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## 1.Abstract

This study was focused on developing a model to estimate the Life Cycle Cost (LCC) for constructing, operating and maintaining a wastewater sewer system. A spreadsheet model has been developed, which is based on population and average household occupancy. Essential components of a wastewater system have been identified and divided into sectors with housing, commercial, educational, industrial and recreational activities. Life cycle cost includes treatment, transportation, maintenance and rehabilitation of the wastewater system with infiltration over a period of 30 years. The model has been calibrated with published data. The model can be used to compare certain rehabilitation and maintenance scenarios and identify the most cost effective approach [(1)].

## 2. Objective of Life Cycle Cost Model

The objective of this study is to develop a LCC model for wastewater systems with infiltration and maintenance. The specific objectives are as follows:

1. Identify the important parameters that influence the cost of constructing and maintaining a wastewater system with infiltration.
2. Develop a LCC model for a period of 30 years.
3. Quantify the major components (length of pipes, number of manholes, size of treatment plants) of the wastewater system.

[(1)] The EPA found that the factors that influence rainfall induced infiltration were as follows: (1) System Age and Construction, (2) Density, (3) Sewer Depth, (4) Groundwater, (5) Soils and Geology, (6) Topography, (&) Roots, (8) Rainfall Patterns, (9) Cold Weather, (10) Maintenance Practices, and (11) Ordinance Enforcement. ["Rainfall Induced Infiltration Into Sewer Systems, Report To Congress," August, 1990]

4. Incorporate certain maintenance and rehabilitation methods for various sizes of

wastewater systems with changing population and identify the most cost effective plan.

Various steps being adopted in developing the model are:

- Estimate the various components of the sanitary sewer system based on the population.
- Determine the capacity of the wastewater treatment plant based on dry weather flow and infiltration magnification factor.
- Develop a Life Cycle Cost Analysis (LCCA) for a wastewater system with infiltration.
- Estimate infiltration cost, wastewater treatment cost and transportation cost associated with the wastewater system.
- Estimate rehabilitation cost associated with various rehabilitation options.
- Perform a parametric study with various factors of the sanitary sewer system and identify the most important cost contributing factors.
- Determine the relationship between Life Cycle Cost and percent reduction in infiltration.

## 3. Model Development

A basic spreadsheet model has been developed to quantify infiltration (caused by rainfall and/or groundwater) per day based on population and average household occupancy. This model is capable of estimating the sizes of various components of a wastewater system based on default settings based on certain databases. These default settings may be reset by the user based on own experience and local data.

### *3.1) Model Layout:*

The population of a city/wastewater district is divided into five basic elements:

- Housing units (H)
- Industrial Parks (I)
- Commercial est.(C)

- Educational est. (E)
- Recreational and other facilities (R)

Figure 1 shows the layout for the model.

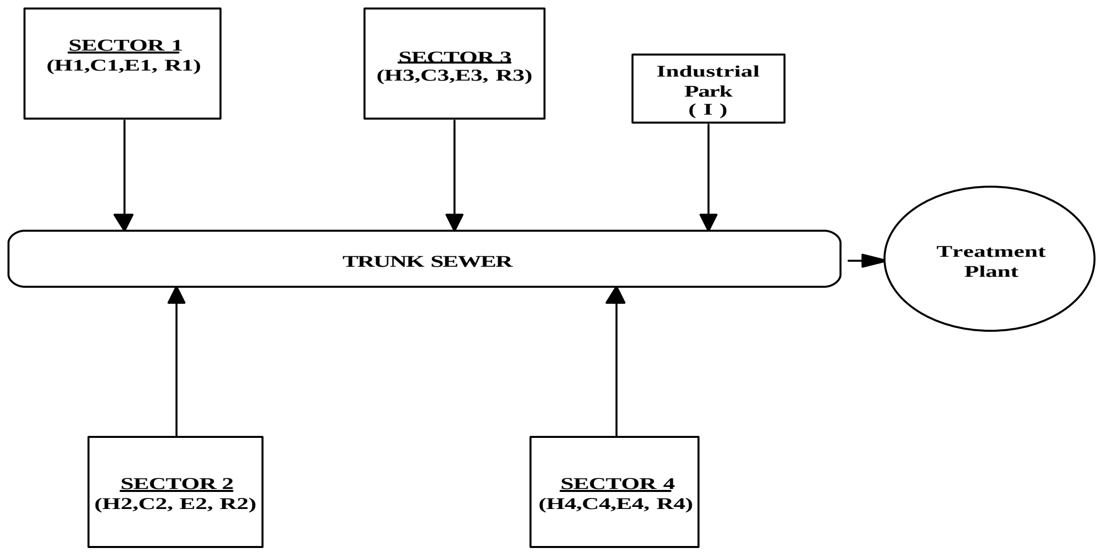


Figure 1 Model Layout

Sectors 1 through 4 are located along the trunk sewer and the industrial park is separated from residential and commercial establishment. The treatment plant is assumed to be at one end of the trunk sewer. These assumptions can be modified based on the actual city layout.

*3.2) Model Assumptions:*

The Basic assumptions were made while developing the model. (These may be used as default values or they can be modified based on the actual city/county layout.) The basic assumptions were:

- Length of the sewer for housing, industrial, commercial, education, recreational and other facilities varied between 0.008 to 0.02 miles per unit.
- One manhole per 200 feet.

- Average per capita daily flow for Residential, Commercial, Industrial population varied between 35 to 60 gallons per capita per day (gpcd).
- Treatment cost varied from $ 0.001 to $ 0.01 per gallon.
- The pipe sizes of the street laterals were 4- inches or larger, the main lines were 8- inches or larger and the sewer trunks were 24- inches or larger.
- The pipe joints are assumed to be at 20 feet/joint.

Appendix 1 details the assumptions.

*3.3) Model Parameter Analysis:*

Based on literature review, information on population, pipeline lengths, number of treatment plants, number of lateral connections, average annual daily flow (mgd) and total pump station horse power (hp), the treatment cost was obtained for various cities around the United States of America. Correlation was observed between various system characteristics. The model values were compared against the values obtained from a literature search. (See Case Study.)

## 4. Capital Cost

The wastewater system is one of the most valuable assets of a city. Hence, a good estimate of the capital cost of the system is necessary based on the needs of the community. The capital cost includes material and installation costs for pipelines, manholes, pump stations and treatment plant installation. A mathematical model was developed to estimate the capital cost for a city. In developing the cost model, it was important to identify the variables. The data available in the literature and the data provided by the City of Victoria, Texas were used to verify the relationship developed in this study. Multiple regression analysis was performed and a correlation was developed between various factors while developing the model, which can best estimate the capital cost of a wastewater system.

*4.1) Model Development:*

The capital cost model was developed by breaking down the cost of construction into three major components:

(1) Material cost, (2) Installation cost and (3) Miscellaneous cost, which involves administrative and other expenses.

Total cost of construction ($T_C$) = $C_{PM} + C_L + C_{MH} + C_{TP} + C_{PS} + OC + M$ …………(4.1)

$C_{PM}$ = Total cost of pipe material.

$C_L$ = Total cost of pipeline installation.

$C_{MH}$ = Cost of manhole material and installation.

$C_{TP}$ = Cost of Wastewater Treatment Plant (WWTP) based on capacity in million gallons per day (MGD) (Includes material and installation cost.)

$C_{PS}$ = Cost of pump stations based on capacity in MGD (Includes material and installation costs.)

OC = Other costs (Includes major cost components like trench system design, mobilization of manpower and machinery, repair existing roads, traffic control etc.)

M = Miscellaneous (Includes minor cost components like site preparation, taxes etc.)

1) Pipe material cost:

$$C_{PM} = \sum_{i=1}^{n} \omega_i \, D \, L_i^{*} \quad \text{……..(4.2)}$$

Where D is the diameter of the pipe and $\omega$ is the cost parameter, which varies with pipe diameter and location.

The figure below shows the cost of the associated with various values of $\omega$ and pipe diameters. Actual data for two most popular types of pipes for wastewater systems was provided by the EPA [EPA 832-F-00-068, Sept 2000] and is fitted against different values of $\omega$.

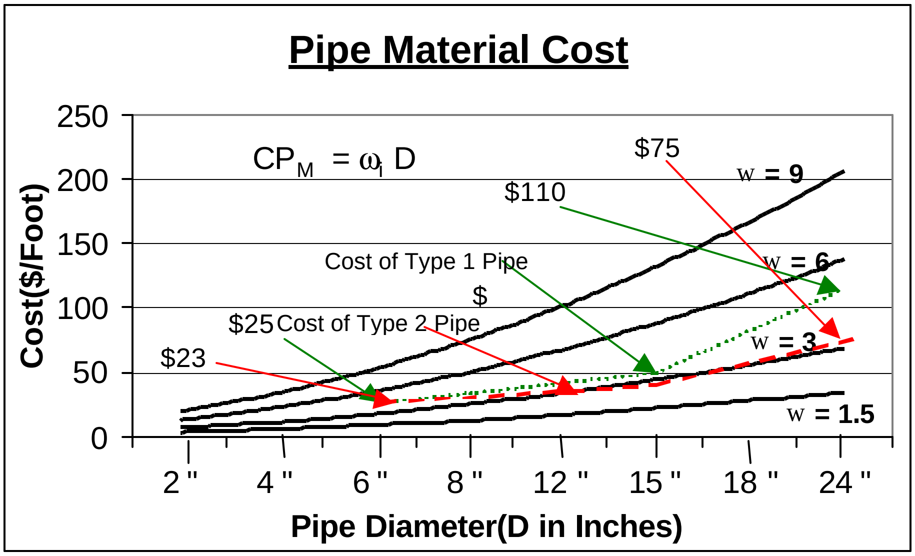


Figure 2 Variation of cost/length with the diameter of the pipe

2) <u>Pipe Installation Cost [Installation less then 20 feet of depth (H < 20 ft)]:</u>

$$C_{Li} = \alpha_1 + \beta_1 D_i + \gamma_1 H_i \qquad (4.3)$$

D is the diameter of the pipe and H is the depth at which the pipe is installed. $\alpha_1$, $\beta_1$ and $\gamma_1$ are cost parameters that vary from place to place.

$$\text{Total Pipe Installation Cost} = \sum_{i=1}^{n} C_{Li}(D_i, H_i)\, L_i^* \qquad (4.4)$$

Figure 3 below shows the cost curves associated with pipe installed at a depth of 20 feet and below. Data from actual bids provided by City of Victoria was fitted against various cost curves.

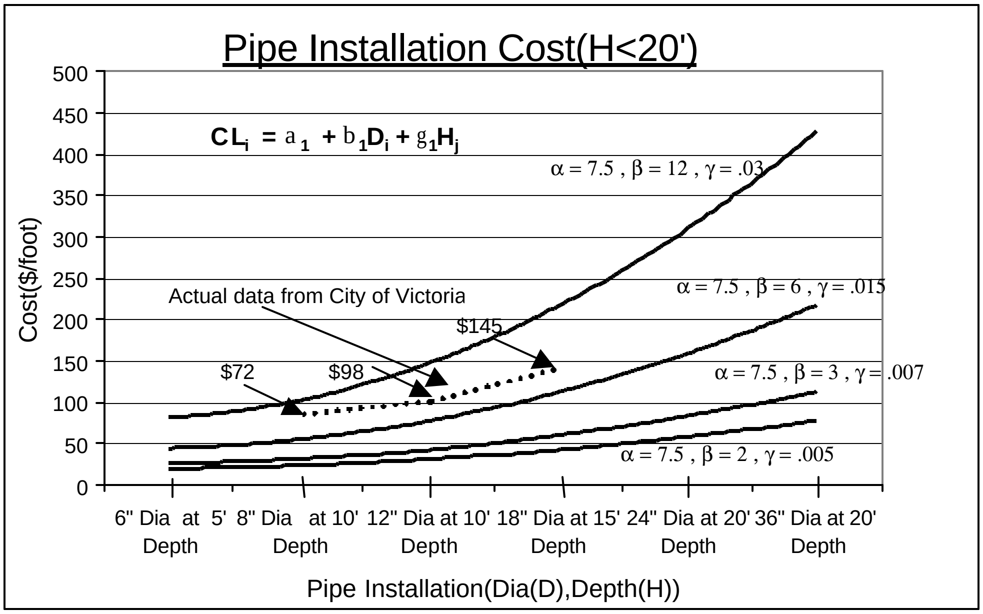


Figure 3 Cost of pipe installation with diameter and depth

3) <u>Pipe Installation Cost [Installation more then 20 feet of depth (H > 20 ft)]</u>:

Based on the available data the following relationship was observed (not using index notation):

$$C_{Lj} = \alpha_2 + \beta_2 D_j + \gamma_2 H_j + \delta_2 D_j H_j \qquad (4.5)$$

$$\text{Total Pipe Installation Cost} = \sum_{i=1}^{n} C_{Lj}(D_j, H_j)\, L_i^* \qquad (4.6)$$

4) Manhole cost: Based on data available, the cost for each manhole can be best represented as

$$C_{MHk} = \alpha_3 + \beta_3 D_k + \gamma_3 H_k, \qquad (4.7)$$

$$\text{Total Manhole Cost} = \sum_{k=1}^{p} C_{MHk}\, N_k^* \qquad (4.8)$$

5) Cost of Wastewater Treatment plant ($C_{TP}$) and Cost of Pump station ($C_{PS}$)

These cost parameters were determined based on their capacity in mgd.

$$C_{TP} = \alpha_4 + \beta_4 C_1 \quad (4.9)$$

where $C_1^*$ is the Capacity in mgd

$$C_{PS} = \alpha_5 + \beta_5 C_2 \quad (4.10)$$

where $C_2^*$ is the Capacity in mgd

The values of $\alpha_i$, $\beta_i$ and $\gamma_i$ were determined by using multiple regression analysis on actual sets of data. $L_i^*$ , $N_k^*$, $C_1^*$and $C_2^*$ are available from CIGMAT/UH Life Cycle Cost Model.

## 5. Life Cycle Cost

The Life cycle costing (LCC) is the total cost of ownership over the life span of the asset. Initial cost and all subsequent expected costs of significance are included in the calculation as well as disposal (or residual) value and any other quantifiable benefits that are derived.

The LCC of a wastewater system is formulated in simple terms with all the costs and values in present-value-constant dollars:

$$LCC = \Sigma C - S + \Sigma(M + R) \quad (5.1)$$

Where

C = Capital Cost,

S = Residual Cost,

M = Operation and Maintenance Cost,

R = Rehabilitation Cost,

The capital cost was estimated in Section 4 and is the actual bid price of a system. The system may have a service life longer than the LCC study period and, consequently, will have a residual future-current-dollar value, which must be discounted back to a present-constant-dollar value, and subtracted from the original cost. Since maintenance occurs periodically and rehabilitation may occur several times during the life of the LCC study period, the future-current-dollar value of each occurrence must be discounted back to a present-constant-dollar value [ASTM A 930-94].

Future costs are normally estimated in constant-dollar-values, which are then converted to future-current-dollar values by an inflation factor and then discounted back to present-constant-dollar values by an interest factor [ASTM A 930-94].

Hence we get

$$PV = A\,((1 + I)/(1 + i))^{n} \quad \ldots\ldots (5.2)$$

Where

PV = present constant dollar value,

A = constant dollar value,

I = inflation rate,

i = interest or nominal discount rate,

n = number of years in the future at which costs are incurred.

Equation 5.2 requires assuming an interest rate and an inflation rate. Interest and inflation rates vary widely, but historical records indicate that the differential between interest and inflation rates has been relatively stable long term [ASTM C 1131-95]. Hence we define an inflation /interest factor, F, as:

$$F = ((1 + I)/(1 + i))^{n} \quad \ldots\ldots (5.3)$$

The use of the inflation /interest factor to simplify life-cycle cost estimation was first proposed by the Jet Propulsion Laboratory of California Institute of Technology [ASTM C 1131-95]. It was proposed for pipe installation, and it was stated that the differential between interest and inflation rates for projects involving state or local funding should be determined using the municipal bond rate average, projects involving federal funding should be determined by the treasury bill rate average, and projects involving private funding should be determined by the prime lending rate.

Table 5.1[ASTM C 1131-95] presents the maximum, minimum, and average values for the inflation / interest factor, F, for inflation rates ranging from 4 through 18% and differential between interest and inflation rates ranging from 1 through 5 %.

Table 5.1

Inflation/Interest Factor (F) Values

| | F = (1 + I )/(1+i ) | | |
|---|---|---|---|
| ( i - I ) % | Maximum | Minimum | Average |
| 1 | 0.9916 | 0.9905 | 0.991 |
| 2 | 0.9833 | 0.9811 | 0.982 |
| 3 | 0.9752 | 0.972 | 0.974 |
| 4 | 0.9672 | 0.963 | 0.965 |
| 5 | 0.9593 | 0.9541 | 0.957 |

The calculations in the Table 5.1 show that the inflation/interest factor is virtually constant for specific differentials between the inflation and interest rates.

Table 5.2[ASTM C 1131-95] presents the 30-year average of the inflation/interest factor and corresponding inflation/interest rate differential for municipal bonds, treasury bills, and the prime rate.

The funding for wastewater system is mainly from state and local sources (Municipal bonds) hence we used F = 0.9953 as default for our model.

Table 5.2 Inflation/Interest Factor 30-Years Average

| **Funding Source (User)** | **F = (1 + I)/(1 + i)** | **Differential (i - I)%** |
|---|---|---|
| **Municipal Bonds** (State and Local) | **0.9953** | 0.52 |
| **Treasury Bills** (Federal Agency) | 0.9853 | 1.66 |
| **Prime Rate** (Private Investment) | 0.9749 | 2.86 |

*5.1) Maintenance cost:*

This is calculated by determining the future value of each cost occurrence of a maintenance activity (routine maintenance), discounting each to a present value, and summing up all the values. Maintenance cost is estimated on an annual basis.

The total present value of all maintenance costs is:

$$M = C_M \Sigma(F^n + F^{2n} \ldots\ldots + F^{mn}) \quad \ldots(5.4)$$

Where:

M = total present value of all maintenance costs,

$C_M$ = constant dollar cost of a maintenance cycle,

n = number of years in maintenance cycle,

m = number of maintenance cycles in project design life.

*5.2) Rehabilitation Cost:*

The wastewater system will require rehabilitation or replacement several times during the system design life. The present value of rehabilitation cost is calculated by determining the future value of each cost occurrence, discounting each to a present value, and summing up all the values.

$$R = \Sigma C_N F^N \qquad (5.5)$$

Where:

R = present value of rehabilitation costs,

$C_N$ = constant dollar cost estimated for a rehabilitation project,

N = number of years after which the rehabilitation cost will incur.

## 6. Analysis and Results

The following life cycle cost analysis was performed for the city of Norfolk, Virginia. The population, sewer length and treatment cost data were available for this city.

### *6.1) Case study (Norfolk, Virginia):*

Various case studies have been documented for cities with different populations. One such example is Norfolk, Virginia. The population of this city is 260,000 [6]. A study on the infiltration problem was conducted based on the data provided by the city. Information on the treatment and transportation cost were $1.40/1000 gallons and $1.29/1000 gallons, respectively [6]. Based on the census data, the household occupancy was 2.5 per unit [6] and the LCC model was used to generate the data for a period of 30 years. Various analyses were performed.

<u>Input Data Available:</u>

Population: 260,000

Average Household Occupancy: 2.5 persons/unit

Wastewater treatment cost: $1.4 / 1000 gallons

Wastewater Transportation cost: $ 1.29 /1000 gallons

Sample Output Data from Model:

Length of sewer Pipeline: 1004 miles.

Number of Manholes: 17,298 numbers.

Total number of pipe joints: 507,574 numbers.

Design Treatment Plant Capacity: 43 MGD.

Total sewer flow per day: 24 MGD.

Cost data from model:

Total sewer treatment cost per day: $67,514

Infiltration treatment cost per day: $5,933 (20% infiltration)

Various sensitivity analyses were conducted for the city of Norfolk. A few of them are presented below:

*6.1.1) Influence of household occupancy on the % Infiltration:*

Figure 4 shows the variation in percent infiltration with change in household occupancy.

*6.1.2) Variation of Infiltration on the pipe joint spacing:*

Figure 5 shows the changes in the percent infiltration as the spacing between various pipe joints is increased.

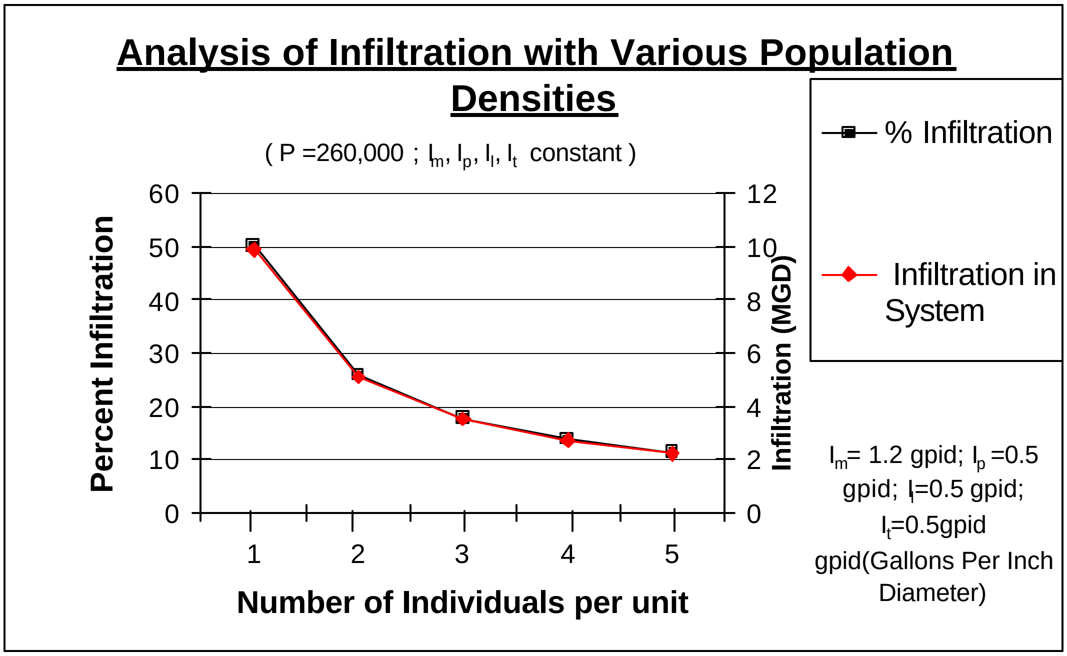


Figure 4 Influence of household occupancy on the % Infiltration

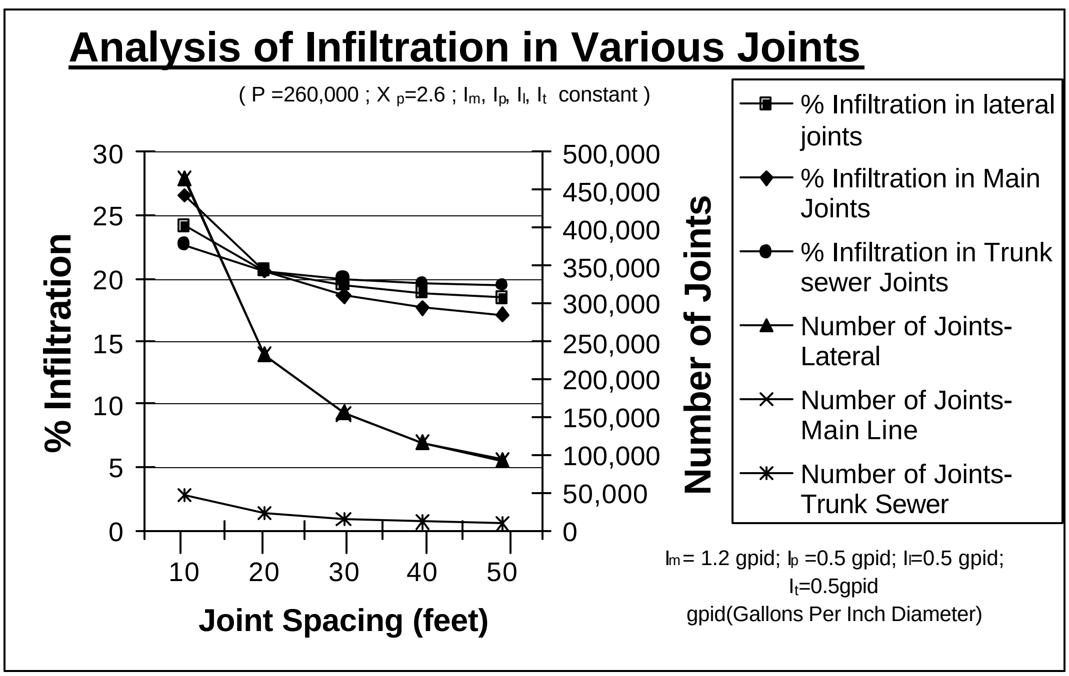


Figure 5 Variation of Infiltration versus the pipe joint spacing

*6.1.3) LCCA for infiltration reduction in the system:*

LCC for various infiltration reductions is compared with the rehabilitation cost and treatment cost. Based on the cost results, it can be stated that up to 50% reduction in infiltration by rehabilitation is cost effective. Higher reduction in infiltration will result in greater rehabilitation cost and greater total cost.

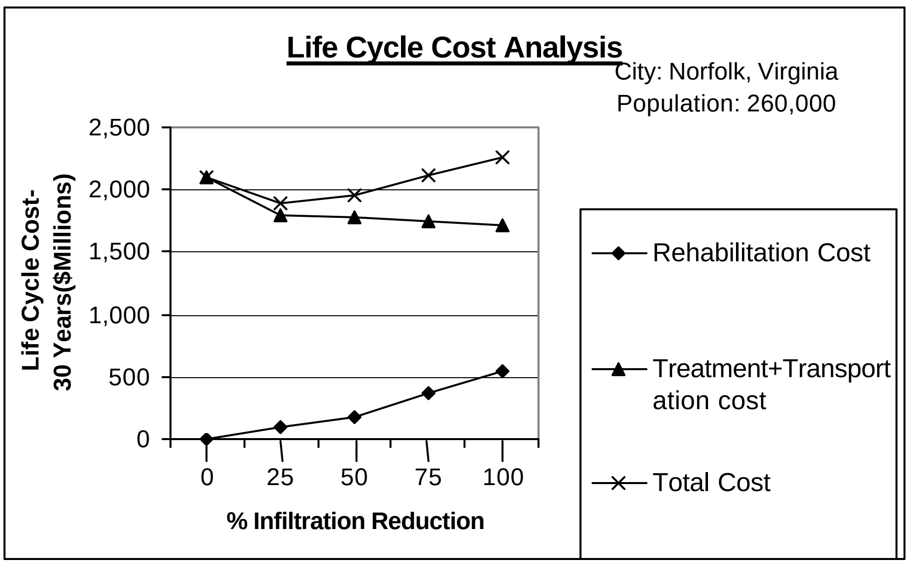


Figure 6 Life cycle cost and infiltration reduction

## 7. Conclusion

A comprehensive LCC model is being developed for constructing, maintaining and operating a wastewater system. Capital cost, operation and maintenance cost, rehabilitation cost and residual cost have been incorporated into the LCCA model. The change in population during the 30 year life cycle period has been included. The model is being calibrated with published data from small and large cities.

## 8. References


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***Glossary of Terms:***

*Addition:* An addition is an expansion or extension to an existing fixed asset. An example of an addition would be the construction of a sector of wastewater system.

*Alternative Analysis:* Involves identifying different ways of meeting the functional requirements of the program, including various construction solutions to a problem. This requires using approaches such as cost benefit or life-cycle costing analysis to determine comparable cost of alternatives.

*Average dry weather flow*: The average non-storm flow over 24 hours during the dry months of the year (May through September). It is composed of the average sewage flow and the average dry weather inflow/infiltration.

*Average wet weather flow***:** The average flow over 24 hours during the wet months of the year (October through April) on days when no rainfall occurred on that or the preceding day.

*Base flow***:** Wastewater flow (including no infiltration) originating from residential, commercial and industrial and other sources.

*CATAD system***:** Computer Augmented Treatment and Disposal System, which monitors flows in the wastewater conveyance system and operates regulator and pump stations to gain maximum use of pipe capacities.

*Clean Water Act (CWA)*: Also known as the Federal Water Pollution Control Act (33 U.S.C. 1251 et seq.).

*Combined sewer overflows (CSOs)*: Overflows, during wet weather, of combined wastewater and storm water. CSOs occur when flows in the wastewater collection system exceed the capacity of that system.

*Combined sewer system***:** A wastewater collection and treatment system where domestic, industrial, commercial and other wastewater is combined with storm runoff.

*Combined sewers***:** A sewer that carries both sewage and storm water runoff.

*Cost-effective alternative***:** An alternative control or corrective method identified after analysis as being the best available in terms of reliability, performance, and costs.

*CSO event***:** A period of rainfall during which an overflow was recorded and that was preceded by 48 hours with no overflow and followed by 48 hours.

*CSO Treatment Plant:* A plant designed to provide primary treatment of combined sanitary sewage and storm water for peak flows above the 2.25 times the average wet weather flow. Such plants operate only intermittently, unlike most wastewater treatment plants, which operate continuously.

*Design event***:** A computer-simulated combined sewer overflow event, usually based on a design storm, which is used to determine the probable response of the sewer system to proposed modifications.

*Design storm*: A rainstorm used in the design of wastewater systems, primarily for systems, which control combined sewer overflows. A particular storm may be selected as a design storm because adequate data exist to allow a calibration of a computer model being used to simulate the behavior of the sewer system during that storm.

*Detention***:** The process of collecting and holding back stormwater or combined sewage for delayed release to receiving waters.

*Discharge, direct or indirect***:** The release of wastewater or contaminants to the environment. A direct discharge of wastewater flows from a land surface directly into surface waters, while an indirect discharge of wastewater flows into surface waters by way of a wastewaer treatment system.

*Domestic wastewater*: Human-generated sewage that flows from homes and businesses.

*Effluent*: Treated water, wastewater or other liquid flowing out of a treatment facility.

*Environmental Protection Agency (EPA)***:** A federal agency established in 1979 by Presidential executive order to control pollution of the environment.

*Force main***:** A pipeline leading from a pumping station that transports wastewater under pressure.

*Gpcd:* Gallons per capita per day, a rate of liquid flow.

*Gped:* Gallons per employee per day, a rate of liquid flow.

*Gpid:* Gallons per inch diameter per Day, a rate of infiltration.

*Gpidpf*: Gallons per inch diameter per foot per day, a rate of infiltration.

*Gpmd:* Gallons per Miles per day, a rate of infiltration.

*Groundwater infiltration***:** Infiltration that enters the sewerage system through pipe defects located below the normal groundwater table.

*Hydraulic Routing Model***:** A computer model used to simulate the flow of water in pipes.

*Infiltration:* Penetration of water from the soil into a sewer system by such means as defective pipes, pipe joints or connections, or manhole walls.

*Inflow***:** Flows of extraneous water into a wastewater conveyance system from sources other than sanitary sewer connections, such as roof leaders, basement drains, manhole covers, and cross-connections from storm sewers.

*Influent:* Water, wastewater or other liquid flowing into a reservoir, basin or treatment plant.

*Influent pump station***:** A pump station that pumps flow from an interceptor sewer into a treatment plant.

*Infrastructure:* Streets, water, sewer lines, and other public facilities basic and necessary to the functioning of an urban area.

*Lateral sewers***:** Pipes that receive sewage from homes and businesses and transport that sewage to trunks and mains.

*Manhole:* This is the access structure that allows filed crews to inspect sewers and perform maintenance and rehabilitation.

*Mg* **:** Million gallons, a measure of liquid volume.

*Mgd:* Million gallons per day, a rate of liquid flow.

*Model***:** A formal set of relationships that attempt to represent some processes of the real world. Some models are intended to explain causes and effects of processes, others are tools to estimate or project the results of those processes, even if the processes themselves are not fully understood.

*National Pollutant Discharge Elimination System (NPDES)***:** Section 402 of the federal Clean Water Act, which prohibits discharge of pollutants into navigable waters of the United States unless a special permit is issued by EPA, a state, or (where delegated) a tribal government on an Indian reservation.

*NPDES Permit***:** Permit issued under the National Pollution Discharge Elimination System, which establishes reporting requirements and other conditions for discharge of pollutants to receiving waters.

*Outfall***:** The exit point, usually a pipe or pipes where flow is discharged from the wastewater system into receiving water and which is engineered to ensure dispersion and dilution of the effluent in the receiving waters.

*Peak flow: The* maximum flow expected to enter a facility.

*Primary treatment***:** The first stage of wastewater treatment involving removal of floating debris and solids by screening and/or settling.

*Pump Station***:** A structure used to move wastewater uphill, against gravity.

*Raw sewage***:** Untreated wastewater.

*Runoff:* That part of precipitation, snow melt, or irrigation water that runs off of the land surface into streams or other surface water instead of infiltrating the land surface.

*Secondary treatment***:** Biochemical treatment of wastewater after the primary stage, using bacteria to consume the organic wastes. The secondary treatment step includes aeration, settling, disinfections and discharge through an outfall. Secondary treatment in conjunction with primary treatment removes about 85 to 90 percent of suspended solids in wastewater.

*Separation, total or partial***:** A method for controlling combined sewer overflow whereby the combined sewer is separated into both a sanitary sewer and a storm drain, as is the practice in new development. Separation may be total, in which case no stormwater is diverted to the sanitary sewer, or it may be partial, involving only the removal of runoff from streets and parking lots from the sanitary system.

*Sewer:* A channel or conduit that carries wastewater or stormwater runoff from the source to a treatment plant or receiving stream. *Sanitary sewers* carry household, industrial, and commercial wastewater. *Storm sewers* carry runoff from rain or snow. Combined sewers carry both kinds of water.

*Smoke Testing:* Use of a harmless smoke to locate inflow and infiltration in sewers.

*Storage***:** A method for controlling combined sewer overflows by storing the combined sewage until the rainstorm subsides, then releasing it back into the conveyance system to be treated at the usual treatment plant.

*Storm sewer***:** A system of pipes (separate from sanitary sewers) that carry only water runoff from building and land surfaces.

*Stormwater***:** Water that is generated by rainfall and is often routed into drain systems in order to prevent flooding.

*Treatment***:** Chemical, biological, or mechanical procedures applied to industrial or municipal wastewater or to other sources of contamination to remove, reduce, or neutralize contaminants.

*Wastewater***:** Total flow within a sewerage system. In separated systems, it includes sewage and infiltration/inflow. In combined systems, it includes sewage and stormwater.

# User instructions for the UH LIFE CYCLE COST MODEL

When starting the LCC model it may ask to enable macros. Please enable macros and then proceed:

## Major Components:

### 1) INPUT SHEET:

Values for all the parameters are to be entered in this sheet. The columns colored Red are the entry column. Default values of each parameter are provided next to the entry column. The user can enter values as per their system requirements.

- **Total Population:** The population at the beginning of the design study.
- **Establishments:** Number of housing, industrial, business, educational and recreational establishments in the study area. The numbers of units are based on population of the city/wastewater district. Note that the number of persons is an important parameter and can be obtained from the U.S. census data.
- **Percent of Population**: Percentage of total population working with or directly associated with various types of sectors. This data is needed to generate the base flow in the model.
- **Length of sewer per Unit:** Length of sewer line added by each unit to the total length of the main lines. Trunk sewer will be a percentage of main sewer pipeline length.
- **Sewer pipe classification:** Pipe sizes are classified in standard sizes. For laterals pipe sizes ranges from 4, 6 and 8 inch diameter while Main lines ranges from 8, 10 and 12 inch diameter pipes and trunk sewer are 24, 30, 36, 42 and 48-inch diameter. The laterals, main and trunk are equally divided among the sizes. User can change the percentage of various sewer pipe sizes according to the system to be designed.
- **Pipe Joint spacing:** The joints in pipeline are classified in three categories. Lateral-Main joints (joints at the intersection of lateral with main line sewer), Mainline joints (joints between the pipes of the mainline sewer) trunk line joints (joints between the pipes of the trunk sewer). The default spacing is 20 feet. User can change the spacing as per their system.

- **Manhole spacing:** Manholes at mainlines and trunk sewers are placed at a default distance of 300 feet and 400 feet apart respectively.

- **Manhole sizes:** Manhole sizes vary from 4 to 8 feet diameter based on the diameter of the pipe where the manhole is placed.

- **Infiltration:** Infiltration considered in the model is rain induced infiltration and ground water infiltration. Infiltration takes place through manholes, pipeline (cracks in main line and trunk line) and pipe joints (main-lateral joints, main line joints, trunk line joints). The intensity of infiltration varies from day to day; the user can determine the intensity of infiltration and number of days associated with it. The default value is 0% infiltration for 250 days, 10% for 100 days and 30 % for 15 days. The percent infiltration and number of days are on a sliding scale; infiltration increases every year with no maintenance performed, so do the number of days associated with the infiltration.

- **Per capita Flow:** Per capita flow is the individual discharge made by per person per day on an average associated with various establishments. Default values are provided.

- **Transportation cost:** Transportation cost is the cost associated with the collection and conveyance of waste water this includes the cost of minor sewer repair, sewer maintenance, pumping station, Operation and Maintenance and other miscellaneous expenses.

- **Treatment cost:** Treatment cost is the cost of treating a gallon of wastewater. Treatment cost depends on the capacity of the treatment plant and the capacity utilized. Treatment plants have three size classifications: small, medium and large treatment plants.

## 2) BASIC MODEL SHEET:

This sheet provides the data for a single event (one day) of occurrence of infiltration in the system. Various parameters can be verified from this sheet: the length of the sewer system, number of manholes, per day sewer flow, treatment cost per 1000 gallons etc; of the city/wastewater district under consideration. The model can be further calibrated for a particular city by making corresponding changes in the input sheet to achieve city specifications.

## 3) CAPITAL COST:

The capital cost sheet shows the cost associated with laying out a wastewater system of the size obtained in the basic model sheet.

## 4) MODEL SHEET 5, 10, 15, 20, 25, 30:

These model sheets incorporate the change in population every 5 years. Infiltration in the system is increased by one percent every year. Default Model values are provided in the Input sheet.

## 5) CHECK FOR SSO (Sanitary Sewer Overflow):

This sheet helps to check when the system flow exceeds the treatment plant capacity and the prescribed regulations of EPA for excessive infiltration (average dry weather flow not exceeding 120 gpcd-gallons per capita per day). Rehabilitation is performed at the end of every 10 years period, when rehabilitation is performed the infiltration is dropped by 50%.

## 6) REHABILITATION COST :

Rehabilitation is performed on a 10-year cycle. Rehabilitation is performed on 10% of the system. The cost calculation is done as per rehabilitation costs provided by the user (default values are also provided). 30 years rehabilitation cost is calculated based on two rehabilitation cycles.

## 7) LIFE CYCLE COST:

The Life Cycle Cost sheet gives us the cost of Wastewater treatment for 30 years period when rehabilitation is performed every 10 years on the system.

## 8) LIFE CYCLE COST(NO MAINTENANCE):

Alternate Life Cycle Cost is achieved for no rehabilitation on the system. The difference in the life cycle cost with maintenance and no maintenance is obtained.