SECTION 4: MODEL INTERPRETATION

If we had understood completely why and how SSOs occurred, then we would have had a model that would explain the fluctuation of SSO frequency perfectly for the last 14 years. In reality, we do not. We attempt to attribute the total fluctuation to some independent factors that we think are relevant. The proportion of the total deviance explained by a factor may be thought of as, how much the factor can be attributed to in the entire problem.

4.01 FLOW

FLOW explains 9.78% of the total deviance. Since **FLOW** is the first variable to be included in the model, one may say that the amount of fluctuation of SSO frequency due to **FLOW** is less or equal to 9.78%.

The estimated coefficients, a and b, for **FLOW** and $\mathbf{FLOW}^2$, are respective 2.5839 and -1.4066. If every other factor is fixed at a constant level, then the results of the analysis suggests that **FLOW** impacts SSO frequency via

$$f(\mathbf{FLOW}) = -1.4066\ \mathbf{FLOW}^2 + 2.5839\ \mathbf{FLOW}. \qquad (12)$$

The flow index has a range from 0.3531 to 1.4280. Over this range, f(**FLOW**) is graphed in Figure 5. This graph indicates that the impact of flow in the system may not be as simple as one may think. While it is clear that more flow is an indication of higher load, it is interesting to observe that as the flow increases over a threshold (0.9185) it may help to lower the likelihood of an SSO. This is an observation we did not anticipate. Upon further consideration, we conclude that this property may be interpreted as a self-cleansing property of the flow. As the flow reaches the threshold, its velocity may help to wash out debris and the like, and in turn makes it harder for blockages to form in the system.

4.02 Seasons

The seasonal effect is modeled by the 12 months of a year as a class variable. When the month of December is fixed as a point of reference, every other month is compared to it, and it leads to an additive term associated with each month as shown in Table 2. A graphical representation of these terms is plotted in Figure 6.

There are two elements in the seasonal effect. First, it causes a seasonal pattern in the flow to the treatment plants. Secondly, it causes the system capacity, or condition, to change. When **FLOW** was included in the model alone, the proportion of the deviance explained should already contain the flow fluctuation due to the seasons. When $\mathbf{M}_i$ (SSOMO in SAS output) is included in the model after **FLOW** is fitted, the proportion of the deviance explained by $\mathbf{M}_i$ could be reasonably attributed to system capacity change due to seasonal effect. This proportion is 24.82%, i.e., the seasonal fluctuation in sewer system capacity is responsible for nearly a quarter of the total fluctuation in SSO frequency.

4.03 Maintenance Activities

Although there are more than a few different types of maintenance activities we can consider, the complicated inter-relationship among them prevents us from including all of them individually together in the model. The index of general maintenance level, **Z** (ZMEAN in SAS output), serves as a good indicator for comprehensive maintenance. The term, Z, explains 17.16% of the total deviance. The impact of **Z** on SSO frequency is modeled via

(13) $$g(Z) = -0.2324\,Z.$$

A graphical representation of (13) is provided in Figure 7, over the range of **Z**, (-0.6612, 0.6355). It is clear in Figure 7 that higher level of maintenance leads to lower likelihood of SSO.

It may be interesting to note that the index for general maintenance explains nearly twice as much deviance as **FLOW** does, 17.16% versus 9.78%. **This comparison suggests how important the general maintenance is relative to the amount of flow in the system.** The deviance by the general maintenance (17.16%) is about 69.14% of the deviance by the seasons (24.82%). **This comparison also helps to gauge the significance of human maintenance activities versus that of nature, on an average.**

4.04 Schaaf's Methodology

Although there have been some studies done in the past regarding Schaaf's methodology in maintenance scheduling, we are not aware of any that evaluated the effect quantitatively in comparison with other major factors. The scheduling methodology used by CMU is a version of scheduling technique in Schaaf's spirit, but not as he had defined (see Schaaf ***). The scheduling method by CMU has also changed in time in the course of the last 14 years. We can still comfortably distinguish the periods when such schedules were followed. The variable (**SCHAAF**), after the **FLOW**, the seasons and the general maintenance level were fitted, explains 3.49% of the total deviance, a quantity smaller than anticipated, but strongly supported by the data.

4.05 Hugo

Natural disasters often blur our vision in seeking the truth. Hugo hit the Carolinas in the fall of 1989 and brought many months of unusual activities to the sewer systems in the Charlotte Mecklenburg area. When we distinguished that year from the others, the variable **HUGO** explains 3.05% of total deviance. This is also a model component strongly supported by the data.

4.06 Time

The variable, **T** (SSOYR in SAS output), is used to capture any remaining linear trend in SSO frequency in time. 5.75% of the total deviance is explained by **T**. This result suggests that the sewer system capacity, on the average, slightly worsened during the last fourteen years despite the maintenance effort by CMU. The coefficient of **T** is estimated to be 0.0611 with the link function being $\ln(\lambda)$. In terms of average number of SSO per year, this number translates to a 6.3% annual increase. This number may reflect an average rate of sewer system aging in this area. It is difficult to say how this rate is linked to the rate of decrease in remaining value of a section of the sewer system - a standard measure for system aging.

4.07 The Final Model

As we stated in the introduction, a model is, at its best, an approximation to the true relationship of SSO frequency and its factors. To prevent ourselves from drawing inferences on unfamiliar grounds, we confined ourselves to a set of important rules in the process of developing the model. The rules that we followed were as follows.

- **Agreement with common sense**. At each model development stage, the results must be in agreement with our common sense. This was achieved by attaching each result with at least one acceptable interpretation, in consultation with CMU maintenance operators and managers.
- **Type 1 analysis support**. Type 1 analysis is a step-wise analysis in Poisson regression. It is carried out by adding a new independent variable in the model after some other independent variables are fitted first. We consider a variable useful if the Type 1 analysis shows that a statistically significant portion of the deviance is explained by that variable. The list and the order of the independent variables are strategically designed to help us to understand the inter-relationships among the variables.
- **ML Estimate Support**. We consider a variable useful if the model parameters corresponding to this variable are estimated to be non-zero with well supported statistical significance. The estimates in the analysis are maximum likelihood estimates.

The percentage of the total deviance explained by the final model is **64.05%.** This number is a reflection of how much we understand the SSO problem. While 64.05% is a considerable part of the total deviance, there is still 35.95% of the deviance which we are not able to explain with scientific confidence. For this very reason, we do not envision our modeling process as an effort to provide a predictive tool, but as an effort to offer an exploratory technique to better understand the SSO and maintenance problems.

With the above study results, we are faced with a very important question: can we reasonably control SSO frequency? The answer, at the current level of maintenance, is unfortunately negative. To start with, there is a significant amount of variation in SSO frequency, 35.95% of the total deviance, unexplained by the model. Though we may be able to explain 64.05% of the total deviance, only two of the factors, the general maintenance activities and the Schaaf-like scheduling method, can be controlled. These two factors together explain only 20.65% of the total deviance, quite a distance away from being a dominating majority.

Can the level of flow, or the system load in general, be controlled? This may be an interesting question to be considered. As seen in this study, the flow explains less than 10% of the total deviance. We may conclude that, as far as Type *B* SSOs are concerned, the flow factor does not seem to be a top-ranked force in the grand picture of things.

The seasonal system capacity change, M_i, is the single most explanatory variable in the model. It seems that the system condition change by nature is at least as significant as that by all the human maintenance activities.

We offer three viewpoints to the results of this study We hope that these viewpoints may be proven worthy in future studies as well as future designs of maintenance programs. These viewpoints are:

1. It is possible that the current level of maintenance, as we have seen in this study, is far below the level that is necessary to make a dominating impact on the SSO frequency. If so, government agencies and municipalities need to re-conceptualize the role of sewer system maintenance and/or raise the intensity level of maintenance.

2. It is also possible that the solutions to the maintenance problem could be found in the optimization of the timing, and the different types of maintenance activities, new and existing. Schaaf's methodology and its like may have already been serving that purpose, and have had some successes in this area. We suggest that much more research and development may be needed. Given the significant role of the seasonal effect, it is not difficult to see that there is much room to fill in the realm of "intelligent maintenance".
3. It is not impossible that we are missing out and unaware of

some key major factors in this study. There could be new dimensions added in the future by continuing researches and experiments so that much better understanding and control of SSO can be achieved.