Section 4
Model Documentation

4.1 Overview

Unlike many engineering models, the integrated model is not a high resolution parametric model aimed at reproducing hydraulic or biochemical processes in a given system. Rather, it serves as a platform in which to integrate general response patterns and interdependencies of various subsystems in a way that will indicate preferability of one alternative over another. This is accomplished by developing mathematical empirical relationships within and between the water, wastewater, stormwater, and reuse subsystems. It was developed specifically to help stakeholders and decision makers understand the interconnectivity between the resources and utilities in Franklin.

The simulation model measures a variety of system responses by simulating different plans and their far-reaching impacts on flows, demands, pollutant loads, costs, and usability of the water resources in the study area.

The goals of the model are to provide the following functions in support of stakeholder decisions:

Provide Technical Information

- Performance measures that are quantitative.
- Impacts of decisions aimed at one utility on all others.
- Sufficient detail to distinguish the broad benefits and impacts of alternatives across the resources and utilities that are under evaluation (e.g., water, wastewater, stormwater, water reuse, Harpeth River).

Screening and Plan Formulation

- What projects appear to work well together?
- Are there certain pairings of project that counteract each other?
- What projects offer little or no benefit?

Alternative Comparison

- How well does any given alternative (groups of projects and policies) satisfy the collective interests of the stakeholders?
- What are the alternatives that will most effectively address the broad interests of the Stakeholder Advisory Group?

4.1.1 Model Approach

Franklin's water resources system is a network of natural and manmade systems that exist to satisfy numerous demands on water (e.g., irrigation, industrial use, human consumption, habitat, and recreation). Water moves between segments in various mechanisms, including completely natural pathways, altered natural pathways, and manmade pathways. The simulation model of Franklin's water resources system is a representation of the system's segments and their interconnectivity. The model will simulate the movement of water and, in some cases, pollutant loads through the system. The following sections will describe how the Franklin system is represented in the model and how the model simulates different configurations and alternatives.

Figure 4-1 is a schematic representation of the Franklin water resources system model. The colored boxes represent the model segments described below. The colored arrows that link the segments represent the flow of water throughout the system. Each colored arrow has an indicator for representation of flow or flow and load. The gray boxes and black arrows indicate data input and calculations involved in determining how the system operates. There are four different types of calculations or values used in the integrated system model, described below and indicated on the schematic using the corresponding number:

1. Data – information input directly into the model from historical records or known values (e.g., plant capacity, rainfall records).

2. Residual Calculations – values resulting from mass balance calculations (e.g., wastewater effluent flowing to the river is the total effluent created less the effluent needed for reuse as irrigation water).

3. Scientific Calculations – calculations using engineering equations or theoretical values (e.g., Manning's equation for open-channel flow).

4. Relational Calculations – values resulting from dependencies on other variables (e.g., phosphorus loading to the river depends on volume of wastewater effluent flowing to the river).

The simulation model operates on a daily time scale in order to examine the effects of system operations on low flows in the river. While a monthly time scale would be most appropriate for the resolution of this model, monthly averaging tends to hide the occurrence of low-flow periods that are important to recognize and consider. A single major storm event can cause an otherwise dry month to appear normal when flows are averaged over that time period. Furthermore, because the flow data are directly available from USGS measurements at two stream gauges in Franklin, there is no reason to consolidate or average the information, as is sometimes done to diminish uncertainty in hydrologic estimates. **Table 4-1** below shows the frequency with which the daily, weekly, and monthly average flow values were at or below the indicated threshold. Monthly average values were applied to each day in the averaging period, so that each time series contains the number of days from January 1, 1975 through December 31, 2007.

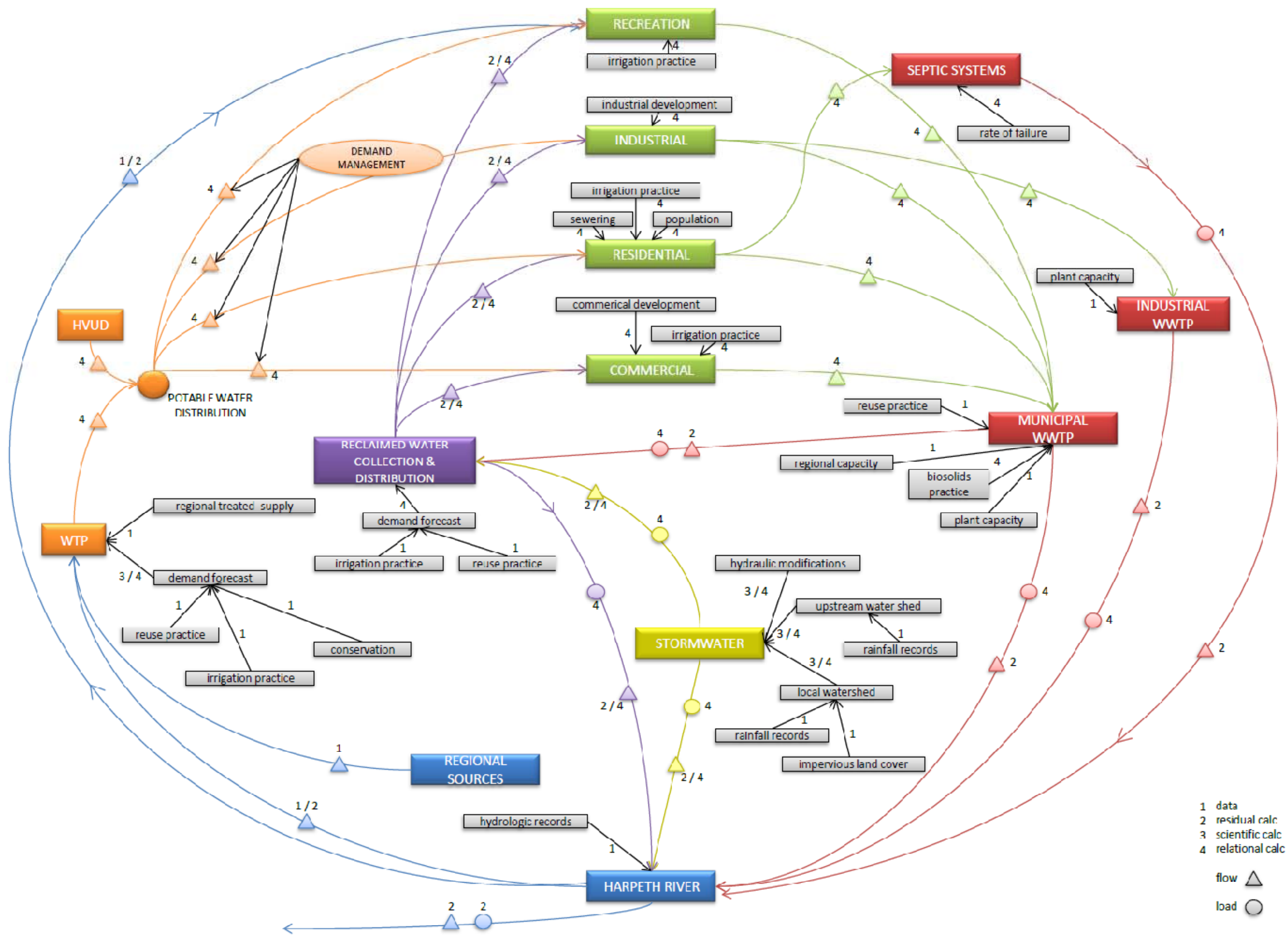


Figure 4-1
Franklin Integrated System Model Schematic

CDM

Table 4-1
Flow Frequency Statistic Based on Daily and Monthly Time Scales

	Streamflow (cfs)	Frequency Evidenced in Daily Time Series	Frequency Evidenced in Monthly Time Series
September Median[1]	5.85	14.6%	7.91%
95th Percentile Daily Low Flow[1]	1.70	5.07%	1.96%
99th Percentile Daily Low Flow[1]	0.81	1.06%	0.25%
7Q10[2]	0.50	0.31%	0.00%
Low Flow Threshold[3]	10.0	20.3%	10.6%

1. USGS Gauge data, 1974-2008
2. USGS, 1995. Flow Duration and Low Flows of Tennessee Streams through 1992.
3. 2007 Aquatic Resource Alteration Permit

4.1.2 Model Sectors

The model is segmented into sectors that represent the categorization of Franklin's water resources: the Harpeth River, water supply, reclaimed water, stormwater, and wastewater. The sectors are interconnected such that decisions or policies aimed at managing water within one sector will affect the rest as appropriate. For example, increasing the reclaimed water distribution infrastructure would decrease the demand on potable water for irrigation and decrease the volume of effluent discharged to the river. The model sectors and their connections are explained in detail in the following sections.

4.1.3 Software

The model was developed with STELLA software (Systems Thinking Experimental Learning Laboratory with Animation). STELLA is a dynamic and graphical tool used to simulate interactions between and within subsystems that are part of a larger interconnected system. It is frequently used in environmental engineering venues to better understand the implications of decisions across a broad array of social and environmental sectors.

STELLA is a graphical system simulation package that allows users to model physical flow systems with operational- or planning-level resolution. The software allows users to develop on-screen control interfaces that facilitate rapid adjustments of system variables for alternatives and sensitivity analyses. When dozens of alternatives are feasible (be they alternate water sources, use and reuse guidelines, operational triggers, etc.), STELLA can rapidly help planners and decision makers screen information, identify key drivers, and understand the causal relationships throughout the big picture of a complex system.

Fundamentally, STELLA helps screen options and alternatives, providing numeric scores for performance measures identified as quantitative. In this context, STELLA does not make decisions, but it can be used to generate information and promote more informed and balanced decisions via rapid comparison of the performance of alternatives using physical, environmental, and economic metrics. Its ability to include multi-sectoral interests in an analytical framework is what distinguishes it from more traditional hydraulic or hydrologic models, which evaluate systems in a purely physical setting. The tradeoff is in resolution. STELLA models do not simulate finely discretized river basins, channels, or pipes but include key system elements and their interdependencies in a lower-resolution network framework in which physical, environmental, and economic response patterns can be effectively examined.

4.1.4 Model Validation

The integrated model is not a parameterized model: that is, it does not rely on calibrated coefficients to reproduce natural or physical processes. Rather, the relationships in the model are based largely on empirical data (stormwater loads, for example) and straightforward combinations of mathematical terms (such as the linear addition or subtraction of flows and loads). The purpose of the model is not to reproduce the watershed and utility processes with scientific precision, but to better understand the interdependence of the processes and their sensitivity to future decisions. Therefore, the model has been tested only inasmuch as the input can be shown to reproduce current or historic patterns or trends and respond appropriately to changes. There are no parameters to calibrate, and the testing of the model relies on expert judgment to determine if the system responses are representative of actual and expected conditions.

4.2 Harpeth River

4.2.1 Historical Flow Record

Conditions for modeled scenarios were defined for the project's 30-year planning period, with utility demands corresponding to projections from 2010 through 2040. These demand levels were applied to a wide range of flow conditions over the hydrologic period of record to calculate the system's average response to the different management conditions. By simulating any given demand level over the historical hydrologic record, the frequency of specific conditions (e.g., limited water withdrawals due to low-flow conditions) can be quantified and interpreted as the probability of occurrence in any given year, given the specified demand levels. This superimposing of lengthy historical hydrologic patterns over any future year of forecasted demand facilitates an understanding of increasing risks with time, without the need to forecast future hydrology.

4.2.2 USGS Gauge Records

The hydrologic period of record for the model is January 1, 1975 through December 31, 2009 (35 years). This is the period of available historic data for the USGS Gauge on the Harpeth River at Franklin, TN (gauge #03432350). The USGS gauging station at Franklin is located downstream of the Franklin Water

Treatment Plant intake and upstream of the Franklin Sewage Treatment Plant (WWTP) discharge. This period includes a sufficient variation in hydrologic conditions including 3 weeks with average flows less than the 7Q10 (0.5 cubic feet per second (cfs) or 0.3 million gallons per day (mgd)) and 3 weeks with average flows greater than the 99th percentile average daily high flow (3,700 cfs or 2,400 mgd). The annual average flows in this time period range from a 93.3 cfs or 60 mgd (1981) to 575 cfs or 370 mgd (1979). Future conditions are evaluated by applying the historical data from the hydrologic period of record over any given future year of projected demand.

There is a second USGS gauging station on the Harpeth River downstream of the City, #03432400, that has streamflow data available from October 1, 1988 through December 31, 2009. This gauge was used in calculating runoff contributions to streamflow, which are discussed in Section 4.5.

4.2.3 Water Supply Withdrawal Records

Monthly operating reports (MORs) from the Franklin Water Treatment Plant (WTP) contain the daily flow through the plant for the hydrologic period of record, 1975 through 2009. There are no records of the actual withdrawal from the river for this period, so the daily volume of treated water delivered by the water plant was used as a proxy for the river withdrawals. This time series was added back into the USGS gauge records in order to develop a naturalized upstream flow boundary condition to the model.

4.2.4 WWTP Discharge Records

MORs from the WWTP containing discharge records are available only for 1999 through 2009. Precipitation records from the WWTP rain gauge are available for 1928 through 2009. Based on Franklin population, seasonal rainfall, and recent WWTP discharge records, the time series of effluent flow to the river was extended back in time to cover the entire hydrologic period of record. An observed relationship between per capita wastewater discharge to the river and annual rainfall volume was used, along with observed seasonal variation in wastewater discharge, to calculate estimated seasonal WWTP discharge for the years prior to 1999. The artificial WWTP discharge record was an input to the stormwater calculations discussed in Section 4-5 and a factor in the Harpeth River model mass balance. **Figure 4-2** shows the synthetic WWTP discharge time series (1975-1998) and the actual MOR data (1999-2009).

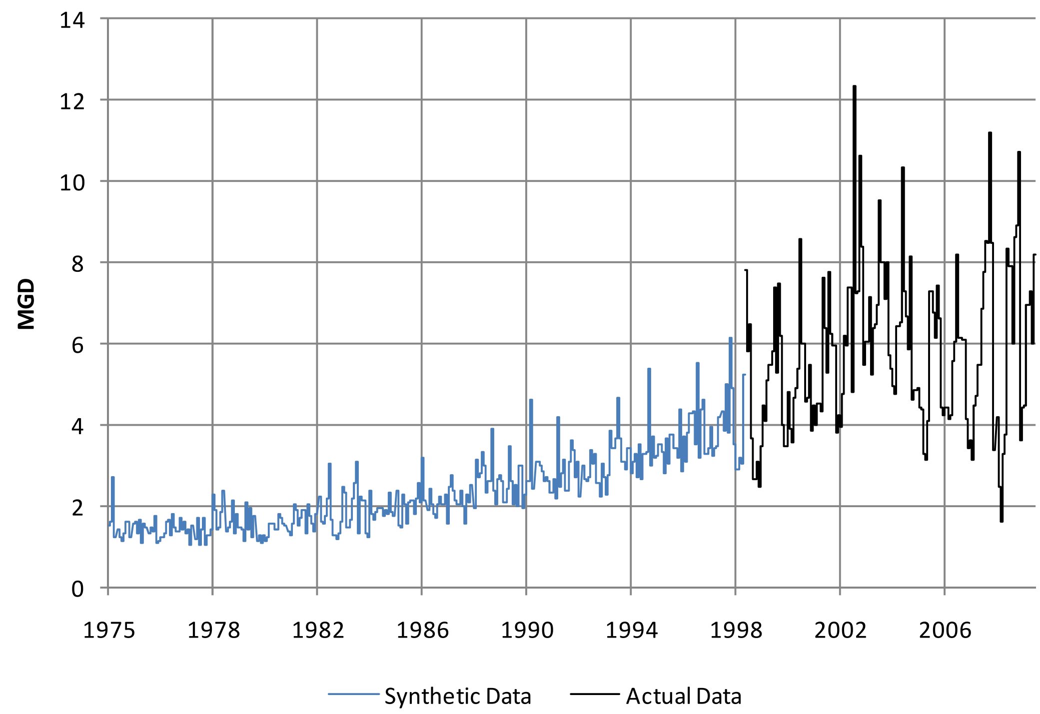


Figure 4-2
Calculated and Actual WWTP Discharges

4.2.5 Mass Balance

Figure 4-3 shows the mass balance diagram for the Harpeth River sector of the Franklin integrated model. For any given scenario, the sum of all inflow and outflow volumes must be equal to zero for over the hydrologic period of record. That is, all water entering the river as an upstream boundary condition, WWTP discharge, stormwater flow, or base flow return must exit the system via withdrawal or simulated flow downstream of the modeled city boundary. The river model balances with respect to total volume in million gallons after each model run covering the entire hydrologic period of record. Historical input data is used as a boundary condition to the model, whereas model calculations are variable with each scenario and depend upon the management conditions applied to the model (e.g., WWTP capacity and stormwater control measures)

Inflows to the Harpeth River model sector include the following:

- Historical USGS gauge records upstream of Franklin WTP
- Historical WTP withdrawals (added to normalize historic USGS gage records)
- Modeled WWTP discharges
- Modeled stormwater flow from managed collection measures (BMPs)

- Modeled stormwater flow from unmanaged conveyance and collection
- Modeled base flow return from irrigation and septic systems

Outflows from the Harpeth River model sector include the following:

- Modeled water treatment plant withdrawal
- Modeled flow downstream of the modeled city boundary

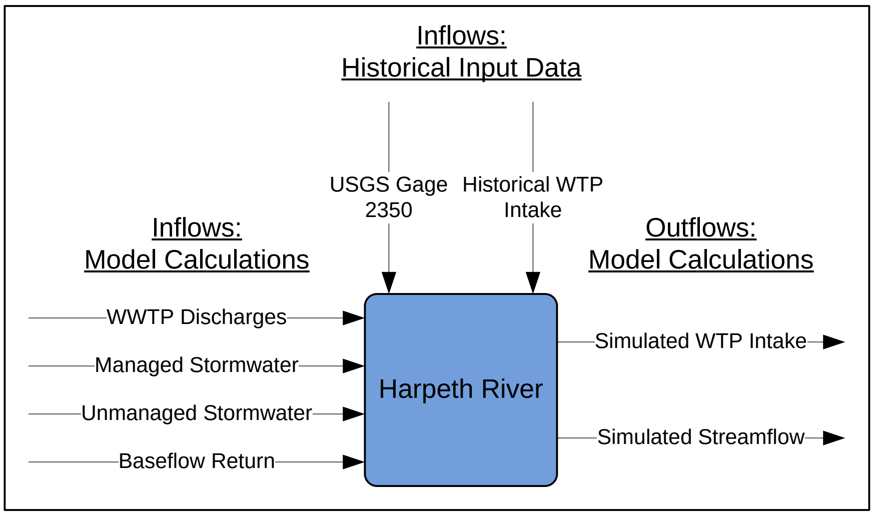


Figure 4-3
Harpeth River Model Sector Mass Balance

4.2.6 Spatial Orientation

Figure 4-4 shows the sequence of inflows into and withdrawals from the modeled Harpeth River system. The inputs are labeled with letters which correspond to how they are added across the system. This summation is shown in the downstream flow equation. Input A is the upstream boundary condition. Inputs B and C are wholly dependent upon the options selection under the scenario being modeled. WTP withdrawal (D) is a result of various factors including, but not limited to, the demand for potable water, the low-flow limitation on river withdrawals, the intake pump capacity, the raw water reservoir level and capacity, and the WTP capacity. Input E, stormwater volume, is represented by a single addition to the river flow, rather than a continuous input along the length of the river. The single point represents the total volume of stormwater flowing to the river within the modeled city area. (Note that the aggregation of stormwater flows is appropriate; because the information required by stakeholders was related to bulk effects of stormwater at downstream locations, rather than the distributed effects throughout the river, which will be examined with more detailed river models.) This input is discussed in more detail in Section 4-5. Though much smaller by comparison, base flow return to the river (G) is also quantified at a single point, and includes only irrigation and septic system recharge. Precipitation infiltration changes are indirectly quantified in stormwater calculations. Input F is the result of various factors including, but not limited to, potable water use, sewering, WWTP capacity, and reclaimed water use.

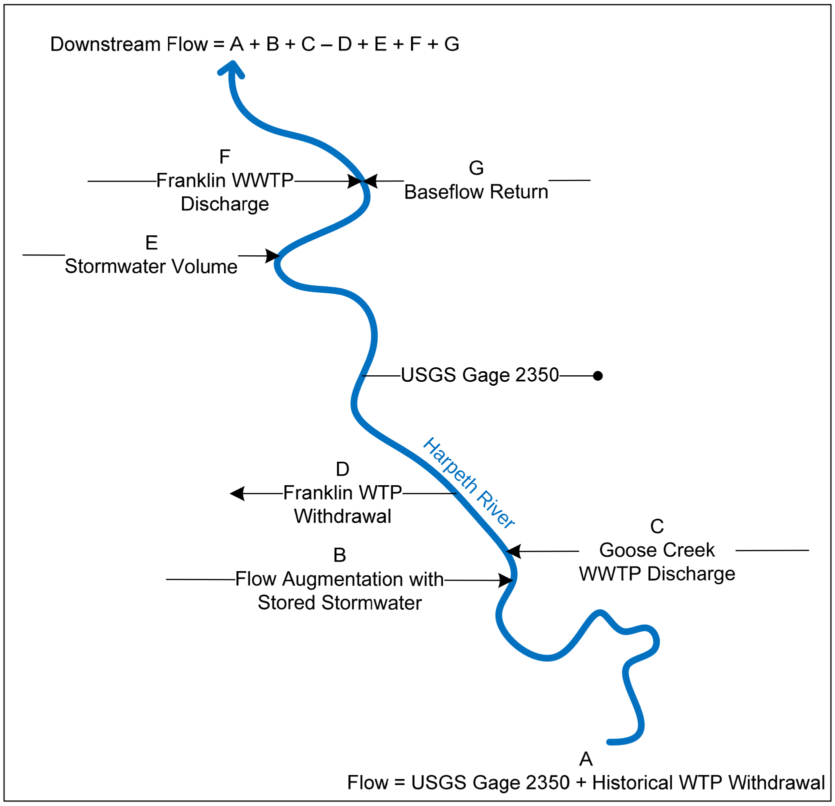


Figure 4-4
Spatial Orientation of Modeled Harpeth River Inflows and Outflows

4.3 Potable Water Supply

4.3.1 Water Demand Projections

Water demands were forecasted in six 5-year increments for the planning period beginning in 2015 and ending in 2040. Water demand projections had previously been developed for the City of Franklin for several development scenarios and reported in the *Jackson Thornton Utilities' Independent Evaluation of Feasibility Study,* conducted by Metcalf & Eddy (June 2008). The annual demands for a moderate growth scenario were disaggregated into water demands by use sector for model input: residential essential, residential irrigation, commercial essential, commercial irrigation, recreational essential, recreational irrigation, and industrial essential. Essential demands are used as an estimate for what is needed for drinking, bathing, necessary industrial processes, and moderate lawn watering. The moderate growth scenario was based on the City's *2004 Land Use*

Plan that specified the average water demand in 2005 at 6.25 mgd, a projected growth of 0.18 mgd per year from 2005 to 2020, and a projected growth of 0.09 mgd from 2020 to 2040. The percentages of total water demand fitting into the seven water use sectors listed above were estimated using the City's recent billing records and were not varied by projected demand year. Recreational demands include the irrigation water use of golf courses. **Table 4-2** lists the annual total water demand projections, and **Table 4-3** lists the percentage of demand partitioned to each of the water use sectors.

Table 4-2
Annual Total Water Demand Projections

Demand Year	Total Annual Demand, MG
2015	2,752
2020	3,081
2025	3,246
2030	3,411
2035	3,576
2040	3,741

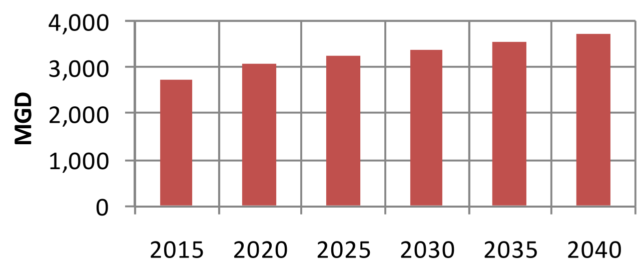
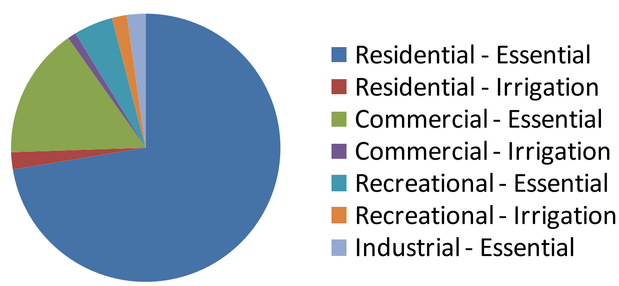


Table 4-3
Demand Partitioning by Water Use Sector

Water Use Sector and Type	Percent of Total Demand
Residential - Essential	72.4%
Residential - Irrigation	2.1%
Commercial - Essential	15.8%
Commercial - Irrigation	1.0%
Recreational - Essential	4.7%
Recreational - Irrigation	1.8%
Industrial - Essential	2.3%



To capture the seasonality of water demands, monthly multipliers were used to develop a monthly average water demand for each use sector. The multipliers were calculated from the City's billing records obtained from 2000 through 2009. **Table 4-4** shows the monthly multipliers for the different use sectors (residential, commercial, recreational, and industrial) and use types (essential or irrigation). The average monthly values were used as the demand for each day in that month.

Table 4-4
Monthly Multipliers for Water Demands

Month	Essential Demand	Irrigation Demand	Industrial Demand
January	0.86	0.12	1.0
February	0.83	0.08	1.0
March	0.83	0.08	1.0
April	0.85	0.15	1.0
May	0.92	0.46	1.0
June	1.04	1.07	1.0
July	1.16	1.77	1.0
August	1.23	2.20	1.0
September	1.21	2.13	1.0
October	1.11	1.71	1.0
November	1.05	1.62	1.0
December	0.91	0.60	1.0

Figures 4-5 through **4-8** show the resulting monthly water demands, by use type and water use sector, used as model input for each of the demand years from 2015 to 2040. The monthly variation is shown in the bar charts, with the darker color bands representing the increasing demand for each 5-year increment.

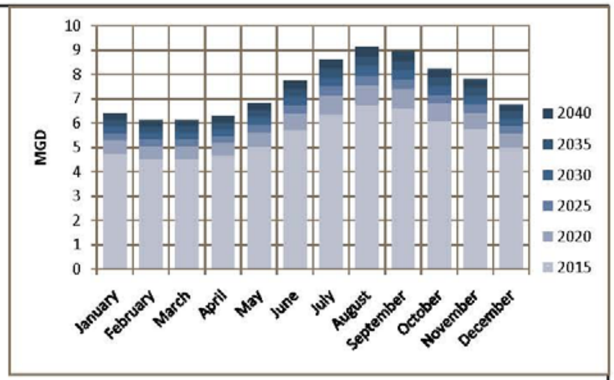
Water distribution system leakage also effectively places a demand on the system. If the City's water users need 10 mgd, for example, but the system will leak 1 mgd, the City must provide 11 mgd to the distribution system. The current leakage rate was estimated at 1 mgd. This estimate is based on data from 2008-2009 records that showed 0.07 mgd of known leaks in the system and a total volume of unaccounted for water of 1.5 mgd. The actual leakage rate is somewhere between these two values, assuming not all leaks are known and not all unaccounted for water is leakage (paper losses, for example). The leakage rate was not escalated for the next 30 years but was reduced by 50 percent when the option to address distribution system leakage was activated.

4.3.2 Water Supply Model Sector

The Franklin IWRP explores multiple pathways for obtaining the water needed to meet the City's demands. They are the following:

- Harpeth River raw water
- Large regional wholesaler – Harpeth Valley Utility District (HVUD)
- Cumberland River raw water

Residential - Essential						
Demand in MGD	Demand Year					
	2015	2020	2025	2030	2035	2040
January	4.71	5.27	5.55	5.83	6.12	6.40
February	4.51	5.05	5.32	5.59	5.86	6.13
March	4.51	5.05	5.33	5.60	5.87	6.14
April	4.63	5.19	5.47	5.74	6.02	6.30
May	5.02	5.62	5.92	6.22	6.52	6.82
June	5.70	6.38	6.72	7.06	7.40	7.74
July	6.34	7.10	7.48	7.86	8.24	8.62
August	6.72	7.53	7.93	8.33	8.74	9.14
September	6.59	7.38	7.77	8.17	8.56	8.96
October	6.06	6.78	7.15	7.51	7.87	8.23
November	5.74	6.42	6.77	7.11	7.45	7.80
December	4.98	5.58	5.88	6.18	6.47	6.77
Average	5.46	6.11	6.44	6.77	7.09	7.42



Residential - Irrigation						
Demand in MGD	Demand Year					
	2015	2020	2025	2030	2035	2040
January	0.02	0.02	0.02	0.02	0.02	0.03
February	0.01	0.01	0.02	0.02	0.02	0.02
March	0.01	0.01	0.01	0.02	0.02	0.02
April	0.02	0.03	0.03	0.03	0.03	0.03
May	0.07	0.08	0.09	0.09	0.09	0.10
June	0.17	0.19	0.20	0.21	0.22	0.23
July	0.28	0.31	0.33	0.34	0.36	0.38
August	0.34	0.39	0.41	0.43	0.45	0.47
September	0.33	0.37	0.39	0.41	0.43	0.45
October	0.27	0.30	0.32	0.33	0.35	0.36
November	0.25	0.29	0.30	0.32	0.33	0.35
December	0.09	0.11	0.11	0.12	0.12	0.13
Average	0.16	0.18	0.18	0.19	0.20	0.21

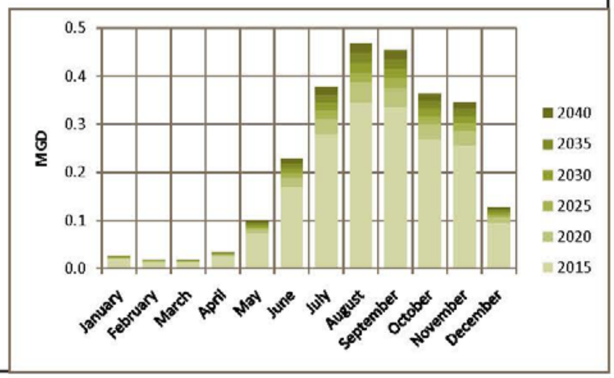
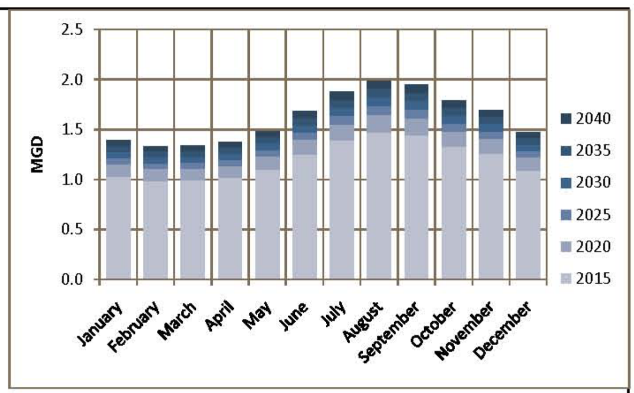


Figure 4-5
Modeled Residential Water Demands 2015 to 2040

Commercial - Essential						
Demand in MGD	Demand Year					
	2015	2020	2025	2030	2035	2040
January	1.02	1.15	1.21	1.27	1.33	1.39
February	0.98	1.10	1.16	1.22	1.27	1.33
March	0.98	1.10	1.16	1.22	1.28	1.34
April	1.01	1.13	1.19	1.25	1.31	1.37
May	1.09	1.22	1.29	1.35	1.42	1.48
June	1.24	1.39	1.46	1.54	1.61	1.69
July	1.38	1.55	1.63	1.71	1.79	1.88
August	1.46	1.64	1.73	1.81	1.90	1.99
September	1.43	1.61	1.69	1.78	1.86	1.95
October	1.32	1.48	1.56	1.63	1.71	1.79
November	1.25	1.40	1.47	1.55	1.62	1.70
December	1.08	1.21	1.28	1.34	1.41	1.47
Average	1.19	1.33	1.40	1.47	1.54	1.62



Commercial - Irrigation						
Demand in MGD	Demand Year					
	2015	2020	2025	2030	2035	2040
January	0.01	0.01	0.01	0.01	0.01	0.01
February	0.01	0.01	0.01	0.01	0.01	0.01
March	0.01	0.01	0.01	0.01	0.01	0.01
April	0.01	0.01	0.01	0.01	0.02	0.02
May	0.04	0.04	0.04	0.04	0.05	0.05
June	0.08	0.09	0.10	0.10	0.11	0.11
July	0.14	0.15	0.16	0.17	0.18	0.18
August	0.17	0.19	0.20	0.21	0.22	0.23
September	0.16	0.18	0.19	0.20	0.21	0.22
October	0.13	0.15	0.15	0.16	0.17	0.18
November	0.12	0.14	0.15	0.15	0.16	0.17
December	0.05	0.05	0.05	0.06	0.06	0.06
Average	0.08	0.09	0.09	0.10	0.10	0.10

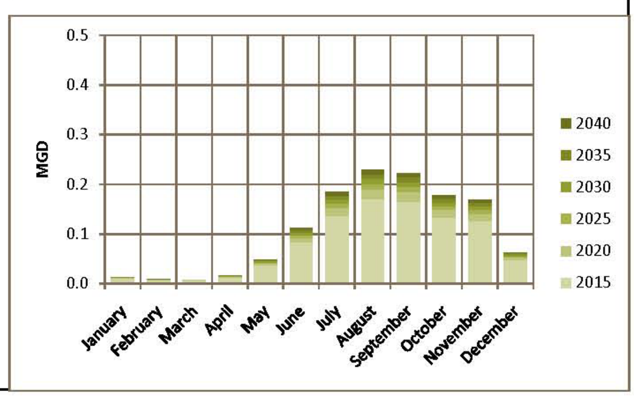
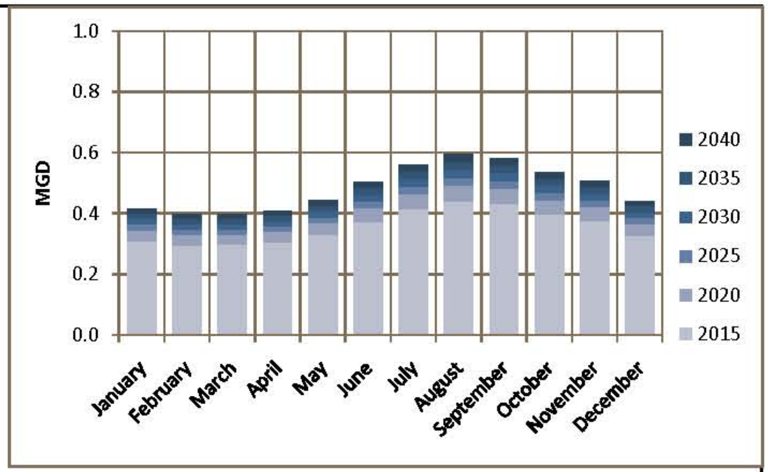


Figure 4-6
Modeled Commercial Water Demands 2015 to 2040

Recreational - Essential						
Demand in MGD	Demand Year					
	2015	2020	2025	2030	2035	2040
January	0.31	0.34	0.36	0.38	0.40	0.42
February	0.29	0.33	0.35	0.36	0.38	0.40
March	0.29	0.33	0.35	0.36	0.38	0.40
April	0.30	0.34	0.36	0.37	0.39	0.41
May	0.33	0.37	0.38	0.40	0.42	0.44
June	0.37	0.41	0.44	0.46	0.48	0.50
July	0.41	0.46	0.49	0.51	0.54	0.56
August	0.44	0.49	0.52	0.54	0.57	0.59
September	0.43	0.48	0.51	0.53	0.56	0.58
October	0.39	0.44	0.46	0.49	0.51	0.54
November	0.37	0.42	0.44	0.46	0.48	0.51
December	0.32	0.36	0.38	0.40	0.42	0.44
Average	0.35	0.40	0.42	0.44	0.46	0.48



Recreational - Irrigation						
Demand in MGD	Demand Year					
	2015	2020	2025	2030	2035	2040
January	0.02	0.02	0.02	0.02	0.02	0.02
February	0.01	0.01	0.01	0.01	0.01	0.01
March	0.01	0.01	0.01	0.01	0.01	0.01
April	0.02	0.02	0.02	0.03	0.03	0.03
May	0.06	0.07	0.07	0.08	0.08	0.08
June	0.14	0.16	0.17	0.18	0.19	0.19
July	0.24	0.27	0.28	0.29	0.31	0.32
August	0.30	0.33	0.35	0.37	0.38	0.40
September	0.29	0.32	0.34	0.36	0.37	0.39
October	0.23	0.26	0.27	0.28	0.30	0.31
November	0.22	0.24	0.26	0.27	0.28	0.30
December	0.08	0.09	0.10	0.10	0.10	0.11
Average	0.13	0.15	0.16	0.17	0.17	0.18

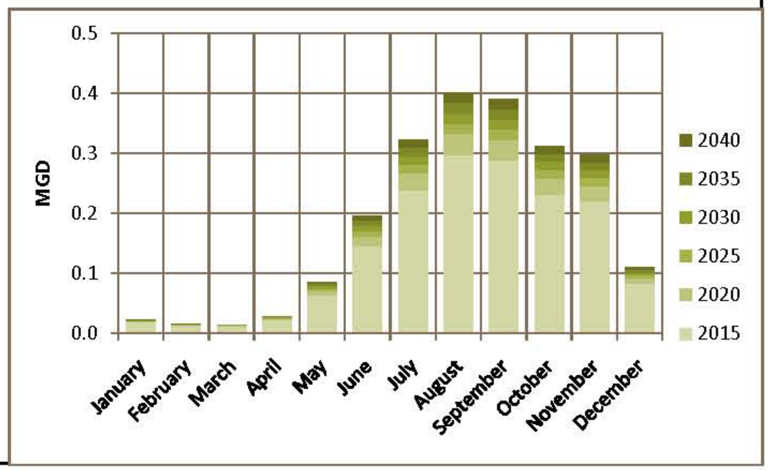


Figure 4-7
Modeled Recreational Water Demands 2015 to 2050

Industrial - Essential						
Demand in MGD	Demand Year					
	2015	2020	2025	2030	2035	2040
January	0.17	0.19	0.20	0.21	0.22	0.23
February	0.17	0.19	0.20	0.21	0.22	0.23
March	0.17	0.19	0.20	0.21	0.22	0.23
April	0.17	0.19	0.20	0.21	0.22	0.23
May	0.17	0.19	0.20	0.21	0.22	0.23
June	0.17	0.19	0.20	0.21	0.22	0.23
July	0.17	0.19	0.20	0.21	0.22	0.23
August	0.17	0.19	0.20	0.21	0.22	0.23
September	0.17	0.19	0.20	0.21	0.22	0.23
October	0.17	0.19	0.20	0.21	0.22	0.23
November	0.17	0.19	0.20	0.21	0.22	0.23
December	0.17	0.19	0.20	0.21	0.22	0.23
Average	0.17	0.19	0.20	0.21	0.22	0.23

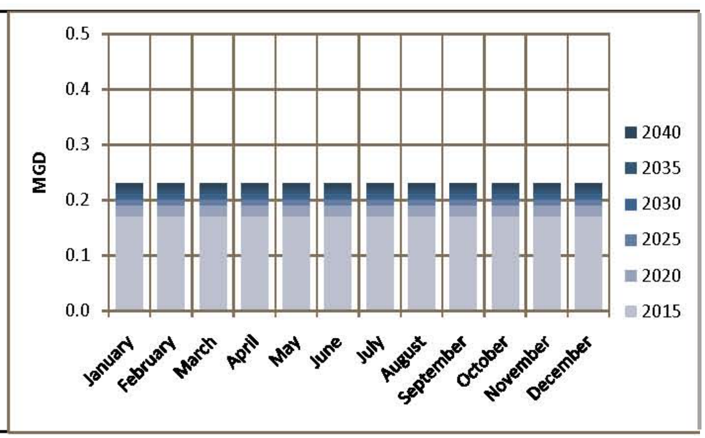


Figure 4-8
Modeled Industrial Water Demands 2015 to 2040

The water supply sector uses user-specified input parameters, along with natural and imposed constraints on the system, to draw water from one or a combination of the sources listed above. **Figure 4-9** shows a representation of the flow of water into Franklin's distribution system. Raw water, either from the Harpeth River or other regional sources, enters the system through the raw water reservoir. Basic reservoir inflows and outflows are included in the model, including direct rainfall, evaporation, leakage, and backwash. Water from the reservoir flows, as demanded, into the Franklin WTP and is then combined with regional treated sources to meet total potable water demands. Different scenarios modeled for the Franklin IWRP used different combinations of water sources to evaluate the cost and performance of Franklin's various water supply options. The following sections discuss the assumptions and specifications of the modeled sources of water.

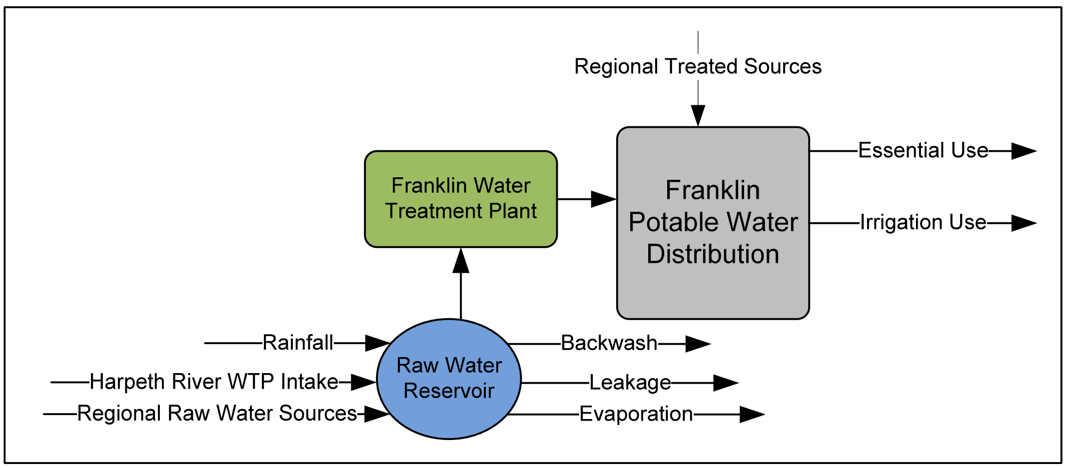


Figure 4-9
Water Supply Sector Schematic

4.3.3 Franklin Water Treatment Plant

The treatment capacity of Franklin WTP presents a constraint for raw water coming into the water supply system. The existing capacity is 2.1 mgd, and three options are included in the model for future capacities: maintain the existing 2.1 mgd, upgrade the plant to 4.0 mgd, and upgrade the plant to a capacity that would treat all of the City's demand for the next 30 years. The modeled demand projections include a maximum monthly average demand of 13 mgd in August 2040. The energy required to operate the WTP was estimated with the equation[1,2]:

[1] One of the measures against which all alternatives were compared, in accordance with stakeholder requests for information, was the amount of energy consumed by each major project.
[2] Carlson, Steven W. and Adam Walburger, 2007. Energy Index Development for Benchmarking Water and Wastewater Utilities. AwwaRF

$$E = e^{8.2+\ln(Q)}$$

Equation 1

E: energy required
Q: flow through the plant

4.3.4 Harpeth River as a Supply Source

Under several modeled IWRP alternatives and under existing conditions, water is drawn from the Harpeth River at maximum allowable rates, as governed by pump capacity and low flow withdrawal constraints. The water available for withdrawal in the Harpeth River is specified by the 2007 Aquatic Resource Alteration Permit (ARAP), which states the following two criteria:

1. Flow in the Harpeth River shall not be reduced below 10 cfs (6.46 mgd) as a result of the withdrawal.

2. Water shall be withdrawn at a rate of no more than 20 percent of the flow in the river at the intake.

The current reported existing capacity of the raw water intake pump is 8.1 mgd but will reportedly discharge only about 7 mgd according to the *2006 Design Report for the Franklin Water Treatment Plant*. The pump capacity is a constraint only when water is available for withdrawal from the Harpeth River at a rate of greater than 7 mgd and when the raw water reservoir requires more than 7 million gallons to meet current demand and maintain its water level.

The raw water reservoir was dredged and a new liner put in around the time that the Franklin IWRP Phase I study and modeling were conducted. The reported reservoir capacity in the 2006 design report was 96.7 million gallons, with only 39.3 million gallons of usable volume. The reservoir leakage rate was estimated at 1 mgd in the 2006 Design Report and assumed to be reduced by 75 percent with the new liner. The reservoir repairs are included as a no-cost option in the integrated model, and when the option is activated the greater reservoir capacity and lesser leakage rate are applied.

4.3.5 Regional Potable Sources

Regional potable sources, namely HVUD, are included in the model to supply remaining City demand that cannot be met with water from the Harpeth River. It is also possible to configure the model to supply all of the City's demand by purchasing treated water from HVUD. The agreement between the City and HVUD stipulates a minimum purchase requirement, or minimum cost to the City to buy any water from the wholesaler. To simulate cost efficient operating procedures, the minimum purchase volume is satisfied before other, cheaper sources are utilized to prevent having the City pay for water that it never uses from HVUD. The current minimum purchase requirement in the agreement between the City and HVUD is 99.7 million gallons per month. In the model, a daily rate of 3.63 mgd is used, which is the estimated minimum purchase volume in 2020 according to the *Jackson Thornton Utilities' Independent Evaluation of Feasibility Study*, conducted by Metcalf & Eddy (June 2008). The capacity of the HVUD pipeline delivering water to Franklin is assumed to be large enough to meet all of the City's demand through 2040.

The energy required to deliver the water via HVUD (originating in the Cumberland River) is estimated using the Darcy-Weisbach friction loss equation and net elevation change to calculate the total hydraulic head:

$$H = f\frac{L}{D} * \frac{V^2}{2g} + z$$

Equation 2a

H = total head loss
f: Darcy friction factor (0.014)
L: pipe length (19 miles)
D: pipe diameter (3 feet)
V: water velocity (flow/area)
g: gravitational acceleration
z: net elevation change of pipeline (360 feet)

Then, using the following equation, the hydraulic head is converted to energy. A pump efficiency of 75 percent was assumed and appropriate conversion factors applied to the equation.

$$E = H * Q * SG$$

Equation 2b

E: energy required
Q: flow through the pipe
SG: specific gravity of water (1.0)

4.3.6 Regional Raw Water Sources

The Franklin integrated model includes an option for the City to meet all of its potable water demand by constructing a pipeline to transport raw water from the Cumberland River. As part of this option, the Franklin WTP would be upgraded to treat all of the City's water supply. A preliminary study was done for the City on various versions of this supply line in 1989 (Franklin Water Facilities and Supply Report). The specifications of the line that are included in the model represent an averaging of the various alternative preliminary designs proposed in this report. **Table 4-5** lists the specifications used in the model. The energy required to transport the water from the Cumberland River to the Franklin WTP is calculated using Equations 2a and 2b above.

Table 4-5
Approximate Cumberland River Supply Line Specifications

Parameter	Model Specification
Length	19 miles
Diameter	3 feet
Darcy friction factor (f)	0.014
Net elevation change	363 feet

4.3.7 Supply Redundancy

An important distinction between Franklin's alternative sources of water is how the City will get water, should its main source be compromised. As part of the integrated modeling analysis, this scenario was simulated for each of the alternatives by turning off the largest source (by volume) and relying only on secondary sources (if any are available). The resulting performance measure was the level to which the City's essential demands could still be met. **Table 4-6** lists the assumptions made as part of this analysis.

Table 4-6
Supply Redundancy Analysis Assumptions

Supply Option	Largest Source by Volume	Secondary Available Source
Withdraw and treat all available water from Harpeth River, satisfy remaining demand with HVUD water purchase	HVUD wholesale purchase	Harpeth River, withdrawal restrictions applied
Shut down WTP, withdraw no water from Harpeth River, satisfy all demand with HVUD water purchase	HVUD wholesale purchase	None (Franklin WTP would be shut down)
Withdraw, transport, and treat water from Cumberland River to satisfy all demand	Cumberland River withdrawal	Harpeth River withdrawal (Assume that this source, while not utilized except in an emergency, would be available, should the City need it. Harpeth River withdrawal restrictions are applied.)

4.4 Wastewater Treatment

The integrated model includes several options for meeting Franklin's long-term wastewater treatment capacity needs. The City's wastewater capacity needs are projected to grow with the increasing water demand, as well as the result of potentially accepting regional wastewater for treatment at the Franklin WWTP. The integrated model compares the daily total demand for treatment with the specified capacity of the wastewater treatment system to calculate the total effluent generated by the plant. The effluent is made available for reclaimed distribution or storage, and that which is not reused is discharged to the Harpeth River. Pollutant loading to the river is calculated based on the discharge volume and permitted concentrations.

Figure 4-10 shows a schematic of the wastewater sector in the Franklin integrated model. The projected demands on wastewater treatment are discussed in the following sections.

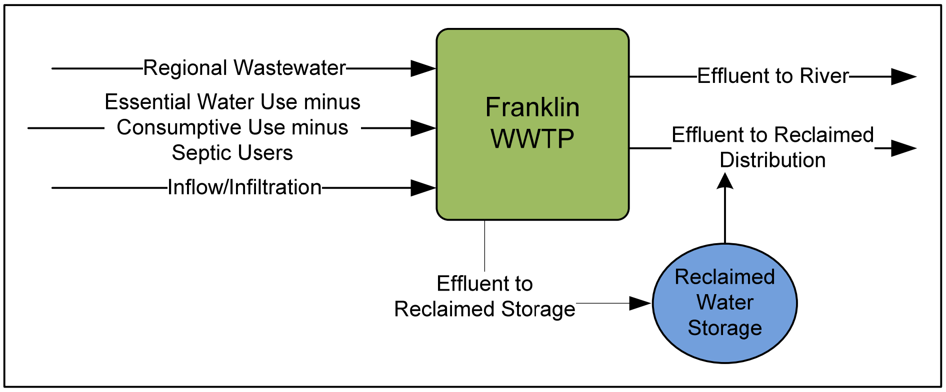


Figure 4-10
Wastewater Treatment Sector Schematic

4.4.1 Wastewater Demand Projections

Demand projections for Franklin's wastewater treatment capacity over the next 30 years are necessarily linked to the City's water supply demand projections. The mass balance of the water resources system depends upon equal volumes of water entering and exiting the system. Wastewater demand projections for use in the integrated model are based on two sources of wastewater: that which is generated within the City as a direct result of water use and that which is imported from outside communities that rely on separate sources of potable water.

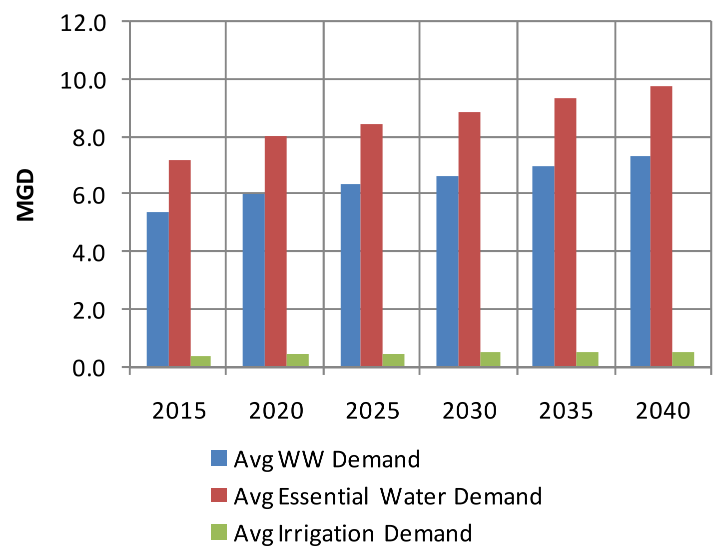
Wastewater demand from City of Franklin water supply customers is calculated using the total essential demand for potable water (see Section 4.3 for water demand values and explanation). The total essential demand is reduced by a factor to represent only usage of water travelling to the WWTP. The wastewater generation factors are estimated monthly averages based on a typical rate of 90 percent of water that is used indoors. Essential use estimates were developed from City billing records that specify some billing for outdoor use. It is assumed that not all outdoor uses (particularly individual residential irrigation) are billed as such. This is apparent in the large increase in indoor residential water demands in the summer months. For wastewater demand purposes, monthly essential water demands were reduced to 90 percent of normal winter essential use. **Table 4-7** shows the wastewater generation factors that were applied to essential potable demand totals to calculate wastewater demand. The percentages are variable throughout the year because, for the purposes of this IWRP, essential demands are greater in the summer than in the winter. **Table 4-8** and the accompanying graph show the in-City wastewater demand projections for 2015-2040.

Table 4-7
Wastewater Generation Factors

Month	Wastewater Generation, as % of Total Essential Demand
January	87
February	90
March	90
April	88
May	81
June	72
July	65
August	61
September	62
October	68
November	72
December	82

Table 4-8
Projected In-City Wastewater Demands

Projection Year	Average Wastewater Demand, mgd
2015	5.5
2020	6.0
2025	6.3
2030	6.7
2035	7.0
2040	7.3



Additional wastewater inflow is added to the total demand on the Franklin system when the option is activated to accept regional wastewater from neighboring communities. Based on discussions with the City, the additional wastewater demand on the system is estimated at 1 mgd.

Inflow and infiltration (I/I) also effectively place a demand on the wastewater treatment system. The volume of I/I entering the collection system is greatly dependent upon rainfall and has not been quantified extensively within the Franklin wastewater collection system. The planning-level estimates of I/I used in the integrated model are based on seasonal rainfall trends and recent wastewater inflow data. The total average monthly rainfall, average wastewater inflow, and estimated sanitary wastewater generation for 2001 through 2009 were compared to develop an average I/I estimate for input into the model. **Table 4-9** shows the monthly values used for I/I into the collection system. The values were not escalated over the next 30 years, but were reduced by 50 percent, if the option to address I/I was activated.

Table 4-9
Estimated Inflow and Infiltration

Month	Inflow and Infiltration (mgd)
January	3.1
February	4.4
March	3.5
April	3.5
May	3.0
June	1.0
July	0.6
August	0.6
September	1.1
October	1.5
November	1.7
December	3.8
Average	2.3

4.4.2 Franklin Wastewater Treatment Plant

The capacity of the existing plant is set to the current design capacity of 12 mgd. The future capacity, when the option to upgrade the WWTP is activated, is set to be 15 mgd. This value was used in cost and energy calculations and would be sufficient to handle the projected seasonal peak demands in 2040. **Figure 4-11** shows the highest average monthly wastewater demands projected for 2015—2040 along with the existing and upgraded WWTP capacities.

Pollutant loading to the Harpeth River related to WWTP effluent was calculated based on the waste load allocation given to the WWTP in its 2009 NPDES permit. Data from the plant's MORs from 2001 through 2009 shows that the actual loadings are less, but for the purposes of relative comparison of alternatives, the NPDES values are appropriate. **Table 4-10** shows the values in pounds per million gallons used, along with the modeled effluent discharged to the river to calculate the total pollutant loading from the plant in pounds per day.

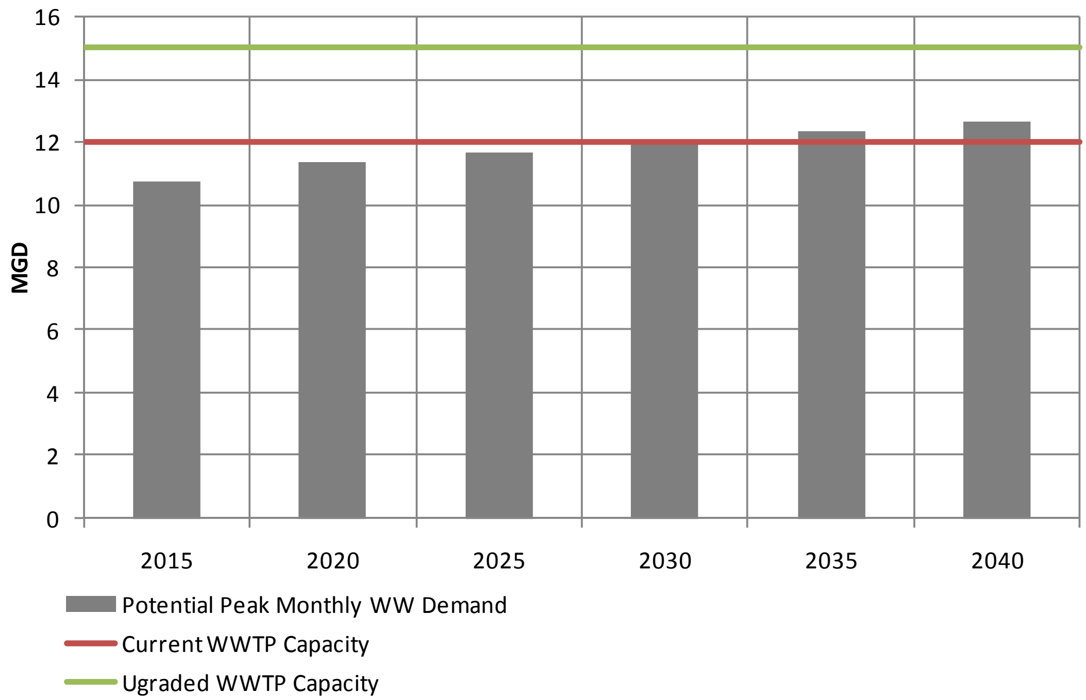


Figure 4-11
Potential Peak Monthly Wastewater Demands and Treatment Capacities (Franklin WWTP)

Table 4-10
Allowable NPDES WWTP Effluent Pollutant Loading Rates

Season	Loading, lbs/MG	
	BOD[3]	Nitrogen
January – April and November – December	83.4	60.0
May – October	33.4	41.7

The integrated model includes an option to reduce the pollutant loading to the river in the summertime by introducing a more advanced method of treatment, which was assumed to be reverse osmosis (RO). The RO system would only be run in the summer months (May-October) and would result in lower nitrogen and BOD loads in those months, which are listed in **Table 4-11**, and derived from RO studies and projects in Tucson, AZ and Miami-Dade County, FL.

[3] Stakeholders identified BOD (Biological Oxygen Demand) and Nitrogen as the two most important indicators of water quality in the Harpeth River. Hence, the model was developed to track these two pollutants.

Table 4-11
Reduced Franklin WWTP Effluent Pollutant Loading Rates

Season	Loading, lbs/MG	
	BOD	Nitrogen
January – April and November – December	83.4	60.0
May – October	10.0	14.6

Energy requirements to run the WWTP were estimated based on the following equation[4]:

$$E = e^{15.8+\ln(Q)}$$

Equation 3

E: energy required
Q: flow through plant

Energy requirements to run the RO system were estimated at approximately 4,000 kWh per million gallons[5].

4.4.3 Goose Creek Wastewater Treatment Plant

A potential solution for meeting Franklin's future wastewater treatment needs is to build a new plant at the location known as Goose Creek. The City has previously acquired this land, which is located on the Harpeth River upstream of the Franklin WTP. The proposed Goose Creek plant capacity was estimated to be 2 mgd. **Figure 4-12** shows the highest average projected wastewater demands for 2015—2040 along with the existing Franklin WWTP capacity and the additional capacity that would be added with the Goose Creek WWTP.

In order to meet anticipated stringent effluent limits and garner public support for a new wastewater plant discharge upstream of a water supply intake, the proposed Goose Creek plant would include advanced treatment processes such as membrane bioreactor (MBR) and tertiary polishing wetlands. The model integrates the advanced treatment into the system by sending 2 mgd of wastewater demand to the Goose Creek plant and reducing the pollutant loads in the effluent. **Table 4-12** shows the reduced pollutant loads that can be expected from using MBR and tertiary polishing wetlands.

[4] Carlson, Steven W. and Adam Walburger, 2007. Energy Index Development for Benchmarking Water and Wastewater Utilities. AwwaRF
[5] Voutchkov, Nikolay. Seawater Reverse Osmosis Design and Optimization. Advance Membrane Technologies, Stanford University 2008.

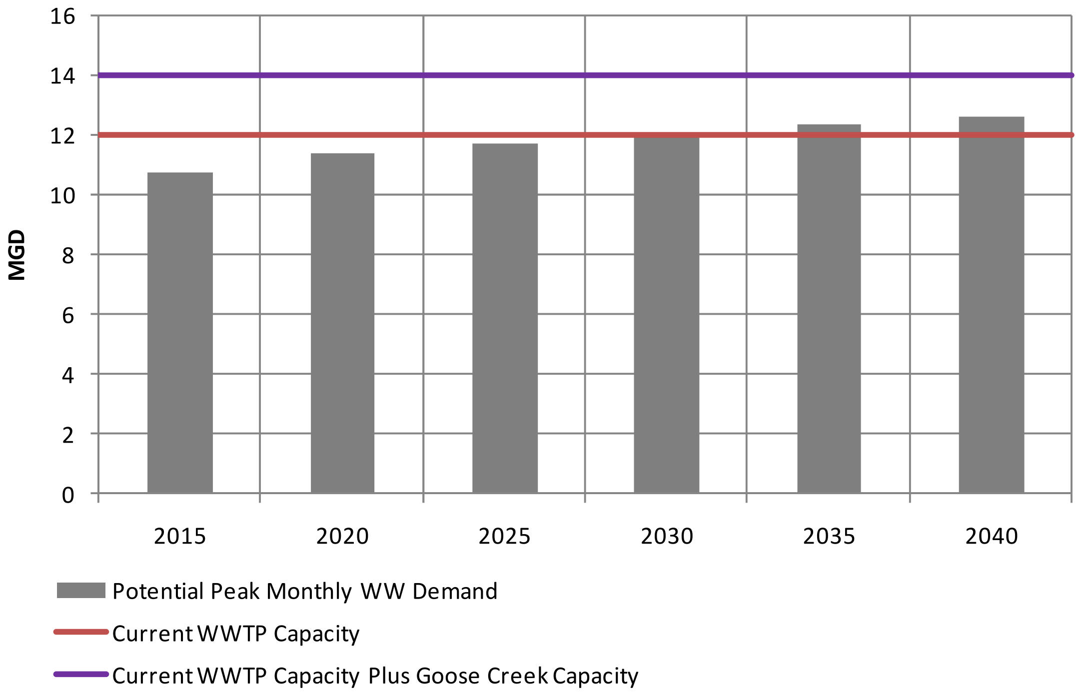


Figure 4-12
Potential Peak Monthly Wastewater Demands and Treatment Capacities (Franklin and Goose Creek WWTPs)

Table 4-12
Estimated Goose Creek WWTP Effluent Pollutant Loading Rates

Season	Loading, lbs/MG	
	BOD	Nitrogen
January – April and November – December	20.9	60.0
May – October	20.9	41.7

4.4.4 Biosolids Management

The integrated model takes into account biosolids management only as far as estimating the volume of solids generated, the cost of each option, and the energy required or generated by the processes. The volume of biosolids generated was estimated based on the total wastewater treated and whether or not processes to generate higher total solids content were activated in the model. The basis of these calculations was an assumption of 11,000 tons of biosolids generated per year under a flow of 10 mgd through the plant, and a 40-percent reduction in weight, if high total solids processes are employed[6]. By using the total WWTP flow to calculated biosolids generation, the total volume of biosolids escalates

[6] Hallsdale-Powell Utility District Beaver Creek WWTP Phase 3 Solids Train Upgrade, Draft Preliminary Engineering Report, November 2009 (CDM)

with wastewater demand over the planning period. The energy required or generated in processing the biosolids varies among the different management options included in the model. **Table 4-13** offers a summary of how the energy estimates are calculated in the model. Energy required to transport biosolids is included in these net estimates, and is based on 15 kWh per gallon of gasoline needed.

Table 4-13
Biosolids Energy Requirements and Generation Estimates

Option	Net Energy Estimate in kWh/ton
Current process with landfill disposal	13 (required)
Current process with Metro Nashville disposal	5 (required)
Upgrade to Class A biosolids	1,800 (required)
Upgrade to ash disposal	1,000 (required)
Upgrade to higher total solids content	650 (required)
Upgrade to Class A and composting	1,000 (required)
Upgrade to biogas	1,000 (generated)
Land application	(no additional energy required)

4.5 Stormwater

The performance of various stormwater management options was evaluated in the model using a simple representation of the Harpeth River drainage basin and Franklin's stormwater system. The stormwater sector of the integrated model is not a hydrologic model of the watershed, nor is it a parameterized model of the City's stormwater collection system. **Figure 4-13** shows a schematic of how the integrated model stormwater sector is set up. Estimated stormwater flows and loads from different land use types are routed either directly to the river (through collection and conveyance), through BMPs, or to localized storage for reuse. Stormwater flowing to the river is quantified at a single point representing the City's aggregated runoff contribution to streamflow. The point of stormwater quantification and measurement of the impact of stormwater is at the downstream end of the modeled City area.

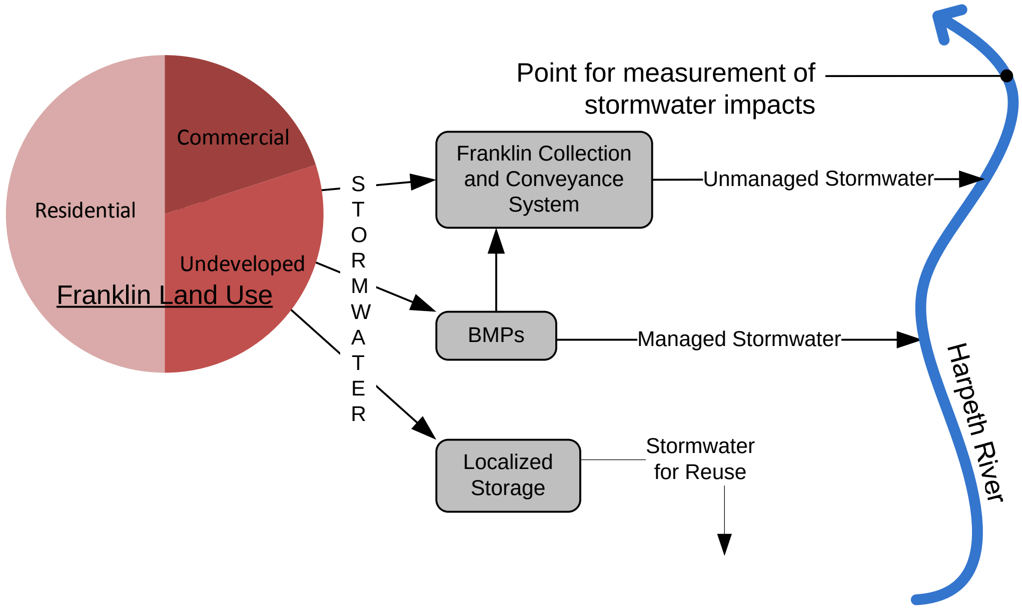


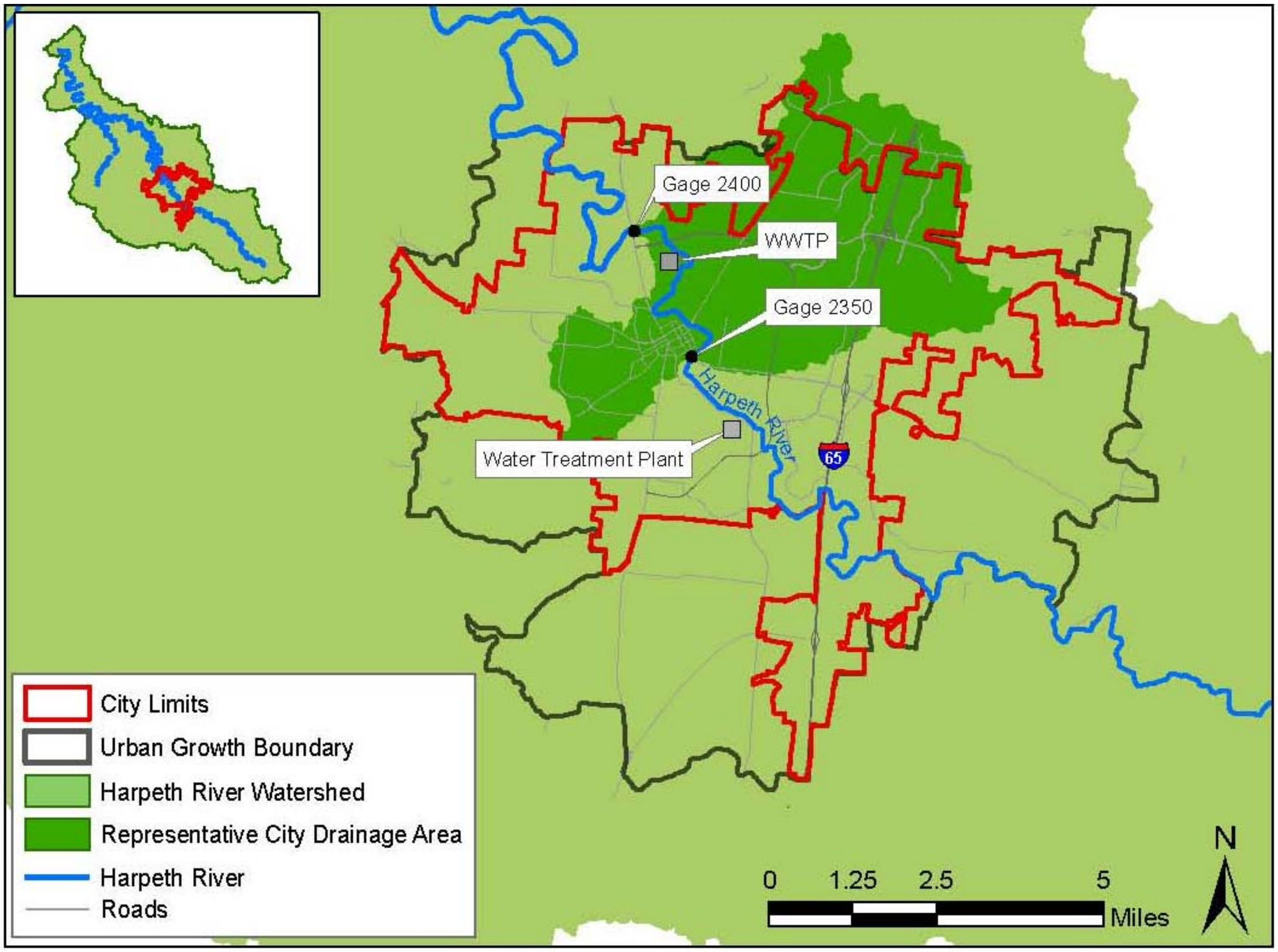
Figure 4-13
Stormwater Sector Schematic

4.5.1 Estimated Stormwater Flow

The model uses a representative volume of stormwater generated by three broad land use types within the City based on streamflow data and river withdrawals and discharges over the hydrologic period of record (1975 through 2009). There are two USGS streamflow gauges on the Harpeth River in Franklin, referred to herein as gauge 2530 and gauge 2400. Gauge 2350 is upstream of most of the City, located just downstream of the WTP intake. Gauge 2400 is located downstream of most of the City and downstream of the wastewater treatment plant discharge. The difference in drainage area of these two gauges (19 square miles) is used as a representative subset of the Harpeth River watershed within the City of Franklin for the purposes of the integrated modeling. **Figure 4-14** shows the stream gauges and the representative drainage area within the City[7]. Streamflow data are available for gauge 2350 for the entire hydrologic period of record, but only incomplete gauge data are available for gauge 2400 from 10/1/1988 through 12/31/2009. A linear relationship between the two gauges was observed (Equation 4 and **Figure 4-15**) and used to calculate the flow at the downstream gauge for days when no data were available.

[7] Note that the representative drainage area for stormwater does not cover the entire watershed nor the entire city of Franklin. However, it was used to study representative stormwater contributions to the Harpeth River because it was bounded by extensive data from which stormwater flow could be directly calculated, it bounds a geographic area that is sensitive to all key decisions on water, wastewater, and reclaimed water, and is a reasonable cross section of land use types in the Franklin community. The model also includes the effects of runoff upstream of this drainage area, as well as projects that may be sited beyond its boundaries, such as the Goose Creek WWTP, for example.

Figure 4-14
Representative City Stormwater Drainage Area



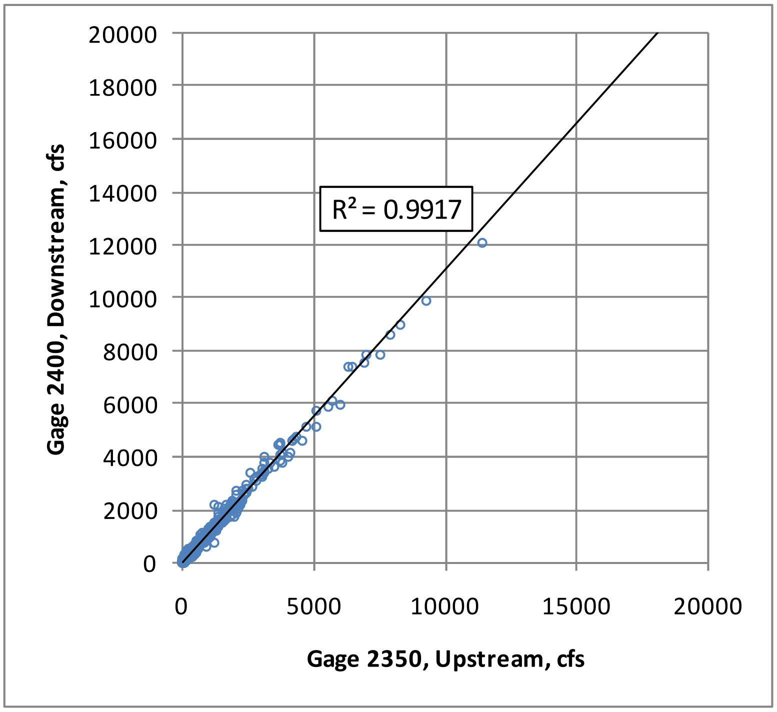


Figure 4-15
Streamflow Gauge Correlation

$$Q_{2400} = 1.105Q_{2350}$$

Equation 4

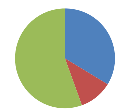
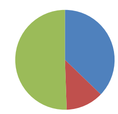
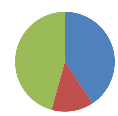
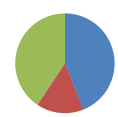
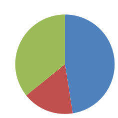
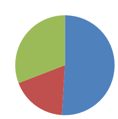
Q_{2400}: flow at downstream gauge
Q_{2350}: flow at upstream gauge

The flow difference between the two gauges (and without the estimated WWTP discharge discussed in Section 4.2) is used in the model as a daily time series of historical stormwater volume from the representative drainage area. This time series represents the stormwater that is available for collection and reuse, has potential to be managed through BMPs, and may eventually be quantified as stormwater flow to the river.

4.5.2 Land Use Types

The stormwater volume is partitioned into daily flow from three landuse types to facilitate calculations of typical runoff loads and estimate stormwater availability for land use specific BMPs and reuse strategies. The development of Franklin's land over the planning period is derived from the 2004 Land Use Inventory and discussions with the City. **Table 4-14** shows the fraction of the City's land that falls into the three relevant land use categories. Runoff from each of the land use categories is not directly proportional to that land cover fractions in the table but, rather, is a function of the percentage of land cover and the typical runoff coefficient for that land use. For example, runoff from commercial land in 2015 would be higher than 11 percent of the total, and this would be balanced by runoff from undeveloped land being less than 55 percent of the total. But the runoff coefficients are only applied to the fraction of land to which they are relevant. The effective runoff coefficients for the three land use types are Residential 1.0, Commercial 1.8, and Undeveloped 0.51.

Table 4-14
Franklin Projected Land Use

Projection Year	Residential	Commercial	Undeveloped	
2015	34%	11%	55%	
2020	37%	12%	51%	
2025	41%	14%	46%	
2030	44%	15%	41%	
2035	48%	17%	36%	
2040	51%	18%	31%	

4.5.3 Pollutant Loads

Pollutant loading to the Harpeth River due to stormwater was estimated using typical values of BOD and nitrogen concentrations found in stormwater from the USGS Nationwide Urban Runoff Program (NURP) database[8]. The concentrations from Knoxville, TN were averaged with the national average concentrations to estimate the pollutant loads in Franklin. It is likely that Franklin's stormwater contains more or less BOD and nitrogen than the values used in the model; but for comparative purposes, the estimations of stormwater pollutants developed

[8] Stakeholders identified BOD (Biological Oxygen Demand) and Nitrogen as the two most important indicators of water quality in the Harpeth River. Hence, the model was developed to track these two pollutants.

from the NURP database are sufficient. **Table 4-15** lists the concentrations used in the model by land use type. These concentrations are multiplied by the modeled stormwater flow from each land use type to calculate loading to the river in pounds per day.

Table 4-15
Estimated Pollutant Concentrations in Stormwater

Land Use Type	BOD, mg/L	Nitrogen, mg/L
Residential	11	2.3
Commercial	11	2.6
Undeveloped	8.3	1.6

Several options included in the IWRP involved stormwater BMPs, ordinance, and other strategic controls to reduce the negative impacts of stormwater on the Harpeth River. As the model is not a representation of watershed or stream channel processes, it is not possible to quantify the effects of these various options on flood levels or flood frequency (i.e., hydraulic response to stormwater runoff). Therefore, flooding impacts have been included as qualitative performance measures: negative impacts of stormwater reduced and change in 100-year flood elevation. The total volume of stormwater, as it affects river flow, is simulated in the model hydrologically, but not hydraulically.

Projects and policies in the IWRP that aim to reduce stormwater pollutant loading to the river are considered in the model by reducing the volume of stormwater or the concentration of pollutants in stormwater that reaches the river. For example, residential rain barrels intercept stormwater flow from pervious surfaces, therefore reducing the volume that flows unabated to the river. Constructed wetlands also reduce volume by facilitating infiltration, but also reduce levels of pollutants in stormwater that eventually flows to the river. In the model, estimates of BMP sizes and pollution reduction capabilities are used to modify the basic flow concentration equation to calculate the resulting, reduced load when BMPs are activated. **Table 4-16** lists the assumptions of size and pollutant reduction capabilities used in the model.

Table 4-16
Stormwater BMP Assumptions

Flow Captured by BMPs	**% of Flow from Total Drainage Area**		
Constructed Wetlands	5%		
Pervious Pavement	5%		
Rain Gardens	7%		
Reductions Performed on Flow Captured by BMPs -			
BMP Pollutant Reductions[1]	**BOD**	**Nitrates**	**TKN**
Constructed Wetlands	20%	30%	30%
Pervious Pavement	20%	65%	65%
Rain Gardens	20%	50%	50%
Runoff Lost through ET, Infiltration, etc.	**% of Inflow to BMP**		
Constructed Wetlands	20%		
Pervious Pavement	80%		
Rain Gardens	10%		

1: State of Georgia Stormwater Manual

4.6 Reclaimed Water Distribution

The Franklin integrated model represents the City's reclaimed water system by comparing the water available for reuse—wastewater effluent and collected stormwater—with the demand for reclaimed water and the infrastructure available to store and transport the water. Several key assumptions were made in model development and will be explained in this section:

- The City predicts that there is an untapped demand for reclaimed water. Historical non-essential use patterns are therefore not completely explanatory in the development of future demand projections. The City believes that the demand for reclaimed water will increase with improved and increased infrastructure to deliver the water to customers. In other words, extrapolating historical use of reclaimed or non-essential water use into the future would likely under predict the actual demand, once the infrastructure and the resource itself are fully available.

- Projected demand for water use sectors is based on the City's 2009 Reclaimed Water System Master Plan.

- Water reuse will offset the demand for potable water for irrigation, but this offset must be limited to the volume of potable water that customers would actually purchase to meet their irrigation needs. In the model, this limit is based on recent billing data for irrigation uses (See Section 4.3 for discussion and values of irrigation water demands).

Figure 4-16 shows a schematic of the modeled reclaimed water distribution system. Similarly to potable water use, reclaimed water use is segmented into 4 sectors: residential, commercial, recreational, and industrial. There are two sources of water available for reuse: WWTP effluent as a large, centralized source requiring major infrastructure for distribution, and collected stormwater as a smaller, decentralized source requiring individual customers to initiate collection and reuse. Both sources would otherwise flow to the Harpeth River.

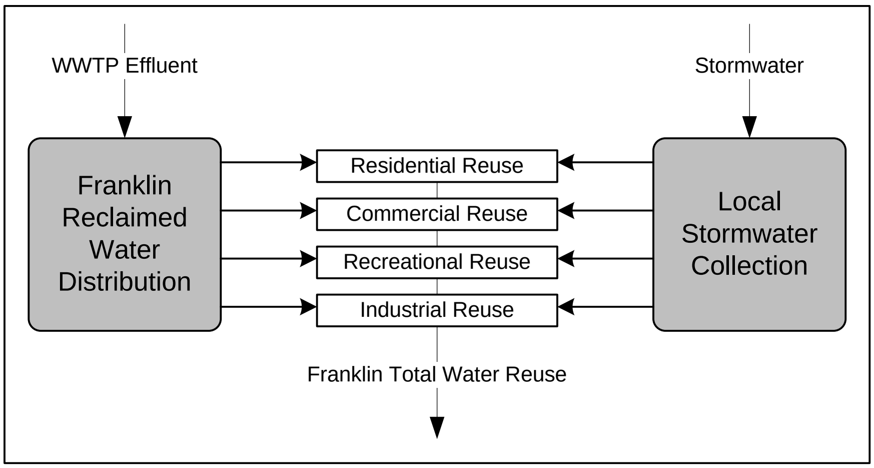


Figure 4-16
Franklin Reclaimed Water Model Schematic

4.6.1 Stormwater Reuse

Stormwater reuse volumes are difficult to estimate with accuracy without further study into potential collection technologies and locations. The model uses estimated rates of capture for residential, commercial, and recreational users to calculate how much stormwater could be made available for reuse on a localized scale. When stormwater reuse options are activated, the demand on the reclaimed wastewater system is reduced by the appropriate amount. **Table 4-17** lists the assumptions that define the amount of available stormwater for reuse. The land use sectors are discussed with the stormwater model sector, Section 4.5, and correspond to the fraction of the land area included in the representative City stormwater drainage basin that could contribute runoff to the respective stormwater collection for reuse. These fractions represent the percentage of stormwater runoff from each land use that is collected and available for reuse. The land fractions change throughout the planning period according to land development projections set forth in the City of Franklin's 2004 Land Use Inventory. The modeled captured runoff is equal to the rainfall volume over the fractional land area, not exceeding the maximum capture volume. Daily rainfall totals for the hydrologic period of record were obtained from the Franklin WWTP rain gauge. The maximum capture rate is small in order to represent the volume of water that would actually be available for use after potential infiltration, evaporation, storage limitations and other factors that may prevent rain water from being reused.

Table 4-17
Assumptions Defining Stormwater Available for Reuse

Sector	Runoff Fraction Available (%)	Maximum Capture Rate (Inches of Rainfall per Day)
Residential	2	0.1
Commercial	20	0.1
Recreational	20	0.1

4.6.2 Reclaimed Wastewater Effluent

The total volume of wastewater effluent available for distribution is decided in the wastewater treatment sector of the integrated model and is ultimately the result of total potable water use within the City (Section 4.4). The wastewater effluent is pumped into the reclaimed water distribution system. The current capacity of the pump is 7.5 mgd, and the modeled future capacity with upgrades is 12 mgd. Reclaimed water distribution options in the model represent the various projects discussed in the *Reclaimed Water System Master Plan* (2009) and establish how much reclaimed water can be transported to customers. Through discussions with the City, the capacities and target sectors for each of the reclaimed water infrastructure projects were established and are listed in **Table 4-18**.

Table 4-18
Reclaimed Water Infrastructure Capacities

Infrastructure Option	Line Capacity (mgd)	Customer Type, Res/Com/Rec/Ind
Current Distribution Lines	1.0	Residential
	2.0	Commercial
	3.0	Recreational
12" Long Lane Line	3.5	All
Horton Lane Force Main	1.6	Residential, Recreational
12" Columbia Ave/SE Pkwy Line	3.6	All
Total	**14.7**	

An option to incorporate significant reclaimed water storage to alleviate the seasonality of demands is also included in the model. The modeled volume of this new storage is 30 million gallons. This would allow alternative plans to manage effluent volumes into the river.

Based on current demands, the recreational sector is the largest user of reclaimed water (principally, golf courses). The model logic is set to supply the recreational sector with reclaimed water to meet its demands first and then split the remaining supply between the commercial and residential sectors. Currently, the industrial sector does not provide a large demand for reclaimed water, though the potential for installing lines to provide a less seasonally variable flow of reclaimed water to industrial users will be explored in Phase II of the Franklin IWRP study.

The energy required to deliver reclaimed water to customers is related to the pumping of wastewater effluent from the treatment plant into the distribution system. The following equation was used to estimate the pumping energy required[9]:

$$E = e^{12+\ln(1.25Q)}$$

Equation 5

E: energy required
Q: flow to reclaimed water distribution

4.6.3 Reclaimed Water Demand Projections

Demand projections for reclaimed water were calculated based on values in the 2009 *Reclaimed Water System Master Plan*. This document lists various potential users and potential demands which were aggregated into the water use sectors (residential, commercial, and recreational) and projected out over the planning period. The escalation of reclaimed water demand is related to the time at which the City anticipates infrastructure could be built to supply those customers. **Table 4-19** lists the projected average reclaimed water demands by projection year and water use sector. The seasonal variation in reclaimed water demands is large, considering that most reclaimed water usage is for irrigation. The monthly variations were developed using records of wastewater effluent sent to reuse and discussions with stakeholders and the City. **Table 4-20** shows the monthly multipliers used for reclaimed water demand for the water use sectors. **Figures 4-17** through **4-19** show the calculated reclaimed water demands used in the model.

Table 4-19
Projected Average Reclaimed Water Demands

Projection Year	Residential (mgd)	Commercial (mgd)	Recreational (mgd)	Total (mgd)
2015	0.49	0.72	1.89	3.10
2020	0.77	0.89	2.00	3.65
2025	1.15	1.18	2.08	4.40
2030	1.93	1.96	2.08	5.97
2035	2.71	2.74	2.08	7.53
2040	3.49	3.52	2.08	9.09

[9] Carlson, Steven W. and Adam Walburger, 2007. Energy Index Development for Benchmarking Water and Wastewater Utilities. AwwaRF

Table 4-20
Projected Monthly Multipliers for Reclaimed Water Demands

Month	Residential and Commercial	Recreational
January	0.22	0.03
February	0.19	0.01
March	0.39	0.01
April	0.70	0.10
May	0.85	0.15
June	2.07	1.03
July	1.69	2.23
August	2.00	3.32
September	1.73	2.18
October	1.24	1.38
November	0.71	1.11
December	0.22	0.46

Residential Reclaimed

Demand in MGD	Demand Year					
	2015	**2020**	**2025**	**2030**	**2035**	**2040**
January	0.11	0.17	0.25	0.42	0.59	0.76
February	0.10	0.15	0.22	0.37	0.53	0.68
March	0.19	0.30	0.44	0.74	1.05	1.35
April	0.34	0.54	0.80	1.35	1.89	2.44
May	0.42	0.65	0.97	1.64	2.30	2.97
June	1.02	1.59	2.37	3.99	5.61	7.23
July	0.83	1.30	1.94	3.25	4.57	5.89
August	0.99	1.54	2.29	3.85	5.41	6.98
September	0.85	1.33	1.98	3.33	4.67	6.02
October	0.61	0.95	1.42	2.38	3.35	4.32
November	0.35	0.55	0.82	1.37	1.93	2.48
December	0.11	0.17	0.25	0.42	0.59	0.76
Average	0.49	0.77	1.15	1.93	2.71	3.49

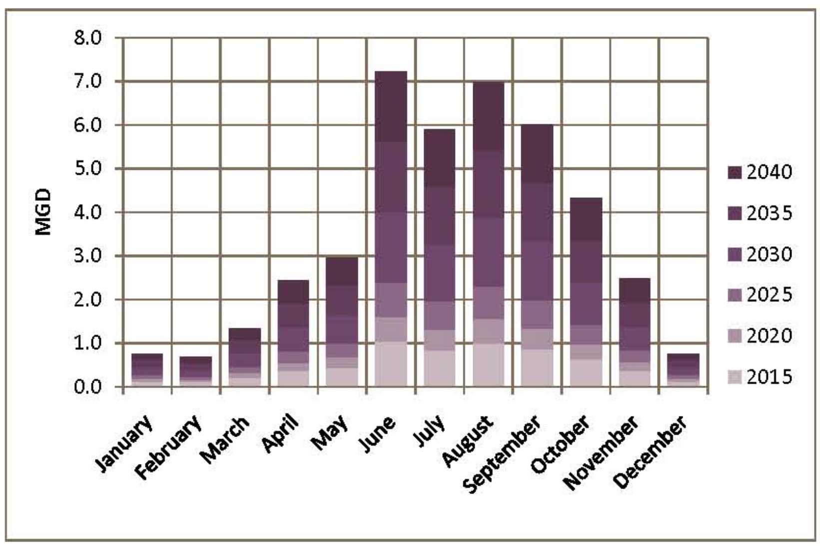


Figure 4-17
Modeled Residential Reclaimed Water Demands 2015 to 2040

Commercial Reclaimed						
Demand in MGD	Demand Year					
	2015	2020	2025	2030	2035	2040
January	0.16	0.19	0.26	0.43	0.60	0.77
February	0.14	0.17	0.23	0.38	0.53	0.68
March	0.28	0.34	0.45	0.76	1.06	1.36
April	0.50	0.62	0.82	1.37	1.91	2.46
May	0.61	0.75	1.00	1.66	2.33	2.99
June	1.49	1.84	2.44	4.05	5.67	7.29
July	1.21	1.50	1.99	3.31	4.62	5.95
August	1.44	1.77	2.35	3.91	5.47	7.04
September	1.24	1.53	2.03	3.38	4.73	6.08
October	0.89	1.10	1.45	2.42	3.39	4.35
November	0.51	0.63	0.84	1.39	1.95	2.51
December	0.16	0.19	0.26	0.43	0.60	0.77
Average	0.72	0.89	1.18	1.96	2.74	3.52

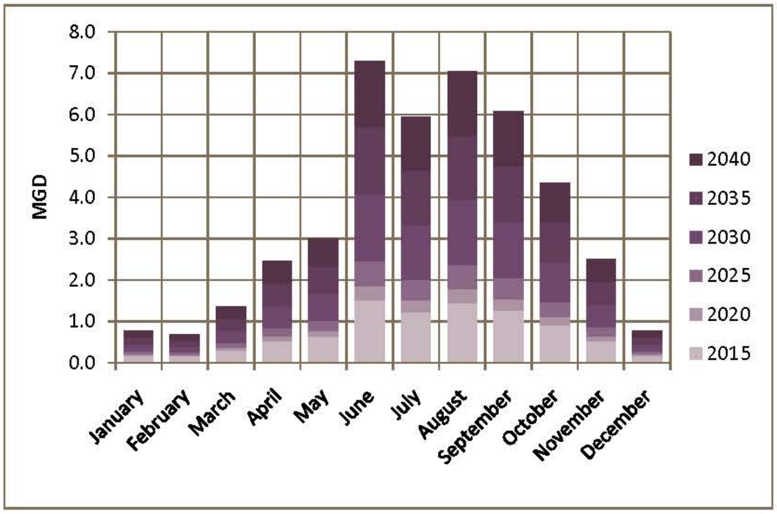


Figure 4-18
Modeled Commercial Reclaimed Water Demands 2015 to 2040

Recreational Reclaimed			
Demand in MGD	Demand Year		
	2015	2020	2025 - 2040
January	0.05	0.05	0.05
February	0.02	0.02	0.02
March	0.01	0.01	0.01
April	0.18	0.19	0.20
May	0.28	0.29	0.30
June	1.95	2.06	2.15
July	4.22	4.45	4.64
August	6.28	6.63	6.91
September	4.13	4.36	4.54
October	2.61	2.75	2.87
November	2.10	2.21	2.31
December	0.87	0.92	0.96
Average	1.89	2.00	2.08

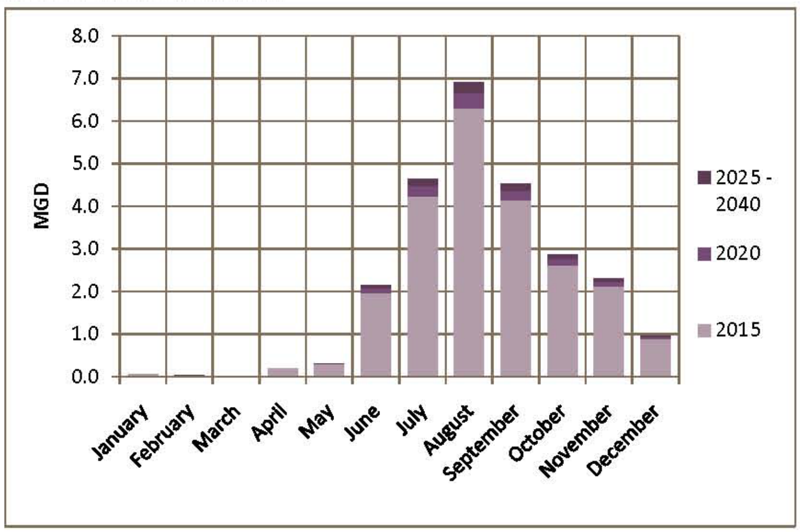


Figure 4-19
Modeled Recreational Reclaimed Water Demands 2015 to 2040

4.6.4 Streamflow Augmentation

In addition to localized stormwater collection and reclaimed wastewater effluent reuse for irrigation, the IWRP includes an option to use Robinson Lake to augment low flows in the Harpeth River. Robinson Lake is located upstream of the Franklin WTP and currently has an unmanaged rock weir structure controlling flow discharge to the river. The project option involves constructing an outlet structure to release flow from the lake when the river flow is extremely low. The specifications of the model representation of this scenario are listed in **Table 4-21**.

Table 4-21
Robinson Lake Streamflow Augmentation
Specifications and Assumptions

Parameter	Model Specification
Lake Area	11 acres
Lake Drainage Area	100 acres
Usable Storage Volume	1 foot over lake area, total 11 ac-ft
River Low Flow Trigger for Robinson Lake Release	Median September flow: 3.78 mgd (5.85 cfs)
Release Rate	Variable with volume, up to 1 mgd

If the drainage area to Robinson Lake was entirely impervious—1.3 inches of rain would fill the 11 acre-feet of usable storage. Considering pervious surfaces, it is assumed that 3.0 inches of rain would be needed to fill the usable storage. Under this assumption, a constant multiplier was calculated to estimate the volume of storage replenishment from rainfall in the 100-acre drainage area and used, along with the historical rainfall time series, to calculate the inflow to the lake from runoff. The release of water from Robinson Lake is triggered when the streamflow in the river falls below the historical September median flow and is released at a rate that varies with lake volume.

4.7 Modeled Option Costs

Preliminary life-cycle costs for each option included in the Franklin IWRP Phase 1 analysis were developed through engineering estimates, using available existing plans, and discussions with the City. The costs are appropriate as planning-level estimates that can be used to compare options and alternatives to help the City see the general tradeoffs between performance and cost. **Table 4-22** lists each option, the estimated capital and annual operating costs, and the source of the estimate. Many costs depend on variables such as volume pumped or flow through a treatment plant, so it is not possible to report a single value for annual operating cost as the value changes with different alternatives.

Category	Options	Capital Cost	Annual or Operating Cost	Source
Water Supply	Upgrade existing 2.1 MGD WTP and purchase remaining water from HVUD	$4,841,500	$2.55 per 1000 gallons purchase, $1.72 per 1000 gallons produced	AECOM - Design Report for Franklin WWTP
	Expand existing WTP to 4.0 MGD, upgrade WTP intake structure and purchase remaining water from HVUD	$6,739,000	$2.55 per 1000 gallon	
	Shut down existing WTP and purchase all water from HVUD	$1,293,350		
	Construct raw water transmission line from the Cumberland River and upgrade water treatment plant to supply all City demand	$67,500,000		Consoer, Townsend & Associates - Franklin Water Facilities and Supply Report
Conservation	Indoor and outdoor conservation (public education, etc)		$20,000 per year	Five Mile Creek Watershed Management Plan
	Low flow incentives		$50,000 per year, for 6 years	
Water Distribution	Remove outdated tanks	$2 per gallon capacity		Engineering estimate
	Address water loss	$350,000	$1.0 to 1.2 million per year	City of Franklin
	Install advanced metering	$3,000,000		
Wastewater Treatment	Construct new WWTP at Goose Creek	$150,000,000	$0.86 per 1000 gallon	Engineering estimate and City of Franklin
	Collect and treat wastewater from adjacent communities or other small systems (e.g., Lynwood, Cartwright Creek)		$0.86 per 1000 gallon	City of Franklin
	Upgrade and rerate existing WWTP	$2.50 per gallon capacity		CDM - Prelim Design Report for Kingsport WWTP Improvements
Collection System	Address inflow and infiltration	$1,350,000		City of Franklin
	Hook up septic users to sewer	$5040 per hook-up		Five Mile Creek Watershed Management Plan
Biosolids	Upgrade biosolids facilities for biogas to energy	$23,950,000	$563,000 per year	CDM - Hallsdale-Powell Prelim Engineering Report
	Upgrade solids handling facilities to produce Class A solids	$21,430,000	$739,000 per year	
	Upgrade solids handling facilities to drying/ERS (ash disposal)	$20,190,000	$845,000 per year	
	Upgrade solids handling facilities to produce higher TS content sludge	$18,760,000	$824,000 per year	
	Class A biosolids to Franklin's composting facility	$21,430,000	$739,000 per year	
	Solids trucked to Metro Nashville for disposal/processing		$37.20 per ton	City of Franklin
	Solids disposal at BFI (108 miles/trip)		$39.00 per ton	
	Land application (Switch grass production)	$55,000		John Buchanan (UT) - Dispersal System Study
Reclaimed Water	Complete the 12" Long Lane line and retrofit the existing 500,000 gallon Long Lane water reservoir for reclaimed water service	$410,000		Smith Seckman Reid - Reclaimed Water System Master Plan
	Complete the distribution loop around the city by constructing the 12" Columbia Avenue/Southeast Parkway reclaimed line and construct a 500,000 gallon storage tank in the vicinity of Winstead Hill	$2,320,000		
	Identify and establish dedicated reclaimed water sites	$2,500,000		
	Increased storage	$14,800,000		
	Convert the Franklin Green/Horton Lane sanitary force main for reclaimed water distribution	$85,000		
	Install additional pumps to increase the station capacity to approximately 12 million gallons per day	$1000 per million gallons capacity		
	Establish additional reclaimed water storage facilities/ convert existing water storage tanks to reclaimed storage tanks	$2 per gallon capacity		
Stormwater	Rain gardens	$25,000/ unit	$25,000 per year	Five Mile Creek Watershed Management Plan
	Constructed wetlands	$625,000 per acre		CDM - Dry Branch Bid Tabulation
	Conveyance upgrades	$4,480,000		CDM - Stormwater Master Plan
	Residential rain barrels	$25 (rain barrel) per cubic foot water savings		Center for Watershed Protection - Urban Stormwater Retrofit Practices
	Pervious pavement	$24,500 per acre		
	Use of Robinson Lake to provide enhanced base flow in the Harpeth River during dry periods	$1,000,000		Engineering estimate
Water Quality & Ecological Health	Treat discharged effluent to higher standard during summer months	$26,250,000	$1,305 per million gallons	UNEP Sourcebook
	Removal of low head dam at the water treatment plant intake	funded		U.S. Fish and Wildlife
	Widespread stream and bank restoration	$66 per linear foot		Five Mile Creek Watershed Management Plan

Table 4-22
Estimated Costs for Project Options