 per year to treat rainwater, as well as penalties of approximately \$4,000 per month when reserved capacity is exceeded for five days. To address the problem the City has two choices. First, the City can undertake a program of lift station improvements to eliminate leaks in the transmission system. This option is a capital improvement project, with a substantially high monetary cost to the City. However, identification of all the sources of rainwater intrusion may not be possible or economically feasible. The second option is to purchase more capacity at the Iron Bridge facility, and continue to incur the monthly charges to have rainwater treated, but eliminate the penalty charges. Although this option appears to be the more economical and practical, the cost to the environment and the capital costs involved in adding additional capacity to the plant may be prohibitive.

Data Table

Date of Observation	Sewer Flow	Rain in Inches	Residential Consumption	Commercial Consumption	Average Monthly Temperature	Number of Commercial Meters	Number of Residential Meters	Number of Commercial Customers	Number of Residential Customers
August-95	37,430	15.3	5,671	34,681	81	311	3,691	248	2,952
September-95	34,909	12	5,121	32,347	79	311	3,693	248	2,953
October-95	34,980	6.7	5,009	32,567	72	311	3,690	248	2,952
November-95	29,810	1.5	4,821	27,777	65	311	3,693	248	2,937
December-95	30,150	2.7	4,599	26,591	59	312	3,714	248	2,955
January-96	29,465	6.2	4,458	27,654	70	312	3,697	248	2,956
February-96	26,194	2	3,954	25,798	57	312	3,698	248	2,957
March-96	29,663	17	4,264	24,987	59	312	3,707	248	2,963
April-96	27,800	5.9	4,150	25,700	65	312	3,710	248	2,964
May-96	25,027	6.2	3,500	23,200	70	312	3,716	248	2,966
June-96	28,530	16.5	3,421	25,321	75	312	3,720	248	2,967
July-96	26,488	9.3	4,009	22,364	80	312	3,729	248	2,970
August-96	30,919	9.3	4,087	25,987	81	312	3,730	248	2,970
September-96	29,396	6.2	3,402	26,987	81	312	3,734	248	2,971
October-96	29,988	0.01	4,891	29,542	79	312	3,746	248	2,975
November-96	25,201	0.1	3,900	24,000	72	312	3,747	248	2,975
December-96	25,826	2.1	4,000	23,928	65	312	3,749	248	2,975
January-97	25,264	1.9	3,950	23,400	59	312	3,756	248	2,977
February-97	22,395	5.2	3,121	20,546	70	312	3,764	249	2,981
March-97	24,425	4.6	3,002	22,750	57	312	3,772	249	2,982
April-97	23,763	3.7	3,102	22,879	59	313	3,776	248	2,980
May-97	27,436	4.8	4,254	25,421	65	313	3,784	248	2,982
June-97	27,286	6.3	4,101	25,201	70	319	3,789	251	2,985
July-97	30,464	7	4,211	27,985	75	316	3,797	250	2,987
August-97	29,654	6.5	4,325	28,951	80	316	3,803	250	2,989
September-97	27,579	2.1	4,024	25,489	81	316	3,809	250	2,991
October-97	27,389	2.7	4,125	24,899	81	315	3,816	250	2,992
November-97	26,530	4.8	4,001	23,555	79	316	3,819	251	2,994
December-97	29,051	15.6	4,177	26,987	72	317	3,820	251	2,995
January-98	29,227	2.6	4,576	27,575	65	315	3,826	251	2,998

Model A, B, C

Model A:

Equation

Sewer Capacity = $225350.8 + 149.20(\text{Rainfall}) + 1.13(\text{Residential Consumption}) + .63(\text{Commercial Consumption}) + 26.70(\text{No. of Residential Meters}) - 21(\text{No. of Commercial Meters}) - 104.00(\text{No. of Residential Customers}) - 156.04(\text{No. of Commercial Customers}) + 42.27(\text{average temperature in degrees})$

Variable	Coefficient	t-Statistic	P-value	Std. Error
Rainfall	149.20	4.04357	0.001	36.90
Residential Consumption	1.13	2.275312	0.034	0.50
Commercial Consumption	0.64	6.139406	0.000	0.10
No. of Residential Meters	26.70	1.065238	0.299	25.06
No. of Commercial Meters	-0.21	-0.00125	0.999	165.57
No. of Residential Customers	-104.00	-1.31895	0.202	78.92
No. of Commercial Customers	-156.04	-0.44685	0.660	349.21
Average Temperature	42.27	1.898247	0.072	22.27
Intercept (C)	225,350.80	1.438673	0.165	158,837.90

Statistics	
R Squared	0.9565
Adjusted R Squared	0.9399
S.E. of Regression	813.6637
Sum Squared Residuals	13,903,021
Durbin-Watson Statistic	2.1421
F-Statistic	57.6949
P Value of F-Statistic	0.0000

Model B:

Equation

Sewer Capacity = $46405.28 + 152.00(\text{Rainfall}) + 1.30(\text{Residential Consumption}) + .68(\text{Commercial Consumption}) + 33.16(\text{No. of Commercial Meters}) - 218.91(\text{No. of Commercial Customers}) + 29.81(\text{average temperature in degrees})$

Variable	Coefficient	t-Statistic	P-value	Std. Error
Rainfall	152.00	4.384152	0.000	34.87
Residential Consumption	1.3	2.700641	0.0128	0.480229
Commercial Consumption	0.68	6.95974	0.000	0.10
No. of Commercial Meters	33.16	0.2053	0.839	161.51
No. of Commercial Customers	-219.91	-0.80845	0.427	272.01
Average Temperature	29.81	1.44599	0.162	20.62
Intercept (C)	46,405.28	1.321701	0.1993	35,110.28

Statistics	
R Squared	0.9521
Adjusted R Squared	0.9396
S.E. of Regression	815.8499
Sum Squared Residuals	15,309,053
Durbin-Watson Statistic	2.0539
F-Statistic	76.1627
P Value of F-Statistic	0.0000

Model C:

Equation

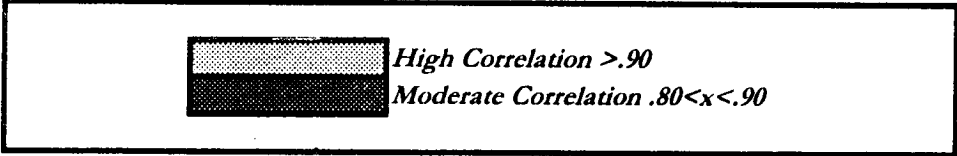
Sewer Capacity = $3400.857 + 157.20(\text{Rainfall}) + 1.24(\text{Residential Consumption}) + .72(\text{Commercial Consumption})$

Variable	Coefficient	t-Statistic	P-value	Std. Error
Rainfall	157.20	4.683506	0.000	33.56
Commercial Consumption	0.72	7.592978	0.000	0.10
Residential Consumption	1.24	2.579814	0.016	0.48
Intercept (C)	3,400.86	2.860893	0.0132	1,278.09

Statistics	
R Squared	0.9457
Adjusted R Squared	0.9394
S.E. of Regression	816.5415
Sum Squared Residuals	17,335,239
Durbin-Watson Statistic	1.7102
F-Statistic	151.0545
P Value of F-Statistic	0.0000

Correlation Matrix

	Sewer Flow	Rain in Inches	Residential Consumption	Commercial Consumption	Average Monthly Temperature	Number of Commercial Meters	Number of Residential Meters	Number of Commercial Customers	Number of Residential Customers
Sewer Flow	1.00	0.46	0.84	0.95	0.41	-0.18	-0.39	-0.11	-0.48
Rain in Inches	0.46	1.00	0.15	0.28	0.23	-0.13	-0.23	-0.02	-0.23
Residential Consumption	0.84	0.15	1.00	0.85	0.26	-0.11	-0.23	-0.05	-0.41
Commercial Consumption	0.95	0.28	0.85	1.00	0.35	-0.15	-0.33	-0.07	-0.77
Average Monthly Temperature	0.41	0.23	0.26	0.35	1.00	0.22	0.15	0.22	-0.43
Number of Commercial Meters	-0.18	-0.13	-0.11	-0.15	0.22	1.00	0.79	0.87	0.73
Number of Residential Meters	-0.39	-0.23	-0.23	-0.33	0.15	0.79	1.00	0.93	0.98
Number of Commercial Customers	-0.11	-0.02	-0.05	-0.07	0.22	0.87	0.93	1.00	0.77
Number of Residential Customers	-0.48	-0.23	-0.41	0.77	-0.43	0.73	0.98	0.77	1.00



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The graphs are not presented in order
to save room.

APPENDIX E

Data Sources

- (1) City of ████████ Utilities Department Monthly Consumption Report,
August, 1995 through January, 1998.
- (2) City of ████████ Utilities Department Water Plant Information Report,
August, 1995 through January, 1998.
- (3) City of Orlando, Iron Bridge Water Pollution Control Facility, Monthly Flow Report,
August, 1995 through January, 1998.
- (4) Southeast Regional Climate Center of the National Weather Service, Monthly
Temperature Averages and Average Monthly Precipitation, <http://www.nws.noaa.gov/climate.shtml>.