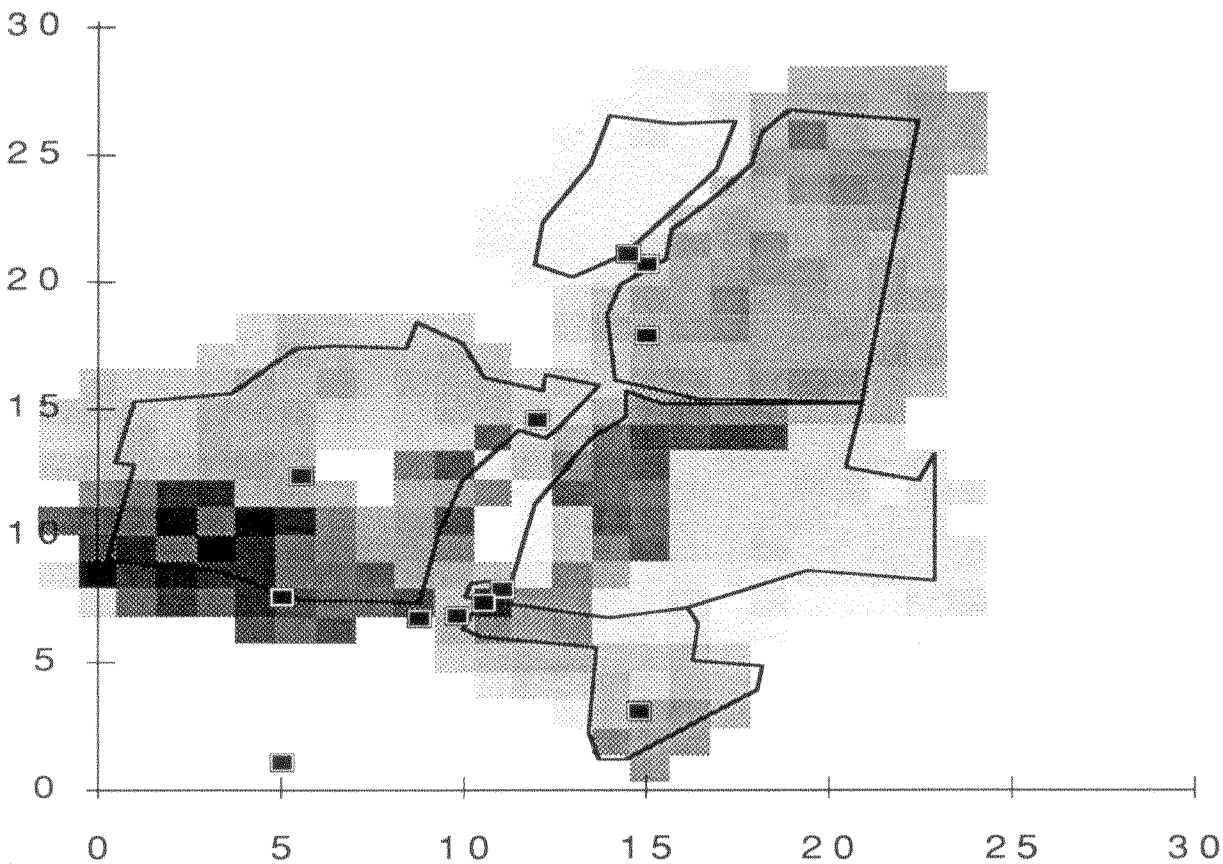
<u>Systematic Inspection and Severity Ranking of a Municipal Sewage Collection System</u>

by Theodore G. Cleveland, Ph.D., Keith Goodwin, and Benjamin Strider



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Summary

The Newport Sewage Treatment Plant (STP) suffers from periodic hydraulic overload. Plans to furhter develop the community will increase the problem. An administrative order from the Texas Water Commission (TWC) requires the plant to address permit violations that are a consequence of the hydraulic overload.

A study that used thematic mapping and sewer water quality monitoring was performed to attempt to determine the severity of inflow and infiltration and its geographic distribution in Newport. The concept of Π Risk was developed to produce a map showing the relative inflow and infiltration risk. The study indicates that inflow and infiltration potential is high in most Sections with the exception of Section 10 , and parts of Section 4.

Targeted rehabilitation in the sections indicated by the Π-Risk map will probably reduce the inflow and infiltration that is contributing to the hydraulic overloading of the STP. Temporary removal from service of sewerage in the undeveloped area of Section 7, and other sections may also help reduce the hydraulic loading. A hydraulic analysis using planning estimates of typical inflow and infiltration suggests that the capacity of the sewage treatment plant is adequate for zero inflow and infiltration, but inadequate for typical estimates of routine inflow and infiltration. Eventual capacity expansion of the STP is probably necessary for Newport to become fully developed (we assumed 3000 homes at full development).

Abstract

The Newport Sewage Treatment Plant (STP) suffers from periodic hydraulic overload. Plans to furhter develop the community will increase the problem. An administrative order from the Texas Water Commission (TWC) requires the plant to address permit violations that are a consequence of the hydraulic overload.

The plant and collection system operators contacted the Department of Civil and Environmental Engineering to conduct systematic research to identify locations of rainfall induced infiltration and develop methods to assess the reliability of the sewage collection system. This report describes the one-year research effort.

Introduction

Inflow is surface water that finds direct entrance into the sanitary sewer system by way of downspouts, sump pumps, floor drains, or storm water catch basins. Infiltration is groundwater that enters a sanitary sewer system through defective pipes, deteriorated manholes, or building connections (USEPA, 1991). Collectively these two sources of clear water are referred to as inflow and infiltration (I&I). In general, all sanitary systems experience I&I and total reduction of I&I is considered infeasible.

Excess inflow and infiltration is considered a problem when it is associated with the structural failure of a sanitary collection system, causes hydraulic loading beyond the capacity of the receiving treatment plant, and/or causes local flooding, sewer system surcharge (system blockages) and residential flooding. Elimination of excess I&I has been the emphasis of I&I studies nationwide during the last 20 years (Blauvelt, R.W., 1991).

Excess inflow and infiltration remediation can be achieved by a variety of engineering means once the sources of excess I&I are identified.

Indication of Excessive Inflow and Infiltration

Excessive I&I may be indicated by the following types of occurrences:

(1) Flow measurement at a waste water treatment plant beyond anticipated flow.
(2) Flooded basements during periods of intensive rainfalls.
(3) Lift station overflow.
(4) Sewer system overflows or by-pass.
(5) Excessive power costs for pumping stations.
(6) Frequent motor changes at lift station facilities due to overtaxed pumping facilities.
(7) Hydraulic overloading of treatment plant facilities.
(8) Excessive costs of sewage treatment.
(9) Water quality problems due to raw sewage bypass.
(10) Surcharging of manholes.
(11) Odor complaints, structural failure such as sinkholes, and corrosion.

Identifying Sources of Excess Inflow and Infiltration

A Sewer System Evaluation Survey (SSES) is a tool that is used to identify sources of excess I&I and to plan, design, and implement remediation strategies. An abbreviated SSES can be conducted that is broader in scope than a traditional detailed SSES. The goals of the abbreviated survey are to delineate sub-areas, identify problem and non-problem areas of a system. This level of survey should also develop a monitoring program, a schedule for more detailed surveys, and a rough budget for planning, designing, and implementing remediation strategies (USEPA, 1991).

The methods used in traditional SSES include: flow monitoring, physical survey, inspection, and cost analysis. Tools used include automated flow meters, television survey, dye and smoke testing, and chemical analysis.

Abbreviated survey techniques have been incorporated into routine maintenance schedules with remarkable success (Blauvelt, 1991) at lower costs than traditional detailed SSES approaches.

Abbreviated survey techniques adopt elements of the traditional techniques, but with an emphasis on existing data or data that are routinely and easily collected. Typically the abbreviated techniques are designed so that the analysis can be conducted in-house by sewer system operations and maintenance personnel.

The data sources used in abbreviated surveys include:

(1) As built sanitary and storm sewer maps.
(2) Sewer system operation and maintenance records.
(3) Existing geographical, geological, climatological, and topographical records.
(4) Existing municipal planning documents.
(5) Sewer system monitoring records.
(6) Interview information from operators and users.
(7) Rainfall, streamflow, and groundwater records.
(8) Population and user history.
(9) Water use records.

The goals of an abbreviated survey are to define sewer system sub-areas and monitoring locations, develop a preliminary ranking of easily identified problems within each subarea, establish a monitoring schedule, and develop information to correlate flows with rainfall and groundwater information (USEPA, 1991). Traditionally the results of this level of survey are used to plan future survey but there is no reason why abbreviated survey results cannot be immediately applied. A caveat for immediate application is that the survey should be incorporated into routine maintenance procedures (Blauvelt, 1991).

An abbreviated Sewer System Evaluation Survey (SSES) is a tool that can be used to identify sources of excess I&I and to plan, design, and implement more detailed surveys and remediation strategies. This level of survey should develop information to correlate rainfall and flow data, as well as delineate problem and non-problem sub-areas in a sewer system for further study or immediate attention. A moderately rich literature of guidance documents exists and is available for implementing such surveys. Appendix I contains a bibliography of useful guidance documents reviewed during this research effort.

Background

The research effort involved using the ideas in the literature from guidance documents for SSES inspections. Particular attention was paid to using cost effective interpretative methods that could be implemented by the Newport system or other similarily sized communities. The research effort was conducted in two phases. The first phase was a water budget study conducted in the summer of 1992 by Benjamin Strider, a senior Civil Engineering Student at the University of Houston. The second phase was started the summer of 1992 and continued through the summer of 1993.

This phase involved the use of 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 confirm the thematic mapping results. The second phase was conducted entirely by Keith Goodwin, a graduate student in Environmental Engineering at the University of Houston, and constitutes a significant portion of his master's thesis.

Site Location and Demographics

Newport is located in Harris County, East of Lake Houston as shown on Figure 1. Newport is a community of single and multi-family housing. It covers an area of approximately 1800 acres and is served by three 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 subdivision layout is shown on Figure 2, with various important features of interest indicated. The layout map indicates the approximate locations of the seven lift stations in the subdivision as well as the sewage treatment plant. Generally the sewage flow east of Gum Gully is southwest towards the sewage treatment plant, while west of Gum Gully, sewage flows southeast towards the sewage treatment plant.

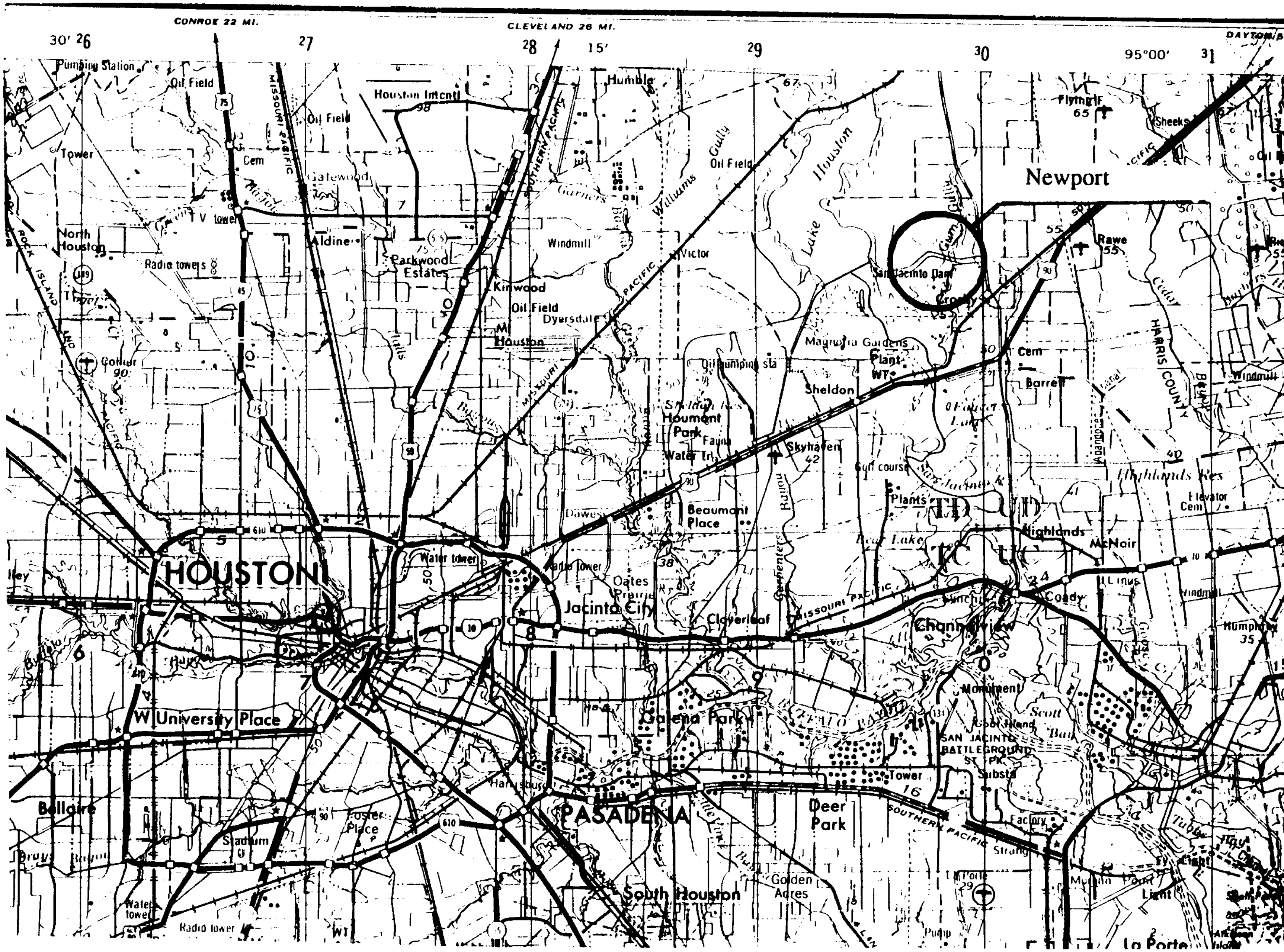


Figure 1. Newport Study Area Location Map

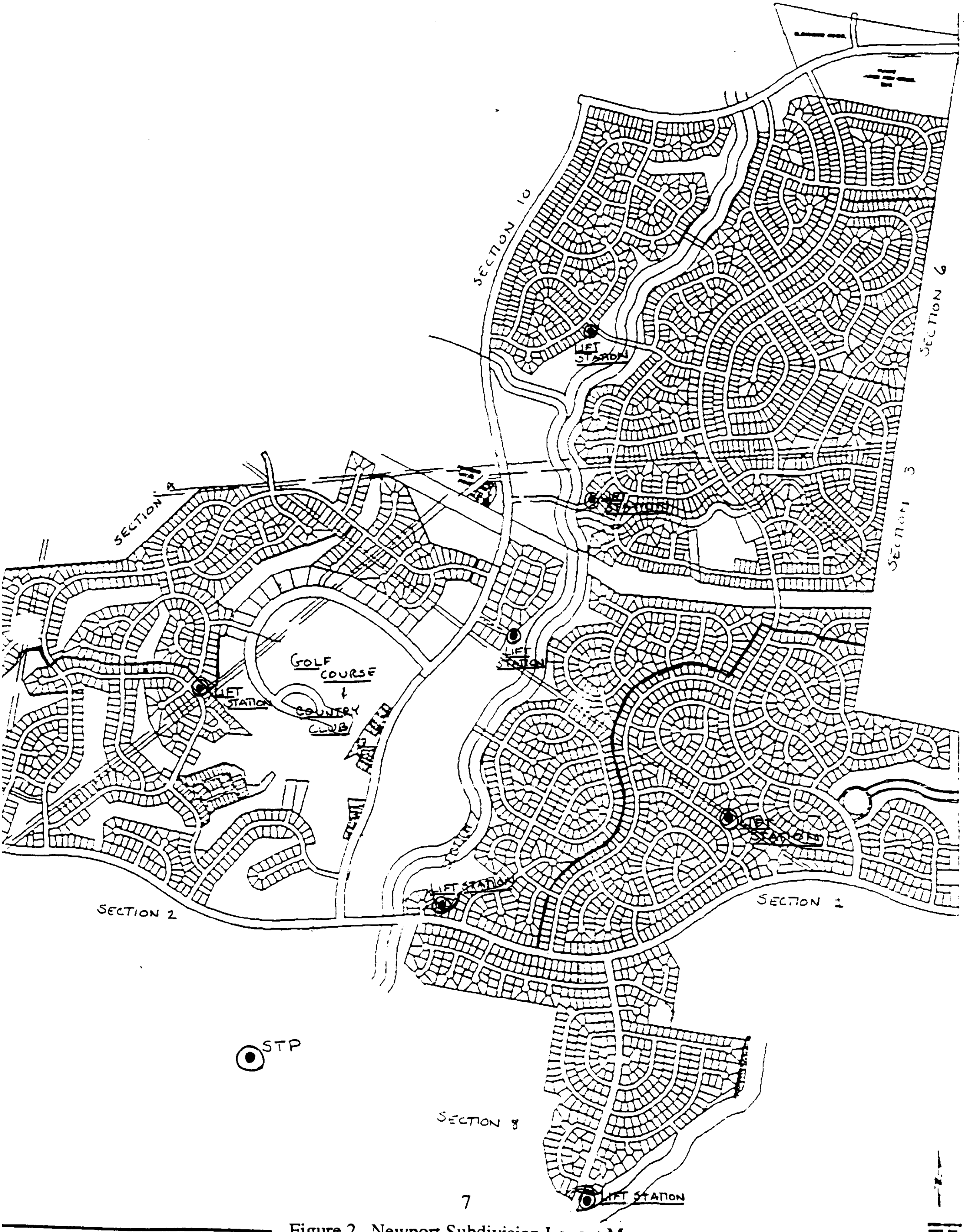


Figure 2. Newport Subdivision Layout Map

Soils

The U.S. Department of Agriculture Soils Maps (USDA) indicates that soils in the area are loams and clays typically found throughout the region, while the Land and Water Resources Map prepared for the Houston-Galveston Area Council (HGAC) shows the soils to be a moderately rechargable sand unit extending to the boundaries of Lake Houston. Figures 3 and 4 are copies of the two maps covering the Newport area. In order to verify the soils description, two shallow soil borings were conducted in the winter of 1992.

A hand-cut soil boring in the vicinity of the northern end of the subdivision along Gum Gulley produced silty sand to a depth of 5 feet. The location of this boring is consistent with the location of a sandy loam unit shown on the U.S.D.A. soils map. A second hand-cut boring in the area south of Black Hope Addition produced a stiff clay to a depth of 5 feet. The location of this boring was consistent with the clay units on the south portion of Section 8 shown on the U.S.D.A. map. The rechargeable sand units indicated on the HGAC map appear to the north and south of the Newport area, and are probably contiguous with the subdivision, especially in the western portion of the subdivision and in parts of the Black Hope Addition.

Based on soils map analysis and field investigation, Newport is underlain by clay soils north of the water canal except along a section of Gum Gully north of the water canal, where the soil type appears to be a silty sand. South of the water canal the subdivision is underlain by sandy loam soil, except in the channel of Gum Gully and at the very southern tip of the Black Hope Addition where the soil is a stiff clay. The surfical flow in the sandy loam units are probably towards Gum Gully, consistent with the general topography.

The different soils types are significant in that they will tend to exhibit different behavior over the course of a typical year. The clay soil types generally have a low permeability and high shrink/swell coefficients. The low permeability implies that rainfall will tend to run off these areas towards surface drainages such as Gum Gully. However, although the saturated permeabilities are small, clay soils readily develop dessication cracks in the summer time that can contribute to rapid infiltration of rainfall. These cracks tend to "heal" during wet weather, but not always completely. The high shrink/swell coefficients indicate that the soils may move considerably depending on the season, with swelling in the winter and shrinkage in the summer. This movement, over time, can generate significant stresses in buried structures and could cause pipe dislocations that would provide a pathway for rainfall induced infiltration to enter the collection system.

The sandy loam soil is more permeable but less reactive in shrink/swell than the clay soil. One would expect the response of these soils to remain relatively uniform throughout the year. Even though these soils may be more stable from an I&I perspective, runoff from the adjacent clay units could percolate into these soils, thereby causing unexpected high I&I response from these units.

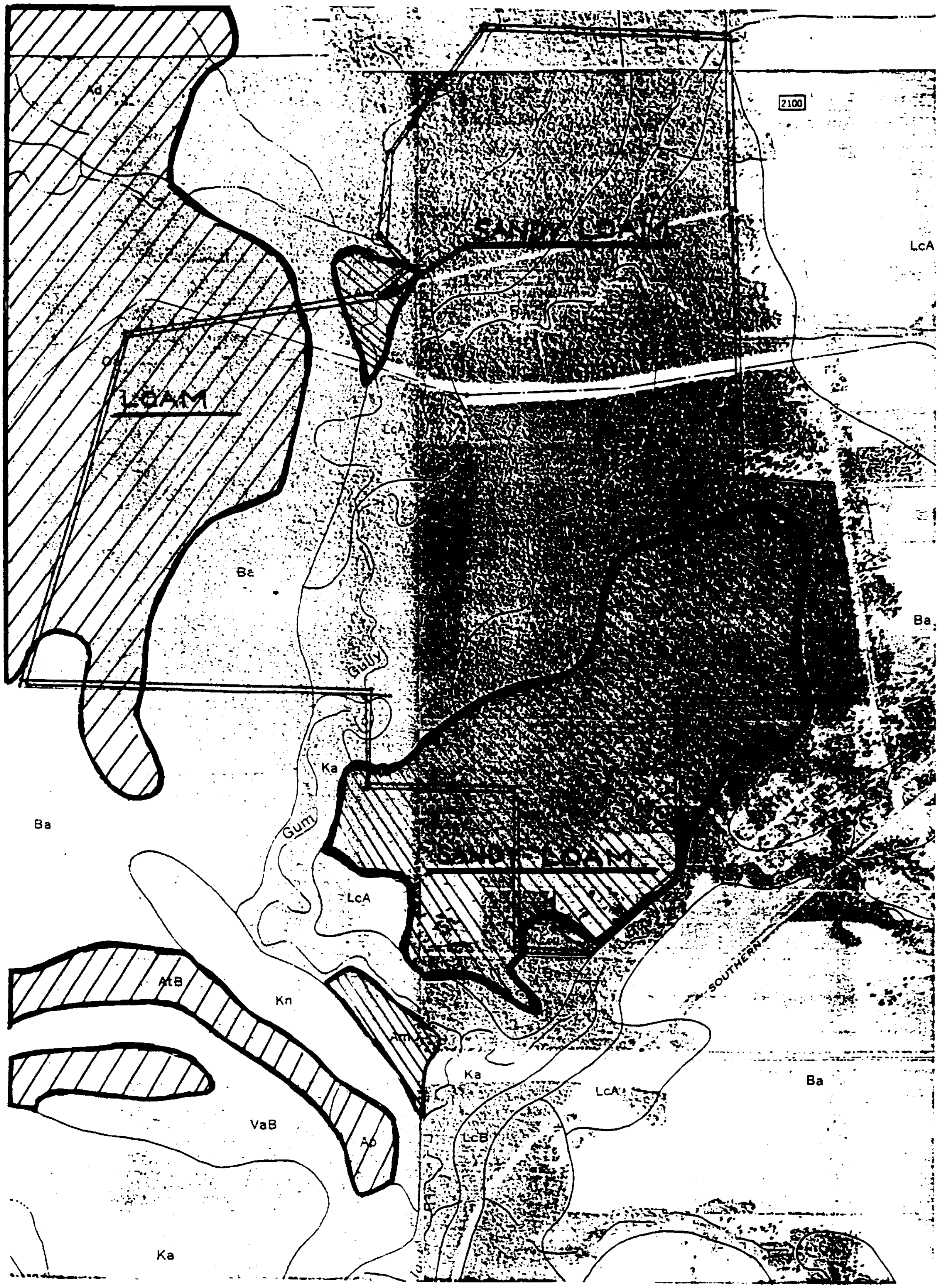


Figure 3. USDA Soils Map for Harris County, Texas

Figure 4. HGAC Land Use Map

Rainfall Analysis

A rainfall analysis was conducted to identify wet and dry seasons in the region of the subdivision. Data for this analysis were obtained from the STP and from the Harris County Flood Control District (HCFCD) rain gage #CIN1001854TX located on the East side of Gum Gully at Diamondhead Blvd.

For this analysis the HCFCD data were initially considered more reliable than the STP data. However, the STP data are in good agreement with the HCFCD data and the two data sets were interchanged when necessary. For consistency we used the HCFCD data whenever possible.

Figure 5 shows the monthly rainfall for the period June, 1987 to May, 1993. The plot suggests a "wet" season starting in December and continuning until July, then a "dry" season from August to November.

A statistical analysis of the HCFCD rainfall data from January, 1987 to March, 1992 indicates the variance in the "dry" period is smaller than in the "wet" period, and that the difference is statistically significant. This result supports the hypothesis that there are two distinct "seasons" in the Newport area.

The rainfall analysis is important because rainfall constitutes the input source of rainfall induced inflow and infiltration water. The other source of I&I water would be lawn irrigation water. This second source of water is difficult to quantify, but it should be part of the water that goes through the homeowner's water meter. These two possible sources were considered for generating a water balance for Newport.

Water Balance

A water balance was performed on data provided by Newport in an attempt to quantify the magnitude of the inflow and infiltration problem. A water balance is based on the principle of the conservation of mass. The idea is that inflows to the system minus outflows from the system plus any change in storage in the system must equal zero if mass is to be conserved. In a simple balance equation this is stated as:

$$\text{Inflows} - \text{Outflows} + \text{Change in Storage} = 0$$

For this study the possible inflows considered are flow from water that enters homes (this flow is normal and expected flow into a sewer system) and rainfall induced infiltration and inflow into the system. Typically only a portion of the water served to a customer will return to the sewer system, the remainder runs off to storm drainage, evaporates, or is consumed as a product water and transported off the site. We called this flow, the return flow, and computed possible return flows as percentages of actual water billed. The lawn irrigation source mentioned in the previous section is included in the return flow component of the water balance.

The outflow from the system is simply the STP flows. The change in storage is assumed negligible over a monthly computation interval, since the entire system has little storage capacity over this time period. This assumption is equivalent to saying that the system operates at steady state. If the modeling interval were shorter - on the order of the system's response time for rainfall, then the steady state assumption would less valid. These concepts are combined into a mass balance equation that constitutes the water balance for the Newport system.

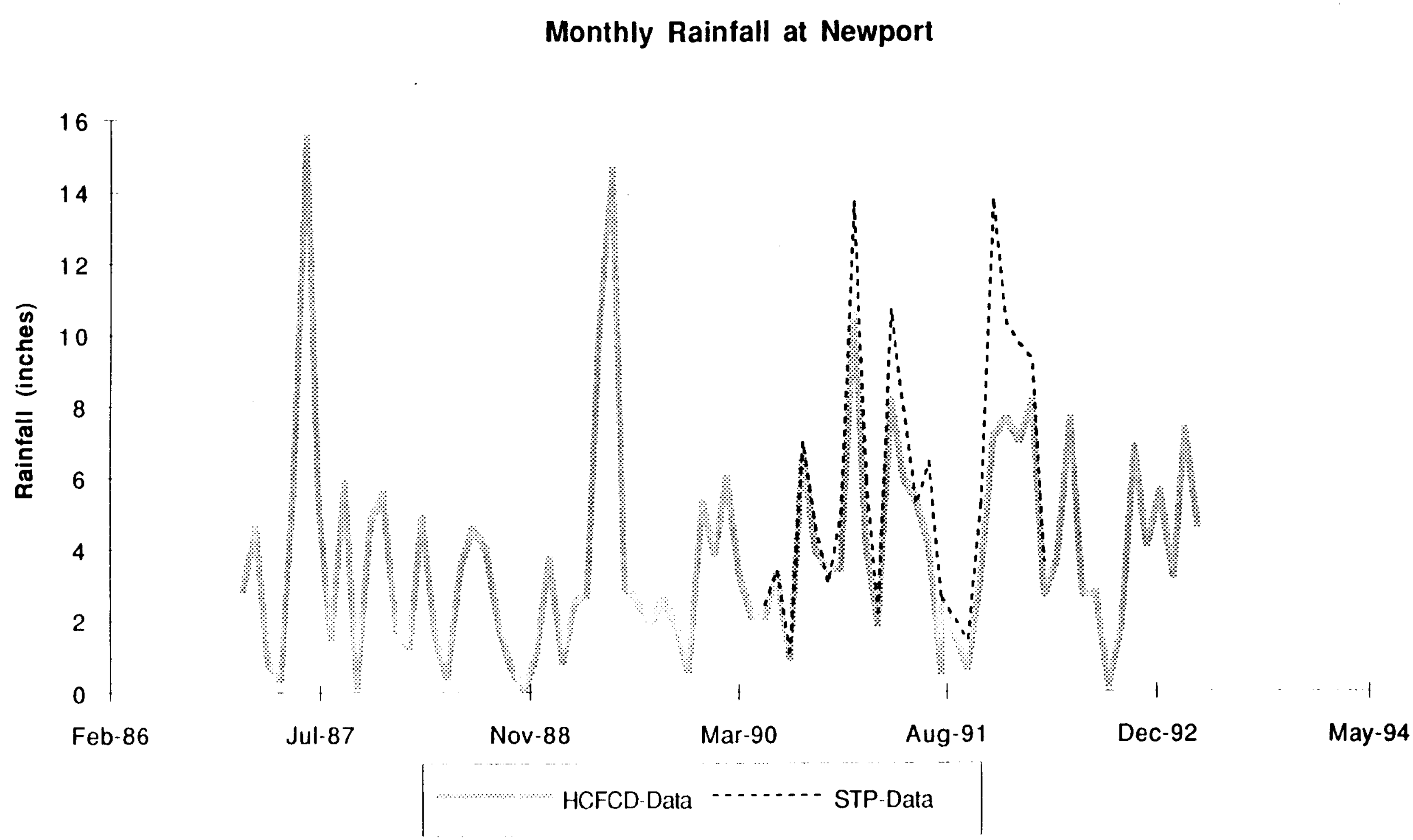


Figure 5. Rainfall Time Series

Mathematically, the water balance model for Newport is expressed as;

Infiltration = STP Flow - Return Flow;

where,

Return Flow = x% * Water Billed

Drinking water purchase records were obtained to quantify the relationship between water served and sewage treated. Table 1 shows the potable water delievered by MUD. The amounts of water bought by MUD #19 were not included in this study because this MUD has no connections to the sanitary sewers and the number of active connections were used to determine the design flow.

The drinking water deliveries are compared to STP treated volumes by assuming a certain proportion of drinking water served eventually becomes sewage. Typically 60-80% of drinking water used becomes wastewater and the lower end is more typical for the arid southwest (Metcalf& Eddy, p. 19). Newport receives between 30 to 39 more inches of rain than the southwest so a value 75% return flow was expected from this study.

Figure 6 shows a water balance for Newport based on this model. From this figure one can observe that even with 100% return flow, the STP 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. A second interpretation is that during the summer months there may be exfiltration from the system, where the sewage actually leaves the system. Only the infiltration computed assuming 50% return flow would allow for the conclusion that exfiltration is not a problem.

A fecal coliform analysis of water in Gum Gully performed in 1992 suggests that such exfiltration is unlikely. A second analysis will be performed in the summer of 1993. Since the water quality analysis suggests that exfiltration is unlikely, the water balance indicates that the average return flow to the system is 50% of water billed. This value is low for Houston's climate and is in fact low for even an arid climate. However, since Newport does maintain a golf course, this unique feature of the development may explain the unusually low return flow based on water billed.

Figure 7 is a plot of infiltration versus service area adapted from Metcalf & Eddy (p. 31) that can be interpreted to determine typical values for peak infiltration in new and old systems. Using 1800 acres as an estimate of the service area, a new sewer system should have a peak infiltration rate of about 800 gpd/acre. Thus the daily expected peak infiltration rate into the sewer system is 1.4 MGD. A 20 year-old sewer system would perform even more poorly at a peak infiltration rate of 5.4 MGD. The reference was published in the late 1970's , about the same time that Newport was designed. Assuming this peak value is correct, the treatment plant is currently underdesigned to handle these peak flows at a permit discharge of 1 MGD. However, rehabilitation of the collection system could alleviate some of the hydraulic overload predicted by this water balance.

Lift Station Flows

Preliminary plots of lift station and STP flow data provided by Jack Murphy of Tebco on May 28, 1992, suggested a distinct correlation between rainfall and pumping at the lift stations. The lift station flows are based on pump running time and pump nominal capacity, not on measured flows. Because these flows are interpreted values, the data should not relied on without supporting quantitative information. Flow meters were recommended and were installed in late 1992.

Table 1. Water Billing and Sewage Treatment Plant Flows

Billed and Treated Water Balance

Date	MUD 20 (gal)	MUD 73 (gal)	Other (gal)	Total Billed (gal)	Total Amount STP (gal)	Return Flow 100%Billed	75%Return	50%Return
Jan-90	8.11E+06	3.69E+06	5.13E+05	1.18E+07		1.18E+07	8.85E+06	5.90E+06
Feb-90	7.51E+06	4.04E+06	5.13E+05	1.15E+07		1.15E+07	8.66E+06	5.77E+06
Apr-90	7.99E+06	3.75E+06	5.06E+06	1.17E+07		1.17E+07	8.80E+06	5.87E+06
May-90	9.11E+06	4.03E+06	6.17E+06	1.31E+07		1.31E+07	9.85E+06	6.57E+06
May-90	1.05E+07	3.99E+06	4.28E+06	1.45E+07		1.45E+07	1.09E+07	7.24E+06
Jun-90	2.50E+07	8.14E+06	1.25E+06	3.32E+07		3.32E+07	2.49E+07	1.66E+07
Jul-90	1.31E+07	5.05E+06	2.55E+06	1.82E+07		1.82E+07	1.36E+07	9.10E+06
Aug-90	2.19E+07	6.89E+06	7.23E+06	2.[illegible]8E+07		2.88E+07	2.16E[illegible]	1.44E+07
Sep-90	1.02E+07	4.29E+06	9.49E+05	[illegible]		1.45E+07	1.09E+07	7.24E+06
Oct-90	1.03E+07	4.08E+06	2.93E+06	1.44E+07		1.44E+07	1.08E+07	7.21E+06
Nov-90	7.84E+06	3.64E+06	1.64E+06	1.15E+07		1.15E+07	8.61E+06	5.74E+06
Dec-90	8.49E+06	3.96E+06	6.00E+05	1.25E+07		1.25E+07	9.34E+06	6.23E+06
Jan-91	7.74E+06	3.25E+06	6.00E+05	1.10E+07	5.32E+07	1.10E+07	8.24E+06	5.49E+06
Feb-91	6.87E+06	3.82E+06	6.00E+05	1.07E+07	2.73E+07	1.07E+07	8.02E+06	5.34E+06
Mar-91	7.82E+06	3.62E+06	6.00E+05	1.14E+07	1.54E+07	1.14E+07	8.59E+06	5.72E+06
Apr-91	8.45E+06	3.83E+06	6.00E+05	1.23E+07	3.61E+07	1.23E+07	9.21E+06	6.14E+06
May-91	8.27E+06	3.86E+06	6.00E+05	1.21E+07	2.44E+07	1.21E+07	9.10E+06	6.07E+06
Jun-91	9.13E+06	4.35E+06	6.00E+05	1.35E+07	1.80E+07	1.35E+07	1.01E+07	6.74E+06
Jul-91	1.03E+07	4.37E+06	6.00E+05	1.46E+07	1.24E+07	1.46E+07	1.10E+07	7.31E+06
Aug-91	1.80E+07	6.31E+06	6.00E+05	2.43E+07	1.07E+07	2.43E+07	1.82E+07	1.21E+07
Sep-91	1.02E+07	4.19E+06	6.00E+05	1.44E+07	1.06E+07	1.44E+07	1.08E+07	7.22E+06
Oct-91	1.44E+07	5.29E+06	5.87E+06	1.97E+07	1.11E+07	1.97E+07	1.48E+07	9.85E+06
Nov-91	8.58E+06	3.90E+06	6.00E+05	1.25E+07	1.52E+07	1.25E+07	9.36E+06	6.24E+06
Dec-91	7.67E+06	3.36E+06	2.85E+06	1.10E+07	3.80E+07	1.10E+07	8.27E+06	5.51E+06
Jan-92	7.50E+06	3.74E+06	1.15E+06	1.12E+07	4.66E+07	1.12E+07	8.43E+06	5.62E+06
Feb-92	7.59E+06	3.98E+06	1.15E+06	1.16E+07	4.[illegible]+07	1.16E+07	8.68E+06	5.79E+06
Mar-92	7.47E+06	3.80E+06	1.15E+06	1.13E+07	2.[illegible]+07	1.13E+07	8.45E+06	5.63E+06
Apr-92	8.85E+06	3.95E+06	1.15E+06	1.28E+07	1.67E+07	1.28E+07	9.60E+06	6.40E+06

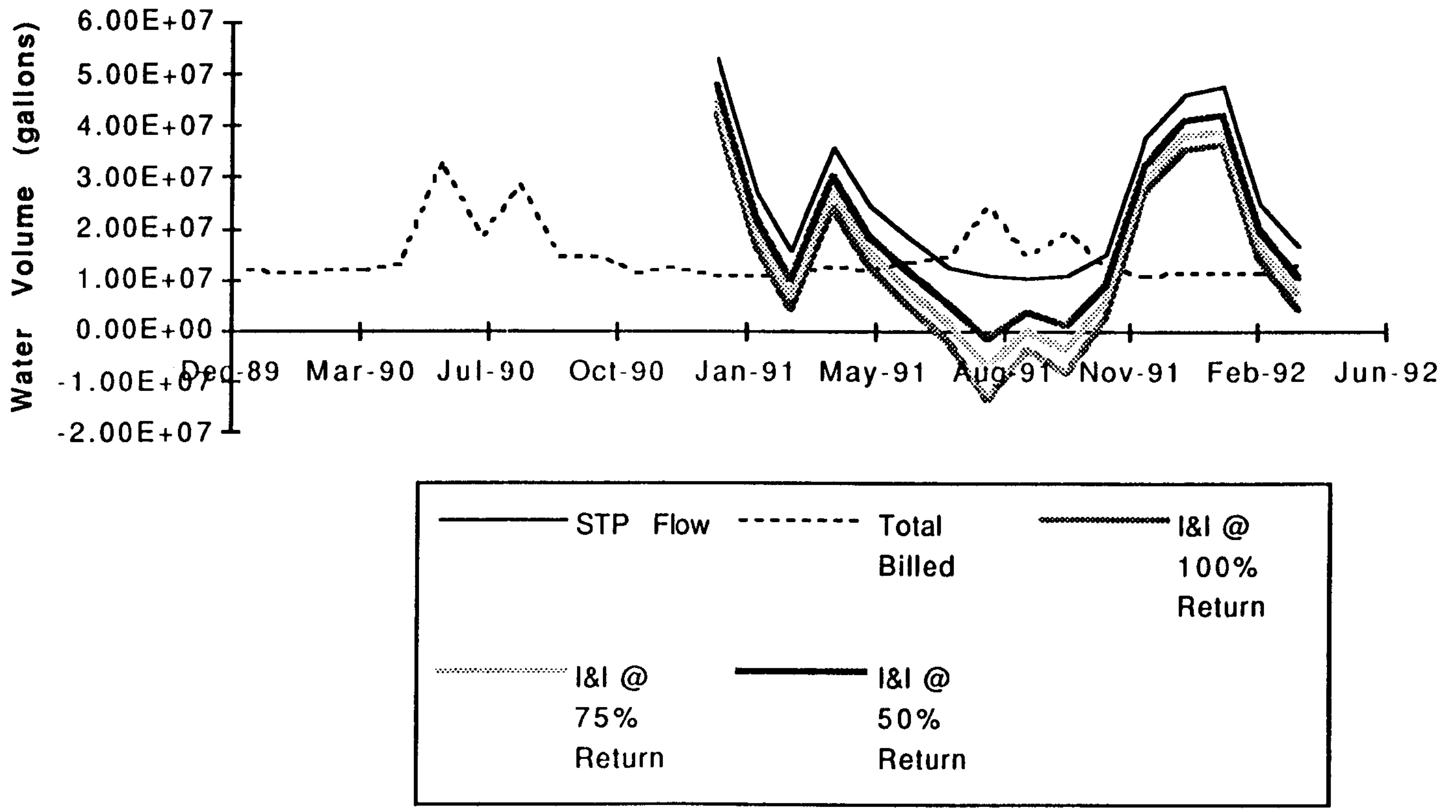


Figure 6. Water Balance for Newport

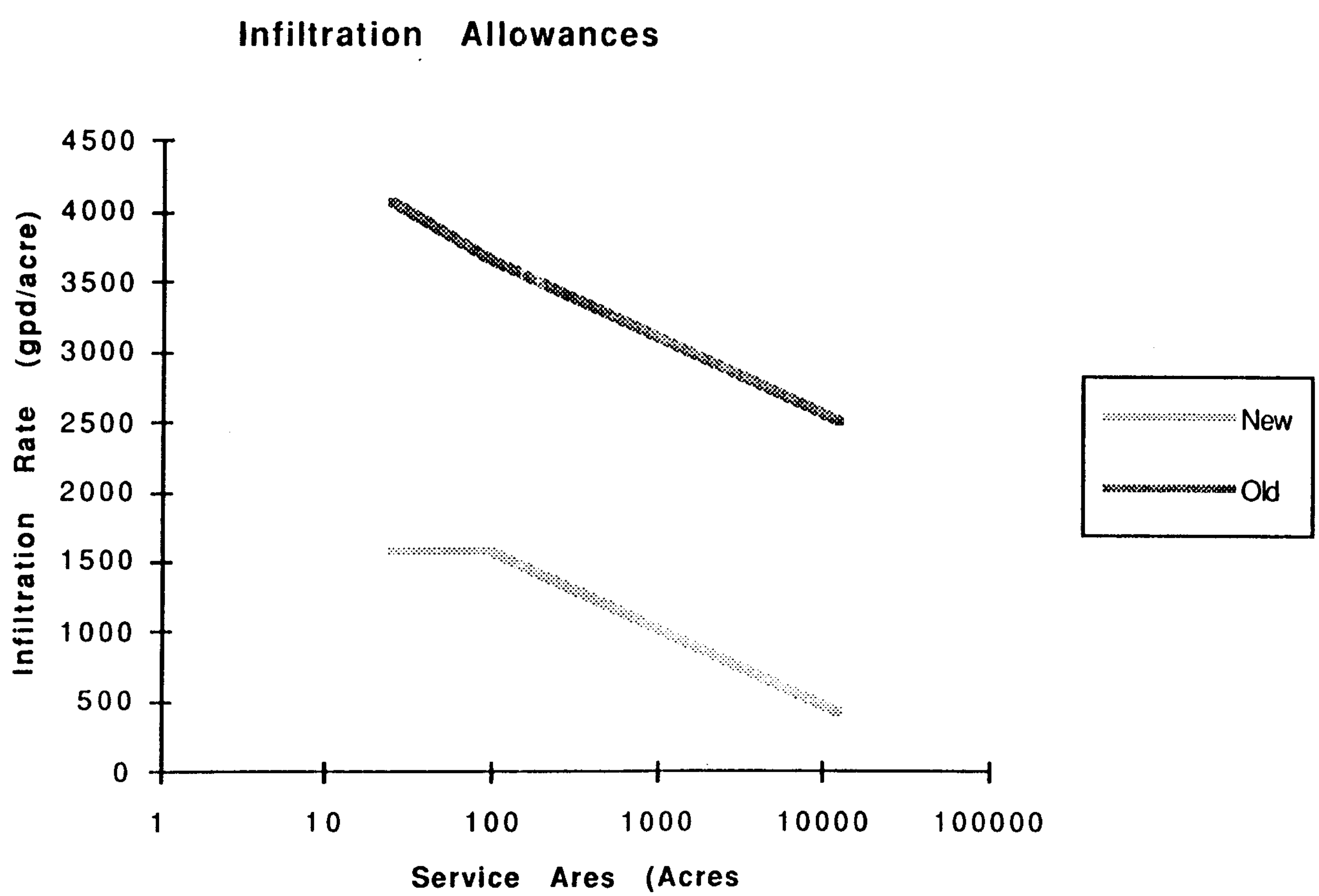


Figure 7. Design Infiltration and Inflow Allowances (Metcalf and Eddy, pg 31)

The same plots also suggested a relationship between the season and the increase flows. During the winter and early spring a standard rainfall has a larger effect on the lift station flows than the same rainfall during the drier months. This relationship would be expected in locations where there are seasonal changes in shallow groundwater levels. In the wet months, the groundwater table would be expected to rise, and near surface soils become nearly saturated. When this situation occurs, additional rainfall infiltration would cause a quick rise in groundwater elevations and contribute to infiltration through defects in the collection system as the groundwater table rises above the sewer system elevation. The reverse would be expected in the drier seasons; sewer water might exfiltrate into the groundwater. Since shallow groundwater is not routinely used for drinking water in the Houston-Galveston region, sewage exfiltration is probably not a health hazard, although such exfiltration may be subject to environmental regulations. This infiltration/exfiltration is dependent on soil type and soil permeability.

The lift station data was intended to be used to quantify the regions with the worst infiltration problems. The lift station data were arranged to compare the percentages of connections for a given lift station to the percentages of lift station flow for each lift station. These data are shown Tables 2-9.

Each table is arranged as follows: The first column is a date corresponding to the table entries of the same row. The column labeled "Actual Flow" is the volumetric flow interpreted from the product of puming hours and nominal pump capacity . The column labeled "Design Flow" is the design flow rate computed from the product of connections served by the lift station and the average expected flow for each connection (350 gallons/day/connection - figure supplied by Tebco) The column labeled "Total Design Flow" is the volumetric design flow that is obtained from the product of design flow per day and the number of days in the month of record. The column labaled "Flow into STP" is the monthly cumulative volume of waste water measured entering the Newport STP. The last column depicts the proportion of total STP flow that was contributed by the respective lift station.

The contribution to total STP flow was computed as the difference between STP measured flow and total lift station flow using the principle of conservation of mass. This data is shown on Table 8. The first column of table 8 is a date corresponding to the table entries of the same row. The second column labeled "Lift Station Total Flow" is the sum of the individual lift station computed actual flows. The third column, labeled "Flow into STP" is the monthly cumlative volume of waste water measured entering Newport's STP. The fourth column, labeled "Gravity Line Flow" is the difference between the third and second column. The last column, labeled "% of Total Flow" is the proportion of total STP flow that was contributed from the gravity-only portion of the system.

The negative entries in the "Gravity Line Flow" column reflect a loss from the system required to achieve the mass balance required by the principle of conservation of mass. Assuming the lift station data are accurate, the data suggest exfiltration occurs in some months. Dry season exfiltration is expected, however the negative entries occur in two wet periods. One interpretation is that flow to the STP would have been even higher without exfiltration.

In one instance (Table 2, Feb-92), the calculated flow through the lift station exceeded the STP flow before taking into account the gravity fed connections. Over the entire dataset, the sum of lift station flows exceeds the STP flow five of the sixteen months for which the data are complete. The five months when lift station flows exceed occur near the end of each wet season. This correlation could be interpreted to indicate that some antecedent rainfall must occur and fill ground storage before infiltration occurs, with a lag of about a month. It could also be interpreted that the rainfall raises the groundwater level so that the sewer water must exfiltrate against a higher head and the rate of exfiltration is reduced, thereby increasing the hydraulic load on the Newport STP.

Table 2. Data for Lift Station 1 8/24/92

Lift Station 1

Connections: 447

% of connections: 27.1%

	Actual Flow (gal)	Design Flow (gal/day)	Days in Month	Total Design Flow (gal)	Actual Flow (gal/conn./day)	Flow into STP (gal)	% of Total Flow
Jun-90	3532680	156450	30	4693500	263.4		
Jul-90	3393120	156450	31	4849950	244.9		
Aug-90	2929280	156450	31	4849950	211.4		
Sep-90	3623400	156450	30	4693500	270.2		
Oct-90	3853200	156450	31	4849950	278.1		
Nov-90	3906360	156450	30	4693500	291.3		
Dec-90	5026560	156450	31	4849950	362.7		
Jan-91	11402880	156450	31	4849950	822.8	53185000	21.44%
Feb-91	11197320	156450	28	4380600	894.6	27283000	41.04%
Mar-91	4508760	156450	31	4849950	325.4	15410000	29.26%
Apr-91	30369120	156450	30	4693500	2264.3	36109000	84.10%
May-91	8647440	156450	31	4849950	624.0	24398000	35.44%
Jun-91	5321040	156450	30	4693500	396.7	17968000	29.61%
Jul-91	4126200	156450	31	4849950	297.8	12353000	33.40%
Aug-91	3845520	156450	31	4849950	277.5	10707000	35.92%
Aug-91	3120360	156450	30	4693500	232.7	10629000	29.36%
Oct-91	3468600	156450	31	4849950	250.3	11115000	31.21%
Nov-91	4780560	156450	30	4693500	356.4	15166000	31.52%
Dec-91	11507280	156450	31	4849950	830.4	37980000	30.30%
Jan-92	38450160	156450	31	4849950	2774.6	46639000	82.44%
Feb-92	25455840	156450	29	4537050	1963.6	48022000	53.01%
Mar-92	8211240	156450	31	4849950	592.5	25191000	32.60%
Apr-92	5484240	156450	30	4693500	408.9	16727000	32.79%
				Average	662.4		
				% of design	189.2		

Table 3. Data for Lift Station 2 8/24/92

	Lift Station 2						
	Connections:	107					
	% of connections:	6.49%					
	Actual Flow (gal)	Design Flow (gal/day)	Days in Month	Total Design Flow (gal)	Actual Flow (gal/conn./day)	Flow into STP (gal)	% of Total Flow
Jun-90	471570	37450	30	1123500	146.9		
Jul-90	618948	37450	31	1160950	186.6		
Aug-90	552288	37450	31	1160950	166.5		
Sep-90	598158	37450	30	1123500	186.3		
Oct-90	672870	37450	31	1160950	202.9		
Nov-90	618552	37450	30	1123500	192.7		
Dec-90	816486	37450	31	1160950	246.2		
Jan-91	3388902	37450	31	1160950	1021.7	53185000	6.37%
Feb-91	2210076	37450	28	1048600	737.7	27283000	8.10%
Mar-91	1171170	37450	31	1160950	353.1	15410000	7.60%
Apr-91	3221988	37450	30	1123500	1003.6	36109000	8.92%
May-91	1651320	37450	31	1160950	497.8	24398000	6.77%
Jun-91	1155858	37450	30	1123500	360.0	17968000	6.43%
Jul-91	715836	37450	31	1160950	215.8	12353000	5.79%
Aug-91	534864	37450	31	1160950	161.2	10707000	5.00%
Aug-91	499554	37450	30	1123500	155.6	10629000	4.70%
Oct-91	543774	37450	31	1160950	163.9	11115000	4.89%
Nov-91	775236	37450	30	1123500	241.5	15166000	5.11%
Dec-91	2849154	37450	31	1160950	859.0	37980000	7.50%
Jan-92	5264622	37450	31	1160950	1587.2	46639000	11.29%
Feb-92	13508088	37450	29	1086050	4353.3	48022000	28.13%
Mar-92	2268222	37450	31	1160950	683.8	25191000	9.00%
Apr-92	1117710	37450	30	1123500	348.2	16727000	6.68%
				Average	611.8		
				% of design	174.8		

Table 4. Data for Lift Station 3 8/24/92

Lift Station 3
Connections: 345
% of connections: 20.93%

	Actual Flow (gal)	Design Flow (gal/day)	Days in Month	Total Design Flow (gal)	Actual Flow (gal/conn./day)	Flow into STP (gal)	% of Total Flow
Jun-90	2628900	123900	30	3717000	254.0		
Jul-90	2586300	123900	31	3840900	241.8		
Aug-90	2740500	123900	31	3840900	256.2		
Sep-90	2669700	123900	30	3717000	257.9		
Oct-90	2861100	123900	31	3840900	267.5		
Nov-90	2735100	123900	30	3717000	264.2		
Dec-90	2764100	123900	31	3840900	258.5		
Jan-91	13648800	123900	31	3840900	1276.2	53185000	25.66%
Feb-91	7489800	123900	28	3469200	775.3	27283000	27.45%
Mar-91	3464400	123900	31	3840900	323.9	15410000	22.48%
Apr-91	37252500	123900	30	3717000	3598.9	36109000	103.17%
May-91	17434500	123900	31	3840900	1630.2	24398000	71.46%
Jun-91	6691200	123900	30	3717000	646.4	17968000	37.24%
Jul-91	3947700	123900	31	3840900	369.1	12353000	31.96%
Aug-91	3870000	123900	31	3840900	361.9	10707000	36.14%
Aug-91	2194200	123900	30	3717000	212.0	10629000	20.64%
Oct-91	2578200	123900	31	3840900	241.1	11115000	23.20%
Nov-91	2799000	123900	30	3717000	270.4	15166000	18.46%
Dec-91	9569100	123900	31	3840900	894.7	37980000	25.20%
Jan-92	24960900	123900	31	3840900	2333.9	46639000	53.52%
Feb-92	11615100	123900	29	3593100	1161.0	48022000	24.19%
Mar-92	5804700	123900	31	3840900	542.8	25191000	23.04%
Apr-92	3166200	123900	30	3717000	305.9	16727000	18.93%
				Average	247.9		
				% of design	70.8		

Table 5. Data for Lift Station 4 8/24/92

Lift Station 4

Connections: 322

% of connections: 19.54%

	Actual Flow (gal)	Design Flow (gal/day)	Days in Month	Total Design Flow (gal)	Actual Flow (gal/conn./day)	Flow into STP (gal)	% of Total Flow
Jun-90	1558320	112700	30	3381000	161.3		
Jul-90	1173120	112700	31	3493700	117.5		
Aug-90	1080480	112700	31	3493700	108.2		
Sep-90	1311840	112700	30	3381000	135.8		
Oct-90	1939200	112700	31	3493700	194.3		
Nov-90	1551360	112700	30	3381000	160.6		
Dec-90	1740600	112700	31	3493700	174.4		
Jan-91	2195760	112700	31	3493700	220.0	53185000	4.13%
Feb-91	1524960	112700	28	3155600	169.1	27283000	5.59%
Mar-91	1355760	112700	31	3493700	135.8	15410000	8.80%
Apr-91	1861080	112700	30	3381000	192.6	36109000	5.15%
May-91	1683120	112700	31	3493700	168.6	24398000	6.90%
Jun-91	1360800	112700	30	3381000	140.9	17968000	7.57%
Jul-91	1159680	112700	31	3493700	116.2	12353000	9.39%
Aug-91	1176360	112700	31	3493700	117.8	10707000	10.99%
Aug-91	974760	112700	30	3381000	100.9	10629000	9.17%
Oct-91	1105800	112700	31	3493700	110.8	11115000	9.95%
Nov-91	1318080	112700	30	3381000	136.4	15166000	8.69%
Dec-91	2210880	112700	31	3493700	221.5	37980000	5.82%
Jan-92	2106720	112700	31	3493700	211.1	46639000	4.52%
Feb-92	1903800	112700	29	3268300	203.9	48022000	3.96%
Mar-92	1446600	112700	31	3493700	144.9	25191000	5.74%
Apr-92	1305000	112700	30	3381000	135.1	16727000	7.80%
				Average	139.4		
				% of design	39.8		

Table 6. Data for Lift Station 5 8/24/92

	Lift Station 5						
	Connections:	13					
	% of connections:	0.79%					
	Actual Flow (gal)	**Design Flow (gal/day)**	**Days in Month**	**Total Design Flow (gal)**	**Actual Flow (gal/conn./day)**	**Flow into STP (gal)**	**% of Total flow**
Jun-90	67140	4550	30	136500	172.1		
Jul-90	73170	4550	31	141050	181.6		
Aug-90	73170	4550	31	141050	181.6		
Sep-90	70650	4550	30	136500	181.1		
Oct-90	77580	4550	31	141050	192.5		
Nov-90	80640	4550	30	136500	206.7		
Dec-90	100710	4550	31	141050	249.9		
Jan-91	147960	4550	31	141050	367.1	53185000	0.28%
Feb-91	401700	4550	28	127400	1103.6	27283000	1.47%
Mar-91	384150	4550	31	141050	953.2	15410000	2.49%
Apr-91	559650	4550	30	136500	1434.9	36109000	1.55%
May-91	495300	4550	31	141050	1229.0	24398000	2.03%
Jun-91	327600	4550	30	136500	839.9	17968000	1.82%
Jul-91	395850	4550	31	141050	982.3	12353000	3.20%
Aug-91	337350	4550	31	141050	837.1	10707000	3.15%
Aug-91	304200	4550	30	136500	779.9	10629000	2.86%
Oct-91	339300	4550	31	141050	841.9	11115000	3.05%
Nov-91	413400	4550	30	136500	1059.9	15166000	2.73%
Dec-91	569400	4550	31	141050	1412.9	37980000	1.50%
Jan-92	602550	4550	31	141050	1495.2	46639000	1.29%
Feb-92	538200	4550	29	131950	1427.6	48022000	1.12%
Mar-92	629850	4550	31	141050	1562.9	25191000	2.50%
Apr-92	294450	4550	30	136500	754.9	16727000	1.76%
				Average	768.1		
				% of design	219.4		

Table 7. Data for Lift Station 6 8/24/92

	Lift Station 6						
	Connections:	25					
	% of connections:	1.52%					
	Actual Flow (gal)	**Design Flow (gal/day)**	**Days in Month**	**Total Design Flow (gal)**	**Average Flow (gal/conn./day)**	**Flow into STP (gal)**	**% of Total Flow**
Jun-90	0	8750	30	262500	0.0		
Jul-90	0	8750	31	271250	0.0		
Aug-90	0	8750	31	271250	0.0		
Sep-90	0	8750	30	262500	0.0		
Oct-90	444690	8750	31	271250	573.8		
Nov-90	461700	8750	30	262500	615.5		
Dec-90	763020	8750	31	271250	984.5		
Jan-91	1820070	8750	31	271250	2348.5	53185000	3.42%
Feb-91	731430	8750	28	245000	1044.9	27283000	2.68%
Mar-91	517590	8750	31	271250	667.9	15410000	3.36%
Apr-91	1117800	8750	30	262500	1490.3	36109000	3.10%
May-91	891810	8750	31	271250	1150.7	24398000	3.66%
Jun-91	544320	8750	30	262500	725.7	17968000	3.03%
Jul-91	413100	8750	31	271250	533.0	12353000	3.34%
Aug-91	345060	8750	31	271250	445.2	10707000	3.22%
Aug-91	308610	8750	30	262500	411.4	10629000	2.90%
Oct-91	315900	8750	31	271250	407.6	11115000	2.84%
Nov-91	486000	8750	30	262500	647.9	15166000	3.20%
Dec-91	1283040	8750	31	271250	1655.5	37980000	3.38%
Jan-92	1659690	8750	31	271250	2141.5	46639000	3.56%
Feb-92	1513890	8750	29	253750	2088.1	48022000	3.15%
Mar-92	865080	8750	31	271250	1116.2	25191000	3.43%
Apr-92	561330	8750	30	262500	748.4	16727000	3.36%
				Average	860.7		
				% of design	245.9		

Table 8. Data for LS7 8/24/92

Lift Station 7
Connections: 84
% of connections: 5.10%

	Actual Flow (gal)	Design Flow (gal/day)	Days in Month	Total Design Flow (gal)	Actual Flow (gal/conn./day)	Flow into STP (gal)	% of Total Flow
Jun-90	0	29400	30	882000	0.0		
Jul-90	0	29400	31	911400	0.0		
Aug-90	0	29400	31	911400	0.0		
Sep-90	0	29400	30	882000	0.0		
Oct-90	763779	29400	31	911400	293.2		
Nov-90	624960	29400	30	882000	247.9		
Dec-90	1263744	29400	31	911400	485.1		
Jan-91	2254752	29400	31	911400	865.5	53185000	4.24%
Feb-91	1174752	29400	28	823200	499.3	27283000	4.31%
Mar-91	2420928	29400	31	911400	929.3	15410000	15.71%
Apr-91	2716416	29400	30	882000	1077.4	36109000	7.52%
May-91	4178880	29400	31	911400	1604.1	24398000	17.13%
Jun-91	1326240	29400	30	882000	526.0	17968000	7.38%
Jul-91	1335744	29400	31	911400	512.8	12353000	10.81%
Aug-91	1243008	29400	31	911400	477.2	10707000	11.61%
Aug-91	1014624	29400	30	882000	402.4	10629000	9.55%
Oct-91	1303488	29400	31	911400	500.4	11115000	11.73%
Nov-91	4296384	29400	30	882000	1704.1	15166000	28.33%
Dec-91	8317152	29400	31	911400	3192.7	37980000	21.90%
Jan-92	3860064	29400	31	911400	1481.8	46639000	8.28%
Feb-92	7344000	29400	29	852600	3013.6	48022000	15.29%
Mar-92	3060000	29400	31	911400	1174.6	25191000	12.15%
Apr-92	1007712	29400	30	882000	399.7	16727000	6.02%
				Average	842.9		
				% of design	240.8		

Table 9. Data for Gravity Connections 8/24/92

Gravity Connections

connections:	305
% of connections:	18.51%

	Lift Station's Total Flow (gal)	Flow into STP (gal)	Gravity Line Flow (gal)	% of Total Flow
Jun-90	8258610			
Jul-90	7844658			
Aug-90	7375718			
Sep-90	8273748			
Oct-90	10612419			
Nov-90	9978672			
Dec-90	12475220			
Jan-91	34859124	53185000	18325876	34.46%
Feb-91	24730038	27283000	2552962	9.36%
Mar-91	13822758	15410000	1587242	10.30%
Apr-91	77098554	36109000	-40989554	-113.52%
May-91	34982370	24398000	-10584370	-43.38%
Jun-91	16727058	17968000	1240942	6.91%
Jul-91	12094110	12353000	258890	2.10%
Aug-91	11352162	10707000	-645162	-6.03%
Aug-91	8416308	10629000	2212692	20.82%
Oct-91	9655062	11115000	1459938	13.13%
Nov-91	14868660	15166000	297340	1.96%
Dec-91	36306006	37980000	1673994	4.41%
Jan-92	76904706	46639000	-30265706	-64.89%
Feb-92	61878918	48022000	-13856918	-28.86%
Mar-92	22285692	25191000	2905308	11.53%
Apr-92	12936642	16727000	3790358	22.66%

Overall, the lift station analysis was inconclusive, and the only general recomendations were to install accurate flow metering equipment for future use, and to collect and analyze water samples for the presence of fecal coliform. The flow meters will be useful not only in detecting infiltration and inflow, but also to allow the operators to develop a maintanence program to reduce pump repairs by preventative maintanence based on total flow through the lift stations.

Fecal Coliform Analysis

The hydraulic indication of exfiltration was tested with chemical sampling and analysis in Gum Gully at several locations. Samples were collected and analysed for Fecal-Coliform(FC) during a dry and wet period to determine if exfiltration occurs in either the dry or wet periods. Presence of a high FC count is in the dry season is direct evidence of exfiltration and direct hydraulic communication between the sewer system and Gum Gully. Presence of a high FC count in the wet period samples could suggest that there is wet weather exfiltration also. The corollary logic does not hold -- the absense of high counts provides no information on infiltration or exfiltration. In other words, if the FC count is high there is evidence of direct connection between the sewer and Gum Gully, yet the absence of a high count in no way negates that connection.

A fecal coliform analysis of water in Gum Gully performed in late November,1992 was inconclusive but we feel that wet-weather exfiltration is unlikely,.

A dry period fecal coliform analysis was performed on August 26, 1993. Ten sample sites along Gum Gulley and its tribuitaries were selected for sampling and analysis. These ten sites include sites on the North side of the subdivision where Gum Gulley enters the Newport Area, several sites internal to the subdivision area, and two sites on the South edge of the subdivision.

The fecal coliform count for water entering the subdivision from the North was 250,000 CFU/100 ml of water. Water in the drainage ditch (North of San Jacinto Canal) that enters Gum Gulley from the East had a count of 68,000 CFU/100 ml. The main portion of Gum Gulley just South of the confluence of the drainage ditch had a count of 109,000 CFU/100 ml. At the Deerpointe area of the subdivision that Gum Gulley water had a count of 60,000 CFU/100 ml.

Two branches of a drainage ditch directly east of the clubhouse off Golf Club Drive carried water that had counts of 230,000 CFU/100ml (North branch) and 350,000 CFU/100 ml. (South branch). Approximately 100 yards downstream of the confluence of these two drainage branches the count was 160,000 CFU/100 ml. At the confluence of this drainage ditch and the main branch of Gum Gulley the count was 120,000 CFU/ 100 ml. As Gum Gulley crossed under Diamondhead the count was 60,000 CFU/100 ml. The last sample site was the confluence of a storm drainage pipe and Gum Gulley 100 feet south of Diamondhead where the count was 210,000 CFU/100 ml.

These results suggest that the water entering the subdivision from the North improves in water quality as it proceedes through the subdivision until the drainage water from Sections 2 and 4 enters the gulley. When these waters enter the gulley the fecal coliform count nearly triples - suggesting that there may be sewage exfiltration from these areas (or some other source of fecal coliform bacteria).

As the water proceedes downstream, it is again improved in quality (with respect to fecal coliform) until the storm sewer drainage pipe that serves Sections 7 and 8 enters the gulley where the fecal coliform count more than triples - suggesting possible sewage exfiltration in these areas too.

Overall there is evidence of dry period exfiltration from Sections 2,4,7, and 8. The existance of such exfiltration in the dry period suggests that these areas will have a high probability of wet period infiltration as the ground becomes saturated and the seepage potentials reverse.

Geographic Analysis

To help establish areas within Newport that have a high probability of severe infiltration a geographic analysis based on a thematic mapping concept was used. This method of data management was first used in collection system analysis by Delbert Jeeter of the City of Bellaire for monitoring sewer repair. Thematic mapping has found less use in favor of full scale Geographic Information Systems (GIS) analysis and physical measurement (flow monitoring), however it appeared useful for Newport.

Thematic Mapping

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. 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 risk map expresses a probability or chance that a particular area will experience excessive inflow and infiltration. Areas of low risk may still have excessive inflow and infiltration and areas of high risk may have no inflow and infiltration. Typically, if the probability assessments are reasonable the high risk areas should have more severe problems than the low risk areas. These high risk areas constitute a thematically based severity ranking of the Newport subdivision and initial efforts should be concentrated in these areas. After these areas have been rehabilitated, the risk associated with them can be modified, and the lower priority areas investigated. Thus the risk maps represent a tool for managing the sewer investigation and rehabilitation in Newport.

The maps were constructed using a grid system approximately 300 x 300 feet per grid cell. Figure 8 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 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. The actual basemap used was much larger than that depicted in Figure 8 so that data entry is easier than it appears here.

A boundary map overlay was prepared to show the approximate boundaries of the study area and help in thematic map interpretation. This overlay map aslo shows the locations of sewer water quality monitoring sites that were used to develop additional quantitative measures of I&I. Figure 9 shows the boundary map overlay expressed in the grid system of Figure 8.

Figure 10 is a study area map that shows the actual study area considered. All the shaded cells in the figure represent areas that were considered eligible for data entry, while the ramaining area was considered external to Newport. Observe that the actual area extends beyond the boundary overlay map - this occurs because the overlay is intended only as an approximation of the actual thematic mapping area. Also observe that all areas are rectangular, when in the actual plat maps some areas are polygons. This deviation occurs because the grid sysetem used was quite coarse. A fine grid alleviates this deviation, but at a high computational cost and data requirement cost. The coarse grid was considered adequate for this initial study.

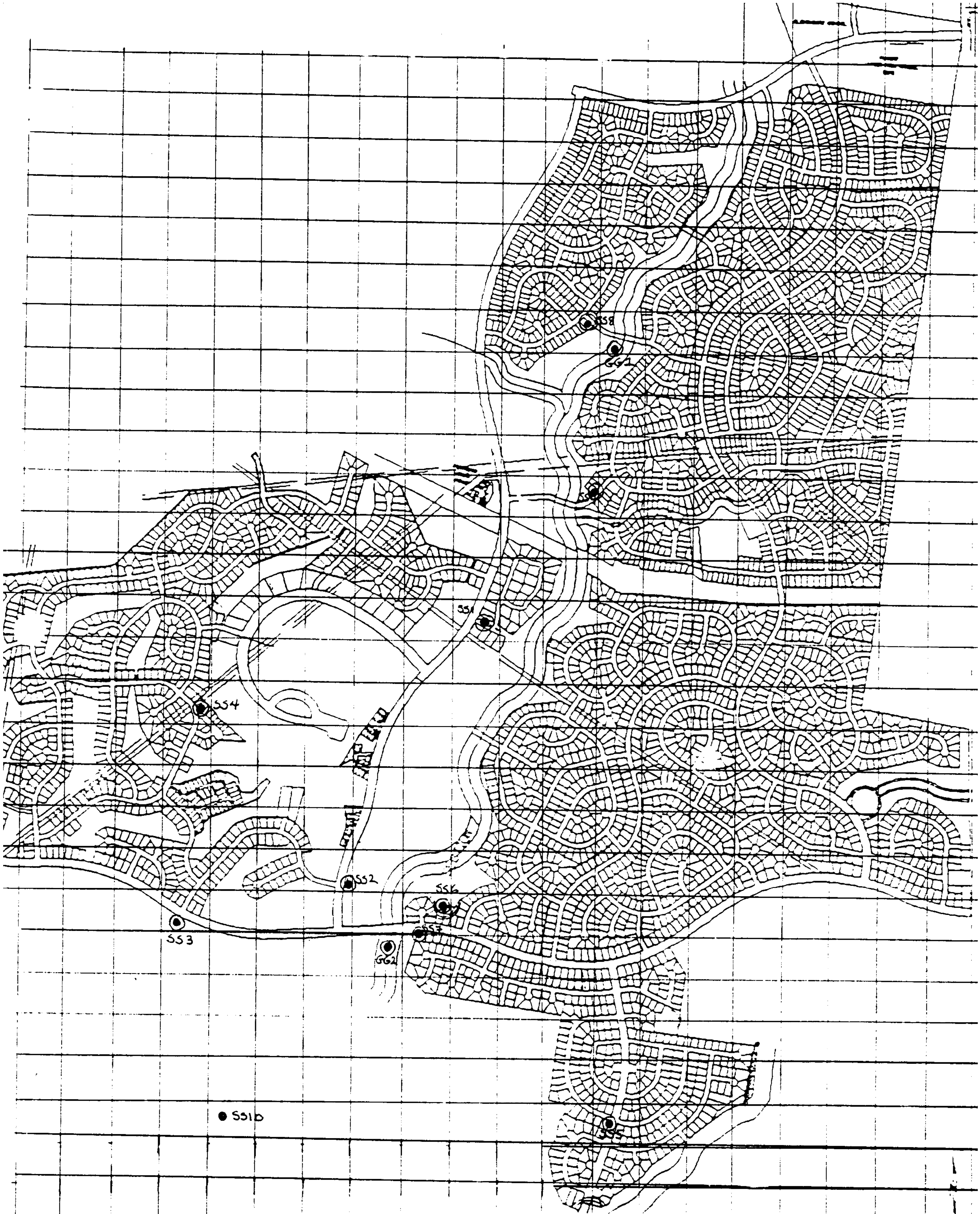


Figure 8. Mapping Grid System for Newport

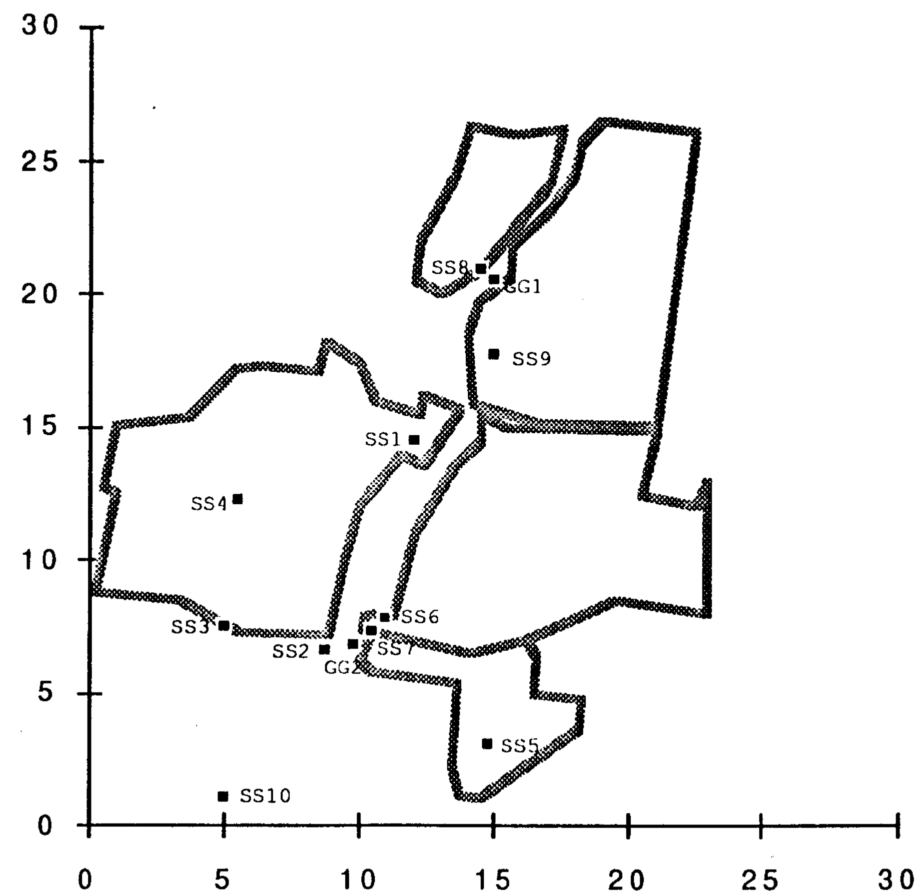


Figure 9. Boundary Map Showing Approximate Newport Study Area and Sampling Sites

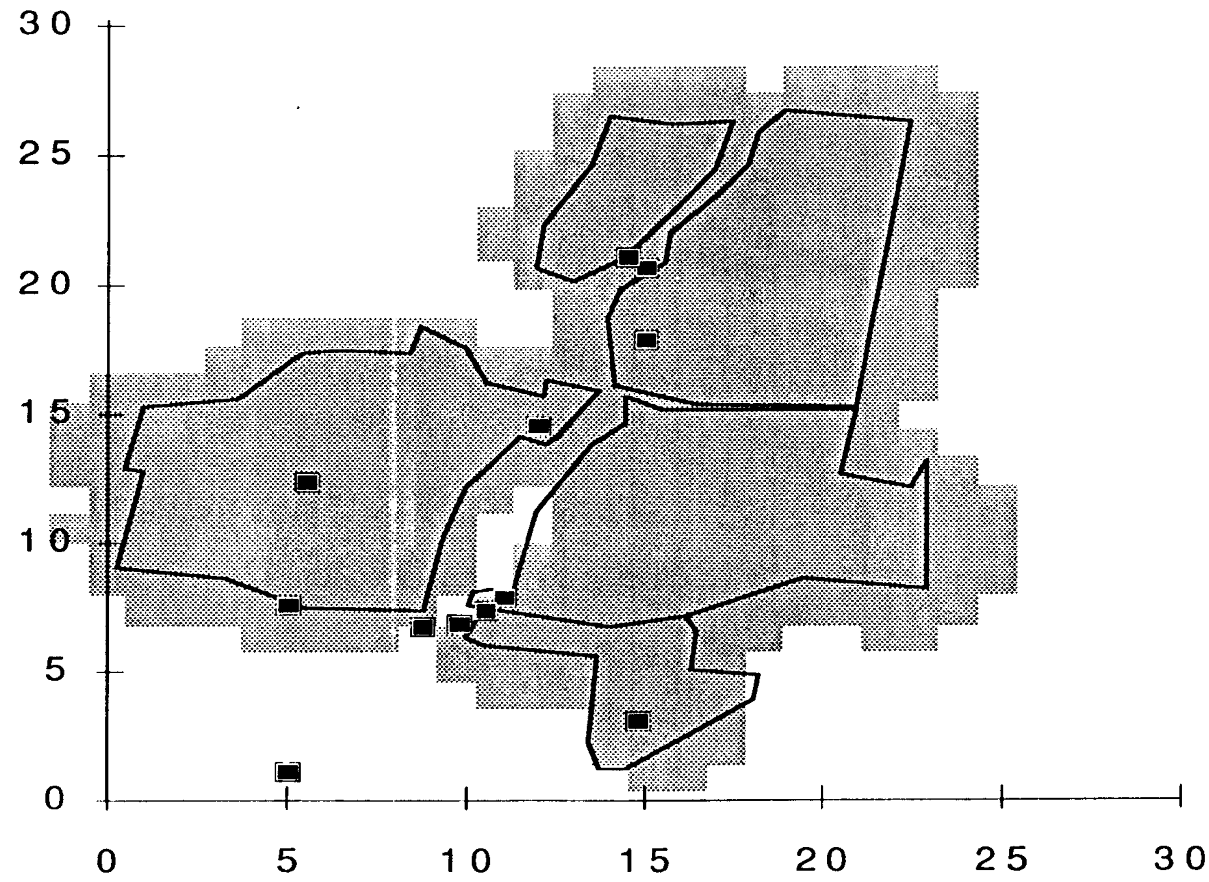


Figure 10. Basemap Showing Study Area for Thematic Mapping Study with Boundary Map Overlay.

The data are entered in a spreadsheet, and changes over time can be incorporated to reflect changes in the state of the subdivision and these theme maps redrawn. Principally rehabilitation effects could be incorporated over time, and as improvements occur, Newport should consider mapping the progress using some thematic mapping system (either computerized or manual) The development of the theme maps for each theme is discussed in the following sections.

Soil Stability

Soil stability was based on the USDA Soils Maps (Figure 3) for the Newport Area. In locations where the map showed a clay type soil the stability was assigned a value of zero to represent the worst soil type in regards to shrinkage and swelling. In locations where the map showed a loam, the value of 0.5 was assigned. And in areas where a sandy loam was underlying the subdivision, a value of 1.0 was assigned. In the absense of any other thematic data the potential for I&I would be expected to be correllated with the soil stability - we assumed that the less stable soil would have a higher risk than the more stable soil, and this assumption is used in the calculation of inflow and infiltration risk.

Figure 11 shows the soil stability map on the gird system used for Newport. In general the soils are mostly unstable clay, with stable inclusions in Sections 8 and 10, and semi-stable inclusions in Sections 1,2, and 4.

Manhole Density

Manhole density was based on the as-designed maps and spot-checked by field survey. Manhole density is defined as the number of manholes per grid cell in the area shown on the basemap. The field spot-check was to verify the approximate location of some manholes as well as determine manhole type. Our field survey found that the subdivision has brick shaft manholes, grouted over brick, and concrete/fiberglass manholes. Brick manholes could have a greater infiltration potential than the other two, but our spot-check was not widely enough distributed to determine the density of brick-only manholes.

Since we could not determine the distribution of brick-only manholes, overall manhole densitywas used as an indicator of potential for infiltration. Manholes can contribute directly to inflow when ponding occurs during severe weather and water flows in through the manhole covers. Additionally, water can infiltrate in the annular space between the outside of the access shaft down to the sewer line and then into the collection system at the first access point along the line. Using this logic we assumed that areas with a high manhole density would have greater probability for infiltration than areas with fewer manholes.

Figure 12 shows the manhole density map. The manhole density is relatively uniform throughout the area with some high density locations along Dunes Drive, Spinnaker Drive, and near Helmsman Drive. There was no apparent reason for the high density locations, except possibly that in these areas several lines from different directions joined to run into a single line.

Backyard Sewer Density

A large proportion of the sewer collection system runs through the backyards of parcels in the subdivision. We prepared maps of the density of backyard sewers for the subdivision. Bellaire, Texas found during their collection system maintenance program that backyard sewers contributed greatly to inflow and infiltration (Jeeter, 1992). In general, many lots were actually designed to drain surface waters towards the backyard sanitary lines, and in Bellaire some backyard sewers actually had direct connections with roof drains, etc. Because of inaccessability, backyard portions of a system may receive less attention except when blockage problems occur. We assumed that

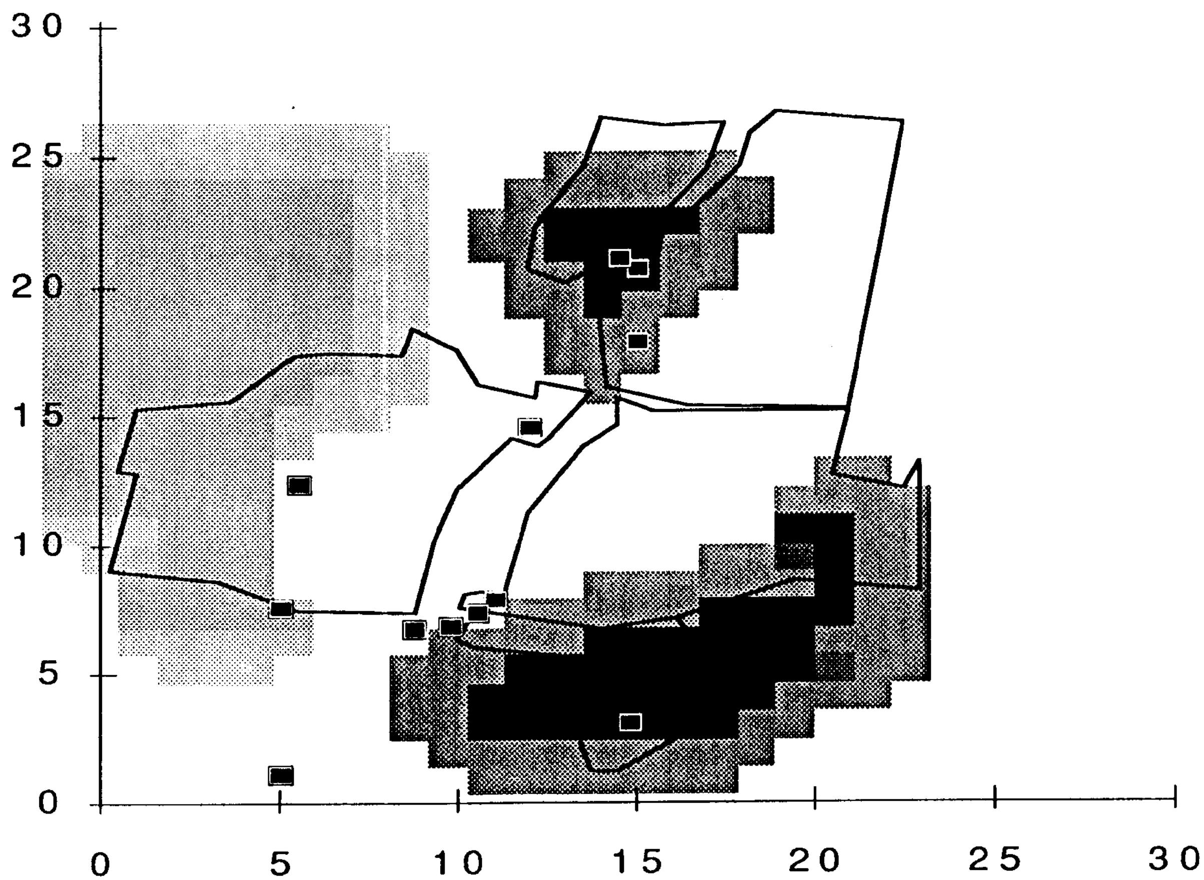


Figure 11. Soil Stability Map based on Soil Type (Dark=More Stable, Light = Less Stable).

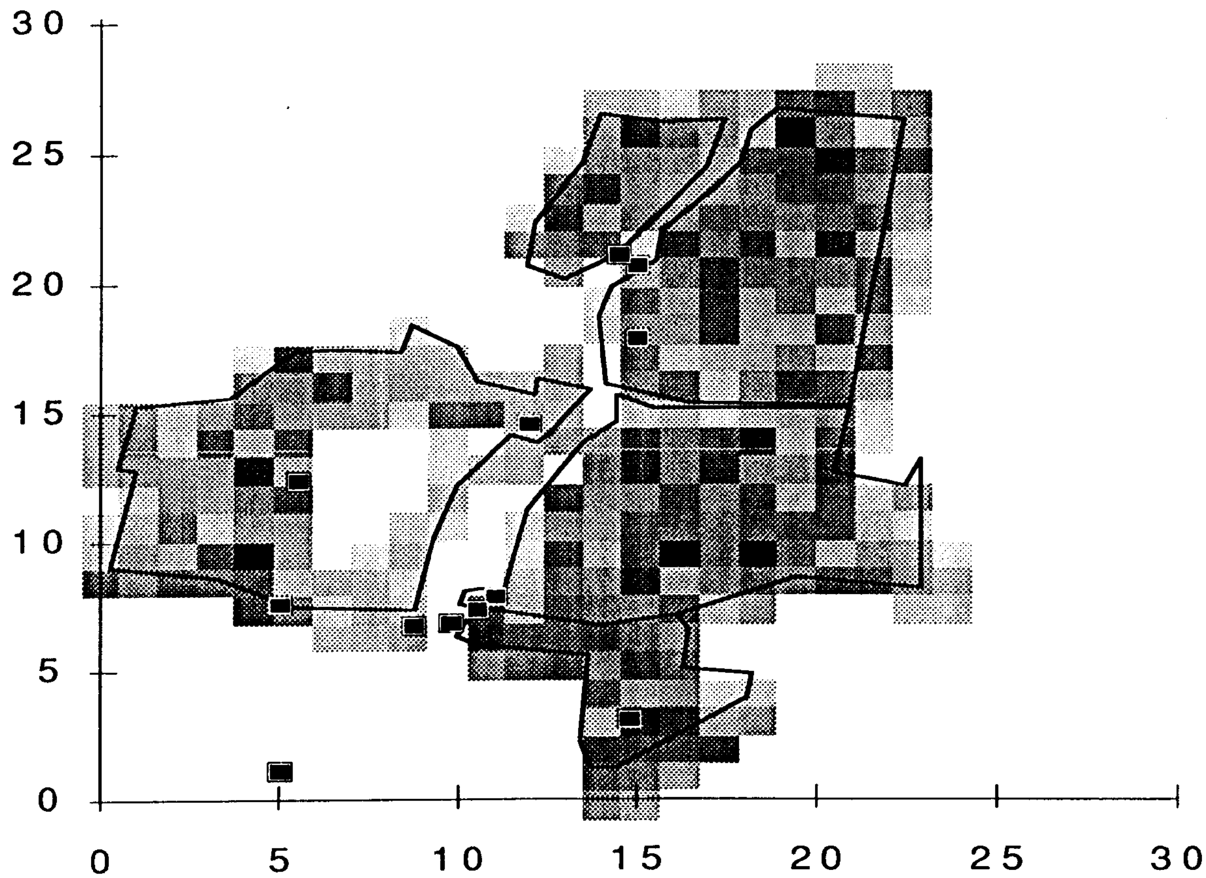


Figure 12. Manhole Density Map based on As-Designed Map and Field Survey (Dark = High Density, Light = Low Density).

because of lower maintenance and the possibility of designed water drainage towards a backyard sewer system that portions of the subdivision with many backyard sewer lines have a greater potential for inflow and infiltration than portions of the subdivision with few backyard sewer lines.

Figure 13 shows the backyard sewer density map. Generally, the density is uniform throughout Newport, probably to the winding street design, rather than a typical municipal grid type street system.

Development Density

Development density is another theme that was used in preparing risk maps. Development density was defined as the proportion of lots in a grid cell that had homes on them or were landscaped. Wooded lots were defined as undeveloped. These data were field verified as of February, 1993. Developed lots are thought to have a lower potential for infiltration because the homeowner would provide for drainage of water to the storm water system, and because the area occupied by the house slab and driveway is unavailable for infiltration. A competing premise is that developed lots represent a lateral connection to the sewer system and in many reported studies these lateral connections are the principal avenue for inflow and infiltration. The risk maps assume that developed areas have lower potential for inflow and infiltration than the undeveloped areas due to more frequent maintenance, and the presence of a homeowner who would report problems as they arise. If the lateral connections have more significant impact than frequent maintenance, then the risk maps would have an entirely different appearance.

Figure 14 shows the development density map. Section 10, part of Section 1, and part of Section 2 are the most highly developed, with Section 8 at the next level of development density. Sections 3, 6, and 7 and the western portions of Sections 2 and 4 have a lower development density.

Sewer Repair Frequency

Sewer repair frequency is a theme that could prove very useful to both Newport and other small communities for maintaining their collection systems. The idea behind this theme is to simply record 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 areas may be indicative of some more severe underlying problem.

If the system is aging uniformily over time, the repair frequency map should be uniformily 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.

Since Newport is just starting its rehabilitation program, the repair frequency map is assumed to indicate areas that have great potential for direct inflow due to failures in the collection system that are just beginning to be addressed.

Table 10 shows the type of data 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 repairs without specific locations were omitted from the map.

Figure 15 shows the repair frequency map. The highest repair frequency is in Sections 2, 3, and 6. A fairly high repair frequency also occurs in Section 1 - this is probably due to the work along Nautilus associated with the power pole that pierced the sewer in that area.

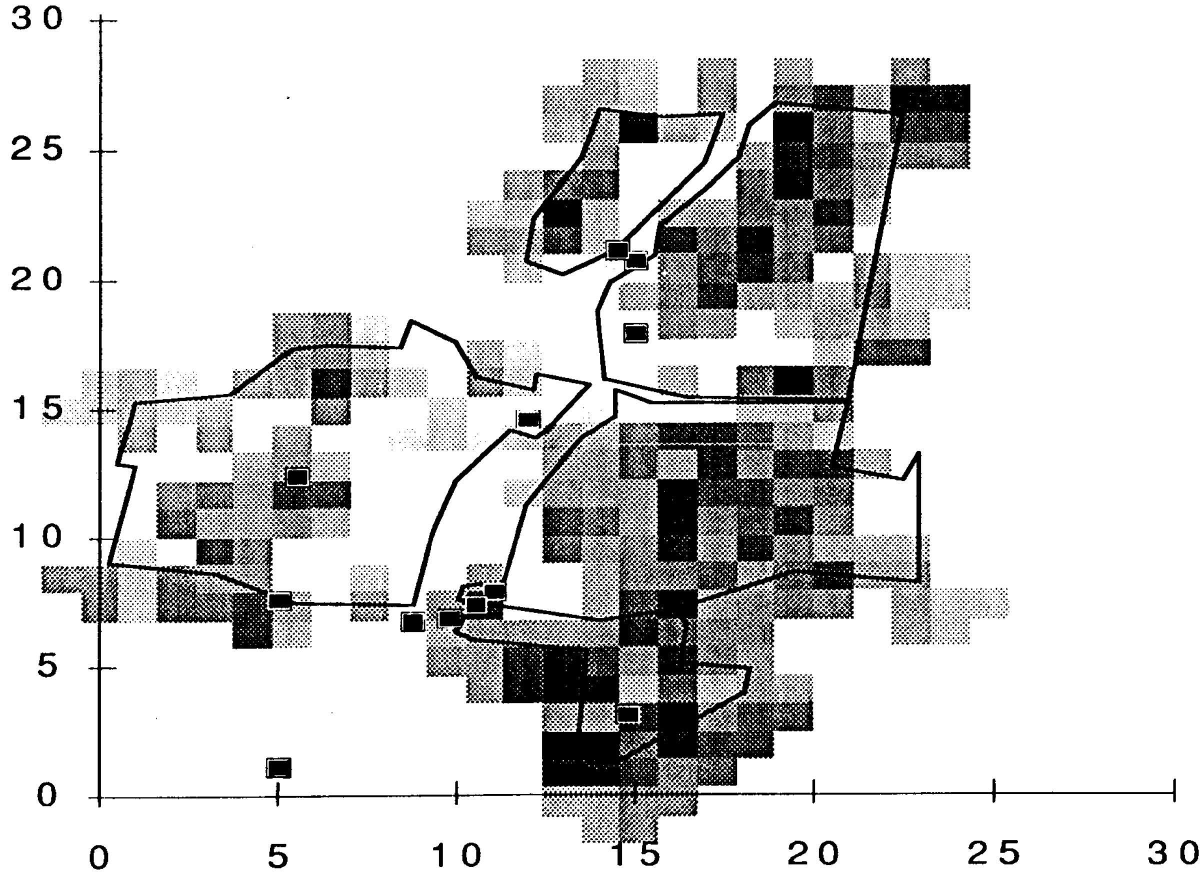


Figure 13. Backyard Sewer Line Density Map based on As-Designed Drawings (Dark = High Density, Light = Low Density).

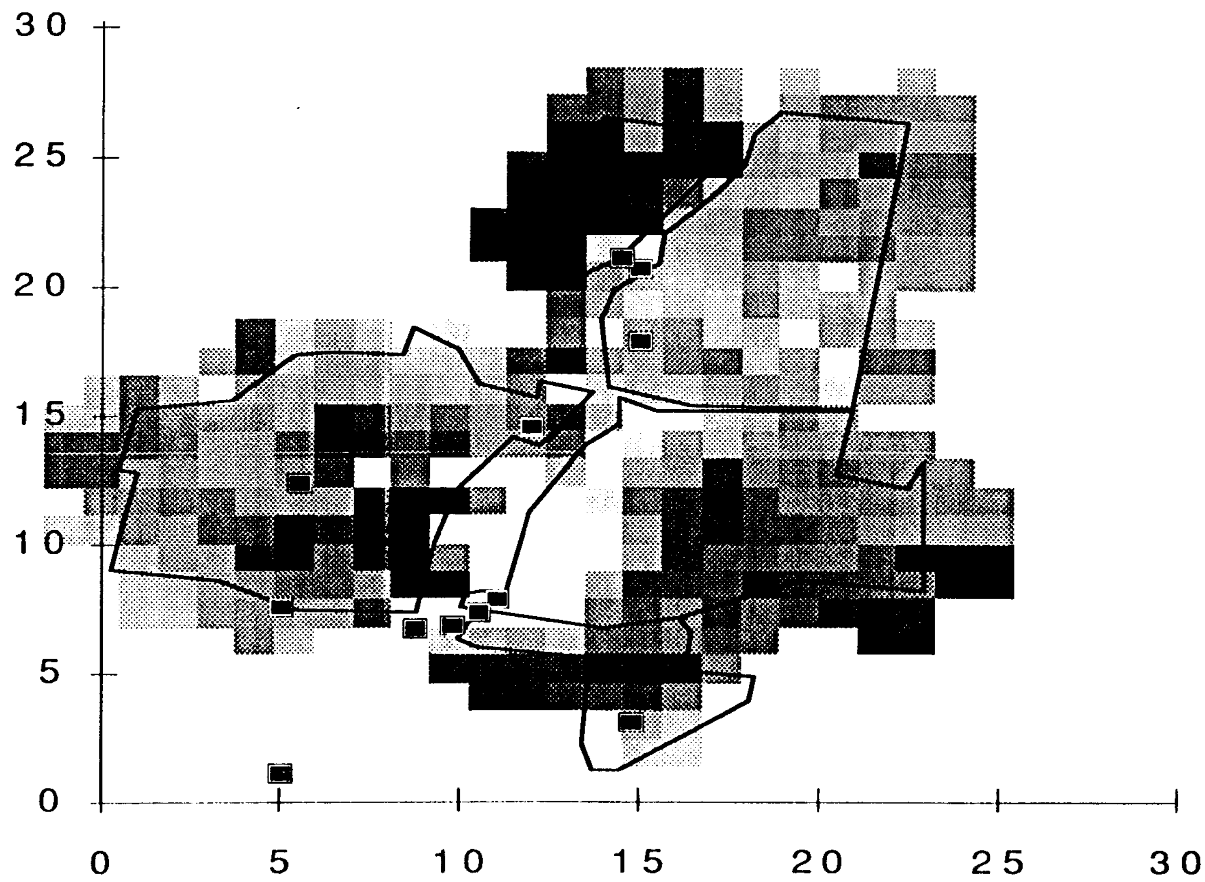


Figure 14. Development Density Map based on Field Survey (Dark = High Density, Light = Low Density).

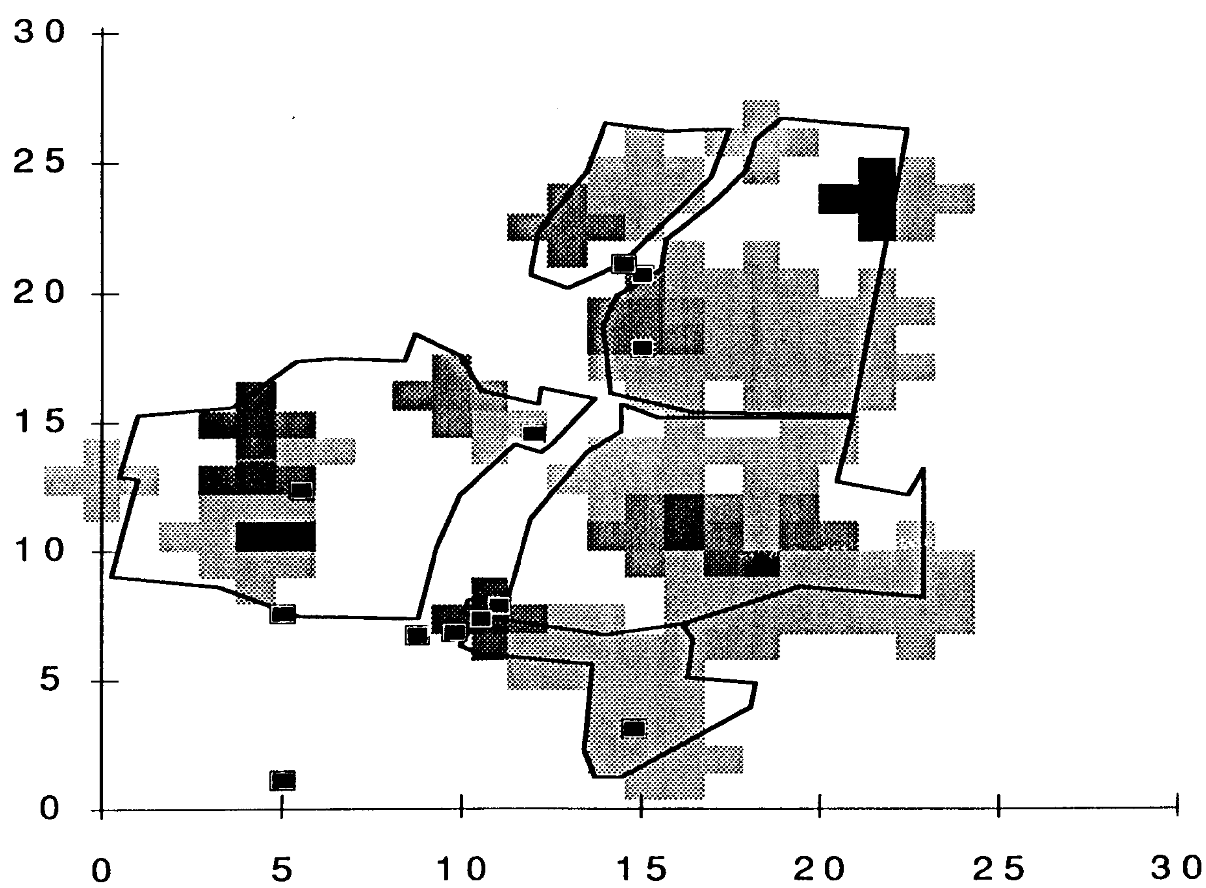


Figure 15. Repair Density Map based on Repair Reports in MUD Meeting Minutes and Field Survey (Dark = High Density, Light = Low Density).

Table 10. Database for Determining Repair Frequency

Reported Repairs/Fault Observations	
Description	Reference
Sewer Blockage - Aloft Court	3/24/93 - MUD20 Minutes
Manhole Repair - Broadwater	1/27/93 - MUD20 Minutes
Sewer Line Damage - Dunes (1)	8/20/92 - MUD20 Minutes
Section of Dunes Sewer Repaired	10/29/93 - MUD19 Minutes
Manhole Repair - Dunes Drive	4/28/93 - MUD20 Minutes
Sewer Repair - 16015 Dunes	8/20/92 - MUD20 Minutes
Sewer Line Damage - Dunes (2)	8/20/92 - MUD20 Minutes
Sewer Line Damage - Dunes (3)	8/20/92 - MUD20 Minutes
Obstruction Bollard and Halyard	5/29/93 - Field Notes
Manhole Repair - Fantail and Bollard	4/28/93 - MUD20 Minutes
Manhole Repair - Bollard and Dunes	4/28/93 - MUD20 Minutes
Tap line leaks Azimuth	4/28/93 - MUD20 Minutes
Manhole Repair - Chart and Azimuth	4/28/93 - MUD20 Minutes
Manhole Repair - 16306 Azimuth	9/24/92 - MUD20 Minutes
Manhole Repair - Turnbuckle and Broadwa	4/28/93 - MUD20 Minutes
Manhole Repair - Chart	4/28/93 - MUD20 Minutes
Manhole Repair - Chart and Quadrant	4/28/93 - MUD20 Minutes
Excess flow - LS6 after rainfall	5/21/93 - Field Notes
Possible cross connection Boom Drive at	5/21/93 - As-designed map
Excess Flow - LS6	2/11/93 - MUD20 Minutes
Manhole Repair - Chart and Launch	4/28/93 - MUD20 Minutes
Manhole Repair - Diamondhead (1)	9/24/92 - MUD20 Minutes
Manhole Repair - Diamondhead (3)	9/24/92 - MUD20 Minutes
Manhole Repair - Forelock Way	4/28/93 - MUD73 Minutes
Sewer Line Repair - Foreloch	3/24/93 - MUD73 Minutes
Sewer Blockage Diamondhead	4/28/93 - MUD20 Minutes
Manhole Repair - Bourrelet	2/24/93 - MUD20 Minutes
Excess Flow - LS7	2/11/93 - MUD20 Minutes
Cleanout Plugs Inoperative - Section 8	Field Notes
Collapsed Sewer Line - Companion	3/24/93 - MUD20 Minutes
Sewer Repair - Spinnaker	1/27/93 - MUD20 Minutes
Sewer Blockage - Spinnaker	9/24/92 - MUD20 Minutes
Inflow and Infiltration - Televised Lin	2/24/93 - MUD73 Minutes
Possible cross connection Midships Way	5/21/93 - As-designed map
Sewer Blockage - Midships Way	4/28/93 - MUD73 Minutes

Sewer Blockage Midships Way	4/28/93 - MUD20 Minutes
Water Line Break - Midship's Way (1)	10/22/92 - MUD73 Minutes
Sewer Blockage - Jollyboat	4/28/93 - MUD73 Minutes
Sewer Blockage - Cable Way	4/28/93 - MUD73 Minutes
4 Manholes in lot 24 South Galley Drive	5/21/93 - As-designed map
Sewer Blockage - Diamondhead	3/24/93 - MUD20 Minutes
Water Line Break - 602 Hyannis Port Nor	9/24/92 - MUD20 Minutes
Water Line Break - Nautilus	9/24/92 - MUD20 Minutes
Sewer Line Damage - 723 Nautilus	8/20/92 - MUD20 Minutes
Sewer Repair - 618 Nautilus	7/23/92 - MUD20 Minutes
Water Line Break - 16518 Jury Rig Court	9/24/92 - MUD20 Minutes
Manhole Repair - Tarpaulin Way	10/22/92 - MUD73 Minutes
Water Line Break - Midship's Way (2)	10/22/92 - MUD73 Minutes
Sewer Line Damage - 611 Fiji	6/25/92 - MUD20 Minutes
Sewer Line Damage - 615 Fiji	6/25/92 - MUD20 Minutes
Water Line Break - 818 Windless Way	8/27/92 - MUD73 Minutes
Sewer Blockage - Forecastle (2)	9/24/92 - MUD20 Minutes
Sewer Blockage - Forecastle (1)	9/24/92 - MUD20 Minutes
Excess flow - Helmsman Lift Station	1/27/93 - MUD19 Minutes
Lot 7 Helmsman street - sanitary line 2	5/21/93 - As-designed map
Sewer Line Damage - Helmsman and Sealan	8/20/92 - MUD20 Minutes
Sewer Blockage Nautilus	4/28/93 - MUD20 Minutes
Sewer Repair 722 Equinox	7/23/92 - MUD20 Minutes
Water Line Break - Morning Star	9/24/92 - MUD20 Minutes
Water Line Break - 17602 Typhoon Way	10/22/92 - MUD73 Minutes
Possible cross connection Sealander at	5/21/93 - As-designed map
Tap leak Harpoon Court	3/24/93 - MUD20 Minutes
Sewer Blockage Port-o-Call	4/28/93 - MUD20 Minutes
Sewer Repair - 16302 Davey Jones	9/24/92 - MUD20 Minutes
Sewer Blockage - Mediterranean	1/27/93 - MUD20 Minutes
Water Line Break - 407 Ahoy Court	9/24/92 - MUD20 Minutes
Manhole Repair - Fishhawk	2/24/93 - MUD20 Minutes
Tap line leaks Harbor Mist	4/28/93 - MUD20 Minutes
Sewer Line Repair - Diamondhead	2/24/93 - MUD20 Minutes
Manhole Repair - Wake Court	2/24/93 - MUD20 Minutes
Manhole submerged - Lot 36 Marlinspike	5/21/93 - Field Notes
Manhole Repair - 16843 S. Lighthouse Dr	9/24/92 - MUD20 Minutes
Water Line Break - North Lighthouse Dri	9/24/92 - MUD20 Minutes
Broken sewer main Monsoon Court	4/28/93 - MUD20 Minutes

Sewer blockage Monsoon Court	4/28/93 - MUD20 Minutes
Sewer Blockage - Monsoon Court	3/24/93 - MUD20 Minutes
Sewer Repair - 17500 Monsoon Court	6/25/92 - MUD20 Minutes
Manhole Repair - Diamondhead (2)	9/24/92 - MUD20 Minutes
Manhole Repair - Coral Bay	2/24/93 - MUD20 Minutes
Sewer Blockage - Coral Bay	2/24/93 - MUD20 Minutes
Tap leak Compass Rose	3/24/93 - MUD20 Minutes
Sewer Line Damage - Sinkhole, Location	5/28/92 - MUD20 Minutes
Manhole Repair - Location Unspecified	9/24/92 - MUD73 Minutes

We feel that this single mapping tool could be of great use to Newport in the future, and although outside the scope of this research we 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.

Thematic Inflow and Infiltration Risk

The thematic inflow and infiltration risk map was prepared by computing a normalized risk value from the five themes discussed above. The following concpets 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 sensity.
- 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:

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

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 16 shows the thematic risk map developed from this formula.

The risk map was further categorized into three priority maps for guiding Newport's rehabilitation strategy. Priority III is the lowest risk areas, that represent risk values ranging from zero (lowest risk) to 33%. The Priority III areas are shown on Figure 17. Priority II is the middle risk areas that represents risk values ranging from 33% to 66%. Figure 18 shows the Priority II areas. Figure 19 is the Priority I risk map. Priority I is the upper risk areas, that represents the areas of the subdivision that the thematic mapping predicts has the greatest potential for inflow and infiltration and should be investigated/rehabilitated first.

In the absence of additional data these maps represent our estimate of the inflow and infiltration severity in the Newport subdivision. To help refine this concept of risk a sewer water quality monitoring program was developed to suppliment these maps and generate an aggregated risk map for the subdivision.

Sewer Water Quality Monitoring

A sewer water quality monitoring program was developed to attempt to obtain quantitative measures of inflow and infiltration severity that could be cross referenced to the geographic analysis. The results of the water quality monitoring can then be used to produce a second priority map that can be combined with first to create an aggregate inflow and infiltration severity map to guide the Newport rehabilitation program.

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 (Glanton, 1992) who suggested the approach. The method used in the Newport study was based on an analogy to the dye dilution method of flow monitoring.

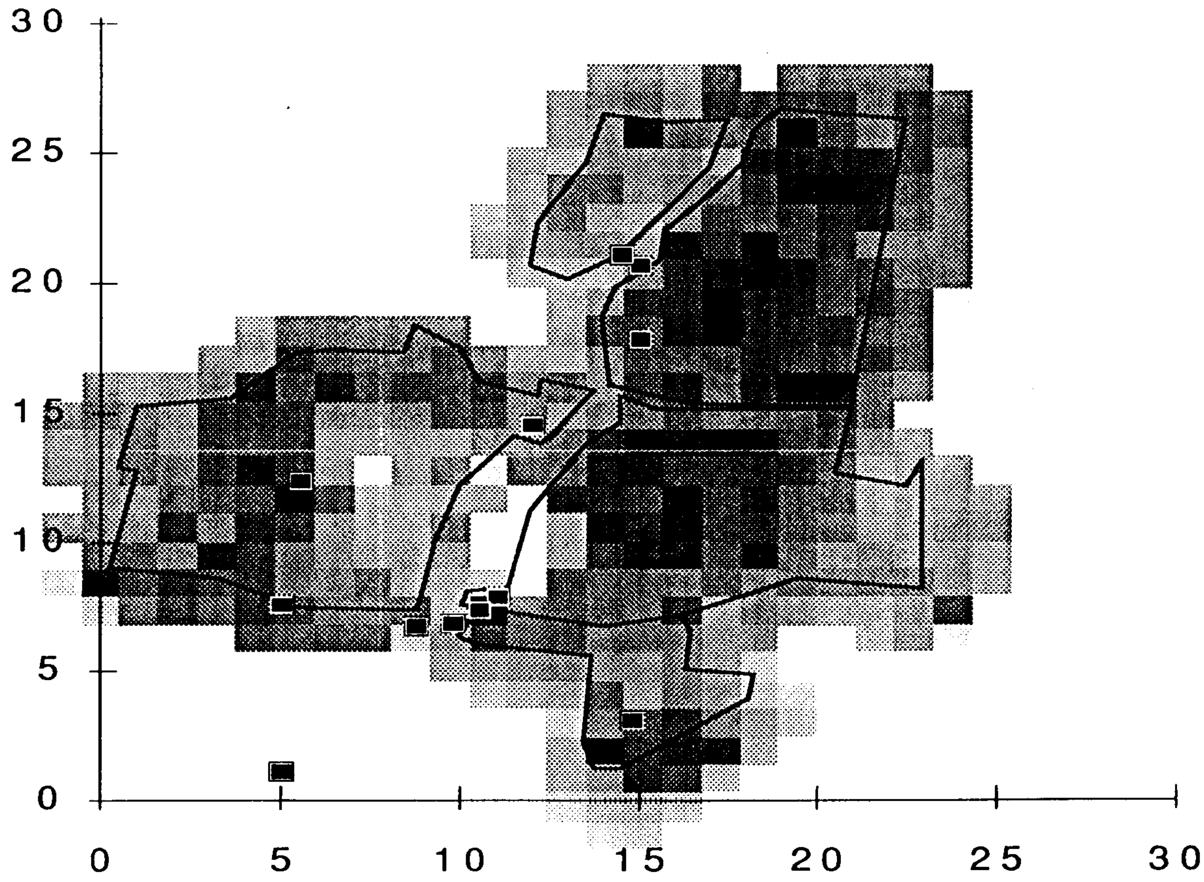


Figure 16. Inflow and Infiltration Risk Map (Dark = High Risk, Light = Low Risk).

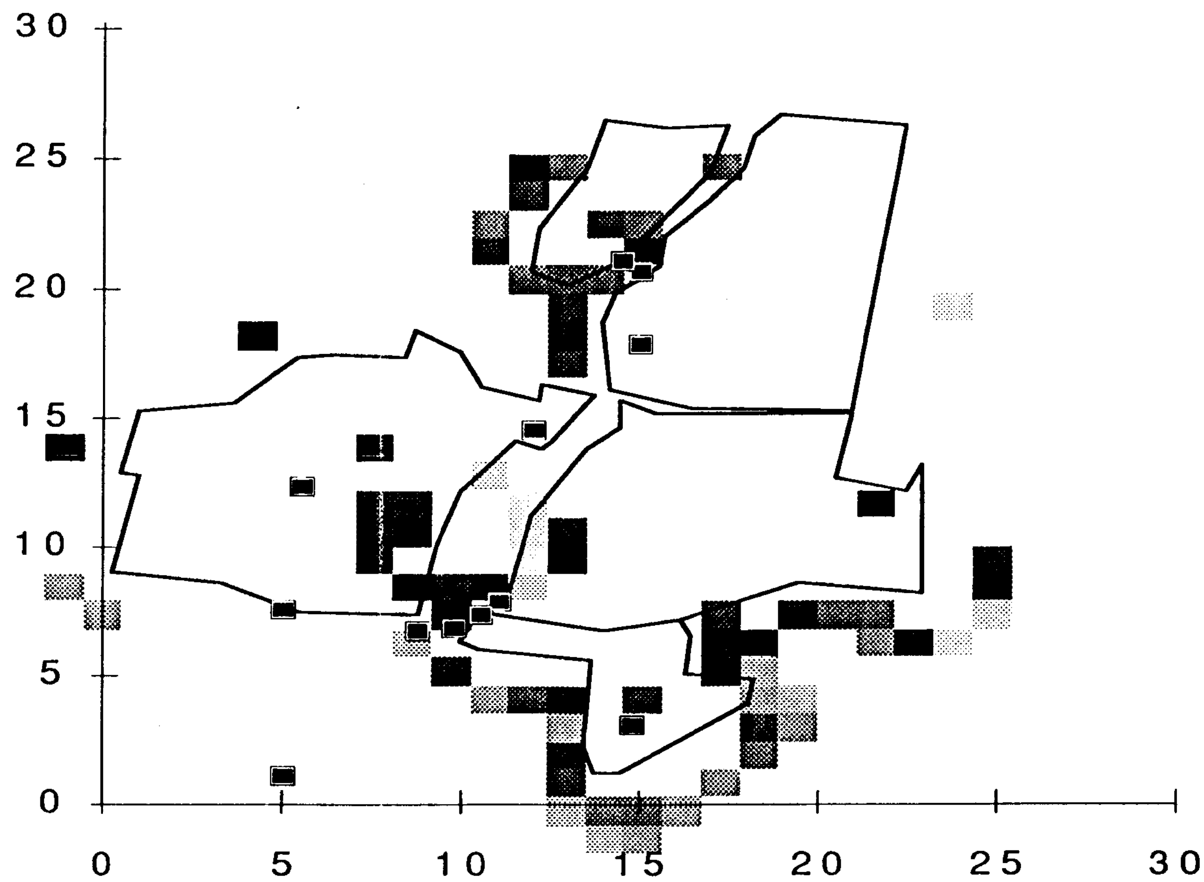


Figure 17. I&I Priority III Risk Map (0% < Risk < 33%)

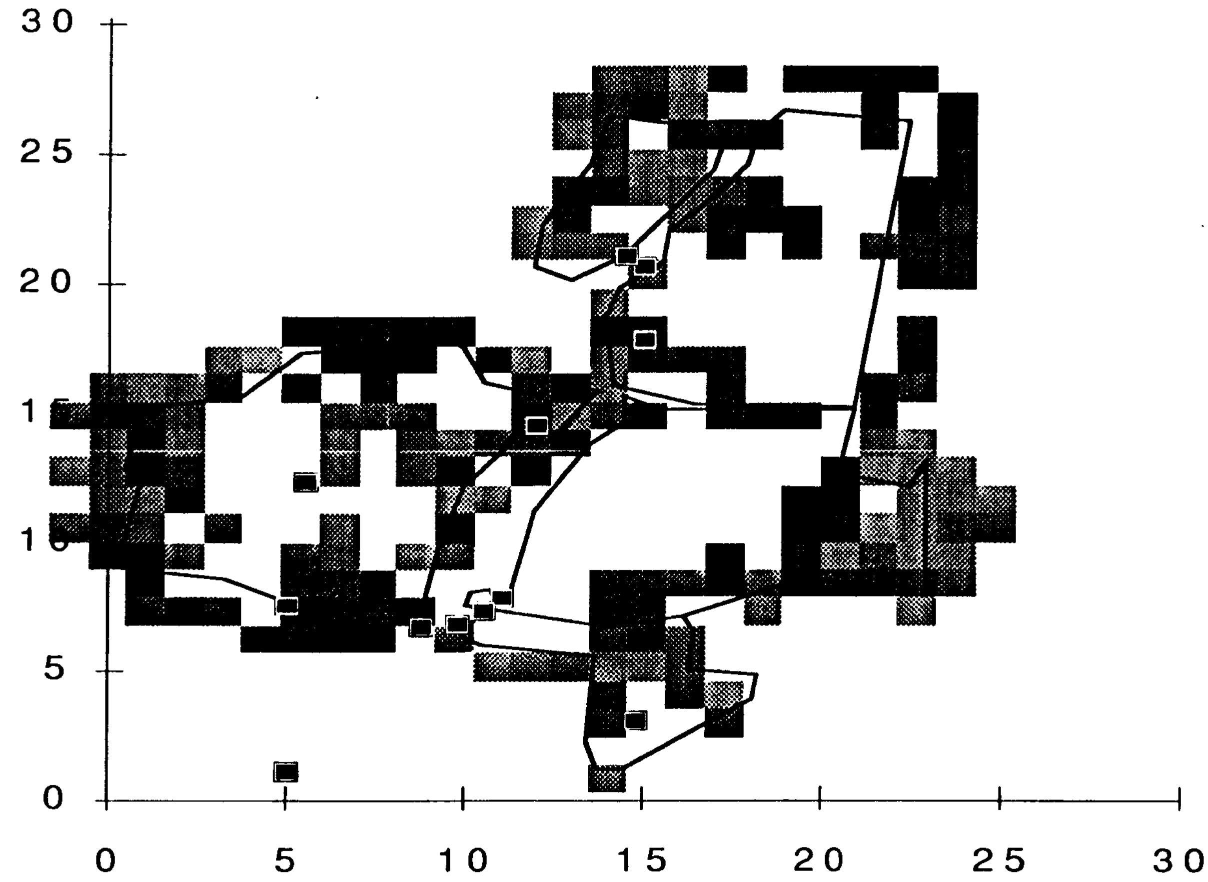


Figure 18. I&I Priority II Risk Map (34% < Risk < 66%)

Figure 19. I&I Priority I Risk Map (67% < Risk < 99%)

Dilution Detection Concept

A sewer water quality monitoring program was used to attempt to quantify areas of inflow and infiltration based on the concept of dilution detection. Figure 20 is used the illustrate the concept.

The concept assumes that the sewage load concentration, C_L is roughly uniform throughout the system so that $C_1 = C_L$. Dry weather monitoring is performed because infiltration and inflow are absent thus the chemical mass balance requires that $C_2 = C_1$.

The next step is to identify quality parameters that have the property that C_1 / C_I is large. Once these parameters have been identified, measurement of concentrations in the system determines proportion of sewage flow that originates from inflow and infiltration.

Once a dilution point is identified, tracking from a dilution point up-stream in the system, the segment of the sewer system where the inflow and infiltration originates can be isolated and video-logged to locate subsurface defects and repaired.

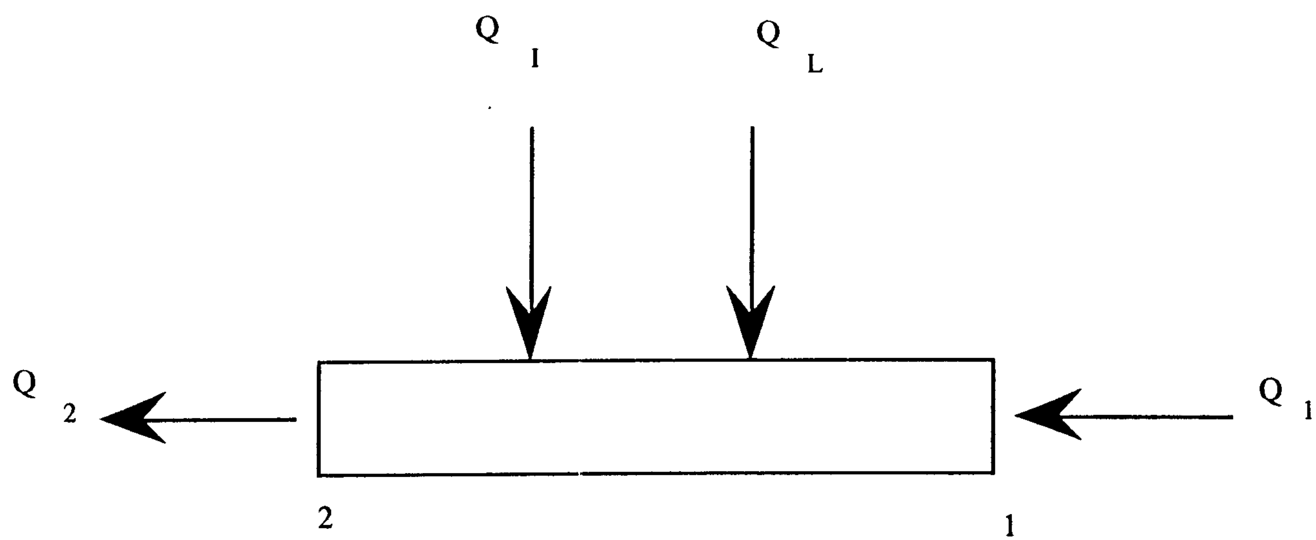
Figure 21 illustrates the importance of identifying compounds that have a large sewage to infiltration ratio. C(mixture) is measured value in the sample, while C(sewer) is background value expected in the sewer. Co is the infiltration value. Q(infiltration) is inflow and infiltration flow rate - unknown. Q(sewer) is normal sewer contribution - unknown, but should be similar to background flows. From the figure one can observe that when the concentration contrast between background and infiltration water is high, relatively small ratios of inflow to sewage flow can be quantified by dilution measurements.

Indicator Parameters

Using the elements of the dilution theory indicator parameters were selected that we hoped would be present in sewage and relatively absent in I&I water. The indicator parameters selected for the sewer water quality monitoring portion of the research were the physical measurements of pH, temperature, total dissolved solids (TDS) and conductivity, and the chemical parameters of ammonia-nitrogen, phosphorous, chemical oxygen demand, and chloride ion.

Nitrogen present in fresh sewage is primarily from proteinaceous matter in feces and urea. Decomposition by bacteria readily changes the form to ammonia. In an aerobic environment, the ammonia is oxidized to nitrates and elemental nitrogen. Since the collection system is essentially anaerobic (a reducing environment) the primary nitrogen form should be ammonia. The primary nitrogen form in infiltration water should be nitrate. The oxygen demand of the sewage should prevent the ammonia in the sewage from being oxidized, so any inflow and infiltration water should simply dilute the ammonia already present in the sewage. This logic was used to select ammonia-nitrogen as a monitoring compound.

Phosphorous in domestic sewage is assumed to be primarily from detergents. Phosphorous is expected to be relatively scarce in the infiltration water as it is a plant nutrient and would be expected to be incorporated into plant metabolisms. Phosphorous was selected as a second compound that would be indicative of sewage, but not rainfall induced inflow and infiltration water. The possibility of phosphorous entering the system from fertilizer was not considered important since fertilizer would be used primarily in the growing season that coincides with the periods when the STP discharges are within acceptable hydraulic limits.



Flow Balance: $Q_2 = Q_1 + Q_I + Q_L$

Chemical Mass Balance : $C_2 = \dfrac{C_1 Q_1 + C_I Q_I + C_L Q_L}{Q_1 + Q_I + Q_L}$

Figure 20. Schematic of Water and Chemical Mass Balance for Dye Dilution Concept

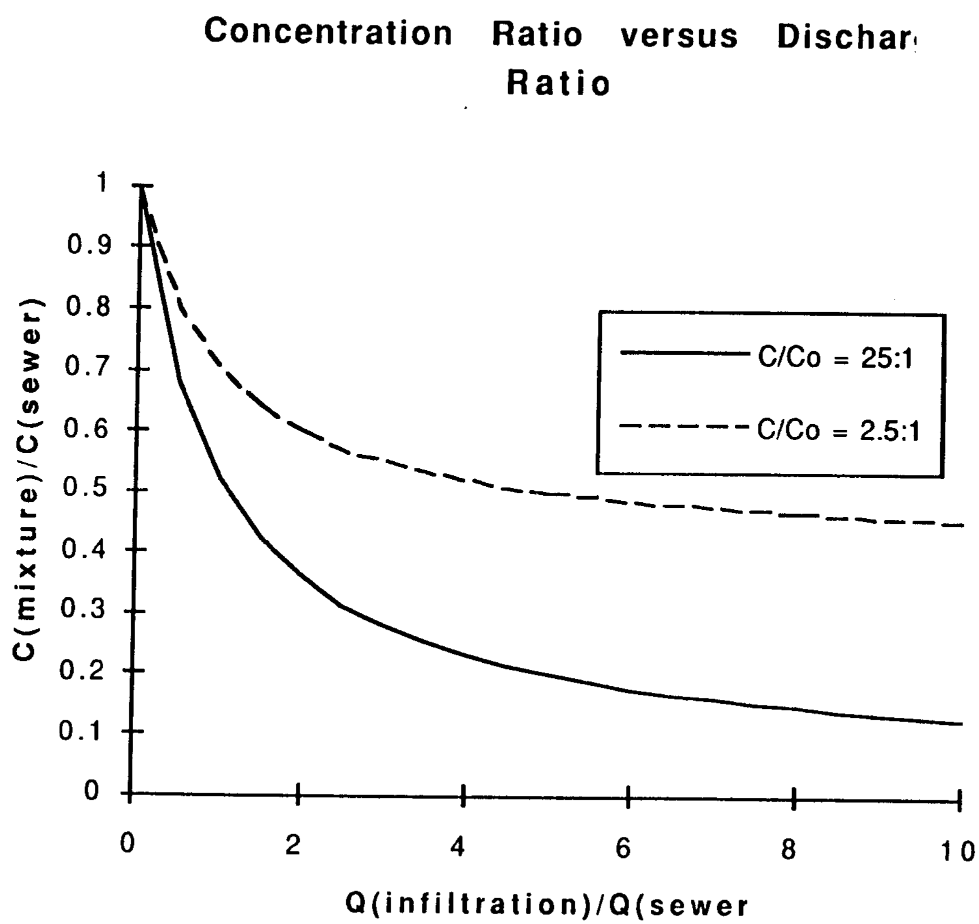


Figure 21. Concentration Ratio Plot Showing the Importance of High Concentration Contrast to Resolve Low Mixing Flow Rates by Dye Dilution Method.

Chemical oxygen demand in domestic is high due to the high concentration of organic matter present. Microbes use all the oxygen to biologically break down the sewage. Therefore sewage has no dissolved oxygen and a high oxygen demand. Rainfall and surface water are exposed to the air and have a high dissolved oxygen content. Any rainfall or surface water entering the system would simply dilute the oxygen demand needed to oxidize C to CO_2, S to SO_4, P to PO_4, and H to H_2O. Chloride in concentrations of 100 mg/l or more can have a minimal effect on the COD test (1%). Chloride tests showed concentrations of 20 mg/l or less. This logic was used to select COD as a monitoring parameter.

Chloride in domestic sewage is higher than domestic drinking water as the human body uses the water and relieves itself of the chloride in higher concentrations. Chloride is expected to be low in rainfall and any infiltration of rain would simply dilute the concentration of chloride. The possibility of salt water entering the system was not considered due to the location of the Newport subdivision being near a fresh water lake. The possibility of upstream chlorination by other wastewater facilities is a potential problem, if Gum Gulley water is entering the sewage system. The chloride concentration in Gum Gulley appears to be higher than in the domestic sewage.

Sampling and Analysis

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.

Field pH and Temperature were measured using the HACH-One pH meter (Model 43800-00). The pH meter was calibrated to a known pH4 and pH7 standard solution before collecting samples on each site visit. TDS and conductivity were measured using a HACH Conductivity/TDS meter (Model 44600-00).

The ammonia-nitrogen analysis used a direct colorimetric technique. The samples are diluted and placed in a graduated cylinder where a stabilizer and dispersing agent are added and mixed. Nessler Reagent which causes a color change proportional to the amount of ammonia present in the sample is added and mixed. After one minute, the sample is placed in a spectrophotometer and a reading at 425 nm wavelength is taken. The reading is compared to a blank standard and the difference is converted to mg/l of ammonia. (EPA Method 8038, HACH, 1992)

The phosphorous analysis also used a colorimetric technique. The samples are diluted and sulfric acid is added to the samples to lower pH. The samples are then heated for 30 minutes to cause the phosphorous to react to a form that can be detected using an indicator. After cooling sodium hydroxide is added to balance the pH and a reactive indicator is then added and mixed. After two minutes, the sample is placed in the spectrophotometer and the reading at 890 nm wavelength is taken. This reading is compared to a blank standard and converted to mg/l of reactive phosphorous. (EPA Method 8048, HACH, 1992)

The chemical oxygen demand analysis is a test performed to measure the amount of oxygen required to oxidize organic matter. The sample, silver sulfate, potassium dichromate, and catalyst mercuric sulfate are mixed in a flask. The solution is heated for two hours so that the organic matter can be oxidized (S to SO_4, P to PO_4, C to CO_2). The flasks are then cooled to room temperature. Ferrion indicator is then added and the solution is titrated with ferrous-ammonium sulfate until a reddish color is present. The milliliters of ferrous-ammonium sulfate needed for the sample is compared to the milliliters needed to titrate de ionized water, to obtain the COD in mg/l. (Standard method 5220, American Public Health Association, 1992.)

The chloride analysis uses mercuric nitrate titration. The analysis is a modification of a standard geochemical measurement that uses silver nitrate. Mercuric nitrate is simply less expensive. The samples are diluted and transferred into a 250 ml flask. Air is bubbled through the sample to remove sulfide that inhibits the analysis. Diphenylcarbazone indicator is then mixed in the sample. Mercuric nitrate is then added slowly using a digital titrator. A standard titration burette could also be used. When the sample turns light pink, the reading from the digital titrator is recorded and converted to mg/l of chloride. (EPA Method 8206, HACH, 1992).

Sampling Network

A sampling system needs to accurately represent each every section of a subdivision to accurately represent the system. Ten sewage system sites were chosen along with two Gum Gulley sites based on their location and the hydraulic flow of the system. Figure 22 shows a "hydraulic" network map of the sampling system. The arrows indicate direction of flow, and the areas are outlined to indicate the variuos sections of the subdivision served by the individual sampling sites. The location of the sampling sites is described below.

Sample site #8 is located on Flying Bridge just before lift station #4 in section 10. That manhole has all of section 10 sewage running through it. Section 10 is the first section on the north-south main line.

Sample site #9 is located on Handspike just before lift station #3 in section 3. That manhole has all of section 6 and section 3 sewage running through it. The sewage from lift station #3 joins the north-south main line south of section 10 and north of Deerpointe section.

Sample site #1 is located at Stem Way and Golf Course Drive. That manhole is the point where the Deerpointe section sewage discharges into the north-south main line.

Sample site #2 is located at Sahara and Golf Course Drive. That manhole is the point where the apartments located on Sahara dumps its sewage into the north-south mainline. This is the last sampling point on the north-south mainline before the sewage gets to the main plant.

Sample site #6 is located just before lift station #6 just north of South Diamondhead (future Boom Drive). That manhole collects sewage from the western part of section 8 and sewage from section 7 (mostly undeveloped land). The sewage from lift station #6 travels east to join the east-west main line 500 feet east of the South Diamondhead bridge.

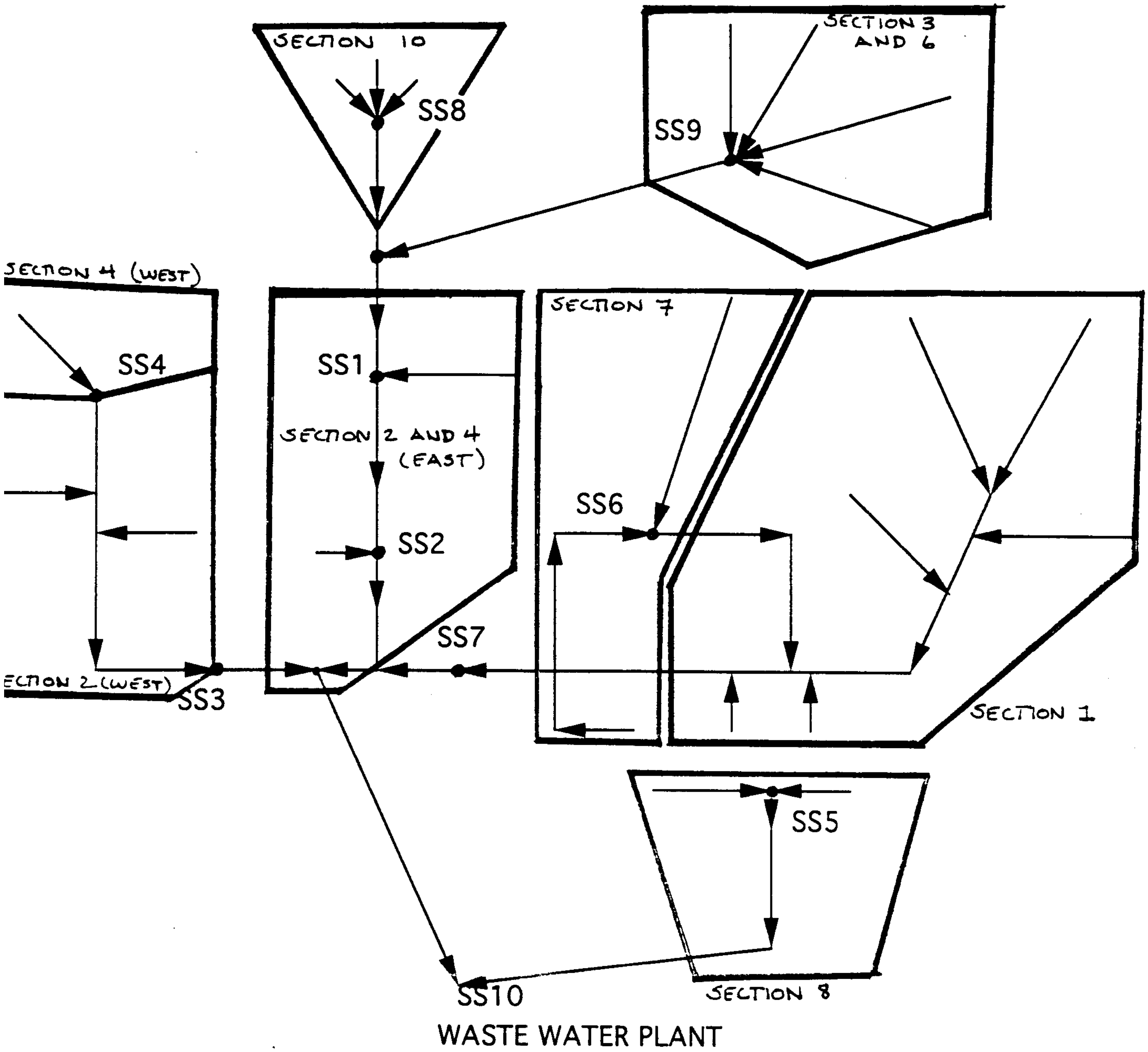
Sample site #7 is located 50 feet east of the Diamondhead bridge. That manhole carries all the sewage from section 1 and from lift station #6. This is the last sample site for the east-west main line before the sewage reaches the plant.

Sample site #4 is located at the last manhole before the lift station located on Dunes Drive. That manhole collects all the sewage from the northern part of section 4. The sewage then travels south until it reaches Diamondhead.

Sample site #3 is located at Sahara and South Diamondhead Drive. That manhole collects all the sewage from section 2 and section 4. This is the last sampling point on the west-east main line before the main plant.

Sample site #5 is located at Dora Drive and South Chamfer Way. That manhole collects all the sewage for the southern part of section 8. The sewage in this line travels south to a lift station where it is pumped into a force main to the plant.

NEWPORT SAMPLING SYSTEM NETWORK



Schematic Map of Sewer Hydraulic Network and Sample Site Locations.

Sample site #10 is the wastewater plant. Samples were taken just before the sewage entered the plant.

Gum Gulley #1 is located where Flying Bridge will cross Gum Gulley. This location represents the quality of the water as it enters the Newport subdivision.

Gum Gulley #2 is located at the South Diamondhead bridge. This location represents the quality of the water as it exits the Newport subdivision.

Sewer Water Quality Data Interpretation

Table 11. shows the results of the sewer water quality sampling program for Newport. The data reported are Temperature, pH, Conductivity, TDS, Chloride, COD, ammonia-nitrogen (NH3), and phosphorous (PO4). COD was abandoned as an indicator in October of 1992 because the concentration ratio in sewage to surface water was too small to detect dilution (as described in the dye dilution concept above). NH4 and PO4 were used as the sole indicators of sewage for the remainder of the study.

Figures 23 through 28 show the results of the sewer water quality monitoring program for ammonia-nitrogen, and phosphorous, two nutrients expected to be high in sewage and low in the surface waters. The figures show STP flows and rainfall as well as the chemical data as a time series.

Figure 23 shows the ammonia-nitrogen sewer water quality data for sample sites SS8,SS9,SS1 and SS2. These sites are arranged in the drainage order towards the STP. Figure 26 shows the same sites for phosphorous. Figures 24 and 27 show the sewer water quality data for sites SS4,SS3,SS6 and SS7 - again in drainage order to the STP. Figures 25 and 28 show the sewer water quality data for sites SS2,SS3,SS5, and at the STP.

In general the sampling program produced data that were difficult to interpret since the effects of rainfall appear to exit the system relatively quickly. The closest a routine sampling day fell after significant rainfall was April 8, 1993, which came after nearly a week of intermittent rainfall with two high STP flow peaks. The chemical data for this sampling event indicate that the entire system experienced dilution due to inflow and infiltration, although some portions were slightly worse off than others. Because a dramatic dilution was not detected as expected, an approximation method was used to try generate a measure of the severity of inflow and infiltration in the system based on the chemical data.

Table 11. Sewer Water Quality Data

Newport Sewer System Evaluation Survey

Wastewater Quality Monitoring Data

Routine Sample Sites			Date																
Location	Site	Parameter	8/25/92	9/11/92	9/17/92	10/9/92	10/19/92	10/30/92	11/13/92	11/27/92	12/22/92	12/31/92	1/28/93	2/4/93	2/18/93	3/18/93	4/8/93	4/15/93	5/2/93
Stem Way and Golf Club	SS-1	Temp(°C)	29.3	26.5	28.7	25.5	24.9	26.1	21.3	20.3	22.1	23.8	20.5	19.2	19.1	21.5	19.6	21.1	22.4
		pH	7.35	7.36	7.26	7.5	7.63	7.59	7.45	7.74	7.7	6.87	7.54	9.71	7.92	7.76	7.17	7.27	7.24
		TDS(g/L)	0.415	0.432	0.417	0.426	0.503	0.419	0.223	0.449	0.415	0.426	0.35	0.387	0.275	0.425	0.169	0.374	0.27
		Cond(mS/cm)	0.834	0.863	0.835	0.857	1.011	0.84	0.447	0.901	0.832	0.852	0.702	0.776	0.551	0.852	0.341	0.75	0.543
		Chloride(mg/L)		80	65.6	·	108		68	58	50	10	10	14	20	4	20	2	6
		COD(mg/L)	287.68	277.76	218.24														
		NH3-N(mg/L)					20.9	26.8	22.6	28.8	24.4	31	23.4		17.6	32.8	4.6	18.4	12
		PO4(mg/L)					10	22	17.6		13.8	17.8	16.2		11	19	8.6	18.4	18.8
Samba and Golf Club	SS-2	Temp(°C)	33.3	26.2	27.7	24.6	24.6	26.1	22.5	20.3	22	23.8	19.9	19.6	18.9	20.3	19.9	21	21.9
		pH	7.26	7.46	7.43	7.38	7.26	7.53	7.51	7.49	7.76	7.59	7.4	8.18	7.54	7.46	7.96	7.35	8.02
		TDS(g/L)	0.58	0.408	0.412	0.392	0.4	0.432	0.361	0.429	0.366	0.441	0.37	0.339	0.185	0.402	0.15	0.405	0.287
		Cond(mS/cm)	1.156	0.818	0.824	0.781	0.803	0.865	0.722	0.862	0.734	0.883	0.745	0.68	0.72	0.806	0.301	0.813	0.576
		Chloride(mg/L)		120	56.4	44	62	80	68	76	20	8	12	15	30	4	20	1	15
		COD(mg/L)	277.76	386.88	173.6														
		NH3-N(mg/L)				18.6	14.6	25.6	22	25.6	24	7.6	25.6		6.2	24.4	5.2	19.6	9.8
		PO4(mg/L)				14.8	10.2	20.2	13.8	14.2	14.2	16.4	12.8		0.8	17.6	9.4	19.6	12.8
Samba and Diamondhead	SS 3	Temp(°C)	31.6	24.4	25.9	23.7	23.7	25.1	21.7	20.9	21.5	22.4	19.6	17.8	16.9	19.6	19.9	20.6	21.3
		pH	7.5	7.54	7.38	7.57	7.45	7.72	7.15	7.57	7.9	7.89	7.45	9.7	8.29	7.62	7.31	7.53	7.58
		TDS(g/L)	0.454	0.378	0.454	0.441	0.46	0.42	0.376	0.436	0.405	0.477	0.376	0.415	0.171	0.393	0.091	0.437	0.262
		Cond(mS/cm)	0.906	0.759	0.91	0.887	0.922	0.841	0.754	0.874	0.811	0.955	0.755	0.833	0.343	0.789	0.185	0.877	0.527
		Chloride(mg/L)		73.6	65.2		84	54	50	74	38	28	16	19	30	6	6	8	8
		COD(mg/L)	555.52	114.08	153.76														
		NH3-N(mg/L)					17.8	26.7	19.6	25	24.8	33.2	21.4		4.2	18.8	0.94	14.8	6.6
		PO4(mg/L)					10	23.3	22.6		16	17.2	14.4		0.8	17.8	3.8	14.8	12.8
Dunes and Beachwalk	SS 4	Temp(°C)	31.8	26.1	26.8	23.5	24.6	25.5	21.6	21.3	21.7	22.9	19.5	17.9	19.4	20	19.5	21.1	21.2
		pH	7.55	7.42	7.41	7.51	7.94	7.51	7.82	7.89	7.52	7.88	7.22	9.54	7.63	7.37	6.84	7.21	7.83
		TDS(g/L)	0.549	0.374	0.45	0.45	0.446	0.452	0.444	0.454	0.478	0.476	0.442	0.352	0.292	0.44	0.172	0.47	0.253
		Cond(mS/cm)	1.122	0.747	0.902	0.903	0.895	0.905	0.891	0.909	0.958	0.953	0.886	0.706	0.586	0.884	0.345	0.942	0.507
		Chloride(mg/L)		60	63.6	58	86	64	76	84	24	12	6	14	20	4	16	3	21
		COD(mg/L)	347.2	535.7	243.04														
		NH3-N(mg/L)					10.7	40.6	30	33.8	28	35.2	20.8		4.2	15.4	1.51	12.8	4.6
		PO4(mg/L)					14.1	24.8	25		22.4	20.6	6		1.6	14	11.2	12.8	8.6
Dora Dr. and S. Camfer	SS 5	Temp(°C)	32.1	27.1	26.8	26.8	27.2	28.2	22.8	22	23	24.4	20.2	19.5	19.4	21.1	20.4	21.2	21.9
		pH	7.72	7.71	7.7	7.83	8.05	8.01	7.52	7.94	8	7.12	7.66	8.78	6.9	7.69	6.85	7.49	7.52
		TDS(g/L)	398	0.412	0.461	0.487	0.362	0.31	0.333	0.461	0.395	0.397	0.404	0.336	0.247	0.46	0.186	0.437	0.304
		Cond(mS/cm)	0.798	0.828	0.924	0.976	0.726	0.622	0.668	0.925	0.794	0.797	0.811	0.674	0.496	0.924	0.373	0.876	0.611
		Chloride(mg/L)		64.4	65.2		68		44	110	12	13.2	10	5	14	5	14	3	18
		COD(mg/L)	228.6	248	243.04														
		NH3-N(mg/L)					15.9	11.2	16.8	34	26	18.6	22.4		8.2	28.4	2.4	32.4	15.6
		PO4(mg/L)					13.5	8.2	11.8		23.2	35	19.6		9.2	2.82	8.2	24	15

Newport Sewer System Evaluation Survey

Wastewater Quality Monitoring Data

Routine Sample Sites			Date																
Location	Site	Parameter	8/25/92	9/11/92	9/17/92	10/9/92	10/19/92	10/30/92	11/13/92	11/27/92	12/22/92	12/31/92	1/28/93	2/4/93	2/18/93	3/18/93	4/8/93	4/15/93	5/2/93
Inflow to LS#6	SS-6	Temp(°C)	31	25.3	26.5	22.8	24.1	25	20.8	19.7	21.4	22.1	18.6	17.1	17.3	20.5	18.6	19.3	20.9
		pH	7.71	7.9	7.53	7.49	7.64	7.83	7.58	7.9	7.67	7.46	8.42	9.4	7.8	7.57	7.49	7.23	7.61
		TDS(g/L)	0.56	0.389	0.418	0.452	0.399	0.405	0.35	0.411	0.319	0.362	0.293	0.211	0.192	0.357	0.087	0.283	0.22
		Cond(mS/cm)	1.105	0.781	0.838	0.905	0.801	0.811	0.701	0.824	0.64	0.726	0.589	0.424	0.386	0.716	0.178	0.567	0.441
		Chloride(mg/L)		80.4	62.4	60	68		66	100	28	58	10	12	10	3	6	4	6
		COD(mg/L)	208.32	297.6															
		NH3-N(mg/L)					9.4	32	21	33.4	17.6	20	13.6		5.8	14	2.2	10	6.8
		PO4(mg/L)					11.1	15	14		7.2	24.2	9.8		2.8	38.2	6.8	9.4	14.2
Diamondhead at Bridge	SS-7	Temp(°C)	33.5	25.7	26.8	27	27.3	27.7	21.3	20.8	21.3	22.5	19.6	18.2	19.4	20.6	19.1	20.7	21.6
		pH	7.26	7.24	7.26	7.26	7.36	7.83	7.65	7.32	7.72	7.56	8.33	9.63	9	7.46	7.85	7.3	8.25
		TDS(g/L)	0.442	0.339	0.415	0.472	0.492	0.45	0.46	0.383	0.395	0.449	0.39	0.354	0.278	0.429	0.119	0.405	0.277
		Cond(mS/cm)	0.886	0.678	0.832	0.949	0.989	0.901	0.923	0.768	0.793	0.898	0.782	0.711	0.558	0.858	0.239	0.813	0.556
		Chloride(mg/L)		63.2	60.4	80	92		60	80	18	10	10	10	60	3	4	2	8
		COD(mg/L)	332.32	143.84	183.52														
		NH3-N(mg/L)					21.2	41.2	30.4	33.8	27.2	33	29		14.6	33.8	2.63	31.2	13.2
		PO4(mg/L)					16.6	17.2	19		17.6	16.4	16.4		11.6	20.8	8	16	16.6
Inflow to LS#4	SS 8	Temp(°C)		27.7	30.7	26.6	25.6	28.2	23.9	21.8	23.3	25.5	19.7	21	8.99	21.3	21.3	21.4	22.4
		pH		8.2	7.57	7.71	8.18	8.26	7.94	7.74	7.88	8.06	8.4	10.24	20.3	7.94	7.13	8.18	8.26
		TDS(g/L)		0.571	0.423	0.49	0.424	0.393	0.359	0.396	0.388	0.414	0.355	0.435	0.389	0.432	0.302	0.435	0.342
		Cond(mS/cm)		1.144	0.847	0.982	0.849	0.788	0.72	0.794	0.779	0.829	0.713	0.873	0.779	0.866	0.606	0.873	0.687
		Chloride(mg/L)		132.4	64	64	72			70	14	24	8	5	12	8	16	2	30
		COD(mg/L)		411.68	292.64														
		NH3-N(mg/L)					12.8	21.6	15.8	23	13.4	26	14.6		17	26.8	6.8	15.4	11
		PO4(mg/L)					21	17.6	25.2		12.4	16.4	11.8		5.8	33.2	10.2	14.4	20.6
Inflow to LS#3	SS 9	Temp(°C)		27.2	25.1	26.1	21.5	26.3	22.6	21.2	21.9	22.3	19.2	19.3	18.8	20.6	19.2	21	22.4
		pH		7.21	7.23	7.31	7.27	7.7	7.53	7.63	7.83	7.26	7.15	9.81	9.03	7.66	6.58	7.26	7.24
		TDS(g/L)		0.48	0.415	0.417	0.455	0.435	0.416	0.437	0.359	0.409	0.358	0.296	0.223	0.407	0.11	0.419	0.27
		Cond(mS/cm)		0.958	0.83	0.838	0.912	0.872	0.833	0.879	0.719	0.818	0.718	0.594	0.448	0.816	0.222	0.84	0.543
		Chloride(mg/L)		93.6	61.6	58	72		66	54	18	54	26	22	16	4	7	2	25
		COD(mg/L)		208.32	238.08														
		NH3-N(mg/L)					13.4	34.4	27.4	33	39.8	29.4	25.6		10.2	27	3	28.4	10
		PO4(mg/L)					17	19.4	16.6		10.4	16	8.2		6	16.8	8.4	31	48.4
Inflow to Sewage Plant	SS 10	Temp(°C)						26.4	23	18.4	21.5	22.7	19.4	17.4	18.4	20.2	19.8	20.1 x	
		pH						7.74	7.63	7.52	7.78	7.71	7.36	8.95	7.15	7.75	6.72	7.48 x	
		TDS(g/L)						0.394	0.479	0.929	0.391	0.446	0.38	0.32	0.245	0.422	0.142	0.394 x	
		Cond(mS/cm)						0.789	0.965	0.46	0.784	0.894	0.762	0.642	0.492	0.847	0.285	0.789 x	
		Chloride(mg/L)							58	90	14	18	38	22	30	6	10	4 x	
		COD(mg/L)																x	
		NH3-N(mg/L)						24.4	28.8	29.2	24.4	26.6	25.8		14.4	25	2.4	29.2 x	
		PO4(mg/L)						25.2	18		1.2	17.8	11.2		3	20.2	30	55 x	
Gum Gulley at Flying Br.	GG-1	Temp(°C)		25.9	26.1	18.9	17.9	23.1	16.1	10.2	18.9	23.3	14.5	13.6	16.1	20	19.2	20.4	22.1
		pH		7.57	7.46	7.21	7.53	7.74	7.72	7.63	7.63	6.58	7.15	9.7	8.04	7.36	7.14	7.03	7.98
		TDS(g/L)		0.307	0.327	0.609	0.352	0.42	0.223	0.206	0.201	0.319	0.279	0.181	0.11	0.325	0.078	0.305	0.125
		Cond(mS/cm)		0.615	0.657	1.232	0.706	0.841	0.447	0.414	0.405	0.642	0.561	0.364	0.221	0.651	0.158	0.612	0.252
		Chloride(mg/L)		86.8	80.4	192	94		64	58		50	36	8	20	44	5	5	19
		COD(mg/L)		69.44	0														
		NH3-N(mg/L)					0		0.16	0.36	0.34	0.2	0.63		0.88	0.21	0.82	0.33	0.91
		PO4(mg/L)					2.62	2.75	2.75		0.8	2.68	0.63		0.11	1.19	0.76	1.1	0.91
Gum Gulley at Diamond.	GG-2	Temp(°C)			26	20.3	19.1	23.9	15	8.8	18	21.5	13.8	14	17.1	20.9	20.5	22	21.1
		pH			7.6	7.58	7.49	7.49	7.86	7.41	7.69	7.96	8	9.49	8.07	7.38	8.16	7.38	8.59
		TDS(g/L)			0.361	0.425	0.242	0.325	0.228	0.17	0.191	0.312	0.246	0.182	0.098	0.322	0.063	0.282	0.115
		Cond(mS/cm)			0.725	0.858	0.485	0.651	0.458	0.341	0.385	0.625	0.495	0.366	0.197	0.647	0.127	0.566	0.231
		Chloride(mg/L)			87.6	95.2	78	100		48		56	32	13	40	40	3	4	17
		COD(mg/L)			109.12														
		NH3-N(mg/L)					0	0.21	0.41	0.1	0.36	0.33	0.53		1.08	0.16	0.86	0.32	1.02
		PO4(mg/L)					0.31	1.59	1.62		0	1.33	0.53		0.24	0.62	0.65	1.07	1.02

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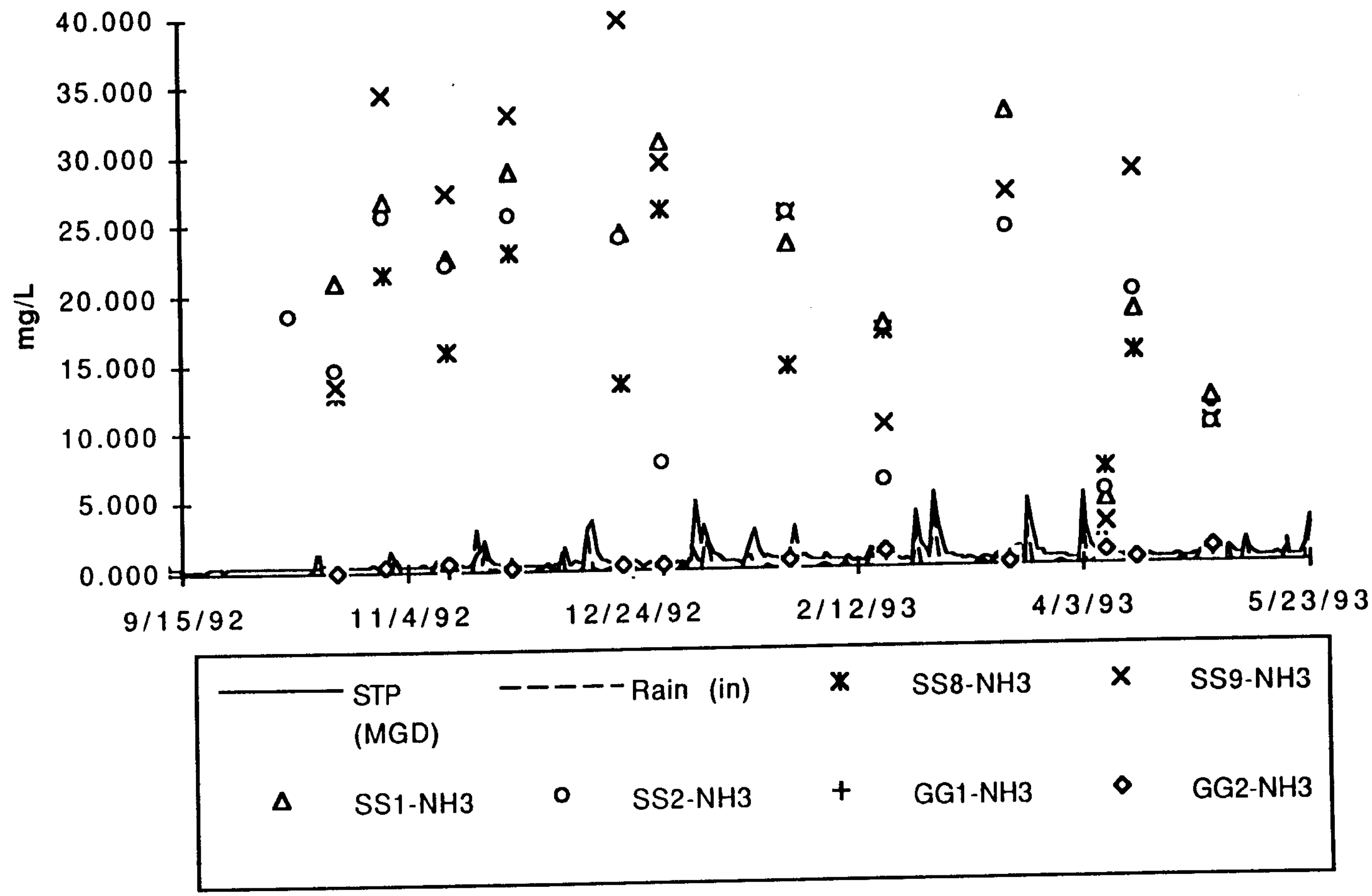

Figure 23. Time Series of Ammonia-Nitrogen for Newport .

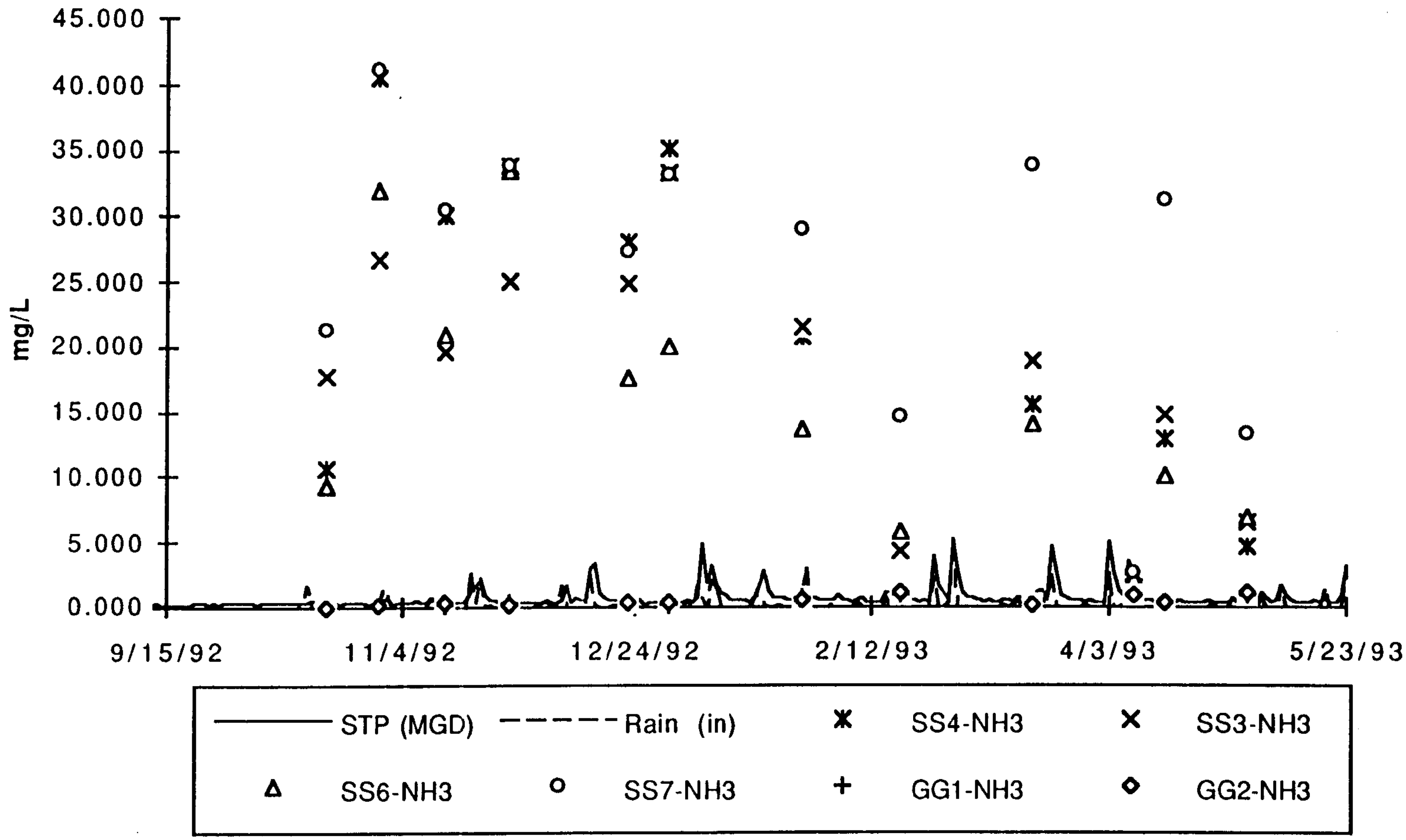

Figure 24. Time Series of Ammonia-Nitrogen for Newport

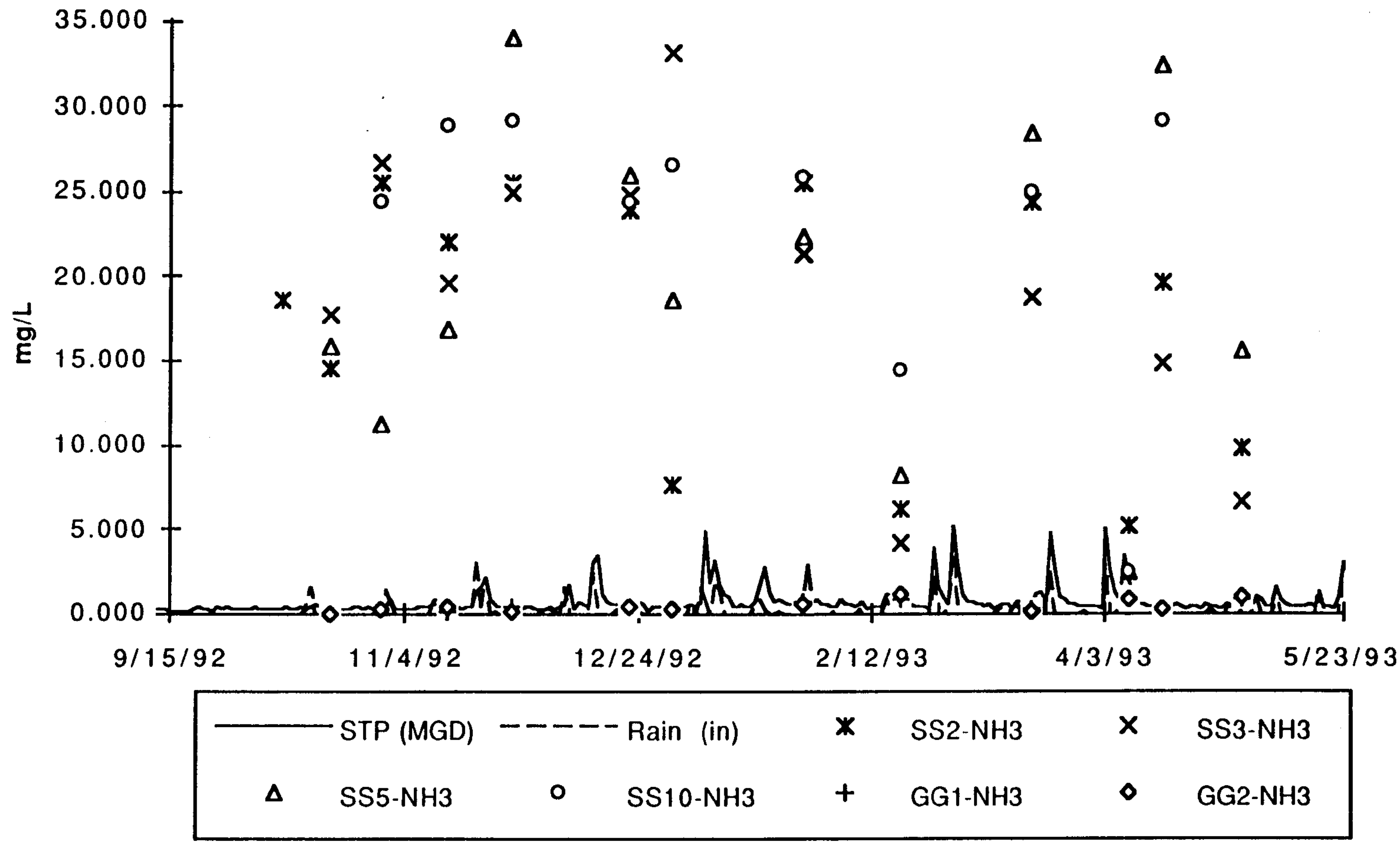

Figure 25. Time Series of Ammonia-Nitrogen for Newport

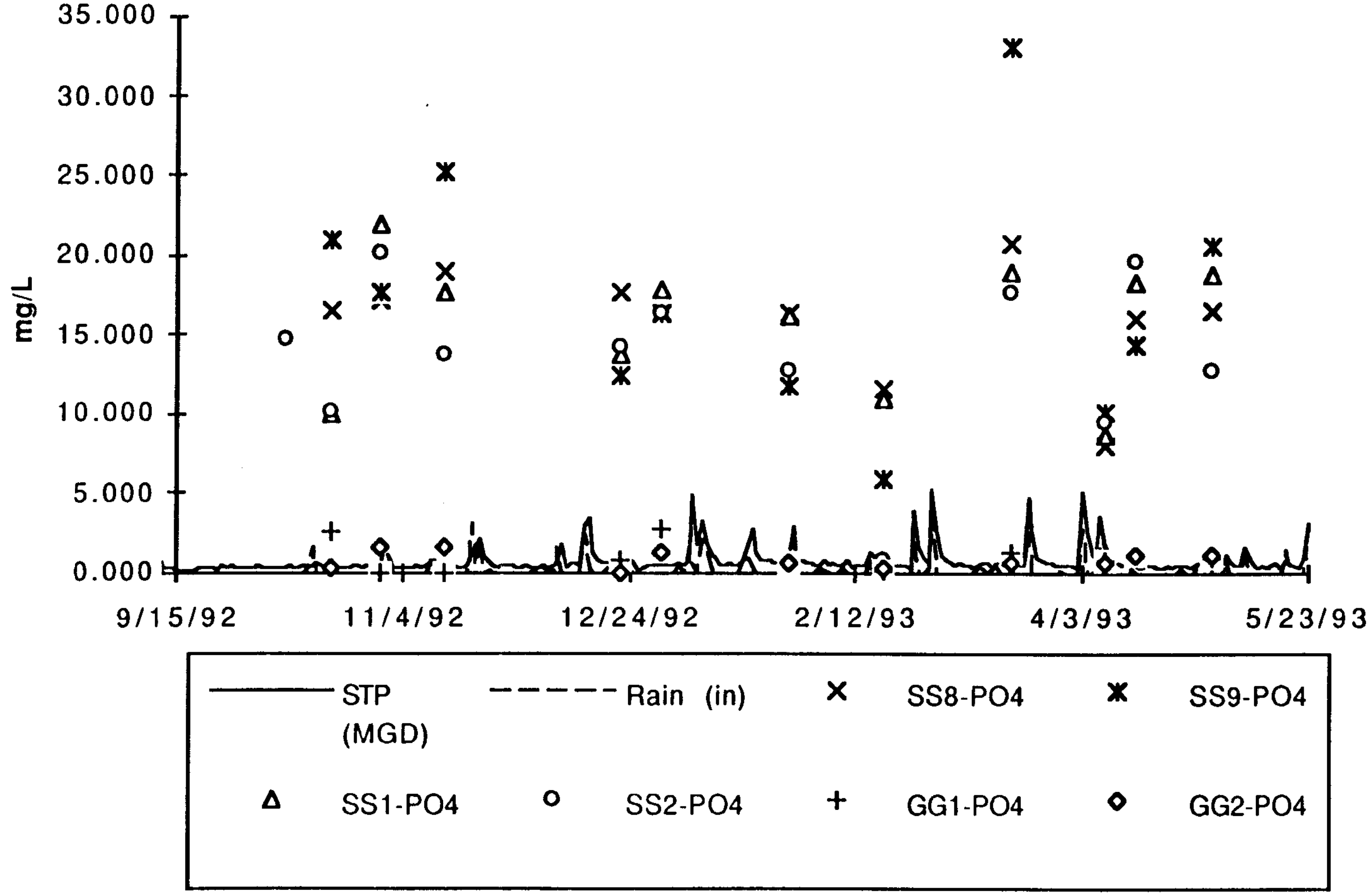

Figure 26. Time Series of Phosphorous for Newport

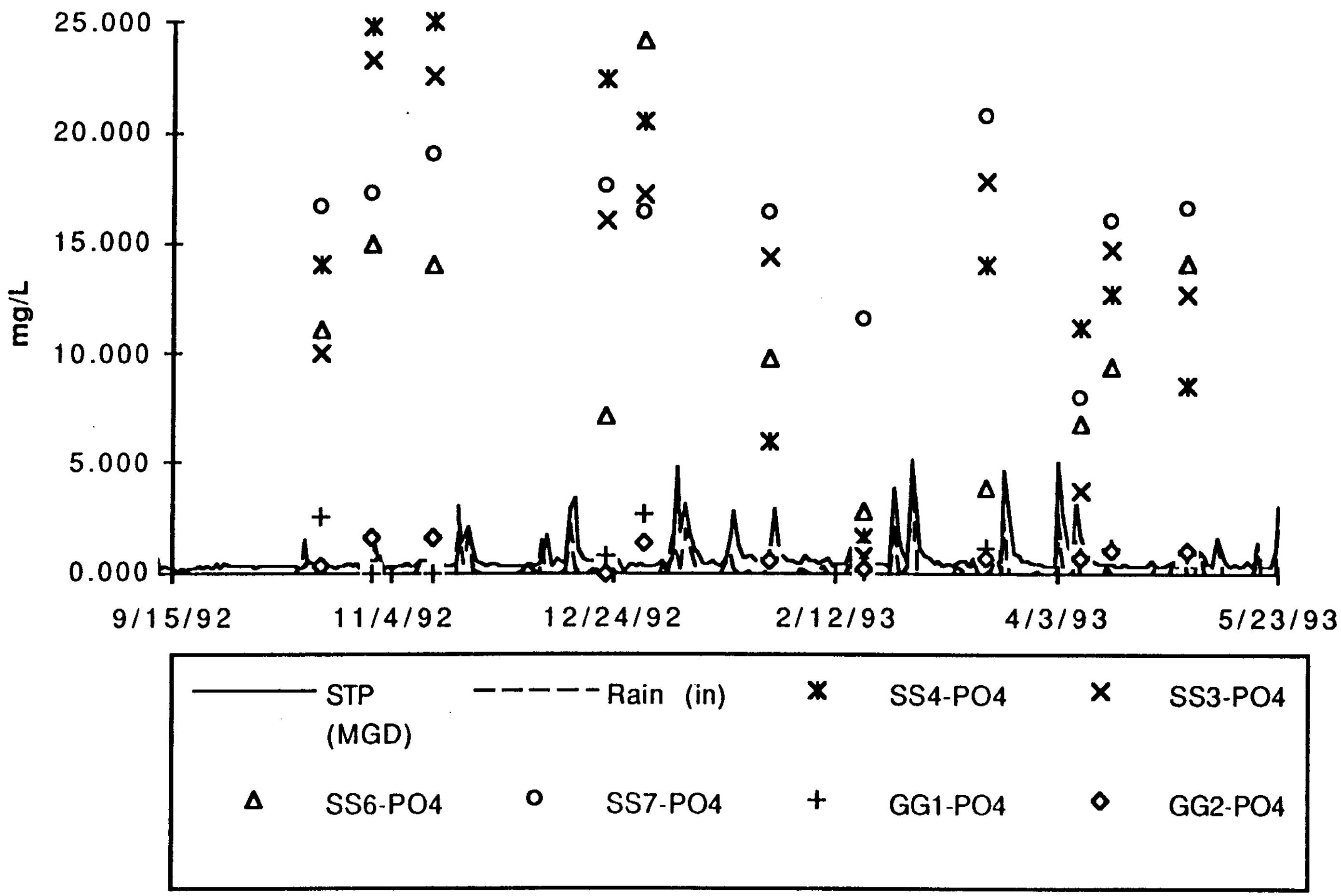

Figure 27. Time Series of Phosphorous for Newport

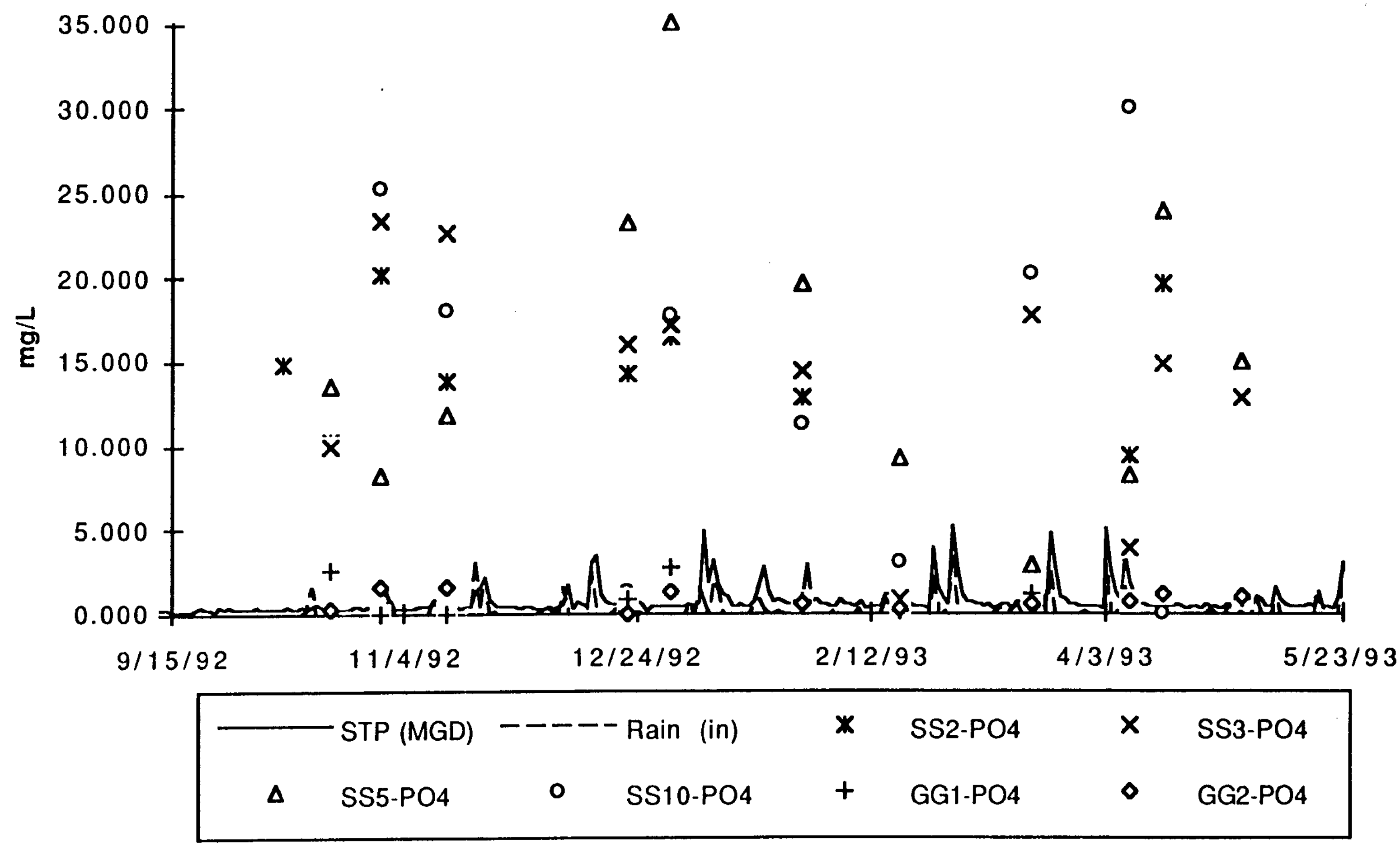

Figure 28. Time Series of Phosphorous for Newport

To generate a severity measure the following procedure was used. For each sampling event the individual sampling location data were compared to the STP data and the surface water data. Those sites whose data that had higher concentrations of sewage specific indicators than at the STP were considered to be sites with no evidence of inflow and infiltration. Those sites whose data had concentrations that fell between the STP 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 STP value than the surface water values; the second group had concentrations that were closer to the surface water value than the STP value. This second group was considered to be representative of sites with strong evidence of inflow and infiltration. The underlying assumption used is that the surface water sites produce data are representative of the inflow and infiltration water that enters the collection system.

The sites showing strong evidence of inflow and infiltration were ranked according to thier frequency of occurance 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 29 shows this chemical based ranked severity map.

Π-Risk Map

The results of the thematic analysis and the chemical montitoring analysis are somewhat in agreement although the chemical monitoring results indicate severe infiltration potential in an area that is considered to be lower severity in the thematic approach. To incorporate both these data types a concept called Π-Risk was developed.

This last mapping variable was defined as the product of thematic risk and infiltration potential based on quantitative chemical monitoring. The maximum possible value of the product variable is one wihle the minimum possible value is zero - so the product still has the properties of risk. The Π Risk will tend to weight risks and infiltration potentials that are less than 50% far less than values of these variables that are greater than 50%.

The Π-Risk represents the aggregate inflow and infiltration risk for Newport based on thematic analysis and sewer water quality monitoring. The map of Π-Risk is shown on Figure 30. This map represents our estimate of the overall inflow and infiltration severity for Newport that incorporates both thematic data and chamical monitoring data.

The results and conclusions in the next section are based on interpretation of the Π-Risk map.

Results

The Π Risk map indicates that the highest risk of inflow and infiltration is located in Sections 2, 7, 8, 3 and 6 with lower risk in Section 1 and negligible risk in Section 10. The higher risks are located in areas of lower development density although the highest risk is shown along Dunes drive, in the area of the intersections of Broadwater and Cloister Drive. The undeveloped areas of Section 7 has relatively high risk, higher than the adjacent Section 1 area.

The widely distributed risk of inflow and infiltration is disturbing because it does not suggest any simple solutions to the hydraulic loading problem being experienced at the STP. The low risk in Section 10, is reassuring because it indicates that that section is currently healthy in regards to inflow and infiltration.

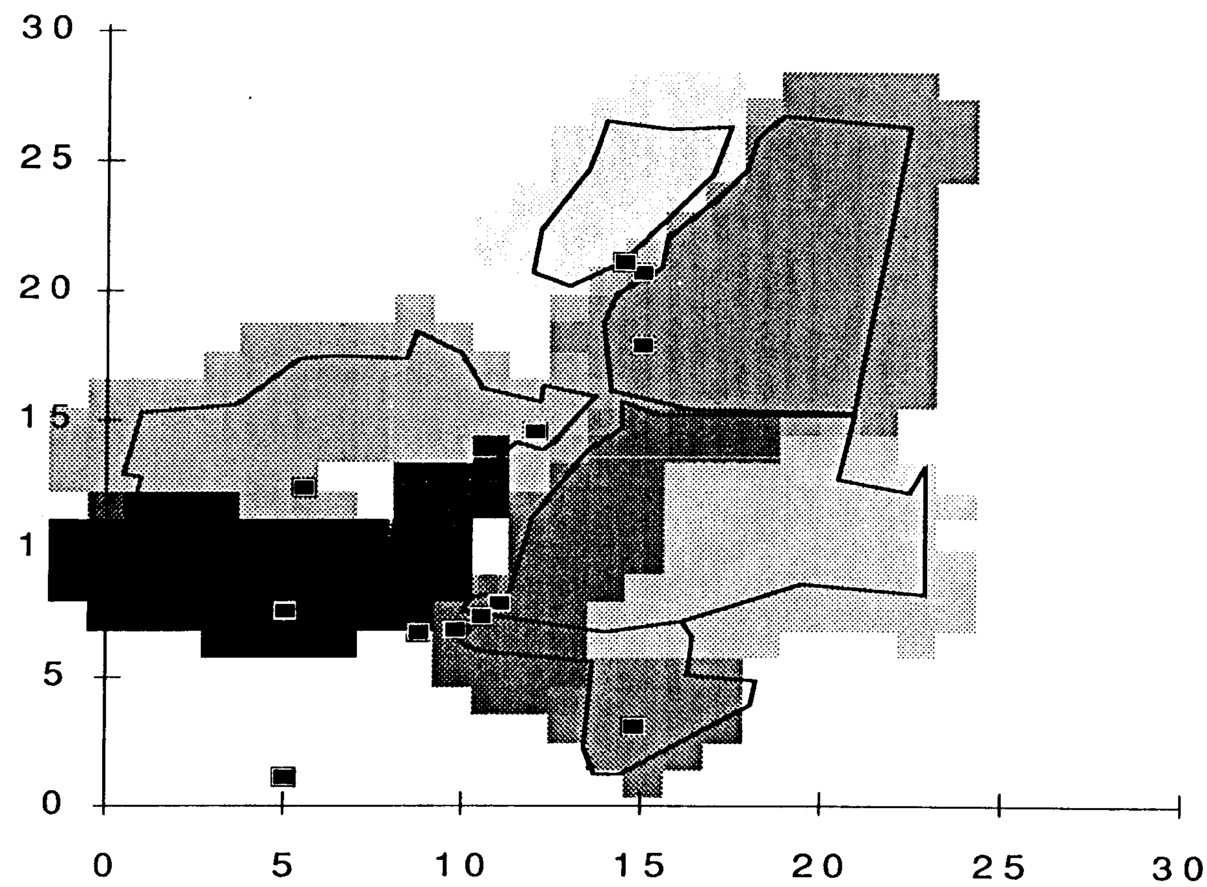

Figure 29. Inflow and Infiltration Contributing Areas based on Sewer Water Quality Monitoring

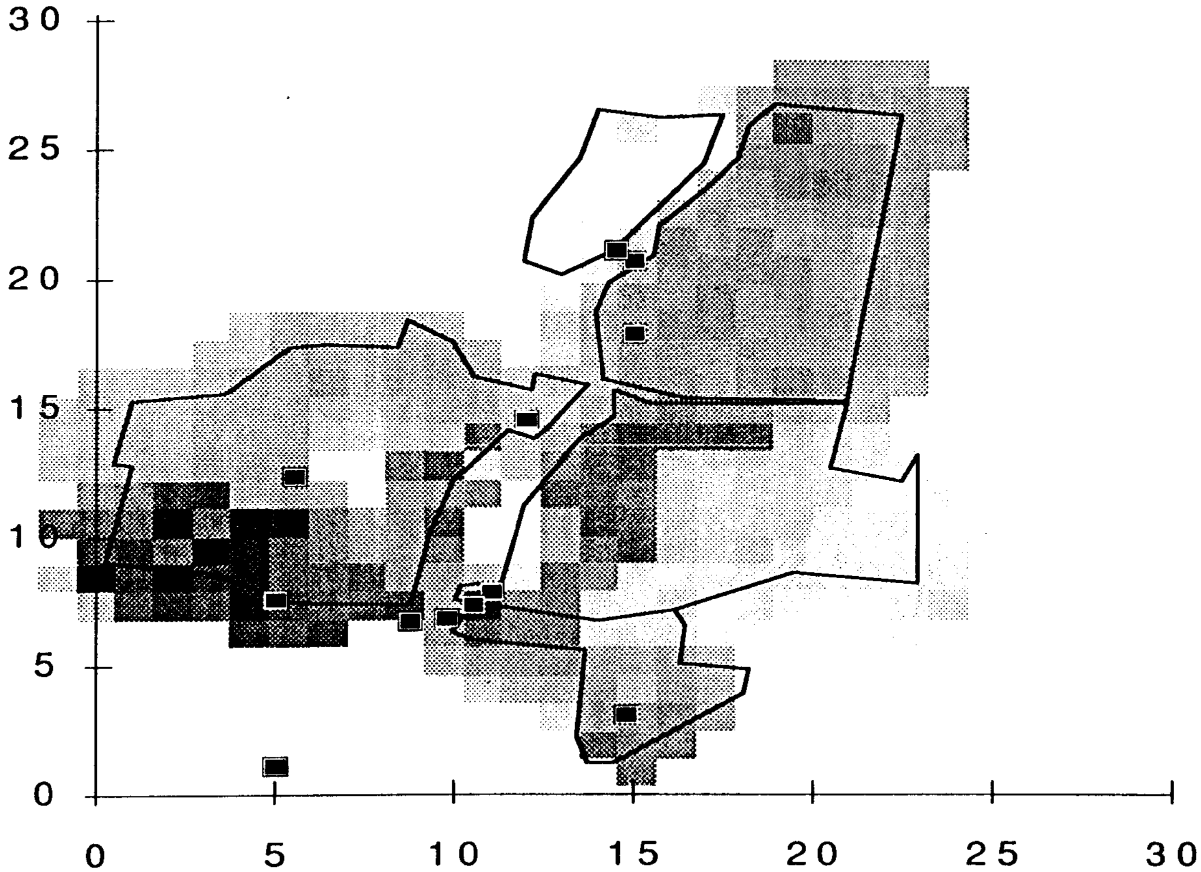

Figure 30. Π-Risk Map based an Thematic and Sewer Water Quality Indicators.

Alternatives to Reduce STP Hydraulic Overloads

This section will discusses some possible approaches that could help solve the hydraulic loading problem at the sewage treatment plant. These approaches are: STP expansion, flow equalization storage at the STP, collection system rehabilitation, reduction of collection system service area with managed reintroduction of service. Some combination of these approaches may provide the most cost effective solution.

One possible approach would be to expand the sewage treatment plant capacity to handle increased hydraulic loads. This solution would not address the inflow and infiltration problem, but could solve the permit compliance problem. Expansion would have the advantage of being able to handle increased sewage loads that are to be expected as new homes are built and added to the system in Newport.

Since the purpose of this study was to help identify inflow and infiltration severity for eventual rehabilitation we have assumed that this option is not acceptable to Newport, however we feel that the directors should consider this option as Newport develops for the following reasons:

Assuming the typical home contributes between 50 and 100 gallons per day of sewage (Metcalf and Eddy, pg 20, and considering that Newport is only 50% developed the STP currently has plenty of capacity at full development with zero infiltration.

3000 homes x 50 gpd/home = 0.15 MGD
3000 homes x 100 gpd/home = 0.30 MGD

Using TEBCO's value of 350 gpd/home the STP will barely have enough capacity at 1.05 MGD at full development assuming zero infiltration.

3000 homes x 350 gpd/home = 1.05 MGD.

However, if peak infiltration estimates are included in any of these calculations (Metcalf and Eddy, pg 31) then the plant is currently underdesigned to handle these peak flows at a permit discharge of 1 MGD, regardless of the return flow. Using the most optimistic estimate of peak infiltration, the STP should be able to handle 1.7 MGD at full development - nearly twice its present capacity.

As a less severe measure, temporary off-line (flow equalization) storage could also be used at the existing plant to handle the rainfall induced hydraulic loads at the plant and then this stored sewage could be bled back into the plant when hydraulic conditions permit. This approach is similar to the feed-forward system currently being installed at the STP, but adds a storage tank so that flows that would overwhelm the plant's system can be diverted into storage. Flow equalization has the added safety advantage in that if the stored sewage must be discharged, emergency disinfection can be accomplished before release to reduce the public health threat from an emergency sewage bypass. As an initial estimate 7 to 10 million gallons of flow equalization storage would have allowed the STP to handle the worst single day flow encountered in 1992, and would have taken about a week to empty after the rain. However, should two severe flow events occur within the same week, this flow equalization scheme would also become overloaded, requiring an emergency discharge. This option would be cost effective, but may not be reliable enough to meet the needs of Newport.

A third approach is to rebuild the entire sewer collection in Newport - an option that is financially infeasible. This option could probably reduce inflow and infiltration to a quite acceptable peak rate. It assumes that the homeowner portion of the system is simultaneously rehabilitated to eliminate these potential sources of I&I.

Targeted rehabilitation is a feasible option that Newport is currently undertaking. This study indicates that the efforts in system assesment and rehabilitation should be in Sections 2,3,4, and 6 initially, followed by Sections 5 and 1. Targeted rehabilitation cannot achieve the sucess of complete rehabilitation, but could achieve good results quickly. Inactive sewerage in Section 7 should probably be temporarily blocked off from the system as discussed in the next paragraph.

The high infiltration potential in undeveloped sections suggests that one simple approach for reducing hydraulic load to the STP could be to block off any existing inactive (no service connections) sewerage in these sections that feeds into the collection system while maintaining service to developed sections. In the Section 7 area this procedure should be relatively straight forward, perhaps sandbags placed in selected access shafts can accomplish the task - at least on a temporary basis.

This approach would also work well in parts of Sections 2 and 4. In Sections 3 and 6 such an approach may be infeasible because the development in these areas is more widely distributed. This temporary blocking off of existing sewer lines that serve undeveloped areas (lines with zero active connections) would reduce the rainfall induced contribution of these areas to the active collection system. Assuming rehabilitation occurs simultaneously, it could significantly reduce hydraulic loads to the STP. However, blocking off lines would also effectively introduce a building moratorium in these undeveloped areas, and some administrative (and financial) mechanism would be needed to assure that as a new area is developed, the sewerage in this area is tested to ensure that it has minimal inflow and infiltration potential.

Additionally we suggest two strategies that would help Newport far into the future: one relates to undeveloped areas, and the second to maintaining a repairs database.

The recomendation related to the undeveloped areas would be to attempt to develop these areas in blocks, rather than in disjointed parcels if possible. The advantage of block development is that during construction in these blocks, the sewer system can be inspected and rehabilitated as part of the construction, thereby reducing the potential for inflow and infiltration.

The recomendation related to maintaining a repairs database is that we feel that this single data management tool could be of great use to Newport in the future. The method we used here (associate each repair item with a grid coordinate) could be easily incorporated into the current mapping done by the district (or done in a computer spreadsheet like we did). Each item could be assigned a color to reflect its current status; red - fault in the system, yellow - repair in progress, green repair complete. This database would provide a history of repairs, and would help establish areas that are problem prone. The database would also provide ongoing evidence that an aggressive maintenance program is being conducted. The increased effort in maintianing such a database would be small. The real benefit of the database would be to built a "corporate memory" that would outlast different district engineering firms and operators.

Conclusions

Overall, the study indicates that inflow and infiltration potential is high in most Sections with the exception of Section 10 , and parts of Section 4. Targeted rehabilitation in the sections indicated by the Π-Risk map will probably reduce the inflow and infiltration that is contributing to the hydraulic overloading of the STP. Temporary removal from service of sewerage in the undeveloped area of Section 7, and other sections may also help reduce the hydraulic loading. The hydraulic analysis using planning estimates of typical inflow and infiltration suggests that the capacity of the sewage treatment plant is probably inadequate. Eventual capacity expansion of the STP is probably necessary for Newport to become fully developed (we assumed 3000 homes at full development). The hydraulic analysis using planning estimates of typical inflow and infiltration suggests that the capacity of the sewage treatment plant is probably inadequate.

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