Chapter 7

Wastewater System Hydraulic Analysis
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7.1 INTRODUCTION

Four hydraulic models of Lacey’s sanitary sewer system were developed for the 2005 Plan Update. The year 2004 model was developed to assess the ability of the existing system to transport current wastewater flows. The 2010 and 2024 models were developed to assist making 6- and 20-year capital improvement recommendations. Lastly, a build out model was developed to evaluate system improvements that may be required once all properties in the UGA have reached their full build out potential. Figure 7-1 shows the extent of the existing and proposed piping and lift stations that were modeled.

Looking forward, these models can be used by the City on an ongoing basis to evaluate the effects of new development, upgrades or extensions within the UGA.

HYDRA version 6.3 was used to prepare the hydraulic models. In this chapter, the methodology used to model and analyze Lacey’s collection system is presented. Some general descriptions of the HYDRA program are given and details of the modeling parameters and assumptions are described. Additional details of how the software works can be found in the HYDRA user’s manual. Selected simulation results output files are provided in Appendix B. For detailed simulation results, please refer directly to the models provided to the City.

The hydraulic models developed for the 2005 Plan Update are based upon the existing system model that was developed for the 1999 Wastewater Comprehensive Plan. The 1999 model’s pipe network was reviewed and revised to eliminate minor connectivity errors that were found and updated to include pipes sized 10-inches and larger that have been constructed since 1999. Generally the unit flow rates, I/I rates and build out population densities used in the 1999 models were retained.

The growth that has occurred within Lacey and its UGA has exceeded the assumptions made in the 1999 Wastewater Comprehensive Plan. In terms of the residential sewer population, the population defined for the newly developed 2004 existing system model is roughly equivalent to the sewer population estimated to occur by the year 2015 in the 1999 Wastewater Comprehensive Plan.

The model drainage basins, herein identified as service areas with reference to HYDRA, were revised to better reflect topographical considerations. The distribution of the residential and nonresidential population across the UGA was studied in detail and revised for the new models as well.
As a result of these revisions, simulation results from the 2004 model could not be directly compared against simulation results from the 1999 6-year CIP model; however, peak flow comparisons at several key locations were made and were found to be within reason. The year 2004 hydraulic model developed for this 2005 Plan Update was developed without the benefit of current flow data. As such, the model could not be validated. However, in using the currently accepted population estimates provided by TRPC, and using unit flow rates and I/I rates developed during the 1999 Wastewater Comprehensive Plan, it is concluded that the current model’s simulation results can be used with reasonable confidence as a planning tool to size future wastewater conveyance facilities.

7.2 HYDRAULIC MODELS

The models were developed to simulate hydraulic conditions within the collection system in pipes 10-inches and larger. The modeling software used for this analysis is HYDRA version 6.3, developed by PIZER, Inc. of Seattle, Washington.

HYDRA does not simulate the true physical nature of the effects of back-water in the collection system. However, HYDRA uses another approach that is quite functional. It draws a hydraulic grade line (HGL) envelope starting from a user provided outfall or free fall HGL and works upstream, using the peak flow it iteratively calculates, to develop a HGL for each pipe segment. The software then connects all these HGLs together. Essentially, the HGL shown in HYDRA’s profile view is the hypothetical worse case combined flow scenario. It is hypothetical in the sense that it is not possible to have peak flow conditions occurring at each pipe in the entire collection system simultaneously. However, this approach provides a useful planning tool for sizing individual pipes, manholes and lift stations.

For lift stations, HYDRA uses a wet well volume-discharge relationship to define when the pumps start pumping and what the discharge rate is.

Because the model uses discrete time steps in its simulations, simulated flows are attenuated both by the hydraulic attenuation due to routing and by the numerical attenuation that is inherent due to the length of the time step being used. When simulations are run HYDRA users must select whether to preserve peak flows or whether to preserve volume, which tends to underestimate peak flows. The benefits of using each approach are discussed in the HYDRA manual.

For the purpose of defining peak flow rates and sizing future sewers the model was set to “preserve peak” flows. This approach is recommended by Pizer so that the magnitude of the peak flows is not compromised. However, because the “preserve peak” approach is used, future users of the model must be cautious when using the volume aspect of the model results. In preserving peak flows, the model does not preserve mass volume balance.

Future users that desire to evaluate volumetric elements of the model results such as
sizing lift station wet wells or other volume sensitive facilities should rerun the system analysis, setting the Hydrograph Attenuation setting to “preserve volume”.

7.3 MODEL BUILDING

Building the year 2004 collection system model was broadly separated into two phases: Model Development, which defines the City’s conveyance network as it is currently constructed, and Flow Generation, which defines existing sewage, inflow and infiltration characteristics. After these tasks were completed, models were constructed that define projected 6-year, 20-year and build out conditions.

Model Development

The Lacey model networks have three basic components: gravity sewers, force mains, and lift stations. The hydraulic models developed for this 2005 Plan Update were based upon the hydraulic model used in the 1999 Wastewater Comprehensive Plan. The items below summarize the development of the 1999 model and the revisions that were made to it for the 2005 Plan Update.

1. When the 1999 model was developed the collection system was reduced to a skeleton network that included the major gravity pipes sized 10-inches and larger and the lift stations associated with those pipelines. Selected 8-inch pipes were included if they were an integral part of the system. There was no survey work conducted; pipe sizes and invert elevations shown on drawings provided by the City were assumed to be correct. A limited amount of field reconnaissance was performed to verify the existence of some system components. No field reconnaissance was done for this 2005 Plan Update.

2. In developing the new models for the 2005 Plan Update, the 1999 model was updated to include newly constructed sewers greater than or equal to 10-inches in diameter. Attributes and location of the new sewers were provided by the City. The new pipes were added to the model via AutoCAD and GISMaster software using information from the sanitary base maps provided by the City.

3. The 1999 model was carefully reviewed and debugged to ensure it correctly represents the Lacey wastewater system. Some system connectivity errors were found and repaired. Invert elevations were checked and adjusted if they were suspected to be erroneous. Profiles of the modeled system were developed as part of the debugging process. Where pipe slopes appeared incorrect, invert elevations were checked against recent AutoCAD drawings provided by the City. In areas with missing data, pipe sizes were assumed to be equal to the adjacent piping and invert elevations were interpolated linearly from the nearest known data points. In particular, the attributes of the section of sewer crossing I-5 at Marvin Rd. was carefully checked for accuracy.
4. While there is some cement pipe installed, the pipe materials in the existing collection and force main systems are predominately PVC. As with the original models constructed in 1999, a Manning’s “n” coefficient of 0.013 was applied to all gravity pipes in the new models. Although this value is somewhat conservative, its use is justified because it offsets the hydraulic losses through manhole structures that are otherwise unaccounted for in the model.

5. A minimum velocity of 2 ft/s was set for all models. All minor losses were assumed to be zero and neglected.

6. The major lift stations and force mains were incorporated in the 1999 model. These lift stations were modeled in the 1999 Plan as they were considered to have contributed a significant amount of flow compared to the gravity flows already present in the line into which they discharged. The attributes of these lift stations were verified against information provided by the City. The modeled lag pump was assumed to have the same “pump off” volume as the lead pump.

7. All lift stations were modeled as constant discharge pumps. The existing lift stations were modeled with discharge rates equal to their nameplate rating. In future year scenarios, where existing discharge rates did not provide sufficient capacity, the discharge rate was increased to match influent flows.

8. For the lift stations incorporated into the 1999 model, attributes such as total volume, pump on volume, pump off volume, and pump capacity were checked against recent data provided by the City and revised. Several of the 1999 lift stations were revised to reflect their nameplate data.

When simulation results indicated that a lift station requires an increase in capacity, the station was configured using a hypothetical wet well volume and a single constant discharge pump. In these cases, the lift station wet well was sized such that no overflow would occur and the pump turns on at least once during the simulation run. The discharge rate of the lift station was set to match the peak flow entering the station. Therefore the peak flow rate entering a station is equal to the required station capacity.

9. The algorithm used by HYDRA to simulate pumping does not account for storage in force mains or dispersion or reduction of the wave front as it moves down the pipeline. Thus, downstream flows can be over-predicted by HYDRA during periods of pumping when the actual pumping rates were used. This error is believed to be minor.

10. A rather conservative Chezy “C” factor of 100 was applied to all force mains to account for force main aging. Analysis results are not particularly sensitive to this value however, so the actual value used is of minor
consequence.

11. In the 1999 model, service areas were connected to individual pipe segments. As a conservative approximation, the 1999 model connected each area at the upstream end of the 1st sewer that resides within the service area. The drain points of the 2005 Plan Update’s modeled service areas were assigned to manholes, based on local conditions including zoning information, TAZ population data, and information provided by the City. Flow from the existing STEP systems are injected into the gravity system at the termination of the 16-inch STEP force main located on Pacific Ave. The STEP force mains were not modeled with the HYDRA collection system model. However, a spreadsheet model was prepared. This is discussed earlier in Chapter 6.

12. Diurnal curves from 1999 Plan were used in the updated model. The curves were derived based on flow data collected when the 1999 Wastewater Comprehensive Plan was prepared.

13. HYDRA flow files from the 1999 Wastewater Comprehensive Plan were replaced with newly generated flow files.

14. In each service area defined in the models, residential and commercial population growth was assumed to occur as defined by Thurston County TAZ data and City of Lacey staff input.

15. Inflow and infiltration is defined and calculated only in those areas that are sewerable. Modeled I/I increases were set to occur in step with the sewerable area growth, which was assumed to grow at a rate of 2% per year.

16. Existing septic systems were assumed to convert over to conventional sewers at a rate of 2% per year between the years 2006 and 2024. The build out condition model was set to assume that 100% of the septic systems had been converted and that no additional septic system had been constructed.

17. The proposed layout of future trunk extensions, major sewer lines and lift stations were added to the newly developed models. Separate hydraulic models were built for each of the reporting years (i.e. 2004, 2010, 2024, and Built-Out). These hydraulic models differ from each other in sewage flows, upgraded pipe sizes and lift station capacities. However, note that pipe improvements necessary for the year 2010 6-year CIP are based on sizes required in 2024. Where new facilities are required or where existing facilities require upgrading by the year 2010, those facilities are sized based on peak hour flow conditions that are projected to occur in 2024. This philosophy was used so that the 6-year capital improvements would not have to be upgraded again until sometime after the 20-year planning...
horizon. The remaining attributes of the sewer system (e.g. ground elevation, pipe inverts, pipe lengths, etc.) essentially remain unchanged among the models.

Flow Generation

Flow files were created that define the wastewater and I/I generated in each service area. Service Area (SE) layers were used to generate residential and commercial sewage flows and I/I. To this end, the entire Lacey UGA was divided into 166 service area polygons, see Figure 7-2. I/I flows were generated based on the extent of the sewerable area within each service area. Wetlands, parks and other unsewerable areas do not contribute to I/I generation in the models.

The following procedures were used to generate wastewater flows in the models.

1. Lacey’s UGA was divided into 166 service areas based on topography, the layout of existing and proposed gravity sewers, STEP sewers, the layout of parcels, and land use information provided by the City.

2. Sewered residential and non-residential flow was defined for each of the 166 service areas for each of the reporting years (i.e. 2004, 2010, 2024, and built-out) based on the following information and assumptions. This information is described in greater detail in Chapter 2.
   - Present population, future population and dwelling unit distribution information provided by TRPC, based on 2000 census data and TAZ distribution.
   - City of Lacey revisions to TRPC’s residential and non-residential TAZ population and land use data, which was provided in the form of a marked-up map.
   - Land use information provided by both City of Lacey and TRPC.
   - Existing gravity and STEP sewer locations from AutoCAD drawings provided by the City.
   - All future sewer connections within the UGA were assumed to be served via Lacey’s conventional gravity sewer and lift station conveyance system. This includes the further assumption that no new STEP sewer systems would be built, effective January 2005. This assumption was discussed and agreed to with Lacey staff so that modeling could proceed and future facilities defined. However as of this writing (mid 2005), neighborhood developments served by new STEP sewers continue to be built. Most, but not all of the new STEP systems discharge into the independent STEP system of force mains, which is hydraulically connected to the lift station/interceptor system.
just upstream of the LOTT Martin Way lift station. If future new development continues to be served by the STEP system, the likely effect on the proposed (and currently modeled) interceptor system will be that projected future line sizes and lift station capacities may be reduced.

- Population growth discussed in Chapter 2, was distributed evenly across all service areas unless otherwise defined by the City.

- All existing STEP systems will continue to be operated as STEP systems in the future.

- No new septic systems will be built.

- Existing septic systems would be gradually converted to conventional gravity/lift station system, based on the conversion rates shown in Table 2.2. The conversion was applied uniformly across all service areas that now contain septic systems.

- By the time build out occurs the entire UGA will be serviced by either the conventional gravity/lift station system or by the existing STEP system. There are no plans to remove the STEP system and it would continue operating as it currently does, serving the areas it now serves. All septic systems would be eliminated by then.
3. As no flow monitoring program was conducted for this 2005 Plan Update, the same unit flow quantities, diurnal curves, and I/I contributions used in the 1999 Wastewater Comprehensive Plan were used in this study’s models. According to the 1999 Plan, the total sewered population was calculated to be 24,658 in 1999. The then total residential wastewater flow was determined to be 1.648 MGD. That resulted in a per capita flow rate of 67 GPCD, which was used in 1999 Plan. This value was also used in this 2005 Plan Update.

4. Similarly, according to the 1999 Wastewater Comprehensive Plan the total sewered employment population was calculated to be 13,859. The then total employee residential wastewater flow was determined to be 0.476 MGD. This results in a per employee flow rate of 31 GPED. In addition, the maximum employee density was estimated at the time as 38.1 employees per acre. That resulted in a per acre commercial contribution of 1,135 GPAD. As a conservative estimate, a value of 1,400 GPAD was used to model the future system in 1999. These non-residential flow values were also used in the new models.

5. Infiltration is the input of groundwater to the sanitary system through cracks, poor joints and connections or other defects in the sanitary system. Inflow is rainfall-dependent flow into the system due to cross connections from the storm drain system or other types of direct inflow. Exfiltration is the opposite of infiltration and may occur when the water table is below the water surface in the pipe.

In the 1999 hydraulic models, 210 GPAD was used to model existing I/I flow and 500 GPAD was used to model future I/I. Although the effects are small, the new 2005 Plan Update models revised this value to 213 GPAD instead of 210 GPAD to define existing I/I flows. This value is based on text located on page 4-15 of the 1999 Wastewater Comprehensive Plan and appears to be the actual 1999 estimate. Future I/I flow rates were left unchanged. I/I was input into the models as constant flow values.

6. Diurnal curves were developed to represent the percentage of the daily amount of wastewater contributed to the system throughout the day. The daily pattern of wastewater generation is related to land use. For example, the peak flows from a residential area are often experienced between 6 and 8 AM, and between 7 and 9 PM. However, peak flows from commercial areas usually occur between 9 AM and 4 PM. The ability of a pipe to carry peak flows may be erroneously identified as insufficient if peak flows from all contributing sources are assumed to occur simultaneously, when in fact the peaks occur at different times. If the diurnal curve is based on average hourly flows, the highest point on the curve, normalized by the average daily flow, represents the peaking factor. Collection system improvements were designed to convey the peak flows.
When the 1999 Wastewater Comprehensive Plan was prepared, temporary flow meters were placed at four locations within the Lacey system. Data was collected for four weeks during a dry period to characterize the diurnal curve in the absence of I/I. The data from the residential area near Lift Station #3 was used to obtain the residential diurnal curve used in the model of the existing system. The data from the commercial area was used to characterize the commercial curve. Both curves defined a peaking factor of 2.5 and were used in the 1999 models. These diurnal curves were also used in this 2005 Plan Update.

7. The residential and non-residential contribution to the wastewater system from a service area is the product of the residential/employee population within that service area and the per capita contribution. For commercial flow, flows in the model are expressed in terms of daily volume. HYDRA flow files were generated based on steps 1 through 6 listed above. The model then converts the modified diurnal curve values into percent of daily flow and applies them to the average daily flow values to generate flow hydrographs for the model. Table 7.1 shows a summary of the unit flows used. Refer to Chapter 4 for additional discussion regarding unit flows.

<table>
<thead>
<tr>
<th>Land Use Type</th>
<th>Unit Flow (GPCD) or (GPED)*</th>
<th>Unit Flow (GPAD)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Space</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Commercial, Industrial, Institutional</td>
<td>31</td>
<td>1,400</td>
</tr>
<tr>
<td>Low Density Residential</td>
<td>67</td>
<td>0</td>
</tr>
<tr>
<td>High Density Residential</td>
<td>67</td>
<td>0</td>
</tr>
<tr>
<td>Medium Density Residential</td>
<td>67</td>
<td>0</td>
</tr>
<tr>
<td>I/I Existing (2004)</td>
<td>0</td>
<td>213</td>
</tr>
<tr>
<td>I/I Future (2010, 2024, Built-Out)</td>
<td>0</td>
<td>500</td>
</tr>
</tbody>
</table>

* Sources of these data can be found on p. 4-15, 6-22, and 6-23 of the 1999 Wastewater Comprehensive Plan.

8. Information from Steps 1 through 7 above was input to the model and flow files were generated for each of the reporting years. One sewage flow and one I/I flow file were generated for each reporting year. These flow files were subsequently input into each model’s analysis runs for each reporting year. Table 7.2 summarizes key information used to develop model flow files.
### Table 7.2
Lacey Model Architecture Summary

<table>
<thead>
<tr>
<th>Service Areas</th>
<th>Existing System Model (2004)</th>
<th>2010 Model</th>
<th>2024 Model</th>
<th>Build-out Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2000 census data from TRPC in form of preliminary 2003 Traffic Analysis Zone (TAZ) data. Service areas are based on sewered area, topography, location of existing &amp; future sewers and type (gravity/STEP), land use information.</td>
<td>TRPC projection of 2010 residential and employee population from 2001 TAZ data. Service areas based on 2004 sewered areas plus 12% growth (2%/yr from 2004*), 8% sewer-septic conversion (2%/yr from 2006 to 2010**), topography, location of existing &amp; future sewers and type (gravity/STEP), and land use information.</td>
<td>TRPC projection of 2025 residential and employee population linearly interpolated to 2024 from 2001 TAZ data. Service areas based on 2004 sewered areas plus 40% growth (2%/yr from 2004*), 28% sewer-septic conversion (2%/yr from 2006 to 2024**), topography, location of existing &amp; future sewers and type (gravity/STEP), and land use information.</td>
<td>Build-out population densities taken from 1999 build out model. Service areas based on buildable parcels in the UGA and all septic systems converted to sewers, topography, location of existing &amp; future sewers and type (gravity/STEP), and land use information.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Residential Flow</th>
<th>67 GPCD</th>
<th>67 GPCD</th>
<th>67 GPCD</th>
<th>67 GPCD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial Flow</td>
<td>31 GPED</td>
<td>31 GPED</td>
<td>31 GPED</td>
<td>1400 GPAD</td>
</tr>
<tr>
<td>I/I</td>
<td>213 GPAD</td>
<td>500 GPAD</td>
<td>500 GPAD</td>
<td>500 GPAD</td>
</tr>
<tr>
<td>Diurnal Curves</td>
<td>Calibrated curve modified to reflect 2.5 peaking factor from 1999 model.</td>
<td>Calibrated curve modified to reflect 2.5 peaking factor from 1999 model.</td>
<td>Calibrated curve modified to reflect 2.5 peaking factor from 1999 model.</td>
<td>Calibrated curve modified to reflect 2.5 peaking factor from 1999 model.</td>
</tr>
</tbody>
</table>

* 2% annual growth is a growth value used in the 1999 Plan and as agreed by the City to be also used in this Plan update.

** See Table 2.2 for detail
7.4 MODEL RESULTS

The capacity of the gravity interceptor system and associated lift stations were analyzed under peak hour flow conditions for the years 2004, 2010, 2024 and build out. Deficiencies in the existing system, using current pipe sizes for each scenario were identified. Where needed, pipe improvements were identified for those sewers that did not have sufficient capacity to satisfy design criteria that would allow maximum depth of water in each pipe segment to reach a depth of 80% of full-pipe depth. In situations where the adjacent upstream and downstream sewers of an overcapacity sewer had sufficient capacity and the overcapacity condition was a localized occurrence, the 80% criterion was relaxed to allow full pipe depth to occur.

To simplify the modeling effort, the modeled pipe networks included proposed piping required for years 2010, 2024 and build out. The extent of the 2010 trunk system expansion was determined by analyzing that year’s simulation results and locating those proposed sewers where there was no modeled flow present. For example, for those pipe segments in the 2010 model where the model predicted that no flow is present, it was established that the pipe segment would not be required until some time in the future, i.e. 2024 or build out. Pipe segments were analyzed iteratively for each succeeding model year. The year that the extension is required was identified by the presence of flow as predicted by the model.

The peak flow demand for each of the modeled lift stations in the existing system and future extension of the system were identified by analyzing simulation results for each model year. Similar to the pipe network, future lift station capacities are based on predicted peak hour flow rates.

As discussed above, pipes that were predicted by the model to operate over 80% full during peak hour conditions were defined as being overcapacity. Overcapacity pipes for the year 2004 are highlighted in Figure 7-3. However, the wastewater depth predicted in each of the overcapacity pipes is at or below full-pipe depth. As such, these pipes do not act as hydraulic bottlenecks within the system. City staff has stated that the current collection system appears to have adequate hydraulic capacity and the 2004 model confirms this.

Figures 7-4, 7-5 and 7-6 show the existing model network as forecasted by the year 2010, 2024 and build out models, assuming no system improvements are made. The highlighted lines indicate pipe segments that are predicted to operate over 80% full during peak hour conditions. Again, not all of the overcapacity pipes are sufficiently under-sized to justify the high cost of upgrading.

For future loading conditions where overcapacity pipes were identified, each pipe segment was evaluated to determine if upsizing was warranted. Where under-sized pipes were predicted to cause hydraulic restrictions or system backups, replacement pipe sizes were determined and entered into the model. This was done iteratively, revising pipe diameters and lift station capacities until all portions of the system were predicted to have adequate hydraulic capacity. Capital improvements recommended for years 2010 and 2024 are discussed in Chapter 8.
LEGEND

- UGA Boundary
- EXISTING GRAVITY SEWERS OPERATING OVER 80% FULL
- MODELED PIPES
- WETLAND/LAKES
- CREEK
- EXISTING LIFT STATION

FIGURE 7-5
YEAR 2024 PEAK HOUR FLOWS
EXISTING SYSTEM PIPES
OPERATING OVER 80% FULL
CITY OF LACEY
2005 WASTEWATER
COMPREHENSIVE PLAN UPDATE

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7.5 FUTURE USE OF THE MODEL

The City will be able to use the models in several ways if they choose to do so. Continued use of the models will require that City staff be trained to operate the software and understand how to interpret simulation results. For the model to be used successfully in the future, it is important that the model is adequately maintained by updating it with newly constructed piping, system upgrades and changes in population. Potential future uses of the model include:

- Evaluating the capacity of the system. The year 2004 model was developed to characterize the system as it currently functions. Future users can revise the population assumptions used in this model or update population values based on new information as it becomes available.

- Report files can be generated. Reports would provide details regarding the location and size of pipes required to correct capacity problems.

- Evaluate system upgrades, repairs or additions to the system. New pipes can be added or existing pipes re-sized to reflect different scenarios. The effects on downstream piping and lift station capacities can be studied.

- New residential or commercial developments can be represented in the model to assess their impact on the existing system. This can be done by increasing the population in selected service areas or by adding new pipe networks and service areas.

A detailed discussion of how the HYDRA models are set up, the layering systems, flow files and a discussion on the continued maintenance of the models is located in Appendix B.5.