GREEN BUILDING WITH ONSITE WASTEWATER SYSTEMS

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ABSTRACT

Concern is growing globally over natural resource consumption and climate change. Many governments, companies, and industries are taking action to reduce the environmental footprint associated with manufacturing, processing, and building. Meanwhile, much of the world is working through an economic downturn that has left governments and individuals in debt and trying to stay afloat. It is therefore imperative that all aspects of building and development are conducted both sustainably and economically, including wastewater management.

The environmental and economic benefits provided through the manufacture and construction of onsite (decentralized) wastewater systems versus centralized wastewater treatment plants (WWTP) were quantitatively examined through an analysis of embodied energy, embodied carbon, and the cost of each system type. Average values per sewer connection were calculated by analyzing the material and construction costs for 40 sewer extension plans from the 2005 Southwest Virginia Regional Wastewater Study. The total system and per sewer connection values of embodied energy, embodied carbon, and costs were then compared to the resource consumption of materials and construction for the same number of onsite wastewater systems.

The average embodied energy, embodied carbon, and cost per connection for the materials and construction of a sewer extension were found to be 157,563 MJ, 7,006 kg CO_2, and $18,590, respectively. In comparison, the embodied energy, embodied carbon, and cost of the materials and construction of an average septic system were found to be 40,025 MJ, 1,908 kg CO_2, and $5,954, respectively. This relates to a savings of 117,538 MJ, 5,099 kg CO_2, and $12,636 per system. Looking from a broader prospective, a shift from 25% to 50% of homes served by decentralized systems through increased federal funding and consumer awareness would lead to a savings of 63 billion MJ, 2.7 billion kg CO_2, and 6.7 billion dollars each year. The energy savings alone are equivalent to 5.25 years of Washington D.C.'s motor gasoline supply or a 26-day supply of motor gasoline for all of Washington DC, Maryland, Delaware, and Virginia combined (7% of yearly supply).

With the clear environmental and economic benefits associated with decentralized wastewater treatment systems, it is imperative that local, state, and national regulators shift the focus of wastewater treatment from centralized sewer systems to the more sustainable decentralized model. Doing so will greatly aid in the efforts to reduce the carbon footprint associated with development as well as reduce the cost of development for both government entities and end users.

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INTRODUCTION

Centralized vs Decentralized Wastewater Management

Concern is growing globally over natural resource consumption and climate change. Many governments, companies, and industries are taking action to reduce the environmental footprint associated with manufacturing, processing, and building. Meanwhile, much of the world is working through an economic downturn that has left governments and individuals in debt and trying to stay afloat. It is therefore imperative that all aspects of building and development are done both sustainably and economically, including wastewater management.

The environmental benefits of operating decentralized over centralized wastewater management have long been cited. Decentralized management is most often passive, allowing for groundwater recharge with little to no operational energy consumption. Decentralized systems require little maintenance and, with proper care and design, perform equally to centralized treatment processes (U.S. EPA, 1997; U.S. EPA, 2003).

Centralized systems, on the other hand, often require pumping stations in conveying the sewage to the wastewater treatment plant (WWTP), where it undergoes energy- and chemical-intensive treatment processes prior to discharging into local water bodies. In addition, gathering all the wastewater into one localized area is often disastrous during inclement weather. The United States Environmental Protection Agency (U.S. EPA, 2001) has estimated that approximately 1.26 trillion gallons of untreated wastewater flows into surface waters nation-wide each year due to combined sewage overflow (CSO) discharges. In comparison, it is estimated that only 200,000 replacement onsite wastewater systems are installed each year in the United States (Permit Data, 2005).

Despite these operational environmental benefits, centralized sewer replacement, expansion, and separation continue to be the focus of federal funding and new development. The funds distributed through the Clean Water Act State Revolving Fund are largely biased toward centralized wastewater management programs; a mere 0.2% of the allocations are used toward decentralized wastewater treatment, despite approximately 25% of all homes currently using decentralized wastewater management schemes (NOWRA, 2011).

While there are areas where decentralized wastewater treatment is not a viable option due to lot size or geologic conditions, the first reaction to sewage problems is usually to connect the area to an existing WWTP through centralized sewer line extensions. However, before reaching this conclusion, the environmental, economic, and cost impacts of each project should be more clearly assessed to ensure it is the best solution.

The Southwest Virginia Regional Wastewater Study (SVRWS)

The SVRWS was developed in 2005 in attempts to manage wastewater in Southwest Virginia. The project focused largely on extending centralized sewer lines to areas with antiquated septic systems and considered some decentralized managed wastewater systems due to remote location, topographic situations, small size, or soil conditions. In all, over 136 sites were examined under the following criteria: degree of health hazard, severity of environmental problems, number of customers served, construction cost per connection, construction feasibility, as well as residential, commercial and industrial growth potential. The top 44 centralized projects, 12 decentralized projects, and 3 hybrid projects were then recommended for implementation. Of the 44 centralized projects, 40 were sewer extensions to existing WWTPs (Thompson & Little, Inc. et al., 2005).

In attempts to quantify the economic and environmental implications of centralized and decentralized wastewater treatment models, material consumption and construction of 40 sewer extension plans from the SVRWS were quantitatively analyzed to determine the environmental and economic impacts per connection for each project.

METHODS AND CALCULATIONS

Overview

An analysis was performed to quantitatively determine the embodied carbon, embodied energy, and fiscal resource consumption of the materials and construction associated with 40 sewer extension projects and equivalent decentralized wastewater treatment systems.

Unit values for embodied carbon and energy were taken from the Inventory of Carbon and Energy (ICE) compiled by the University of Bath. This is a highly cited source of information and has been used in many life cycle and carbon footprint analyses. This document defines embodied energy (carbon) as, "…the total primary energy consumed (carbon released) over its life cycle… includ[ing] extraction, manufacturing and transportation." (Hammond et al., 2008)

The sewer extension projects were identified and individually defined through the SVRWS report. The construction cost of each project was delineated within the report by a breakdown of material and construction costs. The breakdown of materials was used to determine the embodied carbon and embodied energy of the materials in the project, as well as the construction embodied carbon and embodied energy. The construction equipment used in the construction process and the related fuel efficiencies and production rates were estimated through literature review. These values were then used to determine the average resource consumption per connection and compare it to the average resource consumption of a typical decentralized wastewater treatment system (Thompson & Little, Inc. et al., 2005; HOLT CAT, 2012; Methvin, 2014; Georg Fischer Harvel, 2014b; JM Eagle, 2008; Supple, 2010).

A 3-bedroom septic system was used as the model for the decentralized systems, as it is the most common form of decentralized wastewater treatment in Southwest Virginia. The septic tank and drainfield were designed using the State of Virginia's Sewage Handling and Disposal Regulations, 12VAC5-610 (Regulations). The drainfield size and construction equipment typically used were chosen based on industry knowledge and a brief survey of designers and installers in Southwest Virginia. Fuel efficiencies and production rates were based on literature review (Georg Fischer Harvel, 2014a; HOLT CAT, 2012; Methvin, 2014; State of Virginia, 2012; Supple, 2010).

Materials and Processes

The materials included under the sewer extension project are PVC sewer piping, manholes, pumps and pumping stations (where indicated in the SVWRS), gravel bedding for the sewer pipe, and asphalt for repaving the excavated areas. While entire roads are often repaved after sewer construction, it was assumed that only the excavated areas were repaved to be conservative. Virginia Department of Transportation paving codes were used to determine the amount of pavement required over the excavated areas. The centralized sewer also did not include infiltration and inflow (I/I) improvements, clean-outs, or any special railroad or road crossings, as these measures are much more difficult to quantify from a larger point of view (Virginia Asphalt Association, 2011).

From the Regulations, the conventional septic tank was defined as a 900-gallon precast concrete septic tank. The associated drainfield was sized using a 65 mpi percolation rate, for a total of 1488 sf of stone and pipe (washed septic gravel and PVC piping) filled absorption trenches. An estimate of PVC piping from the home to tank and tank to drainfield was also included.

The construction practices included in this study are excavation, backfill, compaction, and paving. Additional processes were not included due to the number of unknowns associated with each project. For instance, hauling excavated material was not included for either the centralized or decentralized models, as fuel consumption relies heavily upon an unknown travel distance.

Outputs

The resource consumption for each of the 40 sewer extension projects was analyzed both in total resource consumption and resource consumption per connection. The average septic system consumption was then multiplied by the number of sewer connections for each project to find the associated environmental and fiscal costs of the septic systems being updated rather than extending the sewer line. An average consumption rate per connection was determined by averaging the per connection results from each of the projects; this was used to correlate the potential resource savings by utilizing decentralized systems over centralized WWTPs throughout the nation.

RESULTS

Sewer Extension Projects

A summary of the total and average embodied energy, embodied carbon, and costs for the 40 projects are shown in Table 1; the full results are provided in Appendix 1. As shown, the average project resource consumption is 58.5 million MJ, 2.5 million kg CO_2, and 6.7 million dollars for an average of 363 connections. The total resource consumption of the 40 sewer extensions is 2,340.8 million MJ, 99.2 million kg CO_2, and 266.5 million dollars for 14,507 connections.

Table 1. Total and average embodied energy, embodied carbon, and costs for sewer extensions.

	Number of Connections	Embodied Energy (million MJ)	Embodied Carbon (million kg CO_2)	Cost (million USD)
Total of 40 projects	14,507	2,340.8	99.2	$266.5
Average	363	58.5	2.5	$6.7
Median	299	38.9	1.9	$5.1
Max	1160	355.5	7.8	$24.3
Min	85	7.3	0.4	$1.5

Average per connection embodied energy, embodied carbon, and costs for the 40 projects are shown in Table 2. As shown, the average per connection resource consumption is 157.6 thousand MJ, 7.0 thousand kg CO_2, and 18.6 thousand dollars.

Table 2. Per connection average embodied energy, embodied carbon, and costs for sewer extensions.

	Embodied Energy (thousand MJ)	Embodied Carbon (thousand kg CO_2)	Cost (thousand USD)
Average	157.6	7.0	$18.6
Median	139.6	6.7	$17.1
Max	766.3	16.5	$34.7
Min	50.8	2.5	$7.2

The median, maximum and minimum values are also shown for both the total project consumption and the per connection values. In all cases, the median value is lower than the average value, showing there are a few higher consumption cases that are raising the average higher than the most common range. These values were left in the study as they represent an actual distribution of cases – some sewer projects are extremely high consumers and some are on the lower end. The frequency of resource consumption values is shown in Figures 1-3.

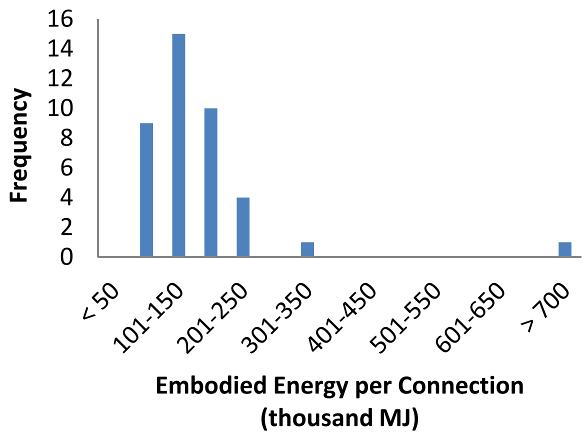

Figure 1. Frequency of Embodied Energy per Connection

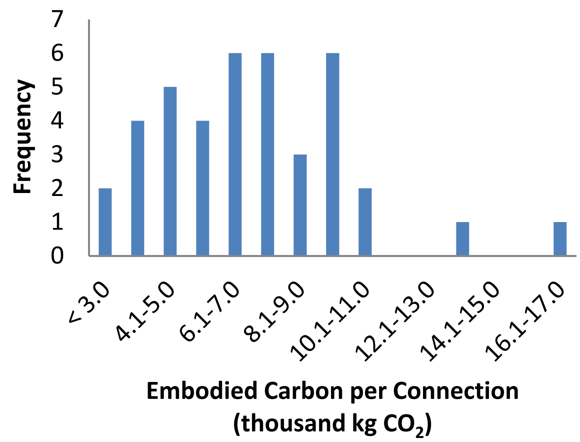

Figure 2. Frequency of Embodied Carbon per Connection

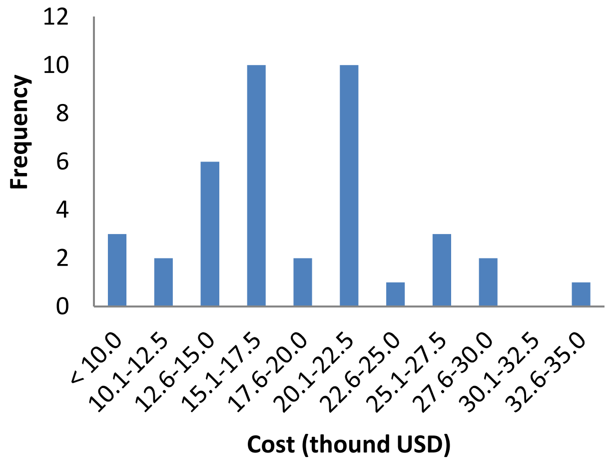

Figure 3. Frequency of Cost per Connection

The sewer extension projects were analyzed for a correlation between the number of connections and both the resource consumption per connection and total resource consumption. There was no correlation found between the number of connections and the embodied carbon per connection and a moderate correlation found between the number of connections and the project total embodied carbon, as would be expected. These results are shown in Appendix 2.

Decentralized Project Equivalents

The average Regulation septic system was analyzed for material and construction resource consumption. The embodied energy, embodied carbon, and costs for each installed decentralized wastewater treatment system was calculated to be 40 thousand MJ, 1.9 thousand kg CO_2, and 5.9 thousand dollars, respectively. Since a typical system was used in the equivalency generation, there are no statistics to show for the per connection resource consumption values.

A summary of the total and average embodied energy, embodied carbon, and costs for the decentralized equivalency of the 40 sewer extension projects are shown in Table 3; the full results are provided in Appendix 1. As shown, the average project resource consumption for the decentralized model is 14.5 million MJ, 0.7 million kg CO_2, and 2.2 million dollars for an average of 363 connections. The total resource consumption of the 40 sewer extensions is 580.6 million MJ, 27.7 million kg CO_2, and 86.4 million dollars for 14,507 connections.

Table 3. Total and average embodied energy, embodied carbon, and costs for decentralized wastewater management.

	Number of Connections	Embodied Energy (million MJ)	Embodied Carbon (million kg CO_2)	Cost (million USD)
Total of 40 projects	14,507	580.6	27.7	$86.4
Average	363	14.5	0.7	$2.2
Median	299	11.9	0.6	$1.8
Max	1160	46.4	2.2	$6.9
Min	85	3.4	0.2	$0.5

DISCUSSION

Resource Savings per Connection

The average per connection resource savings are shown in Table 4 and Figure 4. As shown, there's a 75% savings in embodied energy, 73% savings in embodied carbon, and 68% cost savings on average through the construction of decentralized wastewater systems over the centralized sewer extensions.

Table 4. Comparison of average per connection resource consumption for centralized and decentralized wastewater management.

	Centralized Per Connection	Decentralized Per Connection	Difference	Percent Difference
Embodied Energy (MJ)	157,563	40,025	117,538	75%
Embodied Carbon (kg CO_2)	7,006	1,908	5,099	73%
Cost (USD)	$18,590	$5,954	$12,636	68%

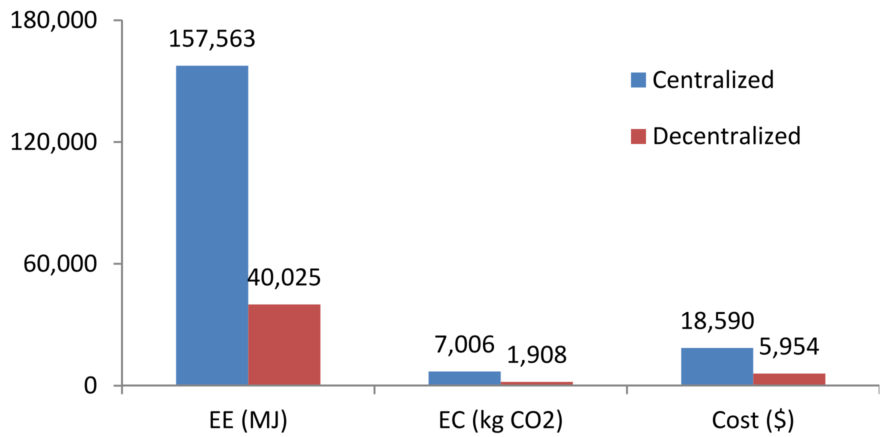

Figure 4. Comparison of Average per Connection Resource Consumption for Centralized and Decentralized Wastewater Management

The savings associated with each decentralized system is significant; the energy savings of 117,538 MJ is equivalent to the energy content of 969 gallons of gasoline – enough to take 2093 cars off the roads in DC for a day (Supple, 2010; U.S. DOE, 2011).

Resource Savings per Project

These per connection savings add up quickly in relation to sewer extension projects; the average number of connections per project was calculated to be 363 connections. Multiplying the average savings by the average number of connections, the savings for utilizing a decentralized scheme over a centralized sewer extension is shown in Table 5.

Table 5. Summary of resource savings from using decentralized over the average sewer extension project.

	Decentralized Savings Per Connection	Average Number of Decentralized Connections	Total Decentralized Savings
Embodied Energy (MJ)	117,538	363	42,666,294
Embodied Carbon (kg CO_2)	5,099	363	1,850,937
Cost (USD)	$12,636	363	$4,586,868

For just one project switching to decentralized wastewater management, the embodied energy savings is 42.7 million MJ (11.8 millon kWh); this is equivalent to taking nearly 2100 people off the Virginia residential electricity grid for an entire year (U.S. DOE, 2011). The carbon savings of 1.85 million kg CO_2 is equivalent to 480 yearly round-trip commutes of 50 miles per day; in other words, the emissions saved by taking 480 people off the roads for the entire year of daily commutes (Amtrak, 2014).

Resource Savings per Year

When multiplied by a mere percentage of the homes being installed each year, the savings have the potential to be astronomical. The U.S. Census Bureau's 30-year average for single-family starts is 1,064 thousand homes (U.S. Census, 2013). Of these, approximately 25% (266,025) of the permits were for decentralized systems. The resource savings from this 25% of homes is estimated in Table 6.

Table 6. Summary of resource savings through current use of decentralized wastewater management.

	Decentralized Savings Per Connection	Number of Decentralized Connections	Total Decentralized Savings
Embodied Energy (MJ)	117,538	266,025	31,267,931,402
Embodied Carbon (kg CO_2)	5,099	266,025	1,356,336,964
Cost (USD)	$12,636	266,025	$3,361,360,285

As shown, the total energy savings are nearly 31 billion MJ each year; this equates to the equivalent amount of energy in motor gasoline consumed in Washington DC, Maryland, Delaware, and Virginia combined for nearly two weeks (4% of the yearly motor gasoline consumed in these states) (U.S. EIA, 2014).

The embodied carbon savings of 1.4 billion kgCO_2 each year equates to 351,019 people (56% of Washington DC's population) with an average commuting distance of 50 miles round trip choosing to carpool to work every day for an entire year (Amtrak, 2014).

With this in mind, greater efforts should be made toward designing sustainable wastewater management systems. With more balanced funding from the U.S. Environmental Protection Agency (U.S. EPA), this could become reality. For every 1% of new homes permitted that switch to using a decentralized wastewater treatment approach, an additional 54 million kg CO_2, 1.3 billion MJ, and 134 billion dollars could be saved each year. If the percentage of homes served by decentralized systems increased to 50%, the total energy savings alone would be equivalent to 5.25 years of Washington DC's motor gasoline supply (U.S. EIA, 2014).

CONCLUSIONS

Benefits and Resource Savings of Decentralized Wastewater Management

Decentralized wastewater management provides both environmental and economic benefits for new communities and those looking to update their current wastewater management systems. They are often passive systems, requiring little to no operational costs, and can provide similar treatment levels to centralized systems when properly designed, sited, and maintained. Where individual onsite wastewater systems are not always feasible due to lot size, soil conditions, or limiting subsurface layers, community decentralized systems can usually be designed, similar to the 14 decentralized projects in the SVRWS. These projects often consist of a septic tank at each connection that lead to an off-site recirculating sand filter and can provide a low-cost, low-maintenance alternative to centralized sewer extensions.

The materials and construction associated with decentralized wastewater managements consume far less embodied energy, embodied carbon, and capital than centralized systems. The average resource savings per connection was calculated to be 117,538 MJ (75%), 5,099 kg CO_2 (73%), and $12,636 (68%). These savings have the potential to add up quickly with the large number of sewer extensions and new developments being installed each year.

Limitations

While this report provides a starting place for the comparison of centralized and decentralized wastewater management, it is based on data from Southwest Virginia that may not be applicable to all areas of the nation. While the embodied energy and carbon of materials remains the same, the cost of both sewer extensions and septic systems changes drastically from location to location, as well as the construction practices and equipment used. Special note should also be taken to the type of centralized wastewater system being proposed; this study covers only sewer extensions from existing wastewater treatment plants and does not include the construction and materials required for new plant construction.

In addition, this study assumes the sewer extension can be replaced entirely with conventional septic systems; this is may not be the case in some places. The typical conventional system was chosen for averaging purposes and to make the study as widely applicable as possible; when looking at a specific project, an average mixture of the onsite wastewater systems permitted in the area at hand should be obtained and used to determine the resource consumption of the decentralized systems.

It should be noted that septic systems require a level of personal responsibility from each homeowner to ensure long term function. Public awareness and education is essential to the proper function and longevity of any wastewater treatment system. Improper use or lack of maintenance can lead to clogging of the infiltrative surface, back-up of sewage into the home, and contamination of water bodies.

However, a greater public awareness is also needed for centralized sewers, as WWTPs are not set up to treat and remove all chemicals that are found in households. Centralizing all of the waste that homeowners and businesses discharge into the sewer system can lead to a high concentration of untreated chemicals and compounds that are then released directly into public surface waters. Homeowner awareness is crucial to protection of public health and the environment, regardless of centralized or decentralized management.

Finally, this report also does not include any operational or longevity data from either decentralized or centralized systems. Future reports should include pumping and processing sewage and the effects of inflow and infiltration (I&I) for the centralized sewer, tank pumping and any non-passive systems that are used for the decentralized version, as well as the expected life span and repair frequency expected for both centralized and decentralized systems.

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APPENDIX 1

Project Number	County	Planning District	Project Name	Number of Connections	Sewer EE (MJ)						Septic EE (MJ)					
					Total	Materials	Construction	Total Per Connection	Materials Per Connection	Construction Per Connection	Total	Materials	Construction	Total Per Connection	Materials Per Connection	Construction Per Connection
1	Lee	LEN	Woodway	510	35336307	34782539	553768	69287	68201	1086	20412850	20019141	393709	40025	39253	772
2	Washington	MTR	West Central (Beaver Creek)	1160	147065190	144546507	2518683	126780	124609	2171	46429228	45533732	895496	40025	39253	772
3	Grayson	MTR	Fairview	335	113603116	111760314	1842802	339114	333613	5501	13408441	13149828	258613	40025	39253	772
4	Lee	LEN	Sandy Ridge/N. Jonesville	261	26604727	26175094	429633	101934	100288	1646	10446576	10245090	201487	40025	39253	772
6	Smyth	MTR	Groseclose	215	43038288	42428911	609377	200178	197344	2834	8605417	8439442	165976	40025	39253	772
7	Tazewell	CP	Baptist Valley East	955	146446093	145572195	873898	153347	152432	915	38224063	37486823	737240	40025	39253	772
8	Tazewell	CP	Baptist Valley West	1108	126463155	124255143	2208012	114136	112144	1993	44347918	43492565	855353	40025	39253	772
9	Wise	LEN	East Stone Gap/Cracker Neck	473	43853946	43145759	708187	92714	91217	1497	18931918	18566772	365146	40025	39253	772
10	Buchanan	CP	Leemaster/Lovers Gap	272	34634405	34075102	559303	127332	125276	2056	10886854	10676875	209978	40025	39253	772
11	Lee	LEN	Dryden Hts/Cross Creek	250	21742469	21260384	482085	86970	85042	1928	10006299	9813304	192995	40025	39253	772
12	Lee	LEN	Rose Hill	358	27634889	27192510	442380	77192	75957	1236	14329020	14052652	276369	40025	39253	772
13	Russell	CP	Hansonville	525	109391494	107156310	2235185	208365	204107	4257	21013228	20607939	405289	40025	39253	772
14	Smyth	MTR	Pleasant Heights	153	20259630	19925770	333860	132416	130234	2182	6123855	6005742	118113	40025	39253	772
15	Tazewell	CP	Gratton	425	42404416	41628415	776001	99775	97949	1826	17010709	16682617	328091	40025	39253	772
16	Washington	MTR	Benhams Road	325	48958827	48118145	840682	150643	148056	2587	13008189	12757296	250893	40025	39253	772
17	Washington	MTR	Spring Creek	727	126790276	124737314	2052962	174402	171578	2824	29098318	28537089	561229	40025	39253	772
18	Wise	LEN	Wildcat/Irondale	377	42748764	41909533	839231	113392	111166	2226	15089499	14798463	291036	40025	39253	772
19	Scott	LEN	Daniel Boone	370	67874830	66584347	1290483	183445	179958	3488	14809323	14523691	285632	40025	39253	772
20	Scott	LEN	Yuma	390	57197996	56275780	922216	146662	144297	2365	15609827	15308755	301072	40025	39253	772
21	Dickenson	CP	Rt 83/Georges Fork	140	28750412	28227040	523373	205360	201622	3738	5603528	5495450	108077	40025	39253	772
22	Buchanan	CP	Poplar Creek	142	22096932	21740094	356838	155612	153099	2513	5683578	5573957	109621	40025	39253	772
23	Smyth	MTR	Watson Gap	193	34786738	34217575	569163	180242	177293	2949	7724863	7575871	148992	40025	39253	772
24	Tazewell	CP	Tazewell to Divides	165	23507908	23022338	485571	142472	139529	2943	6604157	6476781	127377	40025	39253	772
25	Tazewell	CP	Tazewell to Claypool Alt I	464	355544749	353492749	2052000	766260	761838	4422	18571691	18213493	358198	40025	39253	772
26	Tazewell	CP	Abbs Valley	435	28836989	28191310	645679	66292	64808	1484	17410961	17075150	335811	40025	39253	772
27	Washington	MTR	East Central	806	158507303	155924512	2582791	196659	193455	3204	32260309	31638093	622215	40025	39253	772
28	Wise	LEN	Coeburn Mountain	500	44027766	43321086	706679	88056	86642	1413	20012598	19626609	385990	40025	39253	772
29	Wise	LEN	Powell Valley	355	64356686	63331124	1025561	181286	178398	2889	14208945	13934892	274053	40025	39253	772
30	Scott	LEN	Hiltons	263	52203910	50932914	1270997	198494	193661	4833	10526627	10323596	203031	40025	39253	772
31	Tazewell	CP	Birmingham	390	56179744	55113457	1066286	144051	141317	2734	15609827	15308755	301072	40025	39253	772
32	Buchanan	CP	Lower Mill Branch	103	20825518	20489212	336306	202189	198924	3265	4122595	4043081	79514	40025	39253	772
33	Buchanan	CP	Lynn Camp/Looney Creek	132	17541578	17258303	283275	132891	130745	2146	5283326	5181425	101901	40025	39253	772
34	Grayson	MTR	Providence	258	48363150	47419558	943592	187454	183797	3657	10326501	10127330	199171	40025	39253	772
35	Grayson	MTR	Stevens Creek	202	29820683	29339116	481567	147627	145243	2384	8085090	7929150	155940	40025	39253	772
36	Lee	LEN	Red Hill/Poor Valley	141	19286326	18950446	335881	136782	134400	2382	5643553	5534704	108849	40025	39253	772
37	Tazewell	CP	Red Ash	105	12415072	12214584	200488	118239	116329	1909	4202646	4121588	81058	40025	39253	772
38	Washington	MTR	Larwood	126	13373369	13148819	224551	106138	104356	1782	5043175	4945905	97269	40025	39253	772
39	Wise	LEN	Tacoma	144	7308991	7190960	118031	50757	49937	820	5763628	5652463	111165	40025	39253	772
40	Wise	LEN	Banner	169	10592931	10421868	171063	62680	61668	1012	6764258	6633794	130464	40025	39253	772
41	Scott	LEN	Route 871	85	11465152	11267736	197416	134884	132562	2323	3402142	3336523	65618	40025	39253	772
			Total	14507	2341840726	2306744871	35095856	6302511	6203088	99422	580645531	569446428	11199103	1601008	1570129	30879
			Average	363	58546018	57668622	877396	157563	155077	2486	14516138	14236161	279978	40025	39253	772
			Median	299	38870362	38205477	627528	139627	136965	2344	11947521	11717085	230436	40025	39253	772
			Max	1160	355544749	353492749	2582791	766260	761838	5501	46429228	45533732	895496	40025	39253	772
			Min	85	7308991	7190960	118031	50757	49937	820	3402142	3336523	65618	40025	39253	772
			Std. Dev Population	262	62803006	62267674	683853	111186	110477	1057	10472436	10270450	201985	0	0	0
			Std. Dev Sample	265	63603076	63060925	692564	112603	111884	1070	10605848	10401289	204559	0	0	0

Project Number	County	Planning District	Project Name	Number of Connections	Sewer EC (kg CO_2)						Septic EC (kg CO_2)					
					Total	Materials	Construction	Total Per Connection	Materials Per Connection	Construction Per Connection	Total	Materials	Construction	Total Per Connection	Materials Per Connection	Construction Per Connection
1	Lee	LEN	Woodway	510	1727467	1685980	41487	3387	3306	81	972949	943453	29496	1908	1850	58
2	Washington	MTR	West Central (Beaver Creek)	1160	7199464	7010769	188695	6206	6044	163	2212983	2145894	67089	1908	1850	58
3	Grayson	MTR	Fairview	335	5522782	5384723	138059	16486	16074	412	639094	619719	19375	1908	1850	58
4	Lee	LEN	Sandy Ridge/N. Jonesville	261	1301463	1269276	32187	4986	4863	123	497921	482826	15095	1908	1850	58
6	Smyth	MTR	Groseclose	215	2059878	2012730	47148	9581	9362	219	410165	397730	12435	1908	1850	58
7	Tazewell	CP	Baptist Valley East	955	2691320	2625849	65471	2818	2750	69	1821895	1766662	55233	1908	1850	58
8	Tazewell	CP	Baptist Valley West	1108	6158666	5993246	165420	5558	5409	149	2113780	2049698	64081	1908	1850	58
9	Wise	LEN	East Stone Gap/Cracker Neck	473	2145269	2092213	53056	4535	4423	112	902363	875007	27356	1908	1850	58
10	Buchanan	CP	Leemaster/Lovers Gap	272	1694153	1652251	41902	6229	6074	154	518906	503175	15731	1908	1850	58
11	Lee	LEN	Dryden Hts/Cross Creek	250	1071597	1035480	36117	4286	4142	144	476936	462477	14459	1908	1850	58
12	Lee	LEN	Rose Hill	358	1353673	1320531	33142	3781	3689	93	682972	662267	20705	1908	1850	58
13	Russell	CP	Hansonville	525	5365190	5197735	167456	10219	9900	319	1001565	971202	30363	1908	1850	58
14	Smyth	MTR	Pleasant Heights	153	995818	970806	25012	6509	6345	163	291885	283036	8849	1908	1850	58
15	Tazewell	CP	Gratton	425	2081923	2023787	58136	4899	4762	137	810791	786211	24580	1908	1850	58
16	Washington	MTR	Benhams Road	325	2437270	2374288	62982	7499	7306	194	620017	601220	18796	1908	1850	58
17	Washington	MTR	Spring Creek	727	6167484	6013043	154441	8483	8271	212	1386930	1344883	42046	1908	1850	58
18	Wise	LEN	Wildcat/Irondale	377	2099847	2036974	62874	5570	5403	167	719219	697415	21804	1908	1850	58
19	Scott	LEN	Daniel Boone	370	3330302	3233622	96681	9001	8740	261	705865	684466	21399	1908	1850	58
20	Scott	LEN	Yuma	390	2810545	2738697	71848	7207	7022	184	744020	721464	22556	1908	1850	58
21	Dickenson	CP	Rt 83/Georges Fork	140	1410778	1371568	39210	10077	9797	280	267084	258987	8097	1908	1850	58
22	Buchanan	CP	Poplar Creek	142	1080811	1054078	26734	7611	7423	188	270900	262687	8213	1908	1850	58
23	Smyth	MTR	Watson Gap	193	1706971	1664330	42641	8844	8623	221	368195	357032	11162	1908	1850	58
24	Tazewell	CP	Tazewell to Divides	165	1158186	1121808	36378	7019	6799	220	314778	305235	9543	1908	1850	58
25	Tazewell	CP	Tazewell to Claypool Alt I	464	6384212	6230480	153732	13759	13428	331	885193	858357	26836	1908	1850	58
26	Tazewell	CP	Abbs Valley	435	1420922	1372549	48373	3266	3155	111	829868	804710	25158	1908	1850	58
27	Washington	MTR	East Central	806	7757906	7526489	231418	9625	9338	287	1537641	1491026	46615	1908	1850	58
28	Wise	LEN	Coeburn Mountain	500	2150824	2097881	52943	4302	4196	106	953872	924954	28918	1908	1850	58
29	Wise	LEN	Powell Valley	355	3146434	3069601	76833	8863	8647	216	677249	656717	20531	1908	1850	58
30	Scott	LEN	Hiltons	263	2575312	2480091	95221	9792	9430	362	501737	486526	15211	1908	1850	58
31	Tazewell	CP	Birmingham	390	2774788	2690234	84554	7115	6898	217	744020	721464	22556	1908	1850	58
32	Buchanan	CP	Lower Mill Branch	103	1018698	993503	25195	9890	9646	245	196498	190541	5957	1908	1850	58
33	Buchanan	CP	Lynn Camp/Looney Creek	132	858108	836885	21222	6501	6340	161	251822	244188	7634	1908	1850	58
34	Grayson	MTR	Providence	258	2376487	2305795	70692	9211	8937	274	492198	477276	14921	1908	1850	58
35	Grayson	MTR	Stevens Creek	202	1458783	1422705	36078	7222	7043	179	385364	373681	11683	1908	1850	58
36	Lee	LEN	Red Hill/Poor Valley	141	946565	921401	25164	6713	6535	178	268992	260837	8155	1908	1850	58
37	Tazewell	CP	Red Ash	105	607217	592197	15020	5783	5640	143	200313	194240	6073	1908	1850	58
38	Washington	MTR	Larwood	126	659072	642250	16823	5231	5097	134	240376	233088	7287	1908	1850	58
39	Wise	LEN	Tacoma	144	357545	348702	8843	2483	2422	61	274715	266387	8328	1908	1850	58
40	Wise	LEN	Banner	169	518135	505320	12816	3066	2990	76	322409	312635	9774	1908	1850	58
41	Scott	LEN	Route 871	85	563987	549197	14790	6635	6461	174	162158	157242	4916	1908	1850	58
			Total	14507	99145854	96469061	2676792	280251	272729	7522	27675636	26836620	839015	76310	73996	2313
			Average	363	2478646	2411727	66920	7006	6818	188	691891	670916	20975	1908	1850	58
			Median	299	1893673	1849355	47761	6674	6498	176	569461	552198	17264	1908	1850	58
			Max	1160	7757906	7526489	231418	16486	16074	412	2212983	2145894	67089	1908	1850	58
			Min	85	357545	348702	8843	2483	2422	61	162158	157242	4916	1908	1850	58
			Std. Dev Population	262	1960983	1907800	53921	2892	2815	80	499154	484021	15132	0	0	0
			Std. Dev Sample	265	1985965	1932104	54608	2929	2851	81	505513	490187	15325	0	0	0

Project Number	County	Planning District	Project Name	Number of Connections	Sewer Cost ($) Total	Materials	Construction	Total Per Connection	Materials Per Connection	Construction Per Connection	Septic Cost ($) Total	Materials	Construction	Total Per Connection	Materials Per Connection	Construction Per Connection
1	Lee	LEN	Woodway	510	$ 4,524,780	$ 3,480,600	$ 1,044,180	$ 8,872	$ 6,825	$ 2,047	$ 3,036,540	$ 2,335,800	$ 700,740	$ 5,954	$ 4,580	$ 1,374
2	Washington	MTR	West Central (Beaver Creek)	1160	$ 24,273,288	$ 18,671,760	$ 5,601,528	$ 20,925	$ 16,096	$ 4,829	$ 6,906,640	$ 5,312,800	$ 1,593,840	$ 5,954	$ 4,580	$ 1,374
3	Grayson	MTR	Fairview	335	$ 11,637,080	$ 8,951,600	$ 2,685,480	$ 34,738	$ 26,721	$ 8,016	$ 1,994,590	$ 1,534,300	$ 460,290	$ 5,954	$ 4,580	$ 1,374
4	Lee	LEN	Sandy Ridge/N. Jonesville	261	$ 2,996,370	$ 2,304,900	$ 691,470	$ 11,480	$ 8,831	$ 2,649	$ 1,553,994	$ 1,195,380	$ 358,614	$ 5,954	$ 4,580	$ 1,374
6	Smyth	MTR	Groseclose	215	$ 5,294,020	$ 4,072,323	$ 1,221,697	$ 24,623	$ 18,941	$ 5,682	$ 1,280,110	$ 984,700	$ 295,410	$ 5,954	$ 4,580	$ 1,374
7	Tazewell	CP	Baptist Valley East	955	$ 6,910,020	$ 5,315,400	$ 1,594,620	$ 7,236	$ 5,566	$ 1,670	$ 5,686,070	$ 4,373,900	$ 1,312,170	$ 5,954	$ 4,580	$ 1,374
8	Tazewell	CP	Baptist Valley West	1108	$ 14,408,849	$ 11,083,730	$ 3,325,119	$ 13,004	$ 10,003	$ 3,001	$ 6,597,032	$ 5,074,640	$ 1,522,392	$ 5,954	$ 4,580	$ 1,374
9	Wise	LEN	East Stone Gap/Cracker Neck	473	$ 8,085,870	$ 6,219,900	$ 1,865,970	$ 17,095	$ 13,150	$ 3,945	$ 2,816,242	$ 2,166,340	$ 649,902	$ 5,954	$ 4,580	$ 1,374
10	Buchanan	CP	Leemaster/Lovers Gap	272	$ 3,787,160	$ 2,913,200	$ 873,960	$ 13,923	$ 10,710	$ 3,213	$ 1,619,488	$ 1,245,760	$ 373,728	$ 5,954	$ 4,580	$ 1,374
11	Lee	LEN	Dryden Hts/Cross Creek	250	$ 3,952,442	$ 3,040,340	$ 912,102	$ 15,810	$ 12,161	$ 3,648	$ 1,488,500	$ 1,145,000	$ 343,500	$ 5,954	$ 4,580	$ 1,374
12	Lee	LEN	Rose Hill	358	$ 5,804,765	$ 4,465,204	$ 1,339,561	$ 16,214	$ 12,473	$ 3,742	$ 2,131,532	$ 1,639,640	$ 491,892	$ 5,954	$ 4,580	$ 1,374
13	Russell	CP	Hansonville	525	$ 11,670,620	$ 8,977,400	$ 2,693,220	$ 22,230	$ 17,100	$ 5,130	$ 3,125,850	$ 2,404,500	$ 721,350	$ 5,954	$ 4,580	$ 1,374
14	Smyth	MTR	Pleasant Heights	153	$ 3,291,600	$ 2,532,000	$ 759,600	$ 21,514	$ 16,549	$ 4,965	$ 910,962	$ 700,740	$ 210,222	$ 5,954	$ 4,580	$ 1,374
15	Tazewell	CP	Gratton	425	$ 5,041,972	$ 3,878,440	$ 1,163,532	$ 11,863	$ 9,126	$ 2,738	$ 2,530,450	$ 1,946,500	$ 583,950	$ 5,954	$ 4,580	$ 1,374
16	Washington	MTR	Benhams Road	325	$ 7,014,280	$ 5,395,600	$ 1,618,680	$ 21,582	$ 16,602	$ 4,981	$ 1,935,050	$ 1,488,500	$ 446,550	$ 5,954	$ 4,580	$ 1,374
17	Washington	MTR	Spring Creek	727	$ 18,659,056	$ 14,353,120	$ 4,305,936	$ 25,666	$ 19,743	$ 5,923	$ 4,328,558	$ 3,329,660	$ 998,898	$ 5,954	$ 4,580	$ 1,374
18	Wise	LEN	Wildcat/Irondale	377	$ 7,141,030	$ 5,493,100	$ 1,647,930	$ 18,942	$ 14,571	$ 4,371	$ 2,244,658	$ 1,726,660	$ 517,998	$ 5,954	$ 4,580	$ 1,374
19	Scott	LEN	Daniel Boone	370	$ 7,271,680	$ 5,593,600	$ 1,678,080	$ 19,653	$ 15,118	$ 4,535	$ 2,202,980	$ 1,694,600	$ 508,380	$ 5,954	$ 4,580	$ 1,374
20	Scott	LEN	Yuma	390	$ 6,671,197	$ 5,131,690	$ 1,539,507	$ 17,106	$ 13,158	$ 3,947	$ 2,322,060	$ 1,786,200	$ 535,860	$ 5,954	$ 4,580	$ 1,374
21	Dickenson	CP	Rt 83/Georges Fork	140	$ 3,094,260	$ 2,380,200	$ 714,060	$ 22,102	$ 17,001	$ 5,100	$ 833,560	$ 641,200	$ 192,360	$ 5,954	$ 4,580	$ 1,374
22	Buchanan	CP	Poplar Creek	142	$ 2,363,530	$ 1,818,100	$ 545,430	$ 16,645	$ 12,804	$ 3,841	$ 845,468	$ 650,360	$ 195,108	$ 5,954	$ 4,580	$ 1,374
23	Smyth	MTR	Watson Gap	193	$ 5,017,350	$ 3,859,500	$ 1,157,850	$ 25,997	$ 19,997	$ 5,999	$ 1,149,122	$ 883,940	$ 265,182	$ 5,954	$ 4,580	$ 1,374
24	Tazewell	CP	Tazewell to Divides	165	$ 2,767,310	$ 2,128,700	$ 638,610	$ 16,772	$ 12,901	$ 3,870	$ 982,410	$ 755,700	$ 226,710	$ 5,954	$ 4,580	$ 1,374
25	Tazewell	CP	Tazewell to Claypool Alt I	464	$ 13,670,800	$ 10,516,000	$ 3,154,800	$ 29,463	$ 22,664	$ 6,799	$ 2,762,656	$ 2,125,120	$ 637,536	$ 5,954	$ 4,580	$ 1,374
26	Tazewell	CP	Abbs Valley	435	$ 3,838,583	$ 2,952,756	$ 885,827	$ 8,824	$ 6,788	$ 2,036	$ 2,589,990	$ 1,992,300	$ 597,690	$ 5,954	$ 4,580	$ 1,374
27	Washington	MTR	East Central	806	$ 22,208,004	$ 17,083,080	$ 5,124,924	$ 27,553	$ 21,195	$ 6,358	$ 4,798,924	$ 3,691,480	$ 1,107,444	$ 5,954	$ 4,580	$ 1,374
28	Wise	LEN	Coeburn Mountain	500	$ 8,217,300	$ 6,321,000	$ 1,896,300	$ 16,435	$ 12,642	$ 3,793	$ 2,977,000	$ 2,290,000	$ 687,000	$ 5,954	$ 4,580	$ 1,374
29	Wise	LEN	Powell Valley	355	$ 9,055,150	$ 6,965,500	$ 2,089,650	$ 25,507	$ 19,621	$ 5,886	$ 2,113,670	$ 1,625,900	$ 487,770	$ 5,954	$ 4,580	$ 1,374
30	Scott	LEN	Hiltons	263	$ 5,895,110	$ 4,534,700	$ 1,360,410	$ 22,415	$ 17,242	$ 5,173	$ 1,565,902	$ 1,204,540	$ 361,362	$ 5,954	$ 4,580	$ 1,374
31	Tazewell	CP	Birmingham	390	$ 6,515,197	$ 5,011,690	$ 1,503,507	$ 16,706	$ 12,850	$ 3,855	$ 2,322,060	$ 1,786,200	$ 535,860	$ 5,954	$ 4,580	$ 1,374
32	Buchanan	CP	Lower Mill Branch	103	$ 2,174,770	$ 1,672,900	$ 501,870	$ 21,114	$ 16,242	$ 4,873	$ 613,262	$ 471,740	$ 141,522	$ 5,954	$ 4,580	$ 1,374
33	Buchanan	CP	Lynn Camp/Looney Creek	132	$ 1,907,880	$ 1,467,600	$ 440,280	$ 14,454	$ 11,118	$ 3,335	$ 785,928	$ 604,560	$ 181,368	$ 5,954	$ 4,580	$ 1,374
34	Grayson	MTR	Providence	258	$ 5,191,940	$ 3,993,800	$ 1,198,140	$ 20,124	$ 15,480	$ 4,644	$ 1,536,132	$ 1,181,640	$ 354,492	$ 5,954	$ 4,580	$ 1,374
35	Grayson	MTR	Stevens Creek	202	$ 3,205,540	$ 2,465,800	$ 739,740	$ 15,869	$ 12,207	$ 3,662	$ 1,202,708	$ 925,160	$ 277,548	$ 5,954	$ 4,580	$ 1,374
36	Lee	LEN	Red Hill/Poor Valley	141	$ 3,084,094	$ 2,372,380	$ 711,714	$ 21,873	$ 16,825	$ 5,048	$ 839,514	$ 645,780	$ 193,734	$ 5,954	$ 4,580	$ 1,374
37	Tazewell	CP	Red Ash	105	$ 1,448,850	$ 1,114,500	$ 334,350	$ 13,799	$ 10,614	$ 3,184	$ 625,170	$ 480,900	$ 144,270	$ 5,954	$ 4,580	$ 1,374
38	Washington	MTR	Larwood	126	$ 2,665,689	$ 2,050,530	$ 615,159	$ 21,156	$ 16,274	$ 4,882	$ 750,204	$ 577,080	$ 173,124	$ 5,954	$ 4,580	$ 1,374
39	Wise	LEN	Tacoma	144	$ 1,881,360	$ 1,447,200	$ 434,160	$ 13,065	$ 10,050	$ 3,015	$ 857,376	$ 659,520	$ 197,856	$ 5,954	$ 4,580	$ 1,374
40	Wise	LEN	Banner	169	$ 2,402,010	$ 1,847,700	$ 554,310	$ 14,213	$ 10,933	$ 3,280	$ 1,006,226	$ 774,020	$ 232,206	$ 5,954	$ 4,580	$ 1,374
41	Scott	LEN	Route 871	85	$ 1,446,614	$ 1,112,780	$ 333,834	$ 17,019	$ 13,092	$ 3,927	$ 506,090	$ 389,300	$ 116,790	$ 5,954	$ 4,580	$ 1,374
			Total	14507	$266,487,420	$204,990,323	$ 61,497,097	$ 743,580	$ 571,985	$ 171,595	$ 86,374,678	$ 66,442,060	$ 19,932,618	$ 238,160	$ 183,200	$ 54,960
			Average	363	$ 6,662,185	$ 5,124,758	$ 1,537,427	$ 18,590	$ 14,300	$ 4,290	$ 2,159,367	$ 1,661,052	$ 498,315	$ 5,954	$ 4,580	$ 1,374
			Median	299	$ 5,116,956	$ 3,936,120	$ 1,180,836	$ 17,100	$ 13,154	$ 3,946	$ 1,777,269	$ 1,367,130	$ 410,139	$ 5,954	$ 4,580	$ 1,374
			Max	1160	$ 24,273,288	$ 18,671,760	$ 5,601,528	$ 34,738	$ 26,721	$ 8,016	$ 6,906,640	$ 5,312,800	$ 1,593,840	$ 5,954	$ 4,580	$ 1,374
			Min	85	$ 1,446,614	$ 1,112,780	$ 333,834	$ 7,236	$ 5,566	$ 1,670	$ 506,090	$ 389,300	$ 116,790	$ 5,954	$ 4,580	$ 1,374
			Std. Dev Population	262	$ 5,372,518	$ 4,132,706	$ 1,239,812	$ 5,786	$ 4,451	$ 1,335	$ 1,557,841	$ 1,198,339	$ 359,502	$ -	$ -	$ -
			Std. Dev Sample	265	$ 5,440,961	$ 4,185,354	$ 1,255,606	$ 5,860	$ 4,508	$ 1,352	$ 1,577,687	$ 1,213,605	$ 364,082	$ -	$ -	$ -

APPENDIX 2

Total Resource Consumption | **Resource Consumption per Connection**