Energy Index Development for Benchmarking Water and Wastewater Utilities

Subject Area:
Efficient and Customer-Responsive Organization

Energy Index Development for Benchmarking Water and Wastewater Utilities

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Awwa Research Foundation

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The Awwa Research Foundation (AwwaRF) is a member-supported, international, nonprofit organization that sponsors research to enable water utilities, public health agencies, and other professionals to provide safe and affordable drinking water to consumers.

The Foundation's mission is to advance the science of water to improve the quality of life. To achieve this mission, the Foundation sponsors studies on all aspects of drinking water, including supply and resources, treatment, monitoring and analysis, distribution, management, and health effects. Funding for research is provided primarily by subscription payments from approximately 1,000 utilities, consulting firms, and manufacturers in North America and abroad. Additional funding comes from collaborative partnerships with other national and international organizations, allowing for resources to be leveraged, expertise to be shared, and broad-based knowledge to be developed and disseminated. Government funding serves as a third source of research dollars.

From its headquarters in Denver, Colorado, the Foundation's staff directs and supports the efforts of more than 800 volunteers who serve on the board of trustees and various committees. These volunteers represent many facets of the water industry, and contribute their expertise to select and monitor research studies that benefit the entire drinking water community.

The results of research are disseminated through a number of channels, including reports, the Web site, conferences, and periodicals.

For subscribers, the Foundation serves as a cooperative program in which water suppliers unite to pool their resources. By applying Foundation research findings, these water suppliers can save substantial costs and stay on the leading edge of drinking water science and technology. Since its inception, AwwaRF has supplied the water community with more than $300 million in applied research.

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FOREWORD

The Awwa Research Foundation is a nonprofit corporation that is dedicated to the implementation of a research effort to help utilities respond to regulatory requirements and traditional high-priority concerns of the industry. The research agenda is developed through a process of consultation with subscribers and drinking water professionals. Under the umbrella of a Strategic Research Plan, the Research Advisory Council prioritizes the suggested projects based upon current and future needs, applicability, and past work; the recommendations are forwarded to the Board of Trustees for final selection. The foundation also sponsors research projects through the unsolicited proposal process; the Collaborative Research, Research Applications, and Tailored Collaboration programs; and various joint research efforts with organizations such as the U.S. Environmental Protection Agency, the U.S. Bureau of Reclamation, and the Association of California Water Agencies.

This publication is a result of one of these sponsored studies, and it is hoped that its findings will be applied in communities throughout the world. The following report serves not only as a means of communicating the results of the water industry's centralized research program but also as a tool to enlist the further support of the nonmember utilities and individuals.

Projects are managed closely from their inception to the final report by the foundation's staff and large cadre of volunteers who willingly contribute their time and expertise. The foundation serves a planning and management function and awards contracts to other institutions such as water utilities, universities, and engineering films. The funding for this research effort comes primarily from the Subscription Program, through which water utilities subscribe to the research program and make an annual payment proportionate to the volume of water they deliver and consultants and manufacturers subscribe based on their annual billings. The program offers a cost-effective and fair method for funding research in the public interest.

A broad spectrum of water supply issues is addressed by the foundation's research agenda: resources, treatment and operations, distribution and storage, water quality and analysis, toxicology, economics, and management. The ultimate purpose of the coordinated effort is to assist water suppliers to provide the highest possible quality of water economically and reliably. The true benefits are realized when the results are implemented at the utility level. The foundation's trustees are pleased to offer this publication as a contribution toward that end.

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Chair, Board of Trustees
Awwa Research Foundation

Robert C. Renner, P.E., D.E.E.
Executive Director
Awwa Research Foundation

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The work of this project cuts across several areas of expertise. The participation of all made this project possible.

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A special note of thanks to all the utilities that took the time to answer and return the survey and to those utilities that facilitated follow-up discussions. A special thanks to Dale Doerr of Sheboygan for review throughout the project and the information provided about the energy conservation efforts at his plant.

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EXECUTIVE SUMMARY

Sixty thousand water systems and 15,000 wastewater systems account for 3% of the national electricity use. 10% or more of a utility's total operating cost is for energy. Managing energy use requires a means to assess how well energy is being used. Tracking energy use over time can be a valuable tool, especially when load and operational influences can be linked to energy use. Comparing energy use to peers can be a valuable exercise for motivating improvement, given that peers can be properly identified with load and operational factors.

This project set out to develop metrics that allow comparison of energy use among wastewater treatment plants and among water utilities. These comparisons normalized away factors such as specific plant configurations or loading that made comparisons challenging. The project has produced a scoring method that accomplishes this goal.

RESEARCH OBJECTIVES

The project goal was to create metrics that allow comparison of utility energy use among peers. The specific project objectives include the following:

- Review literature for existing energy use data and methods of characterizing a utility.
- Develop a statistically representative sample of utility energy use and characteristics.
- Relate characteristics to energy use.
- Apply and evaluate a multi-parameter benchmark score method similar to the EPA's ENERGY STAR rating system for buildings.
- Review the resulting metric application at sample utilities.

APPROACH

The literature review provided information on characterizing utility energy use and operating characteristics for the development of survey instruments. Surveys were mailed to 2,725 wastewater treatment plants and 1,723 water utilities. The survey effort created a representative data set of energy use and utility characteristics for wastewater utilities exceeding 1.5 MGD of design influent flow and for water utilities serving populations of 10,000 or more. The final filtered analysis data sets consisted of 266 wastewater treatment plants and 125 water utilities.

A regression analysis tested the correlation of individual as well as groups of parameters to energy use. Impacts were reviewed at the level of energy data available. For wastewater utilities the analysis looked at the impact on treatment plant and collection system energy. For water utilities the analysis looked at the utility in its entirety as well as production, treatment and distribution impacts individually.

The EPA ENERGY STAR Benchmark Score method uses the sample of predicted energy use from a model to define a distribution or range in possible energy uses for utilities. The model normalizes external factors that impact energy use, leaving variability due to choices made by designers and operators of the utility. A comparison of a utility's energy use to this distribution gives a score based on its placement at a certain percentile. The distribution allows

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the range in possible energy use for a particular set of utility characteristics to be defined and identifies where in that range a particular utility falls. The distribution provides a context to make a comparison among utilities. This context allows the user to also quantify a level of energy savings needed to achieve a certain target level that can be useful in setting goals and assessing the relevance of energy project savings projections.

Testing the metrics involved applying them to specific utilities to look at how the metrics portray energy use as compared to traditional single parameter metrics. Some comparisons also relate the metric scores to plant configurations and to energy project impacts. The choices made in the metric development on characteristics that were included or omitted become evident. Choices had to be made based on statistical significance and the nature of the characteristic (a characteristic imposed on the utility or a characteristic independently chosen).

CONCLUSIONS

The literature review found water utilities often characterized by water source: ground, surface and purchased, but little information on characterizing the distribution system. There was limited energy information (often cost rather than consumption) usually on a utility-wide basis or only for a small group of utilities. The EPA Community Water System Survey and Safe Drinking Water Information System (SDWIS) databases define the population of utilities and provided some characterization data along with limited contact information.

Wastewater treatment and process information was readily available in EPA databases. The EPA Community Water Needs Survey (CWNS) and Permit Compliance System (PCS) databases defined the population of treatment plants, and provided some characterization data along with contact information.

In order to create a single energy using parameter, all utility energy use was converted to source energy. This conversion mainly impacted electricity use by accounting for generation and transmission energy use. The project evaluated cost as a common factor but found the 3:1 effective energy price range across the country added variability to the resulting analysis. Source energy ultimately captures the total energy impact.

The wastewater treatment plant model relates energy consumptions to: average influent flow, influent BOD, effluent BOD, the ratio of average influent flow to design influent flow, the use of trickle filtration, and nutrient removal. Other parameters are also significantly correlated to energy use: on-site electricity generation, sludge incineration/sludge land application and pure oxygen. These parameters were not included in the model used for the metric so the metric would not normalize for their impact. Collection system energy use was related to average influent flow, pumping horsepower, and number of pumps.

The wastewater treatment plant energy use model used in the metric development applies a logarithmic transformation to account for the wide range in utility sizes. The model form is:

$$
\begin{aligned}
\text{LN(Source kBtu/yr)} \quad &= 15.8741 \\
&+ 0.8944 \times \text{LN(influent Average MGD)} \\
&+ 0.4510 \times \text{LN(influent BOD mg/l)} \\
&- 0.1943 \times \text{LN(effluent BOD ml/l)} \\
&- 0.4280 \times \text{LN(Influent Average / influent Design)} \\
&- 0.3256 \times \text{(Trickle Filtration? 0 or 1)} \\
&+ 0.1774 \times \text{(Nutrient Removal? 0 or 1)}
\end{aligned}
$$

An extension to this model added the impact of weather through the use of heating and cooling degree days. Both models are presented because of the difficulty for the operator in

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obtaining the weather data corresponding to the data collection period of the energy use. Inclusion of the weather data changes the score by ±10 points. The model form is:

$$
\begin{aligned}
\mathrm{LN(Source\ kBtu/yr)} \quad = {} & 12.5398 \\
& + 0.8966 \times \mathrm{LN(influent\ Average\ MGD)} \\
& + 0.4920 \times \mathrm{LN(influent\ BOD\ mg/l)} \\
& - 0.1962 \times \mathrm{LN(effluent\ BOD\ ml/l)} \\
& - 0.4314 \times \mathrm{LN(Influent\ Average\ /\ influent\ Design)} \\
& - 0.3363 \times \mathrm{(Trickle\ Filtration?\ 0\ or\ 1)} \\
& + 0.1587 \times \mathrm{(Nutrient\ Removal?\ 0\ or\ 1)} \\
& + 0.2421 \times \mathrm{LN(Heating\ Degree\ Days\ base\ 65)} \\
& + 0.1587 \times \mathrm{LN(Cooling\ Degree\ Days\ base\ 65)}
\end{aligned}
$$

The water utility model relates energy consumption to: total flow, total pumping horsepower, distribution main length, distribution elevation change, raw pumping horsepower, and the amount of purchased flow. Unaccounted for flow was also found to be significant, but was not included in the metric model, so that its effect would still be reflected in the metric. Energy use of production, treatment and distribution were also correlated to utility characteristics. Production energy use related best to: total flow, purchased flow and raw water pumping horsepower. Treatment energy use related best to: total flow, purchased flow, raw water pumping horsepower and treatment for oxidation, iron removal, direct filtration and ozone. Distribution energy use related best to: total flow, discharge pumping horsepower, distribution system elevation change, pressure filtration, residual gravity thickening, and residual lagoon dewatering thickening.

The water utility energy use model used in the metric development also applies a logarithmic transformation to account for the wide range in utility sizes. Due to the log transformation one is added to the two terms where zero is a valid value to accommodate the transformation. The model form is:

$$
\begin{aligned}
\mathrm{LN(Source\ kBtu/yr)} \quad = {} & 8.2394 \\
& + 0.4993 \times \mathrm{LN(total\ system\ flow\ kGD)} \\
& - 0.0630 \times \mathrm{LN(purchased\ water\ flow\ +1\ kGD)} \\
& + 0.3724 \times \mathrm{LN(total\ pumping\ horse\ power)} \\
& + 0.0620 \times \mathrm{LN(production\ pumping\ horsepower\ +1)} \\
& + 0.2385 \times \mathrm{LN(distribution\ main\ length\ miles)} \\
& + 0.0991 \times \mathrm{LN(distribution\ system\ elevation\ change\ feet)}
\end{aligned}
$$

Example implementations of wastewater treatment plant and water utility metric implementations are shown at the end of this summary. These are the most robust metrics and are suitable for both internal tracking and external comparisons across the industry. The report also presents candidates for a wastewater treatment collection system metric and water utility metrics for production, treatment and distribution. These other metrics are based on models with more variability and smaller sample sizes in the case of water utilities, but might prove useful for internal utility tracking and individual assessments.

A side use of the model is to characterize the typical energy use attributable to specific characteristics or processes on an empirical basis. While not explicitly studied in this project the models implicitly include the average energy impact of characteristics. One can toggle a specific parameter on or off in the metric to see its impact for the typical utility with the specific characteristics of interest. This knowledge might be useful in quantifying perceptions widely held about energy intensive processes, or in focusing study of best practices toward these areas

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of high energy use correlation. This observation illustrates one use of the data set and/or model beyond the metric development project.

Having an energy use distribution is a key feature of the metric, giving it a context in which to make comparisons. The metric score itself (1-100) gives a relative score like a grade. By using the distribution, one can take a target score and determine how much energy use must change to reach the new level. This feature gives a plant operator perspective on how much better energy performance could become. It can be useful in assessing energy project upgrades savings estimates, as the score can be calculated with the proposed project impacts. Any proposed project that greatly increases the score, such that the utility would become one of the lower energy users among its peers, warrants thorough examination and verification of the projected savings.

The metric score can also serve as an initial screening when identifying plants or utilities where energy conservation efforts should be applied. As the application examples illustrate, though, the metric should be complimented with specific site information, as there are still conditions that can skew the score (e.g., a high score due to operating at lower than typical treatment levels that aren't fully captured by the BOD data in the wastewater model). The screening might also be the first basis for identifying utilities to investigate for best practice examples. It would be a natural follow-on to determine why the highest and lowest scoring utilities have their scores.

The metric is based on a snapshot of the industry in 2004. Eventually the data used to develop the models will not reflect the current state of operations. Treatment requirements evolve over time, growing more stringent and possibly requiring more energy intensive processes. After a broad acceptance of energy intensive processes, such as membranes or UV, is adopted by the industry, it would be prudent to update the data on which the model and subsequent metric is based. The EPA ENERGY STAR Buildings Benchmarking system is updated every four years due to the availability of a statistical sampling of the building stock at that time. The water and wastewater industry are routinely surveyed, so it might be most effective to add or revise energy data queries in the existing surveys. Changes occur slowly so a five year or more time-frame between updates should be sufficient.

Having metrics is a first step toward energy management. The metric itself does not save energy or tell how to improve. It merely gives a relative assessment of energy performance – an energy management tool. In order to manage energy there must be an accounting of energy use. Many utilities track their energy use and some relate energy use to operations. Internally for tracking over time, the metrics provide a convenient way to track energy performance accounting for variations in loading. Externally it provides a comparison to other utilities and a framework in which to make the comparison.

Example implementations of the metrics are included in Figures ES.1 and ES.2. The spreadsheet implementation includes basic utility identification information through WSID or NPDES. The annual energy use section asks for energy use by type. The utility characteristics section gathers the model parameters. The energy benchmark score along with the total source energy are calculated and displayed and the target energy section shows the amount of change in energy use needed to achieve other scores along with energy targets in site energy units. These sample presentations compile the metric results, utility parameters, and provide a context for comparing energy use to the range in use expected for utilities with similar characteristics.

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Wastewater Treatment Plant Energy Benchmark Metric (v 2007_1_15)

AwwaRF research project 3009 with additional support by the California Energy Commission and The New York State Energy Research and Development Authority.

Treatment Plant Identification

NPDES Permit Number:	
Date:	

Utility Annual Energy Use

Please enter the annual energy use from all energy sources. If your utility generates power, please enter only purchased fuel.

Site Energy Type	Units	Site Energy Annual Use		
Electricity	kWh	**5,498,400**	1,372	kWh/MG
Natural gas	therms	**150,404**	38	therm/MG
Fuel oil #2	gallons			
Propane	gallons			
Energy use time period covered above:		**2004**		

Utility Characteristics

Please enter the following characteristics to describe the wastewater treatment plant.

Parameter	Units	Value		
Design Daily Influent Flow	MGD	**18.3**		
Average Daily Influent Flow	MGD	**10.98**	0.6	load factor
Average Influent BOD	mg/l	**203**	0.87	kWh/lb BOD
Average Effluent BOD	mg/l	**14**		
Fixed Film - Trickle Filtration Process ?	yes (1) or no (0)	**0**		
Treatment Includes Nutrient Removal ?	yes (1) or no (0)	**1**		

Energy Metric

This wastewater treatment plant energy benchmark is based on a statistical representation of the energy use of treatment plants across the country. It includes the characteristics that were found to have the most impact in explaining energy use among various plants. The resulting score represents your plant's relative energy use within the distribution of plants with your characteristics.

Your Utility Benchmark Score:	**74**
Total Source Energy Use (kBtu/yr):	**76,449,000**

Target Energy Use - Energy Metric Distribution

The following table shows the range in distribution of energy use for utilities with your characteristics. The percentages are relative to your use. The estimated site energy use is based on the actual proportions of site energy used.

	Source Energy Use		Estimated Site Energy Use			
Score	**(kBtu/yr)**	**Percentage Difference (%)**	**Electricity (kWh/MG)**	**Natural Gas (therms/MG)**	**Fuel Oil (gallons/MG)**	**Propane (gallons/MG)**
10	179,690,000	135%	3,225	90	0	0
25	136,730,000	79%	2,454	69	0	0
50	100,900,000	32%	1,811	51	0	0
75	74,457,000	-3%	1,336	37	0	0
90	56,655,000	-26%	1,017	29	0	0

Figure ES.1 Wastewater Treatment Plant Example Benchmark Calculation Sheet

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Water Utility Energy Benchmark Metric (v 2007_8_24)

AwwaRF research project 3009 with additional support by the California Energy Commission and The New York State Energy Research and Development Authority

Utility Identification

Utility Water System Identification (WSID):	
Date:	

Utility Annual Energy Use

Please enter the annual energy use from all energy sources. If your utility generates power, please enter only purchased fuel. Electricity and natural gas entries are provided in various units for convenience.

Site Energy Type	Units	Site Energy Annual Use		
Electricity	kWh	**18,355,000**	1,746	kWh/MG
Natural gas	therms	**9,279**	1	therm/MG
Fuel oil #2	gallons			
Propane	gallons			
Energy use time period covered above:		**2004**		

Utility Characteristics

Please enter the following characteristics to describe the water utility.

Parameter	Units	Value		
Average Daily Total Flow	MGD	**28.8**		
Purchased Daily Flow	MGD	**0**	0%	
Total Pump Horsepower	HP	**4900**	170	hp/MGD
Raw/Source Pump Horsepower	HP	**2750**	56%	
Change in Distribution Elevation	ft	**250**		
Total Water Main Length	miles	**1100**	38	miles/MGD

Energy Metric

This water utility energy benchmark is based on a statistical representation of the energy use of water utilities across the country. It includes the characteristics that were found to have the most impact in explaining energy use among various utilities. The resulting score represents your utility's relative energy use within the distribution of utilities with your characteristics.

Your Utility Benchmark Score:	**58**
Total Source Energy Use (kBtu/yr):	**204,690,000**

Target Energy Use - Energy Metric Distribution

The following table shows the range in distribution of energy use for utilities with your characteristics. The percentages are relative to your use. The estimated site energy use is based on the actual proportions of site energy used.

	Source Energy Use		Estimated Site Energy Use			
Score	(kBtu/yr)	Percentage Difference (%)	Electricity (kWh/MG)	Natural Gas (therms/MG)	Fuel Oil (gallons/MG)	Propane (gallons/MG)
10	506,510,000	147%	4,321	2	0	0
25	337,170,000	65%	2,876	1	0	0
50	215,900,000	5%	1,842	1	0	0
75	139,180,000	-32%	1,187	1	0	0
90	94,297,000	-54%	804	0	0	0

Figure ES.2 Water Utility Example Benchmark Calculation Sheet

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CHAPTER 1
INTRODUCTION

According to the Electric Power Research Institute (Burton 1996) 60,000 water systems and 15,000 wastewater systems account for 3% of the national electricity use. A recent AwwaRF study (AwwaRF 2003) noted that 10% or more of a utility's total operating cost is for energy. This same study recommended applying benchmarking efforts to plant operations to identify and share best practices.

Benchmarking originated as a business management practice designed to systematically evaluate products, services, and work process of organizations for the purpose of improvement (Spendolini 1992). The evaluation often centers on comparisons to similar organizations that operate well or exhibit best practices. The basic steps involved in benchmarking are to properly identify the issues or define the operational metrics, assemble internal data to define current operations, collect external data for comparison, analyze the differences, implement changes and monitor the impact. This project was born out of the need to define useful metrics for comparing energy use among utilities.

The water industry is well versed in measuring and reporting performance in terms of water volume and water quality, as that is their central purpose. From an energy management standpoint there needs to be a means to assess how well a plant or utility is performing to identify improvement opportunities or best practices. This assessment need not just compare total energy use or energy use per unit of water treated or delivered, but also can give an idea of how energy is being used over time, in comparison to other plants or national averages, or comparisons to ideals or best practice.

This project set out to develop energy metrics following a template created by the United States Environmental Protection Agency (EPA) in benchmarking buildings (Sharp 1996, 1998) (MacDonald 2004). The method is implemented on the ENERGY STAR™ web site (www.energystar.gov) as the portfolio manager. The approach was to correlate utility characteristics to energy use in a statistically representative sample of the industry. This correlation provided a means to normalize or remove the influence of multiple factors impacting energy use that are outside the control of the utility, (e.g. water source, distribution topography, effluent quality, etc) so that a meaningful comparison could be made among utilities.

The project progressed though several stages. Initially a literature review investigated existing data and ways of characterizing plants and utilities. Subsequently surveys were developed to collect operating characteristics and energy use from utilities across the country. Analysis of the data probed for correlations, and developed models predicting average energy use that were used to formulate an energy metric or score comparable across utilities. Finally, application of the metrics at individual utilities provided feedback on how plant operators might use the metrics.

LITERATURE REVIEW

The objectives of the literature review were:

- To discern the type of energy related data that has been gathered, and its uses.
- To identify the ways utilities and their facilities are characterized, particularly those characterizations that might relate to energy use.

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- To define the population of water and wastewater utilities pertinent to the scope of the project that would also aid in the development of sampling criteria.
- To review survey methods and instruments applied in previous studies.
- To review energy efficiency studies for information, both on how those looking at utilities as energy consumers characterize the systems and the characteristics of processes and systems that are typically targeted for energy related upgrades.

The results of these efforts are documented in the separate literature review documents for water and wastewater, Appendices A and B, and are briefly summarized in the following sections.

Utility Population

The EPA identifies 52,000 community water systems. Approximately 4,000 of those systems serve populations above 10,000. These 4,000 systems cover 85% of the total U.S. population. In our discussions with the Project Advisory Committee (PAC) we decided to limit the scope of the project to these 4,000 utilities to concentrate effort on a representative scope.

Similarly the EPA identifies about 16,200 wastewater utilities. About 3,200 of those systems have average flows above 1 MGD, representing 92% of the total U.S. wastewater flow. About 2,000 systems have average flows above 2 MGD, representing 86% of the total U.S. wastewater flow. We concentrated effort on representing the 2,700 utilities with design flow rates above 1.5 MGD. This sample corresponds to populations of 10,000 and above.

Water Utilities

Water utilities are generally characterized by water source, namely ground or surface. More intensive treatment is applied to surface water. Surface water is often the source for the largest utilities as 11% of utilities supply 50% of all water from surface sources. 74% of water systems use ground source, but produce only 30% of the total. Except for listing specific treatment objectives and processes at water utilities there are no other general characteristics that distinguish water utilities in previous studies.

With water utility energy use dominated by pumping, there is surprisingly little information on characterizing pumping systems. Some literature distinguishes energy use between ground and water source pumping. Other literature discusses distribution pumping in terms of matching pump efficiency to load, pipe friction and optimization of pump dispatching. This project had to create its own methods to characterize conditions under which a utility must distribute water, namely how to describe topography or the dominance of static versus dynamic pumping head. Useful information for characterizing distribution was thought to be items such as: distribution main length, service area, number of pumps, total distribution pump horsepower installed, distribution pressure and number of pressure zones. Existing data on main length and service area simply show these parameters to be correlated to total flow, being indicative of utility size. The pumping data was thought to be a means to help segregate those utilities with challenging topography from those in relatively flat areas.

The project reviewed three data sets that included energy information on water utilities. The AWWA Water:\Stats database (AWWA 1998) contains electricity expenditures along with treatment process and water quality parameters. A Wisconsin study (Elliot 2003) included both

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electricity cost and use data but minimal information on treatment plant configurations or operating characteristics. An Iowa study (Sauer 2003) covered electricity use and cost of mainly smaller ground water source utilities and identified energy use for treatment and distribution. These data suggest wide variability in energy use ranging from 300 kWh/MG to over 3,800 kWh/MG. The Wisconsin study was able to show lower energy intensity of surface water utilities in the state. The Iowa study surprisingly showed treatment energy dominating distribution at 85% of the total. Perhaps in smaller utilities pumping at a treatment plant is the majority of the distribution energy and is therefore allocated to the treatment plant based on being incorporated in the plant electricity bill. The Water:\Stats data show good correlation of energy cost with flow, explaining 70% of the variation. Applying simple multiple-linear regressions to include treatment and source parameters increases the correlation to 83%. These initial results were encouraging that these characteristics have significance in explaining energy use.

Wastewater Utilities

Wastewater utilities are characterized by treatment level. On a coarse basis, treatment is characterized by primary, secondary, and advanced levels. The EPA expands slightly on this classification with primary, advanced primary, secondary, secondary with nutrient removal, advanced I, advanced I with nutrient removal, advanced II and advanced II with nutrient removal. These classifications are defined based on BOD5 limits and use of biological, chemical, or physical treatment. The secondary treatment process in plants above 1-2 MGD is often the most energy intensive area, suggesting that identification of particular processes is needed (activated sludge, trickling filters, fixed film, etc). Above 2 MGD, EPA process data suggest that 75% of treatment plants use activated sludge. The aeration method employed is often cited as the most energy intensive single process in a plant, suggesting that process configuration characteristics should be collected (mechanical, coarse bubble, fine bubble, pure oxygen, automated dissolved oxygen control, etc).

The EPA maintains data on every treatment plant keyed through the National Pollution Discharge Elimination System (NPDES). Both treatment level classifications and processes are maintained in a publicly accessible database. They caution that the process level data is out of date and prone to errors, but the data were adequate to gain a rough perspective about the frequency of process use in the industry.

The project reviewed two data sets that included energy and characteristics data. The AMSA (Association of Metropolitan Sewerage Agencies, now the National Association of Clean Water Agencies - NACWA) data (AMSA 2003) included energy cost data and limited treatment level data for larger utilities. An Iowa study (Sauer 2003) contained both energy and cost data but was dominated by small lagoon systems. The AMSA flow data explained 64% of the variation in energy cost. Adding treatment and configuration parameters to a regression model increased the explanation of the variability in energy cost to 78%. These data suggest that energy intensity ranges widely from 800 kWh/MG to over 3,500 kWh/MG.

Surveys

The project reviewed industry survey instruments for comparison of how utility characteristics are queried. The AMSA (now NACWA), EPA Community Water System and

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Iowa surveys were readily available. The project also reviewed a parallel effort to survey water and wastewater utilities in New York and sought a means to collaborate with their effort so only one survey was sent to New York utilities.

Contact information for sample selection and survey delivery was readily available from an EPA database for wastewater utilities. Contact information was only partially available for water utilities from the EPA. Its database contains the contact information as it is used in its Community Water Survey, but the data are only available to government employees and EPA contractors. Sufficiently general characteristic data were publicly available to select the survey sample.

Previous surveys have been implemented through mail (EPA), e-mail (Iowa) and entry directly through a web-site (AMSA). Most have included phone follow-ups to encourage response. We chose to use a mail survey as it is the most familiar to utility operators.

PROJECT GOALS AND OBJECTIVES

The over arching goal was to create metrics that allow comparison of utility energy use among peers. The approach followed the EPA ENERGY STAR methodology employed to compare commercial buildings. The specific project objectives included collecting representative data, evaluating the energy impact of utility characteristics, applying a multi-parameter approach to scoring energy use, and testing the metric application at sample utilities.

Develop a Statistical Representative Sample

The analysis is based on having a statistical representative sample of utility energy use and characteristics. The literature review found EPA sources that identified the population of utilities from which to sample. The literature also identified previous means to classify and characterize treatment and processes used within the utilities.

Relate Characteristics to Utility Energy Use

The impact of individual characteristics on energy use uses a regression analysis to test the correlation of individual and groups of parameters to energy use. Impacts were reviewed at the level of energy data available. For wastewater utilities the analysis looked at the impact on treatment plant and collection system energy. For water utilities the analysis looked at the utility in its entirety as well as production, treatment and distribution impacts individually.

Apply and Evaluate the EPA ENERGY STAR Multi-Parameter Benchmark Score Method

The EPA ENERGY STAR Benchmark Score method used the sample of predicted energy use from a model to define a distribution or range in possible energy uses for utilities. The model normalized external factors that impact energy use, leaving variability due to choices made by designers and operators of the utility. A comparison of a utility's energy use to this distribution gives a score based on its placement at a certain percentile. The distribution allows the range in possible energy use for a particular set of utility characteristics to be defined and identifies where in that range a particular utility falls. The distribution provides a context to make a comparison among utilities. This context allows the user to also quantify a level of

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energy savings to achieve a certain target level that can be useful in setting goals and assessing the relevance of energy project savings projections.

Review the Metric Application at Sample Utilities

Testing the metrics involved applying them to specific utilities to look at how the metrics portray energy use as compared to traditional single parameter metrics. Some comparisons also relate the metric scores to plant configurations and to energy project impacts. The choices made in the metric development on characteristics that were included or omitted become evident. Choices had to be made based on statistical significance and the nature of the characteristic (a characteristic imposed on the utility or a characteristics independently chosen).

REPORT ORGANIZATION

The scope of the project covers both water and wastewater utilities. The scope of the report also serves two audiences. A main goal is to disseminate the benchmark metrics to practitioners so they can self-assess how their energy use compares to peers. Another goal is to document the metric development process for the researcher or policy audience. To accommodate these various scopes and audiences the report is organized into two parallel volumes. Chapters 2, 3 and 4 address water utilities while chapters 5, 6 and 7 address wastewater. Each volume discusses utility surveys, metric development and metric application examples and is designed to be standalone so one can read only the water or wastewater section and understand the entire project. Chapters 3 and 6 cover the details of the metric development and are geared toward the researcher or policy reader. The two volumes share a common introduction and conclusion section.

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CHAPTER 2
WATER UTILITY SURVEYS

SURVEY DESIGN

The survey design borrowed from previous surveys wherever possible. This duplication kept terminology consistent with past efforts, especially EPA surveys where the respondent should be familiar with the terms.

The survey design reflected the need to characterize the operating conditions of the utility as well as the treatment and processes, loads and energy use. The smallest level of aggregation was thought to be the point at which energy data are readily available. In other words the items within a utility that have separate electric and gas utility bills are candidates to be treated as single entities. For water utilities it is possible that source pumping, treatment and distribution could be physically separate, having their own energy bills.

The survey instrument is included in the Appendix C. The survey begins with descriptive information about the utility and the person filling out the survey. Characterizations reviewed in the literature survey provided the base for describing treatment and processes. Flow volumes are the primary driver and were represented in a similar fashion to other surveys.

An initial survey was tested in a pilot to get both feedback about the content as well as an indication of the response rate. A technical team of water engineers also reviewed the survey, noting items that were expected to have some impact on energy use.

Water Utility Parameters

The water survey asked about flow volumes and their sources, pumping capacities, and raw water quality. It then moved into treatment objectives, processes and residual management. A section on distribution asked about population, service area, main length, topography, pumping capacities and pressure zones. The energy use section asked for electricity use, demand, and cost segregated by production, treatment and distribution as well as total gas use. Floor area of buildings on the electric meter, use of engine driven pumps and purchase of other energy sources (propane, oil and diesel) area were also queried.

Raw water was characterized by source (ground, surface, purchased), pumping and quality (turbidity) parameters in Table 2.1. Treatment objectives were characterized by the parameters in Table 2.2. Metal removal and contaminate removal were generalized by grouping together relevant subcategories. Specific treatment processes and residual handling were described in the parameters of Table 2.3. Distribution parameters focused on service territory size, physical characteristics and pumping capacities, as well as topography of the system as noted in Table 2.4. Electricity was the primary energy source. The survey collected data on production, treatment and distribution electricity use, Table 2.5. There is likely some cross-over in categories as production pumping may serve other areas that are separate in some utilities. The remaining parameters in Table 2.6 address areas thought to impact energy use, from purchases of additional energy sources, to the size of support/administration buildings included in the utility bills, and to the use of engine driven pumps.

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Table 2.1 Raw Water Parameters

No.	Variable	Survey Question and Description
9	raw_g_num	q01aa: Number of Ground Water Sources
10	raw_g_aflow	q01ab: Average Ground Water Flow
11	raw_g_dflow	q01ac: Design Ground Water Flow
12	raw_g_mflow	q01ad: Maximum Ground Water Flow
13	raw_s_num	q01ba: Number of Surface Water Sources
14	raw_s_aflow	q01bb: Average Surface Water Flow
15	raw_s_dflow	q01bc: Design Surface Water Flow
16	raw_s_mflow	q01bd: Maximum Surface Water Flow
17	raw_p_num	q01ca: Number of Purchased Sources
18	raw_p_aflow	q01cb: Average Purchased Water Flow
19	raw_g_depth	q02: Average Well Depth
20	raw_hp	q03: Source Water Pumping HP
21	raw_npump	q04: Total Number of Pumps
22	raw_g_antu	q05aa: Average Ground Water Turbidity
23	raw_g_pntu	q05ab: Peak Ground Water Turbidity
24	raw_s_antu	q05ba: Average Surface Water Turbidity
25	raw_s_pntu	q05b: Peak Surface Water Turbidity
107	calc_NTU_avg	derived: Average Raw Turbidity (flow weighted average)
108	calc_NTU_peak	derived: Peak Raw Turbidity
106	calc_flow	derived: Total Average Flow

Table 2.2 Water Treatment Objectives

No.	Variable	Survey Question and Description
26	treat_algae	q06a: Algae Control
27	treat_disinf	q06b: Disinfection
28	treat_ox	q06c: Oxidation
29	treat_iron	q06d: Iron Removal
30	treat_mang	q06e: Manganese Removal
31	treat_odor	q06f: Taste & Odor Control
32	treat_TOC	q06g: TOC Removal
33	treat_turb	q06h: Particulate/Turbidity Removal
34	treat_soft	q06i: Softening
35	treat_recarb	q06j: Recarbonation
36	treat_organic	q06k: Organic
37	treat_inorganic	q06l: Inorganic
38	treat_radon	q06m: Radionuclide
109	calc_metals	derived: Treatment for Metals (iron, manganese)
110	calc_contam	derived: Treatment for Contaminates (organic, inorganic, radon)

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Table 2.3 Water Treatment Processes and Residual Handling Parameters

No.	Variable	Survey Question and Description
39	process_aerate	Q07a: Aeration
40	process_UV	Q07b: Ultraviolet
41	process_OZ	Q07c: Ozone
42	process_clar_up	Q07d: Upflow Clarification
43	process_clar_gravity	Q07e: Gravity Clarification
44	process_clar_daf	Q07f: Dissolved Air Floatation Clarification
45	process_floc	Q07g: Flocculation
46	process_filtr_direct	Q07h: Direct Filtration
47	process_filtr_sand	Q07i: Slow Sand Filtration
48	process_filtr_dual	Q07j: Dual Stage Filtration
49	process_filtr_rapid	Q07k: Rapid Rate Filtration
50	process_filtr_dearth	Q07l: Diatomaceous Earth Filtration
51	process_filtr_press	Q07m: Pressure Filtration
52	process_mem_rosmos	Q07n: Reverse Osmosis Membrane
53	process_mem_micfiltr	Q07o: Microfiltration Membrane
54	process_mem_ultfiltr	Q07p: Ultrafiltration Membrane
55	process_mem_nanofiltr	Q07q: Nanofiltration Membrane
56	utility_nplants	Q08: Number of Treatment Plants
57	res_none	Q09a: No Treatment
58	res_gravity	Q09b: Gravity Thickening
59	res_dewat_mech	Q09c: Mechanical Dewatering
60	res_cent	Q09d: Centrifuge
61	res_press_filtr	Q09e: Residual Pressure Filtration
62	res_vac_filtr	Q09f: Vacuum Filtration
63	res_bpress	Q09g: Belt Press
64	res_ppress	Q09h: Plate & Frame Press
65	res_dewat_nmech	Q09i: Non-Mechanical Dewatering
66	res_lagoon	Q09j: Lagoon Dewatering Thickening
67	res_sand	Q09k: Sand Drying Bed
68	res_frz	Q09l: Freezing and Thawing
69	res_weight	Q10: Total Average Daily Residuals

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Table 2.4 Water Distribution Parameters

No.	Variable	Survey Question and Description
70	distrib_pop	q11: Population of Service Area
71	distrib_area	q12: Size of Service Area
72	distrib_main	q13: Length of Water Mains
73	distrib_high	q14a: Highest Elevation
74	distrib_low	q14b: Lowest Elevation
75	distrib_hp	q15: Distribution Pumping HP
76	distrib_npump	q16: Number of Distribution Pumps
77	distrib_storage	q17: Total Storage Volume
78	distrib_press	q18: Average Distribution Pressure
79	distrib_nzones	q19: Number of Distribution Zones
80	distrib_lost	q20: Unaccounted for Treated Water

Table 2.5 Water Energy Use Parameters

No.	Variable	Survey Question and Description
81	raw_kwh	q21aa: Production Electricity Use
82	raw_kw	q21ab: Production Electricity Peak
83	raw_cost	q21ac: Production Electricity Cost
84	treat_kwh	q21ba: Treatment Electricity Use
85	treat_kw	q21bb: Treatment Electricity Peak
86	treat_cost	q21bc: Treatment Electricity Cost
87	distrib_kwh	q21ca: Distribution Electricity Use
88	distrib_kw	q21cb: Distribution Electricity Peak
89	distrib_cost	q21cc: Distribution Electricity Cost
90	utility_kwh	q21da: Total Electricity Use
91	utility_kw	q21db: Total Electricity Peak
92	utility_cost	q21dc: Total Electricity Cost
94	ngas_use	q23aa: Natural Gas Use
95	ngas_cost	q23ab: Natural Gas Cost

Table 2.6 Water General Parameters

No.	Variable	Survey Question and Description
99	oenergy_purch	q25a: Purchased Energy
100	oenergy_type	q25b: Purchased Energy Source
101	oenergy_amount	q25c: Amount of Purchased Energy
102	oenergy_cost	q25d: Purchased Energy Cost
93	floor_area	q22: Total Building Area
96	pump_eng	q24a: Engine Driven Pumps
97	pump_eng_hp	q24b: Engine Driven Pump HP
98	pump_eng_fuel	q24c: Engine Driven Pump Fuel Type
103	check_util	q26: Regularly Checked Utility Bills
104	extra_event	q27: Extraordinary Events

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SURVEY IMPLEMENTATION

An EPA database defined the utility population. The EPA Safe Drinking Water Information System (SDWIS) provided flow and limited contact information for the water utilities.

All utilities serving more than 10,000 people were included in the sample. Utilities serving populations in excess of 10,000 represent over 85% of the flow volume in the country. While there is a large number of utilities below this size, their energy use in aggregate represents a small portion of the total industry energy use.

A pilot survey sent to 20 water utilities tested response rates and provided feedback about the questions. All unprompted responses came back within one month. Four water utilities (20%) returned surveys. Discussions with the respondents indicated that the survey questions were straightforward and the survey was easy to complete.

The water survey was mailed to 1,723 utilities and received a 13% response rate (217 responses). The survey respondents represented a population of 28,000,000 people (24%) of the 118,000,000 people represented in the survey sample. An additional 34 surveys were received in a separate parallel effort in New York. The sample response reflected the surveyed population based on the size of the population served by the utility for all but the smallest utilities as shown in Figure 2.1. The response rate tended to fall off for the smaller utilities.

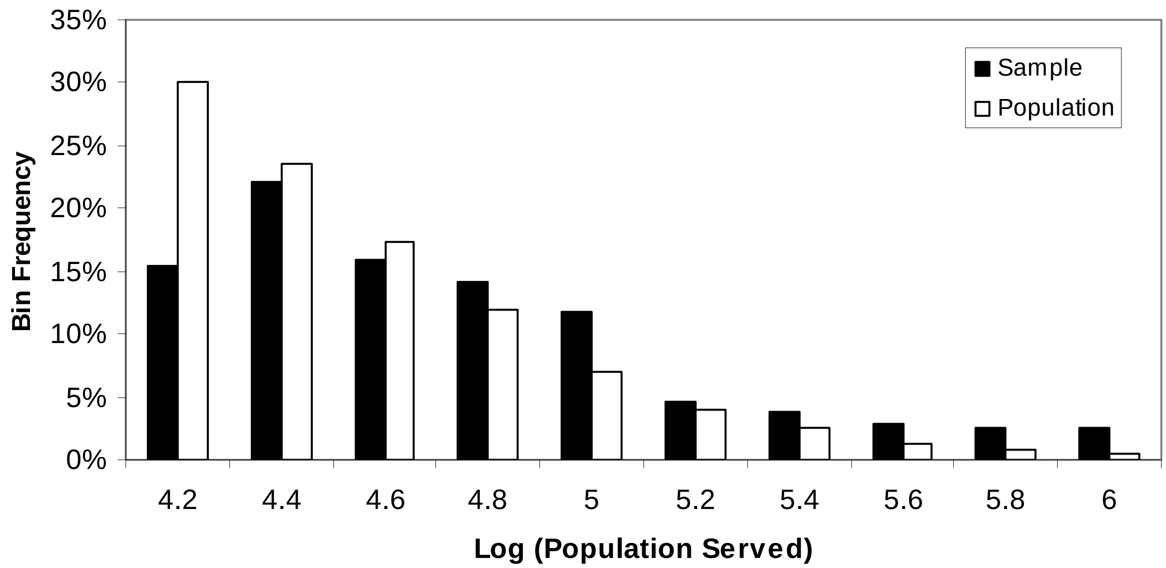

Figure 2.1 Water Utility Survey Respondents and Population Comparison – Representation of Utility Population Served

There were 3,611 water utilities in the sample, but contact and address information were available for only 1,723 utilities. Mailing list organizations were queried as other sources for addresses. They generally classified addresses by SIC code (4941) or NAICS code (221310), but included a high percentage of contacts that were not water utilities or could not be associated with an EPA water system ID. The utilities with missing addresses are evenly distributed throughout the sample as shown in Figure 2.2, so missing addresses should not skew results.

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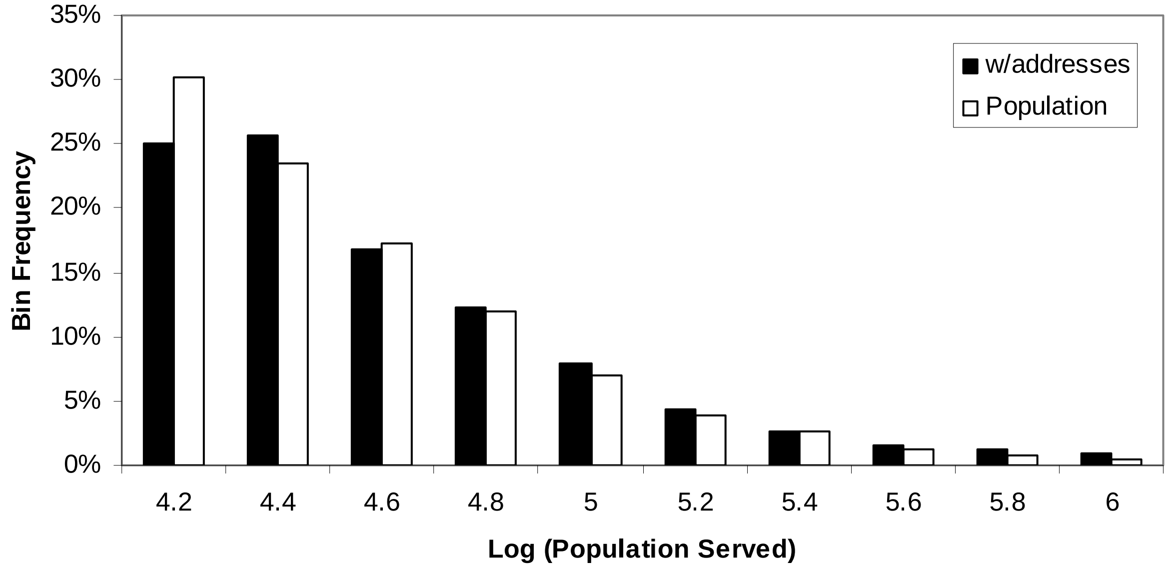

Figure 2.2 Water Utility Impact of Missing Addresses on Representation of Utility Population Served

Regional response rates are shown by census region and division in Table 2.7. The south had the lowest response rate. The sample was smaller than the entire population as it only included utilities with address and contact information.

Table 2.7 Regional Water Utility Survey Response Rate by U.S. Census Regions and Division

Region/Division	Population	Sample	Response	Response Rate	
WEST	**807**	**529**	**76**		**14%**
Pacific	569	419	56	13%	
Mountain	238	110	20	18%	
MIDWEST	**901**	**429**	**53**		**12%**
West North Central	247	160	25	16%	
East North Central	654	269	28	10%	
NORTHEAST	**696**	**386**	**56**		**15%**
Middle Atlantic	441	307	50	16%	
New England	255	79	6	8%	
SOUTH	**1439**	**533**	**54**		**10%**
West South Central	431	184	20	11%	
East South Central	355	114	6	5%	
South Atlantic	653	235	28	12%	
TOTAL	**3843**	**1877**	**239**		**13%**

WATER UTILITY SURVEY SUMMARY

The survey responses to each yes/no question are tabulated graphically in Figure 2.3 and Figure 2.4. The first column shows the responses for all surveys while the second column shows

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the remaining responses after being filtered for parameters used in the metric development. The filter required valid energy data and pumping horsepower responses. Response rates for each parameter appear to remain evenly distributed before and after filtering. The filtering did not bias the response.

Disinfection is almost universally noted as a treatment objective. The next group of treatment objectives was only noted in one-third to one-half of the respondents. Turbidity, metal removal, taste and odor control comprise most of this group. Very few of the more recently introduced high energy using processes such as UV and membranes are represented in the survey.

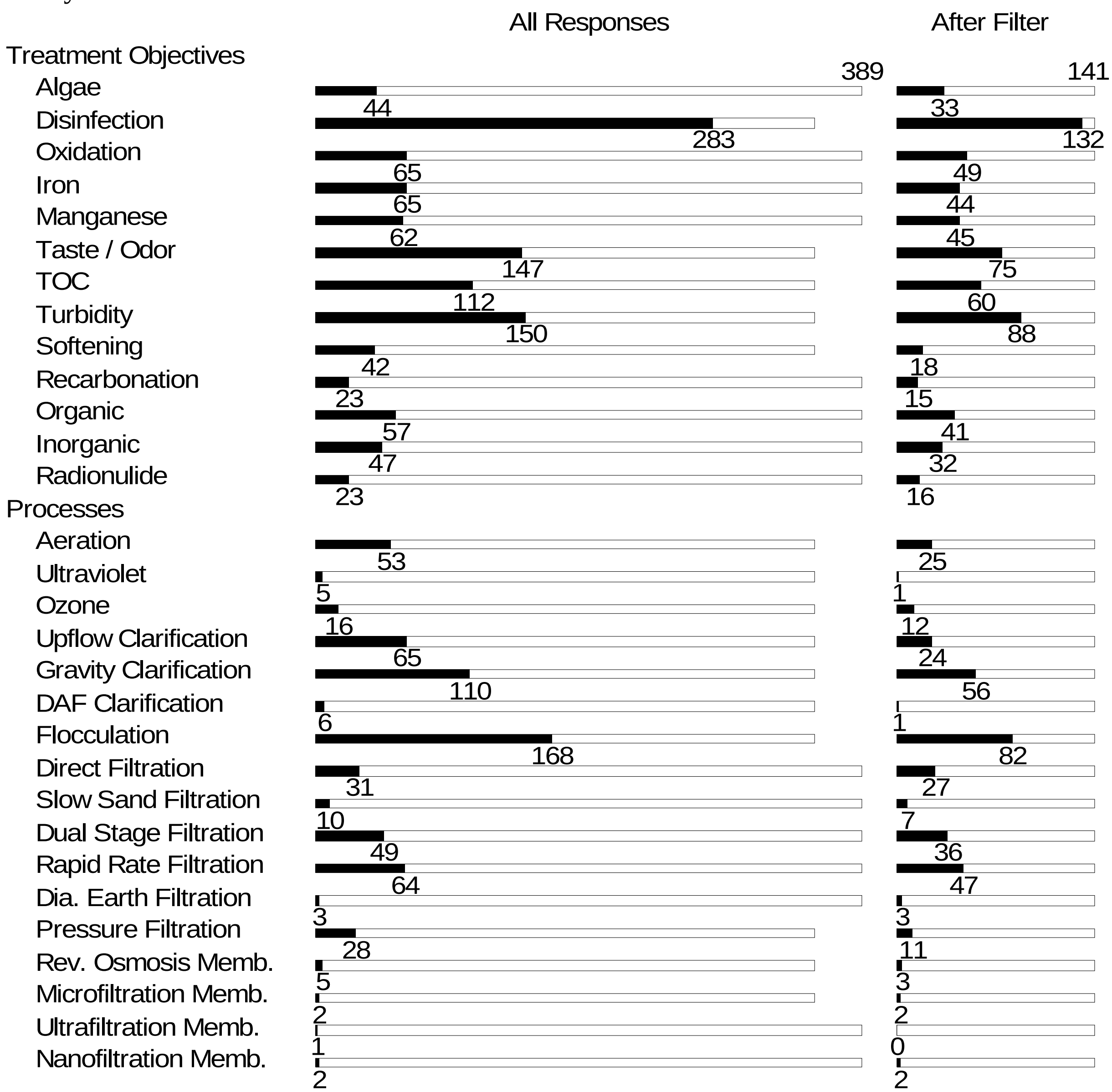

Figure 2.3 Water Utility Survey Response Frequencies to Yes/No Characteristic Questions

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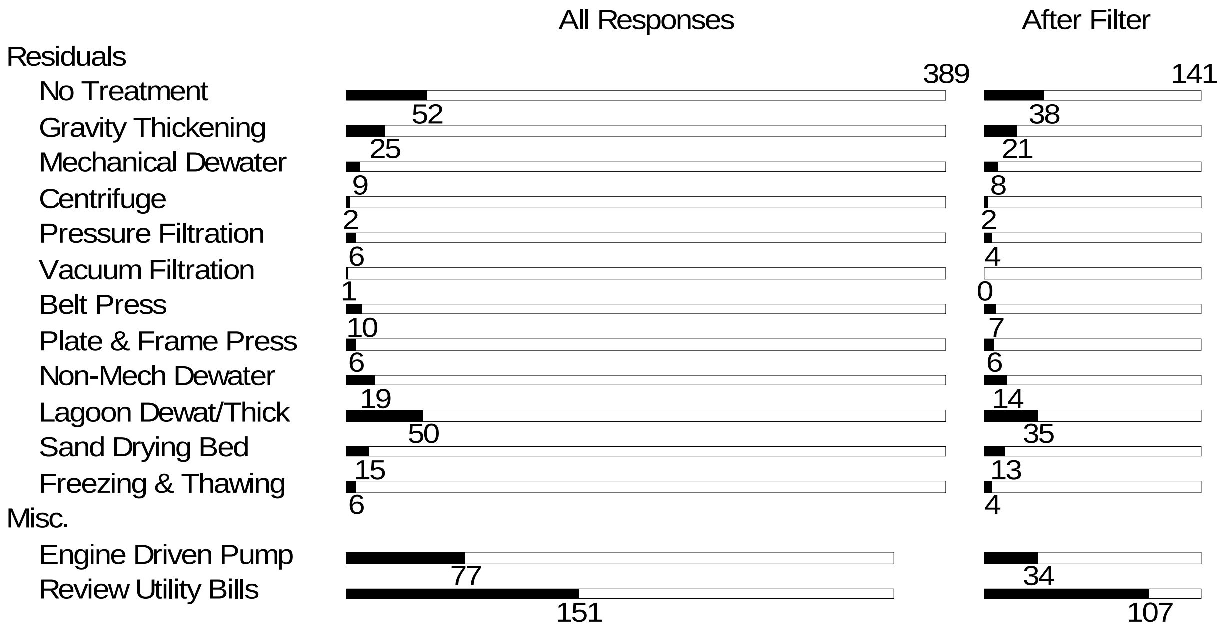

Figure 2.4 Water Utility Survey Response Frequencies to Yes/No Characteristic Questions

Water sources are summarized in Table 2.8. Surface water sources dominate the flow volume, while the number of utilities having ground sources is roughly equal to the number of utilities having surface sources.

Table 2.8 Water Utility Water Sources

Water Source	Number of Utilities	MGD	Flow Fraction
Ground	116 entirely ground 67 mixed sources	1,118	22%
Surface	128 entirely surface 55 mixed sources	3,093	62%
Purchased	42 entirely purchased 35 mixed sources	818	16%

Energy cost varies widely from $25 to $250/MG for most utilities as noted in Figure 2.5. Similarly, energy use varies widely from 250 kWh/MG to 3,500 kWh/MG for most utilities as noted in Figure 2.6. Little distinction is shown between energy use for different portions of a water utility in Figure 2.7. Even though energy data are available from raw water pumping, treatment plants and distribution stations, some of the upstream pumping energy might ultimately meet the distribution pumping needs causing the classification to be less than definitive. For instance, high-service pumps located at the treatment plants will have their energy use included in the treatment plant electric utility bill. Natural gas use in Figure 2.8 is generally below 4 therm/MG, although there are utilities with values exceeding 30 therm/MG.

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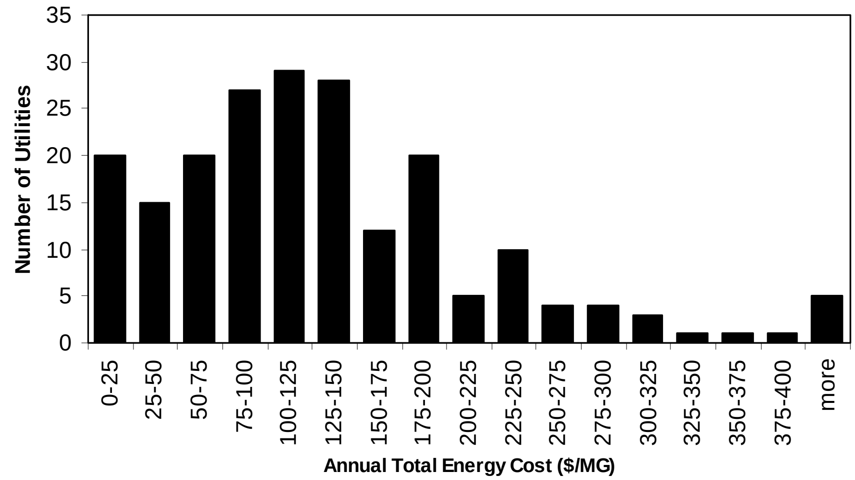

Figure 2.5 Annual Water Utility Flow Normalized Energy Cost Distribution

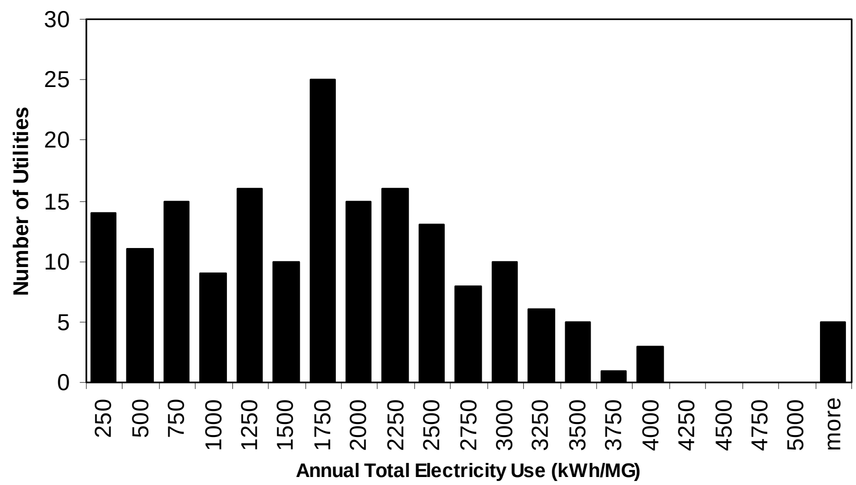

Figure 2.6 Annual Water Utility Flow Normalized Energy Use Distribution

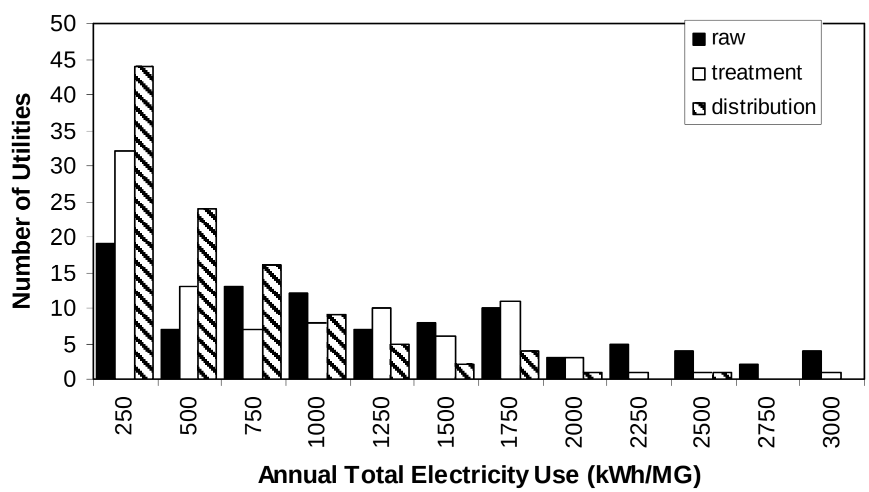

Figure 2.7 Annual Water Utility Flow Normalized Raw, Treatment and Distribution Energy Use

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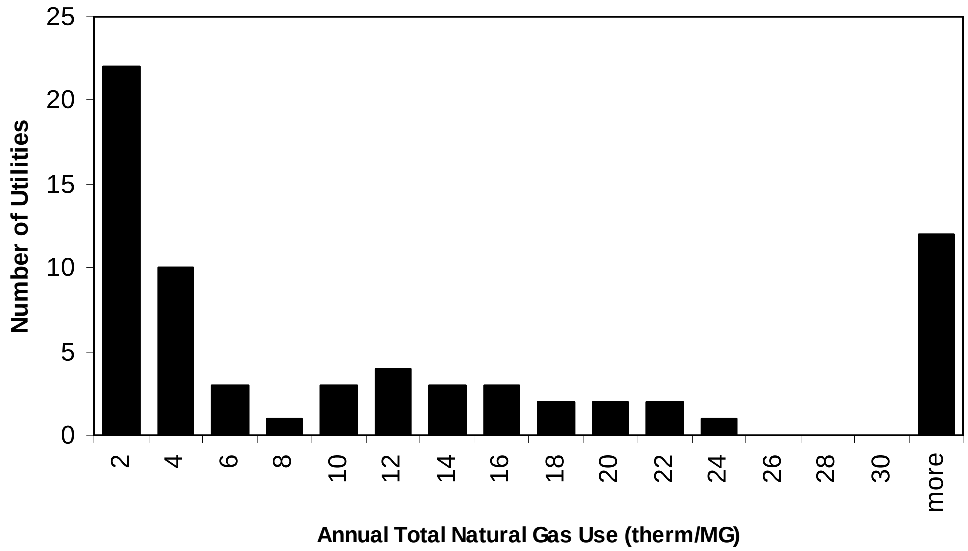

Figure 2.8 Annual Water Utility Flow Normalized Natural Gas Use Distribution

As expected from the population of water utilities, small utilities dominate the sample as shown in Figure 2.9. Various characteristics mainly pertaining to distribution characteristics are summarized in Figure 2.10 through Figure 2.18. They are normalized by flow where appropriate.

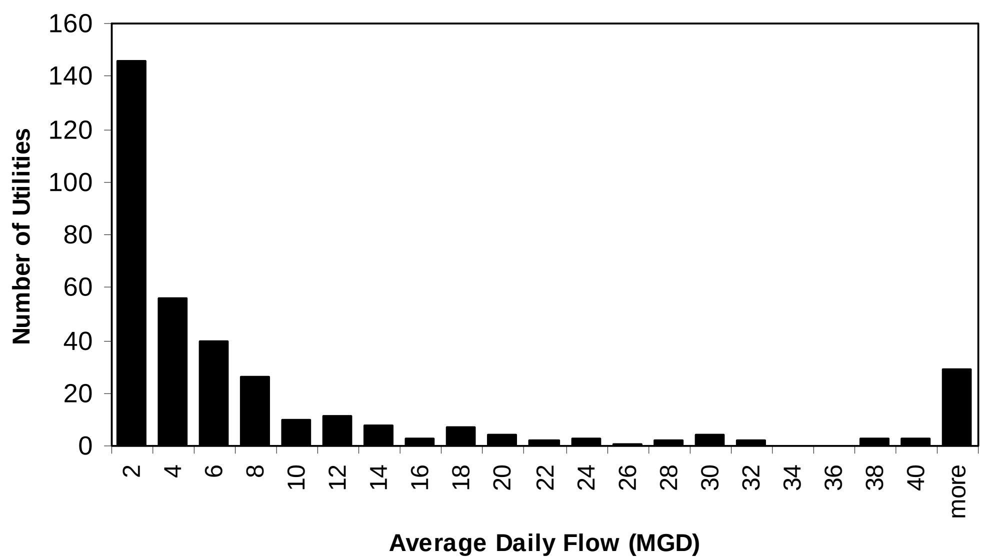

Figure 2.9 Annual Water Utility Average Daily Flow Distribution

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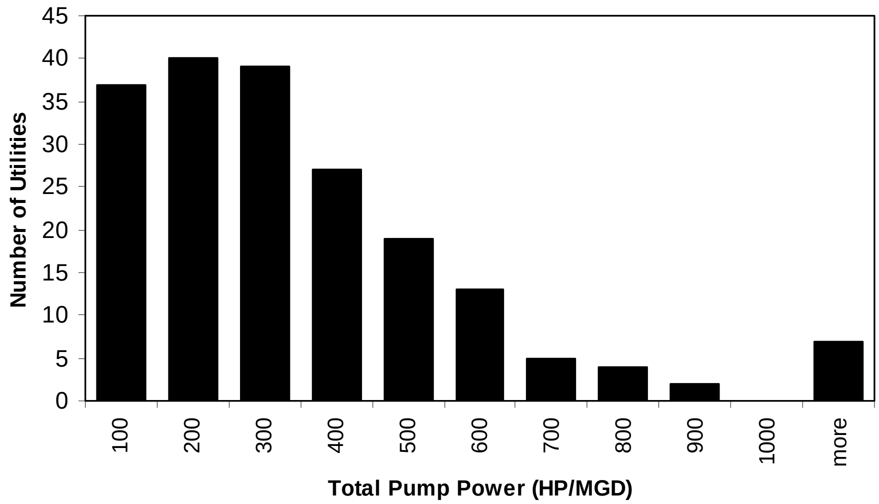

Figure 2.10 Water Utility Flow Normalized Installed Pumping Horsepower Distribution

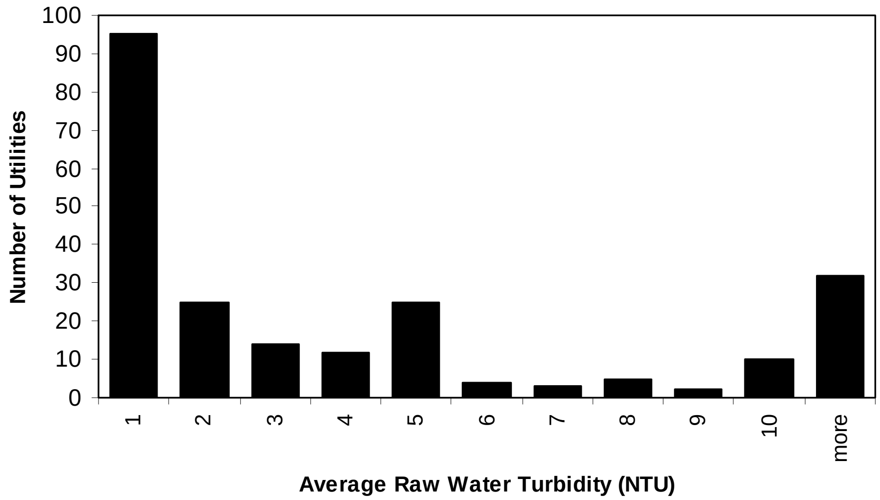

Figure 2.11 Water Utility Average Raw Water Turbidity Distribution

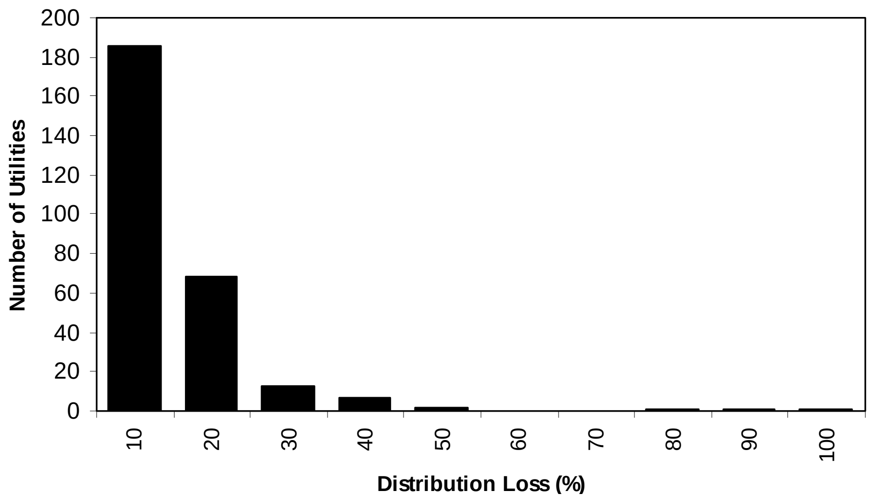

Figure 2.12 Water Utility Distribution Losses

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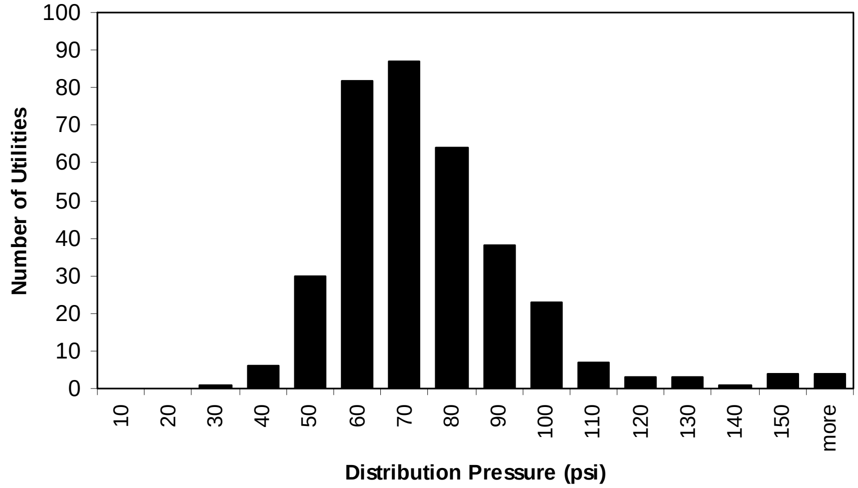

Figure 2.13 Water Utility Distribution Pressure

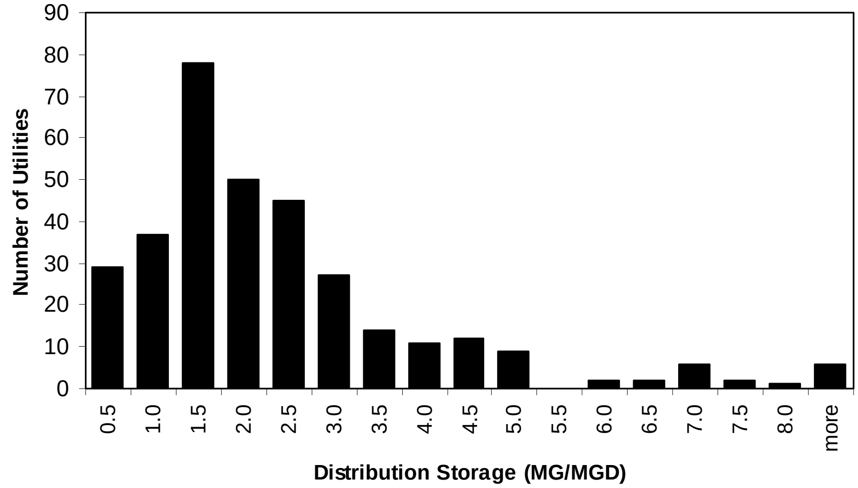

Figure 2.14 Water Utility Flow Normalized Distribution Storage Volume

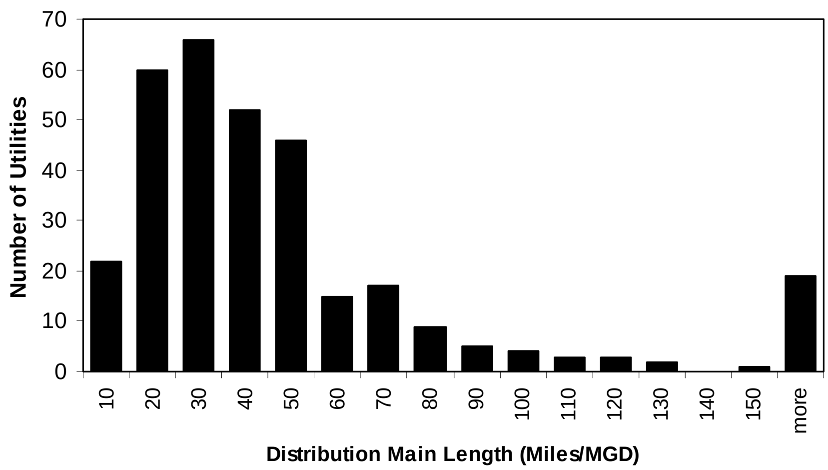

Figure 2.15 Water Utility Flow Normalized Distribution Main Length

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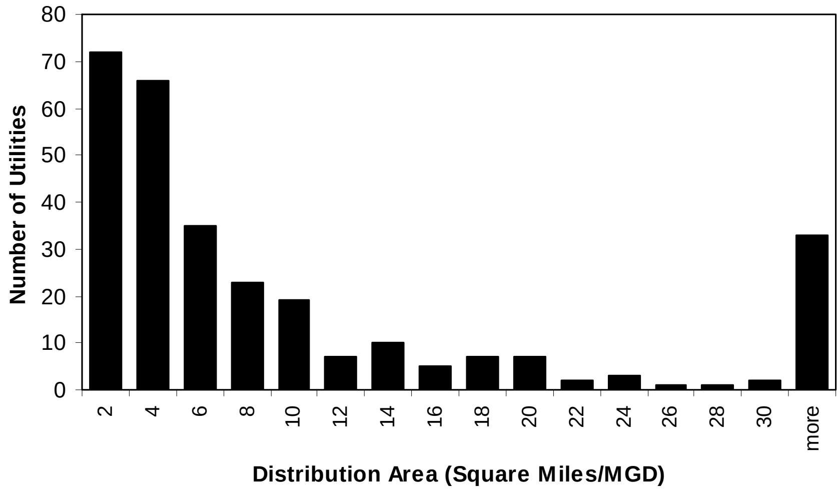

Figure 2.16 Water Utility Flow Normalized Distribution Service Area

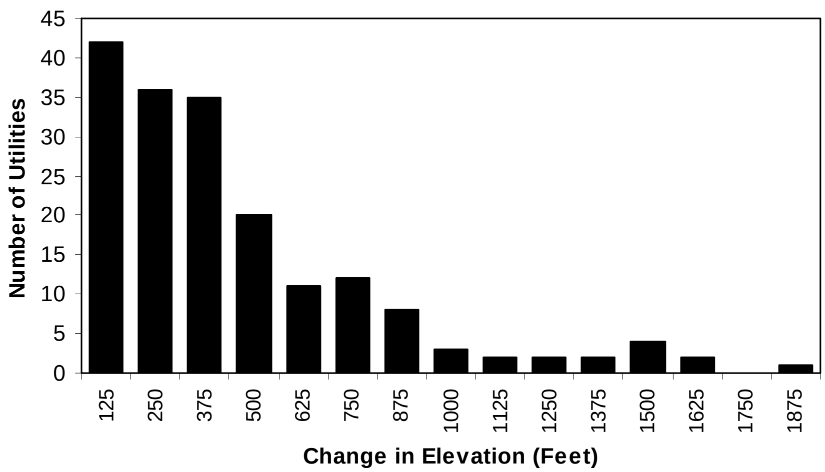

Figure 2.17 Water Utility Distribution Service Area Change in Elevation

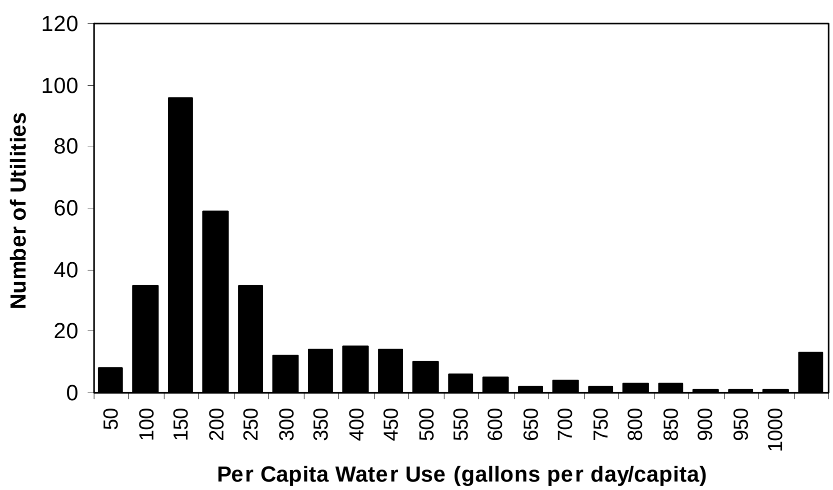

Figure 2.18 Water Utility Water Use per Capita

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CHAPTER 3
WATER METRIC FORMULATION

The goal of the project is to develop a multi-parameter metric that captures the impact of key characteristics on energy use. The development approach closely follows the EPA ENERGY STAR benchmarking system for commercial buildings. In this program the energy use from a statistical sample of buildings was modeled from available building characteristics to normalize for items such as size, hours of use, and internal heat gains.

Similarly this project has created a statistical sample of water utilities that include both energy use and descriptive characteristics. The analysis began by assessing the correlation of each characteristic parameter to energy use in order to find a set of parameters that explained the most variation in energy use among utilities.

SOURCE ENERGY

The analysis sought to identify those parameters that relate to the energy use of the utility. Energy use considers all forms of energy: electricity, natural gas, propane and fuel oil. These energy forms must be combined into a single energy use parameter to define the dependant variable.

Combining electricity and fossil fuel energy use requires conversions that impact the influence of individual fuels on the total energy use. Source energy is widely used to capture the total impact of energy use for energy policy purposes. For the most part, the conversion adjusts the electric energy to be comparable with site consumed fossil fuels. Source energy captures the energy used in the process of producing and transmitting electricity. On a national basis 11,100 BTUs are used to produce and deliver a kWh of electricity (AER 2004). The other energy types use their higher heating value for a conversion to source energy. There is a small 2.4% addition to natural gas to account for transmission losses. Fuel Oil and Propane are converted from sales volumes (gallons) to BTUs based on their higher heating value. Table 3.1 summarizes the conversion factors used in this study.

Table 3.1 Source Energy Conversion Factors

Energy Form	Factor	Units
Electricity	11.1	kBtu/kWh
Natural Gas	102.4	kBtu/therm
Fuel Oil	141	kBtu/gallon
Propane	91	kBtu/gallon

DATA FILTERS

The analysis evaluated utility characteristics for a relationship to energy use on a utility-wide basis. Electricity was the dominant energy type with 64% of the utilities reporting only electricity use and 93% of the utilities reporting 90% or more of total energy use from electricity.

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The survey data were filtered to include only responses with the data used in the analysis. The following filters were applied to the data that eliminated eight samples:

- Total utility electricity use above 2,000 kWh (2 sites)
- Total utility kWh/MG below 5,000 kWh/MG (6 sites)

MODEL DEVELOPMENT

The large range in utility sizes prompted the use of a logarithmic transformation. Figure 3.1 shows the strong relationship between the daily average flow and the total utility source energy use. A total of 176 surveys had sufficient data for the model.

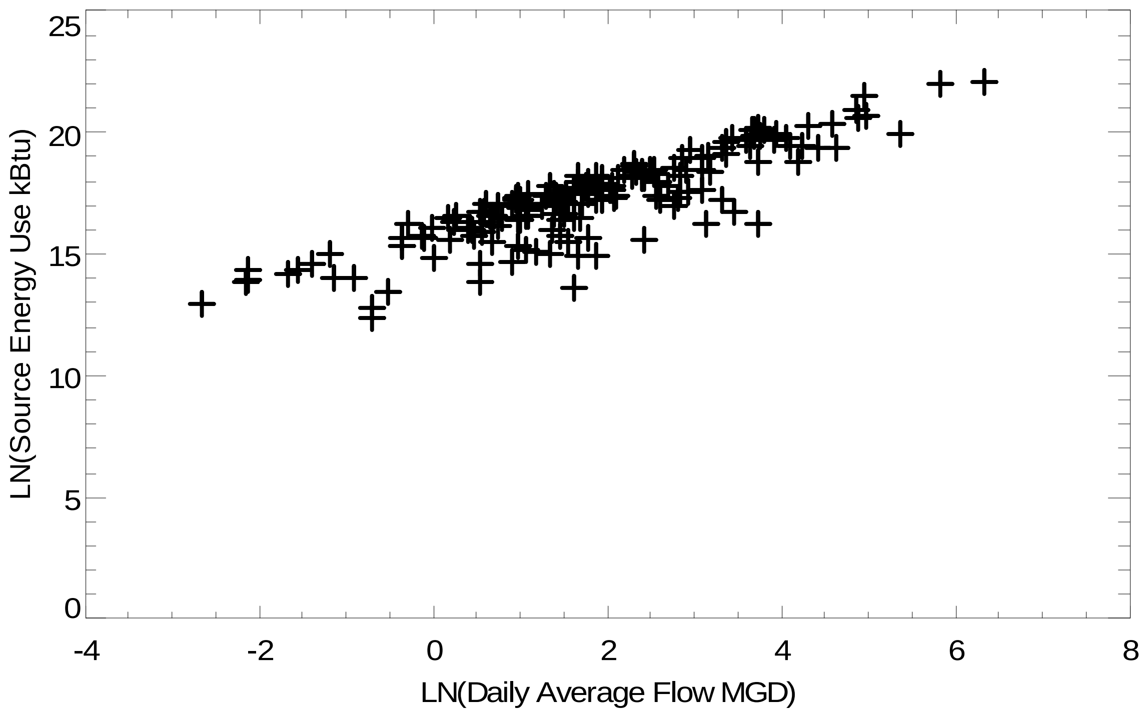

Figure 3.1 Water Utility Energy Use vs Flow

The single parameter model that represents energy use as a function of water flow is shown in Table 3.2. This simple model explains 76% of the energy use variation as noted by the R^2 correlation statistic.

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Table 3.2 Water Utility Energy Use Single Parameter Model

* * * Analysis of Variance * * *

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Model	1	443.61	443.610	565.52	0.00000
Error	174	136.49	0.784		
Corrected Total	175	580.10	444.395		

Std Dev of Model Error	0.89	R-squared	0.7647
Overall mean of y	17.26	adj R-squared	0.7634
Coefficient of variation (%)	5.13		

* * * Parameter Estimates * * *

Parameter	Coefficient	Std Err	T-Value	p-value
Intercept	15.4917	0.0999	155.10	0.00000
ln(flow)	0.9880	0.0415	23.78	0.00000

The analysis took the single parameter model of energy use and flow and tested the impact of each survey parameter. The parameter with the highest significance as judged through a t-test was then the most likely candidate to be added to a two parameter model. This process was repeated, each time adding another parameter with a high significance. The initial model is of the form:

$$y = \beta_0 + \beta_1 x_1 + \varepsilon$$

where,

$y = \ln(utility\_kwh \times 11.1 + ngas\_use \times 102.4)$

$x_1 = \ln(calc\_flow)$

$\beta_i = coefficients$

$\varepsilon = error$

utility_kwh =*reported utility total electricity use (kWh)*

ngas_use =*reported utility natural gas use (therms)*

calc_flow =*total flow from all reported sources (MGD)*

Parameters were tested by adding them individually to the model as term x_2. Parameters with t-test values above 2.0 were considered for the next iteration of the model. The new parameter was included in the model and then the process of assessing the remaining parameters was repeated.

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \varepsilon$$

Table 3.3 lists the initial parameter testing. The first three columns give the variable name, model coefficient value and t-test results. The next column shows the sum of squares of the error. The model correlation represented through an R^2 percentage next shows the variability that is explained by the model. The "N<>0" column shows the number of non-zero values for each parameter. The "T>2" column signifies the parameters with t-test results greater than two, deemed to be significant. The remaining four columns give descriptive statistics of the parameters (including the zero values). The parameters are ranked by the absolute value of the t-test statistic.

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Table 3.3 Water Utility Parameter Influence on Source Energy Use

Parameter	Coef.	T-Test	SSE	R^2 %	N<>0	T>2	Mean	Std Dev	Min	Max
calc_flow	0.9880	23.78	136.49	76.47	175	<<<	1.79	1.61	-2.659	6.342
The following parameters are added independently to above										
ln(raw_hp)	0.1543	7.21	104.96	81.91	176	<<<	11.81	3.28	6.908	16.455
ln(calc_hp)	0.1758	6.88	107.15	81.53	176	<<<	13.01	3.24	6.908	17.868
ln(distrib_hp)	0.1227	5.41	116.75	79.87	176	<<<	11.94	3.31	6.908	17.605
ln(utility_cost)	0.1211	4.89	119.91	79.33	176	<<<	18.64	3.08	6.908	22.884
ln(raw_p_aflow)	-0.2942	-4.11	124.37	78.56	176	<<<	7.20	0.96	4.605	12.231
treat_disinf	0.7596	3.79	126.00	78.28	155	<<<	0.88	0.33	0	1
raw_npump	0.0223	3.65	126.72	78.16	128	<<<	7.92	11.61	0	91
ln(distrib_lost)	0.1993	3.35	128.18	77.90	176	<<<	8.63	1.12	4.605	11.43
raw_p_num	-0.3132	-2.98	129.83	77.62	25	<<<	0.22	0.65	0	5
ln(raw_g_mflow)	0.1371	2.75	130.79	77.45	176	<<<	7.83	1.37	5.298	12.061
raw_g_num	0.0168	2.60	131.36	77.36	92	<<<	6.11	10.54	0	70
ln(raw_g_dflow)	0.1374	2.58	131.43	77.34	176	<<<	7.73	1.33	4.605	11.408
ln(raw_g_aflow)	0.1533	2.53	131.63	77.31	176	<<<	7.44	1.22	4.248	10.966
ln(distrib_main)	0.1207	2.52	131.67	77.30	176	<<<	11.90	1.82	6.908	15.26
distrib_npump	0.0079	2.50	131.75	77.29	133	<<<	14.25	24.69	0	126
ln(raw_g_pntu)	-0.1608	-2.37	132.19	77.21	176	<<<	6.96	0.98	2.996	12.206
ln(raw_cost)	0.0259	2.31	132.39	77.18	176	<<<	13.00	6.00	6.908	22.286
res_gravity	0.4701	2.23	132.69	77.13	20	<<<	0.11	0.32	0	1
res_none	0.3610	2.20	132.76	77.11	39	<<<	0.22	0.42	0	1
ln(calc_elev_chang)	0.0576	2.08	133.16	77.05	176	<<<	10.91	2.63	6.908	14.403
ln(raw_s_antu)	0.0943	1.96	133.53	76.98	176		7.51	1.43	3.401	12.257
ln(raw_kw)	0.0302	1.93	133.61	76.97	176		10.22	4.34	6.908	24.25
check_util	0.2757	1.90	133.69	76.95	109		0.62	0.49	0	1
process_aerate	0.3484	1.89	133.74	76.95	27		0.15	0.36	0	1
utility_nplants	0.0585	1.89	133.72	76.95	102		1.21	2.23	0	20
ln(raw_kwh)	0.0175	1.89	133.74	76.95	176		14.46	7.24	6.908	25.734
ln(raw_g_antu)	-0.1262	-1.84	133.87	76.92	176		6.59	0.97	2.303	9.21
res_sand	-0.4576	-1.80	133.97	76.91	13		0.07	0.26	0	1
res_ppress	0.6250	1.68	134.30	76.85	6		0.03	0.18	0	1
process_OZ	0.4083	1.58	134.55	76.81	13		0.07	0.26	0	1
res_bpress	0.5725	1.54	134.63	76.79	6		0.03	0.18	0	1
ln(distrib_kw)	0.0255	1.53	134.68	76.78	176		9.99	4.14	6.908	23.431
ln(res_weight)	0.0265	1.52	134.69	76.78	176		9.76	4.17	6.908	21.416
ln(utility_kw)	0.0207	1.44	134.87	76.75	176		10.78	4.65	6.908	24.635
process_clar_daf	0.8841	1.41	134.95	76.74	2		0.01	0.11	0	1
ln(raw_g_depth)	0.0319	1.41	134.93	76.74	176		9.68	2.98	6.908	14.732
ln(raw_s_pntu)	0.0395	1.35	135.08	76.72	176		8.51	2.41	3.689	15.525
ln(floor_area)	0.0175	1.28	135.21	76.69	176		12.65	4.91	6.908	22.11
res_cent	0.7910	1.24	135.29	76.68	2		0.01	0.11	0	1
calc_metals	0.1806	1.20	135.36	76.67	48		0.27	0.45	0	1
treat_iron	0.1819	1.17	135.42	76.66	43		0.24	0.43	0	1
treat_ox	0.1752	1.16	135.43	76.65	49		0.28	0.45	0	1
res_dewat_nmech	0.2695	1.16	135.44	76.65	16		0.09	0.29	0	1

(continued)

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Table 3.3 Water Utility Parameter Influence on Source Energy Use (continued)

Parameter	Coef.	T-Test	SSE	R^2 %	N<>0	T>2	Mean	Std Dev	Min	Max
calc_flow	0.9880	23.78	136.49	76.47	175	<<<	1.79	1.61	-2.659	6.342
The following parameters are added independently to above										
ln(ngas_cost)	0.0173	1.16	135.44	76.65	176		11.34	5.09	6.908	20.766
res_dewat_mech	0.3997	1.15	135.45	76.65	7		0.04	0.20	0	1
process_clar_up	0.1912	1.11	135.52	76.64	33		0.19	0.39	0	1
process_filtr_rapid	0.1736	1.11	135.52	76.64	50		0.28	0.45	0	1
ln(distrib_storage)	0.0619	1.09	135.57	76.63	176		9.05	1.68	4.605	18.202
distrib_nzones	-0.0049	-1.08	135.57	76.63	149		6.63	15.98	0	161
process_mem_rosmos	-0.5530	-1.07	135.60	76.63	3		0.02	0.13	0	1
treat_algae	0.1805	1.04	135.64	76.62	35		0.20	0.40	0	1
process_filtr_dual	0.1600	0.94	135.80	76.59	36		0.21	0.41	0	1
treat_soft	0.1815	0.91	135.84	76.58	23		0.13	0.34	0	1
ln(pump_eng_hp)	0.0234	0.88	135.88	76.58	176		8.07	2.62	6.908	16.335
process_filtr_sand	-0.2939	-0.86	135.91	76.57	7		0.04	0.20	0	1
res_lagoon	0.1323	0.82	135.96	76.56	40		0.23	0.42	0	1
treat_mang	0.1257	0.81	135.98	76.56	44		0.25	0.43	0	1
treat_odor	0.1096	0.80	135.99	76.56	87		0.49	0.50	0	1
process_mem_micfiltr	-0.4968	-0.79	136.00	76.56	2		0.01	0.11	0	1
ln(distrib_kwh)	0.0080	0.77	136.02	76.55	176		14.82	6.81	6.908	25.495
ln(raw_s_aflow)	0.0458	0.73	136.07	76.54	176		8.00	1.53	5.347	13.25
ln(oenergy_cost)	-0.0137	-0.70	136.11	76.54	176		8.45	3.43	6.908	18.948
process_UV	0.6019	0.68	136.13	76.53	1		0.01	0.08	0	1
res_frz	0.2680	0.67	136.14	76.53	5		0.03	0.17	0	1
ln(treat_cost)	-0.0069	-0.59	136.22	76.52	176		12.72	5.76	6.908	22.569
process_filtr_dearth	0.2995	0.58	136.23	76.52	3		0.02	0.13	0	1
ln(raw_s_mflow)	0.0252	0.56	136.24	76.51	176		8.40	1.78	6.685	14.192
treat_TOC	-0.0681	-0.49	136.30	76.50	72		0.41	0.49	0	1
ln(treat_kwh)	-0.0041	-0.43	136.35	76.50	176		14.14	6.98	6.908	25.146
treat_recarb	0.0911	0.41	136.36	76.49	18		0.10	0.30	0	1
treat_radon	0.0926	0.39	136.37	76.49	15		0.09	0.28	0	1
process_filtr_press	-0.1014	-0.38	136.38	76.49	12		0.07	0.25	0	1
ln(distrib_cost)	0.0047	0.37	136.38	76.49	176		13.51	5.62	6.908	22.635
process_floc	0.0473	0.34	136.40	76.49	100		0.57	0.50	0	1
calc_contam	0.0461	0.31	136.41	76.48	53		0.30	0.46	0	1
treat_turb	0.0425	0.30	136.42	76.48	98		0.56	0.50	0	1
process_clar_gravity	0.0418	0.29	136.42	76.48	66		0.38	0.49	0	1
oenergy_purch	-0.0456	-0.29	136.42	76.48	44		0.25	0.43	0	1
ln(calc_NTU_peak)	-0.0066	-0.24	136.44	76.48	176		8.97	2.57	4.22	15.951
process_mem_nanofilt	-0.1445	-0.23	136.45	76.48	2		0.01	0.11	0	1
ln(distrib_press)	0.0136	0.21	136.46	76.48	176		10.91	1.02	6.908	11.918
extra_event	-0.0398	-0.20	136.46	76.48	23		0.13	0.34	0	1
ln(treat_kw)	0.0034	0.19	136.46	76.48	176		9.72	3.88	6.908	19.961
res_press_filtr	0.0760	0.17	136.47	76.48	4		0.02	0.15	0	1
ln(raw_s_dflow)	0.0084	0.16	136.47	76.47	176		8.24	1.67	5.991	13.498
ln(ngas_use)	0.0025	0.16	136.47	76.47	176		10.09	4.85	6.908	23.769
ln(calc_NTU_avg)	-0.0069	-0.16	136.47	76.47	176		7.37	1.61	2.949	12.257
process_filtr_direct	0.0194	0.10	136.48	76.47	26		0.15	0.36	0	1
raw_s_num	-0.0032	-0.08	136.49	76.47	72		0.85	1.79	0	15
treat_inorganic	-0.0111	-0.06	136.49	76.47	31		0.18	0.38	0	1
treat_organic	0.0086	0.05	136.49	76.47	41		0.23	0.42	0	1
pump_eng	-0.0056	-0.04	136.49	76.47	42		0.24	0.43	0	1

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The first 20 parameters have t-test values above 2.0 and are candidates for inclusion in the next model. They include parameters related to distribution and raw pumping, raw water volume, elevation range, service area, main length, residual treatment and disinfection.

The two main sets of significant parameters deal with water flow and its various sources as well as the pumping horsepower and its use as raw/source or distribution pumping. The combination that best represented the data was a six parameter model in Table 3.4 that accounted for the purchased water and the raw water pumping horsepower. The model was able to explain 87% of the energy use based on the R^2 correlation statistic. Figure 3.2 shows the model residuals are randomly distributed along the range in energy use data, and the consistent relationship between predicted and actual energy use. Figure 3.3 shows no relationship between the model residuals and the model parameters.

The flow data had to be recoded to accommodate the log transformation and allow for zero values. Since flow data were segregated by source, zero values were acceptable for utilities that do not receive water from that particular source. All of the flows in the model were multiplied by 1,000 and zero values were recoded as one prior to making the log transformation. This pre-processing allowed the zero values to run through the log transformation. Additional filtering to eliminate non-responses to pumping horsepower and distribution main length reduced the total sample size to 125 utilities:

- Total pumping horsepower above zero (34 sites filtered)
- Distribution main length above zero (5 sites filtered)
- Change in elevation above zero (7 sited filtered)

The distribution loss was also a significant parameter, but was excluded from the model so that its impact would affect the score. Had the distribution loss been included in the model, the impact of high loss rates would have been normalized out of the score.

The sign of the model coefficients tells how each parameter impacts the mean energy use. The flow parameter is positive, so as flow increases so does the expected energy use. The purchased flow coefficient is negative, so less energy use is expected as more of the water comes from purchased sources. The remaining parameters all have positive coefficients, so as total pump horsepower, production horsepower, distribution main length and change in elevation increase, the energy use of typical utility is expected to increase.

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Table 3.4 Water Utility Energy Use Model Six Parameter Model

* * * Analysis of Variance * * *

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Model	6	266.59	44.431	141.55	0.00000
Error	118	37.04	0.314		
Corrected Total	124	303.62	44.745		

Std Dev of Model Error	0.56	R-squared	0.8780
Overall mean of y	17.74	adj R-squared	0.8718
Coefficient of variation (%)	3.16		

* * * Parameter Estimates * * *

Parameter	Coefficient	Std Err	T-Value	p-value
Intercept	8.2394	0.4048	20.35	0.00000
ln(calc_flow)	0.4993	0.0899	5.55	0.00000
ln(raw_p_aflow)	-0.0630	0.0152	-4.15	0.00006
ln(distrib_main)	0.2385	0.0922	2.59	0.01090
ln(calc_elev_change)	0.0991	0.0451	2.20	0.03010
ln(calc_hp)	0.3724	0.0637	5.85	0.00000
ln(raw_hp)	0.0624	0.0238	2.62	0.00995

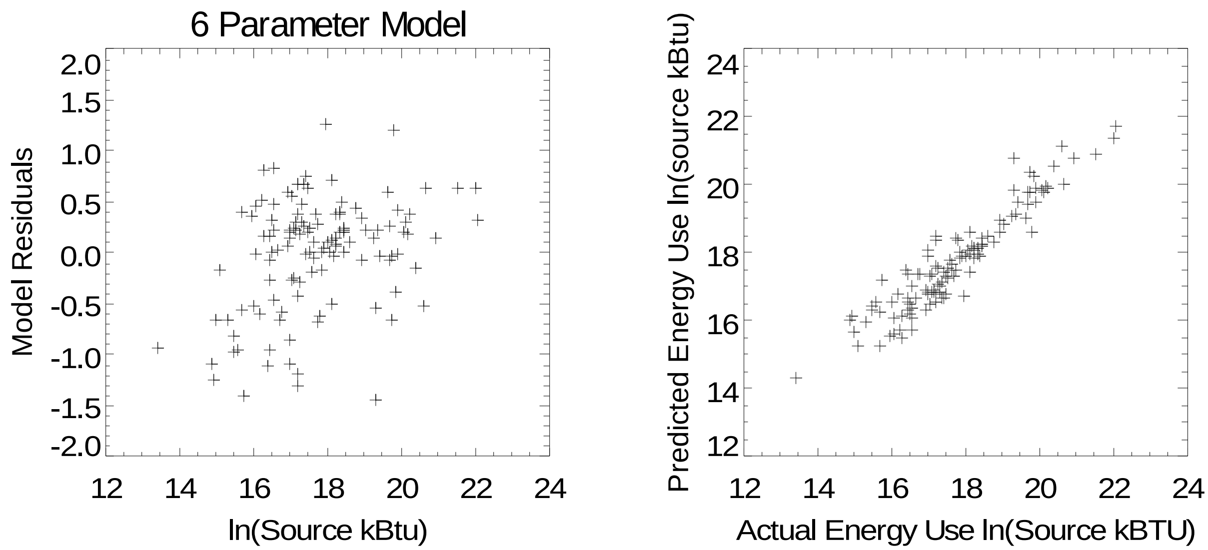

Figure 3.2 Water Utility Six Parameter Model Residuals vs Dependent Variable and Model Fit

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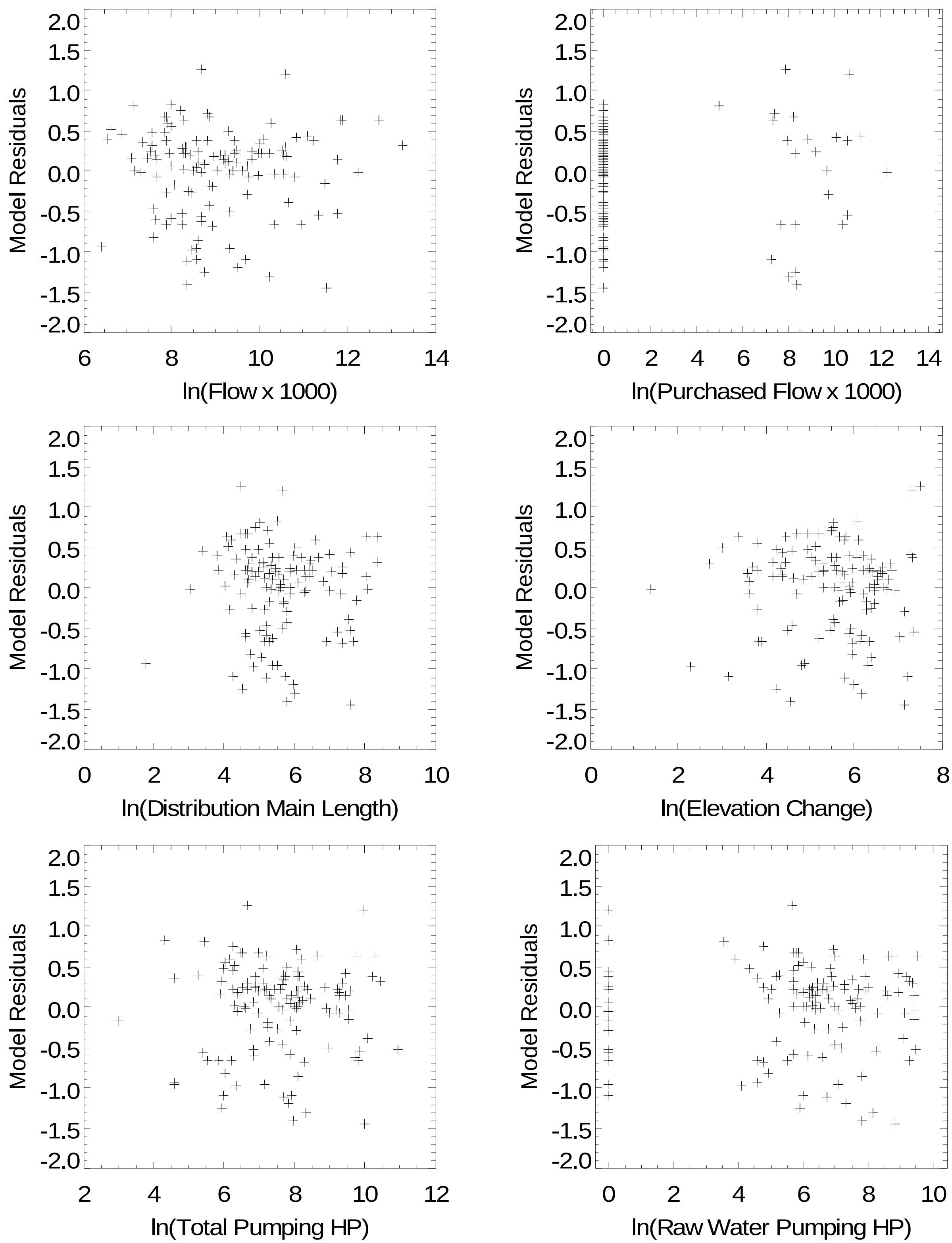

Figure 3.3 Water Utility Six Parameter Model Residuals vs Independent Variables

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ENERGY PERFORMANCE RATING BENCHMARK SCORE

The regression model calculates the expected average energy use for the specific set of characteristics of a particular utility. The ratio of the model result to the overall mean provides a way to compare if the average utility with the specific characteristics uses more or less energy than the overall mean. The overall mean is the model result when each parameter is at its average value. Dividing the actual energy use by this ratio allows a comparison to the adjusted energy use for all utilities used to develop the model.

Adjustment Factor = Predicted / Mean

Energy Adjusted = Energy / (Adjustment Factor)

The adjustment factor can be manipulated algebraically into the following form that illustrates that the deviation in actual energy use to the predicted energy use for the particular utility characteristics is used to determine how far from the overall sample mean the utility's adjusted energy use would appear on the energy distribution curve.

$$y_{adj} = \hat{y}_{mean} \frac{y}{\hat{y}}$$

The distribution of the adjusted energy use, Figure 3.4, captures the variation in the sample relative to the predicted energy use for the utility. The location or percentile of the utility's adjusted energy use on this distribution is the benchmark score.

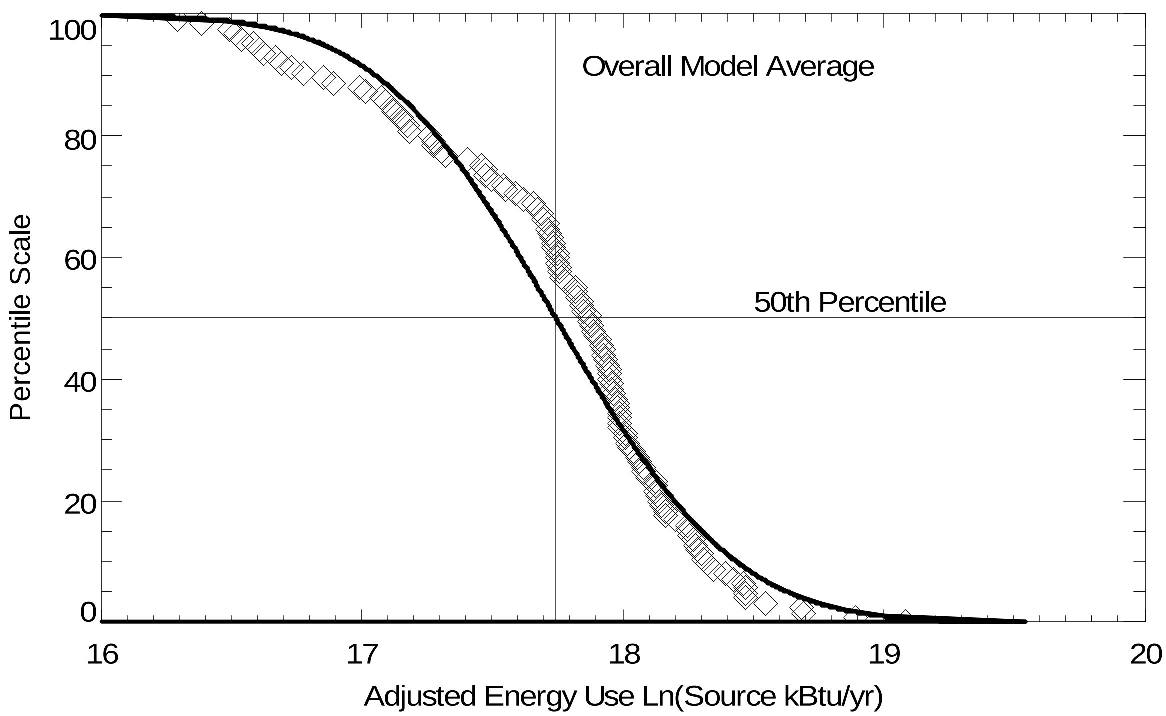

Figure 3.4 Water Utility Modeled Energy Distribution

To account for the non-uniformity of observations, a normal distribution is fitted to the model distribution curve. The distribution is skewed at the lower energy using utilities causing

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the fit to widen at both tails. For the purpose of scoring individual utilities against their peers, it is better to have a wider distribution so that higher scores are more difficult to obtain. This fit becomes the energy performance rating score tabulated in Table 3.5.

Table 3.5 Water Utility Energy Performance Rating Score Based on Adjusted Source Energy Use

Score	Adjusted Energy Use ln(kBtu/yr)		Score	Adjusted Energy Use ln(kBtu/yr)		Score	Adjusted Energy Use ln(kBtu/yr)
100	15.945		66	17.522		33	17.983
99	16.489		65	17.537		32	17.998
98	16.636		64	17.551		31	18.013
97	16.729		63	17.566		30	18.028
96	16.800		62	17.580		29	18.044
95	16.857		61	17.594		28	18.060
94	16.906		60	17.608		27	18.076
93	16.948		59	17.622		26	18.092
92	16.986		58	17.636		25	18.109
91	17.021		57	17.650		24	18.126
90	17.053		56	17.664		23	18.144
89	17.083		55	17.677		22	18.162
88	17.111		54	17.691		21	18.181
87	17.137		53	17.704		20	18.199
86	17.162		52	17.718		19	18.219
85	17.185		51	17.731		18	18.239
84	17.208		50	17.745		17	18.260
83	17.230		49	17.759		16	18.282
82	17.251		48	17.772		15	18.305
81	17.271		47	17.786		14	18.328
80	17.291		46	17.799		13	18.353
79	17.309		45	17.813		12	18.379
78	17.328		44	17.826		11	18.407
77	17.346		43	17.840		10	18.437
76	17.364		42	17.854		9	18.469
75	17.381		41	17.868		8	18.504
74	17.398		40	17.882		7	18.542
73	17.414		39	17.896		6	18.585
72	17.430		38	17.910		5	18.633
71	17.446		37	17.924		4	18.690
70	17.462		36	17.939		3	18.761
69	17.477		35	17.953		2	18.854
68	17.492		34	17.968		1	19.001
67	17.507						

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To determine the score for a utility the first step is to calculate the total source energy use from the annual energy use. Table 3.6 illustrates the conversion for each energy form to source energy. The last line in the table applies the natural logarithm transformation.

Table 3.6 Source Energy Conversion Example Calculations

Utility Energy Type	Units	Utility Annual Energy Use	x Conversion	=	Source Energy Use (kBtu/yr)
Electricity	kWh	**18,355,000**	11.1		203,740,500
Natural gas	therms	**9,279**	102.4		950,170
Fuel oil #2	gallons	**-**	141		0
Propane	gallons	**-**	91		0
Annual Source Energy Use (kBtu per yr)					204,690,670
ln (Source Energy Use)					19.1370

The second step in the score calculation is to determine the average energy use for a utility with the given characteristics. The coefficients from the six parameter regression model are applied to the site characteristics as shown in Table 3.7. The flow data are in kGD rather than MGD so that a recoding of zero values in the purchased flow could be accommodated. The purchased flow and raw/source horsepower have one added to their value so that the log transformation can be applied to match the form of the regression model.

Table 3.7 Modeled Energy Example Calculations

Parameter	Units	Value	Natural Logarithm Transform		Model Coefficient		
Constant					8.2394	=	8.2394
Average Daily Total Flow	kGD	**28800**	10.2681	x	0.4993	=	5.1269
Purchased Daily Flow	kGD	**0**	0.0000	x	-0.0630	=	0.0000
Total Pump Horsepower	HP	**4900**	8.4970	x	0.3724	=	3.1643
Raw/Source Pump Horsepower	HP	**2750**	7.9197	x	0.0624	=	0.4942
Change in Distribution Elevation	ft	**250**	5.5215	x	0.0991	=	0.5470
Total Water Main Length	miles	**1100**	7.0031	x	0.2385	=	1.6704
Mean predicted annual energy use (SUM of above)						=	19.2421

The predicted energy use for the utility with the same characteristics as the utility of interest uses more energy that the actual utility. In other words the utility being studied uses less energy than the typical comparable utility. To assess how much better the utility is than the expected typical utility, an adjustment factor, calculated in Table 3.8, is used to place the actual energy use on a distribution of modeled energy use from the survey sample.

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Table 3.8 Adjusted Energy Use Example Calculations

Adjustment Factor: Divide SUM above by 17.74 (average utility in model)	19.2421	÷	17.7450	=	1.0844
Adjusted Energy Use: Divide ln (primary energy use) by adjustment factor	19.1370	÷	1.0844	=	17.6481

The location of the adjusted energy use on the modeled energy use distribution curve, Figure 3.5, gives the utility's energy use relative to its peers. The percentile location on the curve is a score indicative of how close the energy use is to the best observed energy use (100 = best, 1 = worst). In this example an adjusted energy use of 17.65 intersects the distribution curve at the 58th percentile, resulting in a score of 58.

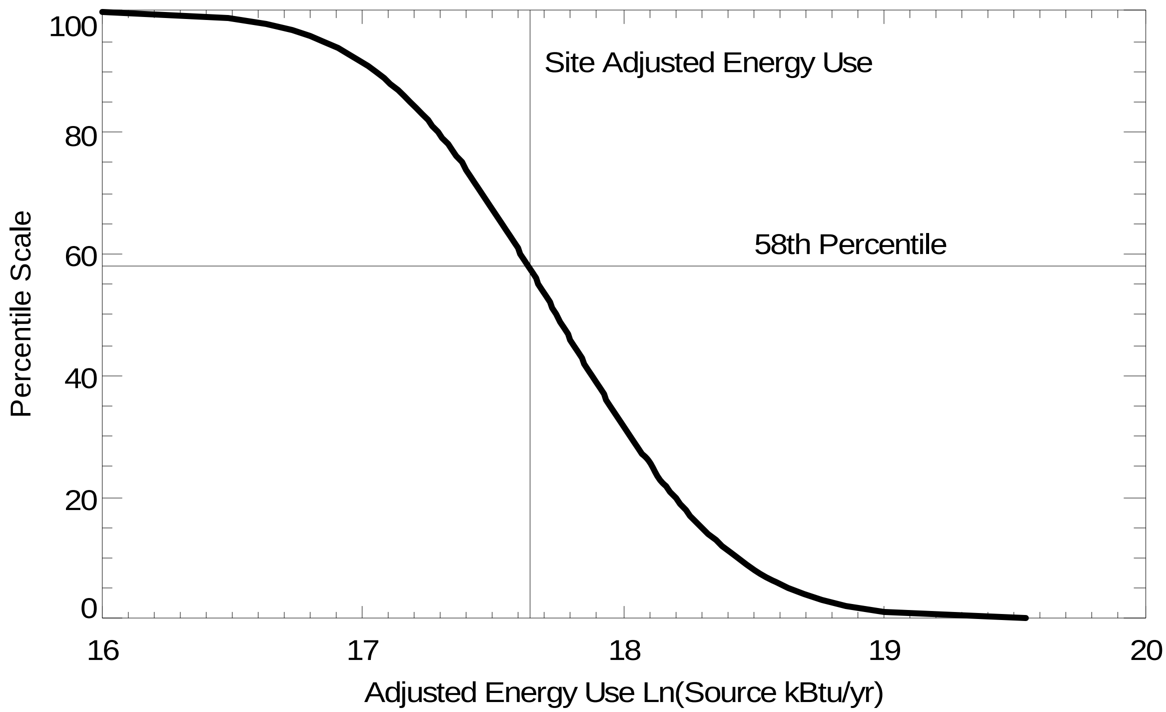

Figure 3.5 Water Utility Example Score on Modeled Energy Distribution

The distribution is useful in giving a sense of the range in observed energy use at its peer utilities. To make comparisons, the energy use from target scores can be calculated. For this site a reduction in source energy use of 32% would be needed to achieve a score in the 75th percentile or a 54% reduction to achieve a score in the 90th percentile. An average utility (one at the 50th percentile) with the same characteristics uses 5% more energy than the example utility being studied.

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Table 3.9 Target Energy Use Example Calculations

				Estimated Site Energy*			
Benchmark Score	Source Energy kBtu/yr	Difference kBtu/yr	Diff. (%)	Electricity kWh/MG	Natural Gas therm/MG	Fuel Oil Gal/MG	Propane Gal/MG
58	204,690,670			1746	0.9	0	0
				100%	0%	0%	0%
10	506,510,140	301,819,471	147%	4321	2.2	0	0
25	337,167,693	132,477,024	65%	2876	1.5	0	0
50	215,895,836	11,205,166	5%	1842	1.0	0	0
75	139,175,368	(65,515,302)	-32%	1187	0.6	0	0
90	94,296,688	(110,393,981)	-54%	804	0.4	0	0
*Site energy estimate is based on actual proportion of fuel source use at the utility							

To further make this comparison meaningful, the source energy of the target scores can be equated to site energy use based on the fraction of use of the various fuel types of energy sources. In this example nearly 100% of the energy use was in the form of electricity and less than 1% was in the form of natural gas. Applying the reciprocal of the source energy conversion from Table 3.1 and the fraction of source energy use gives an estimate of the site energy use. In Table 3.9 the site energy use is divided by the average flow to give a metric in the form with which the industry is familiar (e.g. kWh/MG).

The range in target energy values could be useful in evaluating the impact of proposed energy efficiency projects on the ultimate utility score. A proposed project's projected energy savings that drove the score to the extreme in the range might be suspect as overly optimistic.

The energy metric can be packaged in a concise manner as illustrated in Figure 3.6. This spreadsheet implementation uses the WSID to identify the treatment plant. The annual energy use is collected by energy source in the next section. The utility characteristics section gathers the model parameters. The energy benchmark score along with the total source energy are calculated and displayed and the target energy section shows the amount of change in energy use needed to achieve other scores along with energy targets in site energy units.

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Water Utility Energy Benchmark Metric (v 2007_8_24)

AwwaRF research project 3009 with additional support by the California Energy Commission and The New York State Energy Research and Development Authority

Utility Identification

Utility Water System Identification (WSID):	
Date:	

Utility Annual Energy Use

Please enter the annual energy use from all energy sources. If your utility generates power, please enter only purchased fuel. Electricity and natural gas entries are provided in various units for convenience.

Site Energy Type	Units	Site Energy Annual Use		
Electricity	kWh	**18,355,000**	1,746	kWh/MG
Natural gas	therms	**9,279**	1	therm/MG
Fuel oil #2	gallons			
Propane	gallons			
Energy use time period covered above:		**2004**		

Utility Characteristics

Please enter the following characteristics to describe the water utility.

Parameter	Units	Value		
Average Daily Total Flow	MGD	**28.8**		
Purchased Daily Flow	MGD	**0**	0%	
Total Pump Horsepower	HP	**4900**	170	hp/MGD
Raw/Source Pump Horsepower	HP	**2750**	56%	
Change in Distribution Elevation	ft	**250**		
Total Water Main Length	miles	**1100**	38	miles/MGD

Energy Metric

This water utility energy benchmark is based on a statistical representation of the energy use of water utilities across the country. It includes the characteristics that were found to have the most impact in explaining energy use among various utilities. The resulting score represents your utility's relative energy use within the distribution of utilities with your characteristics.

Your Utility Benchmark Score:	**58**
Total Source Energy Use (kBtu/yr):	**204,690,000**

Target Energy Use - Energy Metric Distribution

The following table shows the range in distribution of energy use for utilities with your characteristics. The percentages are relative to your use. The estimated site energy use is based on the actual proportions of site energy used.

	Source Energy Use		Estimated Site Energy Use			
Score	**(kBtu/yr)**	**Percentage Difference (%)**	**Electricity (kWh/MG)**	**Natural Gas (therms/MG)**	**Fuel Oil (gallons/MG)**	**Propane (gallons/MG)**
10	506,510,000	147%	4,321	2	0	0
25	337,170,000	65%	2,876	1	0	0
50	215,900,000	5%	1,842	1	0	0
75	139,180,000	-32%	1,187	1	0	0
90	94,297,000	-54%	804	0	0	0

Figure 3.6 Water Utility Example Benchmark Calculation Sheet

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COMPARISON TO SINGLE PARAMETER METRICS

The benchmark metric captures the influence of several utility characteristics in defining peers and in comparing energy use. The score only roughly correlates with a traditional single parameter metric of electricity use per total flow (kWh/MG) as shown in Figure 3.7. The normalized electricity use is only slightly correlated to the score, showing a slightly decreasing trend with higher scores. Due to the operating conditions, some utilities with low kWh/MG still achieve low benchmark scores as the score incorporates natural gas and operational factors.

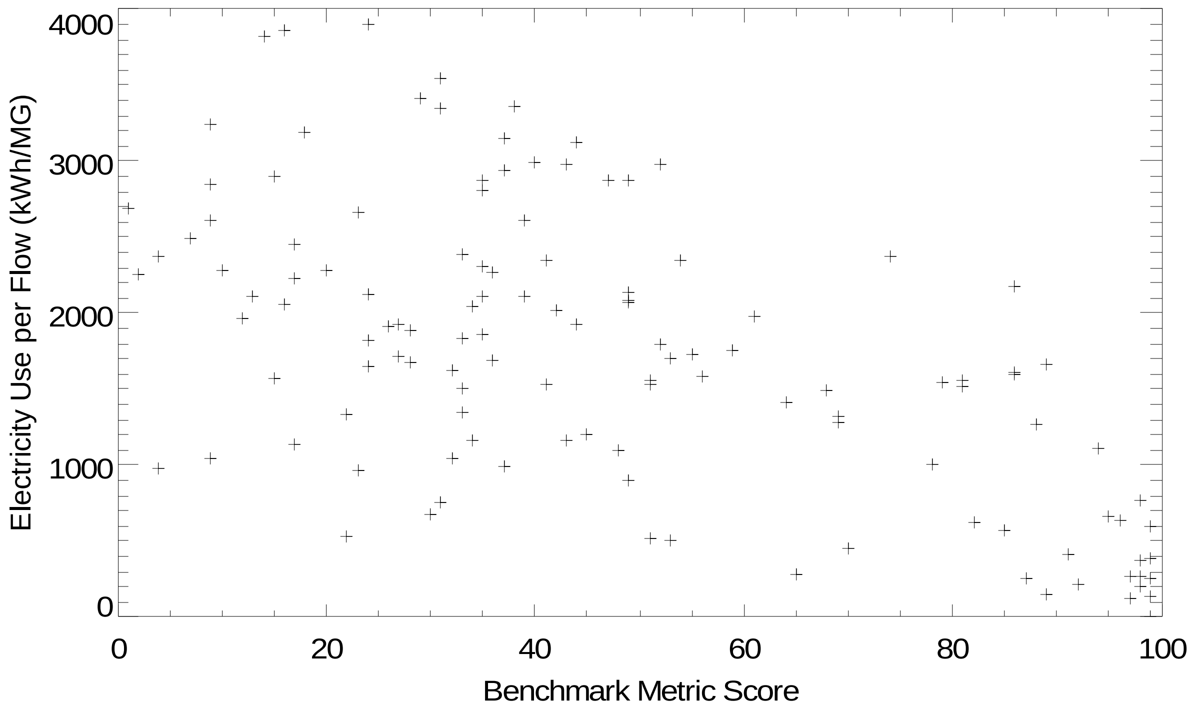

Figure 3.7 Water Utility Benchmark Score Comparison to Simple Flow Based Energy Use Metric

Since the analysis showed that energy use was also strongly correlated to total pump horsepower, the score is compared to a pumping horsepower normalized electricity use metric in Figure 3.8. The range in the simple metric, as well as the overall trend decreases with higher scores.

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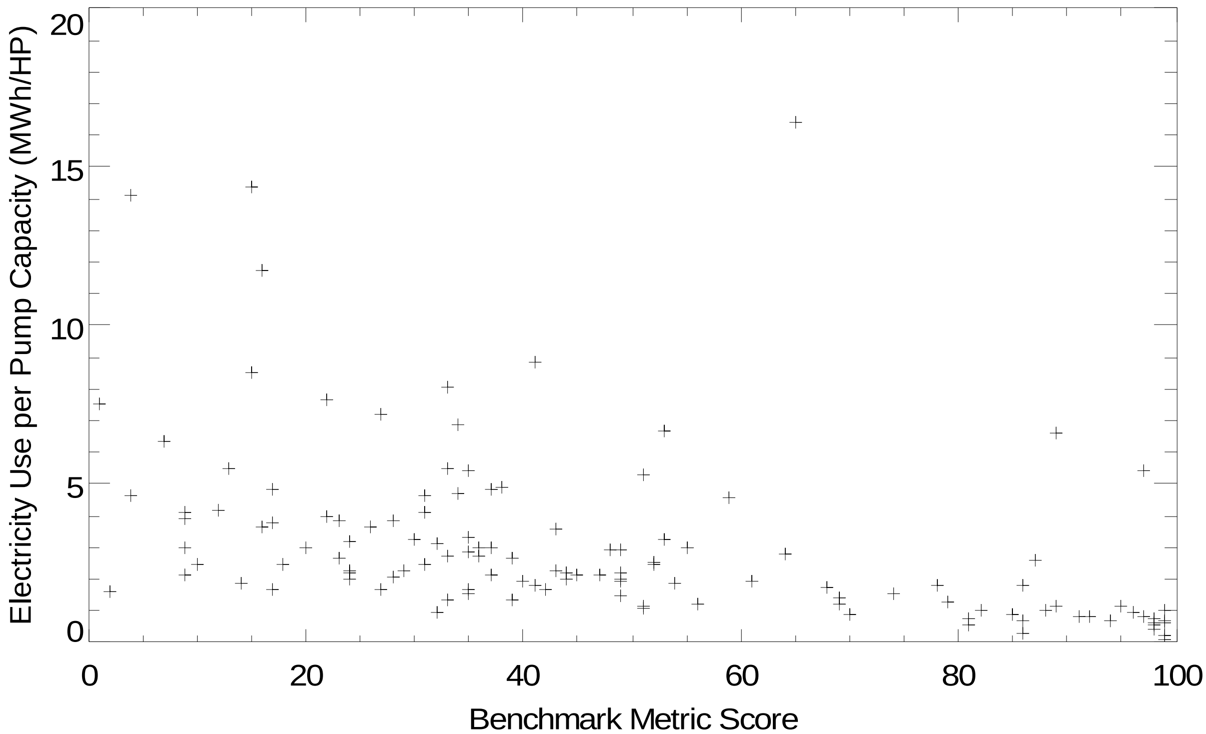

Figure 3.8 Water Utility Benchmark Score Comparison to Simple Pump Capacity Based Energy Use Metric

The benchmark score is compared to each of the independent variables in Figure 3.9. There are no correlations between score and the model parameters.

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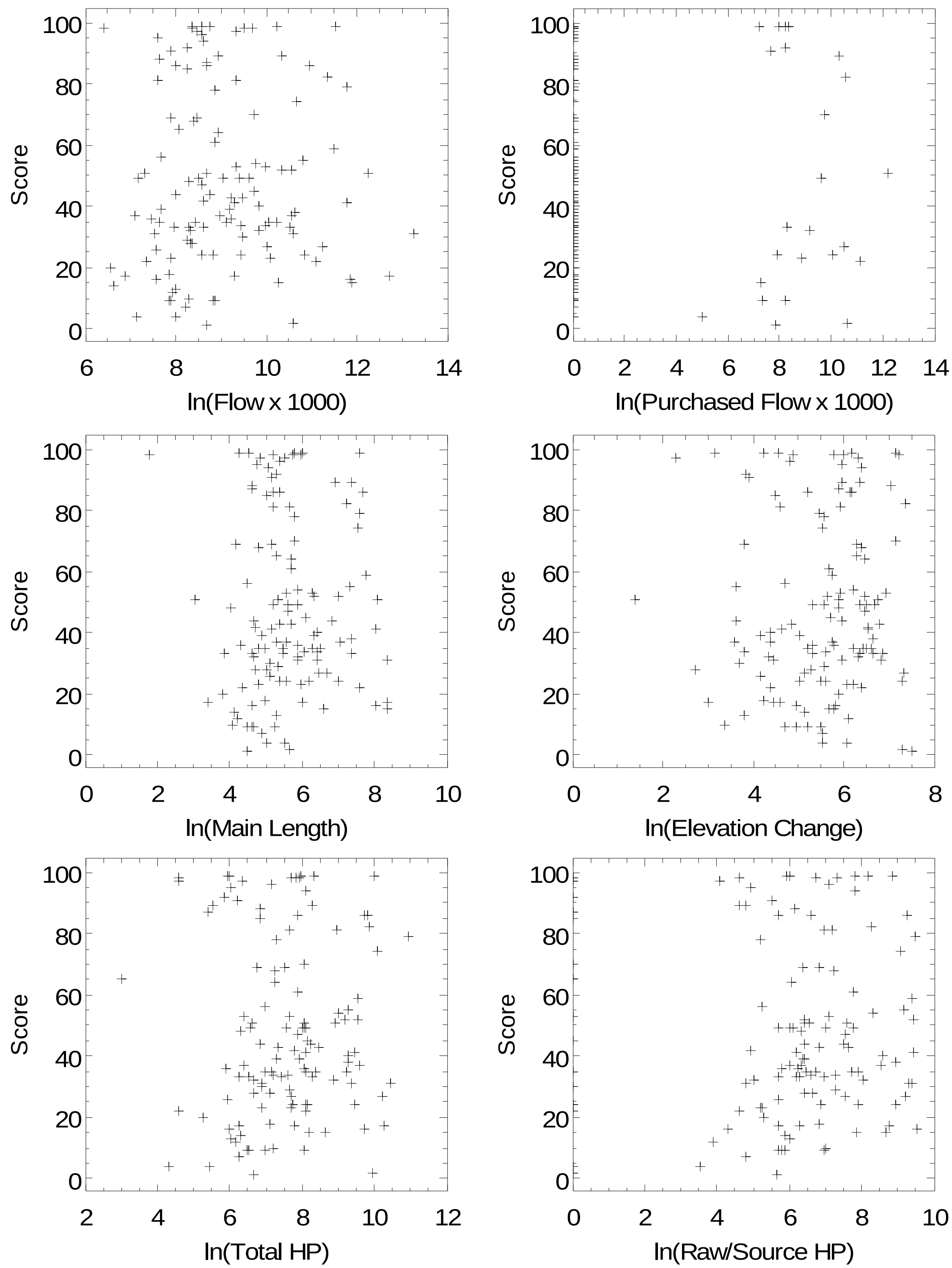

Figure 3.9 Water Utility Benchmark Score Comparison to Independent Variables

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ALTERNATE MODEL FORMULATION

The previous water utility model relied on the strong correlation of the installed pump horsepower to minimize unexplained variation in the energy use. Horsepower is thought to be an appropriate proxy that captures the distribution system characteristics. Systems with high friction losses or high static pressure requirements will have larger pump motor horsepower installed. Since the survey data contains data to try to directly characterize the utility system, this section explores an alternative model that does not use pump horsepower.

The model presented in Table 3.10 uses ten parameters to represent 85% of energy use variation, just slightly less than the 87% explained by the six parameter model based on horsepower. Figure 3.10 shows the model residuals are randomly distributed along the range in energy use data, and the consistent relationship between predicted and actual energy use. Figure 3.11 shows no relationship between the model residuals and the model parameters. The model contains the total flow along with the purchased and ground sourced flows. It also includes the ground water well depth and average ground water turbidity. The distribution system is characterized by the storage volume, main length and range in elevation. Two treatment plant characteristics are also significant: A treatment objective of TOC removal and gravity thickening of residuals.

Table 3.10 Water Utility Energy Use Ten Parameter Model

* * * Analysis of Variance * * *

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Model	10	274.61	27.461	66.46	0.00000
Error	116	47.93	0.413		
Corrected Total	126	322.54	27.874		

Std Dev of Model Error	0.64	R-squared	0.8514
Overall mean of y	17.70	adj R-squared	0.8386
Coefficient of variation (%)	3.63		

* * * Parameter Estimates * * *

Parameter	Coefficient	Std Err	T-Value	p-value
Intercept	12.5815	0.5488	22.92	0.00000
ln(calc_flow)	0.6935	0.0974	7.12	0.00000
ln(raw_p_aflow)	-0.1008	0.0175	-5.77	0.00000
ln(raw_g_aflow)	0.1079	0.0233	4.63	0.00001
ln(raw_g_depth)	-0.0442	0.0188	-2.35	0.02056
ln(raw_g_antu)	-0.0758	0.0353	-2.15	0.03353
ln(distrib_storage)	0.1139	0.0443	2.57	0.01143
ln(distrib_main)	0.3467	0.1053	3.29	0.00131
ln(calc_elev_change)	0.1380	0.0539	2.56	0.01180
treat_toc	-0.3112	0.1478	-2.11	0.03744
res_gravity	0.3772	0.1735	2.17	0.03173

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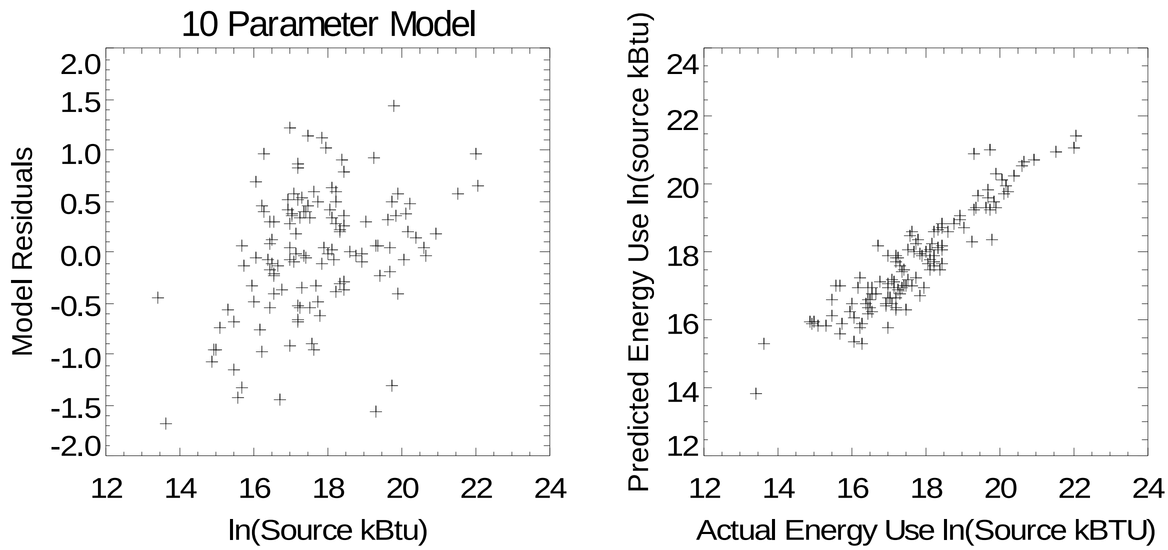

Figure 3.10 Water Utility Ten Parameter Model Residuals vs Dependent Variable and Model Fit

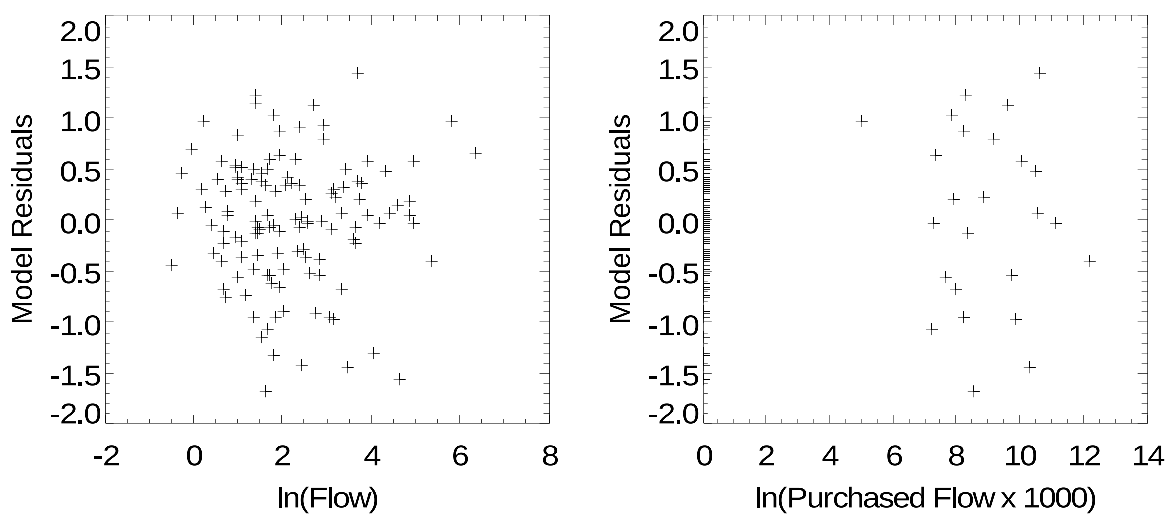

Figure 3.11 Water Utility Ten Parameter Model Residuals vs Independent Variables

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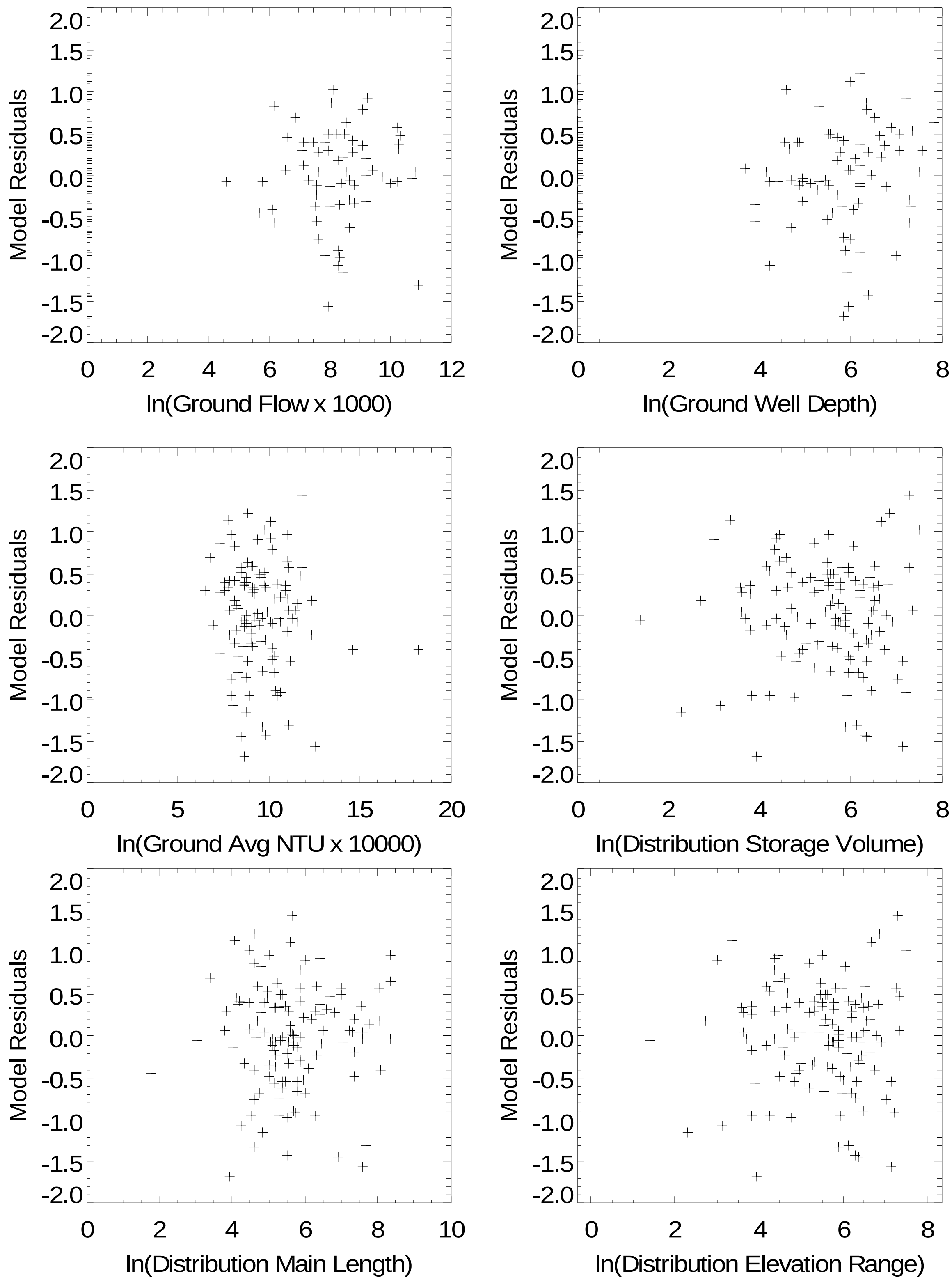

Figure 3.11 (Continued) Water Utility Ten Parameter Model Residuals vs Independent Variables

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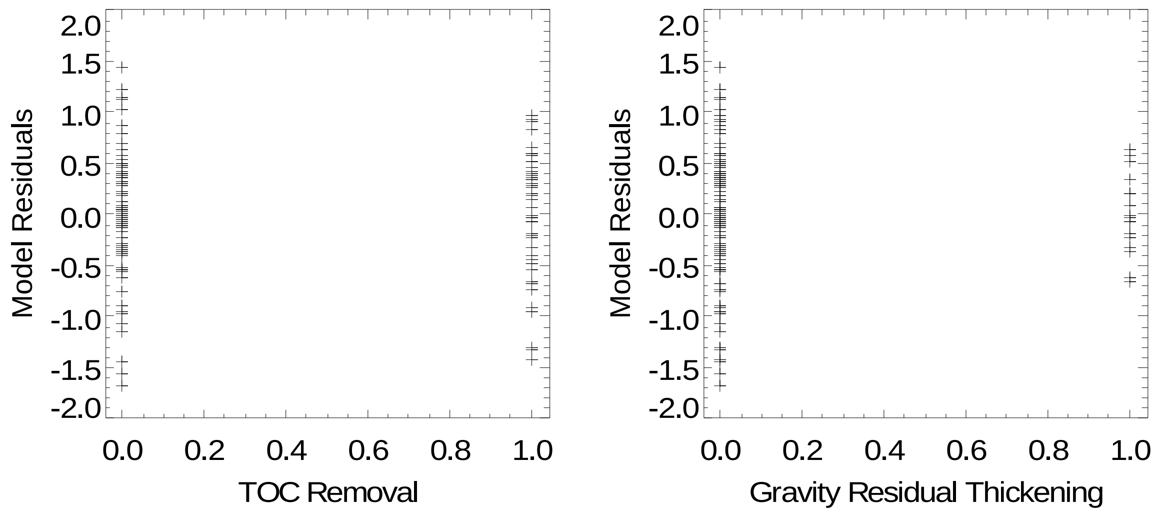

Figure 3.11 (Continued) Water Utility Ten Parameter Model Residuals vs Independent Variables

The smoothed distribution of the adjusted energy use in Figure 3.12 is similar to the six parameter model based on pump horsepower. The ten parameter model is better represented by the gamma fit than the six parameter model. There is no abrupt change in slope just above the mean, but the distribution still remains skewed at the lower energy use levels. The energy performance rating score for this model is tabulated in Table 3.11.

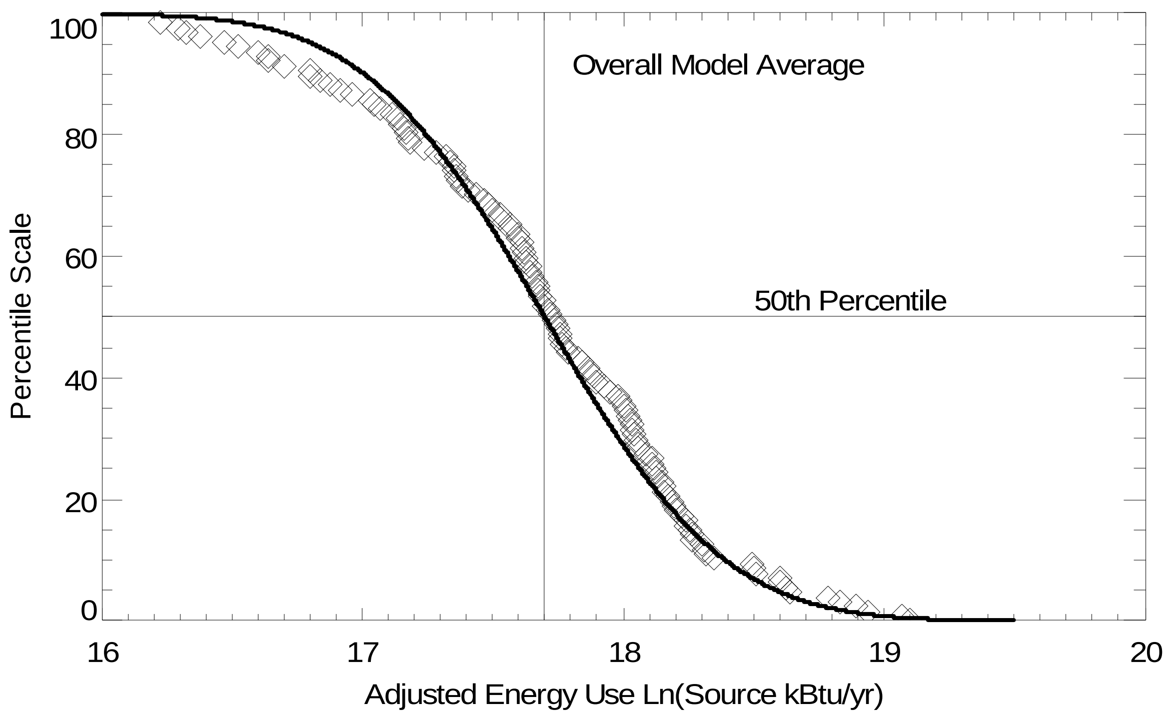

Figure 3.12 Water Utility Energy Distribution of Ten Parameter Model

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Table 3.11 Water Utility Energy Performance Rating Score Based on Adjusted Source Energy Use (Ten Parameter Model)

Score	Adjusted Energy Use ln(kBtu/yr)		Score	Adjusted Energy Use ln(kBtu/yr)		Score	Adjusted Energy Use ln(kBtu/yr)
100	15.901		66	17.478		33	17.939
99	16.445		65	17.493		32	17.954
98	16.592		64	17.507		31	17.969
97	16.685		63	17.522		30	17.984
96	16.756		62	17.536		29	18.000
95	16.813		61	17.550		28	18.016
94	16.861		60	17.564		27	18.032
93	16.904		59	17.578		26	18.048
92	16.942		58	17.592		25	18.065
91	16.977		57	17.606		24	18.082
90	17.009		56	17.620		23	18.100
89	17.039		55	17.633		22	18.118
88	17.067		54	17.647		21	18.137
87	17.093		53	17.660		20	18.155
86	17.118		52	17.674		19	18.175
85	17.141		51	17.687		18	18.195
84	17.164		50	17.701		17	18.216
83	17.186		49	17.715		16	18.238
82	17.207		48	17.728		15	18.261
81	17.227		47	17.742		14	18.284
80	17.247		46	17.755		13	18.309
79	17.265		45	17.769		12	18.335
78	17.284		44	17.782		11	18.363
77	17.302		43	17.796		10	18.393
76	17.320		42	17.810		9	18.425
75	17.337		41	17.824		8	18.460
74	17.354		40	17.838		7	18.498
73	17.370		39	17.852		6	18.540
72	17.386		38	17.866		5	18.589
71	17.402		37	17.880		4	18.646
70	17.418		36	17.895		3	18.717
69	17.433		35	17.909		2	18.810
68	17.448		34	17.924		1	18.957
67	17.463						

The main criticism of the model without pump horsepower is that it does not accommodate systems with varying levels of gravity flow, either on the source or distribution size. The total pump horsepower in a system will be influenced by opportunities to use gravity flow. Without horsepower in the model, utilities that require less than typical pumping would have inflated scores and appear more energy efficient. Figure 3.13 shows a wide difference between the scores from both models. While the highest scoring utilities of both models tend to agree, there is large variation at low score levels. Furthermore of the utilities that reported either zero distribution pumping horsepower or zero source pumping horsepower (the black diamonds in the plot), nearly all have higher scores with the model that omitted pumping horsepower. These

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utilities might have circumstances that require less installed pumping and subsequently less energy use (e.g. gravity feed, source water supplied at pressure from another utility, etc).

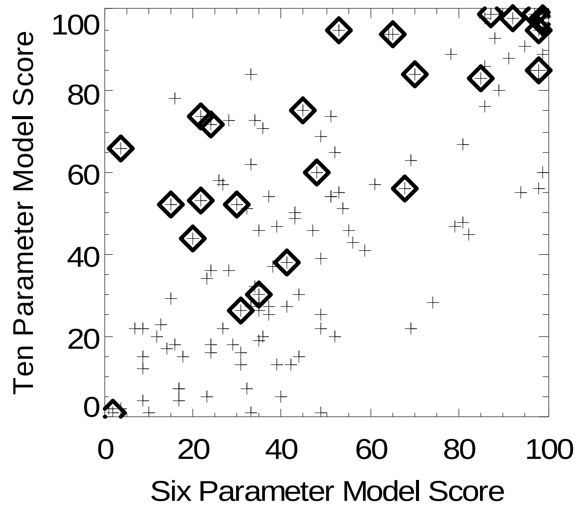

Figure 3.13 Comparison of Six and Ten Parameter Model Scores

Figure 3.14 shows the ten parameter model score as it relates to the specific pump horsepower (total pump horsepower divided by total average flow). While the scores are distributed evenly across the specific pumping horsepower for the entire sample, those utilities that did not report either source or distribution pumping HP have a higher proportion of high scores, and tend to have the lower pumping horsepower (denoted by diamond symbols in the plot). All the scores above 90 with less than 100 HP/MGD are from this group. This group is better distributed when pump horsepower is included in the model as shown in Figure 3.15, suggesting that they are not getting credit merely for having a situation that allows lower pumping horsepower.

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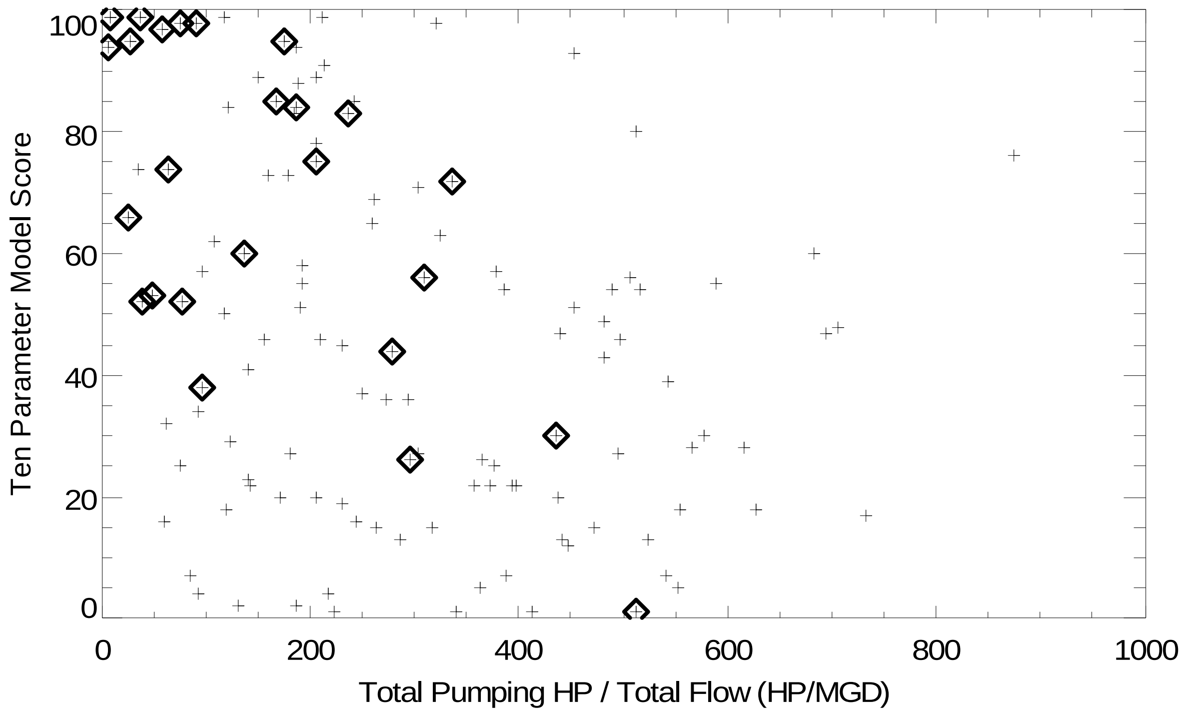

Figure 3.14 Specific Pumping Horsepower Relationship to Ten Parameter Model Scores

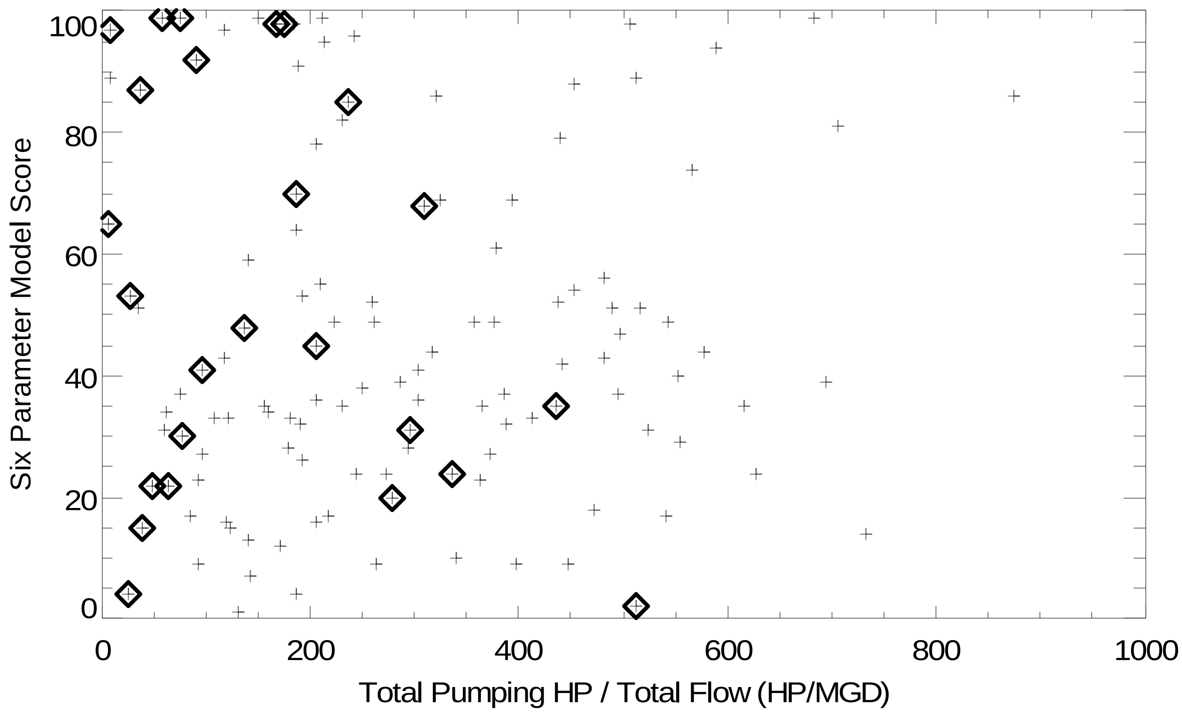

Figure 3.15 Specific Pumping Horsepower Relationship to Six Parameter Model Scores

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SEGREGATING WATER UTILITY ENERGY USE

The survey requested utility energy use at the operating level thought to be most readily available, namely at the facility billing level. It asked for energy use to be categorized by production, treatment and distribution, under the assumption that these three areas are often physically separated and would have distinct energy billing data. Figure 3.16 shows the energy use of each operational category as a function of flow. A benchmark metric can be developed for each of these operational areas based on the available data. The analysis process is identical to the whole utility benchmark process described in the previous section.

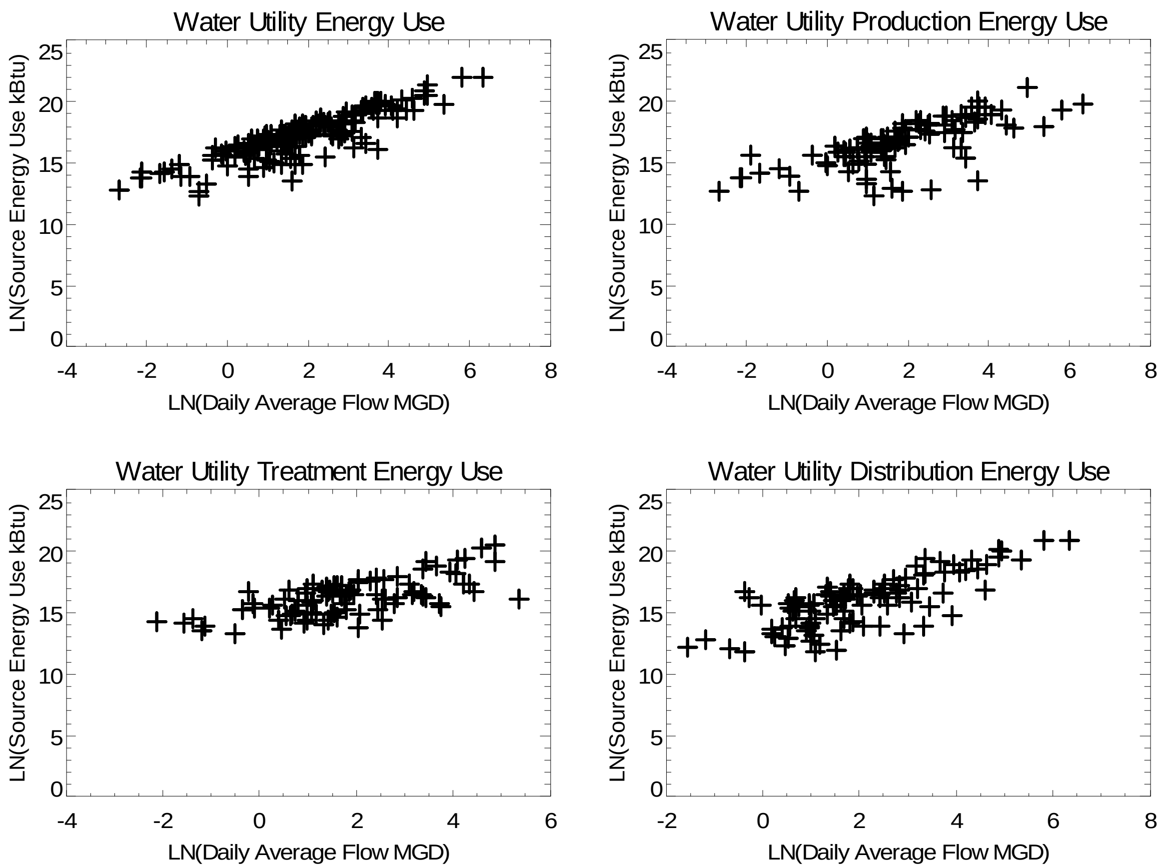

Figure 3.16 Water Utility Energy Use Segregation by Operational Area Related to Flow

Water Utility Production Energy Use

The production energy covers raw/source water pumping. Seventy-six utilities reported production electricity use along with raw/source pumping horsepower. The source energy (dependent variable) was a combination of the treatment electricity and utility natural gas use. The total flow (calc_flow), production pump horsepower (raw_hp) and amount of purchased water (raw_p_aflow) explained 79% of the production energy use variation through the model in Table 3.12. Figure 3.17 shows the model residuals are randomly distributed along the range in energy use, and the consistent relationship between predicted and actual energy use.

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Table 3.12 Water Utility Production Energy Use Model

* * * Analysis of Variance * * *

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Model	3	162.69	54.229	90.33	0.00000
Error	72	43.23	0.600		
Corrected Total	75	205.91	54.830		

Std Dev of Model Error	0.77	R-squared	0.7901
Overall mean of y	17.34	adj R-squared	0.7813
Coefficient of variation (%)	4.47		

* * * Parameter Estimates * * *

Parameter	Coefficient	Std Err	T-Value	p-value
Intercept	8.0924	0.5905	13.70	0.00000
ln(calc_flow)	0.6904	0.0992	6.96	0.00000
ln(raw_hp)	0.4423	0.0971	4.56	0.00002
ln(raw_p_aflow)	-0.0748	0.0279	-2.68	0.00900

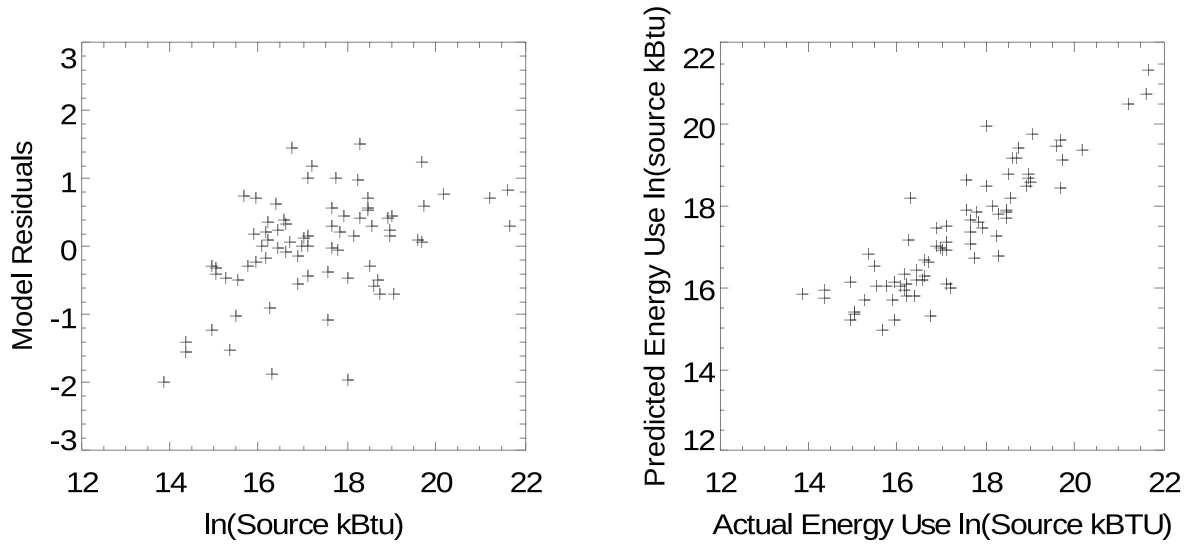

Figure 3.17 Water Utility Production Energy Use Model Residuals vs Dependent Variable and Model Fit

Applying the adjustment of the model mean to the sample mean to create a modeled energy distribution and fitting a normal distribution to the curve produces a benchmark score. As with the total utility energy distribution, the production energy distribution is skewed with the lower energy users as shown in Figure 3.18. This fit becomes the energy performance rating score tabulated in Table 3.13.

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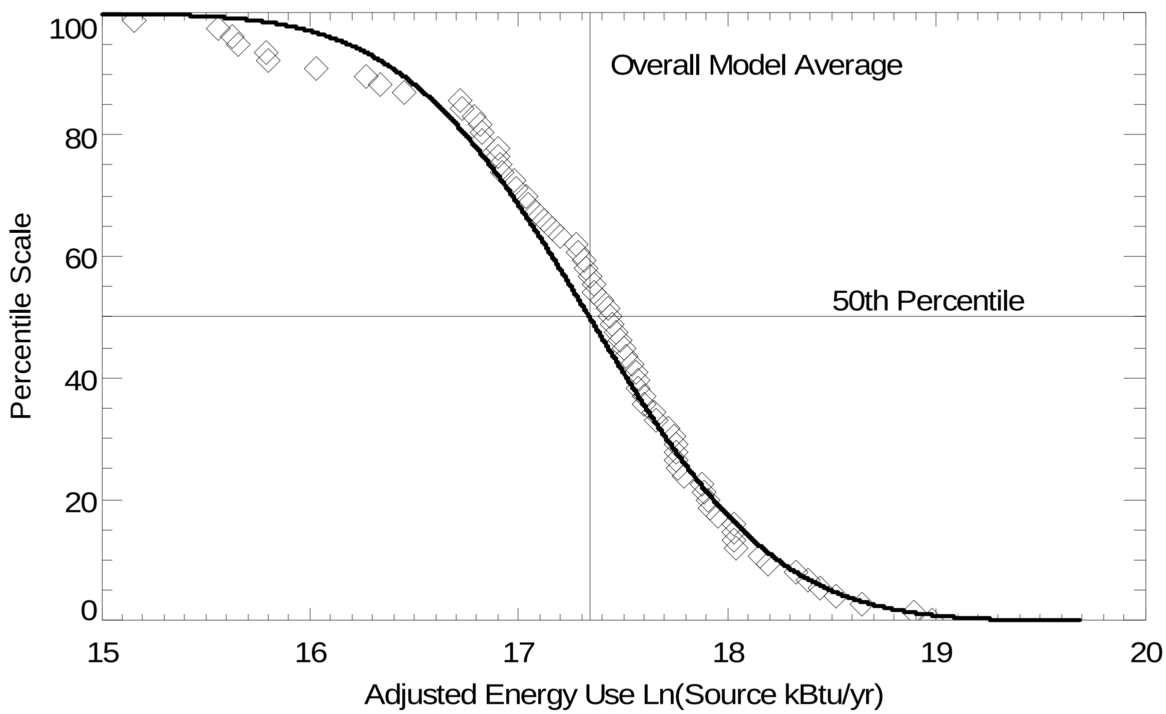

Figure 3.18 Water Utility Production Energy Use Modeled Energy Distribution

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Table 3.13 Water Utility Production Energy Performance Rating Score Based on Adjusted Source Energy Use

Score	Adjusted Energy Use ln(kBtu/yr)		Score	Adjusted Energy Use ln(kBtu/yr)		Score	Adjusted Energy Use ln(kBtu/yr)
100	14.990		66	17.049		33	17.650
99	15.699		65	17.068		32	17.670
98	15.892		64	17.087		31	17.689
97	16.014		63	17.106		30	17.709
96	16.105		62	17.124		29	17.730
95	16.180		61	17.143		28	17.750
94	16.244		60	17.161		27	17.772
93	16.299		59	17.179		26	17.793
92	16.349		58	17.197		25	17.815
91	16.394		57	17.215		24	17.837
90	16.436		56	17.233		23	17.860
89	16.475		55	17.251		22	17.884
88	16.511		54	17.269		21	17.908
87	16.545		53	17.286		20	17.933
86	16.578		52	17.304		19	17.959
85	16.609		51	17.322		18	17.985
84	16.638		50	17.340		17	18.012
83	16.667		49	17.357		16	18.041
82	16.694		48	17.375		15	18.070
81	16.721		47	17.393		14	18.101
80	16.746		46	17.411		13	18.134
79	16.771		45	17.428		12	18.168
78	16.795		44	17.446		11	18.204
77	16.819		43	17.464		10	18.243
76	16.842		42	17.482		9	18.285
75	16.864		41	17.500		8	18.330
74	16.886		40	17.518		7	18.380
73	16.908		39	17.537		6	18.436
72	16.929		38	17.555		5	18.499
71	16.950		37	17.574		4	18.574
70	16.970		36	17.592		3	18.665
69	16.990		35	17.611		2	18.788
68	17.010		34	17.631		1	18.980
67	17.029						

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Water Utility Treatment Energy Use

Treatment energy covers the treatment plant and might contain some pumping energy for pumps located at the treatment plant. Ninety-two utilities reported treatment electricity use. The source energy use (dependent variable) was the combination of treatment electricity and natural gas use. The treatment energy model found terms related to water source (purchased flow, raw pumping horsepower) and treatment processes (oxidation, iron removal, residual sand drying bed, direct filtration, and ozone) to explain 67% of the treatment energy use variation through the model in Table 3.14. Figure 3.19 shows the model residuals are randomly distributed along the range in energy use, and the consistent relationship between predicted and actual energy use.

It is reasonable to expect that the water source would impact the type and amount of treatment required. Various combinations of model parameters are possible. Some models included surface water flow or ground water characteristics rather than the purchased water flow in the model presented here. These parameters all try to capture the impact of water source on treatment energy use.

Similarly various combinations of treatment objectives and processes can correlate to treatment energy use. Some parameters add to the energy use of the model as designated by a positive coefficient while other parameters credit the energy use in the model as designated by negative coefficients. Characteristics such as recarbonation, algae treatment, organic/inorganic treatment, and pressure filtration, were significant in certain combinations of parameters. The ozone treatment process with a marginal significance was left in the model as its energy intensity is high and its use is growing in treatment plants.

Table 3.14 Water Utility Treatment Energy Use Model

* * * Analysis of Variance * * *

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Model	8	142.03	17.754	20.91	0.00000
Error	83	70.47	0.849		
Corrected Total	91	212.50	18.603		

Std Dev of Model Error	0.92	R-squared	0.6684
Overall mean of y	16.38	adj R-squared	0.6364
Coefficient of variation (%)	5.63		

* * * Parameter Estimates * * *

Parameter	Coefficient	Std Err	T-Value	p-value
Intercept	10.8346	0.6651	16.29	0.00000
ln(calc_flow)	0.6100	0.0870	7.01	0.00000
ln(raw_p_aflow)	-0.0861	0.0374	-2.30	0.02388
ln(raw_hp)	0.1221	0.0376	3.24	0.00170
treat_ox	0.7279	0.2964	2.46	0.01614
process_filtr_direct	-0.7214	0.2713	-2.66	0.00940
res_sand	-0.8312	0.3201	-2.60	0.01114
treat_iron	-0.9315	0.3032	-3.07	0.00287
process_oz	0.7946	0.4084	1.95	0.05508

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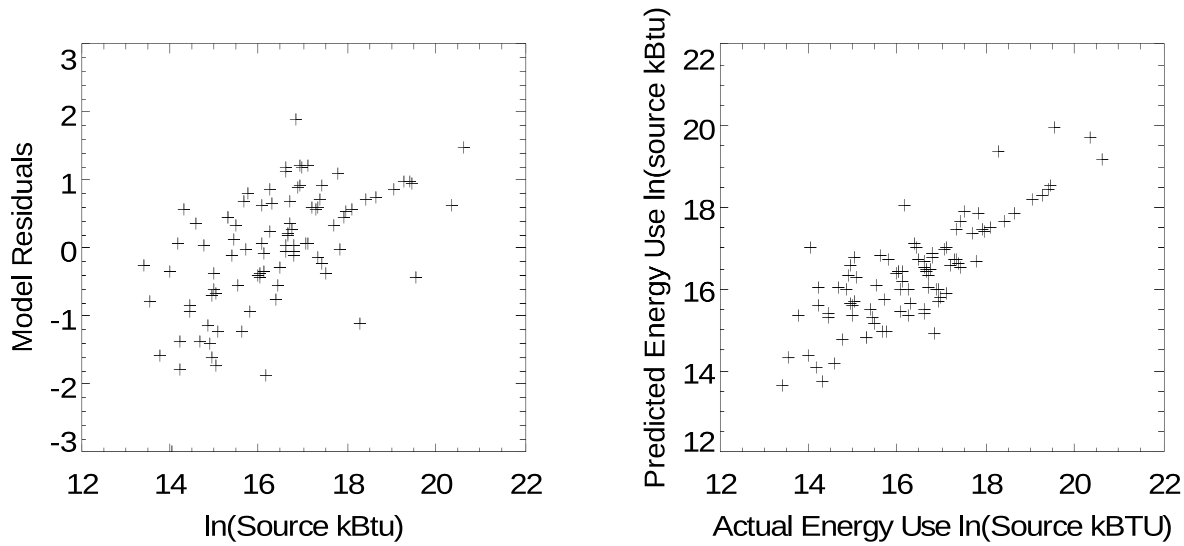

Figure 3.19 Water Utility Treatment Energy Use Model Residuals vs Dependent Variable and Model Fit

Applying the adjustment of the model mean to the sample mean to create a modeled energy distribution and fitting a normal distribution to the curve produces a benchmark score. The normal distribution curve fit smoothes the clump of data in the high energy using tail as shown in Figure 3.20. This fit becomes the energy performance rating score tabulated in Table 3.15.

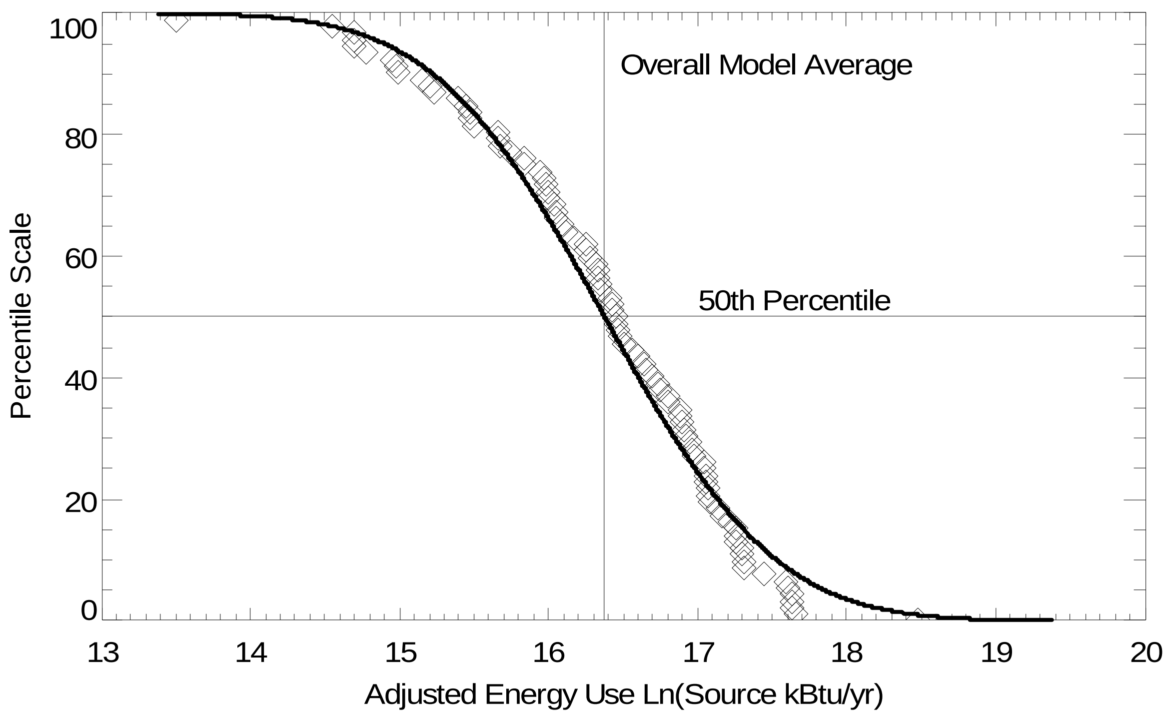

Figure 3.20 Water Utility Treatment Energy Use Modeled Energy Distribution

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Table 3.15 Water Utility Treatment Energy Performance Rating Score Based on Adjusted Source Energy Use

Score	Adjusted Energy Use ln(kBtu/yr)		Score	Adjusted Energy Use ln(kBtu/yr)		Score	Adjusted Energy Use ln(kBtu/yr)
100	13.378		66	16.007		33	16.774
99	14.284		65	16.031		32	16.799
98	14.530		64	16.055		31	16.825
97	14.686		63	16.079		30	16.850
96	14.803		62	16.103		29	16.876
95	14.898		61	16.127		28	16.903
94	14.979		60	16.150		27	16.930
93	15.050		59	16.174		26	16.957
92	15.113		58	16.196		25	16.985
91	15.172		57	16.219		24	17.014
90	15.225		56	16.243		23	17.043
89	15.274		55	16.265		22	17.073
88	15.321		54	16.288		21	17.104
87	15.364		53	16.310		20	17.135
86	15.406		52	16.333		19	17.168
85	15.445		51	16.355		18	17.202
84	15.483		50	16.378		17	17.237
83	15.520		49	16.401		16	17.273
82	15.554		48	16.423		15	17.311
81	15.588		47	16.446		14	17.350
80	15.621		46	16.469		13	17.392
79	15.652		45	16.491		12	17.435
78	15.683		44	16.514		11	17.482
77	15.713		43	16.537		10	17.531
76	15.743		42	16.560		9	17.585
75	15.771		41	16.583		8	17.643
74	15.799		40	16.606		7	17.707
73	15.827		39	16.630		6	17.777
72	15.854		38	16.653		5	17.858
71	15.880		37	16.677		4	17.954
70	15.906		36	16.701		3	18.071
69	15.932		35	16.725		2	18.227
68	15.957		34	16.750		1	18.472
67	15.982						

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Water Utility Distribution Energy Use

The distribution energy mainly covers pumping through the distribution system as measured at pumping stations. Eighty-six utilities reported distribution electricity use along with distribution pump horsepower. The source energy (dependent variable) was the combination of distribution electricity and utility natural gas use. The flow, distribution pump horsepower, and range in elevation along with lagoon dewatering thickening, pressure filtration, and residual gravity thickening explain 78% of the distribution energy use variation through the model in Table 3.16. Figure 3.21 shows the model residuals are randomly distributed along the range in energy use, and the consistent relationship between predicted and actual energy use. Treatment related characteristics might indicate that the distinction between treatment and distribution is not definitive. Pumping at a treatment plant can include initial distribution pumping.

Table 3.16 Water Utility Distribution Energy Use Model

* * * Analysis of Variance * * *

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Model	6	264.25	44.041	45.86	0.00000
Error	79	75.87	0.960		
Corrected Total	85	340.12	45.002		

Std Dev of Model Error	0.98	R-squared	0.7769
Overall mean of y	16.45	adj R-squared	0.7600
Coefficient of variation (%)	5.96		

* * * Parameter Estimates * * *

Parameter	Coefficient	Std Err	T-Value	p-value
Intercept	7.4356	0.7682	9.68	0.00000
ln(calc_flow)	0.5047	0.1131	4.46	0.00003
ln(distrib_hp)	0.5579	0.0997	5.60	0.00000
ln(calc_elev_change)	0.1441	0.0625	2.30	0.02380
res_lagoon	-0.6928	0.2394	-2.89	0.00491
process_filtr_press	-1.7926	0.4211	-4.26	0.00006
res_gravity	0.7122	0.3221	2.21	0.02991

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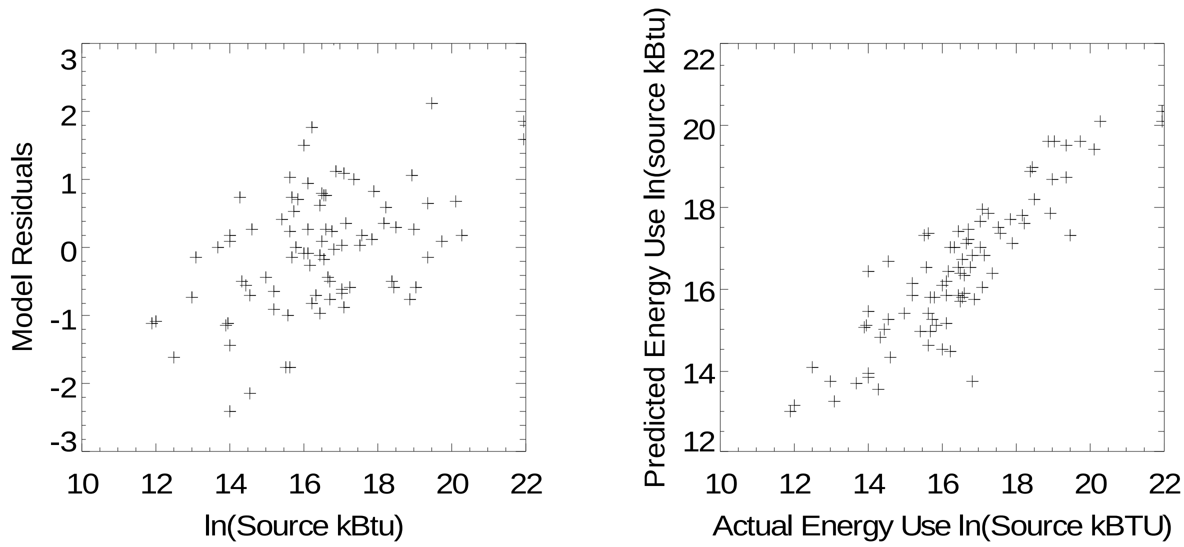

Figure 3.21 Water Utility Distribution Energy Use Model Residuals vs Dependent Variable and Model Fit

Applying the adjustment of the model mean to the sample mean to create a modeled energy distribution and fitting a normal distribution to the curve produces a benchmark score. The distribution energy model data follows a normal distribution well as shown in Figure 3.22. This fit becomes the energy performance rating score tabulated in Table 3.17.

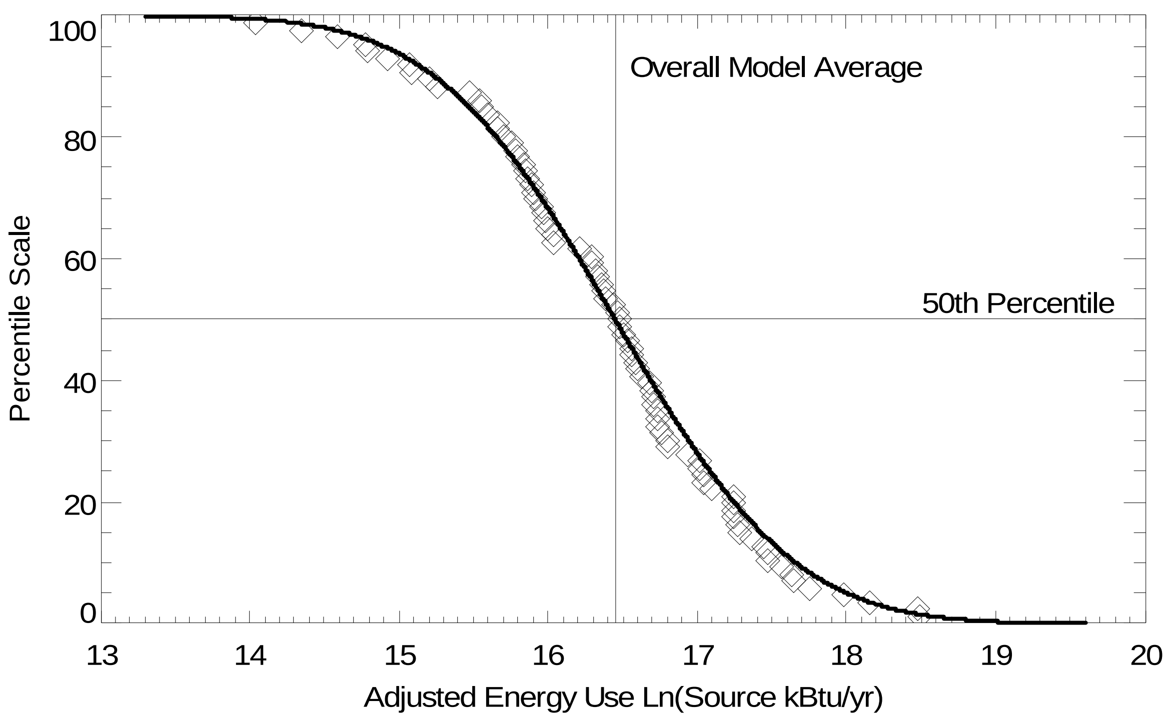

Figure 3.22 Water Utility Distribution Energy Use Modeled Energy Distribution

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Table 3.17 Water Utility Distribution Energy Performance Rating Score Based on Adjusted Source Energy Use

Score	Adjusted Energy Use ln(kBtu/yr)		Score	Adjusted Energy Use ln(kBtu/yr)		Score	Adjusted Energy Use ln(kBtu/yr)
100	13.301		66	16.061		33	16.867
99	14.252		65	16.087		32	16.893
98	14.510		64	16.112		31	16.920
97	14.674		63	16.137		30	16.947
96	14.796		62	16.162		29	16.974
95	14.897		61	16.187		28	17.001
94	14.982		60	16.211		27	17.030
93	15.056		59	16.236		26	17.059
92	15.123		58	16.260		25	17.088
91	15.184		57	16.284		24	17.118
90	15.240		56	16.308		23	17.149
89	15.292		55	16.332		22	17.180
88	15.341		54	16.356		21	17.213
87	15.386		53	16.380		20	17.246
86	15.430		52	16.404		19	17.281
85	15.471		51	16.427		18	17.316
84	15.511		50	16.451		17	17.352
83	15.549		49	16.475		16	17.391
82	15.586		48	16.498		15	17.431
81	15.621		47	16.522		14	17.471
80	15.656		46	16.546		13	17.516
79	15.689		45	16.569		12	17.561
78	15.721		44	16.593		11	17.610
77	15.753		43	16.618		10	17.662
76	15.784		42	16.642		9	17.718
75	15.813		41	16.666		8	17.779
74	15.843		40	16.690		7	17.846
73	15.872		39	16.715		6	17.920
72	15.900		38	16.739		5	18.005
71	15.928		37	16.765		4	18.105
70	15.955		36	16.790		3	18.228
69	15.982		35	16.815		2	18.392
68	16.009		34	16.841		1	18.650
67	16.035						

Delineating production, treatment, and distribution can be troublesome due to the pumping location at a source/raw site providing flow through treatment and/or distribution. Production energy might include pump horsepower for production as well as distribution. It might be difficult to separate out treatment process impacts from production energy when pumping for treatment might be included in the metering at production facilities. Regardless of the potential trouble in classifying energy use appropriately, looking at a utility's energy use on a production, treatment and distribution basis allows the impacts of characteristics beyond flow and pumping to be correlated with energy use.

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CHAPTER 4
WATER UTILITY ENERGY METRIC APPLICATIONS

REVIEW OF HIGHEST AND LOWEST SCORES

The review of the water metrics investigated the highest and lowest scoring utilities. Table 4.1 shows the benchmark scores along with some traditional metrics normalized by flow. As expected, the highest scoring utilities had much lower normalized electricity use averaging 324 kWh/MG versus 2,360 kWh/MG for the lower scoring utilities. All of the utilities were sent follow-up summaries of the survey data along with their scores. The high and low scoring utilities were asked for feedback on why their score might be on the extreme ends. Comments from the utilities and notes on the metrics follow.

Table 4.1 Overview of Metrics from the Highest and Lowest Scoring Utilities

	Benchmark Scores				Flow	Normalized Electricity Use	Normalized Total Pumping Horsepower	Normalized Distribution Area	Production Pumping Horsepower Portion
ID	Utility	Prod.	Treat.	Distrib.	(MGD)	(kWh/MG)	(HP/MGD)	(MI/MGD)	(%)
1	100	-	-	-	4.3	386	684	76	85%
2	99	99	-	82	1.7	322	321	7	83%
3	99	97	-	-	6.4	13	58	14	100%
4	99	99	48	99	28.0	261	151	14	84%
5	99	-	-	-	5.4	139	75	13	100%
6	99	98	91	-	4.7	276	118	26	11%
7	98	-	62	-	0.6	274	167	10	100%
8	98	-	26	-	13.5	202	185	29	60%
9	98	99	96	85	4.3	766	507	41	38%
10	98	99	-	69	102.1	600	212	19	32%
					Average:	324	248	25	69%
128	10	-	-	-	6.9	2616	448	28	34%
129	10	6	-	20	2.7	3246	398	33	31%
130	10	77	34	39	2.6	2844	263	42	44%
131	10	54	38	-	4.1	2134	294	6	50%
132	8	1	-	31	2.7	1962	172	25	11%
133	6	-	8	19	3.7	2492	143	35	23%
134	4	-	-	-	1.3	2370	187	119	15%
135	3	-	-	-	3.0	980	25	83	0%
136	1	3	-	14	6.0	2694	131	15	36%
137	1	-	-	-	40.0	2257	513	7	0%
					Average:	2360	257	39	24%

Note: The utility benchmark scores in the second column of the table were determined by a preliminary model that did not include the change in elevation parameter. Theses utilities retain the extreme scores in both model versions.

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ID #1

The highest scoring utility is a "consecutive system" purchasing all of its water pre-treated from a larger metropolitan utility in Illinois. The water is received at pressure reducing pumping energy requirements. While the benchmark metric accounts for purchased water volumes and raw water pumping (or lack thereof), the influence is based on the average effect in the sample. This utility is clearly to one extreme of these adjustments.

ID #4

This California utility noted that they use a gravity system for distribution, with only a few small pumps for isolated areas of the system. The installed pumping capacity is among the lowest at 151 HP/MGD. The pumping capacity in the sample ranged from 22 HP/MGD to over 4,000 HP/MGD.

ID #5

This Florida utility scored in the 99th percentile for low energy use. This 5.2 MGD system serves mainly a residential community with 5,000 connections. Its production includes a 50% blend from a reverse osmosis process, pulling water from a surficial aquifer at a 70 ft depth. About 25% of the volume is purchased pre-treated from an adjacent utility. The utility must provide the pumping for the purchased water. The system features up-to-date technology with one variable speed pump and seven fixed speed pumps totaling 400 hp. The system pressure is actively managed, with pressure allowed to drop during the day after the peak residential demand. The distribution system is also fairly new, as the original cement-asbestos pipe has been replaced. Water loss is below 4%. The utility participates in a load management program with the local electric utility, so energy use and cost are readily addressed by the operating staff. The utility has received several honors and awards including a State AWWA "Outstanding Treatment Plant" award. The Florida topography allows a low installed pumping horsepower which limits the energy use of the utility. The topography along with the relatively new pumping system, new distribution system, and participation in a load management program combine to make this utility one of the lowest energy users.

ID #8

This Iowa utility obtains its 13.5 MGD of flow from wells averaging 240 ft in depth. The treatment plant uses minimal energy for treatment as it is gravity fed through the plant. A high-service pump located at the plant is variable speed and runs most often. The plant equipment was new in 2003. Distribution includes five booster stations. Two of the stations are new within the last few years and carry the majority of the load. Two stations are from the 1970/80's era and one station is older, but is not used as much. The system operates consistently without many adjustments being made to the set points. The utility thinks of itself as typical with typical loads and does not consider that it does anything extraordinary to reduce energy use. The low score for the treatment sub-metric might be a misnomer as the high-service pump electricity use is contained in the treatment plant electricity bill, although it might be common to find high-service pumps at treatment plants with their electricity use included in the treatment plant bill.

ID #9

This Kansas utility provides 4.34 MGD from two treatment plants. The north plant is less than ¼ mile from an intake on the Missouri river. It is a relatively new plant. The second

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plant pulls water from nine 75 ft deep wells along the bank of the river. It is vintage 1976 with original pumps. Three wells are typically sufficient to meet the load. The treatment flow is by gravity through the plants. One plant flows lime residuals to a lagoon and pumps back water to the plant, while the other plant discharges residuals back to the river. Each plant has three high-service pumps, with only one having variable speed and being used most of the time. The plants supply a 5 MG reservoir that is refilled slowly each night. The reservoir feeds the distribution system through gravity. There is only one booster pump station in the system. Twenty percent of the flow goes to rural water districts and 10% goes to a single institution, reducing the number of connections. Some of the distribution system dates back to the pre-1900 era. Accounted for water exceeds 90%. The utility reports no extraordinary measures to reduce energy use. They were surprised to be noted as one of the lower energy users so they investigated the electricity use they reported and found they under reported by a factor of four. With their revised energy use numbers their score dropped to 27 and normalized electricity use rose to 3,040 kWh/MG. The sub-metric scores changed to 78, 61, and 26 for production, treatment and distribution.

ID #130

This Ohio utility has three surface sources available. Their reservoir would allow gravity feed, but the water quality is the lowest, so it is rarely used. Water usually is drawn from a gravel pit with an 80 hp pump or the river. A single treatment plant provides flocculation and clarifiers, has sludge pumping, backwash pumps and high-service pumps. Some of the equipment dates back to the 1920's. The high-service pumps are constant speed. In the last year they repaired a regulator that allowed them to reduce pumping energy use. The distribution system includes two booster stations and four elevated tanks. They have tried to operate on a single booster station but find that they often need to operate both together. They are in the process of implementing a SCADA system. In the 1960's the plant was rated at 10 MGD, now two filter systems are out of service so the plant is rated at 7 MGD. The operation of oversized equipment might contribute to lower system efficiency along with the lack of variable speed pumping and minimal automation.

ID #131

This Texas utility pumps water 12 miles from its surface source to the treatment plant with two 300 hp pumps using variable speed drives. Operation in the summer often requires the use of both pumps, while winter operation requires only one. The treatment plant energy use is mainly from the high-service pumps (2) 300 hp, (2) 150 hp and (1) 150 hp. All but the 150 hp are variable speed. Most equipment is 30 to 40 years old. The distribution system includes three elevated water towers for 2.25 MG of storage and no booster pumps. Approximately 20% of the water serves rural water districts. One district spreads out 25 miles while the others are in the 10 to 15 mile range. The rural districts have no pumping capability, relying solely on the water utility. The rural district's pipe length was not included in the total main length reported on the survey. At 6 mi/MGD the utility reported one of the lowest relative main lengths in the survey. Typical values were 20 to 50 mi / MGD. The main length impacts the benchmark score. Estimating an additional 35 miles of main length for the rural water districts increases the score from 10 to 20. Using a more typical main length of 30 mi/MGD increases the score to 29. The utility considers itself typical for its size. It tracks electricity use as it is one of the largest expenses.

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ID #133

This California utility uses wells that are in excess of 50 years old and has been over pumping its aquifers. In one well, volumes have decreased from the 600 gpm design to 235 gpm resulting in a large drop in efficiency. Another well achieves only 800 gpm in a well designed for 1,300 gpm and still uses the original 1957 pump, resulting in lower pump efficiency. The wells are usually operating at 100% of the available source capacity. The utility operates a treatment plant for nine months of the year. The distribution system is all 50 year old equipment. Adjustments are made with valves as there are no variable speed drives in the system. A reservoir serves the distribution system, that has four pressure zones and three booster stations. The operator is well aware of the high energy use and has been working to get new pumps, new wells and upgraded equipment.

ID #135

This Colorado utility draws water from a lake, mainly gravity fed with only an occasional need for pumping (75 hp). It operates two treatment plants, each with high service pumps ranging from 75 hp to 125 hp and a 100 hp backwash pump. Water is pumped to a tank that serves the distribution system by gravity. They schedule pump operation to avoid setting peak demand (e.g., only operate the backwash pump when the high-service pumps are off). They generally pump to the tank each afternoon and through the night as they have a large demand from 9 pm to 4 am from lawn sprinklers. The low score is due to under reporting the pumping horsepower. The 75 hp noted on the survey represents what typically runs, but there are actually 475 hp excluding pumps designated solely for backup. With the revised pump hp the utility scores a 40. The utility uses over 42,000 therms of natural gas per year to heat 25,000 sq ft of plant area. The natural gas use keeps the score from reaching 64 based only on electricity use. The two treatment plants use direct-fired gas heaters and operate exhaust fans to ventilate the plants and pipe galleries. The pipe gallery walls are uninsulated and the 20 ft ceilings make it difficult to maintain temperature at floor level. They are evaluating alternative heating means to reduce the need for the large volumes of exhaust air that they currently heat.

ID #137

This California utility acquires all of its water pre-treated from a larger metropolitan area. Its energy use consists of pumping to reservoirs. All of the pumping is to change elevation from 950 ft above sea level to 2,000 ft above sea level in multiple lifts. The total reservoir volume is 132 MG with about 124 MG useable given inlet and outlet pipe heights. All flow is gravity from the reservoirs with only one small 50 hp booster station. Pumping is controlled to maintain reservoir levels. They are in the process of installing a SCADA system for remote monitoring and control. Most pumps are constant speed, but they are adding variable speed / soft-start as motors are replaced. They still have a mix of standard and high efficiency motors in the system. They have an active motor maintenance program and pump testing program. Originally up to 85% of their water use was for agriculture. Recently agricultural lands have been developed for residential uses, but still 75% of the water use is agricultural. They have only 10,000 connections in a 102 sq mi area for a 40 MGD utility. All of their natural gas is for gas engine driven pumps ranging from 200 hp to 250 hp at three pumping stations. The pumps are used in place of electric pumps from 1 pm to 3 pm in the summer to reduce peak electric demand. The pumps are old and are being considered for replacement. The metric makes adjustments for purchased flow, main length and pumping horsepower. The unique configuration of this utility,

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with 100% purchased flow, a very short main length relative to the flow volume, and all of the pump horsepower requirement based on change in elevation, causes the metric to calculate a low 660 kWh/MG average energy use for this configuration. This utility might be too far outside the norm of the sample characteristics to be well represented by the metric.

WATER UTILITY METRIC APPLICATION – SHEBOYGAN

The Sheboygan, Wisconsin water utility sees itself as a conventional system using Lake Michigan water. The treatment plant has a variable speed drive on a low-lift pump, while the high-service pump operates at constant speed. The plant is circa 1929, but in the last ten years most motors have been replaced with high efficiency models. The treatment consists of conventional sedimentation and filtration with no energy intensive operation, but the installation of UV is a strong possibility in the future. Distribution includes two booster stations, a 4 MG elevated reservoir, 2 MG standpipe, and 0.5 MG elevated ball. The normal system head is about 200 ft above the level of the lake. The staff actively tries to schedule production to minimize operation during the peak electric demand period. Summer water demand has caused the utility to operate more and increase electric demand charges in the summer, resulting in the addition of another 6 MG of storage. It has participated in the state's energy efficiency program offering inspection and motor upgrades. The utility serves 20,000 connections and has a large concentration of industrial and wholesale load. The ten largest customers use up to half of the daily production. The three largest customers use 2.5 MGD, 1.7 MGD and 1.5 MGD. This concentration of large customers likely contributes to the lower normalized main length of 15 mi/MGD helping to reduce the distribution pumping energy use.

Energy use and flow have remained stable over the last three years as depicted in Table 4.2. The table also includes some single parameter metrics for comparison to the sample.

Table 4.2 Sheboygan Water Utility Energy Metric Score Over Time

	Year	2004	2005	2006
Utility Annual Energy Use	*Units*			
Electricity	kWh	5,805,883	5,791,200	5,636,300
Total Source Energy Use	(kBtu/yr)	64,445,000	64,282,000	62,563,000
Utility Characteristics				
Design Daily Total Flow	MGD	13.7	13.4	13.6
Purchased Daily Flow	MGD	0	0	0
Total Pump Horsepower	HP	2,900	2,900	2,900
Raw/Source Pump HP	HP	500	500	500
Total Water Main Length	miles	205	205	205
Energy Metric Score		63	63	65
Single Parameter Metrics				
Normalized Electricity Use	kWh/MG	1,161	1,184	1,135
Normalized Pump HP	HP/MGD	212	216	213
Source Pumping HP %	Source HP / Total HP x 100			17%
Normalized Main Length	miles/MGD			15

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WATER UTILITY METRIC APPLICATION SUMMARY

The water utility metric provides a unique comparison between utilities accounting for energy use as well as characteristics. The impact of the metric on relative energy use comparisons can be seen in Figure 4.1. The normalized source energy was computed by converting electricity, natural gas, oil and propane use to source energy BTUs and dividing by the total annual water flow. The percentile was calculated so that zero corresponded to the lowest energy use while 100 corresponded to the maximum energy use. The relationship between this percentile and the metric scores shows fair agreement at the lowest energy using utilities – those with scores above 90. All of these highest scoring utilities had low total normalized energy use. However, all of the lowest normalized energy using utilities did not achieve high scores. The impact of the multi-parameter adjustments on the metric score causes the wide scatter across the remaining range in scores. The utilities with a low score span a wide range in normalized energy use.

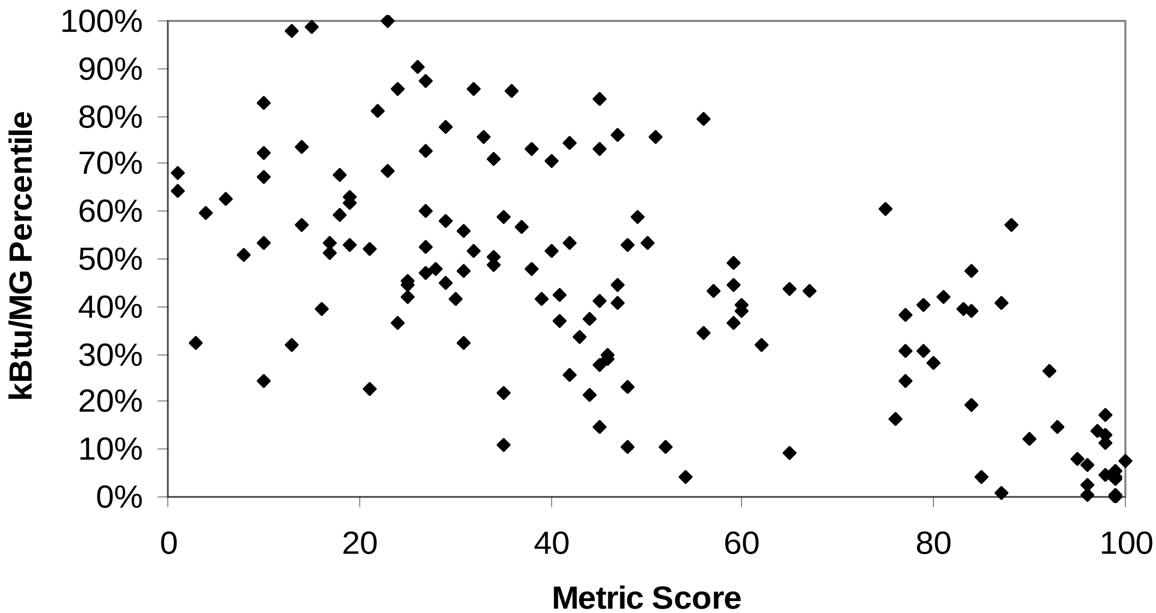

Figure 4.1 Comparison of Normalized Source Energy Use to Metric Score

The goal of the metric development is that the added complexity of the multi-parameter metric makes the score more comparable than a simple normalized energy use. In general the examples identified low energy using utilities that were consistent with their characteristics, had relatively new technologies and paid attention to energy use in planning operations. Some of the examples found high energy using utilities with older equipment and constant speed pumps or operational issues that were consistent with their high energy use.

An example like utility ID #137, that is configured at the extremes of the characteristics in the metric, suggests that there are still configurations that might not be well represented. This example suggests that the ability to better differentiate between distribution pumping for static head (elevation changes) versus dynamic head (main length) might be needed.

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CHAPTER 5
WASTEWATER UTILITY SURVEYS

SURVEY DESIGN

The survey design borrows from previous surveys wherever possible. This duplication keeps terminology consistent with past efforts, especially EPA surveys where the respondent should be familiar with the terms.

The survey design reflects the need to characterize the operating conditions of the plant as well as the treatment and processes, loads and energy use. The smallest level of aggregation was thought to be the point at which energy data are readily available. In other words the items within a utility that have separate electric and gas utility bills are candidates to be treated as single entities. For wastewater it is likely that a treatment plant would have its own energy bills and there might be separate pumping stations within the collection system with independent energy metering.

The survey instrument is included in the Appendix D. The survey begins with descriptive information about the plant and the person filling out the survey. Characterizations reviewed in the literature survey provided the base for describing treatment and processes. Flow volumes are the primary driver and were represented in a similar fashion to other surveys.

An initial survey was tested in a pilot to get both feedback about the content as well as an indication of the response rate. A technical team of wastewater engineers also reviewed the survey, noting items that were expected to have some impact on energy use.

Wastewater Utility Parameters

The wastewater survey asks about flow volumes, treatment level, treatment processes, and loading (biosolids, BOD, COD, TSS). It then quantifies the collection system in terms of the amount of pumping capacity (flow and horsepower). The section on energy asks about electricity use, demand, and gas use and cost. Miscellaneous items that might impact energy use are then queried such as size of buildings on the treatment plant meter, use of engine driven pumps, other energy sources (propane, diesel, oil), digester gas recovery and use, and onsite generation. Summary questions ask if operational personnel regularly review utility energy bills, and if there were any extraordinary events or other information that affected energy use over the year.

Treatment plant loading, Table 5.1, was characterized by the average daily flow, flow from industrial users, measures of contaminants and plant load factor. The BOD and TSS levels are the primary factors characterizing water quality entering and leaving the plant. Few plants had COD levels readily available.

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Table 5.1 Wastewater Plant Loading Parameters

No.	Variable	Survey Question and Description
3	inf_design	q01: daily design influent flow
4	inf_average	q02: daily average actual influent flow
5	inf_industry	q03: percentage of flow from industrial users
30	inf_bod	q07a: average influent biological oxygen demand concentration
31	eff_bod	q07a: average effluent biological oxygen demand concentration
32	ind_cod	q07b: average influent chemical oxygen demand concentration
33	eff_cod	q07b: average effluent chemical oxygen demand concentration
34	inf_tss	q07c: average influent total suspended solids concentration
35	eff_tss	q07c: average effluent total suspended solids concentration
78	inf_lf	derived: influent load factor

The parameters in Table 5.2 describe features of the treatment process. Three specific classifications of nutrient removal were identified in the survey (nitrification, denitrification and phosphorus removal). Nutrient removal is also captured in the treatment level classifications. Disinfection with UV is energy intensive, so it was identified separately. Sludge/biosolids treatment methods or ultimate disposition along with the total amount of biosolids processed is noted. Some plants do not treat sludge on site, but transport it to another plant, while some plants take in sludge from others. Both situations are noted in the survey data.

Table 5.2 Wastewater Plant Process Parameters

No.	Variable	Survey Question and Description
7	process_mech	q05a: aeration – mechanical
8	process_cbub	q05b: aeration - coarse bubble
9	process_fbub	q05c: aeration - fine bubble
10	process_pox	q05d: aeration - pure oxygen
11	process_oxcntrl	q05e: aeration oxygen control
12	process_rbc	q05f: fixed film - rotating biological contactor
13	process_tf	q05g: fixed film - trickle filtration
14	process_nit	q05h: nutrient removal – nitrification
15	process_denit	q05i: nutrient removal – denitrfication
16	process_phos	q05j: nutrient removal – phosphorus
17	dis_chem	q05k: disinfection – chemical
18	dis_uv	q05l: disinfection – ultraviolet
19	sludge_thick	q05m: sludge treatment – thickening
20	sludge_dewat	q05n: sludge treatment – dewatering
21	sludge_aerob	q05o: sludge digestion – aerobic
22	sludge_anaerob	q05p: sludge digestion – anaerobic
23	sludge_compost	q05q: sludge disposal – compost
24	sludge_landap	q05r: sludge disposal - land application
25	sludge_incin	q05s: sludge disposal – incineration
26	sludge_landfill	q05t: sludge disposal – landfill
27	biosolid_prod	q06b: average daily biosolids production
28	biosolid_send	q06a: biosolids sent to another plant for processing?
29	biosolid_recv	q06c: biosolids received from another plant for processing?

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All plants do not treat to the same level of effluent water quality. An alternative method of classifying treatment, Table 5.3, is through broad process classifications (primary, secondary, advanced). The EPA has standardized these definitions based on permitted BOD levels and treatment processes (Table B.5). Since nutrient removal can be added on to three levels of overall treatment, a separate parameter was constructed to represent nutrient removal (treat_nr). Nutrient removal should correlate/duplicate information from the process level data (process_ni, process_denit, process_phos)

.

Table 5.3 Wastewater Plant Treatment Classification Parameters

No.	Variable	Survey Question and Description
69	treat_pri	q4a: treatment level – Primary
70	treat_apri	q4b; treatment level - Advanced Primary
71	treat_sec	q4c: treatment level – Secondary
72	treat_sec_nr	q4d: treatment level - Secondary with nutrient removal
73	treat_adv1	q4e: treatment level - Advanced 1
74	treat_adv1_nr	q4f: treatment level - Advanced 1 with nutrient removal
75	treat_adv2	q4g: treatment level - Advanced 2
76	treat_adv2_nr	q4h: treatment level - Advanced 2 with nutrient removal
77	treat_nr	derived: treatment level - includes any nutrient removal from above

The collection system expands the scope beyond the treatment plant. Some systems have multiple plants on one collection system. Information on pumping tries to define the collection system as noted in Table 5.4.

Table 5.4 Wastewater Collection System Parameters

No.	Variable	Survey Question and Description
36	pump_remote	q08a: are pumps in collection system?
37	pump_mgd	q08b: total pumping capacity
38	pump_hp	q08c: total pumping horsepower
39	pump_num	q08d: total number of pumps
40	pump_nplants	q08e: treatment plants in collection system

Electricity is the primary energy used at most plants. The survey collected data on the collection system and the treatment plant separately. Energy use, demand and cost are represented in the parameters in Table 5.5. Collection system data are likely the most difficult to obtain accurately, as the data would need to be compiled from many sources for a large system with multiple pumping stations.

The final set of data, Table 5.6, looked to characterize other items that might impact overall energy use. The total floor area of buildings was meant to capture the impact of administration facilities that share common utility bills with the treatment plant. Using pumps that are engine driven could shift electricity use to natural gas, or use internally generated biogas. The survey also captured other sources of energy such as propane and oil. The use of on-site generated biogas can impact purchased natural gas. On site generation of electricity also impacts the purchased fuel mix. Finally the survey asked if someone in operations regularly reviewed the utility bills. Reviewing bills is thought to be a precursor to the existence of energy management.

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Also, if all respondents reviewed their bills it might indicate self-selection bias in that only those with access to the billing info might respond to the survey and these sites might be more likely to take active steps in managing energy. Two final fields allowed the respondents to note that 2004 was an extraordinary year and give additional clarification on earlier questions and general notes on energy use.

Table 5.5 Wastewater Energy Parameters

No.	Variable	Survey Question and Description
41	collect_kwh	q09a: collection system electricity use
42	collect_kw	q09a: collection system electricity peak demand
43	collect_cost	q09a: collection system electricity cost
44	treat_kwh	q09b: treatment plant electricity use
45	treat_kw	q09b: treatment plant electricity peak demand
46	treat_cost	q09b: treatment plant electricity cost
47	util_kwh	q09c: total electricity use
48	util_kw	q09c: total electricity peak demand
49	util_cost	q09c: total electricity cost
50	ngas_use	q10a: natural gas use
51	ngas_cost	q10a: natural gas cost
56	oenergy_purch	q13a: is other energy purchased?
57	oenergy_type	q13b: other energy type
58	oenergy_amount	q13c: other energy amount
59	oenergy_cost	q13d: other energy cost

Table 5.6 Wastewater General Characteristic Parameters

No.	Variable	Survey Question and Description
52	floor_area	q11: total building floor included in utility bills
53	pump_eng	q12a: are engine driven pumps used?
54	pump_enghp	q12b: total engine horsepower
55	pump_engtype	q12c: engine fuel type
60	digest_gas	g14a: Is digester gas recovered?
61	digest_ccf	q14b: amount of recovered digester gas used?
62	onsite_gen	q15a: Is electricity generated on site?
63	onsite_fuel	q15b: on site electricity generation fuel type
64	onsite_kwh	q15c: on site electricity generation amount
65	check_util	q16: Are utility bills checked by operations?
66	extra_event	q17: Where there extraordinary events?
67	notes	q18: Additional comments

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SURVEY IMPLEMENTATION

The EPA Permit Compliance System (PCS) provided contacts and flow data for the wastewater treatment plants. All treatment plants with design flow above 1.5 MGD were included in the sample. Utilities with flow above 1.5 MGD represent over 85% of the flow volume in the country. While there is a large number of utilities below these sizes, their energy use in aggregate represents a small portion of the total industry energy use.

A pilot survey sent to 20 wastewater utilities tested response rates and provided feedback about the questions. All unprompted responses came back within one month. Six wastewater utilities (30%) returned surveys. Discussions with the respondents indicated that the survey questions were straightforward and the survey was easy to complete.

The wastewater survey was mailed to 2,725 treatment plants and received a 14% response rate (367 responses). An additional 27 surveys were received in a separate parallel effort from New York. The response rate follows the population as shown in Figure 5.1 with a slight fall off in response rate at the smaller utilities. Only plant sizes from 1.5 MGD to 2.0 MGD are included in the first bin of data, resulting in lower possible totals compared to the other bins. The survey respondents represent 9,365 MGD (30%) of the 30,918 MGD design flow of the survey sample.

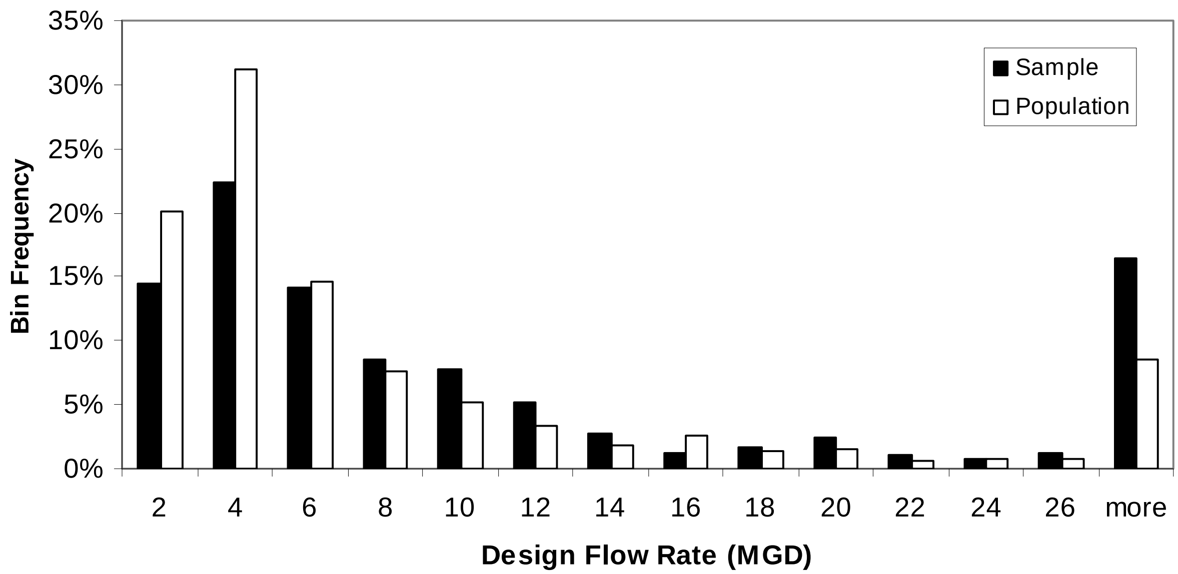

Figure 5.1 Wastewater Treatment Plant Survey Respondents and Population Comparison - Representation of Treatment Plant Design Flow Rate

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Regional response rates are shown by census region and division in Table 5.7. The south had the lowest response rate. The entire population was surveyed.

Table 5.7 Regional Wastewater Treatment Plant Survey Response Rate by U.S. Census Regions and Division

Region/Division	Population	Response	Response Rate	
WEST	**399**	**70**		**18%**
Pacific	244	40	16%	
Mountain	155	30	19%	
MIDWEST	**781**	**104**		**13%**
West North Central	229	31	14%	
East North Central	552	73	13%	
NORTHEAST	**551**	**90**		**16%**
Middle Atlantic	364	64	18%	
New England	187	26	14%	
SOUTH	**1379**	**138**		**10%**
West South Central	558	52	9%	
East South Central	295	34	12%	
South Atlantic	526	52	10%	
TOTAL	**3110**	**402**		**13%**

WASTEWATER SURVEY SUMMARY

The survey responses to yes/no questions describing treatment plant characteristics are summarized graphically in Figure 5.2. The figure shows the distribution of affirmative responses relative to the total number of respondents in the left graphic and relative to a filtered sub-sample of respondents. The filtering required valid energy data along with flow and BOD data. The sub-sample represents those respondents that included all the necessary information to be included in the metric development discussed in the next chapter: treatment plant electricity use, average flow, influent and effluent BOD. Comparing the two sets of graphics indicates that the sub-sampling didn't bias the distribution of affirmative responses, which remained similar in both groupings.

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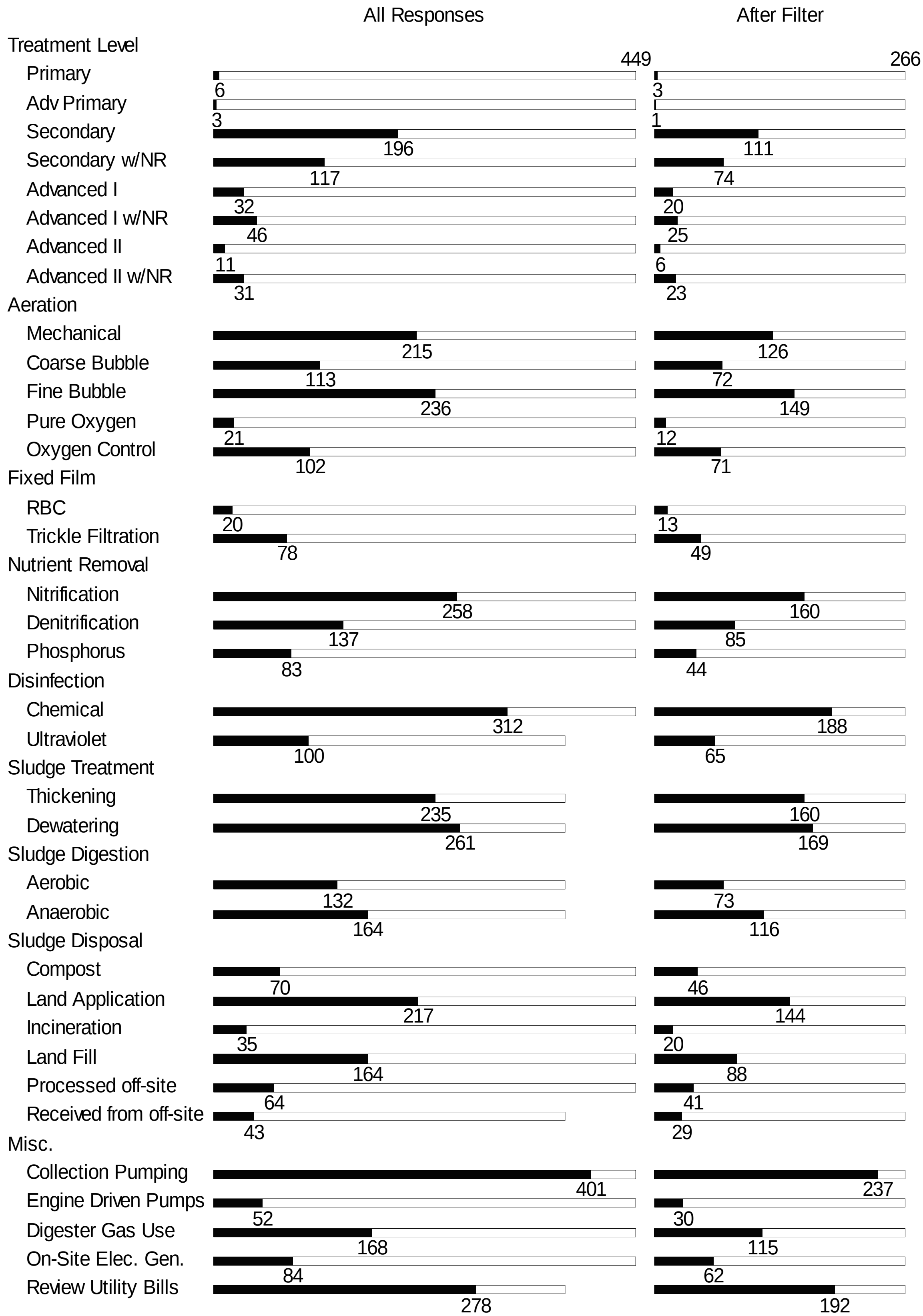

Figure 5.2. Survey Response Frequencies to Yes/No Characteristic Questions

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Energy cost for wastewater treatment plants ranged from $75/MG to $200/MG for the majority of survey respondents as noted in Figure 5.3. Treatment plant electricity use ranged from 1,000 kWh/MG to 3,000 kWh/MG for most respondents as noted in Figure 5.4. In both distributions the largest energy and cost values were as much as twice as high as the high end of the typical range. The natural gas use varied widely (from 1 therm/MG to 400 therm/MG) among the 150 plants reporting any gas use. Figure 5.5 shows slightly more plants having gas use on the lower end of the range.

Collection system electricity use was below 400 kWh/MG for most of the sample as shown in Figure 5.6. Energy cost was below $80/MG for most of the sample as shown in Figure 5.7. Energy use and costs in a few systems exceeded five times these values.

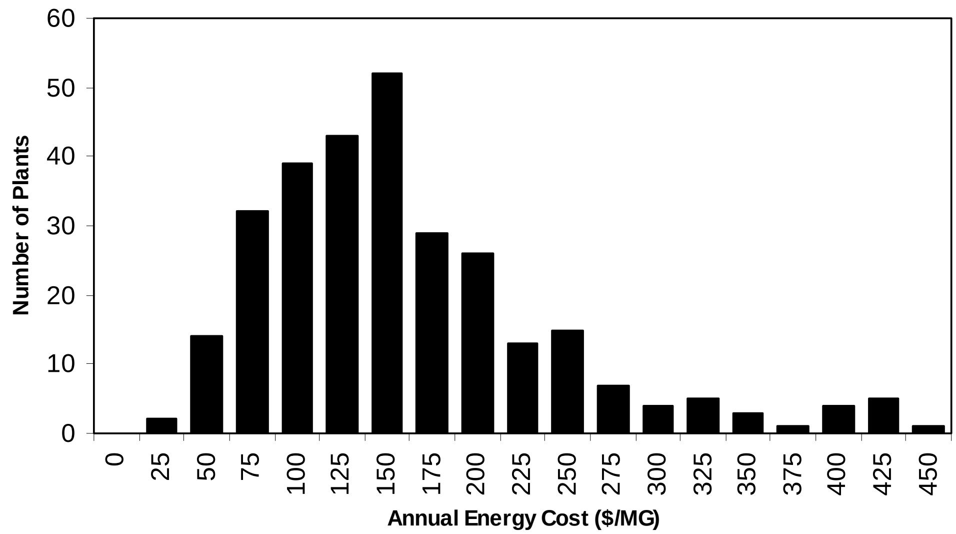

Figure 5.3 Annual Wastewater Treatment Plant Flow Normalized Energy Cost Distribution

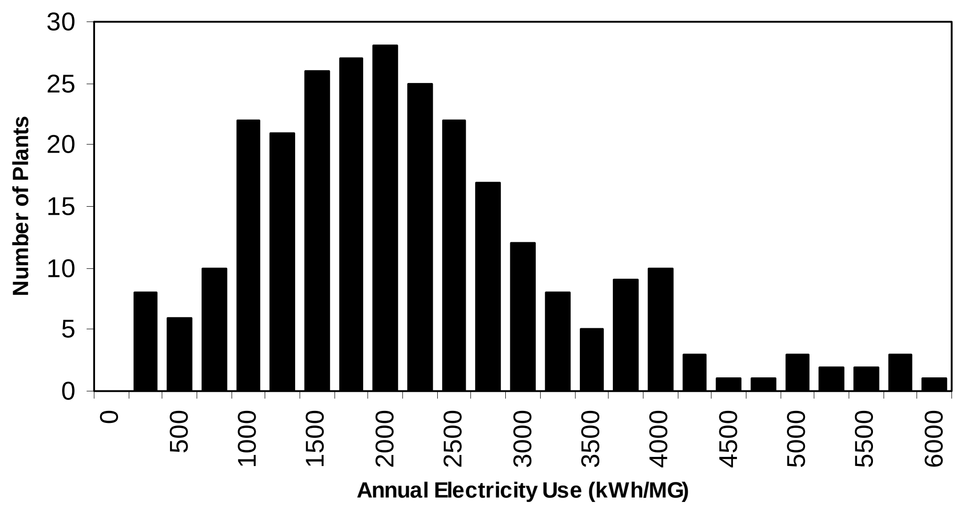

Figure 5.4 Annual Wastewater Treatment Plant Flow Normalized Electricity Use Distribution

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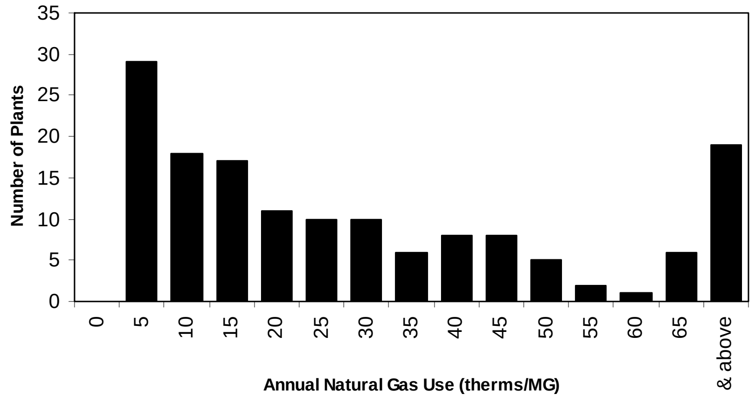

Figure 5.5 Annual Wastewater Treatment Plant Flow Normalized Natural Gas Use Distribution

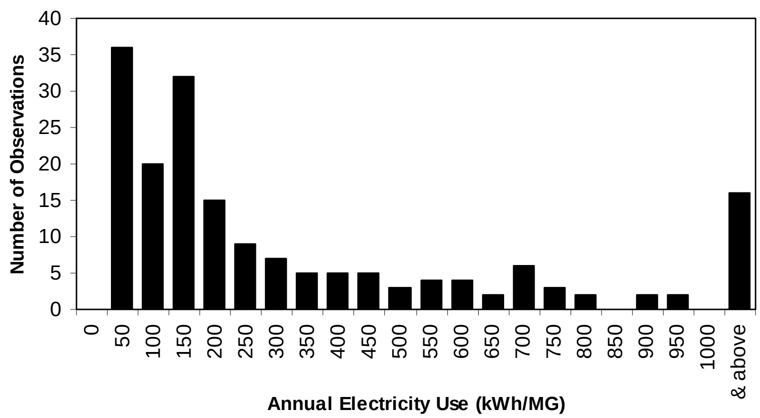

Figure 5.6 Annual Wastewater Collection System Flow Normalized Electricity Use Distribution

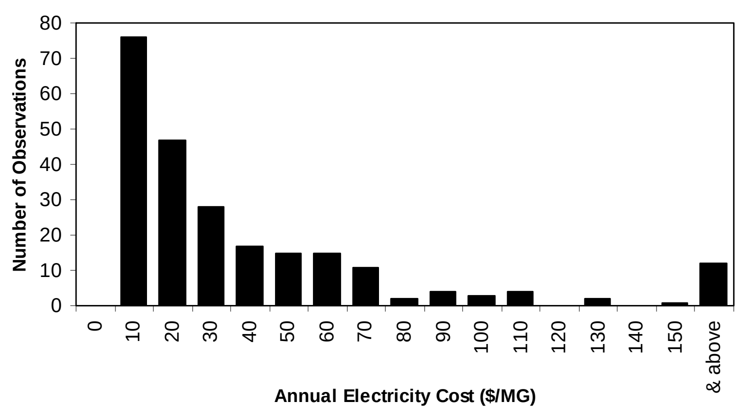

Figure 5.7 Annual Wastewater Collection System Flow Normalized Energy Cost Distribution

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The population of wastewater treatment plants is known to be skewed toward the small size as noted in the review of the population data. The same reflects the skewed distribution with most of the plants between the chosen limit of 1.5 MGD and 12 MGD as shown in Figure 5.8.

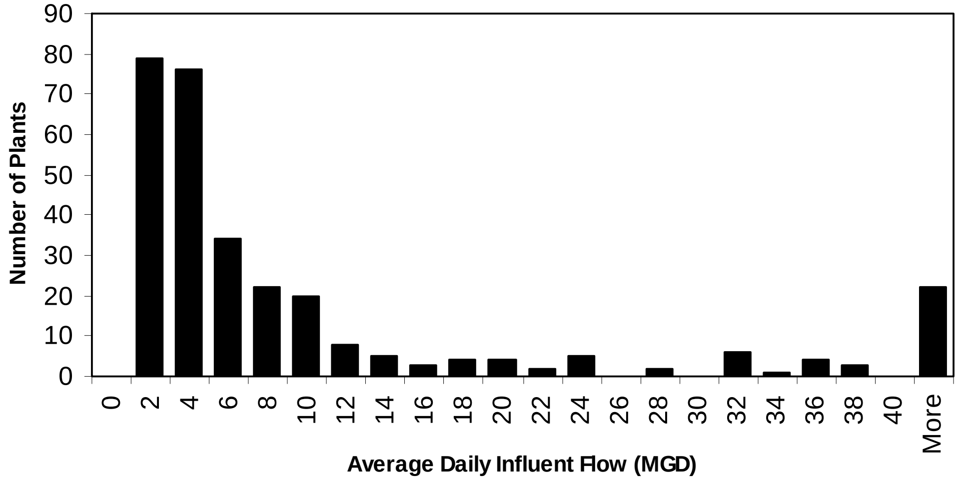

Figure 5.8 Annual Wastewater Treatment Plant Average Daily Flow Distribution

The plant load factor, Figure 5.9, indicates how closely the plant is being operated to design capacity. Most plants indicated that the plants are used within 40% and 100% of design capacity.

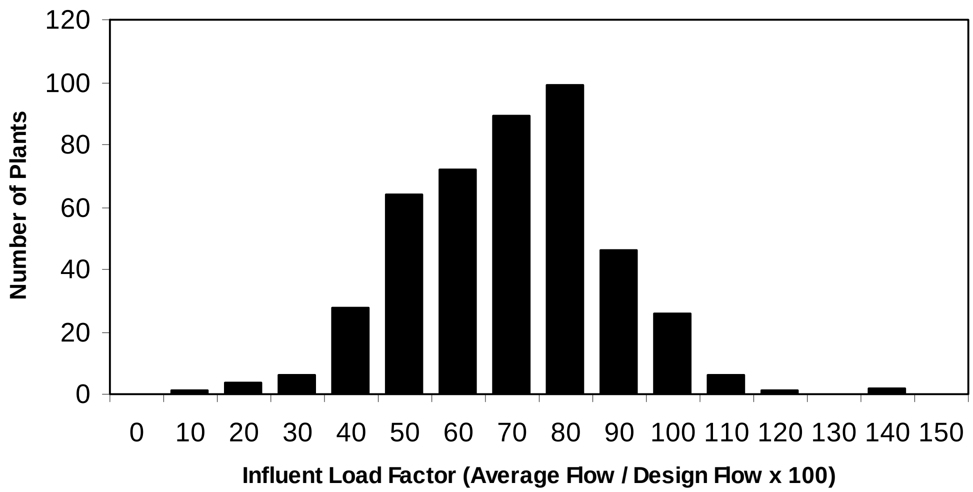

Figure 5.9 Wastewater Treatment Plant Load Factor Distribution

Beyond flow, the biological oxygen demand provides an indication of loading. Figure 5.10 and Figure 5.11 show the influent and effluent average annual BOD levels. Influent ranged from 75 mg/l to 325 mg/l for most plants. Effluent levels were below 20 mg/l at most plants with the majority below 8 mg/l. Figure 5.12 shows the range in biological load normalized electricity use ranging mostly from 0.75 to 2.25 kWh/lb BOD.

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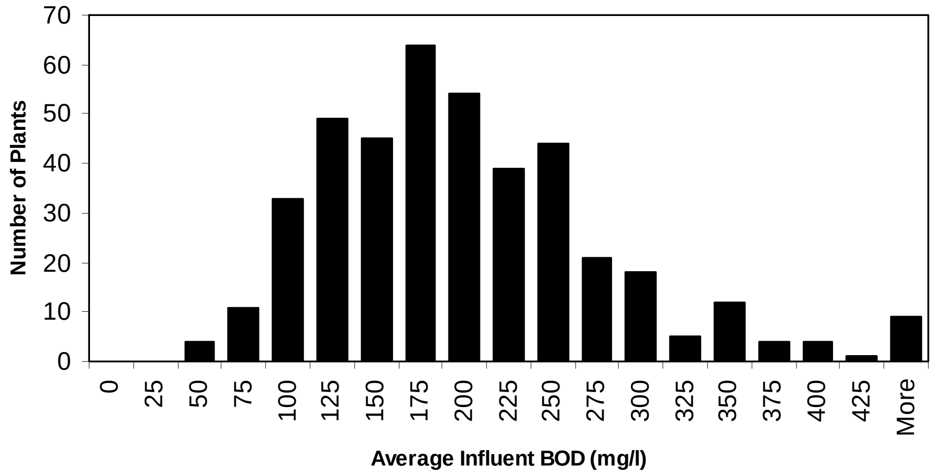

Figure 5.10 Wastewater Treatment Plant Average Influent BOD Distribution

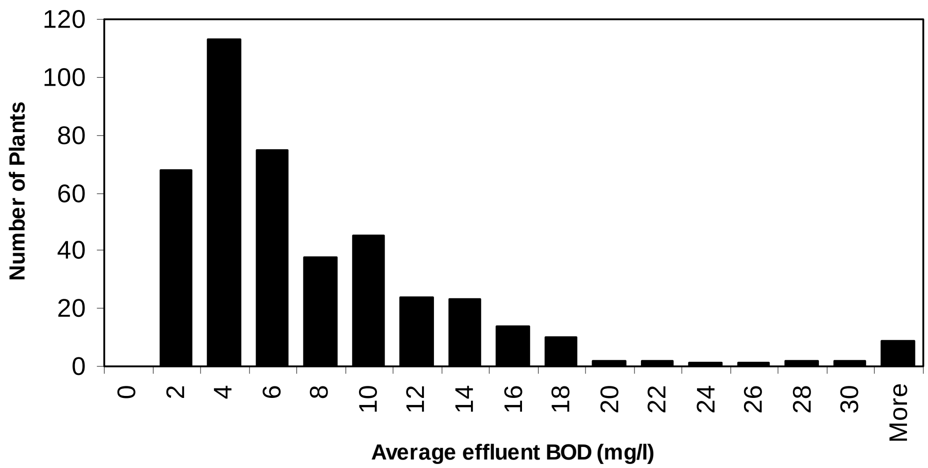

Figure 5.11 Wastewater Treatment Plant Average Effluent BOD Distribution

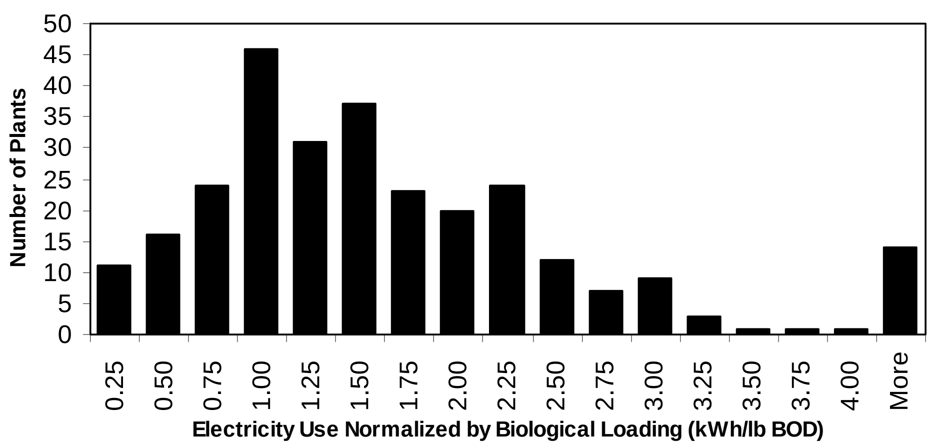

Figure 5.12 Wastewater Treatment Plant Biological Load Normalized Electricity Use

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Flow from industrial users was below 10% at most plants as shown in Figure 5.13.

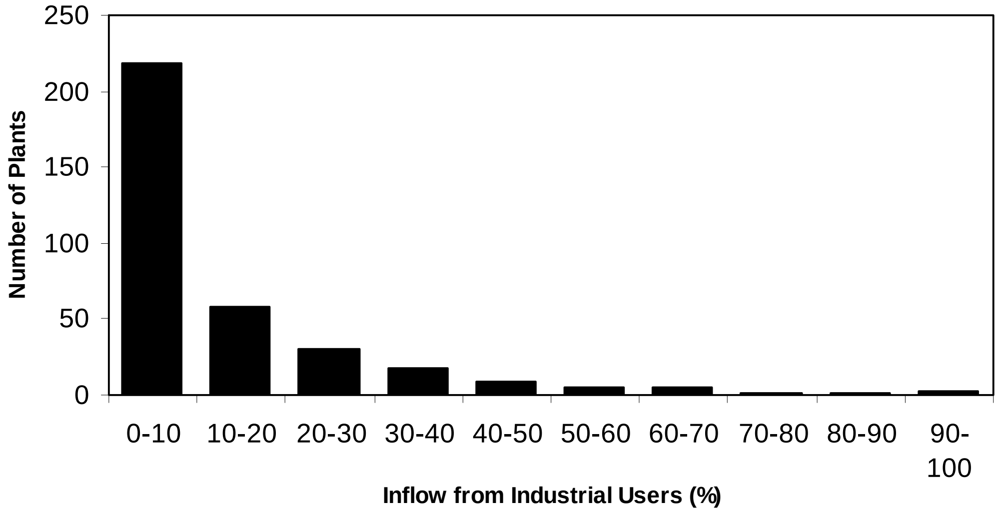

Figure 5.13 Wastewater Treatment Plant Inflow from Industrial Users

On-site electricity production was noted by 84 respondents. Twenty-nine of the surveys contained both electricity use and generation data. Their production levels varied widely from less than 1% to more the 200% of the treatment plant electricity use as shown in Figure 5.14.

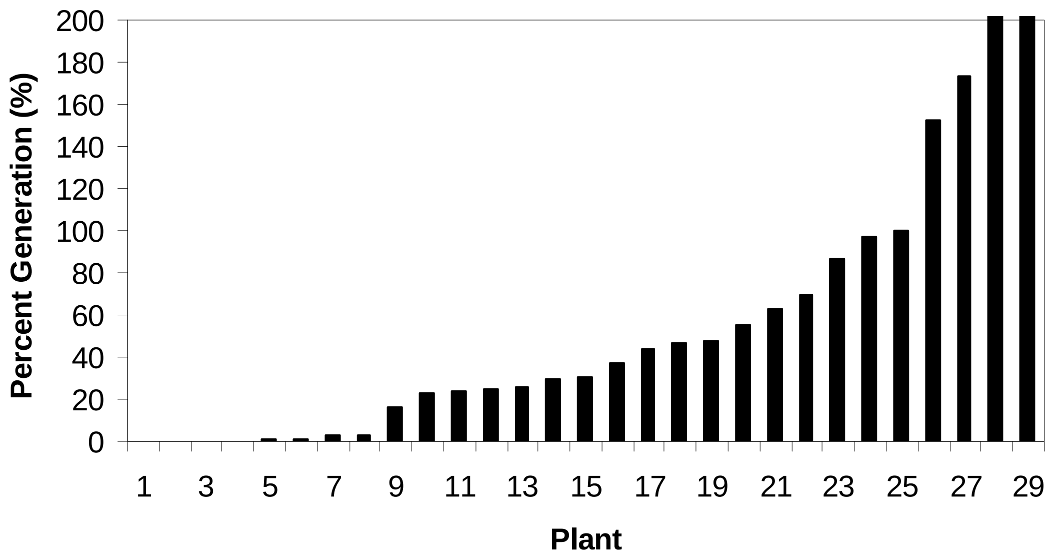

Figure 5.14 Wastewater Treatment Plant Portion of Electricity Use Generated On-Site

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CHAPTER 6
WASTEWATER METRIC FORMULATION

The goal of the project is to develop a multi-parameter metric that captures the impacts of key characteristics on energy use. The development approach closely follows the EPA ENERGY STAR benchmarking system for commercial buildings. In this program the energy use from a statistical sample of buildings was modeled from available building characteristics to normalize for items such as size, hours of use, and internal heat gains.

Similarly this project has created a statistical sample of wastewater treatment plants that include both energy use and descriptive characteristics. The analysis began by assessing the correlation of each characteristic parameter to energy in order to find a set of parameters that explained most of the variation in energy use among utilities.

SOURCE ENERGY

The analysis sought to identify those parameters that relate to the energy use of the treatment plant. Energy use considers all forms of energy at the plant: electricity, natural gas, propane and fuel oil. These energy forms must be combined into a single energy use parameter to create a single dependent variable.

Combining electricity and fossil fuel energy use requires conversions that impact the influence of individual fuels on the total energy use. Source energy is widely used to capture the total impact of energy use from a facility for energy policy purposes. For the most part the conversion adjusts the electric energy to be comparable with site consumed fossil fuels. Source energy captures the energy used in the process of producing and transmitting electricity. On a national basis 11,100 BTUs are used to produce and deliver a kWh of electricity (AER 2004). The other energy types use their higher heating value for a conversion to source energy. There is a small 2.4% addition to natural gas to account for transmission losses. Fuel Oil and Propance are converted from sales volumes (gallons) to BTUs based on their higher heating value. Table 6.1 summarizes the conversion factors used in this study.

Table 6.1 Source Energy Conversion Factors

Energy Form	Factor	Units
Electricity	11.1	kBtu/kWh
Natural Gas	102.4	kBtu/therm
Fuel Oil	141	kBtu/gallon
Propane	91	kBtu/gallon

Electricity is the predominate energy type. Thirty-three percent of the treatment plants noted only electricity use, while 86% noted more than 80% of their energy use was in the form of electricity. Fifty-eight percent of the treatment plants reported natural gas use, with 82% receiving less than 30% of the total energy from natural gas. Thirteen percent of the treatment plants reported the use of oil or propane energy sources.

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DATA FILTERS

The survey data were filtered to include only plants with responses to all the parameters needed in the analysis, including flow, BOD and electricity data. Some limits on these parameters were applied to remove outliers. The data filters below remove responses with insufficient data and outliers. Each filter notes the acceptable level and number of impacted sites:

- average daily flows greater than 0.6 MGD (6 sites)
- average influent BOD levels greater the 30 and less than 1000 (15 sites)
- treatment electricity use greater than 100,000 kWh (6 sites)
- effluent BOD levels greater than zero (3 sites)

MODEL DEVELOPMENT

The comparison among a large range in facility capacities prompted the use of a logarithmic transformation. Figure 6.1 shows the relationship between the daily average flow and the energy use. As expected the variation in flow explains much of the change in energy use among the 266 qualifying survey responses.

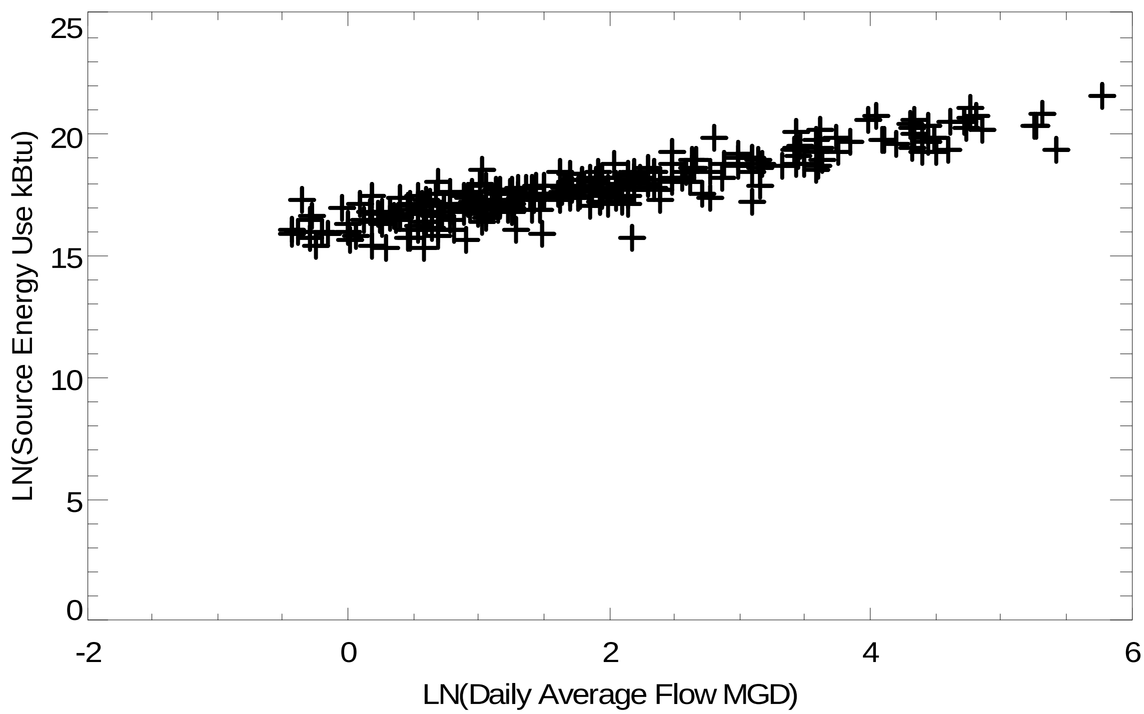

Figure 6.1 Wastewater Treatment Plant Energy Use vs Effluent Flow

A single parameter model that represents the energy use on the basis of effluent flow is shown in Table 6.2. This simple model explains 82% of the energy use variation as noted by the R^2 correlation statistic.

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Table 6.2 Wastewater Treatment Plant Energy Use Single Parameter Model

```
                     * * * Analysis of Variance * * *
                                  Sum of           Mean
             Source        DF     Squares          Square       F Value      P Value
              Model         1      358.59          358.593      1228.72      0.00000
              Error       264       77.05            0.292
    Corrected Total       265      435.64          358.885

        Std Dev of Model Error       0.54       R-squared    0.8231
             Overall mean of y      17.80   adj R-squared    0.8225
   Coefficient of variation (%)      3.03

                      * * * Parameter Estimates * * *
               Parameter        Coefficient           Std Err    T-Value    p-value
               Intercept            16.2408            0.0555     292.69    0.00000
         ln(inf_average)             0.8364            0.0239      35.05    0.00000
```

The analysis started with the single parameter model of energy use and flow and tested the impact of each survey parameter. The parameter with the highest significance as judged through a t-test was then included to make a two parameter model and the process was repeated – testing each survey parameter with the new model. The initial model was of the form:

$$y = \beta_0 + \beta_1 x_1 + \varepsilon$$

where,

$$y = \ln(treat\_kwh \times 11.1 + ngas\_use \times 102.4 + oil\_use \times 141 + propane\_use \times 91)$$

$x_1 = \ln(inf\_average)$

$\beta_i = coefficients$

$\varepsilon = error$

treat_kwh	=	*reported treatment plant electricity use (kWh)*
ngas_use	=	*reported treatment plant natural gas use (therms)*
oil_use	=	*reported treatment plant oil use in (gallons)*
propane_use	=	*reported treatment plant propane use (gallons)*
inf_average	=	*average daily influent flow (MGD)*

Parameters were tested by adding them individually to the model as term x_2. Parameters with t-test values above 2.0 were considered for the next iteration of the model and the process was repeated, testing each parameter with the new model. An example of the parameters tested against the initial model is shown in Table 6.3 and Table 6.4.

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \varepsilon$$

The first three columns give the variable name, model coefficient value and t-test statistic. The next column shows the sum of squares for the error. The model correlation represented through an R^2 percentage next shows the variability that is explained by the model. The "N<>0" column shows the number of non-zero values for each parameter. The "T>2" column signifies the parameters with t-test results greater than two, deemed to be significant. The remaining four columns give descriptive statistics of the parameters (including the zero values). The parameters are ranked by the absolute value of the t-test statistic.

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Table 6.3 Wastewater Treatment Plant Parameter Influence on Source Energy Use (T Statistic greater than 2.0)

Parameter	Coef.	T-Test	SSE	R^2 %	N<>0	T>2	Mean	Std Dev	Min	Max
inf_average	*0.8364*	*35.05*	*77.05*	*82.31*	*264*	<<<	*1.866*	*1.391*	*-0.431*	*5.784*
The following parameters are added independently to above										
ln(eff_bod)	-0.2192	-5.81	68.28	84.33	263	<<<	1.69	0.82	-1.204	4.736
ln(inf_bod)	0.3771	5.12	70.06	83.92	266	<<<	5.21	0.43	3.8	6.585
process_denit	0.3388	4.97	70.43	83.83	85	<<<	0.32	0.47	0	1
inf_bod	0.0017	4.97	70.44	83.83	266	<<<	200.67	95.45	44.7	724
eff_bod	-0.0163	-4.80	70.83	83.74	266	<<<	7.77	9.45	0.3	114
process_nit	0.3146	4.77	70.91	83.72	160	<<<	0.60	0.49	0	1
ln(inf_design)	0.5589	4.63	71.25	83.64	266	<<<	2.30	1.33	0.131	5.991
ln(inf_lf)	-0.5589	-4.63	71.25	83.64	266	<<<	4.17	0.28	2.855	4.882
inf_lf	-0.0091	-4.60	71.31	83.63	266	<<<	67.22	17.10	17.37	131.85
treat_nr	0.2938	4.54	71.45	83.60	122	<<<	0.46	0.50	0	1
process_fixfilm	-0.3322	-4.18	72.24	83.42	56	<<<	0.21	0.41	0	1
process_tf	-0.3331	-3.99	72.65	83.32	49	<<<	0.18	0.39	0	1
treat_sec	-0.2486	-3.77	73.11	83.22	111	<<<	0.42	0.49	0	1
treat_adv2_nr	0.3966	3.42	73.76	83.07	23	<<<	0.09	0.28	0	1
ln(eff_tss)	-0.1058	-3.26	74.05	83.00	226	<<<	1.79	0.85	-1.022	4.043
treat_advanced	0.2326	3.20	74.16	82.98	74	<<<	0.28	0.45	0	1
treat_advanced2	0.3321	3.17	74.20	82.97	29	<<<	0.11	0.31	0	1
sludge_landap	0.2061	3.13	74.28	82.95	144	<<<	0.54	0.50	0	1
dis_uv	0.2383	3.06	74.39	82.92	65	<<<	0.24	0.43	0	1
treat_apri	-1.5404	-2.88	74.68	82.86	1	<<<	0.00	0.06	0	1
dis_chem	-0.2075	-2.83	74.77	82.84	188	<<<	0.71	0.46	0	1
ln(inf_tss)	0.0483	2.44	75.35	82.70	239	<<<	5.35	0.59	1.686	10.463
sludge_landfill	-0.1640	-2.35	75.46	82.68	88	<<<	0.33	0.47	0	1
treat_secondary	-0.1675	-2.35	75.47	82.68	185	<<<	0.70	0.46	0	1
sludge_aerob	0.1837	2.34	75.48	82.67	73	<<<	0.27	0.45	0	1
digest_gas	-0.1615	-2.34	75.48	82.67	115	<<<	0.43	0.50	0	1
treat_primary	-0.6137	-2.27	75.56	82.65	4	<<<	0.02	0.12	0	1
ln(plants_num)	0.1386	2.14	75.73	82.62	58	<<<	1.08	0.57	0.693	2.639
ln(CDD)	0.0876	2.08	75.80	82.60	266	<<<	6.50	0.78	4.554	8.089
ln(biosolid_prod)	0.0365	2.01	75.88	82.58	234	<<<	1.86	2.21	-2.303	9.294

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Table 6.4 Wastewater Treatment Plant Parameter Influence on Source Energy Use (T Statistic less than 2.0)

Parameter	Coef.	T-Test	SSE	R^2 %	N<>0	T>2	Mean	Std Dev	Min	Max
inf_average	*0.8364*	*35.05*	*77.05*	*82.31*	*264*	<<<	*1.866*	*1.391*	*-0.431*	*5.784*
The following parameters are added independently to above										
process_pox	0.3208	1.99	75.91	82.58	12		0.05	0.21	0	1
onsite_gen	-0.1577	-1.96	75.94	82.57	62		0.23	0.42	0	1
process_phos	0.1595	1.79	76.12	82.53	44		0.17	0.37	0	1
process_oxcntrl	0.1324	1.78	76.13	82.52	71		0.27	0.44	0	1
pump_num	0.0012	1.76	76.15	82.52	230		26.05	50.85	0	499
treat_adv1_nr	0.1928	1.70	76.21	82.51	25		0.09	0.29	0	1
sludge_dewat	0.1151	1.67	76.23	82.50	169		0.64	0.48	0	1
ln(HDD)	-0.1145	-1.67	76.24	82.50	266		8.73	0.48	6.775	9.324
plants_num	0.0305	1.65	76.26	82.50	229		1.43	1.79	0	14
treat_sec_nr	0.1227	1.65	76.26	82.50	74		0.28	0.45	0	1
ln(onsite_kwh)	-0.0130	-1.63	76.27	82.49	27		13.90	2.80	7.313	19.023
check_util	0.1195	1.59	76.32	82.48	192		0.72	0.45	0	1
pump_eng	-0.1679	-1.57	76.33	82.48	30		0.11	0.32	0	1
ln(pump_hp)	0.0165	1.45	76.44	82.45	197		5.87	1.53	1.609	9.932
process_mech	-0.0970	-1.41	76.47	82.45	126		0.47	0.50	0	1
ln(pump_num)	0.0332	1.41	76.47	82.45	227		2.70	1.14	0.693	6.213
sludge_thick	0.0952	1.40	76.47	82.45	160		0.60	0.49	0	1
ln(pump_nplants)	0.1096	1.31	76.55	82.43	39		0.98	0.56	0.693	2.639
extra_event	-0.1147	-1.29	76.56	82.42	44		0.17	0.37	0	1
process_rbc	-0.1875	-1.22	76.62	82.41	13		0.05	0.22	0	1
ln(pump_mgd)	0.0234	1.21	76.62	82.41	192		2.35	1.77	-6.751	6.429
treat_advanced1	0.1037	1.17	76.65	82.41	45		0.17	0.38	0	1
oenergy_purch	-0.0924	-1.11	76.69	82.40	54		0.20	0.40	0	1
ln(ind_cod)	0.0165	1.08	76.71	82.39	45		5.89	0.57	4.787	7.272
treat_pri	-0.2978	-0.95	76.78	82.37	3		0.01	0.11	0	1
process_fbub	0.0601	0.89	76.82	82.37	149		0.56	0.50	0	1
pump_nplants	0.0184	0.84	76.84	82.36	204		1.10	1.51	0	14
process_cbub	0.0458	0.61	76.94	82.34	72		0.27	0.45	0	1
ln(pump_enghp)	-0.0135	-0.58	76.95	82.34	13		6.47	1.32	4.7	8.987
ln(digest_ccf)	-0.0031	-0.55	76.96	82.33	65		13.41	3.59	-0.288	19.702
biosolid_send	-0.0380	-0.41	77.00	82.33	41		0.15	0.36	0	1
sludge_anaerob	-0.0221	-0.33	77.02	82.32	116		0.44	0.50	0	1
ln(eff_cod)	0.0076	0.28	77.02	82.32	42		3.41	0.78	1.946	4.836
sludge_incin	0.0310	0.24	77.03	82.32	20		0.08	0.26	0	1
pump_remote	0.0233	0.22	77.03	82.32	237		0.89	0.31	0	1
treat_adv1	-0.0258	-0.21	77.03	82.32	20		0.08	0.26	0	1
biosolid_recv	0.0210	0.20	77.04	82.32	29		0.11	0.31	0	1
treat_adv2	0.0449	0.20	77.03	82.32	6		0.02	0.15	0	1
sludge_compost	-0.0070	-0.08	77.04	82.31	46		0.17	0.38	0	1
ln(floor_area)	-0.0005	-0.07	77.05	82.31	145		9.82	1.36	5.521	13.592
ln(inf_industry)	0.0001	0.01	77.05	82.31	199		2.76	2.74	-2.303	13.879

In this initial test the first 32 parameters are candidates for inclusion in the model. They include influent and effluent water quality, nutrient removal processes, trickle filtration, UV disinfection, sludge processes, digester gas recovery and general treatment level parameters.

Carrying this process through results in a nine parameter model described in Table 6.5. The model is based on the total flow through the plant as well as the load factor (inf_lf = Average Flow / Design flow). Both the entering and exiting BOD levels are significant descriptors of the energy variation (inf_bod, eff_bod). The presence of trickle filtration reduces

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energy use as noted by the negative coefficient. The use of a nitrification process tended to increase energy use. An aerobic sludge digestion process and ultimate land application of sludge tended to occur in plants with higher energy use. Using a pure oxygen aeration process also correlated with higher energy use. Plants with on-site electricity generation tended to have lower energy use. Figure 3.2 shows the model residuals are randomly distributed along the range in energy use data

Table 6.5 Wastewater Treatment Plant Energy Use Nine Parameter Model

* * * Analysis of Variance * * *

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Model	9	388.96	43.218	237.03	0.00000
Error	256	46.68	0.182		
Corrected Total	265	435.64	43.400		

Std Dev of Model Error	0.43	R-squared	0.8929
Overall mean of y	17.80	adj R-squared	0.8891
Coefficient of variation (%)	2.40		

* * * Parameter Estimates * * *

Parameter	Coefficient	Std Err	T-Value	p-value
Intercept	15.9426	0.5481	29.09	0.00000
ln(inf_average)	0.9009	0.0212	42.55	0.00000
ln(inf_bod)	0.4113	0.0650	6.33	0.00000
ln(eff_bod)	-0.1809	0.0369	-4.90	0.00000
ln(inf_lf)	-0.4198	0.1015	-4.14	0.00005
process_tf	-0.3151	0.0705	-4.47	0.00001
process_nit	0.1689	0.0607	2.79	0.00575
sludge_landap	0.1235	0.0554	2.23	0.02665
process_pox	0.2971	0.1315	2.26	0.02471
onsite_gen	-0.1415	0.0661	-2.14	0.03313

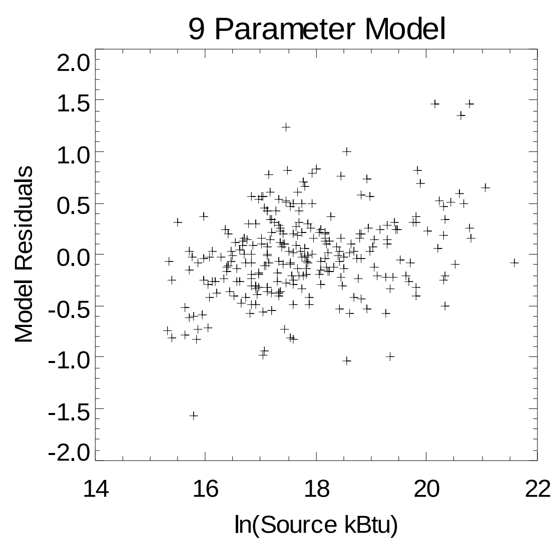

Figure 6.2 Wastewater Treatment Plant Nine Parameter Model Residuals

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The nine parameter model increases the R^2 coefficient to 89% from the 82% achieved when using only the average plant flow. However, the decision on which parameters to ultimately include in the model (the basis for the metric ranking) is not based solely on statistical significance. The purpose of the metric is to define the external characteristics under which the treatment plant must operate. These are parameters that define the operating conditions – outside the operator control.

- Flow and BOD levels certainly fit this requirement.
- The choice of major treatment process as noted by the trickle filtration parameter is not readily changeable and is related to plant size.
- Having trickle filtration in the model allows plants with and without that main process to be compared on other terms.
- Nutrient removal is used based on requirements imposed on the plant.
- Operation at a given load factor is a combination of design and volume loading factors.

The remaining factors are more directed by choice of a particular process or opportunity. A plant that chooses on-site power generation should rank better than a plant that does not choose on-site power generation. In this case the parameter should not be included in the model. The question becomes; is the use of pure oxygen, or sludge land application, or aerobic digestion forced upon the plant, or are these discretionary process choices? Should the use of these processes be reflected in the energy performance score? On-site power generation is an optional choice that should impact the ranking – plants with generation from waste gas should have a better performance score. These parameters also have the smallest t-test statistics.

- Sludge land application (143 sites)
- On-site power generation (59 sites)
- Pure oxygen process (12 sites)

The model without the last three parameters (and treat_nr swapped for prosses_nit), Table 6.6, has an only slightly larger sum of squared errors, but accomplishes the goal of the metric in capturing the effect of only exogenous factors. Figure 6.3 shows the model residuals are randomly distributed along the range in energy use data, and the consistent relationship between predicted and actual energy use. Figure 6.4 shows no relationship between the model residuals and the model parameters.

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Table 6.6 Wastewater Treatment Plant Energy Use Six Parameter Model – Endogenous Parameters Removed

* * * Analysis of Variance * * *

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Model	6	386.83	64.472	342.14	0.00000
Error	259	48.81	0.188		
Corrected Total	265	435.64	64.661		

Std Dev of Model Error	0.43	R-squared	0.8880
Overall mean of y	17.80	adj R-squared	0.8854
Coefficient of variation (%)	2.44		

* * * Parameter Estimates * * *

Parameter	Coefficient	Std Err	T-Value	p-value
Intercept	15.8741	0.5477	28.98	0.00000
ln(inf_average)	0.8944	0.0206	43.42	0.00000
ln(inf_bod)	0.4510	0.0639	7.06	0.00000
ln(eff_bod)	-0.1943	0.0350	-5.56	0.00000
ln(inf_lf)	-0.4280	0.1022	-4.19	0.00004
process_tf	-0.3256	0.0700	-4.65	0.00001
treat_nr	0.1774	0.0565	3.14	0.00188

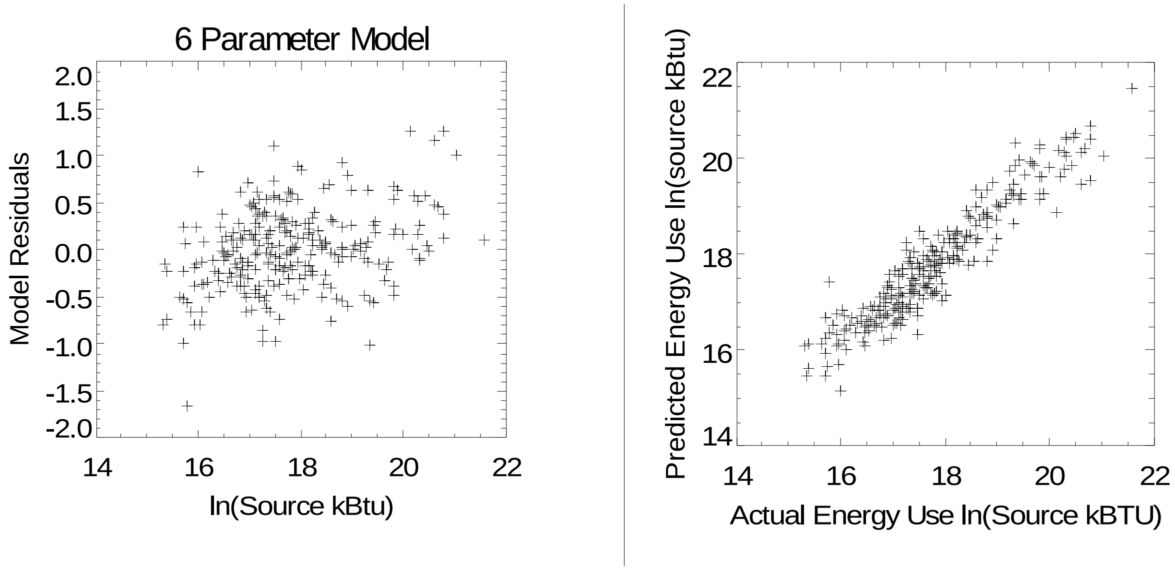

Figure 6.3 Wastewater Treatment Plant Six Parameter Residuals vs Dependent Variable and Model Fit

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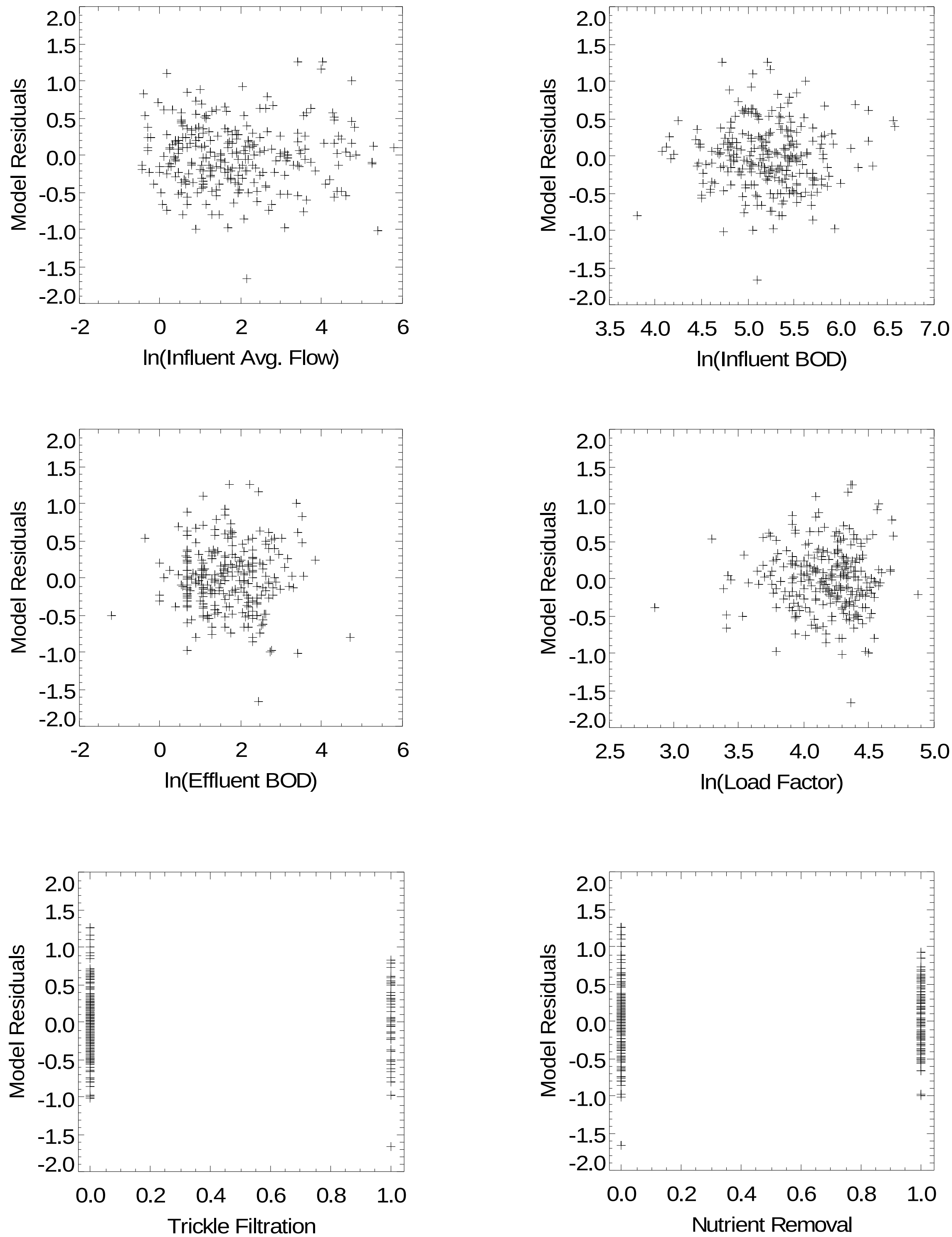

Figure 6.4 Wastewater Treatment Plant Six Parameter Model Residuals vs Independent Variables

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ENERGY PERFORMANCE RATING BENCHMARK SCORE

The regression model calculates the expected average energy use for the specific set of characteristics of a particular plant. The ratio of the model result to the overall mean provides a way to compare if the average plant with the specific characteristics uses more or less energy than the overall mean. The overall mean is the model result when each parameter is at its average value. Dividing the actual energy use by this ratio allows a comparison to the adjusted energy use for all plants used to develop the model.

Adjustment Factor = Predicted / Mean

Energy Adjusted = Energy / (Adjustment Factor)

The adjustment factor can be manipulated algebraically into the following form that illustrates that the deviation in actual energy use to the predicted energy use for the particular plant characteristics is used to determine how far from the overall sample mean the plant's adjusted energy use would appear on the energy distribution curve.

$$y_{adj} = \hat{y}_{mean} \frac{y}{\hat{y}}$$

The distribution of the adjusted energy use, Figure 6.5, captures the variation in the sample relative to the predicted energy use for the plant. The location or percentile of the plant's adjusted energy use on this distribution is the benchmark score.

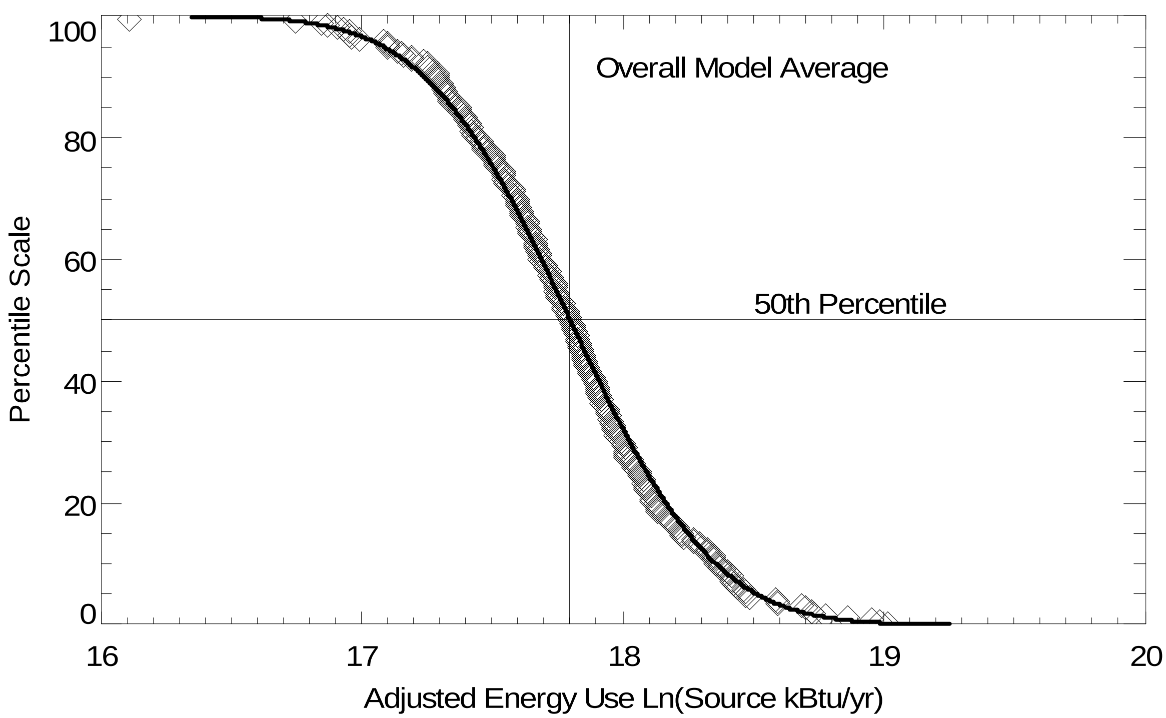

Figure 6.5 Wastewater Treatment Plant Modeled Energy Distribution

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To account for the non-uniformity of observations, especially in the tails, a normal distribution is fit to the model distribution curve. This fit becomes the energy performance rating score tabulated in Table 6.7.

Table 6.7 Wastewater Treatment Plant Energy Performance Rating Score Based on Adjusted Source Energy Use

Score	Adjusted Energy Use ln(kBtu/yr)		Score	Adjusted Energy Use ln(kBtu/yr)		Score	Adjusted Energy Use ln(kBtu/yr)
100	16.350		66	17.621		33	17.991
99	16.788		65	17.632		32	18.004
98	16.907		64	17.644		31	18.016
97	16.982		63	17.656		30	18.028
96	17.039		62	17.667		29	18.041
95	17.085		61	17.679		28	18.054
94	17.124		60	17.690		27	18.067
93	17.158		59	17.701		26	18.080
92	17.189		58	17.712		25	18.094
91	17.217		57	17.723		24	18.107
90	17.243		56	17.735		23	18.121
89	17.266		55	17.746		22	18.136
88	17.289		54	17.756		21	18.151
87	17.310		53	17.767		20	18.166
86	17.330		52	17.778		19	18.182
85	17.349		51	17.789		18	18.198
84	17.367		50	17.800		17	18.215
83	17.385		49	17.811		16	18.233
82	17.402		48	17.822		15	18.251
81	17.418		47	17.833		14	18.270
80	17.434		46	17.844		13	18.290
79	17.449		45	17.855		12	18.311
78	17.464		44	17.866		11	18.334
77	17.479		43	17.877		10	18.357
76	17.493		42	17.888		9	18.383
75	17.507		41	17.899		8	18.411
74	17.520		40	17.910		7	18.442
73	17.534		39	17.922		6	18.476
72	17.547		38	17.933		5	18.515
71	17.559		37	17.944		4	18.562
70	17.572		36	17.956		3	18.618
69	17.584		35	17.968		2	18.694
68	17.596		34	17.980		1	18.812
67	17.609						

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To determine the score for a utility, the first step is to calculate the total source energy use from the annual energy use of the treatment plant. Table 6.8 illustrates the conversion for each energy form to source energy. The last line in the table applies the natural logarithm transformation.

Table 6.8 Source Energy Conversion Example Calculations

Site Energy Type	Units	Site Energy Annual Use	x Conversion	=	Source Energy Use (kBtu/yr)
Electricity	kWh	**5,498,400**	11.1		61,032,240
Natural gas	therms	**150,404**	102.5		15,416,410
Fuel oil #2	gallons	**-**	141		0
Propane	gallons	**-**	91		0
Annual primary energy use (kBtu per yr)					76,448,650
ln (primary energy use)					18.1521

The second step in the score calculation is to determine the average energy use for a plant with the given characteristics. The coefficients from the six-parameter regression model are applied to the site characteristics as shown in Table 6.9. The characteristics have a natural logarithm transform applied first to match the form of the regression model.

Table 6.9 Modeled Energy Example Calculations

Parameter	Units	Value	Natural Logarithm Transform		Model Coefficient		
Intercept	-	-	-		15.8741	=	15.8741
Average Daily Influent Flow	MGD	**10.98**	2.40	x	0.8944	=	2.1430
Influent BOD [30 to 1000]	mg/l	**203**	5.31	x	0.4510	=	2.3963
Effluent BOD	mg/l	**14**	2.64	x	-0.1943	=	-0.5128
Influent Load Factor (Average / Design x 100)	%	**60**	4.09	x	-0.4280	=	-1.7524
Fixed Film - Trickle Filtration Process ?	yes (1) or no (0)	**0**	-	x	-0.3256	=	0.0000
Treatment Includes Nutrient Removal ?	yes (1) or no (0)	**1**	-	x	0.1774	=	0.1774
Mean predicted annual energy use (SUM of above)							18.3257

The predicted energy use for the average plant with the same characteristics as the plant of interest uses more energy than the actual plant. In other words, the plant being studied uses less energy than the typical comparable plant. To assess how much better the plant is than the expected typical plant, an adjustment factor, calculated in Table 6.10, is used to place the actual energy use on a distribution of modeled energy use from the survey sample.

Table 6.10 Adjusted Energy Use Example Calculations

Adjustment Factor: Divide SUM above by 17.80 (average plant in model)	18.3257	÷	17.80	=	1.0354
Adjusted Energy Use: Divide ln (primary energy use) by adjustment factor	18.1521	÷	1.0354	=	17.5320

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The location of the adjusted energy use on the modeled energy use distribution curve gives the plant's energy use relative to its peers. The percentile location on the curve is a score indicative of how close the energy use is to the best observed energy use (100 = best, 1 = worse). In the example in Figure 6.6 an adjusted energy use of 17.53 intersects the distribution curve at the 74th percentile, resulting in a score of 74.

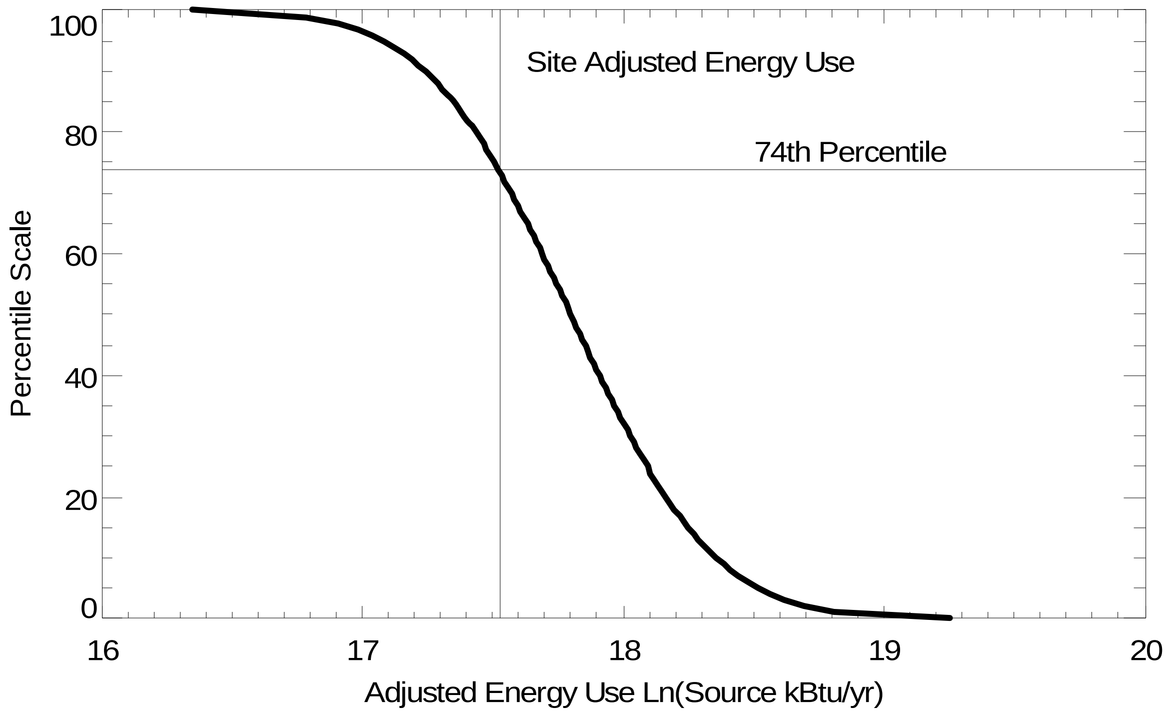

Figure 6.6 Wastewater Treatment Plant Example Score on Modeled Energy Distribution

The distribution is useful in giving a sense of the range in energy use at its peer plants. To make comparisons, the energy use from target scores can be calculated. For this site a reduction in source energy use of 3% would achieve a score in the 75th percentile. Similarly a reduction of 26% would achieve a score of 90, putting it in the group of the 10% lowest energy using plants.

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Table 6.11 Target Energy Use Example Calculations

				Estimated Annual Site Energy Use*			
Benchmark Score	Source Energy kBtu/yr	Difference kBtu/yr	Diff. (%)	Electricity kWh/MG	Natural Gas therm/MG	Fuel Oil Gal/MG	Propane Gal/MG
74	76,448,650			1372	38	0	0
Percentage Source Energy Use at Site:				80%	20%	0%	0%
10	179,686,582	103,237,932	135%	3225	90	0	0
25	136,726,098	60,277,448	79%	2454	69	0	0
50	100,896,796	24,448,146	32%	1811	51	0	0
75	74,456,622	(1,992,028)	-3%	1336	37	0	0
90	56,655,112	(19,793,538)	-26%	1017	29	0	0
*Site energy estimate is based on actual proportion of fuel source use at the plant.							

To further make this comparison meaningful, the source energy of the target scores can be equated to site energy use based on the fraction of use of the various fuel types of energy sources. In this example 80% of the energy use was in the form of electricity and 20% was in the form of natural gas. Applying the reciprocal of the source energy conversion from Table 6.1 and the fraction of source energy use gives an estimate of the site energy use. In Table 6.11 the site energy use is divided by the average effluent flow to give a metric in the form with which the industry is familiar (kWh/MG).

These values could be useful in evaluating the impact on the ultimate plant score of sub-process energy use or proposed energy efficiency projects. For instance a proposed project might have an anticipated savings expressed in kWh/MG that could be compared to the target values. In the example in Table 6.11, a 475 kWh/MG reduction is needed to move the score from the 50th percentile to the 75th percentile. Additionally the benchmark score could be recalculated with the proposed project's energy impact incorporated into the annual energy use.

The energy metric can be packaged in a concise manner as illustrated in Figure 6.7. The spreadsheet implementation uses the NPDES to identify the treatment plant. The annual energy use section shows the various forms of energy used at the plant. The utility characteristics section gathers the model parameters. The energy benchmark score along with the total source energy are calculated and displayed. The target energy section shows the amount of change in energy use needed to achieve other scores along with energy targets in site energy units.

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Wastewater Treatment Plant Energy Benchmark Metric (v 2007_1_15)

AwwaRF research project 3009 with additional support by the California Energy Commission and The New York State Energy Research and Development Authority

Treatment Plant Identification

NPDES Permit Number:	
Date:	

Utility Annual Energy Use

Please enter the annual energy use from all energy sources. If your utility generates power, please enter only purchased fuel.

Site Energy Type	Units	Site Energy Annual Use		
Electricity	kWh	**5,498,400**	1,372	kWh/MG
Natural gas	therms	**150,404**	38	therm/MG
Fuel oil #2	gallons			
Propane	gallons			
Energy use time period covered above:		**2004**		

Utility Characteristics

Please enter the following characteristics to describe the wastewater treatment plant.

Parameter	Units	Value		
Design Daily Influent Flow	MGD	**18.3**		
Average Daily Influent Flow	MGD	**10.98**	0.6	load factor
Average Influent BOD	mg/l	**203**	0.87	kWh/lb BOD
Average Effluent BOD	mg/l	**14**		
Fixed Film - Trickle Filtration Process ?	yes (1) or no (0)	**0**		
Treatment Includes Nutrient Removal ?	yes (1) or no (0)	**1**		

Energy Metric

This wastewater treatment plant energy benchmark is based on a statistical representation of the energy use of treatment plants across the country. It includes the characteristics that were found to have the most impact in explaining energy use among various plants. The resulting score represents your plant's relative energy use within the distribution of plants with your characteristics.

Your Utility Benchmark Score:	**74**
Total Source Energy Use (kBtu/yr):	**76,449,000**

Target Energy Use - Energy Metric Distribution

The following table shows the range in distribution of energy use for utilities with your characteristics. The percentages are relative to your use. The estimated site energy use is based on the actual proportions of site energy used.

	Source Energy Use		Estimated Site Energy Use			
Score	**(kBtu/yr)**	**Percentage Difference (%)**	**Electricity (kWh/MG)**	**Natural Gas (therms/MG)**	**Fuel Oil (gallons/MG)**	**Propane (gallons/MG)**
10	179,690,000	135%	3,225	90	0	0
25	136,730,000	79%	2,454	69	0	0
50	100,900,000	32%	1,811	51	0	0
75	74,457,000	-3%	1,336	37	0	0
90	56,655,000	-26%	1,017	29	0	0

Figure 6.7 Wastewater Treatment Plant Example Benchmark Calculation Sheet

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COMPARISON TO SINGLE PARAMETER METRICS

The benchmark metric captures the influence of several treatment plant characteristics in defining peer plants and in comparing energy use. The score only roughly correlates with traditional single parameter metric of electricity use per total flow (kWh/MG) as shown in Figure 6.8 and electricity use to pound of BOD removal shown in Figure 6.9. The range in normalized electricity use decreases as well as the maximum values as the benchmark score increases. Due to the operating conditions, some plants with low kWh/MG still achieve low benchmark scores as the score incorporates natural gas and operational factors.

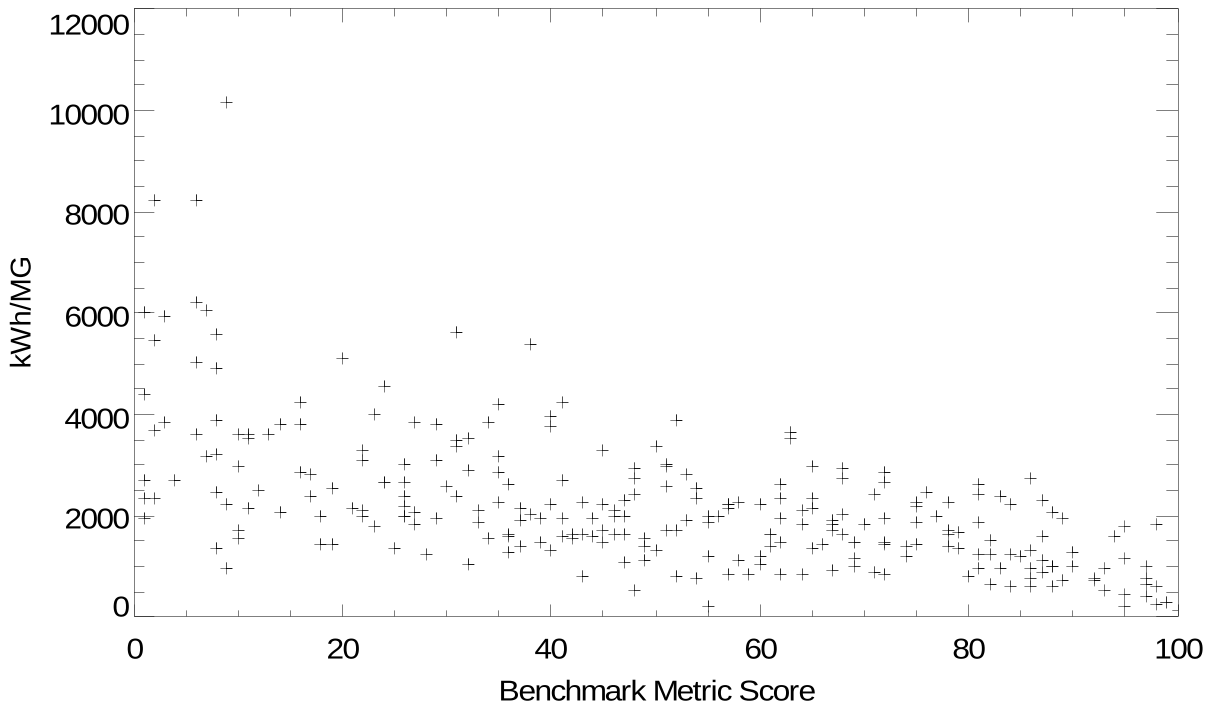

Figure 6.8 Wastewater Treatment Plant Benchmark Score Comparison to kWh/MG Metric

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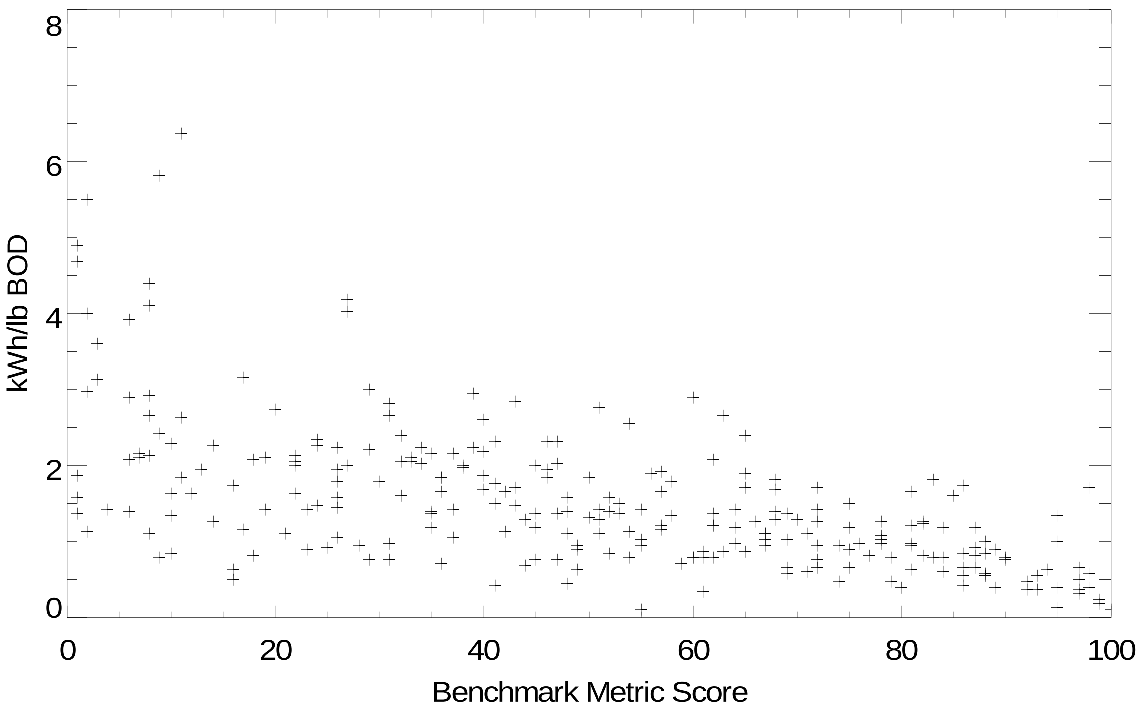

Figure 6.9 Wastewater Treatment Plant Benchmark Score Comparison to kWh/lb BOD Metric

The benchmark score is compared to each of the independent variables in Figure 6.10. There are no correlations between score and the model parameters.

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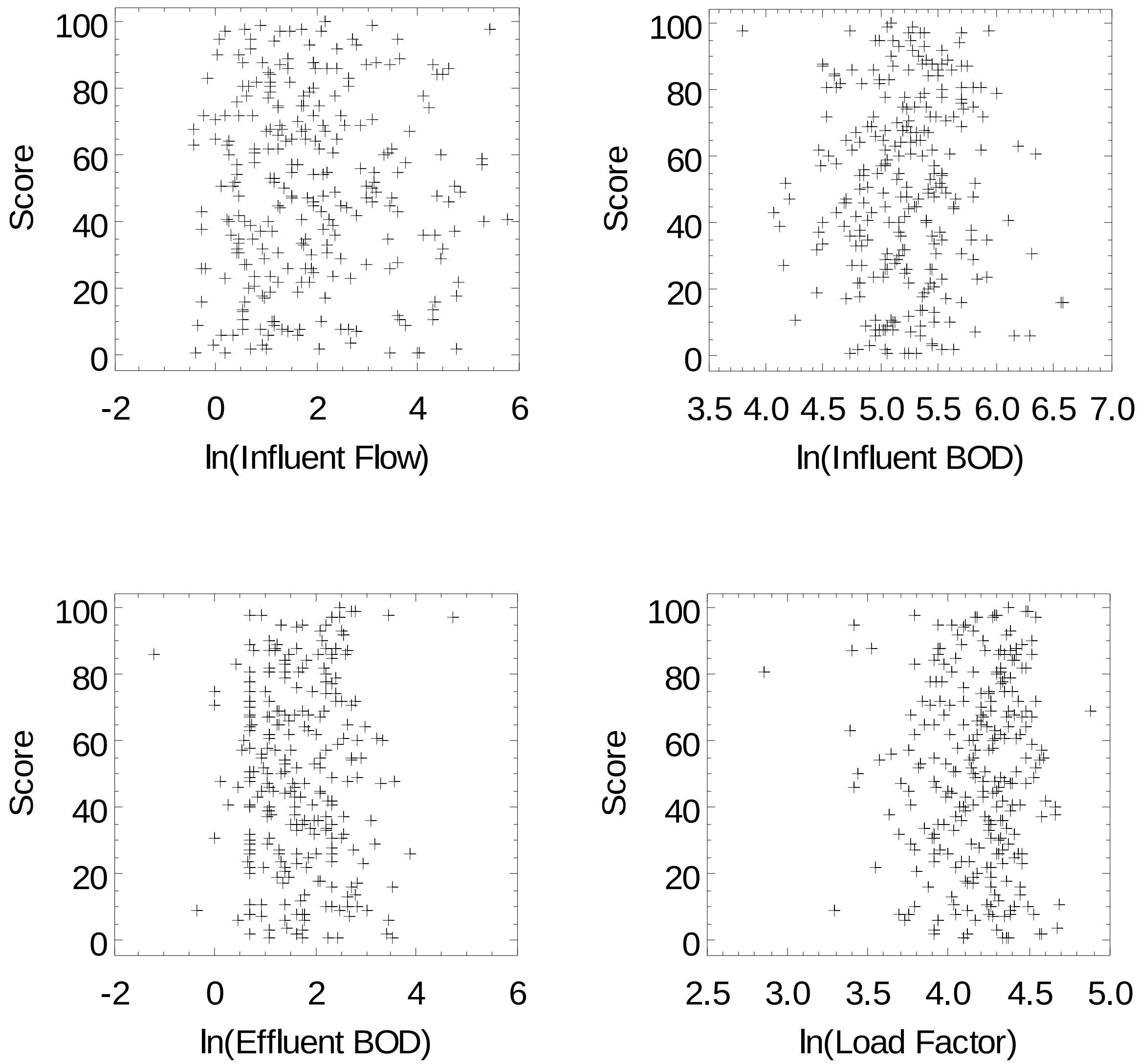

Figure 6.10 Wastewater Treatment Plant Benchmark Score Comparison to Independent Variables

WASTEWATER TREATMENT PLANT ENERGY MODEL WITH WEATHER DEPENDENCE

The wastewater treatment plant energy use showed a correlation with weather when both heating and cooling degree days were included in the analysis. The weather data for the sample points was assigned from state averages.

The model in Table 6.12 shows nearly identical model parameters as the model without the weather parameters. The inclusion of the weather data mainly reduces the constant (intercept) in the model.

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Table 6.12 Wastewater Treatment Plant Energy Use Model with Weather Parameters

* * * Analysis of Variance * * *

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Model	8	388.04	48.505	261.89	0.00000
Error	257	47.60	0.185		
Corrected Total	265	435.64	48.690		

Std Dev of Model Error	0.43	R-squared	0.8907
Overall mean of y	17.80	adj R-squared	0.8873
Coefficient of variation (%)	2.42		

* * * Parameter Estimates * * *

Parameter	Coefficient	Std Err	T-Value	p-value
Intercept	12.5398	1.4378	8.72	0.00000
ln(inf_average)	0.8966	0.0206	43.56	0.00000
ln(inf_bod)	0.4920	0.0655	7.52	0.00000
ln(eff_bod)	-0.1962	0.0357	-5.50	0.00000
ln(inf_lf)	-0.4314	0.1018	-4.24	0.00003
process_tf	-0.3363	0.0695	-4.84	0.00000
treat_nr	0.1587	0.0566	2.80	0.00544
ln(HDD)	0.2421	0.1033	2.34	0.01987
ln(CDD)	0.1587	0.0632	2.51	0.01265

The 2004 heating and cooling degree days are inversely correlated as shown in Figure 6.11. The figure also shows the distributions of heating and cooling degree days across the sample.

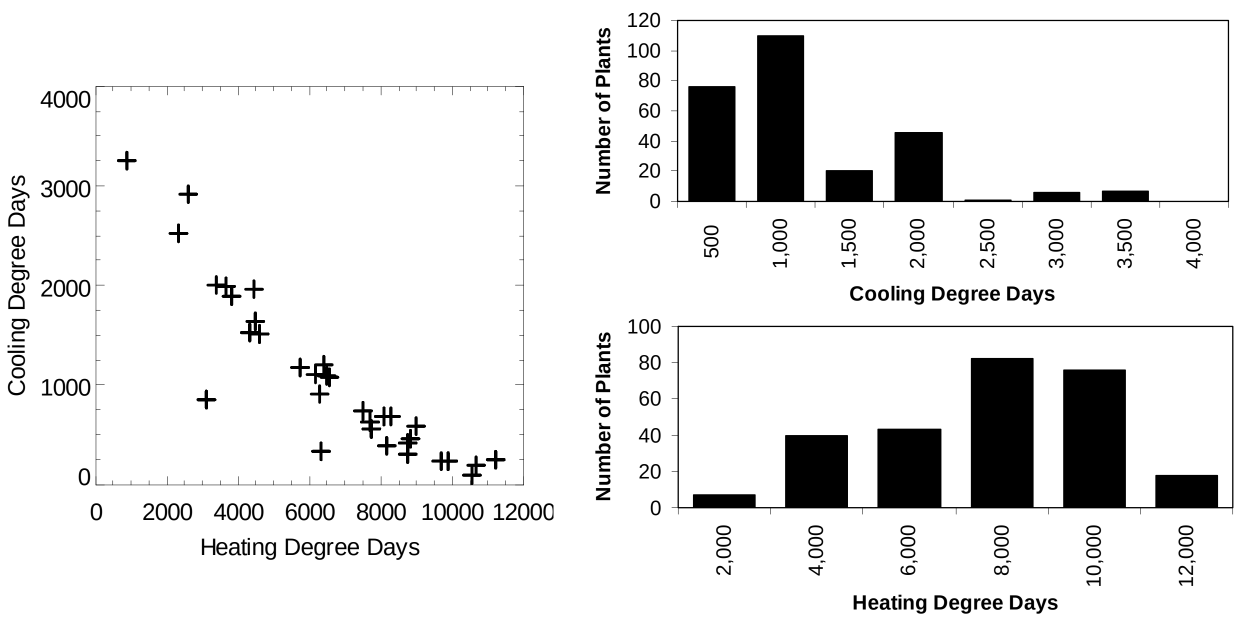

Figure 6.11 Heating and Cooling Weather Parameter Correlation and Distributions

The weather impacts the benchmark score by ± 10 distributed evenly across the entire range as shown in Figure 6.12. One difficulty in including weather in the benchmark is that the weather data must be readily available. This requirement makes it difficult to implement a standalone spreadsheet of the benchmark as the weather data would need to be updated to correlate to the time period that the energy data spans. Plant operators could retrieve the data,

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but it adds one more step and one more reason to avoid implementing the benchmark score. For this reason the model without the weather is used.

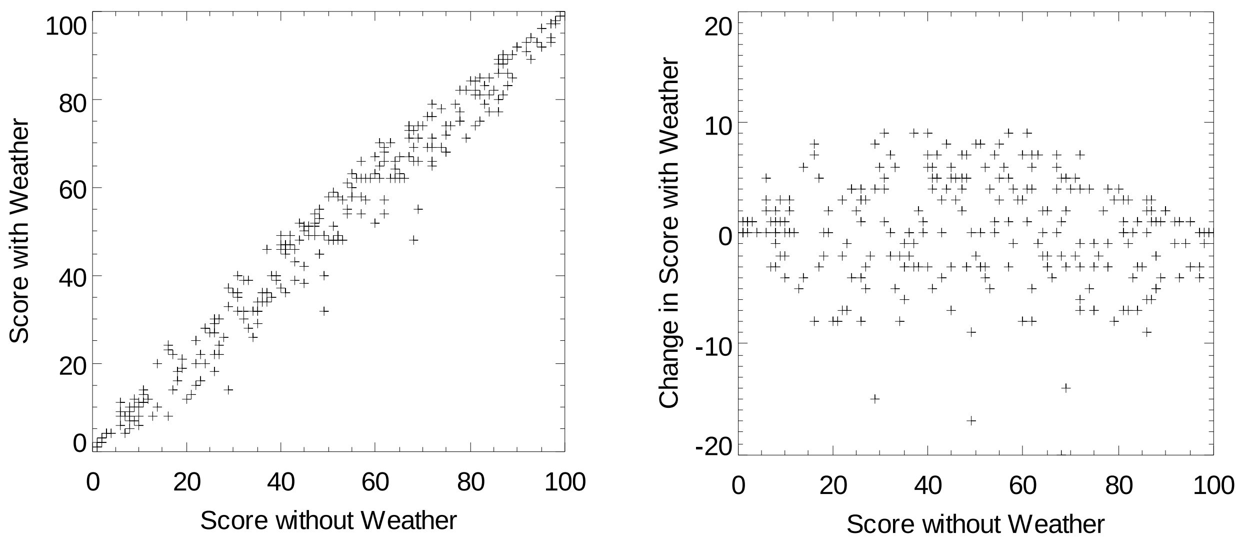

Figure 6.12 Impact of Weather Parameters on Score

WASTEWATER TREATMENT PLANT ENERGY COST BASED MODEL

The energy benchmark metric was developed based on source energy use as the dependent variable. Source energy use was used in commercial building benchmark development and is the item with which energy program and policy developers in the energy field routinely deal. The main issue is making a single energy parameter from the multiple energy forms used at treatment plants.

From an operational standpoint total energy cost is a most vital operating parameter. Combining fuels through total cost gives a single measure of energy impact at the site (although comparing plants adds the impact of varying price). A similar analysis can be formulated with energy cost as the dependent variable.

Filtering the survey data as before, but substituting the treatment electricity use with treatment energy cost greater than $20,000 (eliminating 6 sites), results in 298 qualifying surveys. The total energy cost is mostly explained by the influent flow as shown in Figure 6.13

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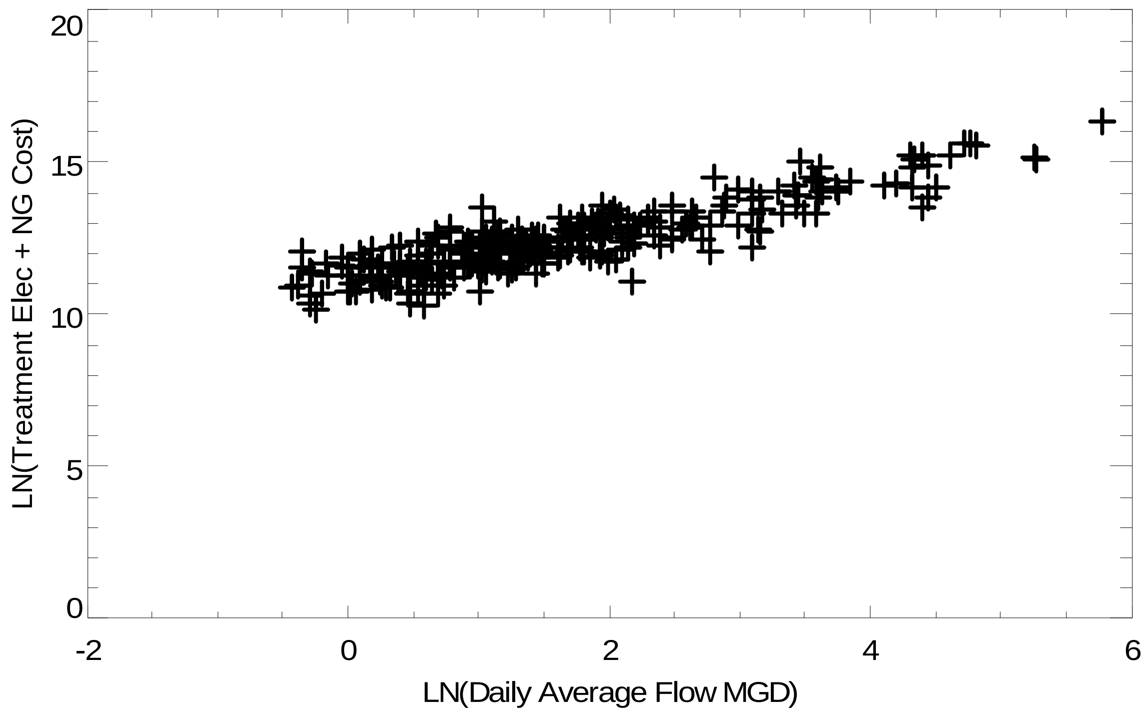

Figure 6.13 Wastewater Treatment Plant Energy Cost vs Influent Flow

Replacing the source energy as the dependent variable with the energy cost in the earlier described model gives the alternate model formulation.

$$y = \ln(treat\_cost + ngas\_cost);\ \textit{Natural log of energy cost (\$)}$$

The resulting single parameter model in Table 6.13 describes the energy cost well with an R^2 correlation statistic of 79%.

Table 6.13 Wastewater Treatment Plant Energy Use Single Parameter Model - Cost

```
                    * * * Analysis of Variance * * *
                                       Sum of          Mean
              Source          DF      Squares         Square       F Value      P Value
               Model           1       286.49        286.493       1108.68      0.00000
               Error         296        76.49          0.258
     Corrected Total         297       362.98        286.751

        Std Dev of Model Error           0.51      R-squared     0.7893
              Overall mean of y         12.40  adj R-squared     0.7886
      Coefficient of variation (%)       4.10

                     * * * Parameter Estimates * * *
                    Parameter       Coefficient            Std Err    T-Value    p-value
                    Intercept           11.1313             0.0481     231.37    0.00000
              ln(inf_average)            0.7879             0.0237      33.30    0.00000
```

Table 6.14 shows the selection of parameters in the cost model results in a similar model as the source energy model. One additional parameter that becomes significant is the

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incineration of sludge. This parameter is thought to be a process choice and is removed from the ultimate model with the other endogenous factors.

Table 6.14 Wastewater Treatment Plant Energy Use Six Parameter Model - Cost

* * * Analysis of Variance * * *

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Model	6	314.31	52.384	313.17	0.00000
Error	291	48.68	0.167		
Corrected Total	297	362.98	52.551		

Std Dev of Model Error	0.41	R-squared	0.8659
Overall mean of y	12.40	adj R-squared	0.8631
Coefficient of variation (%)	3.30		

* * * Parameter Estimates * * *

Parameter	Coefficient	Std Err	T-Value	p-value
Intercept	9.9560	0.4948	20.12	0.00000
ln(inf_average)	0.8144	0.0203	40.13	0.00000
ln(inf_bod)	0.4778	0.0605	7.90	0.00000
ln(eff_bod)	-0.2361	0.0324	-7.28	0.00000
ln(inf_lf)	-0.2393	0.0884	-2.71	0.00720
process_tf	-0.2147	0.0595	-3.61	0.00036
treat_nr	0.1390	0.0504	2.76	0.00622

The modeled energy use distribution can be created for the cost model in Figure 6.14 just as it was for the energy model.

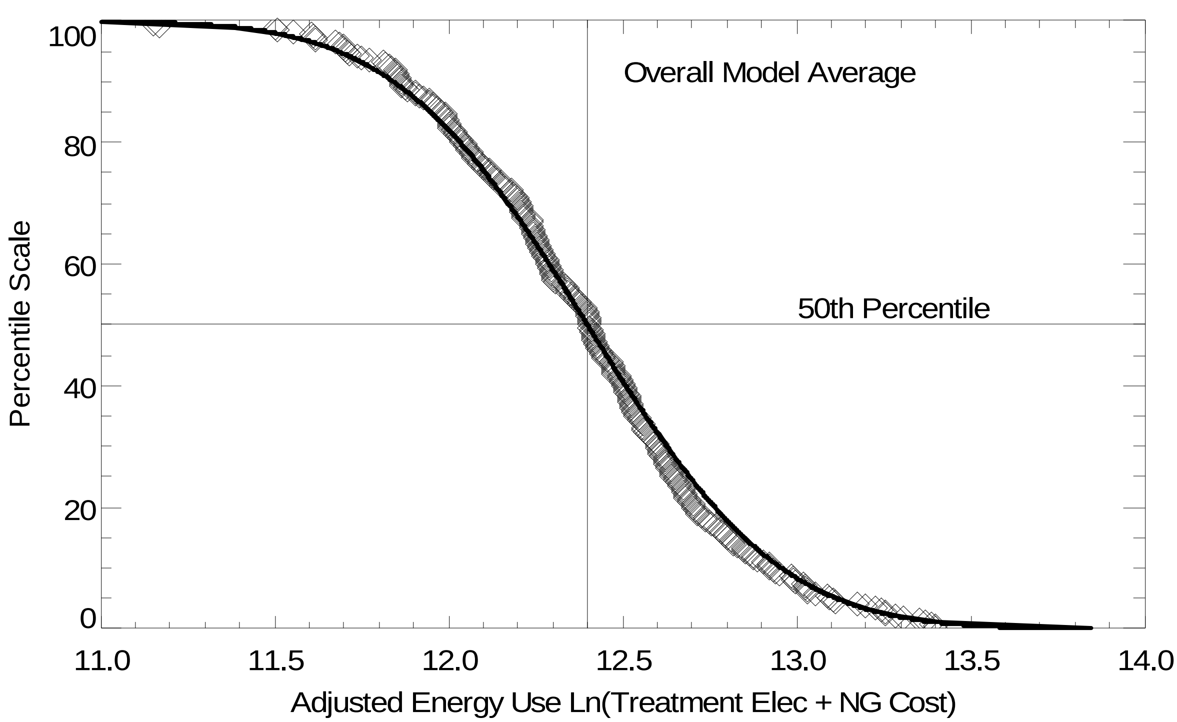

Figure 6.14 Wastewater Treatment Plant Modeled Energy Cost Distribution

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The resultant score from a cost based model varies drastically from the energy based model score as shown in Figure 6.15. A plant with a high energy score is just as likely to receive a low energy cost score as a high score.

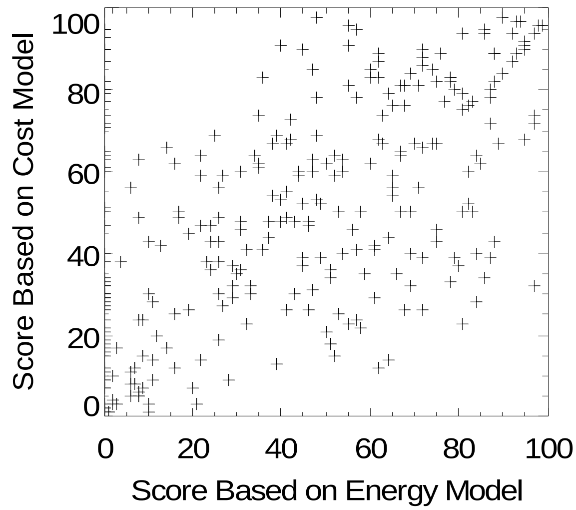

Figure 6.15 Wastewater Treatment Plant Comparison of Energy Model Based Score and Cost Model Based Score

A potential cause for the lack of agreement between energy based and cost based scoring is the price of energy. The source energy use is correlated to energy cost as shown in Figure 6.16, but there is an almost 3:1 change in effective electricity price across the surveyed treatment plants as shown in Figure 6.17. Gas prices cover a range of 2:1 as shown in Figure 6.18. The variation in price would be like varying the source energy conversion factors for each treatment plant, adding an extra element of variation to the analysis and resultant distribution.

While a metric based on cost could make the data more conveniently available, as financial data is readily tracked, the added price variability and the desire to have an impact on energy use favors the energy based model.

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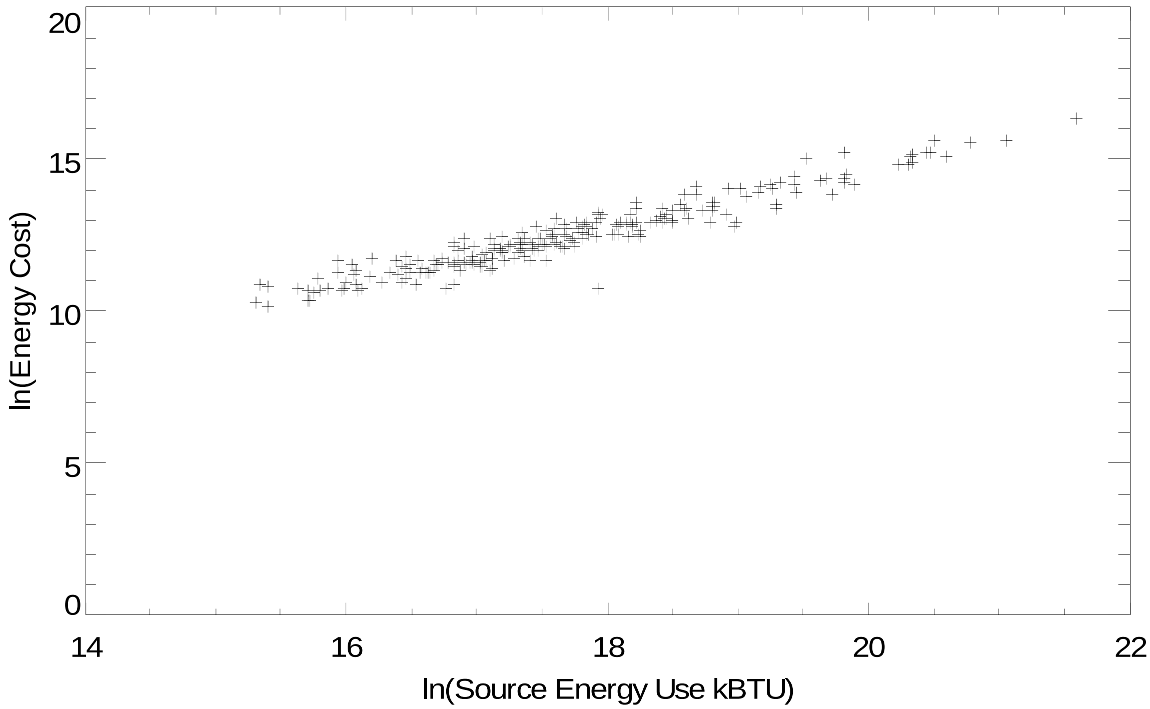

Figure 6.16 Wastewater Treatment Plant Energy Cost vs Source Energy Use

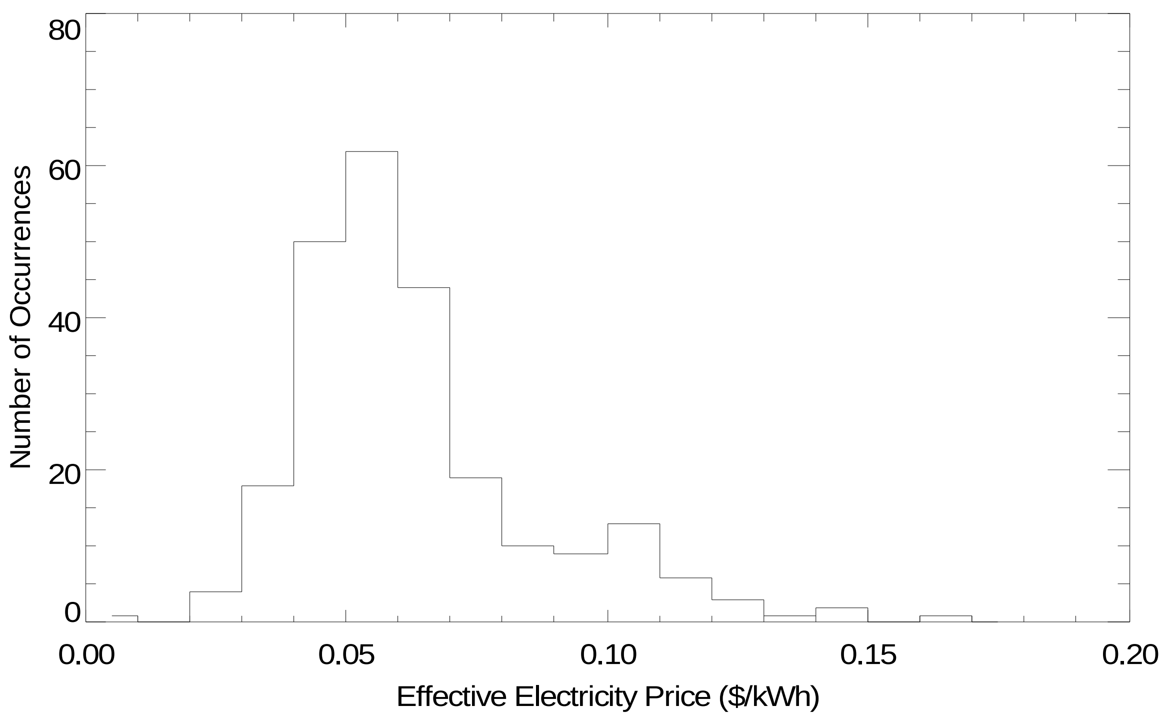

Figure 6.17 Wastewater Treatment Plant Distribution of Effective Electricity Prices

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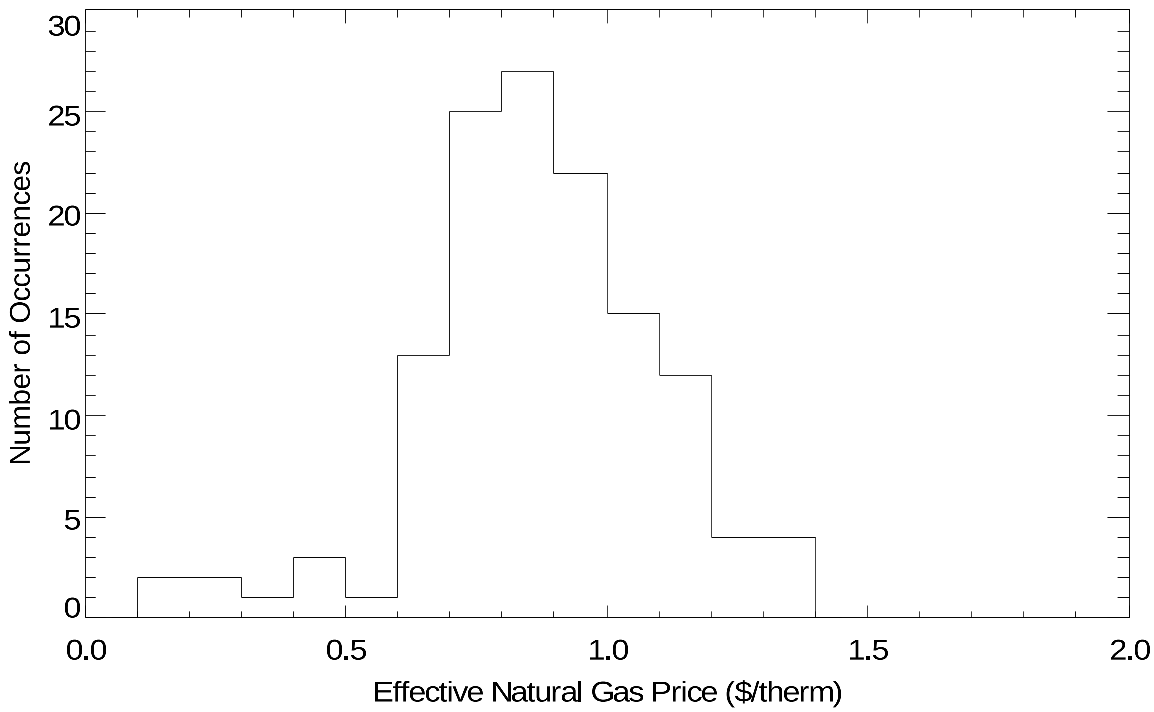

Figure 6.18 Wastewater Treatment Plant Distribution of Natural Gas Prices

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WASTEWATER COLLECTION SYSTEM METRIC

The survey collected energy use data on treatment plants and collection systems. An analysis comparable to the treatment plant analysis is possible for the collection system energy.

One hundred and seventy one survey respondents distinguished between treatment and collection system energy. The collection system energy use has more variability with flow, as shown in Figure 6.19, than the treatment plant energy use. The correlation between treatment plant flow and collection energy use produces an R^2 of only 42% as shown in Table 6.15.

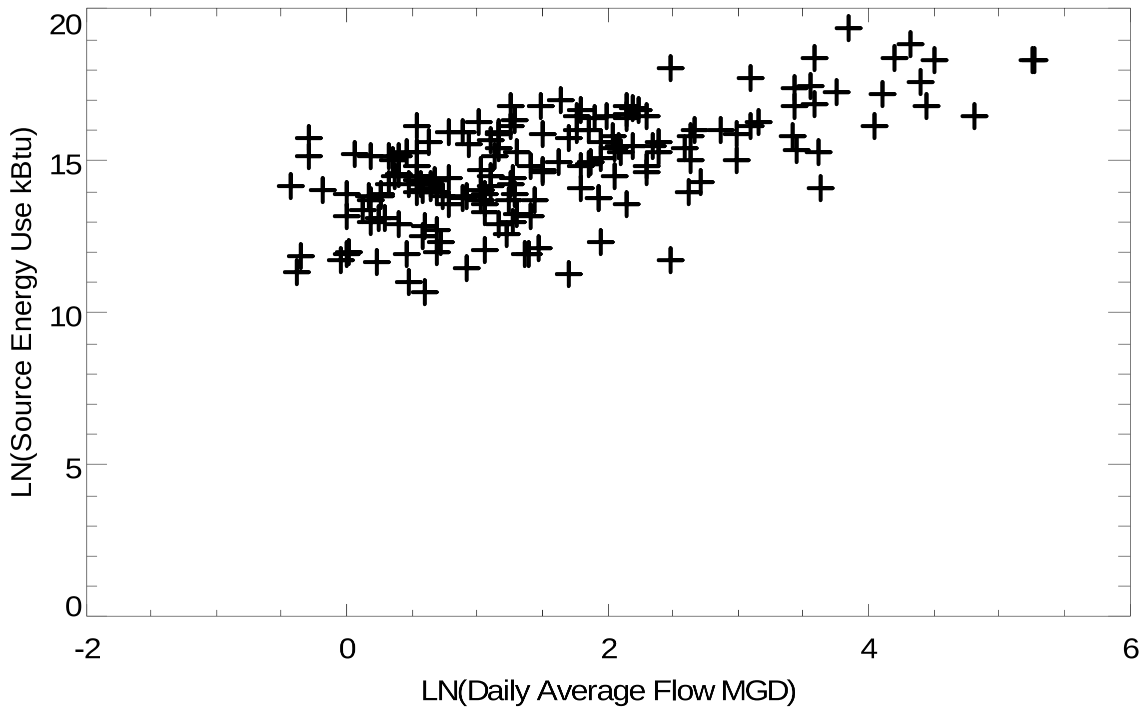

Figure 6.19 Wastewater Collection System Energy Use vs Flow

Table 6.15 Wastewater Collection System Energy Use Single Parameter Model

* * * Analysis of Variance * * *

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Model	1	214.40	214.396	122.20	0.00000
Error	169	296.52	1.755		
Corrected Total	170	510.91	216.150		

Std Dev of Model Error	1.32	R-squared	0.4196
Overall mean of y	14.82	adj R-squared	0.4162
Coefficient of variation (%)	8.94		

* * * Parameter Estimates * * *

Parameter	Coefficient	Std Err	T-Value	p-value
Intercept	13.3928	0.1638	81.74	0.00000
ln(inf_average)	0.9052	0.0819	11.05	0.00000

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Searching for additional model parameters to explain the variation in collection system energy use found that the main parameters affecting collection energy are related to the number of pumps and total pumping horsepower, although parameters like land application of sludge and biosolids production volume are also significant. This five parameter model is depicted in Table 6.16. In some cases the collection system could include significant energy used primarily for influent pumping at the plant, thus causing pumping related plant parameters to be correlated with the collection energy use.

Table 6.16 Wastewater Collection System Energy Use Five Parameter Model

* * * Analysis of Variance * * *

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Model	5	287.00	57.399	68.28	0.00000
Error	140	117.70	0.841		
Corrected Total	145	404.69	58.240		

Std Dev of Model Error	0.92	R-squared	0.7092
Overall mean of y	14.83	adj R-squared	0.6988
Coefficient of variation (%)	6.18		

* * * Parameter Estimates * * *

Parameter	Coefficient	Std Err	T-Value	p-value
Intercept	10.1855	0.3376	30.17	0.00000
ln(inf_average)	0.2829	0.0906	3.12	0.00218
ln(pump_num)	0.2380	0.0861	2.77	0.00645
ln(pump_hp)	0.6394	0.0796	8.04	0.00000
ln(biosolid_prod)	0.0941	0.0473	1.99	0.04854
sludge_landap	-0.3376	0.1558	-2.17	0.03196

Retaining only the parameters physically related to the collection system leaves the flow, number of pumps and total pumping horsepower in the model, shown in Table 6.17. There is only a slight reduction in the R^2 model correlation statistic to 67% with this smaller model. The model does suffer from bias as it over predicts the energy use of the smallest energy using systems as indicated by the residual plot in Figure 6.20. Figure 6.21 shows no relationship between the model residuals and the model parameters.

Table 6.17 Wastewater Collection System Energy Use Three Parameter Model

* * * Analysis of Variance * * *

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Model	3	289.17	96.388	104.43	0.00000
Error	152	140.29	0.923		
Corrected Total	155	429.46	97.311		

Std Dev of Model Error	0.96	R-squared	0.6733
Overall mean of y	14.79	adj R-squared	0.6669
Coefficient of variation (%)	6.49		

* * * Parameter Estimates * * *

Parameter	Coefficient	Std Err	T-Value	p-value
Intercept	10.0264	0.3247	30.88	0.00000
ln(inf_average)	0.3523	0.0835	4.22	0.00004
ln(pump_hp)	0.6409	0.0793	8.08	0.00000
ln(pump_num)	0.2292	0.0883	2.60	0.01034

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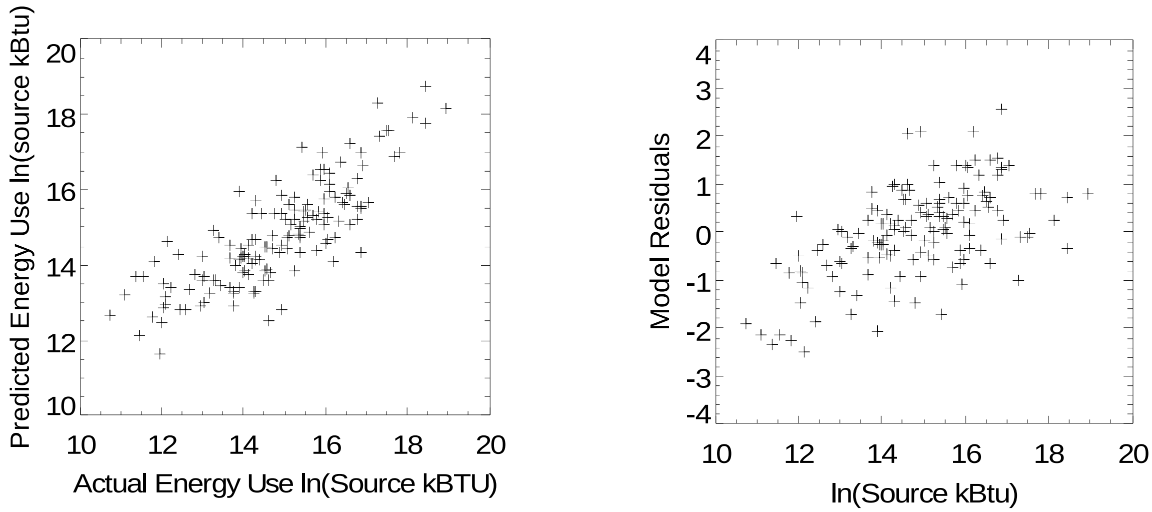

Figure 6.20 Wastewater Collection System Model fit and Residuals vs Dependent Variable

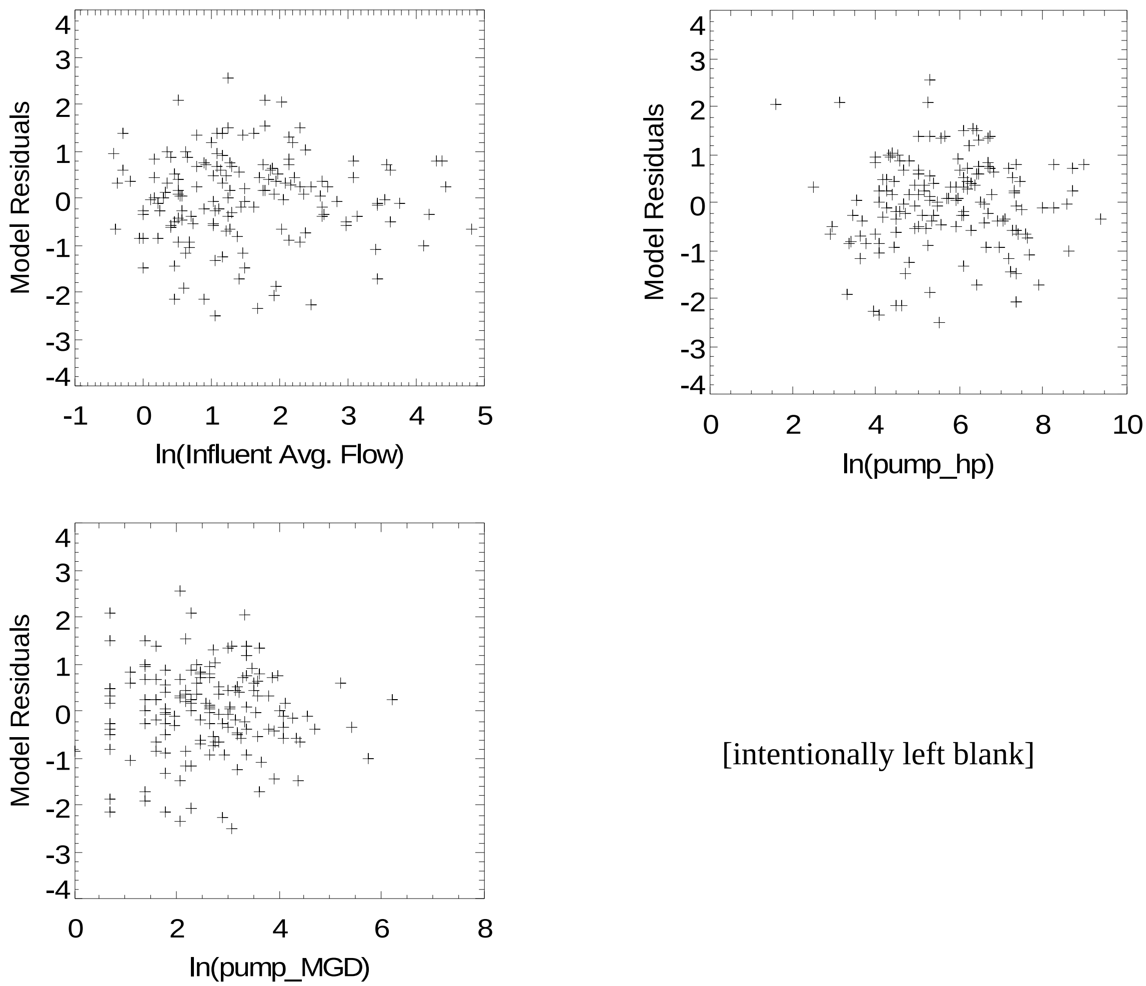

Figure 6.21 Wastewater Collection System Model Residuals vs Independent Variables

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The modeled energy use distribution in Figure 6.22 and Table 6.18 can be created from the adjusted energy use as described in the treatment plant analysis.

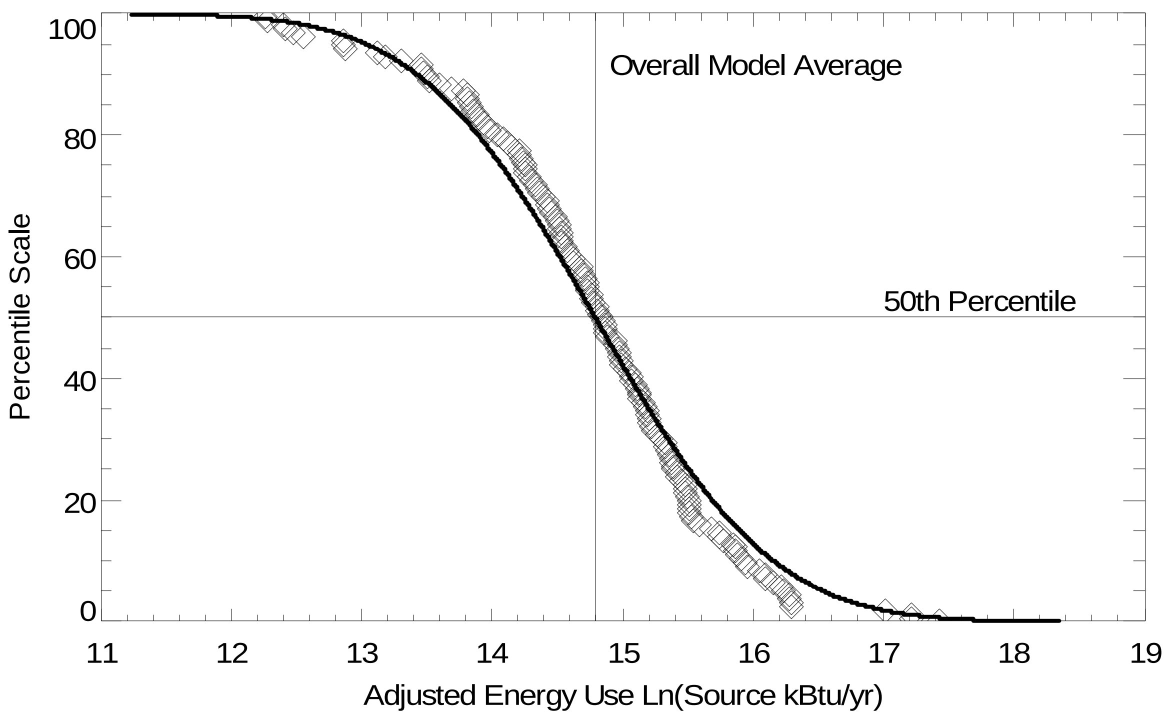

Figure 6.22 Wastewater Collection System Modeled Energy Distribution

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Table 6.18 Wastewater Collection System Energy performance Rating Score Based on Adjusted Source Energy Use

Score	Adjusted Energy Use ln(kBtu/yr)		Score	Adjusted Energy Use ln(kBtu/yr)		Score	Adjusted Energy Use ln(kBtu/yr)
100	11.243		66	14.354		33	15.262
99	12.315		65	14.383		32	15.292
98	12.606		64	14.411		31	15.322
97	12.790		63	14.440		30	15.352
96	12.929		62	14.468		29	15.383
95	13.042		61	14.496		28	15.414
94	13.138		60	14.524		27	15.446
93	13.221		59	14.551		26	15.478
92	13.297		58	14.578		25	15.512
91	13.365		57	14.605		24	15.545
90	13.429		56	14.633		23	15.580
89	13.487		55	14.660		22	15.615
88	13.542		54	14.686		21	15.652
87	13.593		53	14.713		20	15.689
86	13.643		52	14.740		19	15.728
85	13.689		51	14.766		18	15.768
84	13.734		50	14.793		17	15.809
83	13.777		49	14.820		16	15.853
82	13.818		48	14.847		15	15.897
81	13.858		47	14.874		14	15.944
80	13.897		46	14.901		13	15.993
79	13.934		45	14.927		12	16.044
78	13.971		44	14.954		11	16.100
77	14.007		43	14.981		10	16.158
76	14.041		42	15.008		9	16.221
75	14.075		41	15.035		8	16.290
74	14.108		40	15.063		7	16.365
73	14.141		39	15.091		6	16.449
72	14.173		38	15.118		5	16.545
71	14.204		37	15.147		4	16.658
70	14.235		36	15.175		3	16.796
69	14.265		35	15.204		2	16.981
68	14.295		34	15.233		1	17.271
67	14.325						

Comparing the resulting score to a simple electricity use per flow metric in Figure 6.23 shows a decrease in the maximum normalized energy use with increasing score. This trend is similar to the trend observed in the treatment plant metric.

Since the system pumping capacity is more highly correlated to collection system capacity than the average plant flow, the score is compared to another simple metric of electricity use per installed pumping capacity in Figure 6.24.

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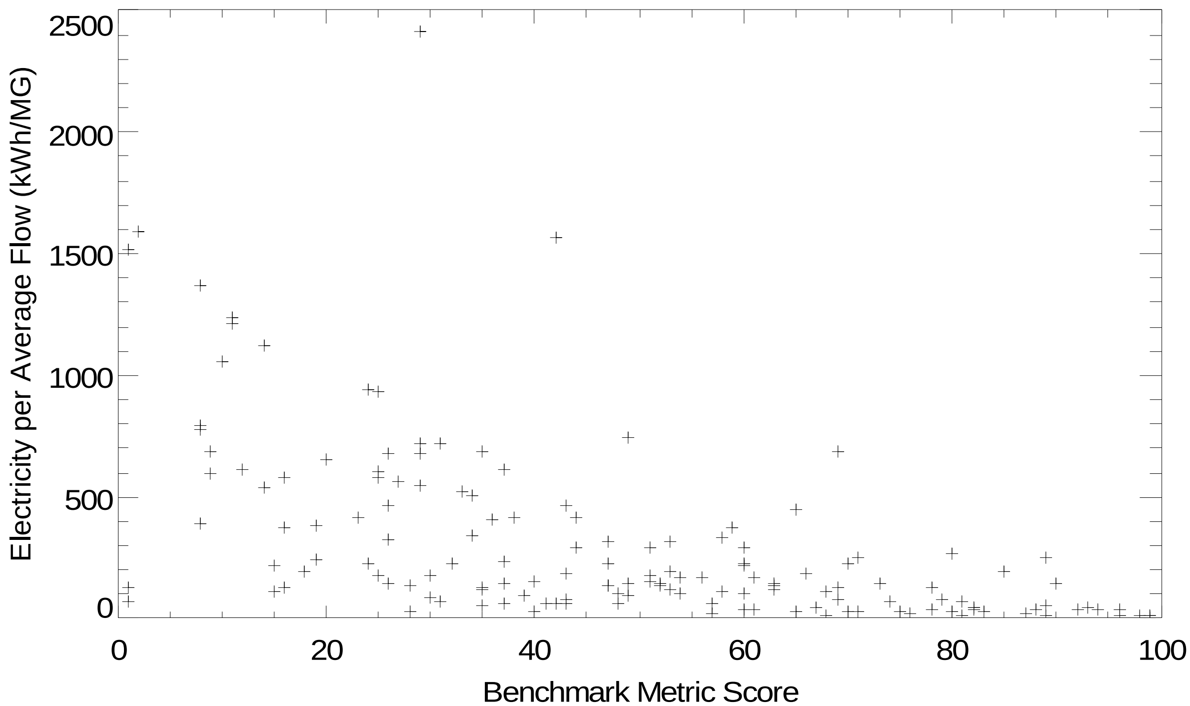

Figure 6.23 Wastewater Collection System Benchmark Score Comparison to Simple Energy Use Metric Based on Average Flow

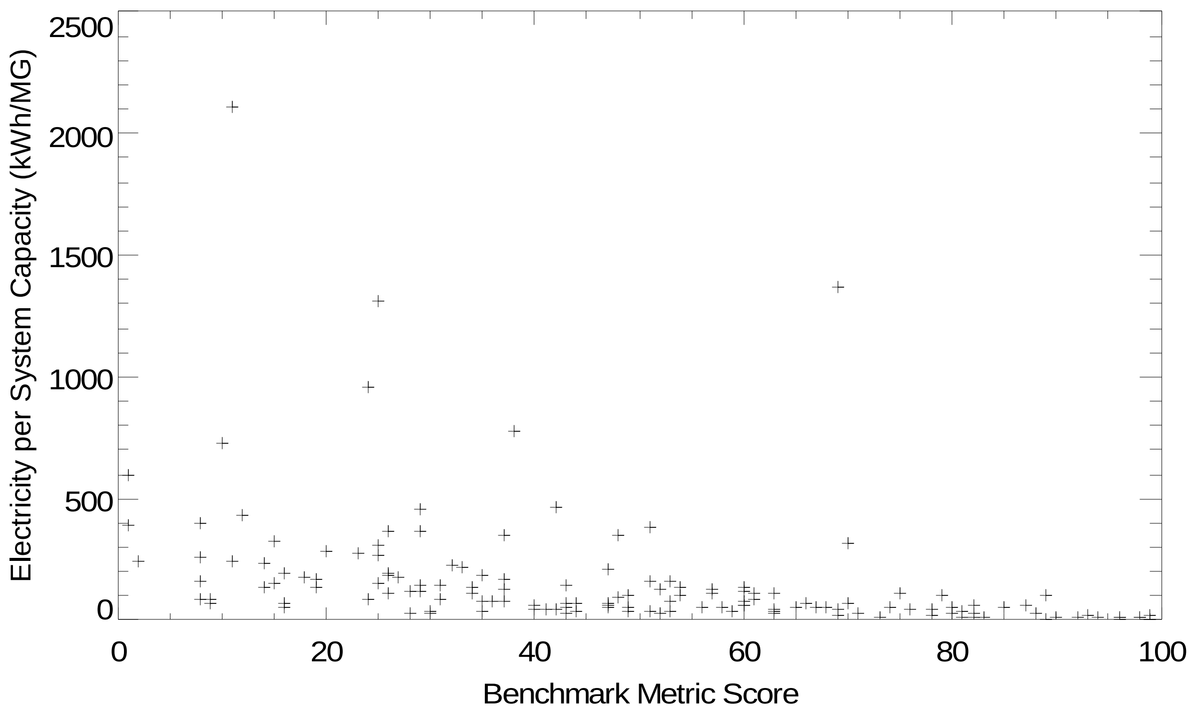

Figure 6.24 Wastewater Collection System Benchmark Score Comparison to Simple Energy Use Metric Based on Pumping Capacity

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Some cross-correlation between flow and installed pumping capacity exists. Thirty-nine surveys reported collection system pumping capacity below the average daily plant influent flow as indicated by the points above the diagonal line in Figure 6.25. These might represent mainly gravity fed plants.

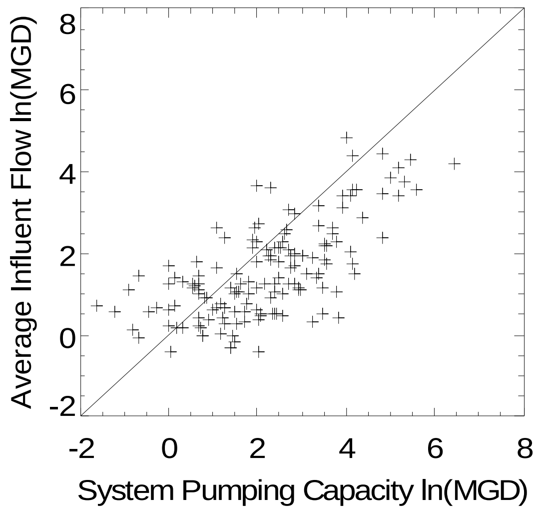

Figure 6.25 Wastewater Collection System Flow and Capacity Comparison

In general the collection system analysis is less robust than the treatment plant benchmark metric development. The collection system electricity use is less correlated to the characteristic parameters and the best model still suffers from larger errors and some bias with the lower energy using systems. The treatment plant energy use is more dominant at most utilities than collection system energy, as shown in Figure 6.26, making the treatment plant metric more valuable. The collection system analysis is presented here as an attempt to analyze the remaining energy use of a wastewater utility.

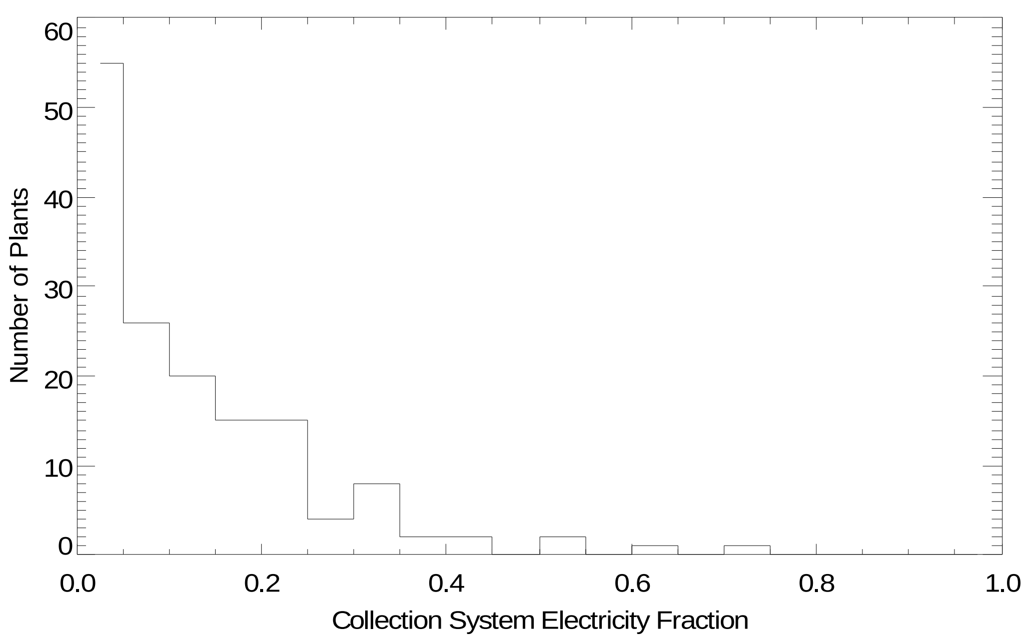

Figure 6.26 Wastewater Collection System Electricity Use Fraction

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CHAPTER 7
WASTEWATER TREATMENT ENERGY METRIC APPLICATIONS

NEW YORK SUB-METERED SITES

The New York State Energy Research and Development Authority "Energy Performance in Wastewater Treatment Plants through Sub-Metering" project (NYSERDA 2006a, 2006b) examined the energy use of sixteen plants in New York State in detail, sixteen of which were analyzed in this project. The plant sizes in the study ranged from 0.8 MGD to 120 MGD in design treatment capacity. The focus of the study was to characterize the energy consumption for each plant, and use the insight gained from the energy use patterns to determine the potential for energy savings. The range of different plant configurations and sizes is shown in Table 7.1.

Table 7.1 NYSERDA Wastewater Treatment Plant Sub-Metering Project Plant Type and Size

Plant	Design Capacity (MGD)	Wastewater Pumping[1]	Secondary Treatment Type[2]	Dewatering	Sludge Disposal	Other
FV	135	No	AAS	Mech.	Incineration	
OM	80	Yes	AAS	Mech.	Landfill	Anaerobic digester
AL	35	Yes	AAS	Mech.	Incineration	
TW	17	Yes	Pure O_2	Mech.	Incineration	
GJ	13.1	No	AAS	Mech.	Landfill	Cogeneration
OT	12.8	No	Trickling Filter	Mech.	Landfill	
IT	10	Yes	AAS	Mech.	Landfill	Cogeneration
CH	9.5	Yes	Trickling Filter	Mech.	Landfill	
AN	7.6	Yes	AAS	Mech.	Landfill	
BH	6	No	AAS	Mech.	Landfill	
CL	4.1	No	AAS	None	None	
WK	4	Yes	Oxidation Basin	Mech.	Landfill	
GI	3.5	Yes	Pure O_2	Mech.	Landfill	
SF	3.3	Yes	Trickling Filter/RBC	Mech. & Non-Mech.	Landfill	
CY	1.1	No	Single Batch Reactor	None	None	
MA	1	No	AAS	Mech.	Landfill	

[1] No indicates either gravity feed or force main with pumping outside of treatment plant
[2] AAS refers to Air Activated Sludge

Annual energy use, flow, and influent conditions, as well as treatment level were available for all sixteen sites. Information collected in the studies was used in the wastewater treatment plant metric. The resulting scores were compared to the knowledge of the actual

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operation of the treatment plants to ascertain the sensitivity of the metric to physical process variations.

Table 7.2 displays the sites examined, and the five parameters required by the treatment plant metric. Annual energy consumption, average flow and plant loading were taken directly from the plant sub-metering reports. The process entries were determined by the EPA 2000 Community Water Needs Survey, which provides the treatment classification for each plant. Electricity and natural gas consumption include only energy purchased from a utility, not fuel or electricity produced within the plant (by biogas or cogeneration).

Table 7.2 Test Sites' Treatment Plant Benchmark Metric Parameters

Plant	Electricity Use (kWh)	Natural Gas Use (therms)	Avg. Flow (MGD)	Influent BOD (mg/l)	Effluent BOD (mg/l)	Design Flow (MGD)	Fixed Film (1 = yes, 0 = no)	Nutrient Removal (1 = yes, 0 = no)
FV	27,350,852	1,374,628	96	134	14.7	135	-	-
OM	26,799,377	353,270	73.2	149.1	22	80	-	1
AL	10,446,539	553,163	22.9	160	3.2	35	-	-
TW	13,405,921	653,243	21.4	104	10.4	17	-	1
GJ	3,540,400	86,975	6.7	132	2.6	13.1	-	-
OT	1,582,880	-	10	136.9	21.6	12.8	1	-
IT	3,484,556	134,263	6.8	186	14.9	10.0	-	-
CH	1,562,220	44,413	5.7	85	10.2	9.5	1	1
AN	3,732,400	25,101	5.5	93.8	2.1	7.6	-	-
BH	1,663,934	-	4.8	90.5	5.4	6.0	-	-
CL	1,570,569	-	2.1	159.3	4.5	4.1	-	1
WK	2,495,483	-	2.8	140	7.0	4.0	-	-
GI	1,857,450	-	2.8	136.2	9.7	3.5	-	1
SF	1,246,050	33,832	2.1	127	10.2	3.3	1	-
CY	413,280	-	0.5	155	11.8	1.1	-	-
MA	563,920	6,347	0.3	260.4	4.6	1.0	-	-

Table 7.3 displays the benchmark scores for each site along with the intermediate energy adjustments used in the score calculations. Scores ranged from a low of 4 to a high of 95.

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Table 7.3 Test Sites' Treatment Plant Benchmark Metric Scores

Plant	Annual Source Energy (kBtu/yr)	Annual Source Energy ln(kBtu/yr)	Predicted ln(kBtu/yr)	Adjustment Factor (-)	Adjusted Energy Use ln(kBtu/yr)	Score
FV	444,493,827	19.912	19.818	1.113	17.885	43
OM	333,683,260	19.626	19.615	1.102	17.810	50
AL	172,655,790	18.967	18.948	1.064	17.818	49
TW	215,763,131	19.190	18.361	1.032	18.603	4
GJ	48,213,378	17.691	17.908	1.006	17.585	69
OT	17,569,968	16.682	17.364	0.976	17.100	95
IT	52,440,529	17.775	17.615	0.990	17.962	36
CH	21,892,975	16.902	17.083	0.960	17.611	67
AN	44,002,493	17.600	17.470	0.981	17.932	39
BH	18,469,667	16.732	17.106	0.961	17.411	82
CL	17,433,316	16.674	16.848	0.947	17.616	67
WK	27,699,861	17.137	16.827	0.945	18.128	23
GI	20,617,695	16.842	16.872	0.948	17.768	53
SF	17,298,935	16.666	16.168	0.908	18.348	11
CY	4,587,408	15.339	15.416	0.866	17.711	59
MA	6,910,080	15.748	15.554	0.874	18.023	31

These scores are compared among sites of similar sizes and discussed in light of the operational details known about the process from the sub-metering project. The following sections discuss the impacts of specific processes on the score and the consistency of the score relative to similar sites in the study.

Comparing Benchmark Scores

Large Plants (> 80 MGD design)

In Table 7.4 the two large plants (FV, and OM) have scores of 43, and 50 respectively. The two plants are comparable with respect to flow volumes and influent and effluent BOD levels, and both plants operate aerobic activated sludge systems.

Table 7.4 Large Plant Energy Use and Benchmark Scores

				Single Parameter Metrics		
Plant	**Annual Electricity Use (kWh/yr)**	**Annual Gas Use (therms/yr)**	**Score**	**Electricity (kWh/MG)**	**Natural Gas (therm/MG)**	**Electricity (kWh/lb BOD)**
FV	27,350,852	1,374,628	43	781	39	0.78
OM	26,799,377	353,270	50	1,003	13	0.95

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The FV plant uses gravity to flow influent through the plant, while the OM plant uses influent pumps located at the plant entrance to flow influent through the plant. Based on the results of the sub-metering projects, adding influent pumping to a treatment plant increases the overall electricity consumption by approximately 10%. The FV plant also operates a multiple hearth incinerator for final sludge disposal, increasing gas use.

The OM plant has a permitted treatment level of *Advanced Treatment I with Nutrient Removal*, while the FV plant is permitted at *Advanced Treatment I* only. Nutrient removal at the OM plant increases the score by 15 points. The OM plant operates anaerobic digesters as part of the solids treatment at the plant. The gas produced from the digester is used to offset natural gas purchases for heating the digester and for space heating of the plant buildings. The OM plant is offsetting approximately 730,000 therms/year of natural gas consumption with biogas production. This offset increases the score by 17 points. The OM plant uses land spreading for its final sludge disposal.

Table 7.5 summarizes the sensitivity of the metric to process changes at these plants. Some hypothetical plant variations are presented, representing the observed differences between these two plants. Adding an estimate for influent pumping to the FV plant impacts both the benchmark score and single parameter kWh/MG metric for the plant. Forcing the OM plant to purchase all the fuel to run its anaerobic digester would reduce the benchmark score. In either case, only one of the single parameter metrics (electricity or natural gas consumption per MG) would change. The benchmark takes the entire energy picture into account when comparing the plants.

Table 7.5 Example Sensitivity of Metric to Process Changes – Large Plants

				Single Parameter Metrics	
Plant	**Annual Electricity Use (kWh/yr)**	**Annual Gas Use (therms/yr)**	**Score**	**Electricity (kWh/MG)**	**Natural Gas (therm/MG)**
FV	27,350,852	1,374,628	43	781	39
FV with influent pumping	30,085,837 (+10%)	1,374,628	38 (-5)	859	39
OM	26,799,377	353,270	50	1,003	13
OM with purchased gas for digester	26,799,377	1,083,270 (+730,000)	33 (-17)	1,003	41

Medium/Large Plants (8 – 20 MGD design) and Large Plants (20 - 80 MGD design)

Six plants are in the medium/large and large category, and cover the largest range of benchmark scores in Table 7.6. Scores for plants this size range from 4 to 95. Two of the plants are trickling filter plants (OT and CH), with substantially lower electricity consumption and higher benchmark scores than most of the other plants in this category. The two largest plants (AL and TW) use incinerators for sludge disposal – resulting in higher natural gas consumption than the other sites in this size category.

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Table 7.6 Medium/Large Plant Energy Use and Benchmark Scores

					Single Parameter Metrics		
Plant	Note	Annual Electricity Use (kWh/yr)	Annual Gas Use (therms/yr)	Score	Electricity (kWh/MG)	Natural Gas (therm/MG)	Electricity (kWh/lb BOD)
AL		10,446,539	553,163	49	1,250	66.2	0.96
TW	PO	13,405,921	653,243	4	1,716	83.6	2.20
GJ		3,540,400	86,975	69	1,469	35.6	1.36
OT	TF	1,582,880	-	95	434	-	0.45
IT		3,484,556	134,263	36	1,404	54.1	0.98
CH	TF	1,562,220	44,413	67	751	21.3	1.20

TF = Trickling filter plant, PO = Pure Oxygen

The average daily flow for the TW plant indicates that the plant typically operates over its design capacity. The TW plant also is using substantially higher amounts of natural gas per MG of wastewater flow than the AL plant, which also performs incineration. These factors combined are resulting in a substantially lower score than any other plant in the data set. The low score is consistent with the high energy metrics of kWh/Mg, therm/MG and kWh/lb BOD. Without processes-level knowledge, it is impossible to begin to understand the reason for the score.

The OT plant is a trickling filter plant that is in need of a plant upgrade. Many portions of the process are no longer in use because of disrepair, and the level of BOD removal of the plant is low (84%) compared to the other plants in the data set (88%+). The lower level of treatment and lack of operating process equipment are resulting in an elevated benchmark score for this plant. While the benchmark score incorporates BOD loading and trickle filtration it can not capture all the impact associated with a large deviation from typical treatment levels. This site illustrates that some assessment of the process conditions is still needed to effectively interpret the metric.

The AL plant uses 443,085 therm/year of its natural gas use to operate the incinerator. If the plant chose to landfill all of its sludge rather than incinerate, the annual natural gas consumption would decrease directly by this amount. Removing this natural gas consumption would increase the plant's benchmark score by 25 points as shown in Table 7.7.

The IT and GJ plants use a cogeneration system fueled by biogas to offset a portion of the plant electricity consumption. Heat from the cogeneration system is used to heat the digester. Assuming the cogeneration system produces sufficient heat to maintain the digester temperature, eliminating cogeneration at the plants would only result in the plants purchasing more electricity from the utility – resulting in a lower benchmark score. Operating the cogeneration system at the IT plant raises the benchmark score by 13 points, and raises the score by 16 points at GJ.

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Table 7.7 Example Sensitivity of Metric to Process Changes – Medium/Large Plants

				Single Parameter Metrics	
Plant	Annual Electricity Use (kWh/yr)	Annual Gas Use (therms/yr)	Score	Electricity (kWh/MG)	Natural Gas (therm/MG)
AL	10,446,539	553,163	49	1,250	66
AL without incinerator	10,446,539	110,078 (-443,085)	74 (+25)	1,250	13
GJ	3,540,400	86,975	69	1,469	36
GJ without cogen	4,501,760 (+961,360)	86,975	52 (-17)	1,841	36
IT	3,484,556	134,263	36	1,404	54
IT without cogen	4,606,712 (+1,122,156)	134,263	20 (-16)	1,856	54

Medium Plants (4 –8 MGD design)

Table 7.8 shows the four plants in the medium plant category. Scores for plants this size are split with two plants with lower scores (WK – 23, AN – 39), and two plants with higher scores (BH – 82, CL – 67).

Table 7.8 Medium Plant Energy Use and Benchmark Scores

				Single Parameter Metrics		
Plant	Annual Electricity Use (kWh/yr)	Annual Gas Use (therms/yr)	Score	Electricity (kWh/MG)	Natural Gas (therm/MG)	Electricity (kWh/lb BOD)
AN	3,732,400	25,101	39	1,859	13	2.44
BH	1,663,934	-	82	950	-	1.34
CL	1,570,569	-	67	2,049	-	1.59
WK	2,495,483	-	23	2,442	-	2.20

The WK and AN plants are complete plants, including wastewater pumping, secondary treatment, and mechanical sludge dewatering. The AN plant includes a large aerobic digester that is used for odor control.

The BH and CL plants do not incorporate all the processes included in the other two plants. The BH plant does not have wastewater pumping. The CL plant does not have wastewater pumping nor perform any solids processing. Solids at CL are separated at the clarifiers and pumped to a nearby treatment plant.

The CL plant has a permitted effluent quality of *Advanced Treatment I with Nutrient Removal*, but the nitrification/denitrification process at the back end of the plant is no longer

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being performed. Had the score been determined by including nutrient removal the score would have increased from 67 to 81 as shown in Table 7.9.

The sub-metering projects indicated that solids processing was on the order of 25% of the total plant energy consumption. If the CL plant performed solids processing, rather than pumping the solids to the adjacent plant, the annual electricity consumption of the plant would increase to approximately 1.9 Million kWh/year, and the benchmark score would decrease 21 points. Wastewater pumping would increase the plant energy consumption by 10% and would decrease the score 9 points. When combined, these modifications would reduce the CL plant score 29 points, resulting in a score similar to that of the AN plant. This example illustrates that there are still factors impacting the energy use that are not adequately represented in the benchmark metric.

Table 7.9 Example Sensitivity of Metric to Process Changes – Medium Plant

				Single Parameter Metrics	
Plant	**Annual Electricity Use (kWh/yr)**	**Annual Gas Use (therms/yr)**	**Score**	**Electricity (kWh/MG)**	**Natural Gas (therm/MG)**
CL	1,570,569	-	67	2,049	-
CL with pumping	1,727,569 (+157,000)	-	58 (-9)	2,254	-
CL with solids processing	1,962,569 (+392,000)	-	46 (-21)	2,560	-
CL with both pumping and solids processing	2,119,569 (+549,000)	-	38 (-29)	2,765	-
BH	1,663,934	-	82	950	-
BH with pumping	1,829,924 (+166,000)		75	1,044	

The BH plant operates a contact stabilization process (a variation of aerobic activated sludge). Based on the metric score, this plant is farther towards the area of best practices than the other plants in this size category. Even if the Bethlehem plant's energy consumption were increased to account for onsite wastewater pumping, the plant's score would only decrease 7 points.

Small Plants (Under 4 MGD design)

Table 7.10 shows the four plants in the small category. Three of the plants in this category returned mid-level benchmark scores (between 31 and 59), but one plant (SF) has a score of only 7.

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Table 7.10 Small Plant Energy Use and Benchmark Scores

				Single Parameter Metrics		
Plant	Annual Electricity Use (kWh/yr)	Annual Gas Use (therms/yr)	Score	Electricity (kWh/MG)	Natural Gas (therm/MG)	Electricity (kWh/lb BOD)
GI	1,857,450	-	53	1,850	-	1.75
SF	1,246,050	33,832	11	1,625	44	1.67
CY	413,280	-	59	5,219	59	1.82
MA	563,920	6,347	31	2,177	-	2.45

Similar to the medium sized plant category, some plants in the small category do not perform all the treatment processes performed at larger plants. The CY plant does not perform any solids processing, nor does it have onsite wastewater pumping. Solids are pumped to an aerobic digester where they are thickened and then hauled to a larger plant for dewatering and further processing. Lack of complete solids processing at the CY plant is presumably leading to its elevated benchmark score. Adding 35% plant electricity use for wastewater pumping and solids processing places the plant in line with scores from other plants with a more all-inclusive treatment as shown in Table 7.11.

Table 7.11 Example Sensitivity of Metric to Process Changes – Small Plant

				Single Parameter Metrics	
Plant	Annual Electricity Use (kWh/yr)	Annual Gas Use (therms/yr)	Score	Electricity (kWh/MG)	Natural Gas (therm/MG)
CY	413,280	-	59	5,219	59
CY with pumping and solids processing	557,928 (+35%)	-	28 (-31)	3,058	-

The SF plant is a trickling filter/rotating biological contactor plant, but the energy use of this plant is on the order of a standard aerobic activated sludge plant. It is unclear from the information collected during the sub-metering project why the energy use for this plant is high relative to its peer group.

Evaluating Energy Savings Potential and Impact on Metric Scores

As part of the sub-metering projects, a list of energy conservation measures (ECM) were developed for each plant, and the annual impact of the combined ECMs was determined. This section reviews the impact of the energy reduction from the ECMs on the benchmark scores

Table 7.12 displays the potential savings for each plant, as well as the relative savings percentage and simple payback period. The payback period provides an indication of the level of complexity of a series of ECMs. Payback periods on the order of five years typically are representative of changes in equipment without substantial redesign at the plant level.

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The average proposed savings for these plants was 20%, and increased the benchmark score 3-5 points. The two plants with largest proposed savings of 20% and 26% also had a higher impact on the benchmark score, increasing the score by 15 points. Plants with extraordinary savings percentages (such as GI) have major process changes proposed. In the case of the GI plant, the proposal would operate the pure oxygen portion of the plant using only liquefied oxygen – eliminating substantial energy consumption from the pressure swing absorption oxygen compressor.

Table 7.12 Proposed Energy Savings and Benchmark Metric Score

	Proposed ECM Savings					
Plant	**(kWh/yr)**	**(%)**	**ECM Payback Period (years)**	**Original Benchmark Score**	**ECM Benchmark Score**	**Difference**
FV	-2,205,000	-8%	5.7	43	47	4
OM	-3,568,000	-13%	4.9	50	60	10
AL	-660,000	-6%	7.5	49	53	4
TW	-871,000	-6%	8.0	4	5	1
GJ	-306,000	-9%	8.1	69	75	6
IT	-168,000	-5%	6.3	36	39	3
CH	-401,000	-26%	3.1	67	84	17
AN	-671,000	-18%	2.2	39	56	17
BH	-315,600	-19%	2.8	82	92	10
CL	-462,300	-29%	18.6	67	90	23
WK	-495,100	-20%	8.0	23	42	19
GI	-976,690	-53%	7.4	53	98	45
SF	-101,137	-8%	0.9	11	14	3
CY	-217,000	-53%	10.9	59	99	40
MA	-177,500	-31%	2.8	31	65	34

The benchmark can be useful in quickly flagging proposed ECMs that might have overstated savings estimates. The CL, GI, and CY plants all move above the 90th percentile after the ECM estimates are applied. This may prompt further review of the ECMs to ascertain if the level of savings proposed is feasible.

The benchmark also allows for the determination of the energy savings required to achieve a desired ranking. After the reduction in energy from the ECMs was accounted for, eight of the sites in Table 7.12 still did not exceed the 50th percentile. Using the metric, and a goal of reaching the 50th percentile, the required change in source energy for these plants was computed and displayed in Table 7.13. On average these plants required an additional 18% source energy reduction on top of the prescribed ECMs to achieve a 50th percentile score.

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Table 7.13 Required Source Energy Reduction to Reach Target Score

	Energy Change to Reach Target Score		
Plant	**50**	**75**	**90**
FV	-9%	-34%	-51%
OM	-1%	-28%	-46%
AL	-2%	-28%	-46%
TW	-56%	-68%	-75%
GJ	-	-8%	-29%
OT	-	-	-
IT	-15%	-36%	-51%
CH	-	-10%	-30%
AN	-12%	-34%	-49%
BH	-	-	-15%
CL	-	-10%	-30%
WK	-27%	-44%	-57%
GI	-	-22%	-39%
SF	-39%	-53%	-63%
CL	-	-16%	-33%
MA	-18%	-36%	-49%

WASTEWATER TREATMENT PLANT METRIC APPLICATION – SHEBOYGAN

The Sheboygan, Wisconsin wastewater treatment plant management actively pursues energy conservation. The plant has implemented several energy project upgrades and made four years of energy data available along with project upgrade information. Table 7.14 summarizes the annual energy use, operating characteristics and resulting energy metric over four years. The score has increased as projects have been implemented and remained constant before the changes.

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Table 7.14 Sheboygan Wastewater Treatment Plant Energy Metric Score Over Time

	Year	2003	2004	2005	2006
Utility Annual Energy Use	**Units**				
Electricity	kWh	5,731,200	5,536,800	5,234,400	5,224,800
Natural gas	therms	148,758 (estimated)	148,758	88,338	80,883
Total Source Energy Use	(kBtu/yr)	78,864,000	76,706,000	67,156,000	66,286,000
Utility Characteristics					
Design Daily Influent Flow	MGD	18.4	18.4	18.4	18.4
Average Daily Influent Flow	MGD	9.3	11.2	9.3	11.6
Average Influent BOD	mg/l	246	203	222	204
Average Effluent BOD	mg/l	12	14	6	5
Fixed Film – Trickle Filtration Process ?	yes (1) or no (0)	0	0	0	0
Treatment Includes Nutrient Removal ?	yes (1) or no (0)	1	1	1	1
Energy Metric Score		74	74	89	93

The projects are described in the Table 7.15. The pump and blower motor upgrades are evident in the annual electricity use, with a decrease of 500,000 kWh. The 60,000 therm reduction in natural gas is due to the boiler replacement and interconnection with the house boiler.

The cogeneration impact on electricity is not included as the billed electricity and does not change. Biogas is sold to the utility for onsite power generation and recovered heat is used in the sludge heating process. Had the on-site generation been offset by the billed electricity, the benchmark score would have reached 99. This example illustrates that sites with on-site generation using biogas should have higher scores. However depending on the use of the score, one might want to remove the impact of the on-site generation. For example, to make a comparison of plant based solely on operations, the on site power generation should be added into the billed electricity use. This eliminates the cogeneration aspect on the score and allows comparison on an equal basis.

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Table 7.15 Sheboygan Wastewater Treatment Plant Energy Projects

	Project Completion Date	Project Energy Impacts: Electricity (kWh)	Project Energy Impacts: Natural Gas (therms)
Pump Station - Increased motor efficiency - Installed variable frequency drives - new (2) 125 hp motors	Dec-04	-94,800	0
Aeration System - Blower replacement - new (2) HW blowers and motors	Dec-05	-752,120	0
Sludge Boiler Replacement - new (2) 3.5 MMBTU boilers - interconnection with house boilers	Nov-05	0	-32,000
Plant Influent Pump - Increase motor efficiency - Installed variable frequency drives - new (2) 200 hp motors	Jan-06	-157,033	0
Cogeneration - new (10) 30 kW micro-turbines - biogas sold to produce electricity - heat recovery for sludge heat	Feb-06	-2,300,000	-86,000
CUMULATIVE IMPACT		-3,303,953	-118,000

WASTEWATER TREATMENT PLANT METRIC APPLICATION SUMMARY

The applications show examples of the metric for actual plants. They give additional details about the plant operations that relate to the benchmark score.

The New York examples bring to light characteristics that have an impact on energy use, but were not included in the metric. Plant pumping as opposed to gravity feed is one such parameter. The sub-metering quantified the portion of electricity used for plant pumping at several plants. This amount of electricity also roughly corresponded to the difference in score between plants with and without plant pumping. The survey queried about collection system pumping, but could be improved by explicitly identifying if influent pumping is included in the treatment plant electricity use.

Another parameter for which the sub-metering projects could quantify the energy use was sludge processing. The survey queried about incineration and land application as well as sending sludge for offsite processing. The modeling was unable to find the off-site processing of sludge a significant factor. Incineration was significant but was not deemed to be an external factor imposed on the treatment plant, so it was not included in the model.

The impact of cogeneration was illustrated in the Sheboygan example. The impact of the cogeneration is implicitly included in the metric as it was not included in the model. This formulation allows sites with on-site generation to score higher. The impact of cogeneration can be removed from the score, if one desires to make comparison only on an operational basis. By

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adding the site generated electricity into the billed electricity the impact of cogeneration is removed.

The Sheboygan example also shows how energy project upgrades can change the benchmark score over time. The metric has a built in range (1-100) useful for assessing how much potential energy savings is achieved by individual projects. The time factor suggests that as more utilities apply upgrades the metric will eventually become outdated. Reviewing and redeveloping the metric distribution based on future energy and characteristics data should realign utility scores to the current state of treatment plants.

The examples show that the metric accomplishes the goal of using a single parameter to rank the energy use of a treatment plant. There are other characteristics that would be desirable to include (plant pumping, sludge processing), but they weren't found to have significant correlation to energy use in the model development or they were judged to be independent choices of the designers and operators.

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CHAPTER 8
CONCLUSIONS AND RECOMMENDATIONS

The project set out to develop metrics that allowed comparison of energy use among wastewater treatment plants and water utilities. These comparisons were to account for factors that have made comparisons challenging in the past. The project has produced a scoring method that accomplishes this goal.

A survey effort created a representative data set of energy use and utility characteristics for wastewater utilities exceeding 1.5 MGD of influent flow and for water utilities serving populations of 10,000 or more. The final filtered analysis data sets consisted of 266 wastewater treatment plants and 125 water utilities.

Correlations of utility characteristics to energy use were evaluated through multiple linear regression analysis to arrive at models that best described the observed variation in energy use among the utilities. These models form the basis for producing a single score that compares energy use among utilities.

The wastewater treatment plant model relates energy consumption to: average influent flow, influent BOD, effluent BOD, the ratio of average influent flow to design influent flow, the use of trickle filtration, and nutrient removal. Other parameters are also significantly correlated to energy use: on-site electricity generation, sludge incineration/sludge land application and pure oxygen. These parameters were not included in the model used for the metric so the metric would contain their impact.

The collection system energy use was separately studied, finding that collection system energy every use was related to average influent flow, pumping horsepower, and number of pumps. The correlation of energy use to system characteristics was less robust than the treatment plant analysis. Collection system energy use was generally less than 25% of a utility's energy use with most utilities reporting less than 5% of total energy being used in the collection system.

The water utility model relates energy consumption to: total flow, total pumping horsepower, distribution main length, distribution elevation change, raw pumping horsepower, and the amount of purchased flow. Unaccounted for flow was also found to be significant, but was not included in the metric model, so that its effect would still be reflected in the metric. Energy use of production, treatment and distribution were also correlated to utility characteristics. Production energy use related best to: total flow, purchased flow and raw water pumping horsepower. Treatment energy use related best to: total flow, purchased flow, raw water pumping horsepower and treatment for oxidation, iron removal, direct filtration and ozone. Distribution energy use related best to: total flow, discharge pumping horsepower, elevation change in the distribution system, pressure filtration, residual gravity thickening, and residual lagoon dewatering thickening.

Judgments were made about parameters to include in the model, based on the expected use of the metrics. Certain parameters that correlated well to energy use were excluded from the model so their impact would be credited in a comparison metric. The desire is for the metric scores at the highest level to correspond with the impact of potential best practices. Scores can be high because of low energy operational practices or because of low energy process choices. The key to the judgment was to assess if the parameters were imposed on the utility or the characteristic was an independent choice. For instance on-site electricity generation from biogas can substantially reduce net energy use and increase the score. If, however, the on-site generation had been included in the metric, the score would not have reflected the benefit that

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this choice brought in energy use. As example applications illustrated, the impact of on site generation can be added back into the score after-the-fact if one wants to make a comparison without the bias of on site generation. It was demonstrated that it is relatively easy, knowing the energy impact of any process, to develop a modified score that accounts for or removes the impact of a specific process.

A side use of the models is to characterize the typical energy use attributable to specific characteristics or processes on an empirical basis. While not explicitly studied in this project the models implicitly include the average energy impact of characteristics. This knowledge might be useful in quantifying perceptions widely held about energy intensive processes, or in focusing study of best practices toward these areas of high energy use correlation. This observation illustrates one use of the data set and/or model beyond the metric development project.

The metric score is generated from the distribution of energy use observed in the sample. The model predicts the average energy use for a specific set of characteristics. It is the deviation of the actual energy use from the predicted energy use that determines the score when adjusted to the distribution of modeled energy use from the sample.

Having an energy use distribution is a key feature of the metric, giving it a context in which to make comparisons. The metric score itself (1-100) gives a relative score like a grade. A score of 75 means the utility is in the quartile of the lowest energy users. Only 25% of all utilities use less energy. By using the distribution, one can take a target score and determine how much energy use must change to reach the new level. This feature gives a plant operator perspective on how much better energy performance could become. It can be useful in assessing energy project upgrades savings estimates as the score can be calculated with the proposed project impacts. Any proposed project that greatly increases the score, such that the utility would become one of the lower energy users among its peers, warrants thorough examination and verification of the projected savings. The metric gives a means to assess the effectiveness of a large project by allowing a comparison of before and after energy use without the confounding impacts of changes in main flow and loading conditions.

The metric score can also serve as an initial screening when identifying plants or utilities where energy conservation efforts should be applied. This could be useful to large utilities with multiple facilities or more likely to industry organizations looking to identify places to illustrate best practices (high scores) or utilities where efficiency upgrades might be readily apparent (low scores). As the application examples illustrate, though, the metric should be complimented with specific site information, as there are still conditions that can skew the score (e.g. a high score due to operating at lower than typical treatment levels that aren't fully captured by the BOD data in the wastewater model). The screening might also be the first basis for identifying utilities to investigate for best practices examples. It would be a natural follow-up to determine why the highest and lowest scoring utilities have their scores.

The metric is based on a snapshot of the industry in 2004. Eventually the data used to develop the models will not reflect the current state of operations. Treatment requirements evolve over time, growing more stringent and possibly requiring more energy intensive processes. After a broad acceptance of energy intensive processes, such as membranes or UV, are adopted by the industry, it would be prudent to update the data on which the model and subsequent metric is based. The EPA ENERGY STAR Buildings Benchmarking system is updated every four years due to the availability of a statistical sampling of the building stock at that time. The water and wastewater industry are routinely surveyed, so it might be most

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effective to add or revise energy data queries in the existing surveys. Changes occur slowly so a five year or more time-frame between updates might be sufficient.

The project focused on collection of a representative data set and creation of a benchmarking scoring metric. As a convenience and example of potential use, the benchmark scoring distribution was packaged into a simple spreadsheet tool. Follow-on work by the EPA promises to make the results of this research readily available to utilities throughout the industry. EPA's ENERGY STAR program is committed to helping businesses and organizations protect the environment through superior energy efficiency. EPA offers proven resources to help organizations develop strategic approaches to energy management. One of the key resources offered through ENERGY STAR is the national energy performance rating system. The EPA has adopted the analysis in this project as the basis for their implementation of water and wastewater utility benchmark tools in their ENERGY STAR program. This adaptation will provide a web accessible tool through their portfolio manager system. The portfolio manager is a tool to track and manage energy use information that is tied to the metric benchmark scoring system. This system will allow users to easily track energy use and automatically track energy performance once the simple utility characteristics identified in the models are entered. It will also facilitate a more advanced version of the model that would be difficult to handle in a spreadsheet, such as the inclusion of weather data into the wastewater model based on zip code, so the user will not have to track and enter heating and cooling degree days. The collaboration with the EPA leverages this research to bring its application efficiently to industry members.

The EPA is in the process of reformulating all of their models to represent the energy utilization index (EUI) directly without the need for log transformations used in the current models. The log transformations were required to handle the large order of magnitude ranges in flows across the range in utilities studied. While this log transformation simplified the statistical analysis, it reduced the intuitive meaning of the model coefficients. This improvement in model structure gives the parameters of the model physical meaning assigning a kBTU/MG value directly to each model parameter. For instance in the new formulation, flow rate might represent 800 kWh/MG of energy use, while changes in elevation might represent 2 kWh/MG/ft and water main lengths might account for 3 kWh/MG/mile. These parameters would be additive in the model to produce the total projected energy use on a kBTU/MG basis (converted from site kWh to source kBTU). With the model in engineering units without mathematical transformations, the coefficients have direct physical meaning to the users of the model. In this way the models assign average energy use values for key utility characteristics and give users a sense of relative impact of key utility characteristics.

The rating is a valuable tool that utilities can use to track energy performance over time, target specific facilities for energy efficiency upgrades, and evaluate the success of energy efficiency projects. To the extent the models include loading characteristics, the benchmarks will adjust performance for load variations, weather, etc over time. This normalization feature makes year over year comparisons possible that could allow the operators to access their energy management program effectiveness over time. The industry can use the metrics to identify utilities that exhibit high energy efficiency (high scores). These utilities could be studied as potential sources of best practices, both in process configuration and in management practices. Individual utilities can also use the metric to assess the impact of energy efficiency projects and programs. Before a project is implemented the anticipated impact can be used to generate a new score – a target. The actual operation can then be tracked and compared to the target to verify

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that the project effectiveness was achieved. The metric gives the means to remove factors that might have masked the project impact, such as increased flow or loading.

Beyond the metric, the project has also produced a rich data set of characteristics about the water and wastewater utilities. As the models were developed for the specific purpose of rating performance, some characteristics parameters that were correlated to energy use were discarded. These parameters were thought to be voluntary features that particular utilities had undertaken for energy efficiency. Their impact should affect their score, presumably improving it beyond their peers that did not implement the feature (e.g, on site power generation, capture and use of biogas, etc). These data, particularly those characteristics correlated to energy use might be useful to researchers or program developers in quantifying what a particular process or design option has had on energy use in the industry.

Having metrics is a first step toward energy management. The metric itself does not tell how to improve. It merely gives a relative assessment of energy performance. In order to manage energy there must be a measure of energy use. Many utilities track their energy use and some relate energy use to operations. Internally for tracking over time, the metrics provide a convenient way to track energy performance, accounting for variations in loading. Externally it provides a comparison to other utilities and a framework in which to make the comparison. The score is a measure of performance that must be implemented within a management practice of setting targets, making improvements and assessing feedback to become an effective energy management tool.

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APPENDIX A
LITERATURE REVIEW - WATER
January 2005

Objective

The purpose of this literature review is to identify the background information needed to frame the creation of energy benchmark metrics for water utilities. It seeks to identify existing data sets for preliminary review paying particular attention to how processes are characterized. The identification of energy intensive processes and issues that lead the requirement of energy intensive treatment methods are also of interest.

Water Overview

The Environmental Protection Agency has compiled information on water utilities from regulatory monitoring pertaining mostly to water quality and from surveys seeking background to assess the economic impact of regulation changes. No energy data are collected.

The 2000 EPA Community Water Survey notes the following water statistics:

- There are 52,000 community water systems.
- 4,000 utilities serve populations above 10,000 covering 85% of the total US population.
- 9,000 utilities serve populations above 3,300 covering 93% of the total US population.

Water utilities produce 51 billion gallons per day. While 74% of water systems use ground water they produce only 30% of the total. 11% of water systems use surface water and produce 50% of the total. The remaining 15% of water systems purchase water and account of the remaining 20% of the total production. The ultimate source of purchased water is not noted in EPA summaries. 10% of water production is unaccounted for (unbilled).

Utility Characterization and Existing Data

Water utilities are usually characterized by their water source – ground or surface. The few statewide studies that have surveyed energy use present average electricity use grouped by ground water and surface water source utilities.

Burton estimates electricity use at a utility by process across utilities of various sizes. The largest single user of electricity in a water utility is pumping. Almost all the electricity use in a ground water utility is pumping, often with over 85% of electricity used for pumping in surface water utilities (Table A.1).

Table A.1 Relative Energy Use Projections

Ground Water Utilities (1,800 kWh/MG)		Surface Water Utilities (1,400 kWh/MG)	
Well Pumping	33%	Raw Water Pumping	9%
Chlorination	1%	Treatment	5%
Booster Pumping	66%	Treated Water Pumping	86%

(Based on data in Burton 1996)

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A Wisconsin study found energy use ranging from 300 kWh/MG to 3,800 kWH/MG with the central 50% of utilities ranging from 1,400 kWh/MG to 1,800 kWh/MG for 204 ground water utilities. Surface water utility energy use from 67 sites ranged from 600 kWh/MG to 2,600 kWh/MG with the central 50% of utilities ranging from 800 kWh/MG to 1,600 kWh/MG.

With the majority of energy use from pumping, the literature presents little information of categorizing or classifying pumping and distribution systems. One parameter often record is main length. Figure A.1 shows an example of main length density distribution. From fundamental engineering the energy use is proportional to flow and total head and inversely proportional to motor, pump and drive efficiency. Discussions of energy opportunities note minimizing head (reducing friction losses and minimizing height differences between clearwell storage and distribution storage) and maximizing pump and motor efficiencies. Flow control through discharge valves, variable speed drives and multiple pump staging is also mentioned. One would expect the static head to be a function of service area topography and system design, while dynamic head would be a function of pipe length, pipe diameter (velocity) and pipe roughness. None of these parameters is easily characterized across an entire distribution system.

The AWWA Water:\Stats database provides information related to distribution covering: the area served, population served, water use by sector, customer line pipe material, distribution pipe material, distribution length, storage volume, and storage type. As expected, the distribution main length is correlated to the water production rate (Figure A.2).

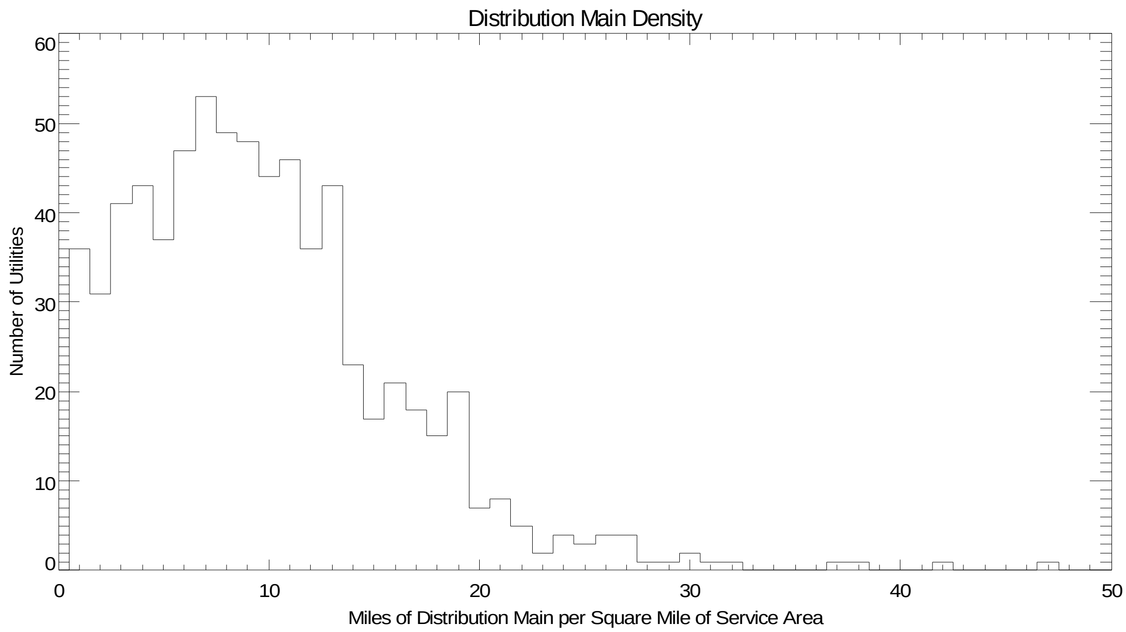

Figure A.1 AWWA Water:\Stats Distribution Main Density

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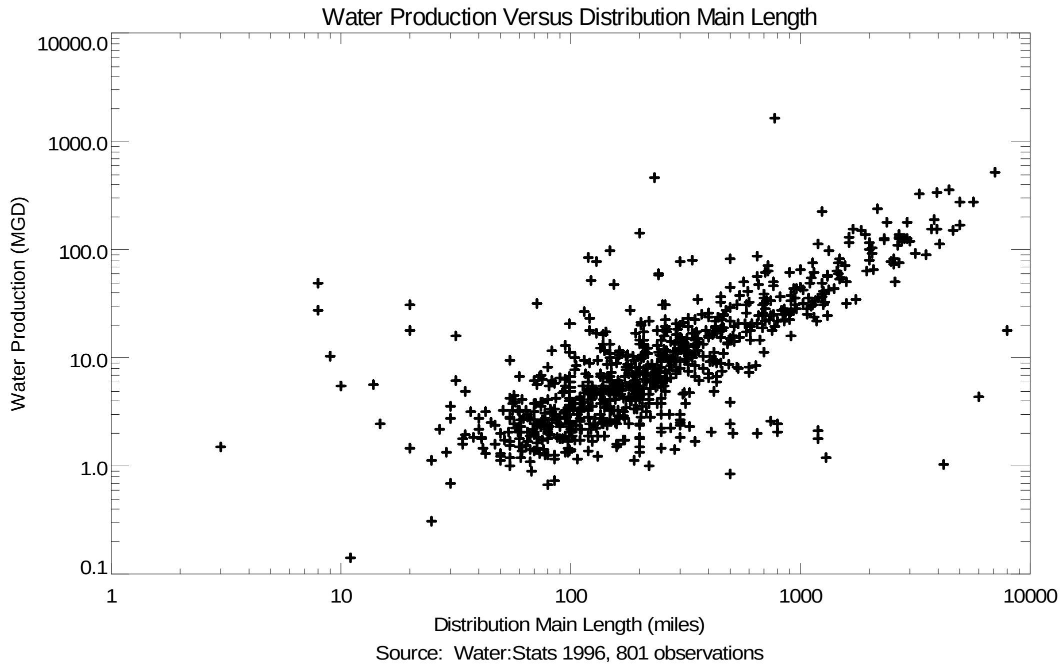

Figure A.2 AWWA Water:\Stats Water Production vs Distribution Main Length

Extensive data are available on water treatment types and their prevalence (Table A.2), but treatment processes are typically listed for a plant rather than used to create broad treatment categories. Some studies note specifically the energy increases due to membrane filtration, or ozone disinfection. Surveys collect information on treatment objective (Table A.3), the existence of various processes (Table A.4), and raw and finished water quality. Again these summaries are often segregated only by the broad class of ground or surface water utility.

Table A.2 AWWA Water:\Stats Treatment Processes

Process	Ground Water	Surface Water
Aeration	133	56
Ozone	8	23
UV	2	1
Filtration	15	50
Micro Strain	1	1
Slow Sand Filter	4	11
Rapid Sand Filter	57	126
Dual Media Filter	90	305
D. E. Filter	2	6
Pressure Filter	66	13
Any of the above filtration	165	392

Notes:
- Utilities with at least one plant with indicated process
- Data only note existence of process. They do not distinguish between no response and no use of the process.

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Table A.3 EPA 2000 Community Water System Survey Treatment Objectives

Percentage of Plants with Each Treatment Objective		
Treatment Objective	**Ground Water Plants**	**Surface Water Plants**
Algae Control	1%	34%
Corrosion Control	26%	58%
Oxidation	11%	21%
Iron or Manganese Removal/Sequestration	45%	32%
Fluoridation	21%	49%
Taste and Odor	8%	49%
TOC Removal	1%	31%
Particulate/Turbidity Removal	9%	86%
Organic Contaminant Removal	2%	19%
Inorganic Contaminant Removal	4%	17%
Radionuclides Removal	2%	5%
Other	15%	18%

Table A.4 EPA 2000 Community Water System Survey Treatment Schemes

Percentage of Plants Using Various Treatment Schemes		
Treatment Practice	**Ground Water Plant**	**Surface Water Plants**
Disinfection Only	55%	11%
Disinfection and other Chemical Addition Only	16%	1%
IX, AA, Aeration	14%	4%
Filters	8%	12%
Direct Filtration	0%	14%
Conventional Filtration	0%	35%
Membrane Filters	0%	2%
Softening	6%	21%

Treatments are classified in the following manner in an Iowa energy survey:

- Disinfection
- Fluoridation
- Iron removal
- Cation/Anion Exchange
- Bi-Product Management

The Iowa data are dominated by small water utilities serving populations of less than 10,000. Energy use averaged 2,360 kWh/MG for treatment and 380 kWh/MG for distribution.

Water treatment processes are classified by complexity mainly for setting minimal staffing education to operate plants in some localities. A Canadian classification formula (Table A.5) assigns points for each process at a plant and divides the points into four classifications.
(http://www.irac.pe.ca/legislation/EPA-DrinkingWaterandWastewaterFacilityOperatingRegulations.asp)

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Table A.5 Example Classification System for Water Treatment Facilities

TABLE 1
FACILITY CLASSIFICATION SYSTEM

Facility	Units	Small Facility	CLASS I	CLASS II	CLASS III	CLASS IV
WT	Range of Points	N/A	30 or less	31-55	56-75	76 & greater
WD*	Population served	0-100	100 to 1,500	1,501 - 15,000	15,001 - 50,000	50,001 & greater
WWT	Range of points	N/A	30 or less	31 - 55	56 - 75	76 & greater
WWC*	Population served	N/A	100 to 1,500	1,501 - 15,000	15,001 - 50,000	50,001 & greater

*Simple "in-line" treatment (such as booster pumping or preventive chlorinating or odor control) is considered an integral part of a distribution or collection system.

TABLE 2
POINT SYSTEM CLASSIFICATION OF
WATER TREATMENT FACILITIES (WT):

A drinking water supply facility with only chlorination added is considered a distribution system, not a water treatment facility. The addition of any chemical, other than chlorine, to a public drinking water supply facility shall be considered water treatment and the person in direct responsible charge should use this rating worksheet to determine the classification of the facility. Each unit process shall have points assigned only once.

Item	Points
Size (2 points minimum to 20 points maximum)	
Maximum population or parts served, peak day (1 point minimum to 10 points maximum)	1 point per 10,000 persons or fraction
Design flow average day or peak month’s part flow average day, whichever is larger (1 point minimum to 10 points maximum)	1 point per 4,546 m^3/d or fraction
Water supply sources	
Groundwater	3
Groundwater under the influence of surface water	5
Surface water	5
Average raw water quality varies enough to require treatment changes 10% of the time	2 - 10
• Little or no variation	0
• High variation. Raw water quality subject to periodic serious industrial waste pollution	10
Raw water quality is subject to or has elevated:	
• Taste and/or odor levels	3
• Color levels	3
• Iron and/or manganese levels	5
• Turbidity levels	5
• Coliform and/or fecal counts	5
• Algal growths	5
Raw water quality is subject to periodic:	
• Industrial and commercial waste pollution	5
• Agricultural pollution	5
• Urban runoff, erosion, and storm water pollution	3
• Recreational use (boating, fishing, etc.)	2
• Urban development and residential land use pollution	2

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Table A.6 Example Classification System for Water Treatment Facilities (continued)

Chemical treatment/addition process			
	Fluoridation		5
	Disinfection		
		• Gaseous chlorine	5
		• Liquid or powdered chlorine	5
		• Chlorine dioxide	5
		• Ozonization (on-site generation)	10
	pH adjustment* (Calcium carbonate, carbon dioxide, hydrochloric acid, calcium oxide, calcium hydroxide, sodium hydroxide, sulfuric acid, other)		5
	Stability or corrosion control (Calcium oxide, calcium hydroxide, sodium carbonate, sodium hexametaphosphate, other)		10
Coagulation and flocculation process			
	Chemical addition (1 point for each type of chemical coagulant added, maximum 5 points) (Aluminium sulfate, bauxite, ferrous sulfate, ferric sulfate, calcium oxide, bentonite, calcium carbonate, carbon dioxide, sodium silicate, other)		5
	Rapid mix units		
		• Mechanical mixers	3
		• Injection mixers	2
		• In-line blender mixers	2
	Flocculation tanks		
		• Hydraulic flocculators	2
		• Mechanical flocculators	3
Clarification/sedimentation process			
	Horizontal-flow (rectangular basins)		5
	Horizontal-flow (round basins)		7
	Up-flow solid-contact sedimentation		15
	Inclined-plate sedimentation		10
	Tube sedimentation		10
	Dissolved air flotation		30
Filtration process			
	Single media filtration		3
	Dual or mixed media filtration		5
	Microscreens		5
	Diatomaceous earth filters		5
	Cartridge filters		5
	Slow sand filters		5
	Direct filtration		5
	Pressure or greens and filtration		20
Other treatment processes			
	Aeration		3
	Packed tower aeration		5
	Ion-exchange/softening		5
	Lime-soda ash softening		20
	Copper sulfate treatment		5
	Powdered activated carbon		5

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Table A.7 Example Classification System for Water Treatment Facilities (continued)

Special processes (reverse osmosis, electrodialysis, other)				15
Residuals disposal				
	Discharge to lagoons			5
	Discharge to lagoons and then to raw water source			8
	Discharge to raw water source			10
	Disposal to sanitary sewer			3
	Mechanical dewatering			5
	On-site disposal			5
	Land application			5
	Solids composting			5
Facility characteristics				
	Instrumentation			
			• The use of SCADA or similar instrumentation systems to provide data with no process operation	0
			• The use of SCADA or similar instrumentation systems to provide data with limited process operation	2
			• The use of SCADA or similar instrumentation systems to provide data with moderate process operation	4
			• The use of SCADA or similar instrumentation systems to provide data with extensive or total process operation	6
	Clearwell size less than average day design flow			5

Water utility energy use data are not readily available across the industry. The AWWA Water:\Stats survey includes energy cost data from a sample of over 800 utilities serving populations greater than 10,000 (Figure A.3). 70% of the energy cost variation is explained by the total water production. The correlation can be improved up to 83% by including the water source (surface, or ground), storage volume, raw water quality and select treatment processes (Table A.8).

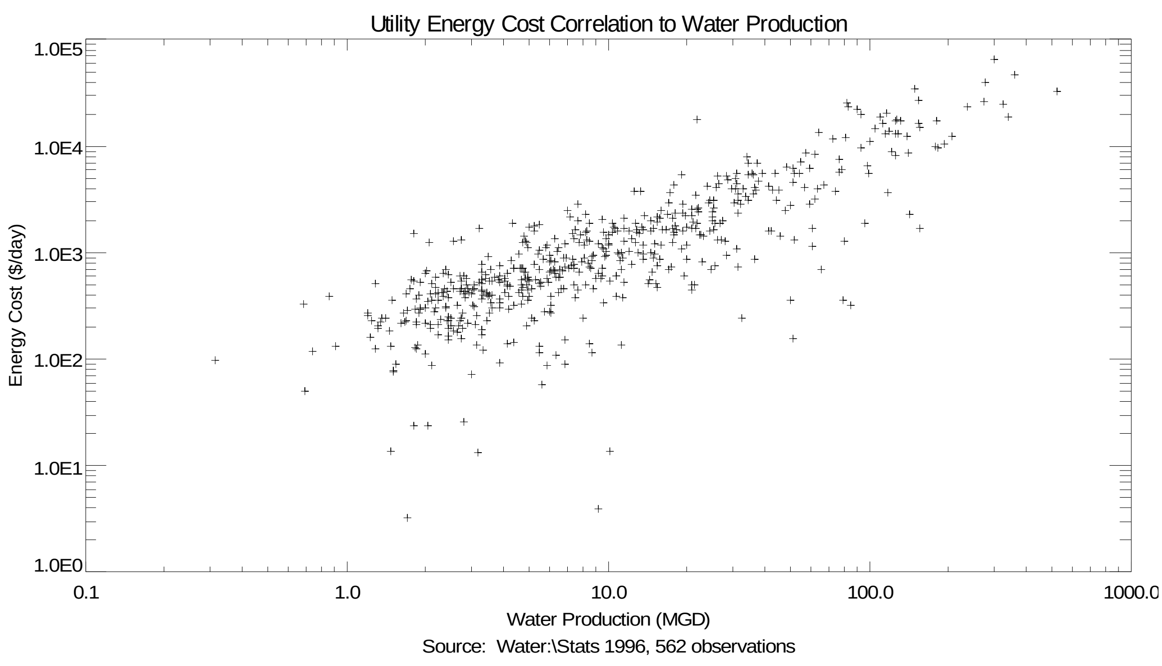

Figure A.3 AWWA Water:\Stats Energy Cost vs Water Production

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Multiple Linear Regression Results Relating Total Energy Cost to Flow, Water Source (ground, surface, purchased), Storage Volume, Raw Water Total Dissolved Solids, Raw Water Turbidity, Surface Water Aeration, Surface Water Rapid Sand Filtration, Dual Media Filtration, and Ozone Disinfection.

Table A.6 Model Relating Energy Cost to Utility Characteristics

Regression Statistics	
Multiple R	0.91
R Square	0.83
Adjusted R Square	0.83
Standard Error	872486
Observations	562

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	16	2.10231E+15	1.31E+14	172.6075	2.9943E-201
Residual	546	4.15632E+14	7.61E+11		
Total	562	2.51794E+15			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Production_GW	159.5	6.14	25.97	2.03E-97	147	172
Production_SW	70.3	6.00	11.72	1.88E-28	59	82
Production_PW	48.8	13.40	3.64	0.000298	22	75
Storage	-313.6	123.35	-2.54	0.011279	-556	-71
TDS_raw	133.6	127.35	1.05	0.294568	-117	384
Turbidity_raw	4563.1	1749.22	2.61	0.009339	1127	7999
Aeration_SW	-482184.4	188287.78	-2.56	0.010708	-852041	-112327
Areation_SW x Production_SW	80.2	6.74	11.90	3.39E-29	67	93
RapidSand_SW	132205.0	113908.01	1.16	0.2463	-91547	355956
RapidSand_SW x Production_SW	-32.1	5.67	-5.66	2.42E-08	-43	-21
DualMedia_GW	266646.9	120191.42	2.22	0.02693	30553	502741
DualMedia_GW x Production_GW	-97.1	8.94	-10.85	5.61E-25	-115	-79
DualMedia_SW	-61310.3	82946.20	-0.74	0.460129	-224243	101622
DualMedia_SW x Production_SW	29.8	7.03	4.23	2.69E-05	16	44
Ozone_SW	-214866.4	257070.52	-0.84	0.403618	-719835	290102
Ozone_SW x Production_SW	11.7	7.51	1.56	0.120014	-3	26

Assuming an average electricity price of \$0.06/kWh suggests energy use ranging as much as 300 kWh/MG to 3,500 kWh/MG as shown in Figure A.4.

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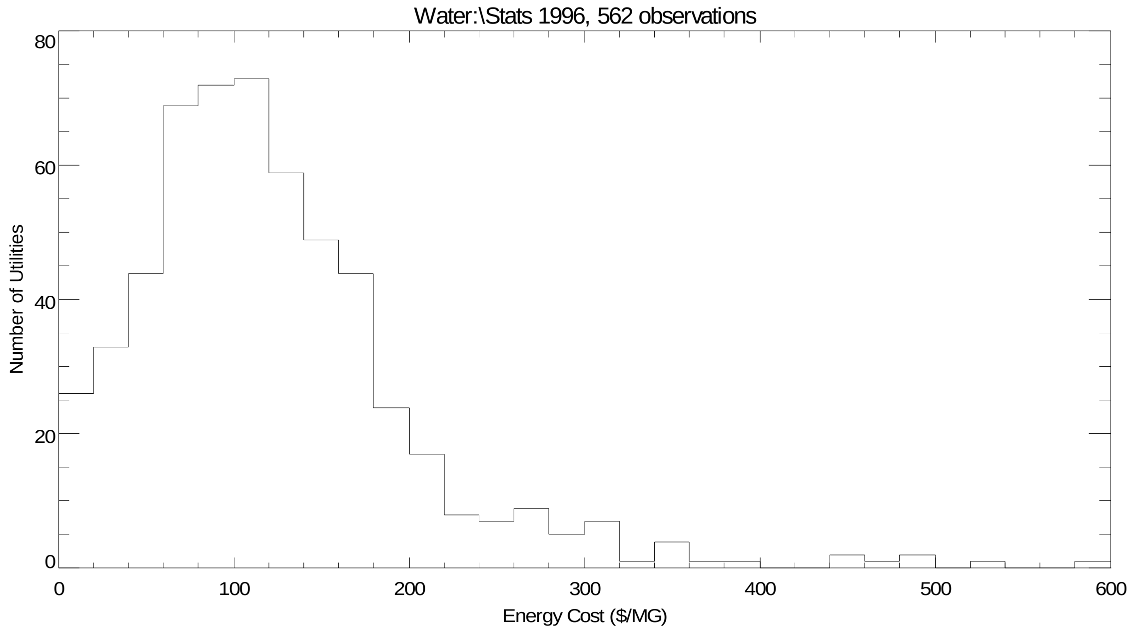

Figure A.4 AWWA Water:\Stats Energy Cost Distribution

Efficiency Upgrades

Many of the references come from the electric power industry so they cover motors, pumps and lighting equipment upgrades as well as scheduling to limit peak electric demand. References from the water treatment industry discuss some process optimization. Industrial references concentrate on pumping system design, operation and maintenance. The following is a brief compilation listing efficient practices or upgrades.

- use premium efficient motors
- apply variable frequency drives to vary load to account for over sizing at part-load
- pump optimization to match highest efficiency with actual load with proper impeller
- use efficient lighting
- HVAC – equipment efficiency and building insulation
- SCADA – monitor energy performance of equipment and control to limit peak demand, and schedule pumps for most efficient selection to match load.

An EPRI presentation at an ACEEE conference noted the following impacts of energy efficiency upgrades and the potential additional energy use of emerging treatment processes.

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Energy Impact of new treatments (due to new regulations)

UV Disinfection	70-100 kWh/MG
Membranes	
Nanofiltration	1,800 kWh/MG
Ultrafiltration	1,000 kWh.MG
Low pressure microfiltration	100 kWh/MG
Ozone	170 kWh/MG

Summary

The existing wastewater data sets are useful in both evaluating the impact of potential parameters on energy use, defining treatment classification schemes, defining the population of interest, and in selecting survey participants. Unfortunately there is little descriptive information on distribution systems to correlate with the limited energy data. Our characterizations are best developed from engineering principals.

There are adequate examples of treatment plant descriptions from previous surveys. The AWWA data suggest that some treatment characteristics and raw water quality characteristics will be useful in characterizing energy use of treatment plants.

Bibliography

USEPA Community Water System Survey, 2000
http://www.epa.gov/safewater/cwssvr.html

The EPA periodically surveys water utilities for the purpose of developing background information for regulations. The 2000 survey gathered characteristics of 1,200 utilities out of 52,000 identified systems. The data are classified by both volume of water produced and size of population served. Characteristics on the source, treatment, storage and distribution of the utilities were collected. No energy data were collected. The survey instruments along with discussion of sample design are included.

USEPA Drinking Water Needs Survey, 816-F01-001, 2001
http://www.epa.gov/safewater/needs.html

The EPA surveyed 4,000 water utilities in 1999 to characterize infrastructure needs. They surveyed the largest 1,111 utilities (serving more than 40,000) and sampled one third of the medium size utilities. They conducted onsite interviews at 599 systems serving fewer than 3,300. Transmission and distribution are noted as the areas with the largest need, with treatment the next largest need.

UEPA Safe Drinking Water Information System (SDWIS)
http://www.epa.gov/enviro/html/sdwis/sdwis_query.html
http://www.epa.gov/enviro/html/technical.html (complete access, but restricted)

This online data base contains basic descriptive information for every water system including source and population characteristics served as well as contact information. Complete access is available but is restricted to government employees and EPA contractors. Public reports include only Name, County, Population, Primary Source, and Water System ID.

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Water:\Stats, American Water Works Association, 1996

This periodic survey includes characteristic and operational data on 898 utilities and 1,162 treatment plants. Information is included on water source, raw and finished quality, treatment processes and electric energy cost.

Elliott, Energy Use at Wisconsin's Drinking Water Utilities, ECW Report 222-1, 2003
http://www.ecw.org/prod/222-1.pdf

This report developed an energy baseline for water utilities in Wisconsin based on data collected from all utilities obtained from the Public Service Commission. It characterizes the average energy use and cost by water source and discusses the impact of ozone and membrane filtration on energy use. Energy use ranged from 1,000 to 1,800 kWh/MG for the central 50% of utilities, with cost ranging from 6.6 to 13.2 cents/1000 gallons for the same group.

Sauer, P., Kimber, A., *Energy Consumption and Costs to Treat Water and Waste Water in Iowa*, Iowa Association of Municipal Utilities, November 2002
http://www.iamu.org/main/studies_reports/reports.htm

The report summarizes the methods and results from a state-wide survey effort of water and wastewater utilities. The survey included nine surface water utilities and 317 ground water utilities. Five responding utilities served a population greater than 10,000. The survey found that the mean 2,770 kWh/MG utility electricity use was dominated by treatment at 85% of the total.

Water/Wastewater Cost Analysis Tool, Iowa Association of Municipal Utilities
http://65.112.125.101/ww%2Dcat/

The WW-CAT website allows access to the IAMU survey data as a comparison for individual utilities. It asks for characteristics and then presents data from the survey that is comparable. Survey data are summarized by category and are not available for individual sites.

Burton, F. 1996. *Water and Wastewater Industries Characteristics and Energy Management Opportunities*, Report CR-106941, Electric Power Research Institute

This widely cited reference provides a primer on water and wastewater utilities for electric utility staff. It discusses the impacts of specific technologies on energy use: motor efficiency, variable frequency drives, optimized pump selection, storage, peak clipping with generators, instrumentation and control, ozone, and pump efficiency tests. It also offers an overview of the characteristics of the industry and trends in regulations that will impact energy use. It discusses treatment processes and lists their relative energy intensities. It also states typical energy use metrics of 1,410 kWh/MG for surface water and 1,820 kWh/MG for ground water.

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***Best Practices for Energy Management*, Awwa Research Foundation, 2003**

This report summarizes energy information (management practices and usage) gathered from 24 water and wastewater utilities. It shows a wide variety of energy intensities from 50 to 450 $/MG and energy cost ranging from 2% to 35% of operating costs. The survey mainly covered energy management practices.

***Roadmap for the Wisconsin Municipal Water and Wastewater Industry*, Focus on Energy, 2002**

http://www.ecw.org/prod/ww_roadmap.pdf

This report outlines topics of interest for the water and wastewater industry in Wisconsin. Its background section summarizes, from other report, energy use in the industry – Burton 1996, Elliot 2992). It presents best practice energy efficiency opportunities from broad categories of motors, and pumping.

***Market Research Report: Pacific Northwest Water and Wastewater Market Assessment*, Northwest Energy Efficiency Alliance, 2001**

http://www.nwalliance.org/resources/reports/79.pdf

This report summarizes energy use of facilities by process type. It discusses energy savings opportunities and the frequency of their implementation based on survey data. It also discusses characteristics of the industry and how these characteristics facilitate or inhibit the adoption of energy saving opportunities. Energy characteristics are adapted from Burton 1996.

***Summary Report for California Energy Commission Energy Efficiency Studies*, EPRI, Palo Alto, CA: 2001. WO-6710.**

http://www.energy.ca.gov/pier/iaw/reports/2003_09_26_Appendix_2_7.pdf

This report covers energy assessments in four water and wastewater plants in California. A brief summary of the plant treatment processes along with flow and energy data are presented with a listing of upgrades and their impacts.

***Energy Audit Manual for Water/Wastewater Facilities*, Energy Commission Report CR-104300, 1994**

http://www.cee1.org/ind/mot-sys/ww/epri-audit.pdf

This report guides utility staff in energy audit background relevant to water and wastewater utilities. It discusses typical energy efficiency upgrade options by process. It recognizes that pumping in surface water plants is 70% or more of total energy use, so it emphasized motor, pump and drive efficiency. Mixing and backwashing is also discussed, including the impact on electric demand. Ozone is noted as possibly increasing plant energy use by 20% with an intensity of 300 kWh/MG. The use of storage to minimize on-peak demand and energy use is also considered. Ground source systems are noted as having little treatment, with almost all energy used for pumping. Water distribution can also have a large impact on energy use depending on elevation changes and booster pump needs.

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***Consortium Benchmarking Methodology Guide*, AwwaRF, 2003**
http://www.awwarf.org/research/topicsandprojects/execSum/PDFReports/2621_CBGuide.pdf

This report discusses benchmarking approaches as they can be applied to the water and wasterwater industry. It discusses the definitions of metric, process, and practices benchmarking, stressing the goal of identifying exemplary performance and then adopting improvements in one's own organization.

Carns K. *Bringing Energy Efficiency to the Water & Wastewater Industry: How Do We Get There?*, presentation to Water & Wastewater Energy Roadmap Workshop in Washington DC, Electric Power Research Institute – Global Energy Partners for the American Council for an Energy Efficient Economy 2004.
http://www.aceee.org/industry/carns.pdf

This presentation summarizes water utility energy use as an average of 1,500 kWh/MG, breaking down at 350 kWh/MG for raw water pumping and treatment, and 1,150 kWh/MG for distribution. It estimates energy savings potential of 5% to 20% from load shifting, efficiency motors, variable speed drives and optimized control systems. It notes added energy use from increased regulations in treatment. Energy use increase ranges from 100 kWh/MG for UV disinfection, 1,800 kWH/MG for nanofiltration, 1000 kWh/MG for ultrafiltration, 100 kWh/MG for low pressure microfiltration, and 170 kWh/MG for ozone.

***Quality Energy Efficiency Retrofits for Water Systems*, P400-97-003, Report CR-107838, Electric Power Research Institute, American Water Works Association Research Foundation, State of California Energy Commission, 1997**

This report discusses the implementation issues involved with scheduling to shift electrical demand, process changes that reduce backwash frequency as well as maximize storage use, motor efficiency, pump impellers, variable frequency drives, SCADA, HVAC, and lighting.

***Development of Energy Consumption Guidelines for Water/Wastewater*, Focus on Energy, 2003**
http://www.energybenchmark.org/Articles/WFOEc.pdf

This report focuses mainly on wastewater plant design and operation issues, but includes energy assessments from two water utilities. Pumping is the largest energy consumer. The report discusses the pumping sequencing and control. One of the plants had membrane filtration and noted that the process used 18% of the treatment plant energy, while conventional filters used 5%.

Olsen, S., Larson, A., *Opportunities and Barriers in Madison, Wisconsin: Understanding Process Energy Use in a Large Municipal Water Utility*
http://www.cee1.org/ind/mot-sys/ww/mge2.pdf

This study of a single large utility noted that its energy intensity was above state averages by $182,000 per year on a cost basis. Savings potential was identified by deep well rehabilitation, variable frequency drives, distribution pump controls, and energy efficient motors.

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***Quality Energy Efficiency Retrofits for Water Systems*, Report CR-107838, Electric Power Research Institute, 1997**

This document summarizes implementation issues for specific energy efficient upgrades for motors, drives, pumps, SCADA, lighting, operation and maintenance, and scheduling.

US Department of Energy, Office of Industrial Technology, *Improving Pumping System Performance: A Sourcebook for Industry*, January 1999
http://www.oit.doe.gov/bestpractices/pdfs/pump.pdf

This reference discusses the technical issues associated with pumping systems concentrating on identifying and applying energy savings upgrades. It covers matching design with application, maintenance, multiple pump systems, impeller trimming, variable frequency drives, and common problems. It also contains an extensive list of resources for more information.

Alliance to Save Energy, *Watergy: Taking Advantage f Untapped Water and Energy Savings in Municipal Water Systems*, 2002
http://www.watergy.org/resources/publications/watergy.pdf

This document presents best practices that promote water and energy efficiency. It covers management and program level approaches to water and energy savings. The report highlights improvements made at several utilities around the world. From a management perspective the report discusses metrics for determining performance of water systems and advocates system monitoring. Monitoring characteristics include – flow rate, pressure, input power, pump speed and pump head. Metrics include cost per flow, flow per kWh, flow per person, flow per connection, and flow delivered per flow produced. It mentions a World Bank led effort in several countries to benchmark utilities against each other and share operating practices. The report includes 17 case studies of utilities implementing management upgrades to address both water and energy efficiency.

Iowa Association of Municipal Utilities, *Tap into Savings: How to Save Energy in Water and Wastewater Systems*, August 1998
http://www.iamu.org/main/DSM/water/waterreport.htm

This report provides energy efficiency case studies at seven utilities. It discusses pumps, motors, control systems, and disinfection.

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APPENDIX – B
LITERATURE REVIEW - WASTEWATER
January 2005

Objective

The purpose of this literature review is to identify the background information needed to frame the creation of energy benchmark metrics for wastewater utilities. It seeks to identify existing data sets for preliminary review, paying particular attention to how processes are characterized. The identification of energy intensive processes and issues that lead the requirement of energy intensive treatment methods are also of interest.

Wastewater Overview

The Environmental Protection Agency has extensive data on wastewater treatment plants as each plant is required to have a permit under the national pollution discharge elimination system. Data typically available from the EPA include contact information, population size, plant flows, and treatment processes. The NPDES permit compliance program collects monthly data on treatment parameters (BOD, TSS, and various contaminant concentrations and process parameters). No energy data are collected.

There are 16,255 municipal wastewater treatment plant permits on file with the EPA. Data summarized in Table B.1 from the 2000 community watersheds needs survey shows that the 3,198 plants having flows above 1 MGD account for 92% of the total flow.

Table B.1 EPA 2000 Community Water Needs Survey - Number of Treatment Facilities by Flow Range

Treatment Facilities in Operation in 2000		
Existing Flow Range (MGD)	**Number of Facilities**	**Total Existing Flow (MGD)**
0.001 to 0.100	6,583	290
0.101 to 1.000	6,462	2,339
1.001 to 10,000	2,665	8,328
10,001 to 100,000	487	12,741
100,001 and greater	46	11,201
Other	12	---
Total	16,255	34,899

(From USEPA 2003)

Treatment Characterization and Existing Data

The purpose of an energy metric is to facilitate the comparison of plants among their peers. Past studies have noted the wide range of energy use and differing treatment processes. In a gross sense, all plants are peers in that they process influent to a set of specifications, but there is little to be gained from comparing a low energy intensive, high land intensive rural lagoon system to a high energy intensive, low land intensive urban activated sludge plant. On

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the other extreme, noting detailed differences in treatment processes will show that all plants are unique (e.g. the EPA database has ten different process entries for activated sludge variations). With a finer level of treatment segregation there are fewer peers available to make a reasonable comparison.

One of the challenges in making a metric useable is including an appropriate amount of characteristics data to define appropriate peers. A common treatment plant characterization defines the process options as primary, secondary and tertiary (or advanced). This is the level of treatment summarized in the EPA Community water sheds needs survey of 2000 (Table B.2). It is also the level of treatment distinguished in the American Metropolitan Sewage Association Financial survey (AMSA 2002).

Table B.2 EPA 2000 Community Water Needs Survey Number of Treatment facilities by Level of Treatment

Treatment Facilities in Operation in 2000				
Level of Treatment	**Number of Facilities**	**Present Design Capacity (MGD)**	**Number of People Served**	**Percent of U.S. Population**
Less than Secondary	47	1,023	6,426,062	2.3
Secondary	9,156	19,268	88,221,896	32.0
Greater then Secondary	4,892	22,165	100,882,207	36.6
No Discharge	1,938	2,039	12,283,047	4.5
Partial Treatment	222	563	---	---
Total	16,255	45,058	207,813,212	75.4

(From USEPA 2003)

The AMSA survey included energy cost data for 132 wastewater utilities along with process parameters. The survey has only total utility energy costs rather than plant level utility data, but the data show no difference in energy costs between utilities with plants having only secondary treatment compared to utilities with all plants having tertiary treatment (Figure B.1).

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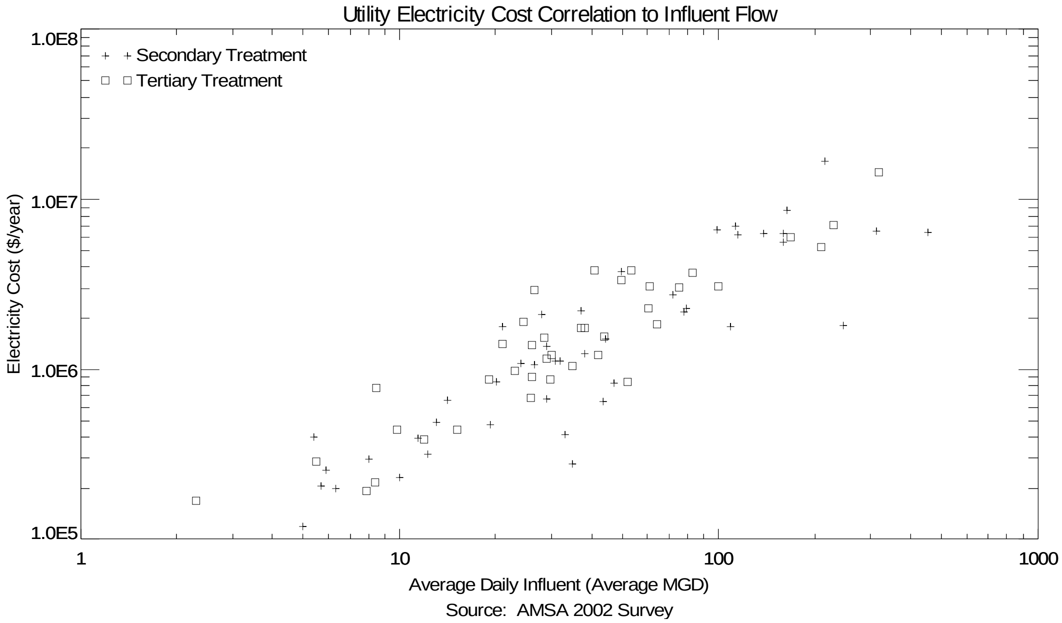

Figure B.1 AMSA 2002 Survey Electricity Cost vs Influent Flow

While the AMSA data identifies individual utilities, it does not identify individual plants, nor does it present energy cost data at a facility level. Therefore it is not feasible to try to cross correlate the AMSA cost data with the EPA treatment process data to assess impacts of particular treatment processes.

Energy audit guides and efficiency studies note that the largest single energy user is secondary treatment for the activated sludge process. One refinement to the initial classification of Primary/secondary/tertiary treatment levels is to note the use of advanced primary treatment and flow equalization. Advanced primary treatment increases solid removal in the low energy primary process, thus avoiding some of the higher energy secondary process. Flow equalization can reduce energy cost by maintaining a more constant process flow and thus reduce peak demand.

Classification by the secondary process is used in several energy assessment reports. A characteristics report (Burton 1996) estimates energy use by process for four treatment type classifications across a range of design plant flows (Table B.3 and Table B.4), resulting in the following comparisons:

- Trickle Filter (393 – 1,811 kWh/MG net)
- Activated Sludge (678 – 2,236 kWh/MG net)
- Advanced w/o nitrification (838 – 2,596 kWh/MG net)
- Advanced with nitrification (1,208 – 2,950 kWh/MG net)

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Table B.3 Relative Energy Use Projections for a 20 MGD Plant

Trickling Filtration		Activated Sludge		Advanced without Nitrification		Advanced with Nitrification	
Trickling filters	30%	Aeration (diffused air)	50%	Aeration (diffused air)	40%	Aeration (diffused air)	30%
Dissolved air flotation	20%	Dissolved air flotation	13%	Dissolved air flotation	13%	Biological nitrification	20%
Wastewater pumping	20%	Anaerobic digestion	12%	Anaerobic digestion	10%	Dissolved air flotation	10%
Anaerobic digestion	14%	Wastewater pumping	11%	Wastewater pumping	10%	Anaerobic digestion	10%
Lights & Buildings	8%	Lights & Buildings	5%	Filter feed pumping	6%	Wastewater pumping	8%
				Lights & Buildings	5%	Filter feed pumping	5%
						Lights & Buildings	4%

(Based on data in Burton 1996)

Table B.4 Relative Energy Use at a 7.5 MGD Secondary Plant

Activated sludge	55%
Primary P.S. Clarifier	10%
Heating	7%
Solids dewatering	7%
Raw wastewater pumping	5%
Secondary Clarifiers RAS	4%

(Based on data in California Energy Commission 1994)

With aeration such a large proportion of the plant energy use, it would be advisable to classify the aeration process (e.g. mechanical, coarse bubble, fine bubble, etc).

An energy Audit Manual published by EPRI gives ranges for energy use for various plant treatment types and states that plants at the low end of the range can be considered efficient while plants at the high end should consider a detailed process audit (Figure B.2).

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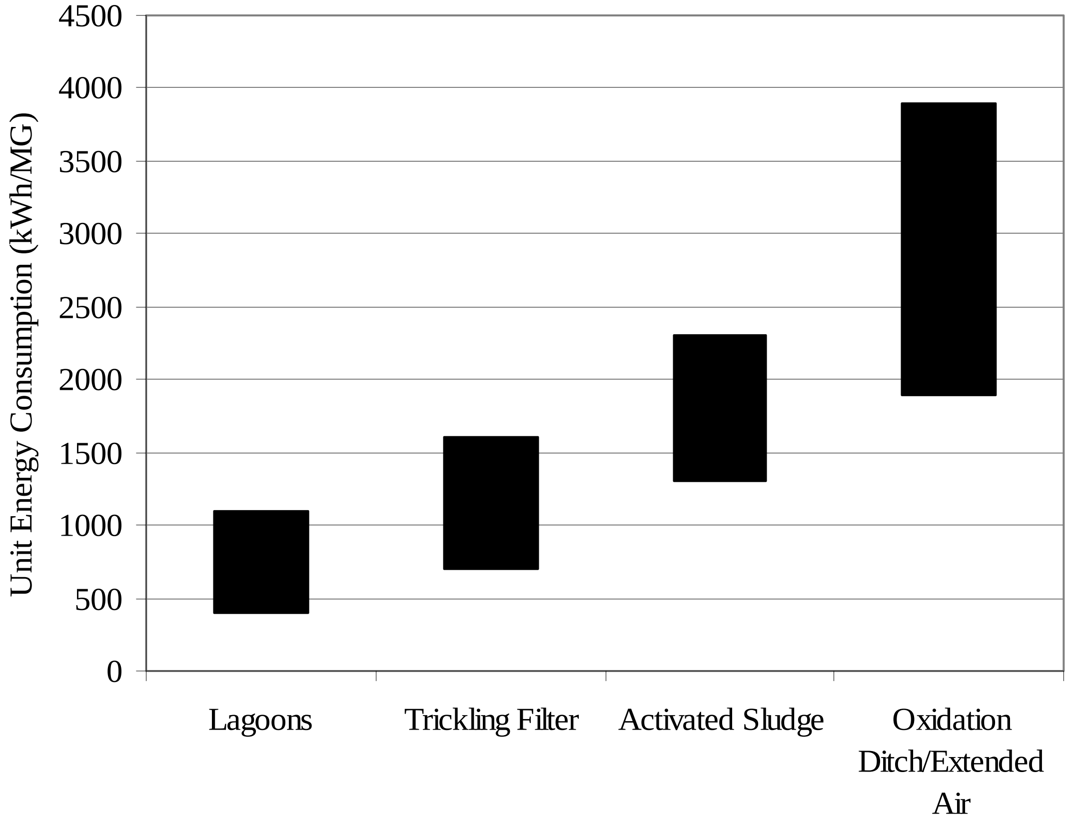

Figure B.2 Ranges of Unit Energy Consumption for Wastewater Treatment Plants

(Adapted from Energy Commission 1994)

An Iowa survey was dominated by lagoon systems and found average energy use of 1,150 kWh/MG for treatment and 420 kWh/MG for collection. It classified treatment as follows:

- Activated Sludge
- Trickling Filter
- Activated Sludge + Trickle Filtration
- Rotating biological contactor
- Aerated Facultative Lagoon

The EPA classifies treatment levels in the Community Watershed Needs Survey (CWNS) as presented in their facility fact sheets based on the permit BOD5 concentration. The criteria are listed in

Table B.5 and further described in the CWNS Users Manual.

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Table B.5 EPA 2000 Community Watershed Needs Survey Treatment Level Classification

	Criteria: BOD5 (30 day average) NPDES permit level [mg/l]	
Effluent Quality Category	**Lower Limit**	**Upper Limit**
Raw Discharge	Without any form of treatment	
Primary	>45	-
	AND some preliminary or primary treatment	
Advanced Primary	>30	<45
	AND extensive primary treatment	
Secondary	>20	<30
	AND biological and/or chemical/physical treatment	
	OR the use of lagoons or trickle filters regardless of BOD5	
Advanced Treatment I	>10	< 20
	AND biological and/or chemical/physical treatment	
Advanced Treatment II	-	<10
	AND biological and/or chemical/physical treatment	
Added to above "With nutrient removal"	The use of any process to remove nutrients (e.g., nitrogen, phosphorus, etc)	

(From USEPA 2003 User's Manual)

The EPA adds more detail to process descriptions in their Clean Watersheds Needs Survey process database accounting for 196 different characteristic entries. A subset of the entries relating to biological treatment show that activated sludge use increases as plant size increases, while the use of trickling filters remains constant (Table B.6). About one third of the plants note some form of nitrification or denitrification, with a slight increase in frequency of use in larger plants.

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Table B.6 EPA 2000 Community Watershed Needs Database Selected Process Frequency

Process	3,198 plants > 1 MGD	1,966 plants > 2 MGD	906 plants > 5 MGD
Activated Sludge - Anaerobic/Anoxic/Oxic	1	1	0
Activated Sludge - Complete Mix	7	6	3
Activated Sludge - Contact Stabilization	299	163	74
Activated Sludge – Conventional	1,174	835	443
Activated Sludge - Extended Aeration	364	189	65
Activated Sludge - High Rate	22	15	10
Activated Sludge - Other Mode	122	91	44
Activated Sludge - Pure Oxygen	107	99	69
Activated Sludge - Step Aeration	15	15	15
Activated Sludge With Biological Denitrification	6	5	2
SUBTOTAL Activated Sludge	**2,117**	**1,419**	**725**
	66%	**73%**	**80%**
Trickling Filter - Other Media	61	38	21
Trickling Filter - Plastic Media	126	87	44
Trickling Filter - Redwood Slats	30	22	10
Trickling Filter - Rock Media	575	354	141
SUBTOTAL Trickling Filter	**792**	**501**	**216**
	25%	**25%**	**24%**
Oxidation Ditch	243	102	25
Aerated Lagoon	240	121	41
Rotating Biological Contactor (RBC)	191	109	38
Sequencing Batch Reactor (SBR)	32	13	2
Stabilization Pond	341	175	67
Total Containment Pond	43	23	10
Biological Phosphorus Removal	41	23	12
Biological Denitrification - Separate Stage	79	58	34
Biological Nitrification – Separate Stage	279	197	100
Combined Biological Nitrification And BOD Reductn	517	364	185
SUBTOTAL Nitrification/Denitrification	**875** **27%**	**619** **31%**	**319** **35%**

The EPA gross classification can be compared to the survey process classification by linking the two databases through NPDES and Survey ID. This comparison for utilities of different sizes in New York is shown in Table B.7. The EPA notes that the process data may contain errors and is out of date. They plan to update the process data in future efforts.

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Table B.7 Comparison of Process Classifications and Treatment Levels

NY Flow > 1 MGD Treatment and Process Data	EPA Treatment Level (based on NPDES)						
	Secondary	Secondary With Nutrient Removal	Advanced I	Advanced I with Nutrient Removal	Advanced II	Advanced II with Nutrient Removal	TOTAL
PLANT COUNT	88	9	25	30	4	5	161
CWNS PROCESS							
Activated Carbon - Granular	-	-	-	2	1	1	4
Activated Sludge - Anaerobic/Anoxic/Oxic	-	-	-	-	-	-	-
Activated Sludge - Contact Stabilization	3	-	1	3	-	-	7
Activated Sludge - Conventional	26	-	5	9	1	1	42
Activated Sludge - Extended Aeration	6	-	-	3	1	1	11
Activated Sludge - High Rate	-	-	-	-	-	-	-
Activated Sludge - Other Mode	20	1	9	7	1	-	38
Activated Sludge - Pure Oxygen	-	-	-	4	-	-	4
Activated Sludge - Step Aeration	6	8	-	1	-	-	15
Aerated Lagoon	1	-	1	2	-	-	4
Aerobic Digestion - Air	8	-	2	5	-	1	16
Aerobic Unit	-	-	-	-	-	-	-
Air Drying - Sand Beds	20	1	6	6	1	3	37
Alum Addition - Primary	-	-	-	-	-	-	-
Alum Addition - Secondary	1	-	1	3	1	-	6
Anaerobic Digestion	47	9	16	16	1	2	91
Bar Screen	51	8	14	24	1	2	100
Biological Denitrification - Separate Stage	2	-	-	1	1	-	4
Biological Nitrification - Separate Stage	2	-	1	3	1	-	7
Biological Phosphorus Removal	4	-	1	13	1	1	20
Biosolids Composting - Static Pile	4	-	2	-	-	-	6
Biosolids Lagoons	2	-	-	-	-	1	3
Breakpoint Chlorination	-	-	1	-	-	-	1
Chlorination	52	7	13	20	-	1	93
Clarification Using Tube Settlers	-	-	-	-	-	-	-
Collectors	1	-	-	-	-	-	1
Combined Biological Nitrification And BOD Reductn	4	8	2	3	-	1	18
Comminution	45	1	13	15	3	2	79
Control/Lab/Maintenance Building	33	8	7	13	1	2	64
Custom Built Plant	45	8	9	22	1	3	88
Dechlorination	4	-	2	1	-	-	7
Digestor Gas Utilization Facilities	8	3	-	1	-	-	12
Dissolved Air Flotation Thickening	8	-	3	3	-	-	14
Distribution And/Or Marketing Of Biosolids	6	5	5	1	1	-	18
Elutriation	-	-	-	1	-	-	1
Facultative Lagoon	1	-	-	-	-	-	1
Ferric Chloride Addition To Biosolids	28	6	9	12	1	-	56
Flow Equalization	1	-	-	-	-	-	1
Force Main	-	-	-	-	-	-	-
Fully Automated Using Analog Controls	4	-	2	4	1	-	11
Fully Automated Using Digital Control	1	-	-	1	-	-	2
Gravity	46	9	9	21	1	-	86
Gravity Thickening	46	9	9	21	1	-	86
Grinder Pump- Low Pressure Sewer	-	-	-	-	-	-	-
Grit Removal	73	9	24	28	4	3	141
Heat Recovery And Utilization	7	8	-	1	-	-	16
Heat Treatment	3	-	2	3	-	-	8
Imhoff Tank	2	-	-	-	-	-	2
Incineration - Fluidized Bed	2	-	-	2	-	-	4
Incineration - Multiple Hearth	10	-	5	5	-	-	20
Incineration - Rotary Kiln	1	-	-	2	-	-	3
Influent Pumping	67	9	22	26	4	5	133
Land Spreading	6	-	1	1	-	1	9
Landfill/Trenching	56	1	16	26	1	4	104
Lime Stabililization	-	-	-	-	-	-	-
Manually Controlled	-	-	-	-	-	-	-
Mechanical Bar Screens	1	-	-	1	-	-	2
Mechanical Dewatering - Centrifuge	12	5	2	5	-	-	24
Mechanical Dewatering - Pressure Filter	-	-	-	-	-	-	-
Mechanical Dewatering - Vacuum Filter	38	1	11	19	-	3	72
Mechanical Dewatering -Filter Press	9	-	3	6	-	1	19
Microstrainer - Secondary	-	-	1	-	-	-	1
Mixed Media Filter	-	-	-	2	1	-	3
Mound System	-	-	-	-	-	-	-
Neutralization	-	-	-	1	-	-	1

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Table B.7 Comparison of Process Classifications and Treatment Levels (continued)

NY Flow > 1 MGD Treatment and Process Data	EPA Treatment Level (based on NPDES)						
	Secondary	Secondary With Nutrient Removal	Advanced I	Advanced I with Nutrient Removal	Advanced II	Advanced II with Nutrient Removal	TOTAL
PLANT COUNT	88	9	25	30	4	5	161
CWNS PROCESS							
Ocean Disposal Of Biosolids	2	-	2	-	-	-	4
Other Biosolids Disposal	8	-	3	3	3	-	17
Other Biosolids Treatment	8	-	5	2	2	-	17
Other Chemical Addition	-	-	1	3	-	1	5
Other Dewatering	2	-	-	-	-	-	2
Other Disinfection	22	1	8	5	2	1	39
Other Filtration	5	-	-	-	-	-	5
Other Land Treatment System	-	-	-	-	-	-	-
Other Non-Centralized Treatment	18	1	1	4	2	2	28
Other Physical/Chemical	8	-	4	5	1	1	19
Other Preliminary Or Primary Treatment	17	-	5	5	-	1	28
Other Suspended Growth Process	1	-	-	-	-	-	1
Outfall Diffuser	1	-	1	-	-	-	2
Outfall Pumping	1	-	-	-	-	-	1
Overland Flow System	-	-	-	-	-	-	-
Oxidation Ditch	2	-	1	2	-	2	7
Ozonation	-	-	-	-	-	-	-
Package Plant	1	-	2	1	-	-	4
Polishing Lagoon	-	-	-	-	-	-	-
Polymer Addition	1	-	-	2	-	-	3
Polymer Addition To Biosolids	1	-	-	1	-	-	2
Post Aeration	3	-	3	6	1	2	15
Preaeration	2	-	1	4	-	-	7
Pressure Filter	-	-	-	-	-	-	-
Primary Sedimentation	71	9	18	22	3	5	128
Pump Station	-	-	-	-	-	-	-
Rapid Infiltration System - No Underdrain	-	-	-	-	-	-	-
Rapid Sand Filter	-	-	-	-	-	-	-
Recalcination	1	-	1	-	-	-	2
Recarbonation	1	-	-	1	-	-	2
Sand Filtration/Recirculating	2	-	-	-	-	-	2
Scum Removal	1	-	1	-	-	-	2
Secondary Clarification	4	-	2	2	-	2	10
Semi-automated	43	8	10	18	1	3	83
Semi-package Plant	3	-	2	1	-	-	6
Septic Tank	-	-	-	-	-	-	-
Septic Tank Effluent Pump Sewer System	-	-	-	-	-	-	-
Sewer System Separation	-	-	-	-	-	-	-
Single Stage Tertiary Lime Treatment	6	-	2	6	-	1	15
Slow Rate Application System - No Underdrain	-	-	-	-	-	-	-
Slow Sand Filter	2	-	3	10	1	3	19
Small Diameter Gravity Sewer	-	-	-	-	-	-	-
Stabilization Pond	-	-	-	-	-	-	-
Standard Leach Field	-	-	-	-	-	-	-
Total Containment Pond	-	-	-	1	-	-	1
Trickling Filter - Other Media	14	-	5	-	1	-	20
Trickling Filter - Plastic Media	2	-	2	-	-	-	4
Trickling Filter - Rock Media	7	-	2	3	-	-	12
Two Stage Tertiary Lime Treatment	1	-	-	1	-	-	2
Ultraviolet Disinfection	2	-	2	1	-	1	6
Vacuum Sewer	-	-	-	-	-	-	-
Wet Air Oxidation	1	-	-	1	-	-	2

Another approach is to include the process loading as characteristics describing the plant. The AMSA data is the largest data set available that includes both process parameters and energy cost data (there were no energy use data collected). The plant data from utilities with multiple plants were combined as the energy cost data were only available for the entire utility entity.

In the AMSA data the energy cost is highly correlated to the total flow (Figure B.3). The correlation explains 64% of the variation in the cost data. Including factors such as service area, plant capacity factor, Total Suspended Solids (TSS) loading and biosolids produced increases the correlation to 78% (Table B.8).

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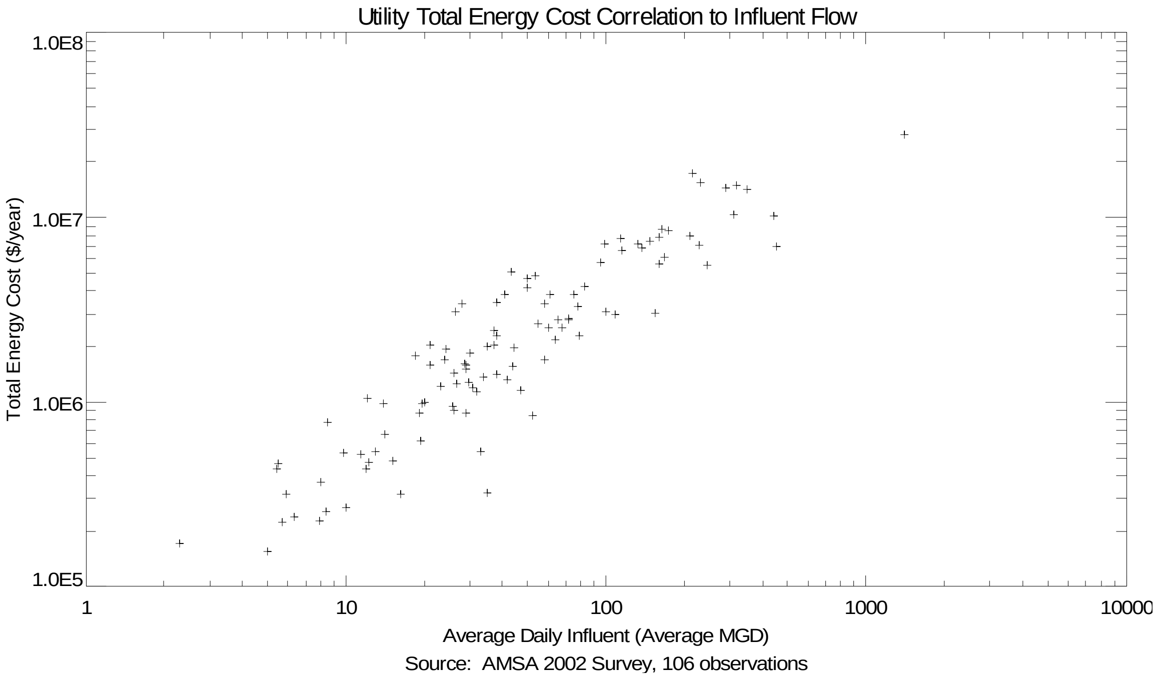

Figure B.3 Utility Total Energy Cost Correlation to Influent Flow

Multiple Linear Regression Results Relating Total Energy Cost to Flow, Service Area, Capacity Load Factor and TSS

Table B.8 Model Relating Total Energy Cost to Flow, Service Area, Capacity Load Factor and Total Suspended Solids

Regression Statistics	
Multiple R	0.88
R Square	0.78
Adjusted R Square	0.76
Standard Error	2120746.7
Observations	100

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	1.53307E+15	3.83E+14	85.21658	1.42577E-30
Residual	96	4.31766E+14	4.5E+12		
Total	100	1.96484E+15			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Flow	38161	6181	6.17	1.59E-08	25893	50430
Area	2037	645	3.16	0.002123	757	3317
Load Factor	1534411	368772	4.16	6.91E-05	802404	2266419
TSS x Flow	-67	24	-2.83	0.005648	-114	-20

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Assuming an energy price of $0.06/kWh equates the cost data to energy use ranging from 800 kWh/MG to 3,500 kWh/MG as shown in Figure B.4.

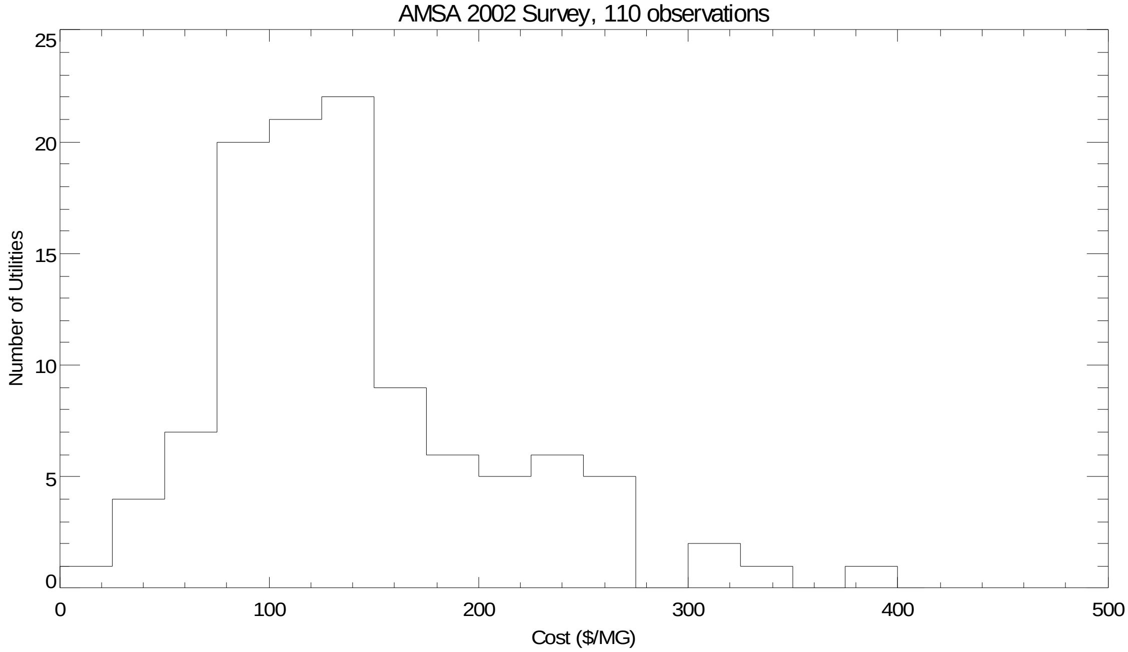

Figure B.4 AMSA 2002 Survey Total Energy Cost Distribution

Efficiency Upgrades

Since aeration is noted as the single largest energy user in treatment plants, nearly every reference concerning energy efficiency discusses the aeration process and options for upgrades. Many of the references come from the electric power industry so they also cover motors, pumps and lighting equipment upgrades as well as scheduling to limit peak electric demand. References from the water treatment industry add references to biogas production and use as well as process optimization. The following is a brief compilation listing efficient practices or upgrades:

- use premium efficient motors
- apply variable frequency drives to vary load to account for oversizing at part-load
- pump optimization to match highest efficiency with actual load with proper impeller
- aeration retrofits – control of mechanical aerators, fine/ultra-fine bubble diffusers, dissolved oxygen control, manipulate solids retention time
- limiting excess air in grit chamber
- limiting trickle filter pump recirculation rates
- limiting over-pumping of biosolids from primary and secondary clarifiers during low flow periods
- limiting RBC rotational speed during low plant flows
- limiting utility water systems pressure to actual needs or use localized pressure boost
- limiting digester mixers and heating pump use (limit peak demand), and using efficient pumps

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- digester gas use – digester heating, electricity generation, gas engine driven pumps
- lighting
- HVAC – consider heat pumps using effluent as heat source
- SCADA – monitor energy performance of equipment and control to limit peak demand
- advanced primary treatment – chemical addition to increase solids removal in primary treatment that reduces treatment needs in energy intensive secondary treatment
- flow equalization – recirculation/storage to maintain constant process flow while influent flow varies

An EPRI presentation at an ACEEE conference noted the following impacts of energy efficiency upgrades and the potential additional energy use of emerging treatment processes.

Energy upgrades noted (savings)

Fine pore diffusers	140 kWh/MG
Ultra-fine pore diffusers	210 kWh/MG
DO control systems	50 – 100 kWh/MG
Blower control systems	50-100 kWh/MG
Energy Efficient Blower	50-100 kWh/MG

Summary

The existing wastewater data sets are useful in both evaluating the impact of potential parameters on energy use, defining treatment classification schemes, defining the population of interest, and in selecting survey participants. The NPDES permit number is the key identification element that will link existing data to energy data to be surveyed.

The degree of specificity of treatment classification balances the ultimate usefulness of the metric with the level of needed process detail that needs to be collected and the ultimate number of peers available for comparison with similar processes. Existing data suggest that gross classification limited to primary/secondary/tertiary does not explain differences in energy cost data. The dominance of aeration energy in plant energy use suggests that more detail about aeration configuration will be needed to adequately represent differences in treatment process configurations.

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USEPA. 2003. Clean Watersheds Needs Survey 2000 *Report to Congress*. EPA-832-R-03-001
http://www.epa.gov/owm/mtb/cwns/

The EPA Office of Wastewater Management compiles information on wastewater treatment for a report to Congress. The report's purpose is to present investments needed to bring the nation's treatment system to a certain level. It summarizes industry data pertaining to the level of treatment and total treatment volumes. The survey data are available on-line, identifying each treatment plant by name and zip code in a Facility Inventory. A Population and Flow report adds existing flow and population data for each site. A Process Report provides the above data as well as process inventories for each treatment plant in an Access™ database. A Facility Report details the above information in a fact sheet format for each facility. The Facility Report includes the NPEDS permit number. Data are available for all 16,255 municipal wastewater treatment plants.

USEPA Water Discharge Permits (PCS)
http://www.epa.gov/enviro/html/pcs/index.html

This database contains permit compliance data. Monthly flows, TSS and BOD loadings are recorded along with concentrations of various regulated elements. The database has predefined queries and allows customizable queries. Contact information for each permit holder, as well as monthly compliance data are available for each permit holder. Individual data can be queried directly by facility name or NPDES permit number.

AMSA Financial Survey 2002
http://www.amsa-cleanwater.org/pubs/

Periodically the American Metropolitan Sewage Association (AMSA) surveys its 300 members. Along with financial data, the survey includes technical characteristics as well as loading data and energy cost data for 132 respondents. The raw data are provided along with the summaries and the survey instrument.

AMSA/WERF Cleanwater Central
http://www.cleanwatercentral.org/

This on-line database is a compilation of AMSA and WERF survey data from 500 wastewater utilities serving a population of 150 million. It includes facility characteristics, flow, treatment types, BOD and TSS loading.

Sauer, P., Kimber, A. 2002. *Energy Consumption and Costs to Treat Water and Waste Water in Iowa*, Iowa Association of Municipal Utilities
http://www.iamu.org/main/studies_reports/reports.htm

The report summarizes the methods and results from a state-wide survey effort of water and wastewater utilities. 355 wastewater treatment systems provided useable data. Lagoon systems dominate the survey at 260 systems. The report summarizes energy metrics ($/1000 gallons, kWh/1000 gallons, kWh/lb BOD) use by process categories and presents count, mean,

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median, range and standard deviations in each metric for each process category. The survey instrument is included in an appendix.

Water/Wastewater Cost Analysis Tool, Iowa Association of Municipal Utilities
http://65.112.125.101/ww%2Dcat/

The WW-CAT website allows access to the IAMU survey data as a comparison for individual utilities. It asks for characteristics and then presents data from the survey that are comparable. Survey data are summarized by category and are not available for individual sites. Wastewater treatment plants are categorized by secondary treatment, such as: activated sludge, bio towers, SBR, rotating biological contactors, oxidation ditches, trickling filters, aerated facultative lagoons, and non-aerated facultative lagoons.

Burton, F. 1996. *Water and Wastewater Industries Characteristics and Energy Management Opportunities,* Report CR-106941, Electric Power Research Institute

This widely cited reference provides a primer on water and wastewater utilities for electric utility staff. For wastewater it presents industry summary information obtained from EPA surveys. It outlines the main processes in treatment facilities and notes the relative impact on energy use of each process. It makes statements about trends in processing and the potential subsequent impact on facility energy use. It also makes estimates that quantify sub-process energy use for trickling filter, activated sludge, advanced treatment without nitrification, and advanced treatment with nitrification across plants ranging in size from 1 MGD to 100 MGD.

***Development of Energy Consumption Guidelines for Water/Wastewater*, Focus on Energy, 2003**
http://www.energybenchmark.org/Articles/WFOEc.pdf

The report presents the findings of an energy and process review of seven facilities in Wisconsin. The facilities processes were modeled, and predicted totals were compared to measured energy use from utility bills. The calibrated models were used to estimate sub-process energy use. Operating and design recommendations were made for each facility for investigation of potential improvements. Metrics such as $/person, kWh/person, kWh/BOD were used for comparisons among the plants and for comparisons with 15 European plants. Recommendations focus on motor efficiency, pump scheduling and sizing, aeration efficiency, and digester gas utilization. Aeration efficiency improvements were implementing dissolved oxygen control and replacing coarse bubble diffusers with fine bubble diffusers. The report offers rule-of-thumb design guides (process motor sizes) for plants of various sizes based on European experience.

***Best Practices for Energy Management*, Awwa Research Foundation, 2003**

This report summarizes energy information (management practices and usage) gathered from 24 water and wastewater utilities. It shows a wide variety of energy intensities from $50 to 450 $/MG and energy cost ranging from 2% to 35% of operating costs. The survey mainly covered energy management practices.

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***Roadmap for the Wisconsin Municipal Water and Wastewater Industry*, Focus on Energy, 2002**
http://www.ecw.org/prod/ww_roadmap.pdf

This report outlines topics of interest for the water and wastewater industry in Wisconsin. Its background section summarizes energy use in the industry from other reports – Burton 1996, Elliot 2992). It presents best practice energy efficiency opportunities from broad categories of motors, pumping, and aeration. It also notes energy intensities of upcoming technologies and includes a checklist of design considerations for new facilities.

***Market Research Report: Pacific Northwest Water and Wastewater Market Assessment*, Northwest Energy Efficiency Alliance, 2001**
http://www.nwalliance.org/resources/reports/79.pdf

This report summarizes energy use of facilities by process type. It discusses energy savings opportunities and the frequency of their implementation based on survey data. It also discusses characteristics of the industry and how these characteristics facilitate or inhibit the adoption of energy saving opportunities. Energy characteristics are adapted from (Burton 1996)

***Municipal Wastewater Treatment Plant Energy Baseline Study*, Pacific Gas & Electric, 2003**
http://www.cee1.org/ind/mot-sys/ww/pge1.pdf

This report argues that it is impractical to establish universal baseline performance for wastewater treatment plants due to the wide variety of system configurations and loadings. It concentrates on case studies of ten aerobic activated sludge plants showing monitored energy use for main sub-processes (secondary treatment). Comparisons were based on kWh/MG processes and found secondary treatment to use between 27% and 57% of the total plant energy. Energy data includes comparisons of low and medium pressure UV disinfection at seven plants. The report overviews the main treatment processes and identifies typical energy savings opportunities.

***Summary Report for California Energy Commission Energy Efficiency Studies*, EPRI, Palo Alto, CA: 2001. WO-6710.**
http://www.energy.ca.gov/pier/iaw/reports/2003_09_26_Appendix_2_7.pdf

This report covers energy assessments in four water and wastewater plants in California. A brief summary of the plant treatment processes along with flow and energy data are presented with a listing of upgrades and their impacts.

***Energy Audit Manual for Water/Wastewater Facilities*, COMMISSION Report CR-104300, Electric Power research Institute, 1994**
http://www.cee1.org/ind/mot-sys/ww/epri-audit.pdf

This report guides utility staff in energy audit background relevant to water and wastewater utilities. It discusses typical energy efficiency upgrade options by process. The background section lists typical energy intensities for plants with differing treatment systems – lagoons, trickling filters, activated sludge, oxidation ditch/extended air. It suggests those plants at the high end of the range, for the appropriate treatment type, consider detailed audits. The

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report also notes the energy intensity of individual sub-processes for a 7.5 MGD plant. It details efficiency of various forms of aeration systems in its discussion of potential upgrades. It lists data that should be collected to characterize the plant including activated sludge dissolved oxygen (DO) and solids retention time (SRT)

***Quality Energy Efficiency Retrofits for Wastewater Systems*, CR-109081, Electric Power Research Institute, 1998**
http://www.cee1.org/ind/mot-sys/ww/epri-retrofit.pdf

This document summarizes implementation issues for specific energy efficient upgrades for motors, drives, pumps, SCADA, cogeneration, aeration retrofits, UV disinfection, operation and maintenance, and lighting.

Consortium Benchmarking Methodology Guide, AwwaRF, 2003
http://www.awwarf.org/research/topicsandprojects/execSum/PDFReports/2621_CBGuide.pdf

This report discusses benchmarking approaches as they can be applied to the water and wastewater industry. It discusses the definitions of metric, process and practices benchmarking, stressing the goal of identifying exemplary performance, and then adopting improvements in one's own organization.

***Multi Agency Benchmarking Project*, Publication 1282, King County Department of Natural Resources, 1999**
http://www.cee1.org/ind/mot-sys/ww/multi.pdf

Seven agencies met and shared operating data to formulate and test benchmarking methods. The operations and maintenance cost metrics included $/MG, $/BOD, and $/TSS. They recognized that energy was the second largest operation cost and noted the difficulty in making comparisons between utilities, due to system configuration and treatment process differences. They agreed upon efficiency energy practices ranging from the use of fine bubble aeration, matching plant operating units to loading, steam turbines, gravity feed and energy procurement. Secondary treatment used 19% of O&M costs and had the highest energy use. Residual handling used 39% of O&M costs. Costs for biosolids handling processes were compared along with changes that had been made to reduce total residual handling costs. The report also discussed advanced primary treatment to reduce secondary treatment costs. Disinfection amounted to 5% of total O&M for all but two with stringent permits where the cost escalated to 15% of total O&M.

Carns K. *Bringing Energy Efficiency to the Water & Wastewater Industry: How Do We Get There?*, presentation to Water & Wastewater Energy Roadmap Workshop in Washington DC, Electric Power Research Institute – Global Energy Partners for the American Council for an Energy Efficient Economy 2004.
http://www.aceee.org/industry/carns.pdf

This presentation highlights energy use in wastewater facilities and includes estimates of the impacts of efficiency upgrades and new technologies that are being adopted. It overviews the history of EPRI's involvement in the water and wastewater industries.

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APPENDIX C
WATER UTILITY SURVEY INSTRUMENT

Dear Operators of Community Water Systems:

The Awwa Research Foundation (AwwaRF) in cooperation with the California Energy Commission and the New York State Energy Research and Development Authority is conducting a national survey of drinking water systems using the attached questionnaire. This survey is part of a research effort to develop energy metrics that will ultimately support energy management benchmarking efforts in the water industry.

Comparing energy use among utilities requires consideration of the constraints of operating conditions and requirements imposed by local conditions and existing configurations. The survey asks about your energy use as well as key characteristics of water production, treatment, and distribution that impact energy use. The goal of the project is to produce the analysis that will consider all of these parameters in a metric that will make energy use among different utilities comparable. More information about the project scope is available on the AwwaRF website at:

http://www.awwarf.org/research/TopicsAndProjects/projectSnapshot.aspx?pn=3009

The success of the project depends on the availability of statistically representative data about the water industry. Your utility was chosen to represent a portion of the industry. Please complete the survey and return it in the enclosed envelope. We will only make use of the information you provide when it has been aggregated with responses of many other utilities. We will never disclose your name or the name of your water system in any public documents.

Should you have any questions you may contact the contractor performing the survey at 608-882-0111.

Please return the survey in the enclosed envelope

or mail it to:

CDH Energy Corp.
P.O Box 641
Cazenovia, NY 13035-0641

Sincerely,

Steven W. Carlson, P.E.
Principal Investigator
CDH Energy Corp.
608-882-0111
Fax: 775-890-5505
carlson@cdhenergy.com

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Water Utility Energy Use Survey

Contact Information

Water System ID:...... ____

Facility Name:........... ____

Facility Address: .... ____

____

Name of Person Completing Survey: ____

Phone: ____________________ E-mail: ____________________________

Water Source Characteristics

1. What was the daily amount of water produced from each source in 2004?

Source	*Number of Wells/Sources*	million gallons per day – MGD		
		Average	*Maximum*	*Design*
Ground	aa.	ab.	ac.	ad.
Surface &GWUDI	ba.	bb.	bc.	bd.
Purchased	ca.	cb.		

2. For ground sources what is the average well depth?...(feet) ___________

3. What is the total raw water pumping motor horsepower (excluding backup pumps)?....(hp)___________

4. How many raw water pumps are included above?... (No. pumps)___________

5. What was the average raw water turbidity for each source in 2004?

Source	Nephelometric turbidity units - NTU	
	Average	*Peak*
Ground	aa.	ab.
Surface	ba.	bb.

Treatment Objectives

6. Please mark [yes] or [no] for each water treatment objective pertaining to the majority of your treatment plants.

Algae control ....a. [yes] [no]
Disinfection ....b. [yes] [no]
Oxidation.....................................c. [yes] [no]
Iron removal ....d. [yes] [no]
Manganese removal.....................e. [yes] [no]
Taste/odor control........................f. [yes] [no]
TOC removal...............................g. [yes] [no]
Particulate/Turbidity removal.............h. [yes] [no]
Softening (hardness removal).............i. [yes] [no]
Recarbonation....................................j. [yes] [no]
Organic contaminate removal.............k. [yes] [no]
Inorganic contaminate removal ....l. [yes] [no]
Radionuclide contaminate removal ....m. [yes] [no]

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Treatment Processes

7. Please mark [yes] or [no] for each water treatment process pertaining to the majority of your treatment plants.

Aeration (conventional)	a.	[yes] [no]
UV	b.	[yes] [no]
Ozone	c.	[yes] [no]
Clarification		
- Upflow	d.	[yes] [no]
- Gravity	e.	[yes] [no]
- Dissolved Air Floatation	f.	[yes] [no]
Flocculation	g.	[yes] [no]
Filtration		
- Direct	h.	[yes] [no]
- Slow sand	i.	[yes] [no]
- Dual Stage	j.	[yes] [no]
- Rapid Rate	k.	[yes] [no]
- Diatomaceous earth	l.	[yes] [no]
- Pressure	m.	[yes] [no]
Membranes		
- Reverse osmosis	n.	[yes] [no]
- Microfiltration	o.	[yes] [no]
- Ultrafiltration	p.	[yes] [no]
- Nanofiltration	q.	[yes] [no]

8. How many treatment plants are typically in use? .... (No. plants)________________

Residual Management

9. Please mark [yes] or [no] for each residual process pertaining to the majority of your plants.

No treatment	a.	[yes] [no]
Gravity thickening	b.	[yes] [no]
Mechanical dewatering	c.	[yes] [no]
Centrifuge	d.	[yes] [no]
Pressure Filtration	e.	[yes] [no]
Vacuum Filtration	f.	[yes] [no]
Belt Press	g.	[yes] [no]
Plate & Frame Press	h.	[yes] [no]
Non-Mechanical Dewatering	i.	[yes] [no]
Lagoon dewatering, thickening	j.	[yes] [no]
Sand drying bed	k.	[yes] [no]
Freezing and thawing	l.	[yes] [no]

10. What was the total daily average residuals production in 2004? .... (lbs/day)________________

Distribution

11. What is the population of the service area? .... (No. people)________________

12. What is the approximate size of the service area? ....(square miles)________________

13. What is the total length of distribution mains? .... (miles)________________

14. What are the high and low elevations of the distribution system.......... (high/low ft)_______/________

15. How much pumping horsepower is used in distribution (exclude backup)? ....(hp)________________

16. How many distribution pumps are included above .... (No. pumps)________________

17. What is the total storage volume? .... (millions of gallons MG)________________

18. What is the average distribution pressure? .... (psi)________________

19. How many pressure zones are used in the distribution system? ....(No. zones)________________

20. How much treated water is unaccounted for? .... (%)_______________

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Energy Use

21. Please provide electricity use and cost for production, treatment and distribution in 2004. Peak demand is the largest monthly demand (kW) recorded in 2004.

Electricity	*Use (kWh)*	*Peak Demand (kW)*	*Total Electricity Cost ($)*
Production	aa.	ab.	ac.
Treatment	ba.	bb.	bc.
Distribution	ca.	cb.	cc.
Total	da.	db.	dc.

22. Total floor area of buildings served by above electricity........................ (square feet)________________

23. Please provide natural gas use and cost for the entire utility in 2004.

Natural Gas	*Use (therms)*	*Total Natural Gas Cost ($)*
Total	aa.	ab.

24a. Are any engine driven pumps used? ....[yes] [no]

24b. What is the total engine horsepower..(hp)________________

24c. What is the engine fuel?.................................. natural gas, diesel, other:________________

25a. Do you purchase other energy?...[yes] [no]

25b. Type of energy source? (propane, oil, etc) ....specify:________________

25c. Amount of energy used? .... (specify units:______________)________________

25d. Energy cost? ....($)________________

26. Does someone in operations regularly (monthly/quarterly) review the utility energy bills?...[yes] [no]

27. Were there any extraordinary events in 2004 that impacted energy use?................................[yes] [no]

ID Label

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APPENDIX D
WASTEWATER TREATMENT PLANT SURVEY INSTRUMENT

Dear Operators of Wastewater Treatment Systems:

The Awwa Research Foundation (AwwaRF) in cooperation with the California Energy Commission and the New York State Energy Research and Development Authority is conducting a national survey of wastewater systems using the attached questionnaire. This survey is part of a research effort to develop energy metrics that will ultimately support energy management benchmarking efforts in the wastewater industry.

Comparing energy use among utilities requires consideration of the constraints of operating conditions and requirements imposed by local conditions and existing configurations. The survey asks about your energy use as well as key characteristics of collection and treatment that impact energy use. The goal of the project is to produce the analysis that will consider all of these parameters in a metric that will make energy use among different utilities comparable. More information about the project scope is available on the AwwaRF website at:

http://www.awwarf.org/research/TopicsAndProjects/projectSnapshot.aspx?pn=3009

The success of the project depends on the availability of statistically representative data about the wastewater industry. Your utility was chosen to represent a portion of the industry. Please complete the survey and return it in the enclosed envelope. We will only make use of the information you provide when it has been aggregated with responses of many other utilities. We will never disclose your name or the name of your water system in any public documents.

Should you have any questions you may contact the contractor performing the survey at 608-882-0111.

Please return the survey in the enclosed envelope

or mail it to:

CDH Energy Corp.
P.O Box 641
Cazenovia, NY 13035-0641

Sincerely,

Steven W. Carlson, P.E.
Principal Investigator
CDH Energy Corp.
Voice: 608-882-0111
Fax: 775-890-5505
carlson@cdhenergy.com

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Wastewater Utility Energy Use Survey

Contact Information

NPDES Permit Number: .... ____

Facility Name: .... ____

Facility Address: .... ____

____

Name of Person Completing Survey: ____

Phone: ______________________ E-mail: ______________________________

Number of wastewater treatment plants in utility....................................... (No. plants)_________

Plant Characteristics (*please provide data for the single plant identified by the NPDES permit number on the ID label on page 3. You might receive separate surveys for other plants in your utility.)*

1. What is the design flow rate?.. (million gallons per day - MGD) __________

2. What is the average flow rate?... (million gallons per day – MGD)__________

3, What percentage of flow is from industrial users?... (%)__________

4. What is the treatment level (check one)?

   a. ☐ Primary
   b. ☐ Advanced Primary
   c. ☐ Secondary
   d. ☐ Secondary with Nutrient Removal
   e. ☐ Advanced I
   f. ☐ Advanced I with Nutrient Removal
   g. ☐ Advanced II (Permit BOD < 10 mg/l)
   h. ☐ Advanced II with Nutrient Removal

5. Please mark [yes] or [no] for each treatment process used at your treatment plant.

Activated Sludge - Aeration Method
- Mechanical .... a. [yes] [no]
- Course Bubble .... b. [yes] [no]
- Fine Bubble .... c. [yes] [no]
- Pure Oxygen .... d. [yes] [no]
  - Is automated dissolved oxygen control use to modulate air flow in the aeration process? .... e. [yes] [no]

Fixed Film
- Rotating Biological Contactor ...... f. [yes] [no]
- Trickling Filter.............................. g. [yes] [no]

Nutrient Removal
- Biological Nitrification................. h. [yes] [no]
- Biological Denitrification .... i. [yes] [no]
- Biological Phosphorus Removal.... j. [yes] [no]

Disinfection
- Chemical....................................... k. [yes] [no]
- Ultraviolet (UV) .... l. [yes] [no]

Sludge Treatment
- Thickening.................................... m. [yes] [no]
- Dewatering .... n. [yes] [no]

Sludge Digestion
- Aerobic .... o. [yes] [no]
- Anerobic .... p. [yes] [no]

Sludge Use
- Composting................................... q. [yes] [no]
- Land Application .... r. [yes] [no]
- Incineration.................................. s. [yes] [no]
- Land Fill .... t. [yes] [no]

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Plant Loading

6a. What was the average daily biosolids production in 2004? ....(dry tons per day)___________

6b. Does the plant send biosolids to another plant for processing? ....[yes] [no]

6c. Does the plant process biosolids from another plant? ....[yes] [no]

7. What were the average concentration levels of conventional pollutants in 2004?

Concentration (mg/l)	*Influent*	*Effluent*
a. Average BOD		
b. Average COD		
c. Average TSS		

Collection System *(The collection system data may serve multiple plants, if so, please note in 8e.)*

8a. Do you operate pump stations within your collection system? ....[yes] [no]

8b. What is the total pumping capacity? .... (million gallons per day - MGD)___________

8c. What is the total motor horsepower (excluding backup pumps)? ....(hp)___________

8d. How many pumps are included above? .... (No. pumps)___________

8e. How many treatment plants are served by the collection system........ (No. plants)___________

Energy Use *(For a utility with multiple treatment plants, please provide energy data for the treatment plant that corresponds to the plant characteristics noted on page 1.)*

9. Please provide electricity use and cost for the collection system and treatment plant in 2004.

Electricity	*Use (kWh)*	*Peak Demand (kW)*	*Total Electricity Cost ($)*
a. Collection			
b. Treatment Plant			
c. Total			

10. Please provide natural gas use and cost for 2004.

Natural Gas	*Use (therms)*	*Total Natural Gas Cost ($)*
a. Total		

11. Total floor area of buildings served by above utilities............................ (square feet)________________

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12a. Are any engine driven pumps used? ....[yes] [no]

12b. What is the total engine horsepower..(hp)________________

12c. What is the engine fuel?......................biogas, natural gas, diesel, other:________________

13a. Do you purchase other energy?..[yes] [no]

13b. Type of energy source? (propane, oil, etc) ....specify:________________

13c. Amount of energy used? .... (specify units:______________)________________

13d. Energy cost? ....($)________________

14a. Is digester gas recovered? ....[yes] [no]

14b. How much biogas is used? ....(ccf) ________________

15a.. Is electricity generated on-site?...[yes] [no]

15b. What is the fuel source?............................biogas, natural gas, or other: ________________

15c. What was the annual electricity production in 2004?..................(kWh) ________________

16. Does someone in operations regularly (monthly/quarterly) review the utility energy bills?...[yes] [no]

17. Were there any extraordinary events in 2004 that impacted energy use or plant loading?......[yes] [no]

18. Please feel free to make any additional comments on utility energy use, plant loading or system characteristics below:

ID Label

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An annotated bibliography is included with the literature searches in Appendices A and B

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ABBREVIATIONS

ACEEE	American Council for an Energy Efficiency Economy
AMSA	American Municipal Sewage Association (now NACWA)
AWWA	American Water Works Association
AwwaRF	Awwa Research Foundation
BOD	Biochemical (biological) Oxygen Demand
BOD5	BOD five day test
COMMISSION	California Energy Commission
CDD	Cooling Degree Day
COD	Carbonaceous Oxygen Demand
CWNS	Community Water Needs Survey
DAF	Dissolved Air Flotation
DF	Degrees of Freedom
DO	Dissolved Oxygen
ECW	Energy Center of Wisconsin
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
GAL	Gallon
GWUDI	Ground Water Under Direct Influence (of surface water)
HDD	Heating Degree Day
HP	Horsepower
HVAC	Heating Ventilating and Air Conditioning
IAMU	Iowa Association of Municipal Utilities
kBTU	Thousand British Thermal Units
kGD	Thousand Gallons per Day
kWh	Kilowatt Hour
lb	Pound
MG	Million Gallons
MGD	Million Gallons per Day
mg/l	milligram per liter
MMBTU	Million British Thermal Units
NACWA	National Association of Clean Water Agencies
NAICS	North American Industry Classification System
NPDES	National Pollutant Discharge Elimination System

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NR	Nutrient Removal
NTU	Nephelometer Turbidity Units
NYSERDA	New York State Energy Research and Development Authority
O&M	Operations and Maintenance
PAC	Project Advisory Committee
PCS	Permit Compliance System
R^2	Coefficient of Determination
RBC	Rotating Biological Contactor
SCADA	Supervisory Control and Data Aquisition
SDWIS	Safe Drinking Water Information System
SIC	Standard Industrial Classification
SRT	Solids Retention Time
Therm	100,000 BTUs
TOC	Taste, Odor, and Color
TSS	Total Suspended Solids
UV	Ultra-Violet
WSID	Water System Identification

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