Water/Wastewater Engineering Report
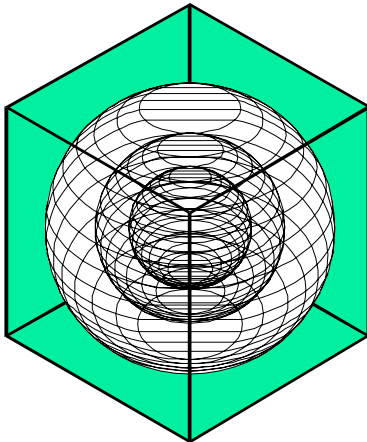
(Storm Sewer/Infiltration Sanitary Sewage Separation-M1 Model)

Report to the
Texas Commission on Environmental Quality

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Acknowledgements

Executive Summary

This report presents the methodology used to develop the storm sewer/infiltration sanitary sewer separation model (M1) for a wastewater treatment plant. It reviews the history of the ASHRAE's Inverse Model Toolkit (IMT), and the linear and change-point linear models, which are used to develop the M1 Model. It also includes a detailed description of an example to illustrate the methodology and the IMT weather-normalization analysis.

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INTRODUCTION

In some cities, the municipal sewer system collects both storm water and sanitary sewage in the same pipes. During dry weather these sewers carry all the sanitary sewage to the wastewater treatment plant for treatment. However, when rainstorms or snow melt increase the amount of runoff, the combined flow of sanitary sewage and storm water can exceed the capacity of the sewer system, which can cause serious problems like the storm water and sewage mix are discharged untreated into the river or the sewage backs up into streets and basement. Storm water treated in the sewage treatment plant also causes unnecessary energy use. Sewer systems can also have unintended ground water entering the network, which occurs because of hydraulic pressure on the buried sewer lines infiltration. Therefore, separating the storm water/infiltration and sanitary sewage reduces the possibility of sewage discharge during heavy rain periods, and saves energy.

In this document, a statistical methodology for calculating the savings from the storm water/infiltration sanitary sewage separation (i.e., the "M1 model") is presented. This method uses ASHRAE's Inverse Model Toolkit (IMT) for the weather-normalization analysis. This document provides a review of the ASHRAE IMT, a description of the M1 model, and provides an example to illustrate the methodology.

DESCRIPTION OF M1 MODEL

The intention of M1 model is to calculate the energy savings and emissions reductions from storm sewer/infiltration sanitary sewage separation. As shown in Figure 1, the user is required to input the pre-retrofit monthly wastewater treated, and the coincident electricity use (a minimum of ten periods), estimate growth rates covering 1999, 2002, 2007, and 2010, and estimate the percent of storm water or infiltration that can be blocked or fixed. Next, the ASHRAE Inverse Model Toolkit (IMT) is used to determine the regression coefficients for the weather normalization of the monthly wastewater vs. rainfall and monthly wastewater vs. energy consumption using two-parameter linear regression models. In the output report, the annual energy savings (kWh/yr), Ozone Season Day (OSD) energy savings (kWh/day), and NOx emissions reductions in 1999/2007/2010 and 2002/2007/2010 for annual and OSD period are provided.

For this analysis the 2007 eGRID, developed by the EPA for the TCEQ, was used to predict the 2007 electricity and pollution for utilities in the ERCOT Power Control Area. The 2007-OSD eGRID was used for calculating the daily emissions on Ozone Season Days, and the annual 2007 eGRID was used for the annual calculations. Both the annual and OSD calculations assume eGRID's 25% plant capacity factor. In eGRID the NOx production for each power plant is provided for ten electric utility suppliers (i.e., AEP, Austin Energy, Brownsville Public Utility, LCRA, Reliant, San Antonio Public Service, South Texas Coop, TMPP, TNMP, and TXU). In the case of an unknown power provider, the M1 model assigns the utility based on the Texas Public Utility Commission's (PUC's) 2002 Power Control Authority (PCA) listing[1]. Once the utility

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[1] For more information on the assumptions behind this assignment see the ESL's 2004 Annual Report to the TCEQ (Haberl et al. 2004a, b, c).

provider has been chosen for a given county the eGRID emission factor for 2007 is used for both 2007 and 2010 calculations.
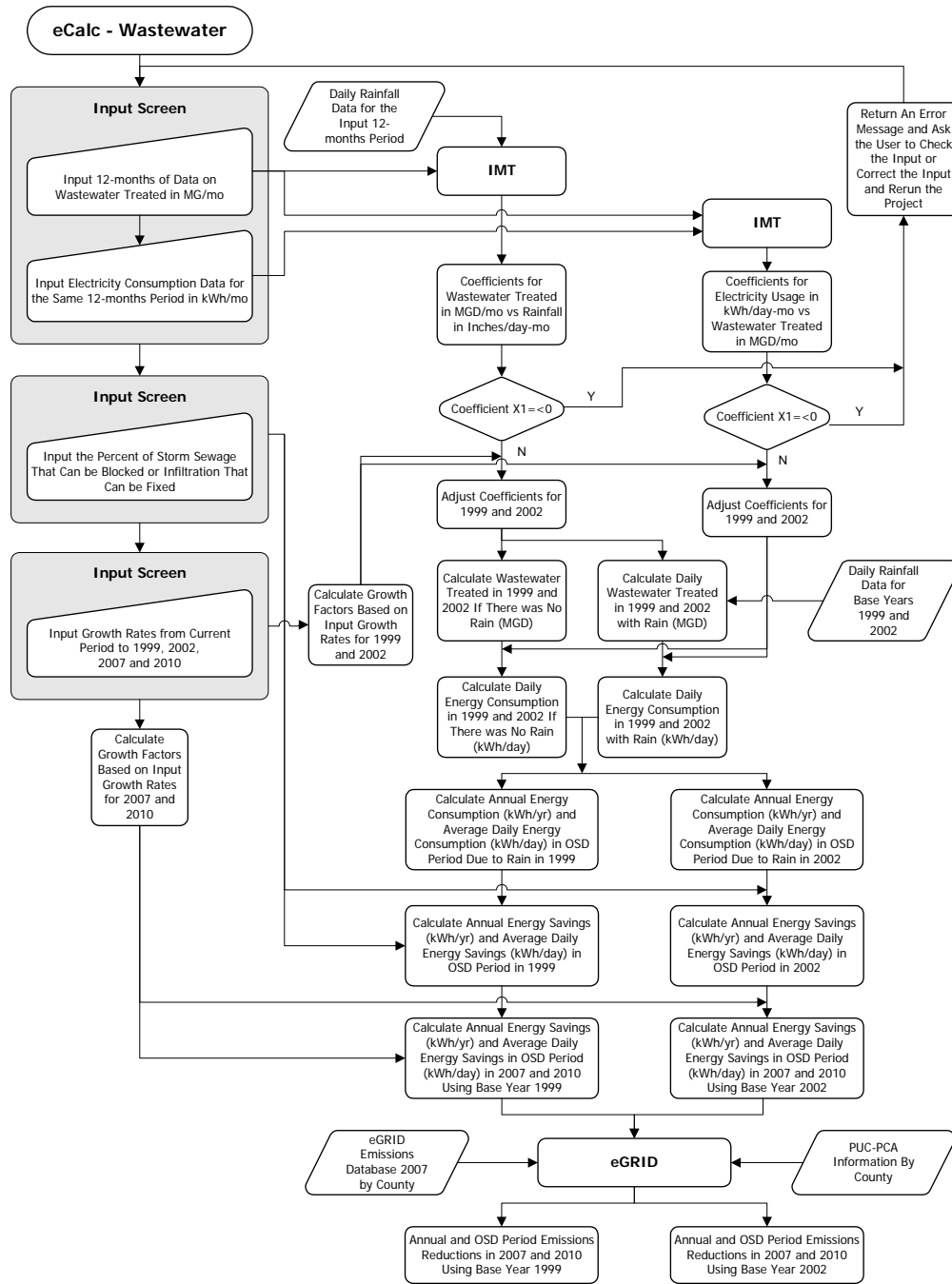

Figure 1. Flow Chart for M1 Model.

INVERSE MODEL TOOLKIT (IMT)

ASHRAE's Guideline 14-2002 has identified three methods for measuring energy savings, including component isolation, before-after measurements, and calibrated

simulation (ASHRAE 2002). These methods are intended to be guidelines that will serve as a foundation for the development of reliable and accurate measurement of energy and demand savings from energy conservation retrofits. Guideline 14 describes linear, change-point linear, variable-based degree-day, and multivariable linear regression models for calculating before-after savings from energy conservation retrofits.

ASHRAE's Inverse Model Toolkit (IMT) is a public domain FORTRAN 90 application for calculating linear, change-point linear (CP), variable-based degree-day (VBDD), multi-linear, and combined regression models (Kissock et al. 2001). The development of the IMT was sponsored by ASHRAE research project RP-1050 under the guidance of Technical Committee 4.7 -- Energy Calculations.

Figure 2 shows the history of the different models contained in the IMT (Cho and Haberl 2004). During the 1980s, Goldberg (1982) and Fels (1986) developed the PRInceton Scorekeeping Method (PRISM) method for use in measuring savings in residential buildings. PRISM uses a Variable-Based Degree Day methods (VBDD) for weather-normalizing the monthly energy use of a residence. The algorithm finds the base-temperature that gives the best statistical fit between energy consumption and the number of variable-base degree-days in each energy use period. Goldberg (1982) developed the mathematical basis of the PRISM model, which includes a detailed uncertainty analysis in her Ph.D. dissertation, "A Geometrical Approach to Non-differentiable Regression Models as Related to Methods for Assessing Residential Energy Conservation," Department of Statistics, Princeton University.

PRISM was one of the first methods to include an estimate of the standard error for all regression parameters (Goldberg 1982). The method found widespread use in the utility industry, especially in evaluating residential energy conservation programs. Subsequently, PRISM was found to provide adequate statistical fits with commercial building billing data (Eto 1988, Haberl and Vajda 1988, Haberl and Komer 1990, Kissock and Fels 1995). However, the physical interpretation of the variable-base degree-day method does not always apply to all commercial buildings that may have varying degrees of heating or cooling energy use (i.e., the energy use is not well described by a three-parameter model), as pointed out by Rabl et al. (1992) and Kissock (1993).

To resolve this problem, Schrock and Claridge (1989) and later Ruch and Claridge (1992) developed a four-parameter change-point model of energy consumption, along with accompanying error diagnostics for the model's parameters. Their four-parameter change-point model finds the optimal change-point by searching within an interval known to contain the change-point. Ruch and Claridge (1993) also developed the statistically rigorous methods for estimating Normalized Annual Consumption (NAC) with four-parameter change-point and linear regression models, and investigated how best to incorporate additional variables for the weather normalization using principal component analysis (Ruch et al. 1993).
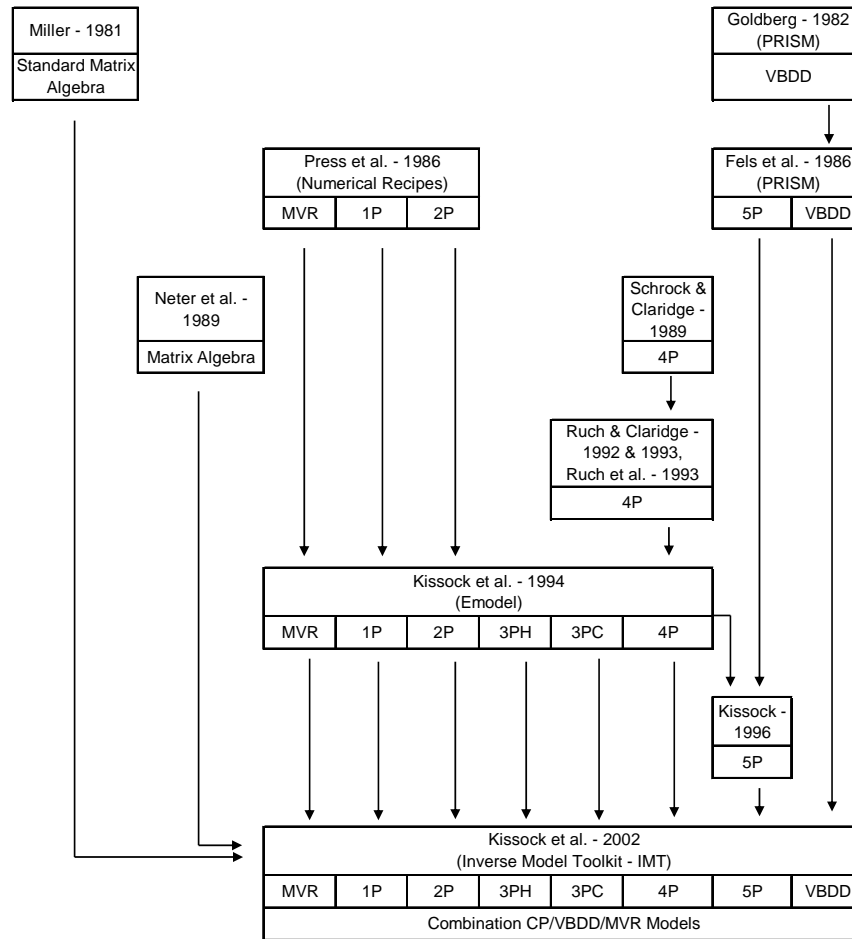
Figure 2. History Diagram of the Inverse Model Toolkit.

Kissock (1993) developed the algorithms for the EModel software as part of his Ph.D. dissertation, which was then developed into the EModel software by Kissock et al. (1994). The algorithms of the software use a two-stage grid search to identify the best change point. In this method, the minimum x value is selected as the initial change point in a standard piece-wise linear regression equation. The change point is then incremented and the regression is repeated across the range of x-values. The change point that results in the lowest RMSE is selected as the best-fit change-point temperature. This method is then repeated with a finer grid centered about the initial best-fit change point. The uncertainty with which the change-point temperature is known can be approximated as the width of the finest grid. The method is easily adaptable to three-parameter heating, three-parameter cooling and four-parameter models. The original EModel software also included one-parameter, two-parameter and multi-variable regression models, which used algorithms from Press et al. (1986).

A five-parameter Variable-Based Degree Day (VBDD) model was first reported in Fels (1986) and Fels et al. (1995). An algorithm for five-parameter change-point model was also developed by Kissock et al. (2001). These models have been used extensively with

building energy data that have both heating and cooling related loads and have proven to be extremely robust (Haberl et al. 1998).

CP and VBDD models have been shown to provide good statistical fits between building energy use and ambient temperature. However, other variables also influence building energy use. Combination CP-MVR and VBDD-MVR models contain this ability to describe energy use as a function of ambient temperature while including the effects of additional independent variables. One approach reported in the literature (Rabl and Railhe 1992, Ruch et al. 1993, Sonderegger 1997, Sonderegger 1998) is to sequentially identify the change-point or base temperature and then use this result in a MVR model. An alternative approach is to use indicator variables to produce separate CP or VBDD models for each operating or occupational mode (Austin 1997, Kissock et al. 1998).

To develop CP-MVR models for Inverse Model Toolkit, the change-point algorithms developed by Kissock (1994, 1996) were extended to include multiple independent variables. Using this approach, CP-MVR models can be identified in a single step, rather than sequentially, and without breaking up the data according to operational modes. Therefore, the Inverse Model Toolkit produces VBDD-MVR models by first running the VBDD model and then running the MVR model on the VBDD residual file.

From the literature it was found that the algorithms in the IMT almost exactly reproduce the same regression analysis one would get by running any one of the programs that it was compared against (i.e., usually to several significant digits). Four sets of accuracy and precision tests (Haberl et al. 2003) were performed as part of the testing for ASHRAE Research Project 1050-RP. The first set of tests was designed to test the accuracy and precision of IMT's computational and regression engines by comparing IMT results with results from the widely used SAS software (SAS 2001). These tests showed that IMT's 1P and 2P and MVR models were accurate to two significant decimal figures, (i.e., 99.99 % accurate or better).

In the second set of tests, IMT 3P, 4P and 5P change-point model results were compared to model results from EModel (Kissock et al. 1994). These tests also showed agreement to two significant figures (i.e., 99.99 % accurate or better). The third set of accuracy tests was designed to see how closely IMT change-point models could identify known change-points and slopes from synthetic data (Sreshthaputra et al. 2001). The results of the third set of tests showed that IMT's 3PC, 3PH and 4P models were accurate to three significant figures (i.e., 99.999 % accurate or better). In the fourth set of accuracy tests, IMT's variable-base heating and cooling degree-day models were compared to PRISM HO and CO models (Fels et al. 1995). The results of the fourth set of tests showed agreement within 99.0 % of the values calculated with PRISM.

In summary, in the case of IMT's 1P, 2P, 3P, 4P and MVR models, the program performs to within several significant decimal places to the same results from other widely accepted models. In the case of IMT's variable-based degree-day model, agreement is within 1% of the values reported by the Princeton Scorekeeping method (PRISM), which is considered acceptable since IMT and PRISM use different search algorithms for

finding the change-point temperature, and both report results in units that require conversion prior to comparison. Therefore, it can be concluded that the IMT is accurate, when it is called upon to perform weather normalized regressions for modeling building energy use, or other weather normalization tasks.

EXAMPLE APPLICATION OF THE M1 MODEL

In this section, a step-by-step example is given to illustrate the methodology used in M1 model.

1. User Input

First the user enters 12 months of data for the waste water treated and coincident electricity use as shown in the upper data block in Figure **3**. Next, the user needs to input the percent of storm sewer or infiltration that can be blocked or fixed. Finally, the user provides the estimated growth of their system covering 1999, 2002, 2007 and 2010.

a. User input 12-month of data on wastewater treated and electricity consumption with begin and ending date

Per	Month	Beginning Date	Ending Date	No. Of Days	Total Wastewater Treated (MG/mo)	Total Electricity Consumption (kWh/mo)
1	Jan-04	1/1/2004	1/31/2004	31	179.18	564,000
2	Feb-04	2/1/2004	2/29/2004	29	197.49	504,800
3	Mar-04	3/1/2004	3/31/2004	31	196.54	537,600
4	Apr-04	4/1/2004	4/30/2004	30	201.60	468,000
5	May-04	5/1/2004	5/31/2004	31	218.86	496,400
6	Jun-04	6/1/2004	6/30/2004	30	214.80	524,000
7	Jul-04	7/1/2004	7/31/2004	31	196.54	502,000
8	Aug-04	8/1/2004	8/31/2004	31	206.46	514,400
9	Sep-04	9/1/2004	9/30/2004	30	193.20	467,600
10	Oct-04	10/1/2004	10/31/2004	31	202.12	458,800
11	Nov-04	11/1/2004	11/30/2004	30	193.50	488,000
12	Dec-04	12/1/2004	12/31/2004	31	159.03	564,800

Note: MG/mo means million gallon per month

b. Other Input

If the input starting period is after Jan 01, 2002, use Screen B-I for input
Screen B-I:

b1	Percent of Storm Sewer that can be blocked, or Percent of Infiltration that can be fixed:	80%
b2	Total Growth Rate From 1999 to Current Period	20%
b3	Total Growth Rate From 2002 to Current Period	10%
b4	Total Projected Growth From Current Period to 2007	15%
b5	Total Projected Growth From Current Period to 2010	30%

If the input starting period is between Jan. 01, 1999 to Jan 01, 2002, use Screen B-II for input
Screen B-II:

b1	Percent of Storm Sewer that can be blocked, or Percent of Infiltration that can be fixed:	80%
b2	Total Growth Rate From 1999 to Current Period	10%
b3	Total Growth Rate From current period to 2002	10%
b4	Total Projected Growth From Current Period to 2007	30%
b5	Total Projected Growth From Current Period to 2010	45%

Note: 1999 and 2002 mean 1/1/1999 and 1/1/2002 respectively.

Figure 3. User Input Requirement.

In this example, the user inputs the growth rates from 1999 and 2002 to 2004 and from 2004 to 2007 and 2010. This allows the calculations to evaluate the conditions in the base year (i.e., 1999 or 2002), and in the 2007 and 2010 future years.

2. First Application of IMT

Next, the IMT is run to calculate the coefficient for the wastewater vs. rainfall relationship through the following steps:

Step 1: Retrieve daily rainfall data from the nearest NOAA weather station assigned to this city for the input period and create the IMT input data file RF.DAT, as shown in Figure 4. These data are used by IMT for the regression. This non-uniform data file contains daily date information (columns 1, 2 and 3), monthly sewage processed (column 4), and daily rain data (column 5).

RF.DAT:

1	1	2004	0	0
1	2	2004	-99	0
1	3	2004	-99	0
1	4	2004	-99	0.05
1	5	2004	-99	0
1	6	2004	-99	0
1	7	2004	-99	0
1	8	2004	-99	0.1
1	9	2004	-99	0
1	10	2004	-99	0
1	11	2004	-99	0
1	12	2004	-99	0
1	13	2004	-99	0.03
1	14	2004	-99	0.01
1	15	2004	-99	0.08
1	16	2004	-99	1.53
1	17	2004	-99	0.25
1	18	2004	-99	0.02
1	19	2004	-99	0
1	20	2004	-99	0
1	21	2004	-99	0
1	22	2004	-99	0
1	23	2004	-99	0
1	24	2004	-99	2.29
1	25	2004	-99	0
1	26	2004	-99	0
1	27	2004	-99	0
1	28	2004	-99	0
1	29	2004	-99	0.17
1	30	2004	-99	0.01
1	31	2004	5.78	0
2	1	2004	-99	0.1

Figure 4. IMT Input Data File RF.DAT.

Step 2: Create the instruction file RF.INS as shown in Figure 5. These instructions are used by the IMT to determine what type of input file is being used, what the variables are and what to do with the data.

Step 3: The IMT is then invoked, with RF.INS as the instruction file, which then reads from RF.DAT file, producing the IMT.OUT and RF.RES files (Figure

6). Steps 1 to 3 above are used to determine the average rainfall for each period by running IMT's CDD model.

Step 4: Create the instruction file RF-2P.INS for use by the IMT during the 2-parameter model (Figure 7).

RF.INS:

```
Line 1: Path and name of input data file = RF.dat
Line 2: Value of no-data flag = -99
Line 3: Column number of group field = 0
Line 4: Value of valid group field = 0
Line 5: Residual file needed (1 yes, 0 no) = 1
Line 6: Model (1:Mean,2:2p,3:3pc,4:3ph,5:4p,6:5p,7:MVR,8:HDD,9:CDD) = 9
Line 7: Column number of dependent variable Y = 4
Line 8: Number of independent variables (0 to 6)  = 1
Line 9: Column number of independent variable X1 = 5
Line 10: Column number of independent variable X2 = 0
Line 11: Column number of independent variable X3 = 0
Line 12: Column number of independent variable X4 = 0
Line 13: Column number of independent variable X5 = 0
Line 14: Column number of independent variable X6 = 0
```

Figure 5. IMT Instruction File RF.INS for CDD Model.

RF.RES:

1.00	31.00	2004.00	5.78	0.15	0.00	928.92	-923.14
2.00	29.00	2004.00	6.81	0.20	0.00	928.92	-922.11
3.00	31.00	2004.00	6.34	0.09	0.00	928.92	-922.58
4.00	30.00	2004.00	6.72	0.14	0.00	928.92	-922.20
5.00	31.00	2004.00	7.06	0.25	0.00	928.92	-921.86
6.00	30.00	2004.00	7.16	0.39	0.00	928.92	-921.76
7.00	31.00	2004.00	6.34	0.08	0.00	928.92	-922.58
8.00	31.00	2004.00	6.66	0.08	0.00	928.92	-922.26
9.00	30.00	2004.00	6.44	0.01	0.00	928.92	-922.48
10.00	31.00	2004.00	6.52	0.12	0.00	928.92	-922.40
11.00	30.00	2004.00	6.45	0.31	0.00	928.92	-922.47
12.00	31.00	2004.00	5.13	0.03	0.00	928.92	-923.79

Figure 6. IMT Residual File RF.RES.

RF-2P.INS

```
Line 1: Path and name of input data file = RF.RES
Line 2: Value of no-data flag = -99
Line 3: Column number of group field = 0
Line 4: Value of valid group field = 0
Line 5: Residual file needed (1 yes, 0 no) = 0
Line 6: Model (1:Mean,2:2p,3:3pc,4:3ph,5:4p,6:5p,7:MVR,8:HDD,9:CDD) = 2
Line 7: Column number of dependent variable Y = 4
Line 8: Number of independent variables (0 to 6)  = 1
Line 9: Column number of independent variable X1 = 5
Line 10: Column number of independent variable X2 = 0
Line 11: Column number of independent variable X3 = 0
Line 12: Column number of independent variable X4 = 0
Line 13: Column number of independent variable X5 = 0
Line 14: Column number of independent variable X6 = 0
```

Figure 7. IMT Instruction File RF-2P.INS for 2P Model.

Step 5: The IMT is then invoked again, with the RF-2P.INS as the input file, which then reads from the RF.RES file, producing the IMT.OUT file, renamed to be RF.OUT (Figure 8). This process determines the statistical coefficients for wastewater treated vs. rainfall by using IMT's two-parameter regression model, which acts upon the RF.RES data file.

Step 6: Extract the coefficients in the output file. In this file the coefficient (A) represent the offset and (X1) represent the slope. If coefficient (X1<0) it means that the wastewater treated did not increase with the increased rainfall. Therefore, the M1 model returns a message to the user to check the input or correct the input to rerun the model.

RF.OUT

```
*******************************************
 ASHRAE INVERSE MODELING TOOLKIT (1.9)
*******************************************
   Output file name = IMT.Out
*******************************************
   Input data file name =  RF.RES
   Model type =          2P
   Grouping column No =    0
   Value for grouping =    0
   Residual mode =         0
   # of X(Indep.) Var =    1
   Y1 column number =       4
   X1 column number =   5
   X2 column number =   0 (unused)
   X3 column number =   0 (unused)
   X4 column number =   0 (unused)
   X5 column number =   0 (unused)
   X6 column number =   0 (unused)
*******************************************
   Regression Results
   --------------------------------------
        N =     12
   --------------------------------------
       R2 =     0.339
   --------------------------------------
     AdjR2 =    0.339
   --------------------------------------
      RMSE =     0.4700
   --------------------------------------
    CV-RMSE =    7.286%
   --------------------------------------
        p =     0.358
   --------------------------------------
       DW =     0.801 (p>0)
   --------------------------------------
       a =     6.0180 (     0.2343)
   --------------------------------------
       X1 =     2.8074 (    1.2391)
   --------------------------------------
```

Figure 8. IMT 2P Model Output File RF.OUT.

Figure 9 shows the two-parameter model of average daily wastewater treated vs. average daily rainfall and the measured wastewater data. The following equation was used in the next step for calculating the normalized daily wastewater treated using daily rainfall data.

Wastewater Treated (MGD) = a + X1 * Daily Rainfall (inches/day)
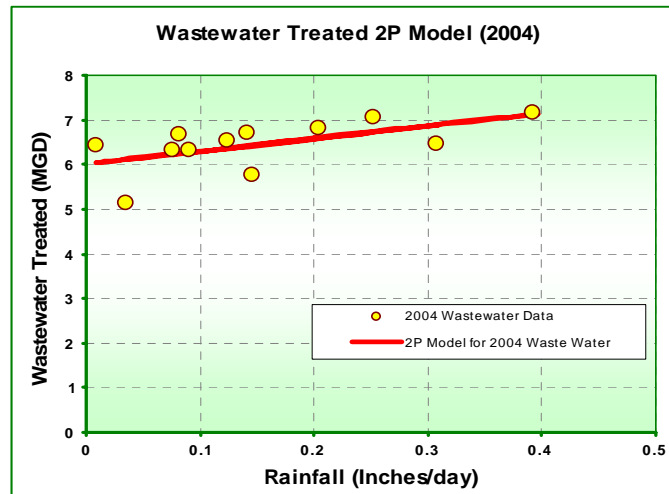
Figure 9. IMT 2P Model Wastewater vs. Rainfall.

3. Predict Daily Wastewater Treated in Base Year 1999 and 2002

After running the IMT 2P model, the growth factors input by the user are applied to the coefficients obtained in the previous step. As shown in screen B-I in Table 1, both the slope and offset are adjusted to reflect the growth of the wastewater treatment system from 1999 and 2002 to 2004 in this example. If the input period is before 1/1/2002, the second table (screen B-II) will be used to adjust coefficients. Then weather normalized daily wastewater treated in 1999 and 2002 is calculated using the adjusted coefficients and daily rainfall data in 1999 and 2002. The wastewater treated annually (million gallons/yr) and the wastewater treated in OSD period (MGD) in 1999 and 2002 is listed in Table 2.

Table 1. Adjustment of Coefficients (Wastewater vs. Rainfall) Based on Growth Rate.

Screen B-I (current period is from 1/1/2003 to 12/31/2004):

Year	Input Factor [3a]	Calculated Factor [3b=1/(1+3a)]	a [3c=$a_{current}$ *3b]	X1 [3d=$X1_{current}$ * 3b]
Current Period			6.0180	2.8074
1999	20%	83%	5.0150	2.3395
2002	10%	91%	5.4709	2.5522

Screen B-II (current period is from 1/1/1999 to 12/31/2002):

Year	Input Factor [3a]	Calculated Factor [3b=1/(1+3a) or 1+3a]	a [3c=a$_{current}$ *3b]	X1 [3d=X1$_{current}$ * 3b]
Current Period			6.0180	2.8074
1999	10%	91%	5.4709	2.5522
2002	10%	110%	6.6198	3.0881

Table 2. Annual and OSD Period Wastewater Treated.

Year	Total Wastewater (MG/yr) [3e]	Average Daily OSD Wastewater (MGD) [3f]
1999	1,881.03	5.04
2002	2,108.71	5.69

4. Predict Daily Wastewater Treated in Base Year 1999 and 2002 if No Rain

As shown in Figure 9, the offset (coefficient "a") indicates the wastewater treated daily when there is no rain (i.e., this is used to estimate how the municipal sewage treatment system would have operated if there was no storm water or infiltration). Table 3 shows the annual and OSD period wastewater treated if there is no rain.

Table 3. Annual and OSD Period Wastewater Treated if No Rain.

Year	Total Wastewater If No Rain (MG/yr) [4a]	Average Daily OSD Wastewater If No Rain (MGD) [4b]
1999	1,823.15	4.99
2002	1,998.88	5.48

5. Second Application of IMT

The IMT is run again to determine the coefficients of electricity consumption vs. wastewater treated by following steps.

Step 1. Retrieve the wastewater and electricity data for the input period and create the IMT data file FE.DAT.

Step 2. Create the instruction file FE.INS.

Step 3. The IMT is then invoked, with the FE.INS file, using FE.DAT data file, and producing the IMT.OUT file and the FE.RES residual file. This process determines the average daily wastewater treated and electricity consumed for each period by running the IMT's CDD model.

Step 4. Create the instruction file FE_2P.INS.

Step 5. The IMT is then invoked again, with FE_2P.INS as the input file, which then reads from FE.RES, producing the IMT.OUT file, renaming it to FE_2P.OUT. This process determines the coefficients for electricity vs. wastewater treated by running IMT's two-parameter regression model.

Step 6. Extract the IMT coefficient X1, if it is positive then continue with the following steps. Otherwise (i.e., if it is negative), stop the program and tell the user that according to their input, there is no savings available for this project.

Ask the user to check the electricity consumption input data or perhaps edit the data by deleting data for the months with abnormal usage due to holidays or other reasons and rerun the program.

Figure 10 shows the output of the 2P model for average daily electricity consumption vs. average daily wastewater. The following equation is then used to calculate the normalized daily electricity consumption using the predicted daily wastewater.

FE_2P.OUT

```
**********************************************

 ASHRAE INVERSE MODELING TOOLKIT (1.9)
**********************************************

  Output file name = IMT.Out
**********************************************

  Input data file name =  FE.RES
  Model type =        2P
  Grouping column No =    0
  Value for grouping =    0
  Residual mode =         0
  # of X(Indep.) Var =    1
  Y1 column number =      4
  X1 column number =   5
  X2 column number =   0 (unused)
  X3 column number =   0 (unused)
  X4 column number =   0 (unused)
  X5 column number =   0 (unused)
  X6 column number =   0 (unused)
**********************************************

Regression Results

  -----------------------------------
       N =    12
  -----------------------------------
       R2 =    0.189
  -----------------------------------
     AdjR2 =    0.189
  -----------------------------------
     RMSE =    585.3240
  -----------------------------------
    CV-RMSE =    3.537%
  -----------------------------------
       p =    0.303
  -----------------------------------
      DW =    1.327 (p>0)
  -----------------------------------
      a =  19704.5664 (  2071.9329)
  -----------------------------------
      X1 =   -489.1296 (   320.1186)
  -----------------------------------
```

Figure 10. IMT 2P Model Output File FE_2P.OUT.

Electricity Consumption (kWh/day) = a + X1 * Predicted Daily Waste Water Treated (MGD).

However, as shown in Figure 11, the coefficient X1 for this example is negative, which means there is no savings for the example project. Analysis of the input data shows the wastewater treated in January and December was low compared to other months due to

the holidays and school break in this community (i.e., College Station). Another reason is that the electricity consumption obtained from this wastewater treatment plant is not only for treating wastewater, but also includes the office electricity usage. More accurate data on electricity consumption will better represent the real savings that may be achieved from this project.
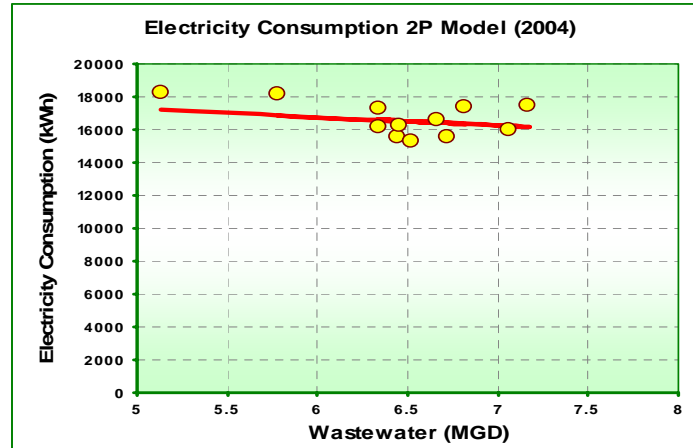

Figure 11. IMT 2P Model Electricity vs. Wastewater.

To complete this example analysis, the data set were reconfigured to exclude January and December as shown in Table 4 and the analysis was rerun by repeating the steps 1-5 described in previous sections. Figure 12 shows the new 2P model for wastewater vs. rainfall (left plot) and the new 2P model for the electricity vs. wastewater (right plot). As shown in Figure 12, a very slightly positive correlation exists. The very low correlation of wastewater flow and energy use in College Station is heavily influenced by the relative newness of the city's wastewater infrastructure. It is doubtful that much water infiltrates the sanitary sewer system, and combined sewer lines are probably very few. Greater energy savings are possible for older systems suffering from higher infiltration and having combined sewer flows by design. The new coefficients, and the resulting annual and OSD period wastewater treated for 1999 and 2002 (with and without rain) are presented in the three tables in Table 5.

Table 4. Updated User Input Excluding January and December Data.

Per	Month	Beginning Date	Ending Date	No. Of Days	Total Wastewater Treated (MG/mo)	Total Electricity Consumption (kWh/mo)
1						
2	Feb-04	2/1/2004	2/29/2004	29	197.49	504,800
3	Mar-04	3/1/2004	3/31/2004	31	196.54	537,600
4	Apr-04	4/1/2004	4/30/2004	30	201.60	468,000
5	May-04	5/1/2004	5/31/2004	31	218.86	496,400
6	Jun-04	6/1/2004	6/30/2004	30	214.80	524,000
7	Jul-04	7/1/2004	7/31/2004	31	196.54	502,000
8	Aug-04	8/1/2004	8/31/2004	31	206.46	514,400
9	Sep-04	9/1/2004	9/30/2004	30	193.20	467,600
10	Oct-04	10/1/2004	10/31/2004	31	202.12	458,800
11	Nov-04	11/1/2004	11/30/2004	30	193.50	488,000
12						

6. Predict Daily Energy Consumption in Base Year 1999 and 2002

To calculate daily energy consumption in 1999/2002, first the growth factors input by the user are applied to the coefficients obtained in Step 5. As shown in screen B-I in Table 6, only the offset is adjusted to reflect the growth of the wastewater treatment system from 1999 and 2002 to 2004 in this example. If the input period is before 1/1/2002, the second table (screen B-II) will be used to adjust coefficients. Then the daily electricity consumption in 1999 and 2002 is calculated using the adjusted coefficients and the predicted daily wastewater data in 1999 and 2002. The annual electricity consumption (kWh/yr) and average daily electricity consumption in OSD period (kWh/day) in 1999 and 2002 are listed in Table 7.
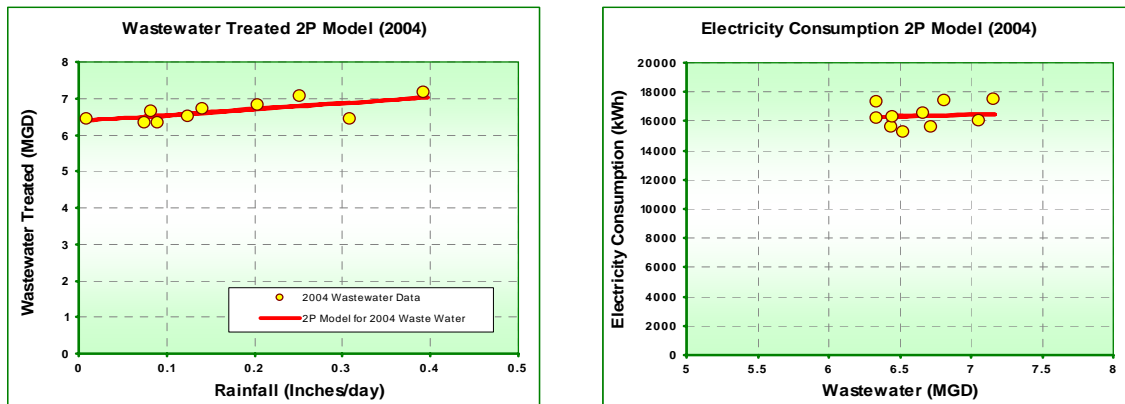
Figure 12. IMT 2P Models Excluding January and December Data.

Table 5. Updated Calculation on Wastewater Excluding January and December Data.

Year	Input Factor [3a]	Calculated Factor [3b=1/(1+3a)]	a [3c=a$_{current}$ *3b]	X1 [3d=X1$_{current}$ * 3b]
Current Period			6.3713	1.6686
1999	20%	83%	5.3094	1.3905
2002	10%	91%	5.7921	1.5169

Year	Total Wastewater (MG/yr) [3e]	Average Daily OSD Wastewater (MGD) [3f]
1999	1,964.59	5.32
2002	2,181.50	5.92

Year	Total Wastewater If No Rain (MG/yr) [4a]	Average Daily OSD Wastewater If No Rain (MGD) [4b]
1999	1,930.19	5.29
2002	2,116.23	5.80

Table 6. Adjustment of Coefficients (Electricity vs. Wastewater) Based on Growth Rate.

Screen B-I (current period is from 1/1/2003 to 12/31/2004):

Year	Input Factor [6a]	Calculated Factor [6b=1/(1+6a)]	a [6c=$a_{current}$ *6b]	X1 [6d=$X1_{current}$]
Current Period			14966.9697	213.3271
1999	20%	83%	12472.4748	213.3271
2002	10%	91%	13606.3361	213.3271

Screen B-II (current period is from 1/1/1999 to 12/31/2002):

Year	Input Factor [6a]	Calculated Factor [6b=1/(1+6a) or 1+6a]	a [6c=$a_{current}$ *6b]	X1 [6d=$X1_{current}$]
Current Period			14966.9697	213.3271
1999	10%	91%	13606.3361	213.3271
2002	10%	110%	16463.6667	213.3271

Table 7. Annual and OSD Period Electricity Consumption.

Year	Total Energy Consumption (kWh/yr) [6e]	Average Daily OSD Energy Consumption (kWh/day) [6f]
1999	4,953,343	13,557
2002	5,436,653	14,883

7. Predict Daily Energy in Base Year 1999 and 2002 if No Rain

Next, based on the predicted wastewater (i.e., no rain) in Step 4, the annual and average daily OSD electricity consumption in 1999 and 2002 are calculated and listed in Table 8.

Table 8. Annual and OSD Period Electricity Consumption if No Rain.

Year	Total Energy Consumption If No Rain (kWh/yr) [7a]	Average Daily OSD Energy Consumption If No Rain (kWh/day) [7b]
1999	4,946,004	13,551
2002	5,422,728	14,857

8. Calculate Energy Consumption Due to Rain for 1999 and 2002

In this step, the energy consumption due to separating the storm water (Table 9) is calculated by subtracting the numbers in Table 7 by the corresponding numbers in Table 8.

Table 9. Annual and OSD Period Electricity Consumption Due to Rain.

Year	Total Energy Consumption Due to Rain (kWh/yr) [8a=6e-7a]	Average Daily OSD Energy Consumption Due to Rain (kWh/day) [8b=6f-7b]
1999	7,339	6
2002	13,925	26

9. Calculate Energy Savings Due to % Separation

Next, the energy savings due to the separation of the storm sewer or fixing the infiltration (Table 10) are calculated by multiplying the numbers in Table 9 by the % of separation input by the user.

10. Project Annual and OSD Savings for 2007 and 2010

To project the annual and OSD savings for 2007 and 2010, first the growth factor from 1999 to 2007/2010 and the growth factor from 2002 to 1007/2010 are calculated, as shown in Table 11 and Table 13. Then the annual and average OSD electricity savings are calculated based on the base year savings and growth factor from the base year to 2007/2010. Table 12 and Table 14 show the projected electricity savings in 2007 and 2010 using 1999 base year and 2002 base year respectively.

Table 10. Annual and OSD Period Electricity Savings.

Year	Total Energy Savings Due to Separation (kWh/yr) [9a = 8a * b1]	Average Daily OSD Energy Savings Due to Separation (kWh/day) [9b = 8b * b1]
1999	5,871	5
2002	11,140	21

Table 11. Calculation of Growth Factor from 1999 to 2007/2010.

Screen B-I (current period is from 1/1/2003 to 12/31/2004):

Year	Calculated Factor for 2007 [10a=b2 +b4]	Calculated Factor for 2010 [10b= b2 +b5]
2007	35%	
2010		50%

Table 12. Electricity Savings in 2007 and 2010 Using Base Year 1999.

Screen B-I (current period is from 1/1/2003 to 12/31/2004):

Year	Savings for 2007 (kWh/yr) [10c=(1+10a)* $9a_{1999}$]	Savings for 2010 (kWh/yr) [10d=(1+10b) * $9a_{1999}$]	Savings for 2007 OSD (kWh/day) [10e=(1+10a)* $9b_{1999}$]	Savings for 2010 OSD (kWh/day) [10f=(1+10b) * $9b_{1999}$]
2007	7,926		7	
2010		8,807		7

Table 13. Calculation of Growth Factor from 2002 to 2007/2010.

Screen B-I (current period is from 1/1/2003 to 12/31/2004):

Year	Calculated Factor for 2007 [10g=b3	Calculated Factor for 2010 [10h= b3 +b5]
2007	25%	
2010		40%

Table 14. Electricity Savings in 2007 and 2010 Using Base Year 2002.

Screen B-I (current period is from 1/1/2003 to 12/31/2004):

Year	Savings for 2007 (kWh/yr) $[10i=(1+10g)*9a_{2002}]$	Savings for 2010 (kWh/yr) $[10j=(1+10h)*9a_{2002}]$	Savings for 2007 OSD (kWh/day) $[10k=(1+10g)*9b_{2002}]$	Savings for 2010 OSD (kWh/day) $[10l=(1+10h)*9b_{2002}]$
2007	13,925		26	
2010		15,596		30

11. Emissions Reduction in 2007 and 2010

Finally, in the next step the USEPA's eGRID database is used to project annual and average daily OSD period NOx, SOx, and CO2 reductions in 2007/2010 using base year 1999 and 2002. Table 15 shows a sample of emissions reduction report that will be sent to the user.

Table 15. Emissions Reduction Report.

SUMMARY REPORT

Project Information

Project ID	406
Job ID	146
County	BASTROP
Project Name	Mockup 2
Project POC EMail	dgilman@tamu.edu
Project Type	M1 - Pump Efficiency

1: ANNUAL SAVINGS BASE YEAR 1999   1999

1.1: Energy Consumption	1999 Electricity (kWh/yr)	1999 to 2007 Ttl Growth %	2007 Electricity (kWh/yr)	1999 to 2010 Ttl Growth %	2010 Electricity (kWh/yr)
Electrical	154,884	6.00%	164,177	12.00%	173,470

1.2 Emissions By Type	1999 Emissions (lbs/yr)	1999 to 2007 Ttl Growth %	2007 Emissions (lbs/yr)	1999 to 2010 Ttl Growth %	2010 Emissions (lbs/yr)
NOx	2.00	6.00%	2.12	12.00%	2.24
SOx	14.00	6.00%	14.84	12.00%	15.68
CO2	1,425.00	6.00%	1,510.50	12.00%	1,596.00

2: TYPICAL OSD SAVINGS BASE YEAR 1999   1999

2.1: Energy Consumption	1999 Electricity (kWh/day)	1999 to 2007 Ttl Growth %	2007 Electricity (kWh/day)	1999 to 2010 Ttl Growth %	2010 Electricity (kWh/day)
Electrical	61,954	6.00%	65,671	12.00%	69,388

2.2 Emissions By Type	1999 Emissions (lbs/day)	1999 to 2007 Ttl Growth %	2007 Emissions (lbs/day)	1999 to 2010 Ttl Growth %	2010 Emissions (lbs/day)
NOx	0.80	6.00%	0.85	12.00%	0.90
SOx	5.60	6.00%	5.94	12.00%	6.27
CO2	570.00	6.00%	604.20	12.00%	638.40

3: ANNUAL SAVINGS BASE YEAR 2002   2002

3.1: Energy Consumption	2002 Electricity (kWh/yr)	2002 to 2007 Ttl Growth %	2007 Electricity (kWh/yr)	2002 to 2010 Ttl Growth %	2010 Electricity (kWh/yr)
Electrical	165,484	5.50%	174,586	11.50%	184,515

3.2 Emissions By Type	2002 Emissions (lbs/yr)	2002 to 2007 Ttl Growth %	2007 Emissions (lbs/yr)	2002 to 2010 Ttl Growth %	2010 Emissions (lbs/yr)
NOx	1.00	5.50%	1.06	11.50%	1.12
SOx	78.00	5.50%	82.29	11.50%	86.97
CO2	950.00	5.50%	1,002.25	11.50%	1,059.25

4: TYPICAL OSD SAVINGS BASE YEAR 2002   2002

4.1: Energy Consumption	2002 Electricity (kWh/day)	2002 to 2007 Ttl Growth %	2007 Electricity (kWh/day)	2002 to 2010 Ttl Growth %	2010 Electricity (kWh/day)
Electrical	61,954	5.25%	65,206	11.25%	68,923

4.2 Emissions By Type	2002 Emissions (lbs/day)	2002 to 2007 Ttl Growth %	2007 Emissions (lbs/day)	2002 to 2010 Ttl Growth %	2010 Emissions (lbs/day)
NOx	7.00	5.25%	7.37	11.25%	7.79
SOx	5.60	5.25%	5.89	11.25%	6.23
CO2	570.00	5.25%	599.93	11.25%	634.13

SUMMARY

This report has presented the methodology used to develop the storm sewer/infiltration, sanitary sewer separation model (M1) for a wastewater treatment plant. It reviewed the history of the ASHRAE IMT toolkit, which was used to develop the model. It also included a detailed example of the application of the methodology using data provided by the city of College Station. Texas.

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