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Environmental Protection Department

Post-Rehabilitation Flow Monitoring and Analysis of the Sanitary Sewer System at Lawrence Livermore National Laboratory

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March 1996

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Executive Summary

Background

Lawrence Livermore National Laboratory (LLNL) is operated by the University of California under contract with the U.S. Department of Energy (DOE). The Livermore site, approximately 50 miles southeast of San Francisco, occupies 819 acres. The sanitary sewer system at LLNL is designed to collect and transport wastewater from LLNL and Sandia National Laboratory (SNL) to the City of Livermore's collection system. The system was installed in stages, beginning in 1942, and now consists of mainlines, building laterals, manholes, waste-retention facilities, a monitoring station, and a diversion facility.

The study reported in this document was designed to evaluate changes made to the sanitary sewer system during a rehabilitation project that was prompted by a 1989 study of the system's adequacy.

Pre-Rehabilitation Flow Monitoring and Analysis

As the first step in the master planning effort, the existing sanitary sewer system was studied in 1988–1989 to determine its ability to accommodate present and future peak flows. A 5-week flow-monitoring program (from December 1, 1988, to January 6, 1989) determined the flow characteristics and flow components, including rainfall-dependent infiltration and inflow (RDI&I), at 10 locations. From the data obtained during this study (hereafter referred to as the "1989 study"), design flows—including a peak sanitary base flow and an RDI&I allowance—were estimated using computer simulation analyses for then-current (1988), 5-y (1993), and 20-y (2008) scenarios. The average base flow at each monitoring site was developed by analyzing flow data from dry days. RDI&I was then determined by subtracting the average base flow from the flow on a particular rainy day. An evaluation of historical data was used to estimate that 4.3% of the rain falling on the LLNL/SNL site enters the sanitary sewer system.

Finally, various ways to improve the system were identified and evaluated.

Sanitary Sewer Rehabilitation Project

The Sanitary Sewer Rehabilitation (SSR) project was designed to assess the condition of the system and to determine and take appropriate corrective actions. Goals included compliance with state, federal, and local requirements.

Smoke testing, observation via closed-circuit television (CCTV), and dye testing were employed during the assessment. Specific design solutions for rehabilitating the sanitary sewer piping system were identified; repairs (performed on the basis of a prioritized ranking scheme) followed. Direct outdoor connections to the sanitary sewer were identified and targeted for disconnection or modification.

During the life of the SSR project, over 130 point repairs were completed, 24,000 linear feet of sewer mains and laterals were inversion lined, 42 lateral lines were replaced, and 150 cleanouts and 10 new manholes were installed. Other benefits of the SSR project included development of an accurate site map, lowered maintenance costs, greater system accessibility and capacity, and minimized possibility of overflow.

Post-Rehabilitation Flow Monitoring and Analysis

The primary goal of the post-rehabilitation flow monitoring and analysis reported here was to evaluate the effectiveness of the SSR project. Effectiveness can be quantified by the reduction in RDI&I and by the ability of the system to handle maximum predicted flow. In addition, it is important to know if peak flows will be less than 1,170 gallons per minute (gpm), the maximum flow rate reserved for LLNL/SNL by the City of Livermore.

To the extent possible (given changes in the sanitary sewer system), we repeated the monitoring conducted in the 1989 study and used comparable computer simulation software. Monitoring began on January 13 and ended February 15, 1995. We selected dry days and calculated the average base flows for each basin and for the LLNL/SNL system as a whole. RDI&I was estimated by subtracting the average base flow from the flow for a particular rainy day.

We estimated that approximately 0.5% of the rain falling on the LLNL/SNL sites enters the sanitary sewer system. This represents an 88% reduction in RDI&I as quantified in the 1989 study. With this RDI&I, flow rates attributable to rainfall (from a 10-y storm event) were estimated at 0.46 million gallons per day. Computer simulations of flow rates (using this average RDI&I rate) indicate that, even in the future scenario (year 2008), the system will be sufficient for predicted peak flows (1,076 gpm in 2008) and that peak flow rates will be less than the maximum rate reserved for LLNL/SNL by the City of Livermore (1,170 gpm). Some pipes, however, will be at approximately 75% of their theoretical capacity.

As with any environmental study, there is inherent variability in the data. Our work to date has quantified the average RDI&I rate, but its variability remains unclear. Therefore we recommend an ongoing monitoring program.

Introduction

Lawrence Livermore National Laboratory (LLNL) is operated by the University of California under contract with the U.S. Department of Energy (DOE). The Livermore site, approximately 50 miles southeast of San Francisco, occupies 819 acres.

So far, there have been three phases in an assessment and rehabilitation of the LLNL sanitary sewer system:

- A 1989 study that used data collected from December 1, 1988, to January 6, 1989, to determine the adequacy of the LLNL sewer system to accommodate present and future peak flows.
- A Sanitary Sewer Rehabilitation (SSR) project, from October of 1991 to March of 1996, in which the system was assessed and rehabilitated.
- The post-rehabilitation assessment study that is reported in this document.

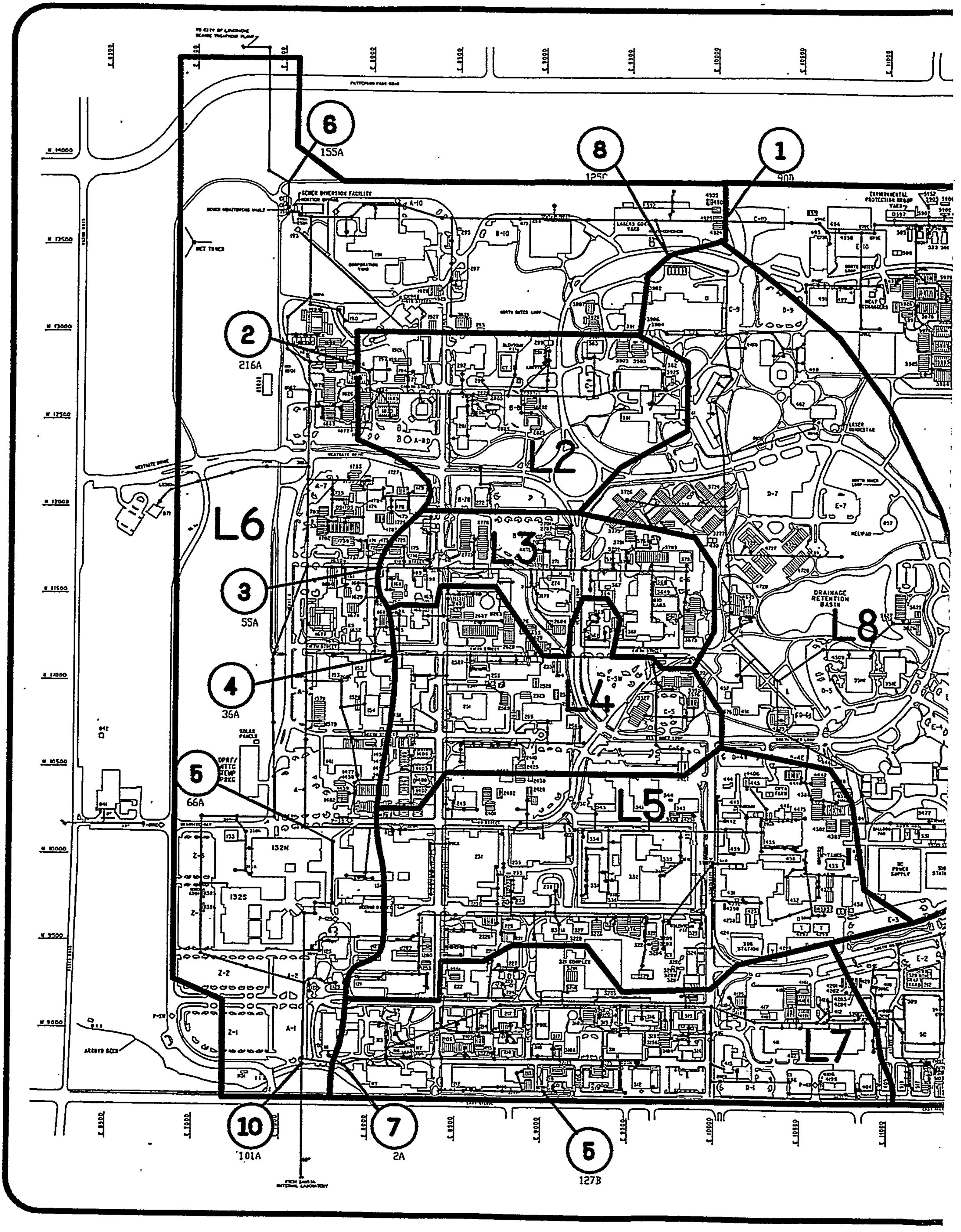
On the following pages, we first describe the sanitary sewer system and summarize the goals and results of the 1989 study and the SSR project. We follow with the goals of the post-rehabilitation assessment study and a description of our analytical procedures and simulation model. We close with results, conclusions, and recommendations for further work or study. Field operations are summarized in Appendix A. References are provided in Appendix B.

The LLNL Sanitary Sewer System

The sanitary system at LLNL is designed to collect and transport wastewater from LLNL and Sandia National Laboratory (SNL) to the City of Livermore's collection system. Wastewater flow from LLNL and SNL is transported through a system of gravity sewers to the northwestern corner of the LLNL site. From that point, wastewater enters the City of Livermore's collection system and is ultimately treated in the Livermore Water Reclamation Plant (LWRP).

The LLNL sanitary sewer system collects and transports all building wastewater except known hazardous wastewater, which is disposed of separately. Scheduled and unscheduled releases from some buildings enter the sewer system on a regular basis. The largest releases come from cooling-tower blowdown; this occurs once or twice a week and can contribute up to 300 gallons per minute (gpm).

The system (see Fig. 1), which was installed in stages beginning in 1942, consists of mainlines, building laterals, manholes, waste-retention facilities, a monitoring station, and a diversion facility. Over all, it contains 56,000 linear feet of primarily vitrified-clay pipe that ranges from 4 to 15 in. in diameter. Building laterals (the pipe from the main line to the first building cleanout) are either 4 or 6 in. in diameter. The system includes 36,220 linear feet of building laterals, 271 manholes, and about 500 cleanouts (primarily in the building laterals).



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DRAINAGE RETENTION BASIN
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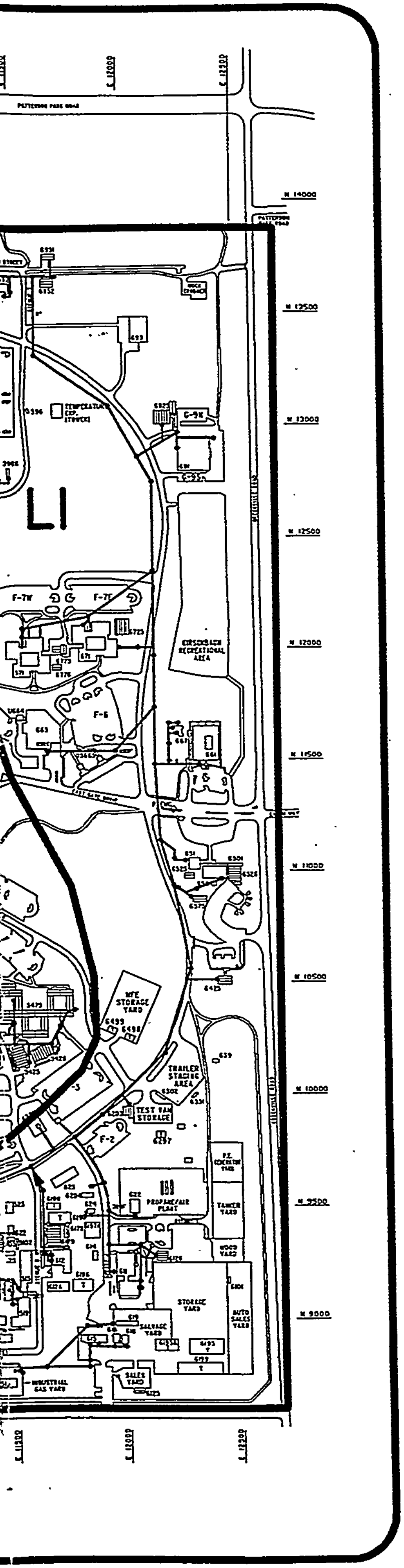
132S
SEWER DIVERSION FACILITY



LEGEND

Sanitary Sewer & Manhole

3 Flow Monitor

Basin Boundary

LI Basin Number

SCALE: 1" = 200'

0 100 200 300 400

Figure 1.

Study area and monitoring plan.

Earlier Studies and Rehabilitation Efforts

1989 Study of the Sanitary Sewer System

The LLNL sanitary sewer system was studied in 1988-1989[1] to determine its adequacy to accommodate present and future peak flows. It was then estimated that by the year 2008 the working population at LLNL would increase to 12,400 and the building area to 6.9 million ft^2. A 5-week flow monitoring program was implemented at that time to determine present and projected flow characteristics.

- LLNL was divided into eight drainage basins using 10 flow monitors. Flow components, including rainfall-dependent infiltration and inflow (RDI&I), were quantified at each location. From the data obtained during this study, design flows, including peak sanitary base flow and an RDI&I allowance, were estimated using computer simulation analyses for then-current (1989), 5-y (1993), and 20-y (2008) scenarios.
- The average base flow at each monitoring site was determined by analyzing monitored flow data from dry days. RDI&I for a given rainy day was then calculated by subtracting the average base flow from the total flow.
- As part of the 1989 study, CH2MHILL contract personnel evaluated historical data and estimated that 4.3% of the rain that falls on the LLNL/SNL sites enters the sanitary sewer system. They said that this percentage would be equivalent to a peak rainfall-induced flow rate of 4.38 million gallons per day (mgd), compared to a peak base-flow rate that they estimated at 0.76 mgd.
- The CH2MHILL study concluded that

  (a) The sanitary system was sufficient to transport peak dry-weather flow, but—

  (b) The system had insufficient capacity to transport projected flows under peak wet-weather conditions (i.e., the amount of RDI&I that would enter the sewer system during a 10-y storm event). This lack of capacity was true for the then-current state of site development and would also be true after any future growth.

  (c) A 55 to 70% reduction in RDI&I could be achieved through improvements in the sewer system.
- Finally, CH2MHILL identified and evaluated various ways to improve the system.

Sanitary Sewer Rehabilitation Project

During the SSR project, LLNL personnel followed up on the solutions recommended by CH2MHILL by assessing the condition of the system and proposing specific design solutions for rehabilitating the piping system. The result aimed at compliance with the California Water Quality Control Act (1969), which prohibits the discharge to the environment of any waste that may potentially adversely impact the quality of waters in California, i.e., no exfiltration is allowed. There are also required federal and local compliances. The SSR project therefore targeted areas with the highest exfiltration potential.

Investigators first performed an in-depth analysis of data from smoke testing, flow monitoring, and dye tests; from observations obtained via closed-circuit television (CCTV); and from water-balance investigations. Repairs were then made on the basis of a prioritized ranking scheme. Direct outdoor connections to the sanitary sewer were identified and targeted for disconnection. Over 130 point repairs were completed, 24,000 linear feet of sewer mains and laterals were inversion lined*, 42 lateral lines were replaced, and 150 cleanouts and 10 new manholes were installed for site-wide access. Only one building (B251) was left with a direct rain-water inflow to sanitary sewer from three roof drains. After extensive review and safety consideration it was agreed to allow this connection.

The "no exfiltration" goal was not achieved, partly because of a DOE-directed, $8.5 million funding cut to the SSR project and partly because "no exfiltration" is not practical for most current systems.

* When a pipe is inversion lined, a sock of lining material is first installed inside out at the mouth of the opening. Then, using head pressure from a tower erected over a manhole, the lining material is inverted as it is drawn through the pipe.

Post-Rehabilitation Study

Goal

The primary goal of the current post-rehabilitation study was to evaluate the effectiveness of the SSR project. The study included the following:

- Duplicating (to the extent possible given changes in the sanitary sewer system) the monitoring conducted in the previous study by CH2MHILL.
- Quantifying the effectiveness of the rehabilitation effort by measuring the reduction in RDI&I since measurements were taken by CH2MHILL in 1989 and by evaluating the ability of the present system to handle maximum predicted capacity.
- Knowing if peak flows will be less than 1,170 gpm. This is important because the City of Livermore has, in its planning, reserved capacity to treat a maximum flow rate of 1,170 gpm from LLNL/SNL.
- Evaluating compliance with the Porter-Cologne Act, specifically regarding "no exfiltration."

Flow-Data Analysis

The peak flow rate during the monitored period (January 13 through February 15, 1995) was 860 gpm. The average peak flow during the same period was 593 gpm. Flow typically peaks at 600 gpm; daily low flows drop to 30 gpm.

Raw data from ISCO flow-monitoring devices were converted from MS-DOS files to MS-EXCEL format for analysis and plotting. To identify anomalies, plots of flow data for each location, for the entire monitoring period, were closely examined and compared to information from the field logbook (e.g., when clogged tubes in the flow meters were observed and cleared). Refer to Appendix A for additional details.

Using data from the monitoring program, we quantified flow components, including sanitary flow and RDI&I, at each location. Design flows were then calculated for existing and future (year 2008) conditions and were used to assess the adequacy of the collection system for each scenario.

Average Base Flow

Choice of Dry-Weather Days

The average base flow (ABF) at each flow-monitoring site was developed by analyzing monitored flow data from dry days. These dry days were chosen on the basis of data obtained from the LLNL meteorological tower, which continuously monitors air temperature, wind speed, and rainfall.

For the purpose of the ABF calculation, a dry day was defined as a midnight-to-midnight period of no rain, preceded by 24 h of no rain (to minimize the amount of long-term infiltration included in the ABF calculation). The meteorological tower can measure rainfall amounts as small as 0.001 in. For the purposes of this study, such minute amounts of rainfall were considered insignificant; therefore, "no rain" was defined as rainfall amounts less than 0.02 in./h and less than 0.05 in./day. The dry days during the study period that were chosen for determining the ABF were January 18–20, January 29, and February 2–6.

Discharges

To more accurately quantify the amount of RDI&I, known large (greater than 10,000 gal) industrial discharges (i.e., those resulting from cooling-tower blowdown, retention-tank releases, and treatment-facility releases) were subtracted from flows. Correcting for the reported industrial discharges required identifying the affected zones, computing an approximate discharge duration, and then converting the reported volume to a discharge rate. The discharge volumes were then subtracted from the basin hydrographs to produce corrected flow hydrographs. This procedure minimizes the amount of "noise" in the data and allows the detection of a smaller "signal" (the RDI&I). Discharges are summarized in Appendix A.

Other Considerations

In addition, it was necessary to remove from a calculation data from those days for which there was a known problem with the monitor (such as a clogged tube) or other unexplained flow irregularities. For example, data from Monitor 6 were highly irregular. The reason is not entirely clear, but may relate to the application of Manning's equation to the data. The monitors actually measure depth, not flow; Manning's equation is then used to convert depth to flow. However, Manning's equation requires certain conditions in order to be accurate, including a length of uninterrupted upgradient pipe of constant slope, and no change of slope downgradient and upgradient of the monitored location. It may be that these conditions were not met for the location of Monitor 6. Regardless of the cause, it was decided that the data were too erratic to be used. Therefore, data from a permanent flow-monitoring station in Building 196 were used in place of Monitor 6 data. Building 196 was considered an equivalent location because both Monitor 6 and the monitor in Building 196 measure the combined sanitary sewer flow just before the flow leaves the LLNL site.

Calculation

After these screenings and adjustments, data for the remaining days were averaged to create the ABF for each basin and for the LLNL/SNL site as a whole. Weekdays and weekends were treated separately to produce separate hydrographs for weekday ABF and weekend ABF. Because of differences between the data-collection schemes at the Building 196 flow-monitoring station and at the basin monitors, data from the basin monitors were stored and averaged on a 15-minute basis, and site-wide data were stored and averaged on a 5-minute basis.

Scaling

Basins 1–5, 7, 8, and 10 all flow into Basin 6. Basin 10 is SNL, there is no Basin 9, because the sewer line corresponding to location 9 of the 1989 study has since been abandoned. Thus, the contribution from flow within Basin 6 can be obtained by summing the flows in the upgradient basins and subtracting this sum from the Building 196 flow. However, when the ABF calculation was complete, the upgradient flow sum was greater than the Building 196 flow.

We believe that some of this discrepancy can be attributed to the lack of accuracy because the basin monitors measured only depth. A velocity factor was obtained by putting dye in the manholes upstream of the monitoring locations and measuring the time of travel to the downstream manhole. Based in part on the measured velocity, scale factors were applied to the flow results in order to achieve a mass balance. The scaled data were used to recalculate the ABF and in all subsequent plots and calculations.

Rainfall-Dependent Infiltration and Inflow

Rainfall-dependent infiltration and inflow (i.e., RDI&I) is the volume of the storm-induced ground-water and storm-water runoff that gets into the sanitary sewer collection system during and following rain events. It is determined by subtracting the ABF from the wet-weather hydrograph.

Choice of Wet-Weather Days

As in the ABF calculation, we accounted for large discharges and anomalies in this wet-weather flow data. Initially, we used data from a storm on January 23–24. This was one of the largest (0.53 in. of rain) and most intense weekday storms during the monitoring period. For some basins, data problems on these dates could not be resolved; therefore, for the affected basins we used data from January 27. On this date, there was 0.55 in. of rain, but it was spread out over a longer time period.

Because a larger (0.8 in.) storm occurred on a weekend (January 14–15), RDI&I analysis was also conducted for the weekend flows. Finally, an even larger storm (1.7 in.) occurred January 9–10. Although flow data by basin were not collected at that time, we wanted to investigate the effects of larger storms on RDI&I and therefore used the data from the Building 196 monitor to calculate site-wide RDI&I.

For each date, a time period from the first measurable (0.01 in.) rainfall to 12 h after the last measurable rainfall was used in the RDI&I calculation. We used a 12-h period, which was consistent with the 1989 study, in order to be certain that all long-term RDI&I was included.

Figure 2 presents the RDI&I data for January 23, 1995, for the entire LLNL/SNL site. This plot represents the period from 6:00 p.m. January 23 to 6:00 p.m. January 24. To properly couple the wet day with the ABF, the portion of the storm that occurred on January 23 was plotted to the right of the portion that occurred on

January 24. Any wet-weather flow greater than the ABF was assumed to be RDI&I. The area under the RDI&I curve, then, gives the total volume of RDI&I for the storm event.

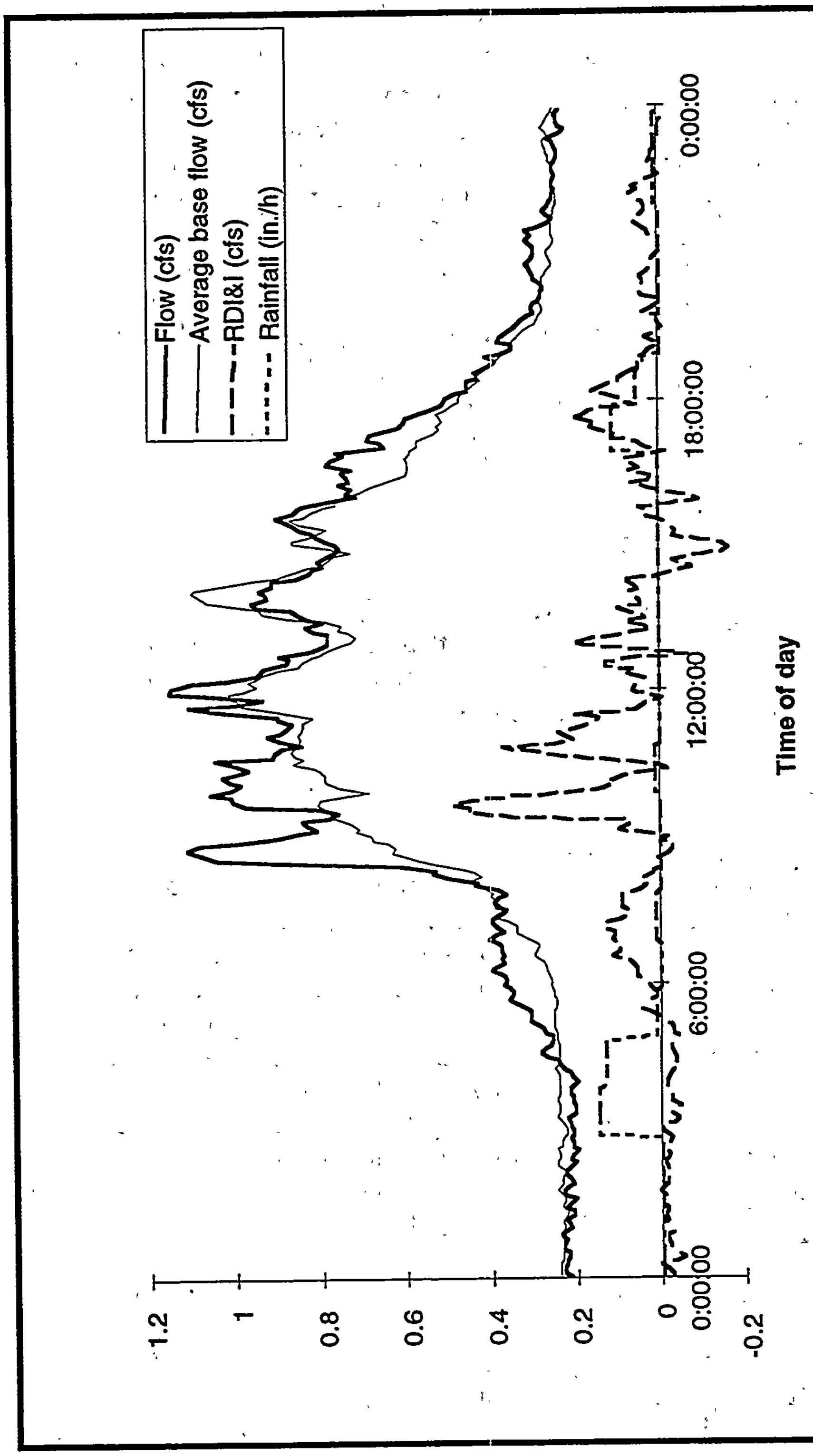


Figure 2. LLNL/SNL site-wide data for January 23, 1995: rainfall, measured flow, average base flow (ABF), and rainfall-dependent infiltration and inflow (RDI&I).

R-*value*

The absolute volume of RDI&I will, of course, also depend on the size of the storm. All else being equal, it is generally assumed that, for example, a doubling in the rainfall volume will result in a doubling of the RDI&I volume. Therefore, RDI&I volumes are often scaled by dividing by the rainfall volume:

$$R = \frac{\text{RDI\&I volume}}{\text{Rainfall volume}} .$$

This unitless R-value then provides a measure of RDI&I that can be used to compare different storm events and different basins.

R-values were developed for each of the eight basins and for the LLNL/SNL sites as a whole. R-values are presented in Table 1. For each storm event, the amount of rainfall is given, followed by the LLNL/SNL site-wide R-value, then the basin R-values. The R-value for LLNL/SNL ranged from 0.22 to 0.91, with the average being about 0.5.

Table 1. Calculated R-values[a] for selected storm events.

Date:	1/9/95–1/10/95	1/14/95–1/15/95 (weekend)	1/23/95—1/24/95 or 1/27/95
Rainfall:	1.7 in.	0.8 in.	0.5 in.
R-values:			
Site-wide:	0.22[b]	0.91[b]	0.36[b]
By basin:			
L1	na[c]	0.57	0.84
L2	na	1.43	0.14
L3	na	0.43	1.00
L4	na	0.52	0.89
L5	na	1.57	0.12
L6	na	1.56	0.34
L7	na	0.93	0.04
L8	na	0.10	0.79
SNL10	na	0.85	0.02

[a] Where R = a unitless value that provides a measure of rainfall-dependent infiltration and inflow (RDI&I).

[b] Value based on Building 196 data.

[c] na = data not available.

Sources of Uncertainty

The amount of RDI&I depends on the physical condition of the sanitary sewer system and on the number and type of storm-water sources. The volume of RDI&I that enters a system is also highly dependent upon antecedent soil conditions. If the soil is already saturated, the volume of RDI&I is maximal. Conversely, if the soil is dry, most of the rainfall is absorbed by the soil, and the amount of RDI&I is minimal. During the 1989 study, soil conditions were relatively dry. Therefore, CH2MHILL used historical data to scale the results obtained during that study to comparably saturated values. During the current study, soil conditions were relatively saturated, and it can, therefore, be assumed that our RDI&I value is at or near the maximum.

A number of potential sources of uncertainty could affect both the calculation of the base flow and RDI&I:

- Undocumented releases on a dry day would increase the calculated base flow, thereby decreasing the calculated RDI&I; conversely, undocumented releases during a rain event would increase the wet-weather flow, potentially be counted as part of the RDI&I, and could result in an overestimate of the RDI&I.
- Clogged tubes and other operational problems with the flow monitors, shifts in recorded flows due to the "drift" in the bubble rate or to recalibration, and, in general, the accuracy of the ISCO flow monitors all contribute to the uncertainty. Similarly, the Building 196 data are accurate only to about ±30 gpm.
- Variability in daily base flow (due to day of week, number of people on site, different operations, etc.) and soil conditions (as mentioned above) add to the uncertainty as well. For example, because the soil was saturated even on dry days, base-flow data may have included long-term infiltration, resulting in an over-estimation of base flow and a corresponding under-estimation of RDI&I.
- Finally, the R-value calculation assumes that the "non-rain" flow (i.e., the sanitary sewer flow resulting from LLNL/SNL operations) during the storm event is equal to the ABF calculation based on the dry days. Thus, variation in non-rain flow contributes to variability in the calculated RDI&I.

The Simulation Model

Comparison to 1989 Study

The simulation model used in the 1989 study was proprietary to CH2MHILL. Because this contractor was not involved in the current study, the same model could not be used. Instead, we used the Personal Computer Storm Water Management Model (PCSWMM) to develop a dynamic, hydraulic-routing model of the entire LLNL sanitary sewer system. PCSWMM is based on the Storm Water

Management Model (SWMM), which was developed and promulgated by the Environmental Protection Agency (EPA) and which is widely used in the industry.

To ensure that changes in results (between the 1989 and 1995 studies) could not be attributed to differences in the models, the PCSWMM model was first set up using 1989 conditions. To model the LLNL system, approximately 450 manholes and pipe segments, along with their relative positions, were entered into PCSWMM data files. For each pipe segment, we also entered length, radius, and slope. These data were based primarily on printouts from CH2MHILL's model runs and, in part, on maps from the time. For the 1989 condition, CH2MHILL had assumed that the Manning's roughness coefficient for all pipes was 0.013. Therefore, we used the same value in this comparison.

The 1989 peak-flow condition was then simulated using the new model; results were virtually identical to CH2MHILL's results. Thus, we confirmed that the two models produce comparable results.

Hydraulic Model Update

Next, it was necessary to update the model to 1995 conditions. Most changes resulted from lining the pipes, i.e., the pipes now had reduced inside radii and different Manning's roughness coefficients. Two types of lining had been used, and each had a different thickness. To update the PCSWMM files, we used a current site map that showed the locations of the two types of lining.

In addition, the PCSWMM files were changed to reflect the numerous places where pipes had been eliminated or added or manholes added.

Design Flow Determinations

The method used to quantify design waste-water flows at LLNL and SNL was the same as was used in the 1989 study. That is, design flows included peak sanitary base flow and an RDI&I allowance, but did not allow for unscheduled releases. Waste-water flow was determined for both existing conditions and future conditions (year 2008). Future development information for SNL and LLNL was obtained from the *Sandia National Laboratories' 1994 Site Development Plan*[3], and from the Lawrence *Livermore National Laboratory Site Development Plan (Calendar Year 1995)*[4], respectively.

Refer to Tables 3 and 4 for the design flows derived as explained in the following paragraphs.

Design Base Flow

Although growth was predicted at the time the model was run, this growth was based on unfunded projects; therefore, growth may in fact be relatively flat. We updated the data used to determine the wastewater flow for each building in the 1989 study to reflect existing conditions. The *Associate Director Responsibility*

Table 2. Design flows for current (1995) scenario.

Basin	ABF[a] (mgd)	PDWF[b] (mgd)	Peak RDI&I[c] (mgd)	PWWF[d] (mgd)
L1	0.03071	0.07328	0.14929	0.22257
L2	0.03114	0.07415	0.00776	0.08191
L3	0.01248	0.03399	0.05623	0.09022
L4	0.02167	0.05443	0.06850	0.12293
L5	0.07475	0.15650	0.01680	0.17330
L6	0.01915	0.04898	0.05997	0.10895
L7	0.03324	0.07840	0.00394	0.08234
L8	0.03033	0.07250	0.09500	0.16750
SNL	0.05113	0.11319	0.00084	0.11403
Total:	0.30459	0.70542	0.45833	1.16375

[a] ABF = average base flow.
[b] PDWF = peak dry-weather flow.
[c] RDI&I = rainfall-dependent infiltration and inflow.
[d] PWWF = peak wet-weather flow.

Table 3. Design flows for future (year 2008) scenario.

Basin	ABF[a] (mgd)	PDWF[b] (mgd)	Peak RDI&I[c] (mgd)	PWWF[d] (mgd)
L1	0.05889	0.12769	0.14929	0.27698
L2	0.05479	0.12007	0.00776	0.12783
L3	0.01962	0.05001	0.05623	0.10624
L4	0.03397	0.07987	0.06850	0.14837
L5	0.08636	0.17701	0.01680	0.19381
L6	0.10328	0.20620	0.05997	0.26617
L7	0.04259	0.09686	0.00394	0.10080
L8	0.05455	0.11962	0.09500	0.21462
SNL	0.05196	0.11477	0.00084	0.11561
Total:	0.50602	1.09210	0.45833	1.55043

[a] ABF = average base flow.
[b] PDWF = peak dry-weather flow.
[c] RDI&I = rainfall-dependent infiltration and inflow.
[d] PWWF = peak wet-weather flow.

Report First Quarter Fiscal Year (FY) 1995[5] and *Retired Buildings/Trailers (December 12, 1994)*[5] provided update information for LLNL. Existing developed condition information for SNL was obtained from the *Sandia National Laboratories' 1994 Site Development Plan*[3].

There are 173 permanent buildings and 331 temporary structures at LLNL, for a total of about 5.7 million ft^2. The flows were distributed to individual manholes on the basis of the buildings connected to or contributing to the particular manhole, as follows:

- Sanitary flow was estimated for each building at LLNL on the basis of the net area of the building and the number of personnel in it.
- Unit flow rates in gallons per square foot per day (gpsfd) or gallons per capita per day (gpcd) were applied to each building depending on its use.
- Each building was assigned a use code and associated unit flow rate as defined in Table 4.

Table 4. Building uses and associated flow rates.

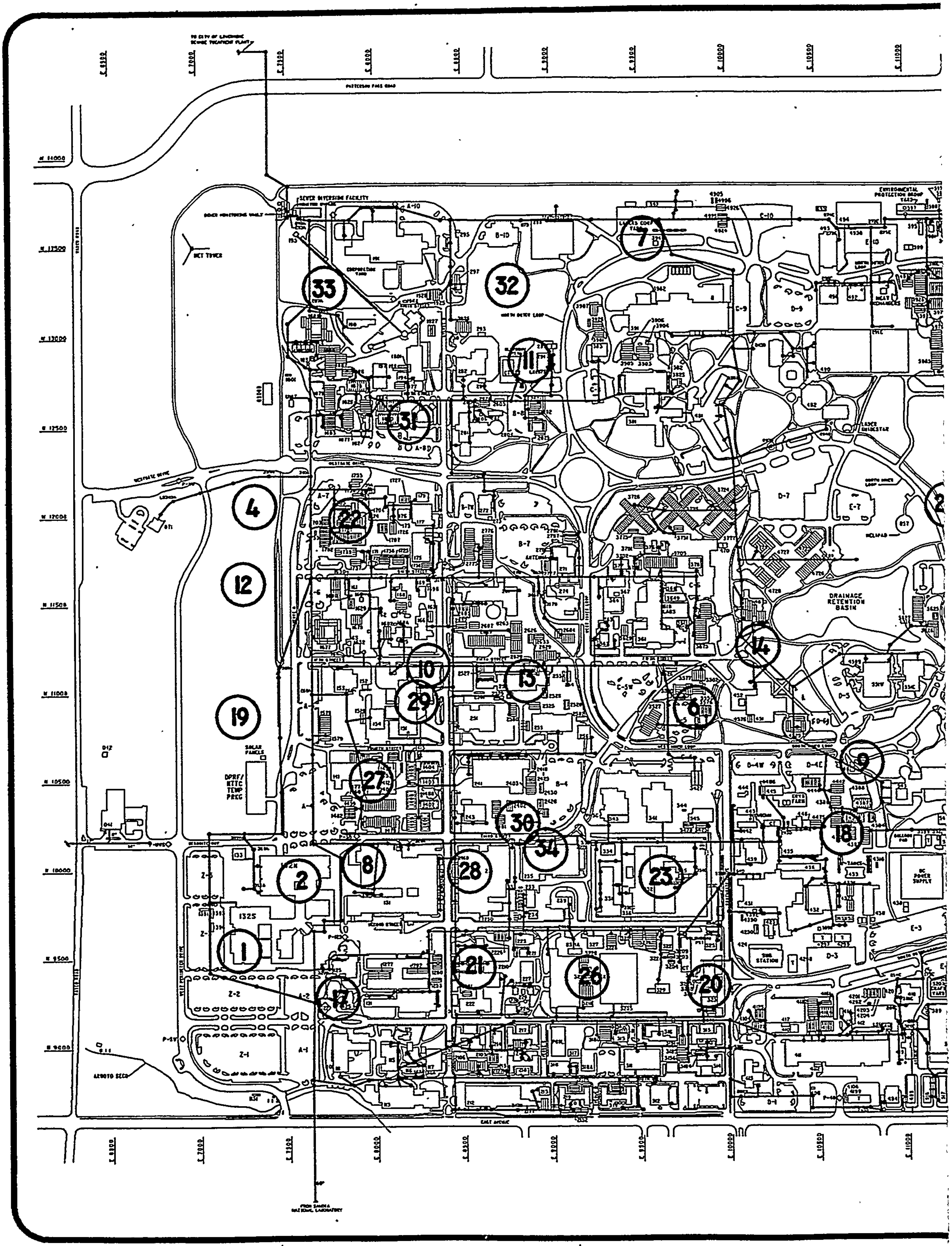
Building use	Use code	Associated flow rate
No sanitary flow	N	None
Office	O	• 0.0607 gpsfd[a] plus 14.9 gpcd[b] if both population and area are known for a building. • 0.121 gpsfd if only area is known.
Laboratory	L	0.161 gpsfd
Heavy sanitary contributor	H	0.243 gpsfd

[a] gpsfd = gallons per square foot per day.
b gpcd = gallons per capita per day.

Future Sanitary Flows

We used data from the most recent *LLNL Site Development Plan* [4] for projecting peak dry-weather and wet-weather flows for the year 2008. Each building was assigned a use code and an assumed discharge manhole. The unit flow rates presented in the existing condition were applied to the future buildings to determine the average flow. Future RDI&I for each basin was assumed to remain constant at existing levels.

The funded and proposed buildings used in these projections are shown in Figure 3. Based on the Site Planning 1995 draft of the Line-Item Construction Plan Project Summary (included in Ref. 4), these buildings will total approximately 1.5 million ft^2.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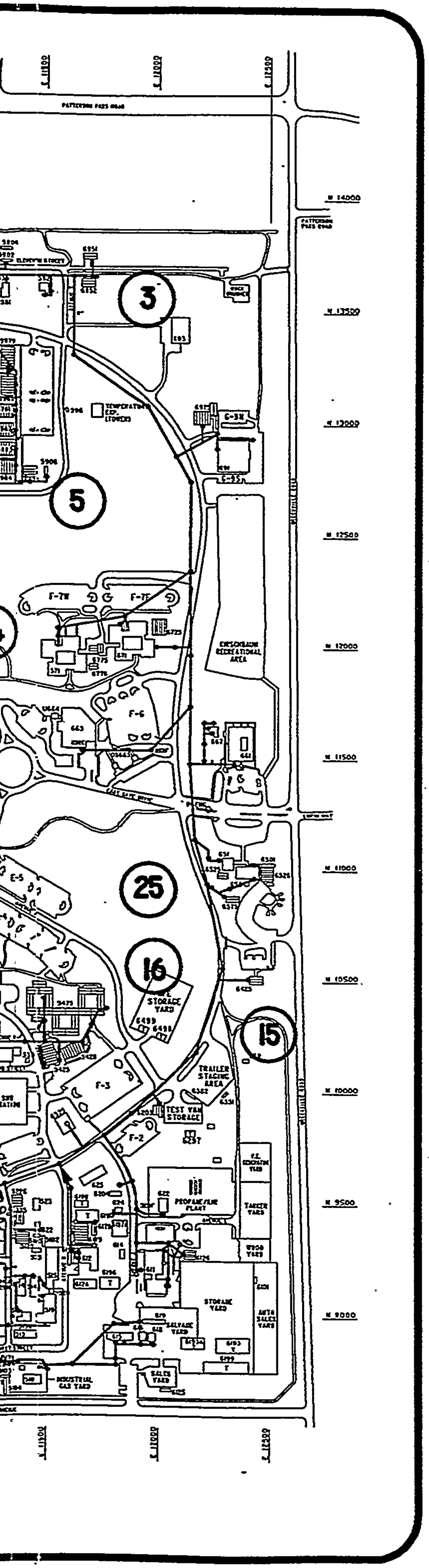
Z-1
Z-2
Z-3
A-1
A-2
D-7
D-3
E-3
E-7
B-7
B-4
B-10
C-10



LEGEND

(3) Future Plan Building

Sanitary Sewer & Manhole

FUNDED PROJECTS

1. Nuclear Test Technology Complex (NTTC)
2. Defense Programs Research Facility (DPRF)
3. Decontam./Waste Treatment Facility (DWTF)
4. Atmospheric Emerg. Resp. Facility (AERF)

PROPOSED PROJECTS

5. National Ignition Facility
   Protection of Real Property (roofs) Phase I
6. Genomics & Structural Biology
7. Advanced Optical Technology Center
8. SCIF Area for NAI
9. B543 Addition
10. B151 Plant and Seismic Upgrade
11. NW Low Conductivity Water (LCW) Station
12. Earth Science Building
13. Refurbish Hazard Control Facility
14. Central Cafeteria & Conference Center
15. Public Affairs Center
16. Environ., Safety and Health Facility (ES&H)
17. B123 General Upgrade (Conf. Ctr. Upgrade)
18. Energy Program Office Building
19. Technology Transfer Complex
    Fire Safety Training Facility
20. Hazards Control Fire Science Facility
21. B222 Chem. Bldg. Decon./Demolition
22. Replace Deteriorating Offices
23. Plutonium Facility Upgrade
24. Laboratory Administration Center
25. Laboratory Business Center
26. B321 Genreal Upgrade
27. B141 General Upgrade
28. B231 General Upgrade
29. B151 Effluent Systems Upgrade
30. B241 Renovation/Replacement
31. B181 Addition (replace 1700 block trailers)
32. Generic Office Bldg #1 (replace "Iron Crosses")
33. Generic Office Bldg #2 (replace 1800 Block trailers)
34. B235 Upgrade

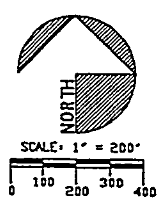


Figure 3.

Future development at LLNL.

Design Flows for the 10-y Storm Event

Following the example of the 1989 study, we chose the 10-y, 4-h storm as the design storm event. In 1989, this choice had been based on criteria used by the San Francisco Regional Water Quality Control Board (Regional Board). At that time, the Regional Board had allowed predicted sanitary sewer overflows at intervals ranging from 5 to 20 y. For the East Bay planning community, the Regional Board had recommended allowing overflows in sensitive areas in 10- to 20-y intervals. Because LLNL is considered a sensitive area, a 10-y design storm was selected. Currently, the Regional Board acknowledges the existence of overflows, but does not make specific allowances.

For the Livermore area, the 10-y storm would have an average intensity of 0.32 in./h for a 4-h period. The peak hourly RDI&I responses that we developed for each basin for the design storm event were based on storm characteristics determined from flow-monitoring data for 1995. That is, the same percentage of rainfall was assumed to enter the sanitary sewer system of each basin as was determined for the January 23–24 and January 27 storms. Future RDI&I for each basin was assumed to remain constant at existing levels.

Current and future peak wet-weather flows were then obtained by adding RDI&I to current and peak sanitary flows, respectively.

$$PDWF = PSF + GWI,$$
$$PWWF = PSF + RDI\&I,$$

where,

PDWF = peak dry-weather flow (in mgd),
PWWF = peak wet-weather flow (in mgd),
GWI = ground water infiltration (in mgd), and
PSF = peak sanitary flow (in mgd).

Because the 1989 study had determined that ground-water infiltration is not present in the LLNL collection system, we did not consider ground-water infiltration (i.e., PDWF = PSF).

For the 1989 study, CH2MHILL had developed an equation that related peak sanitary flow to average base flow (ABF). This equation was based on a regression between the two variables, using data from the 10 basins. In the present study, we used the same formula to estimate peak sanitary flows:

$$PSF = 1.43 \times (ABF)^{0.853}.$$

For the design average base flow, the peaks of each contributing flow component were assumed to occur simultaneously. That is, the peak RDI&I resulting from the 10-y storm would occur at the same time as the peak daily sanitary flow. The probability of the two events occurring simultaneously once during a 20-y period was reported in the 1989 study as 8%, corresponding to a recurrence interval of 12 y.

To determine the capacity deficiencies for existing and future sanitary flows, PCSWMM was used to route design flows through the collection system. As in the 1989 study, the system was divided into eight drainage basins based on the flow monitoring conducted in January and February 1995. The design flows were distributed through each basin by assigning appropriate flows to each manhole. Peak base flow was distributed according to the estimated building flows already described. Peak wet-weather flow for each manhole was determined as follows:

- The rainfall rate (in./h) was converted to a volume rate [cubic feet per second (cfs), where 1 cfs = 448.86 gpm] by multiplying the rainfall rate by the area of the drainage basin, along with appropriate unit conversions.
- This volume rate was then converted to an RDI&I rate (cfs) per basin, by multiplying it by the R-value for that basin.
- Finally, the RDI&I rate was distributed throughout the basin in proportion to the length of pipe upgradient from a given manhole. That is, if the pipe length upgradient of a particular manhole represented 5% of the pipe length modeled for the basin, then 5% of the RDI&I was assigned to that manhole.

Scenarios

Scenarios modeled included 1989 conditions, current (1995) peak dry- and wet-weather flows, and future (year 2008) peak dry- and wet-weather flows. Peak dry- and wet-weather flows were simulated in a single model by first running the model at peak dry-weather flow conditions and then superimposing upon this the 4-h, 10-y storm event RDI&I. A 24-h simulation was used, with peak dry-weather flows as input from 12 a.m. to 10 a.m. and 2 p.m. to 12 a.m., and peak wet-weather flows as input from 10 a.m. to 2 p.m.

Results

Capacity

The capacity of each pipe segment was determined by PCSWMM according to Manning's equation. The maximum capacity of pipes on-site (flowing full with no overflow) was calculated as 1,215 gpm. To identify deficiencies, the routed flow to each segment was compared to the capacity.

Locations near capacity are summarized in Table 5. Locations downgradient from Building 196 (i.e., pipes leading to manholes 155 and 156) were at as much as 50 to 60% of their capacity. In the peak-flow condition, some locations upgradient of Building 196 were at approximately 75% of their capacity.

Table 5. Pipes near capacity in future peak-flow scenario (year 2008).

Downgradient manhole[a]	Theoretical maximum capacity (cfs)[b]	Modeled maximum flow (cfs)	Percent of capacity[c]
191	0.86	0.646	0.75
192	0.85	0.629	0.74
193	0.9	0.627	0.70
88	1	0.619	0.62
89	1	0.611	0.61
156	2.7	1.6	0.59
50	3.4	1.953	0.57
190	1.2	0.648	0.54
155	3.2	1.6	0.50
292	3.4	1.59	0.47
293	3.4	1.59	0.47

[a] Each pipe is identified by the manhole immediately downgradient from it.

[b] Where 1 ft^3/s (cfs) = 448.86 gallons/min (gpm).

[c] Ratio of maximum flow to capacity.

Flow

Tables 6 and 7 summarize our RDI&I results and compare them with the results of the 1989 study. RDI&I values per drainage basin are based on the results of the January 23–24 and January 27 storms. Peak dry-weather flow is about the same in 1995 as it was in 1989. Peak dry-weather flows are predicted to increase slightly by the year 2008. Most notable is that the 1995 peak RDI&I (for the 10-y storm) is estimated to be 0.46 mgd (320 gpm), compared to 4.38 mgd in 1987. This represents an 88% improvement in the amount of rainwater entering the sanitary sewer. Maximum flow leaving the site in the 1995 was estimated at 1.17 mgd (820 gpm), well below the discharge limit (1,170 gpm). The estimated peak year 2008 flow (1.55 mgd, or 1,076 gpm), however, is only slightly below the discharge limit.

Uncertainty

A number of assumptions were made to develop and run the model. The 10-y storm was used as the source of RDI&I water, and it was assumed that the peak RDI&I occurs simultaneously with the peak base flow (i.e., between 10:00 a.m. and 2:00 p.m.). An average R-value of 0.5% was used for the simulations (i.e., 0.5% of the rainwater enters the sewer system). Finally, the model assumed that no large releases to the sanitary sewer system occurred during storm events.

Table 6. Comparison of 1987 and 1995 flows.

Basin	Peak dry-weather flow (mgd)		Peak RDI&I[a] (mgd)		Peak wet-weather flow (mgd)	
	1987	1995	1987	1995	1987	1995
L1	0.0609	**0.0733**	0.2995	**0.1493**	0.3604	**0.2226**
L2	0.0827	**0.0742**	0.2294	**0.0078**	0.3121	**0.0819**
L3	0.0387	**0.0340**	0.2672	**0.0562**	0.3059	**0.0902**
L4	0.0431	**0.0544**	0.5537	**0.0685**	0.5968	**0.1229**
L5	0.1593	**0.1565**	0.7426	**0.0168**	0.9019	**0.1733**
L6	0.1143	**0.0490**	1.4972	**0.0600**	1.6115	**0.1090**
L7	0.0867	**0.0784**	0.2459	**0.0039**	0.3326	**0.0823**
L8	0.0769	**0.0725**	0.2637	**0.0950**	0.3406	**0.1675**
SNL	0.1133	**0.1132**	0.2765	**0.0008**	0.3898	**0.1140**
Total:	0.7759	**0.7054**	4.3757	**0.4583**	5.1516	**1.1638**

[a] RDI&I = rainfall-dependent infiltration and inflow.

Table 7. Comparison of 1987 and 2008 flows.

Basin	Peak dry-weather flow (mgd)		Peak RDI&I[a] (mgd)		Peak wet-weather flow (mgd)	
	1987	2008	1987	2008	1987	2008
L1	0.0609	**0.12769**	0.2995	**0.14929**	0.3604	**0.27698**
L2	0.0827	**0.12007**	0.2294	**0.00776**	0.3121	**0.12783**
L3	0.0387	**0.05001**	0.2672	**0.05623**	0.3059	**0.10624**
L4	0.0431	**0.07987**	0.5537	**0.06850**	0.5968	**0.14837**
L5	0.1593	**0.17701**	0.7426	**0.01680**	0.9019	**0.19381**
L6	0.1143	**0.20620**	1.4972	**0.05997**	1.6115	**0.26617**
L7	0.0867	**0.09686**	0.2459	**0.00394**	0.3326	**0.10080**
L8	0.0769	**0.11962**	0.2637	**0.09500**	0.3406	**0.21462**
SNL	0.1133	**0.11477**	0.2765	**0.00084**	0.3898	**0.11561**
Total:	0.7759	**1.09210**	4.3757	**0.45833**	5.1516	**1.55043**

[a] RDI&I = rainfall-dependent infiltration and inflow.

Conclusions and Recommendations

We believe that we successfully duplicated the monitoring and modeling techniques used in the 1989 baseline study. We believe that (with the caveats described below) our study accurately represents current conditions at the LLNL/SNL site and permits evaluation of improvements made to the sanitary sewer system as a result of the SSR project.

Our conclusions can be summarized as follows:

- The SSR project reduced calculated values of RDI&I by 88% compared to the values derived in the 1989 study.
- The system has sufficient capacity to transport present and projected (year 2008) peak dry-weather flow; however, some pipes will be at 75% of their theoretical capacity.
- The system has sufficient capacity (1,215 gpm) to transport projected peak wet-weather flows (i.e., RDI&I from a 10-y storm) both now and after future (year 2008) development.
- Predicted peak flows (820 gpm now; 1,076 gpm in 2008) are less than the maximum reserved for the LLNL/SNL system by the City of Livermore (1,170 gpm).
- Although the focus of this study has been on infiltration, rather than on exfiltration, it is generally true that reduction in infiltration is accompanied by reduction in exfiltration. This study indicates that the rehabilitation effort has resulted in an appreciable reduction in infiltration. Therefore, although exfiltration has not been eliminated, in part due to a DOE-directed $8.5 million funding cut to the SSR project, it has been reduced to levels as low as is reasonably achievable, and the SSR project has achieved the Building Drain Repair objective of reducing exfiltration of waste water into the surrounding soil.

Some uncertainties, however, lead to specific recommendations:

- In this study, we studied three storms on a site-wide basis and two storms on a basin-by-basin basis (essentially three and two data points, respectively). Although we succeeded in quantifying the LLNL/SNL site-wide RDI&I in a fairly narrow range (R-values of 0.22 to 0.91), it remains unclear how much variability there is in RDI&I. A greater degree of uncertainty is associated with the by-basin R-values; Basin 6 flow, because calculations for it are based upon the flow at all other locations, is the most difficult to quantify adequately. Thus, there is no guarantee that the maximum RDI&I has been determined.

  Recommendation: We recommend an ongoing program consisting of (at a minimum) representative, annual monitoring of wet-season and dry-season flow. This further collection of data would verify conclusions reached in this report, maintain current flow data, permit better quantification of the RDI&I (including establishing its upper bound), identify basins having the greatest problems with capacity or with RDI&I, and determine the probability that the flow could exceed either the capacity of the system or the discharge rate reserved by the City of Livermore.

Recommendation: Because of the uncertainties, we concur with the 1989 study's recommendation that significant batch discharges not occur during rain storms.

- In the simulations, the peak flow rates per basin were based on the R-values calculated from the January 23–24 and January 27 storms. For SNL, this R-value was 0.02%, whereas the R-value for the January 14–15 storm was much higher, at 0.85%. As previously discussed, this is indicative of the variability of the R-values on a by-basin basis. If this higher value were used, the SNL peak RDI&I would be 0.36 mgd. In terms of the amount of rainfall entering the sanitary sewer system, about 92% is associated with LLNL and 8% is associated with SNL. This indicates that there is potential for decreased RDI&I at SNL.

Acknowledgments

The authors gratefully acknowledge the contributions by other LLNL Environmental Protection Department personnel: Bruce Fritschy and Shari Brigdon coordinated field operations; Shari also compiled data on batch discharges from retention tanks, cooling towers, and Treatment Facility F; and Frank Gouveia provided rainfall data.

Ted Mayer, the ISCO representative, assisted with setup and configuration of the flow monitors.

APPENDIX A: Field Work

Preparation

Flow Meters

Plant Engineering (PE) leased 10 ISCO Model 4230 (bubbler) flow meters—one for each monitoring location—plus 15 batteries, one five-station charger, and mounting rings. Later, we requested and leased 10 more batteries. All meters were checked and calibrated prior to installation by following instructions provided by the vendor; in addition, the ISCO representative gave an on-site briefing to PE and EPD personnel regarding setup, installation, and operation of the flow meters.

Monitoring Locations

This study was designed to mimic an investigation conducted in 1989 by CH2MHILL. Therefore, because our intent was to duplicate monitoring locations as closely as possible, the monitoring locations were the same except as follows:

- In 1989, CH2MHILL had used 10 locations, one for each basin. However, one of those locations (flow meter No. 9 at manhole 127B) was eliminated from this study, because the sewer line had been abandoned. Therefore, during this study the tenth meter was used to monitor other locations of interest.
- Manhole 67A has been abandoned, and a meter was placed down manhole 66A instead.
- Manhole 155A was used instead of manhole 157A for two reasons: because access is more convenient from manhole 155A, and because the pipe downstream from 155A is cured, in-place pipe (CIPP) and, therefore, is considered an integral part of manhole 157A.
- Manhole 101C was used instead of manhole 24A because the line upstream from manhole 24C has been abandoned.

Maps of the sanitary sewer system were marked with monitoring locations and basins.

Installation

PE crews prepared the monitoring locations beforehand by cleaning the sewer lines and fabricating holders and other equipment for the ISCO flow meters. The following equipment was designed to allow maintenance and visual inspection without the need for confined-space entry.

- The flow-meter holders, which PE customized for each location, also ensured that the manhole covers still fit properly.
- PE attached a nonbreakable mirror to an extension pole to allow visual inspection of the tubing.

In addition, PE also designed a clog-removal tool, consisting of a claw attachment on the extension pole, which allowed them to clear most clogged tubes without a confined-space entry.

PE personnel, assisted by EPD personnel, then installed the meters, tubing, and mounting rings.

Confined-space entry permits were obtained from Hazards Control for meter installation/removal, and were attached to the application log sheets. In addition, all EPD and PE crew members completed the HS-4150 Confined Space Entry course.

The mezzanine at Building 432 was used as the staging area. There, meters were programmed and calibrated, batteries were charged, and logbooks and other materials were stored.

Implementation

Although we had originally planned to begin the study the first week of December, we experienced delays in the leasing process; therefore, the project began in January 1995.

Installation

To gain familiarization with the flow meters and their operation prior to startup, a meter was installed at one location (manhole 90D) on December 28, 1994. We began installation of the remaining nine meters on January 9, 1995, and completed installation on January 13.

Maintenance

The meters were checked daily, from January 17 until January 25, when we were comfortable enough with their reliability to scale back the maintenance schedule to three times per week (Monday, Wednesday, and Friday) for the rest of the study. On Mondays (or on Tuesdays, if Monday was a holiday) they were checked twice—once in the morning to be sure they had survived the weekend, and again in the evening for routine maintenance.

Maintenance of the flow meters was scheduled during off-hours to take advantage of the reduced sewage flow and reduced traffic on the roads. Also, it was timed to avoid the following activities:

- Cleaning and maintenance of EPD's satellite samplers. This coordination avoided clogging of the flow meters caused by the unclogging of the satellite samplers.
- PE's routine sewer line maintenance. This coordination was done to ensure that the meters would not be disturbed or affected by debris.

Other considerations for determining the maintenance schedule were:

- Life of the batteries.
- Life of the desiccant.
- Bubbler fouling rate.
- Bubble drift rate.
- Supply of strip-chart paper.
- Requirements for downloading the data.
- Need for confined-space entry permits.
- Time required for each installation and maintenance.
- Whether weekend and holiday coverage would be necessary.

One two-person crew and two trained backups were required to perform the necessary maintenance. The crew usually consisted of one PE Pipe Shop Technician and one EPD Technical Support Group (TSG) technician.

Maintenance consisted of the following:

- Clearing any clogged tubes.
- Checking to see that the meter was operating.
- Checking (and, if necessary) changing the battery.
- Checking (and, if necessary) adjusting the bubble rate.
- Recording the depth of sanitary sewer flow.
- Checking the supply of paper and desiccant.
- Changing the batteries every other day (as a minimum; to avoid downtime, they were often changed daily).
- Changing strip-chart paper, ribbons, and desiccant on an as-needed basis.

On three separate occasions, the ISCO representative, Ted Mayer, came onsite to check the operation of the meters. During these visits, he spot-checked the strip charts and programming of some units to ensure that they were correctly programmed and functioning properly.

Documentation

Official monitoring began on January 13 and ended February 15. Data were downloaded from the meters once a week using a laptop computer, Flowlink software, and special cables. Floppy disks containing downloaded data, as well as graphical printouts, were provided to Erich Brandstetter, EPD's Environmental Analyst, for use in the model. Any downtime or batch discharges were noted on these graphs. Strip charts from the meters were also given to the EPD Analyst. The batch-discharge records are reproduced here as Table A-1.

Table A-1. Batch releases to the sanitary sewer system.

Location	Volume (gal)	Dates	Time	Down-stream monitor	Source of batch release
TFF[a]	8,450	1/9/95		7	
612	5,000	1/10/95	930	1	Berm water
612	1,400	1/10/95	1330	1	S300 steam cleaning
222	4,500	1/10/95	1330	5	Retention tank
291	7,900	1/10/95–1/12/95		2	Cooling-tower blowdown
TFF[a]	21,900	1/11/95		7	
612	8,000	1/12/95	930	1	Retention tank
291	12,500	1/12/95–1/13/95		2	Cooling-tower blowdown
222	4,000	1/13/95	1000	5	Retention tank
291	100	1/13/95–1/17/95		2	Cooling-tower blowdown
291	8,600	1/17/95–1/18/95		2	Cooling-tower blowdown
291	14,000	1/18/95		2	Cooling-tower blowdown
153	1,850	1/18/95	830	6	Retention tank
325	6,900	1/18/95–1/19/95		5	Cooling-tower blowdown
612	43,000	1/19/95	1340	1	Retention tank
291	11,000	1/19/95		2	Cooling-tower blowdown
291	34,600	1/20/95–1/23/95		2	Cooling-tower blowdown
612	3,500	1/24/95	1050	1	Retention tank
514	990	1/24/95	1535	1	Retention tank
325	4,000	1/24/95–1/25/95		5	Cooling-tower blowdown
514	2,000	1/25/95	1045	1	Retention tank
514	2,400	1/26/95	1045	1	Retention tank
325	1,000	1/26/95–1/27/95		5	Cooling-tower blowdown
612	5,800	1/27/95	1315	1	Retention tank
291	75,300	1/28/95	645	2	Cooling-tower blowdown
325	5,000	1/28/95–1/30/95		5	Cooling-tower blowdown
151	2,490	1/31/95	1440	4	Retention tank
325	2,000	1/31/95		5	Cooling-tower blowdown
325	61,000	2/1/95		5	Cooling-tower blowdown
TFF[a]	28,980	2/2/95		7	

Table A-1. Batch releases to the sanitary sewer system (continued).

Location	Volume (gal)	Dates	Time	Down-stream monitor	Source of batch release
325	2,000	2/2/95		5	Cooling-tower blowdown
TFF[a]	30,620	2/3/95		7	
612	4,000	2/3/95	1100	1	Retention tank
TFF[a]	22,800	2/6/95		7	
TFF[a]	26,080	2/7/95		7	
514	2,270	2/7/95	1100	1	Retention tank
325	2,000	2/7/95–2/8/95		5	Cooling-tower blowdown
TFF[a]	31,670	2/9/95		7	
291	3,000	2/9/95–2/10/95		2	Cooling-tower blowdown
325	19,000	2/9/95–2/10/95		5	Cooling-tower blowdown
TFF[a]	14,210	2/10/95		7	
612	2,166	2/10/95	1300	1	Retention tank
291	2,400	2/10/95–2/13/95	0800 on 2/10 –0800 on 2/13	2	Cooling-tower blowdown
325	113,000	2/10/95–2/13/95		5	Cooling-tower blowdown
TFF[a]	22,320	2/13/95		7	
514	1,200	2/13/95	1030	1	Retention tank
291	7,000	2/13/95–2/14/95	0800 on 2/13 –0800 on 2/14	2	Cooling-tower blowdown
TFF[a]	21,790	2/14/95		7	
291	5,700	2/14/95–2/15/95	0800 on 2/14 –0800 on 2/15	2	Cooling-tower blowdown
TFF[a]	29,750	2/15/95		7	
514	1,381	2/16/95	1410	1	Retention tank
325	14,000	2/16/95–2/17/95		5	Cooling-tower blowdown
325	80,000	2/17/95–2/21/95		5	Cooling-tower blowdown
325	30,000	2/21/95–2/22/95		5	Cooling-tower blowdown
514	1,030	2/22/95	1355	1	Retention tank
325	12,000	2/22/95–2/23/95		5	Cooling-tower blowdown
612	5,000	2/23/95	900	1	Retention tank

[a] TFF = Treatment Facility F.

Data from each flow meter were entered in a logbook with numbered pages that was taken out into the field by the maintenance crew. Information from the field logbook was then entered on customized log sheets that had been developed for each meter (except for the tenth flow meter, which had a generic form). Included in the customized information about each meter were data on the slope, the friction coefficient, the inside diameter of the pipe, and the length and size of the tubing being used. The information transferred to the customized log sheets included date and time of maintenance; names of the crew members; any equipment adjustments; water level in the sewer at the time; weather; the condition of the desiccant, battery, and paper; and flow conditions.

Confined-space entry permits were issued by Hazards Control whenever the crew had to enter a manhole. These permits were then stapled to the applicable log and kept as part of the permanent record.

Two complete sets of documentation are available—one resides with the EPD analyst and one resides with the PE engineers who worked on this project.

APPENDIX B: References

1. *Sanitary Sewer System Master Plan, Part 1: Sewer System Study,* prepared for the Plant Engineering Department, Lawrence Livermore National Laboratory, by CH2MHILL, Emeryville, CA (1989).
2. R. J. Vellinger, R. Burton, and B. Fritschy *Sanitary Sewer System Rehabilitation at Lawrence Livermore National Laboratory,* LLNL Rept. UCRL-JC-120626 (1995); presented at the US EPA National Conf. on Sanitary Sewer Overflows, April 1996.
3. *Sandia National Laboratories' Site Development Plan (SDP),* Sandia National Laboratories, Albuquerque, NM (1994).
4. *LLNL Site Development Plan (Calendar Year 1995),* Plant Engineering Administration, Lawrence Livermore National Laboratory, Livermore, CA, LLNL Rept. UCRL-LR-110253-95 (1995).
5. *Report First Quarter Fiscal Year (FY) 1995* and *Retired Buildings/Trailers (December 12, 1994* are part of the Space and Site Planning Database that is maintained at Lawrence Livermore National Laboratory; they are updated quarterly. For this report, the reference was dated January 1, 1995.