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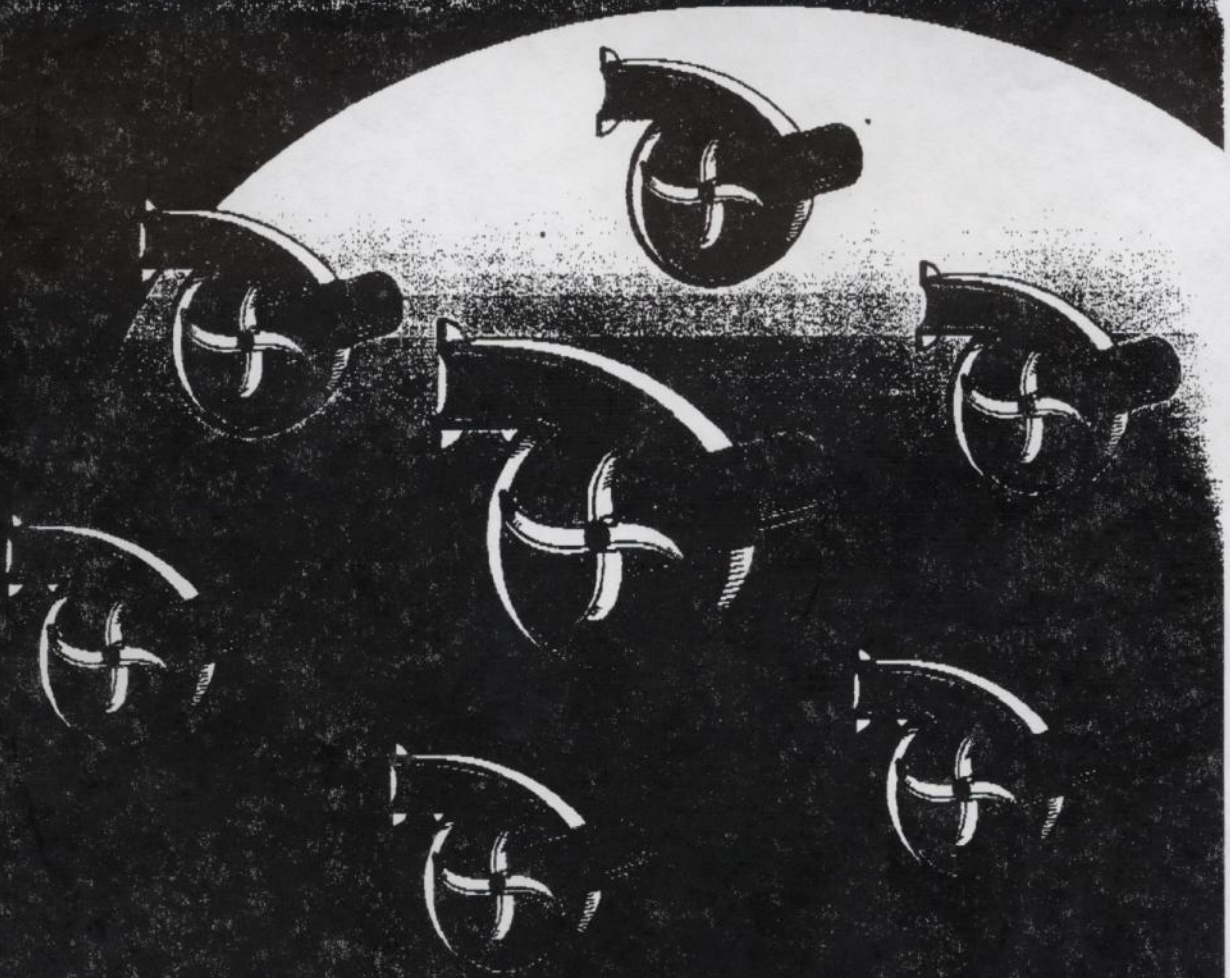

COLLECTION SYSTEMS

A SYSTEMS APPROACH FOR ADDRESSING STORMWATER INFILTRATION INTO SEWAGE COLLECTION SYSTEMS

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Abstract

Newport is a small subdivision that occupies about 3 square miles located about 30 miles northeast of Houston. In 1992 the municipal utility districts responsible for Newport contacted the University of Houston to develop a geographically distributed severity index of inflow and infiltration in Newport.

The University's research program adopted a mapping approach developed by the city of Bellaire and experimented with an inverse interpretation of a successful field screening approach for detecting sewage excursions into storm sewers currently underway at the City of Houston. Computer spreadsheets were developed that generate a geographically distributed severity (risk) index of inflow and infiltration in Newport. The spreadsheets are then used to draw thematic maps representing these severity (risk) indices.

Although the results of the research were inconclusive for Newport, the techniques developed are straightforward to apply and over time will help Newport manage its rehabilitation progress. The technique developed is generic and is applicable to other communities.

Keywords: Infiltration, Severity Index, Spreadsheets, Chemical Indicators, Mapping

Introduction

A Sewer System Evaluation Survey (SSES) is a tool that is used to identify sources of excess inflow and infiltration (I&I) and to plan, design, and implement rehabilitation strategies (USEPA, 1991). The current accepted practice of collection system surveys is monitoring and modeling of wet weather sanitary pipe flows. However, flow monitoring data are limited to conditions when the collection system pipes are not surcharged and it requires information at every node in the collection system grid to effectively evaluate the area. Hydraulic flow modeling is used to identify locations and causes of performance deficiencies and recommend alternatives to correct these deficiencies. Modeling requires extensive as-built geometric and hydraulic data and considerable expertize to interpret. These approaches to collection system surveying are expensive; the City of Houston in 1990 projected the cost for their survey using these tools at 62 million dollars for an area of 578 square miles.

The City of Bellaire is a small community that covers 3.6 square miles and has 15,000 inhabitants. It is enclaved by the City of Houston. In 1950 a new waste water treatment plant (WWTP) was completed and was immediately hydraulically overloaded during wet weather. Over the last forty years the City of Bellaire has been aggressively attacking their chronic infiltration problem.

Bellaire experimented with aerial photography following severe storms to isolate infiltration areas, they developed a remotely operated still camera for physical inspection (years before video logging was available), and they initiated thematic mapping of repairs and line servicing. In 1990 their successful thematic mapping system was computerized and has evolved into a management system that now drives the collection system rehabilitation efforts of the City of Bellaire.

In 1992 the municipal utility districts responsible for Newport, Texas were placed under an administrative order by the Texas Water Commission for treatment plant overflows. The problem is that the WWTP is hydraulically overloaded during wet weather. Lacking funds for a conventional approach of flow system monitoring, modeling, and complete televised logging they contacted the University of Houston for an innovative solution. The objective of the study was to develop a geographically distributed severity index of inflow and infiltration in Newport.

The University's research program adopted the innovative approach developed by the city of Bellaire and has experimented with an inverse interpretation of a successful field screening approach for detecting sewage excursions into storm sewers,currently underway at the City of Houston (unrelated to the City's sanitary sewer survey). Combining the practical experience of the City of Bellaire, and an inverse interpretation of the City of Houston's storm water screening program, computer spreadsheets were developed that generate a geographically distributed severity (risk) index of inflow and infiltration in Newport. The spreadsheets are then used to draw thematic maps representing these severity (risk) indices. The technique developed is generic and is applicable to other communities.

Background

Newport is located in Harris County, Texas, about 30 miles east of Houston. Newport is a community of single and multi-family housing. It covers an area of approximately 1800 acres and is served by three municipal utility districts (MUDs). MUD #20 contains 1055 houses and 76 condominiums with an area of 1347.5 acres while MUD #73 covers 434.98 acres and has 486 single family dwellings and 78 apartments. Within these two MUDs there are 305 gravity connections and 1343 sewer connections that must travel through one of seven lift stations.

The Newport WWTP suffers from periodic hydraulic overload. Plans to further develop the community will increase the problem. An administrative order from the Texas Water Commission (TWC), the enforcement representative of the U.S. Environmental Protection Agency (USEPA) in the state of Texas, requires the plant to address permit violations that are a consequence of the hydraulic overload.

Figure 1 shows a plot of the rainfall and the measured WWTP flows. The discharge permit for the WWTP is 3894 cubic meters/day (1 million gallons/day). Figure 1 shows that the permitted discharge is exceeded several times over the last two years, and these violations are strongly correlated with periods of high rainfall.

A water balance was performed on data provided by Newport in an attempt to quantify the magnitude of the I&I problem. The water balance equation is expressed as,

$$\text{WWTP Flow} = \text{Return Flow} + \text{I\&I}. \qquad (1)$$

The return flow is unknown for Newport, so the water balance was computed using different assumed values of return flow as percentages of actual water billed. Figure 2 shows inflow and infiltration computed from a water balance for Newport based on this model. From this figure one can observe that even with 100% return flow (all billed water enters the sewer collection system), the WWTP is treating excess water except in the summer months. This result indicates that inflow and infiltration represents a significant portion of the water treated on an annual basis, and suggests that rehabilitation of the system could greatly reduce the frequency and severity of the plant's discharge violations.

Methodology

The research effort consisted of a thematic mapping approach to identify areas of the subdivision that have high probability of contributing to inflow and infiltration combined with sewer water quality monitoring to attempt to refine the thematic mapping results.

The idea of thematic mapping is to construct maps of certain themes for an area, and then cross reference the themes based on subjective and objective assessment of each theme's contribution to an overall problem. Bellaire has successfully used this method of data management for monitoring sewer repair; Bellaire's approach was initiated by Delbert Jeeter nearly three decades ago. The availability of personal computer spreadsheets simplifies the effort and makes the thematic mapping feasible for many smaller communities.

For Newport the following themes were available and used: Soil Stability, Manhole Density, Backyard Sewer Density, Development Density, and Sewer Repair Frequency (expressed as a density). These themes were combined into a single map showing risk of inflow and infiltration as a function of location in Newport.

the Newport study was based on an analogy to the dye dilution method of flow monitoring (Cleveland, et al. 1993). The principal advantage of the chemical measurements is that they can be accomplished quickly, and less expensively. Fundamental to the monitoring program was to collect a large number of samples over time, so that random fluctuations would have a small effect on the interpretation of the analyses.

Ten sewage system sites were chosen along with two surface runoff sites based on their location and the hydraulic flow of the system. The sites were selected so that the areas served by each site could be readily delineated. The indicators used for testing the sewage system in the Newport subdivision were ammonia-nitrogen, phosphorus, chloride, and chemical oxygen demand (COD). The sewage samples were field analyzed for pH, temperature, total dissolved solids (TDS), and conductivity. Samples were collected into washed amber glass bottles, pH adjusted as necessary, and placed in an ice chest for transportation to the University of Houston Civil and Environmental Engineering Laboratories for analysis. These particular indicator parameters were selected because we expected some would be present in sewage and relatively absent in I&I water.

A dramatic dilution was not detected as expected, an approximation method was used to try generate a refinement measure of the severity of inflow and infiltration in the system based on the chemical data. The procedure used was as follows: For each sampling event the individual sampling location data were compared to the WWTP data and the surface water data. Those sites whose data that had higher concentrations of sewage specific indicators than at the WWTP were considered to be sites with no evidence of inflow and infiltration. Those sites whose data had concentrations that fell between the WWTP data and the surface water data were considered to be sites with possible inflow and infiltration for that sampling event. These sites were further screened into two groups: the first group had concentrations that were closer to the WWTP value than the surface water values; the second group had concentrations that were closer to the surface water value than the WWTP value. This second group was considered to be representative of sites with strong evidence of inflow and infiltration.

The sites showing strong evidence of inflow and infiltration were ranked according to their frequency of occurrence over the one year study period, then these ranked sites were placed into three groups: severe, moderate, and low infiltration. An inflow and infiltration rick map based on these rankings was then prepared by assigning severity values to the grid areas that are served by each sample site. Figure 8 shows these ranked severities based on chemical monitoring.

Finally the two risk maps, one from the thematic study and one form the chemical study were combined into an overall risk map that expresses the current risk of inflow and infiltration in the Newport subdivision. The aggregate map was taken as the product of the two maps, then normalized again to the range [0,1]. Figure 9 shows the aggregate map of I&I severity (risk) for Newport.

Since the maps are based on data contained in spreadsheets, they can be updated quickly as conditions change or repairs are made, by making changes in the spreadsheet and instructing the computer to redraw the maps.

Results

The results of this study indicates that inflow and infiltration potential is high in most of Newport with exceptions in the north west section where the risk is quite low. Targeted rehabilitation in the sections indicated by the risk map will probably reduce the inflow and infiltration that is contributing to the hydraulic overloading of the WWTP. Temporary removal from service of sewerage in the undeveloped areas may also help reduce the hydraulic loading.

Conclusions

The results of the research were inconclusive for Newport, however the techniques developed are straightforward to apply and over time will help Newport manage its rehabilitation progress. The mapping was all done using spreadsheet software that is available to nearly any community, regardless of size. We feel that the repair frequency map is probably the most useful

The maps were constructed using a grid system approximately 300 x 300 feet per grid cell. Figure 3 shows the grid system used. The theme for each cell was compiled into a computer spreadsheet, and then a gridding algorithm was used to generate an image whose shading represents the numerical value of the grid cell. Color could also be used where appropriate. This method can be applied to other geographically distributed themes at different resolutions (the 300 x 300 is a coarse grid) depending on the availability of the data.

A boundary map overlay was prepared to show the approximate boundaries of the study area and help in thematic map interpretation. This overlay map also shows the locations of sewer water quality monitoring sites (discussed later) that were used to develop additional quantitative measures of I&I. Figure 4 shows the boundary map overlay expressed in the grid system of Figure 3.

The sewer repair frequency theme records the location of repairs (or failures, blockages, etc.) into a data base. Each report is assigned some value of severity, in this study all reports are considered to be of equal value. Maps of these data sets will show areas where repairs are frequent. These maps can be used to determine where repair resources are being spent and high frequency areas may be indicative of some more severe underlying problem.

Management of this data is easily accomplished using a computer spreadsheet. Figure 5 shows an example spreadsheet used in developing the repair frequency map. Each entry of the spreadsheet is coded with a grid coordinate corresponding to the grid cell nearest the reported repair or fault. The map can be created directly in the spreadsheet program or exported to a graphics program.

Figure 6 shows the repair frequency map. In this map (and subsequent maps) the darker shaded areas represent higher values of the indicator variable being mapped. For repair frequency, the frequency of repairs is highest in the dark areas, and low in the lighter areas (areas outside the mapping area are automatically assigned a repair frequency of zero). We feel that this single mapping tool could be of great use to Newport in the future and recommend that the directors consider having all maintenance items coded to some grid system so that both they and the operators can manage repair and maintenance over the long term.

The other themes such as soil stability, manhole density, backyard sewer density, and development density are prepared in a similar fashion (Cleveland et al. 1993). An overall thematic inflow and infiltration severity (risk) map was prepared by computing a normalized risk value from the five themes discussed above. The following concepts were used to arrive at the aggregate risk:

- Risk is assumed to be inversely proportional to soil stability.
- Risk is assumed to be directly proportional to manhole density.
- Risk is assumed to be directly proportional to backyard sewer density.
- Risk is assumed to be inversely proportional to development density.
- Risk is assumed to be directly proportional to sewer repair frequency.

Using these concepts the formula used to compute risk was:

$$\begin{aligned} \text{Risk} = \; & 0.20*(1 - \text{Soil Stability}) + 0.20*(\text{Manhole Density}) + \\ & 0.20*(\text{Backyard Sewer Density}) + 0.20*(1\text{-Development Density}) \\ & 0.20*(\text{Sewer Repair Frequency}) \end{aligned}$$

The weights (0.20) simply make risk the arithmetic mean of each of the indicator maps. The value of risk is normalized to fall in the range [0,1], where zero is the lowest risk and one is the highest risk. Figure 7 shows the thematic risk map developed from this formula.

A sewer water quality monitoring program was developed to generate a quantitative (measurable) theme that could be used to refine the qualitative risk. The idea behind this monitoring program is that quantitative measures should produce similar patterns of severity as the qualitative themes.

Chemical analysis is not commonly used in sewer collection systems, flow monitoring being preferred, however it is suggested as one possible technique in EPA guidance documents (USEPA, 1975). The method has proved quite successful in detection of sewer exfiltration into the storm water system for the City of Houston who suggested the approach. The method used in tool that could be used by any community, primarily because it can be easily interpreted; If the system is aging uniformly over time, the repair frequency map should be uniformly shaded indicating that the repair frequency is independent of location. Conversely, if the repair frequency map indicates a large proportion of repairs centered in a single area, then this area should be investigated for potential rehabilitation, rather than continuing the repairs. The remaining themes are site specific for Newport, but the technique is generic. The chemical monitoring for Newport was also inconclusive because the sewage specific indicators were not sufficiently diluted by I&I water during our sampling events. In future studies we suggest that researchers spend effort identifying sewage unique, or I&I unique indicators to improve the reliability of the chemical monitoring technique.

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