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An Energy Cost Comparison – Vacuum & Gravity Sewer Systems

Thursday, May 30th, 2013

Presented by
Jeff Gilbert, P.E.
Dan Burden, Ph.D., P.E.

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Presenters

Speakers:

Jeff Gilbert, P.E.
Associate
WadeTrim

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Senior Associate
WadeTrim

Moderator:

Bob Drake
Editor-in-Chief, CE News & RAI
ZweigWhite

Wade Trim's Involvement w/Vacuum Sewers

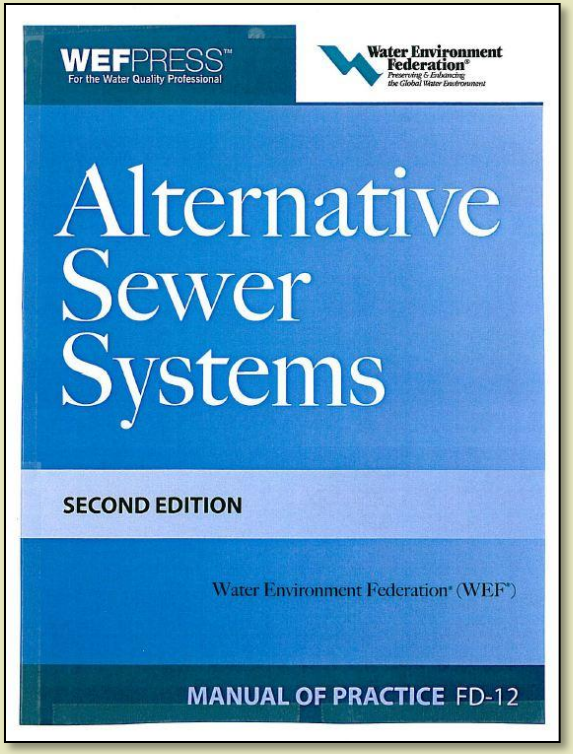
- Florida Keys Design Experience
  - Key Largo Wastewater Treatment District, Area C
  - Middle Plantation Key, Islamorada
- Owner's Representative – Islamorada Wastewater Program (DBO)

Jeff Gilbert, P.E.

- B.S. Civil Engineering
- Florida registered professional engineer
- Worked for last 6 years in Key Largo and Islamorada as part of the state mandated wastewater improvement program
- Design and construction experience with vacuum sewer technology in the Florida Keys
- Resident engineer for Village of Islamorada's Wastewater Improvement Program

Dan Burden, Ph.D., P.E.

- Ph.D. and Master in Civil Engineering
- Florida registered professional engineer
- 25+ years of consulting experience in FL
- Technical Reviewer for WEF Manual of Practice FD -12 "Alternative Sewer Systems"
- Program Manager for Sarasota County Septic Tank Replacement Program
- Technical Review Committee Member for Islamorada Wastewater Program (Present)

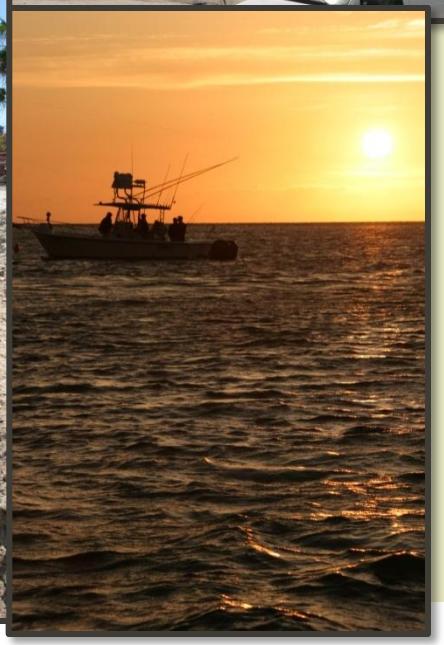


Learning Objectives

- Basic understanding of sewer collection technologies
- Operational theory of gravity and vacuum sewer systems
- Major components used in designing a sewer collection system
- Evaluation of power usage at a conventional wastewater lift station and a vacuum pump station
- Comparison of power usage and identification of energy savings

Presentation Outline

- Study Purpose
- Sewer Collection Technologies
- Design & Construction Components
- Study Location
- Comparative Methodology
- Analysis Results
- Conclusions



Study Purpose

- Provide accurate power costs for future vacuum projects and O&M budgets
- Compare vacuum power costs against Water Environment Federation (WEF) published data
- Determine if vacuum sewers require more or less energy for operation than a gravity sewer system in a similar sized service area

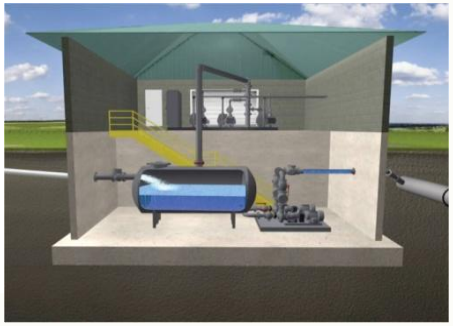
Part 1 – Jeff Gilbert, P.E.

- Vacuum Sewer System Components
- How A Vacuum Sewer Works
- Gravity Sewer Collection Systems

Vacuum Sewer System Components

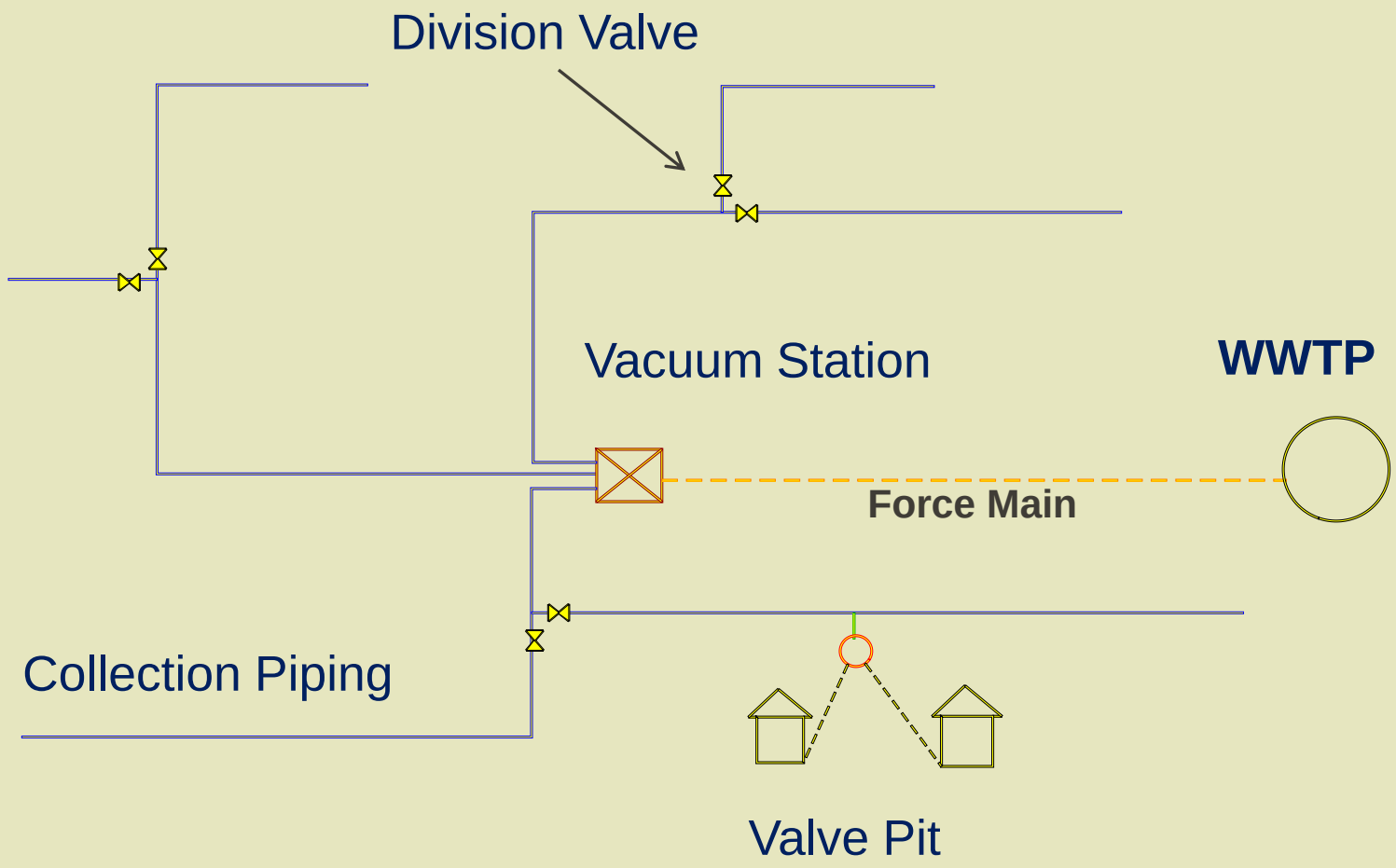
Valve Pits

Vacuum Mains



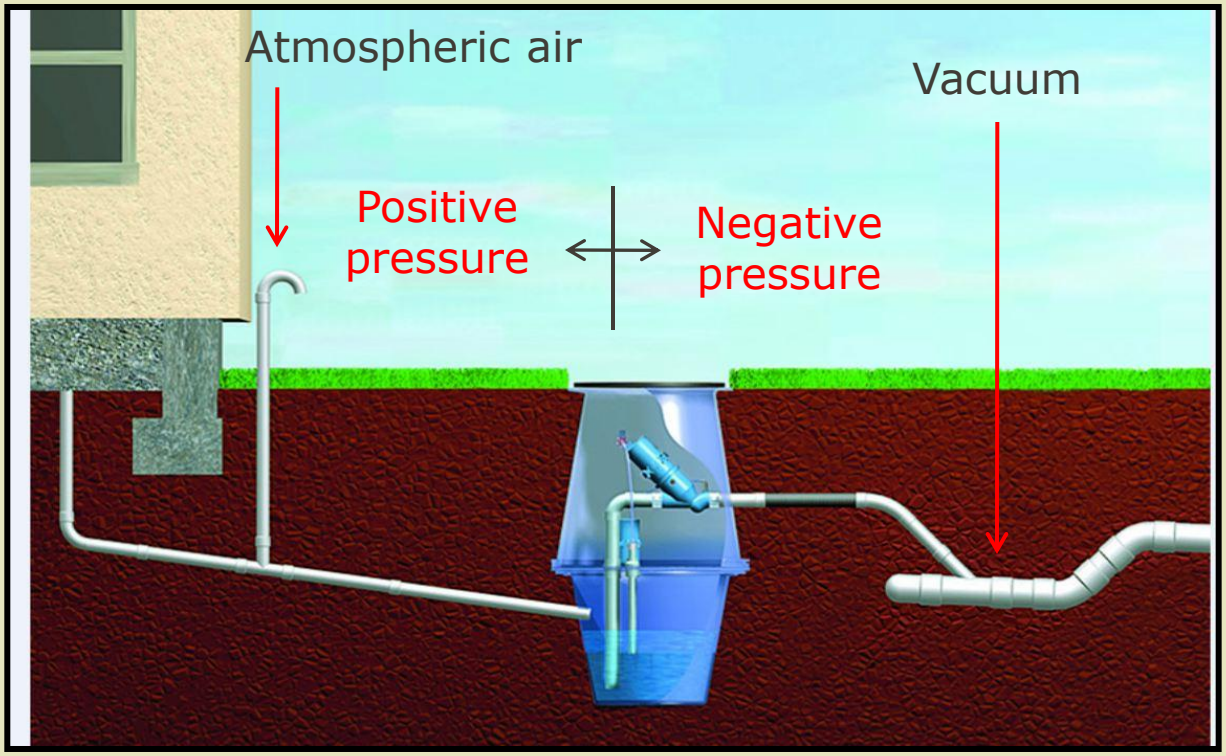
Vacuum Station

Vacuum System Schematic



How a Vacuum Sewer Works – At the House

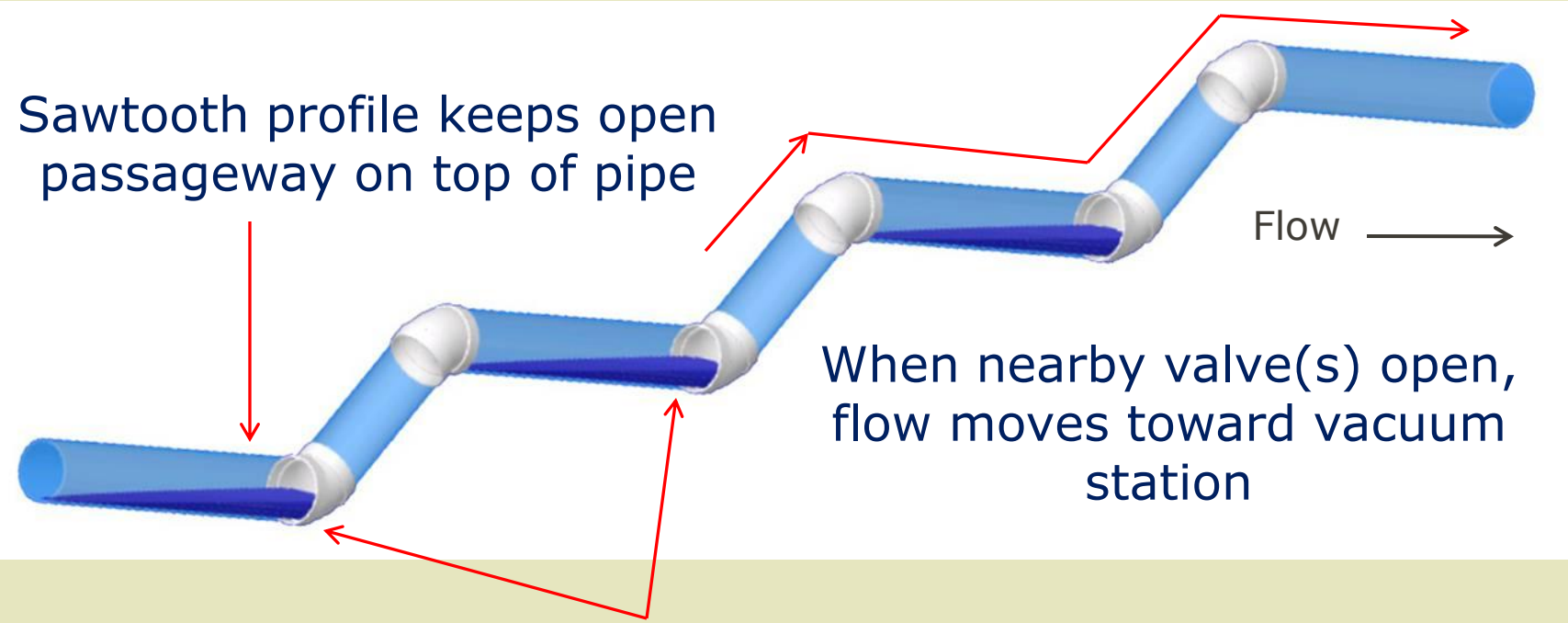
(1)
House to pit via gravity lateral



(3)
Differential pressure propels sewage toward vacuum station

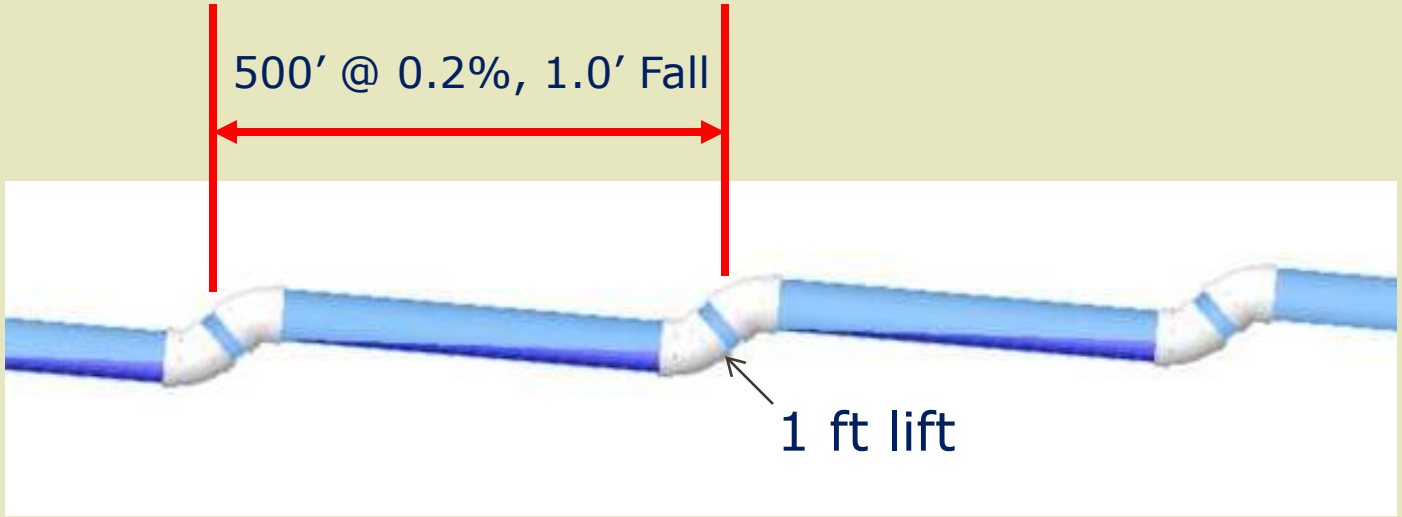
(2)
Interface valve opens and the contents are sucked out

How a Vacuum Sewer Works – In the Vacuum Main



Vacuum Main Profile

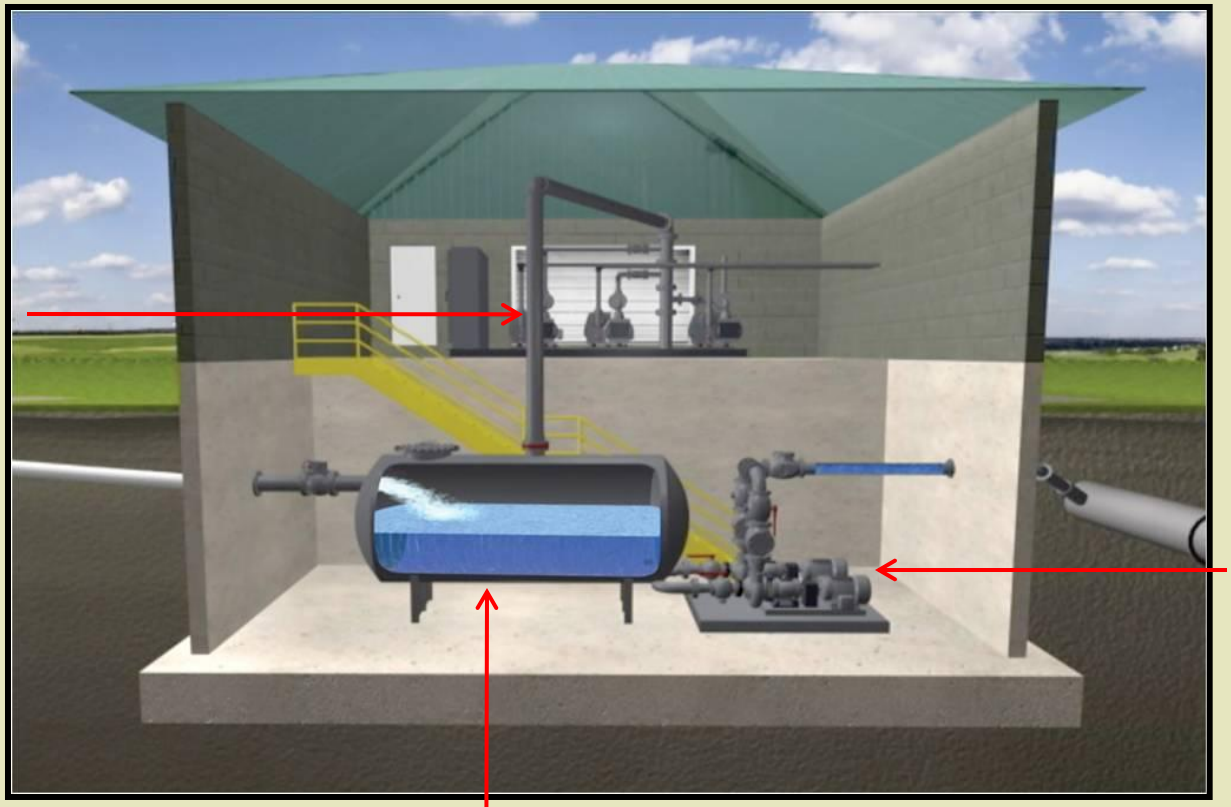
Vacuum main drops 1 ft every 500 ft
then a 1ft lift is used to return the main to the original invert



Minimum 0.2% slope towards the vacuum station

How a Vacuum Sewer Works – At the Vacuum Station

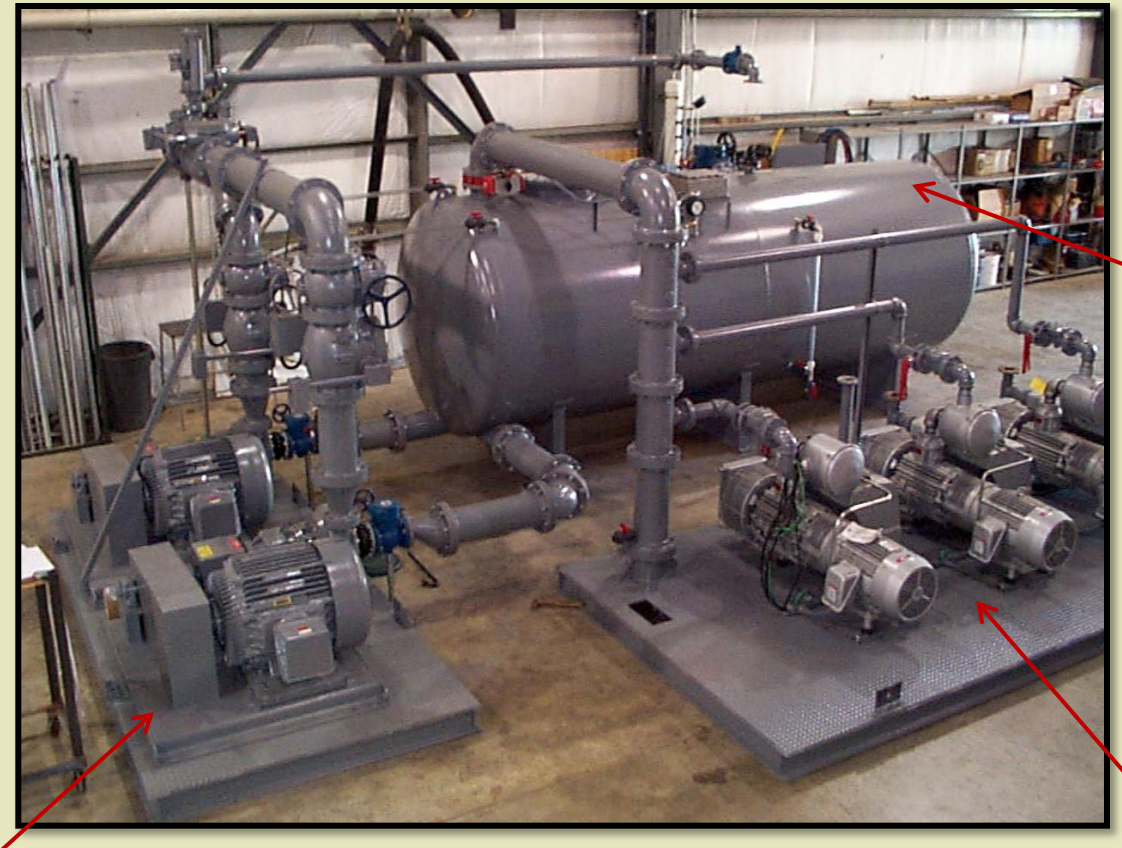
(1)
Vacuum pumps cycle on and off 16”–20” Hg



(3)
Sewage pumps transfer the contents to WWTP

(2)
Wastewater enters the collection tank

Vacuum Station



COLLECTION TANK
is liquid and vacuum reservoir

SEWAGE PUMPS
Sends sewage to gravity main, force main, or WWTP

VACUUM PUMPS
Cycle to maintain vacuum

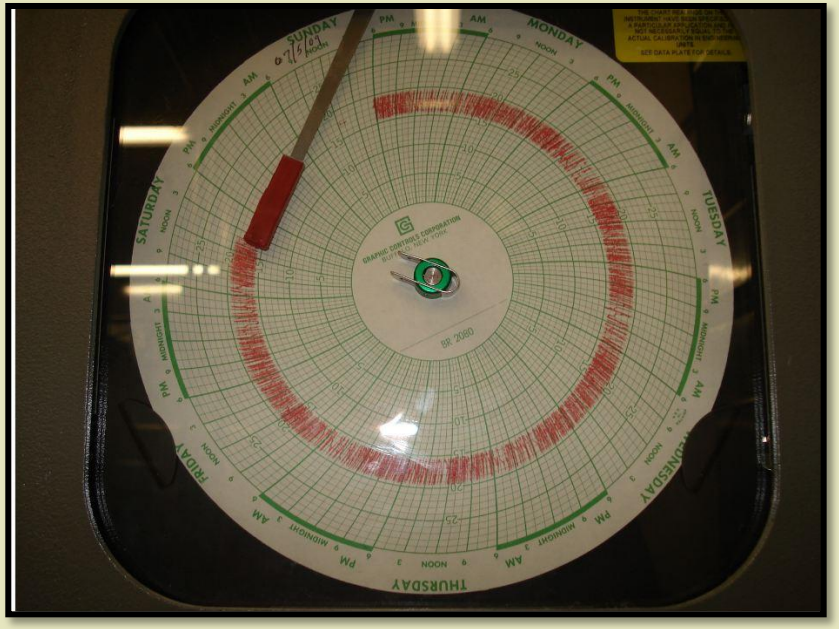
Vacuum Pumps

Sewage Pumps & Collection Tank

Vacuum Chart Recorder

7-day Chart Recorder

Continuous Monitoring of the System



Touch Screen and Run Meters

Interface touch screen
Pump run-time meters (vacuum & sewage pumps)

Vacuum Station – Various Building Styles

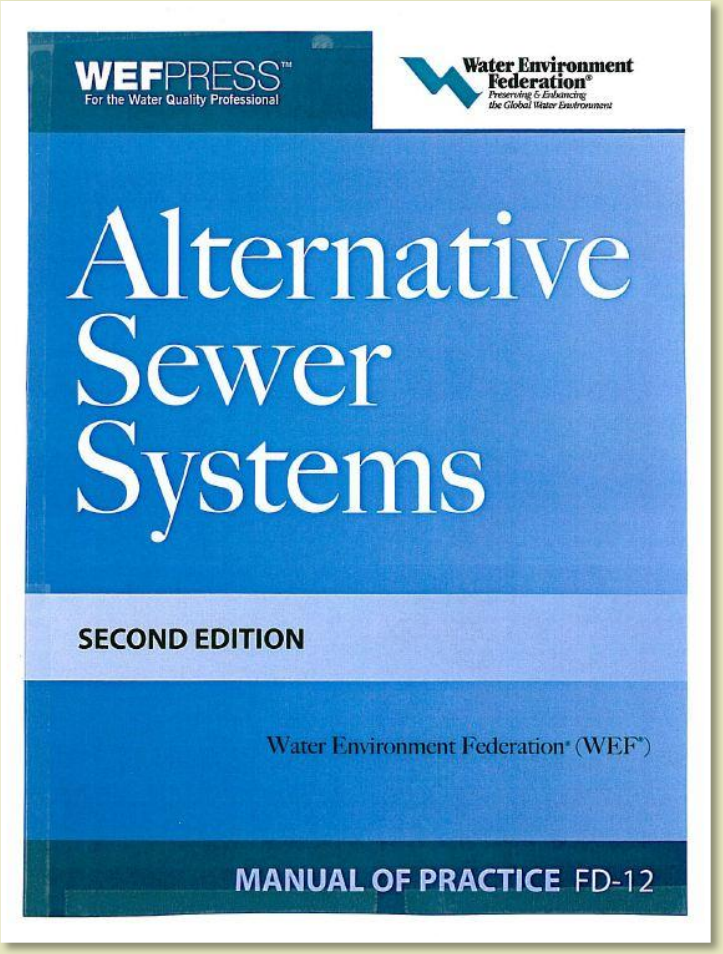

Gregory, MI


Key Largo, FL


Ocean Shores, WA


Barnstable, MA

WEF Manual of Practice FD-12

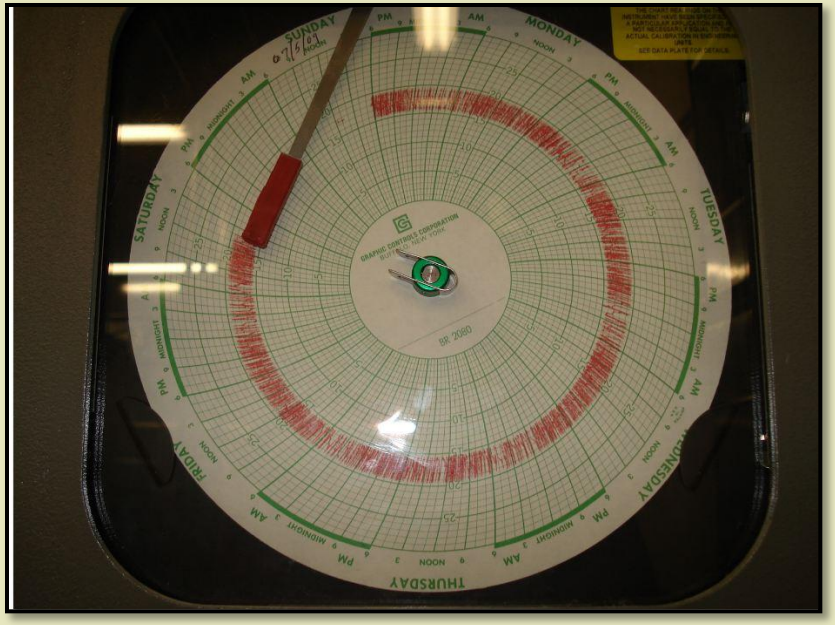


Manual contains about 120 pages on vacuum sewers

- Planning
- Design
- Construction
- O&M
- System Management
- Sample Regulations

Vacuum Sewer Misconceptions

- Vacuum pumps do not operate continuously. They cycle on/off for an approx. 3 minutes (see illustration w/ chart)
- Infiltration/Inflow is not a common occurrence
- A vacuum leak will not take an entire system down



Gravity Sewer Basics

- Minimum pipe velocity 2 fps required
- Corrosion control and protection needed due to H_2S gas production
- Pumping stations are required
- Manholes are required at 300-500 ft (typical)
- Manhole designs need to address inflow/infiltration

Gravity Sewers – Lift Station Design

Lift stations – Hydraulic structures which are used to transport wastewater

Key components:

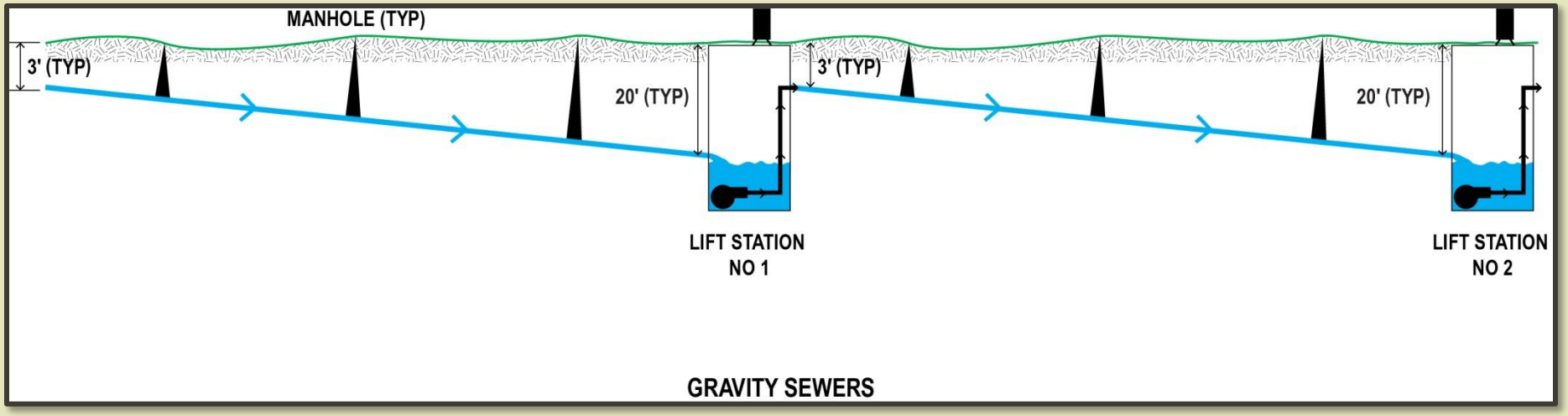
- Wet well
- Pumps
- Motors
- Controls
- Power

2 Types of Lift Stations

- Submersible Lift Stations (small to medium in size)
  - Generally smaller in size, < 700 gpm
  - Duplex pumps, usually constant speed
  - Wet well detention times < 20-30 mins

- Dry Pit Lift Stations (medium to large in size)
  - Larger stations, usually a master lift station
  - Variable speed pumps typically used
  - Wet well detention times usually < 15 mins
  - Standby generator system

Lift Station Illustration



Typical Gravity Sewer & Lift Station Profile

Typical Gravity Sewer System

- Advantages:
  - Allows for handling of grit and solids
  - By maintaining a minimum velocity, the production of H_2S and methane gases can be reduced
- Disadvantages:
  - Minimum slope requirements result in deep excavation
  - Pumping stations are required
  - Manholes are usually a source of inflow/infiltration
  - Potential for manhole overflows during power failures (lift stations)

Gravity Sewers – Design & Construction

- Construction can be disruptive due to the depth of construction, multiple lift stations, and dewatering requirements
- Manholes required at set intervals, pipe intersections, changes in pipe direction and changes in pipe slopes
- Infiltration and inflow always a concern
- Buoyancy considerations
- Renewal and replacement costs associated with manholes & lift stations (corrosion problems).

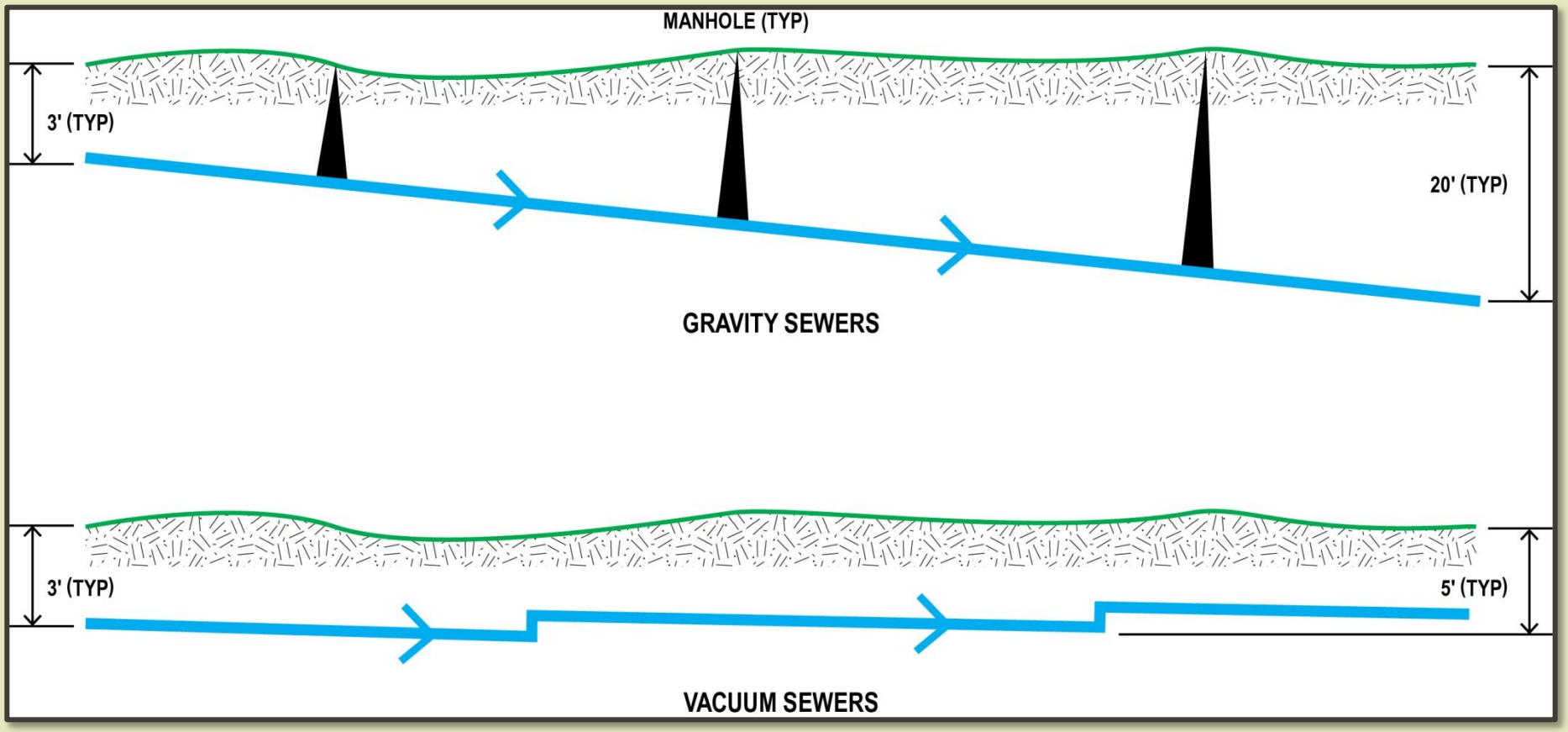
Part 2 – Dan Burden, Ph.D., P.E.

- Comparative Study
- Study Location
- Methodology
- Data Analysis
- Results

Gravity vs. Vacuum Sewers

Parameter	Gravity Sewer	Vacuum Sewer
Pipe Size	8 to 42 inch	4 to 10 inch
Minimum Slope	0.40 ft/100-ft (8” dia) 0.037 ft/100-ft (42” dia)	0.20 ft/100-ft independent of pipe dia
Manholes	4-ft min. diameter; Spaced every 300-600 ft; Coatings required	Manholes not required
Construction Depth	Range from 3.0 to 6.5 feet below surface	Shallow (30-48 inches below surface), saw-tooth profile
Energy Costs	**???**	**???**

Vacuum & Gravity Sewer Comparisons



Vacuum & Gravity Sewer Comparisons

- Vacuum sewers are typically installed in the right-of-way, require shallow trenches with minimal disruption; and less environmental impact

- Gravity sewers are installed along roadway centerlines; can result in short term road closures due to the depth of construction and dewatering requirements; and require more pavement restoration

Which is More Energy Intensive?

Compared to a gravity lift station, a vacuum station has vacuum pumps in addition to sewage pumps. So the answer is obvious if the gravity layout does not require a lift station at all or if only 1 lift station is required.

Gravity	Vacuum	Less power required
0 lift station	1 Vacuum station	Gravity
1 lift station	1 Vacuum station	Gravity
Multiple lift stations	1 Vacuum station	???

But, when multiple lift stations are required to do the same job as 1 vacuum station, the answer is not so obvious.

When Multiple Stations are Required – Which Technology is More Energy Intensive: Gravity or Vacuum?

Even though vacuum has fewer pumps, does the additional power required for the vacuum pumps result in more power for vacuum?

Or, does the pumping and re-pumping associated with gravity result in more power for gravity?

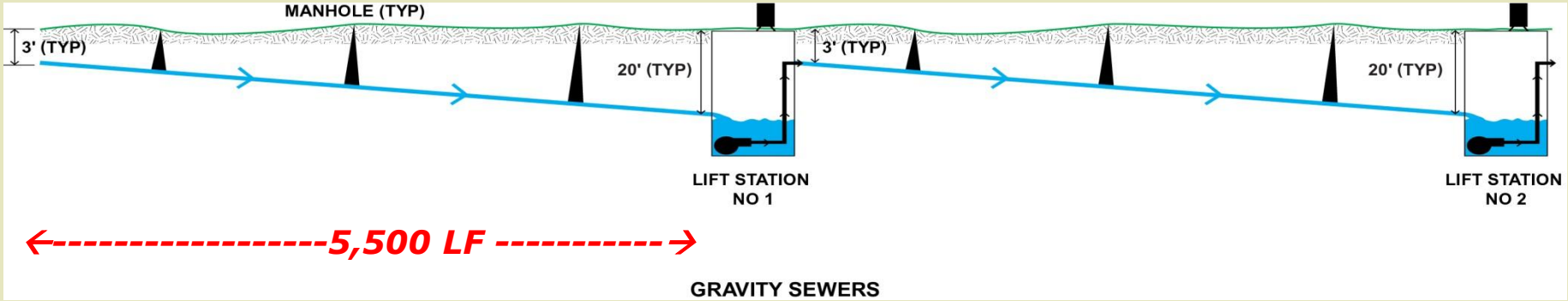
Gravity or vacuum?

Gravity or vacuum?

Gravity Main – Some Simple Math

Problem: Determine the depth required for a lift station using an 8-inch diameter gravity sewer for a total distance of 11,000 linear feet based on the following assumptions:

1. Minimum slope = 0.40% min slope for 8” (4 ft/1,000 ft)
2. 3-foot minimum cover
3. Ground elevation = 5.0 ft NGVD



Solution:

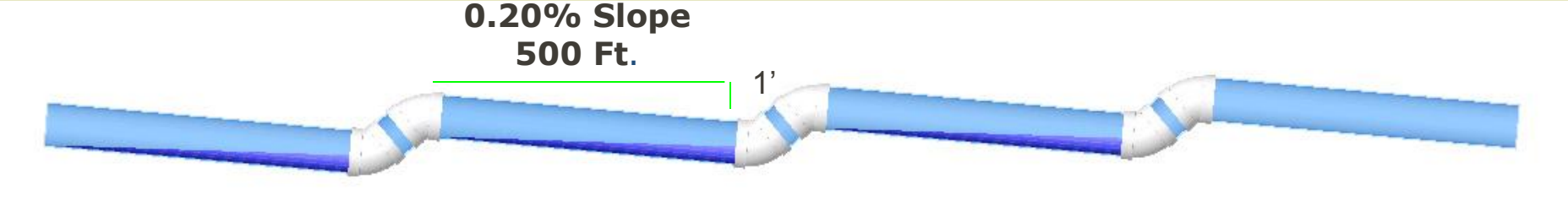
5.0 – (3.0 minimum cover) – (4/1,000)*(5,500) = 5-3-22 = **-20 ft NGVD**

Using a lift station every 5,500 LF, would result in an elevation fall of -17 ft.

Vacuum Main – Some Simple Math

Min slope = 0.20% min slope (1 ft/500 ft); Lifts used to regain elevation

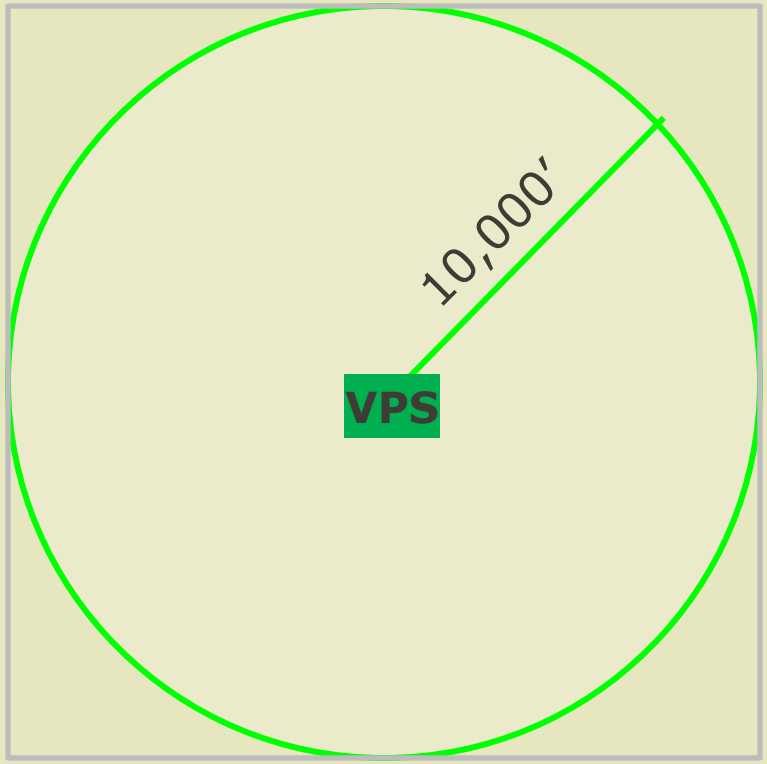
Following this general pattern of 1 ft of fall in 500 ft followed by a 1 ft lift allows the trench depth to stay within a foot of the starting depth throughout (3 to 4 ft typical)



With a 6" diameter vacuum main, it is possible to use (20) - 1 ft lifts and still stay within AIRVAC's design criteria for static loss

This equates to a total line length of 10,000 ft (20 lifts every 500 ft = 10,000 ft)

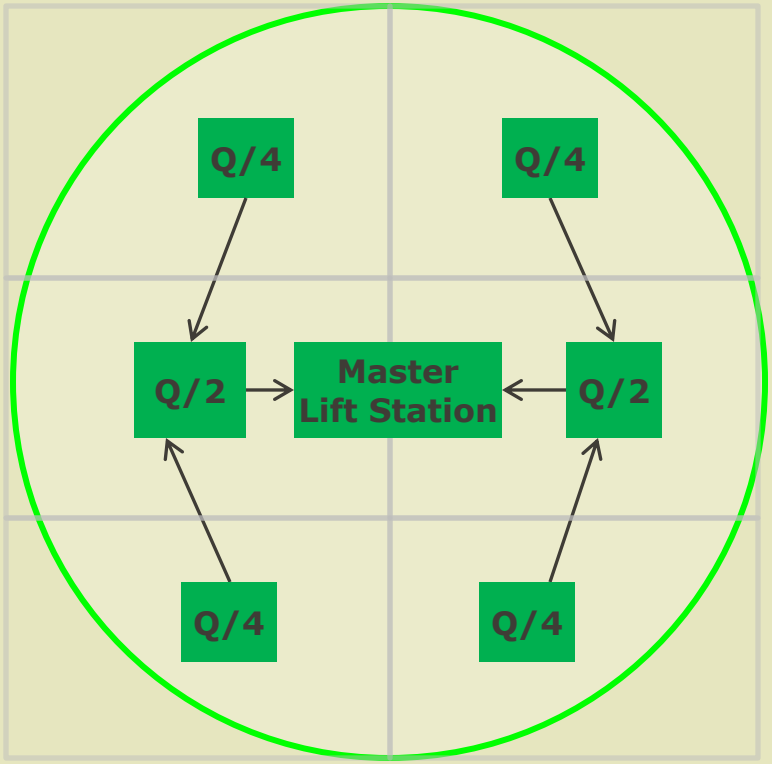
Potential Service Area Limits: Vacuum Sewer



In flat terrain, a single, large centrally located vacuum pump station (VPS) can serve an area roughly 3 to 4 square miles

Same Service Area – Gravity Sewer

To serve the same 3 to 4 square mile service area with gravity sewers would require a total of 7 lift stations



<u>7 Lift Stations</u>

- 4 small sized LS (each Q/4);
- 2 medium sized LS (each Q/2); and
- 1 Master LS (Q)

Sewer Pump Station Comparison-Typical

Parameter	Gravity Sewers	Vacuum Sewers
# Stations Required	7 Lift Stations	1 Vacuum Station
# Vacuum Pumps	None	2 or 3 (10 – 25 Hp/ea)
# Sewage Pumps	14 (Hp varies)	2 (Hp varies)
TOTAL	7 Pump Stations & 14 Pumps	1 Pump Station & 5 Pumps

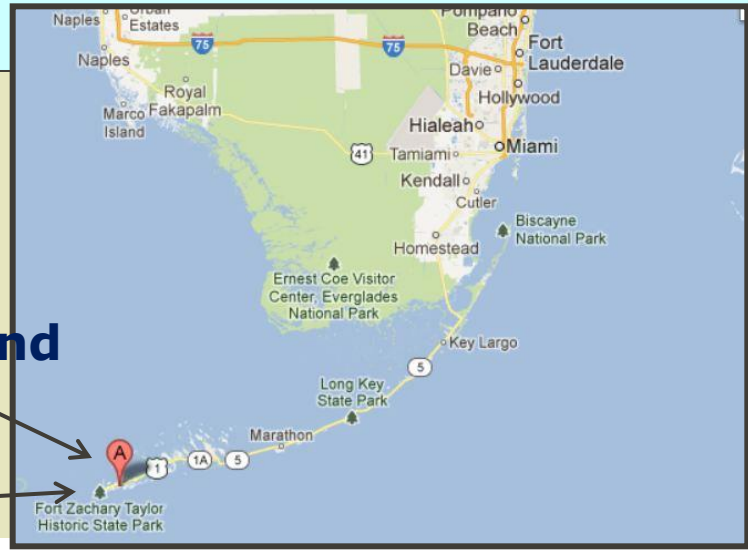
Comparative Energy Study

Objectives:

1. Evaluate existing power usage at conventional wastewater lift stations
2. Compare lift station power data with AIRVAC vacuum pump stations
3. Document the energy savings achieved with the use of a vacuum pump station

Study Location

- Stock Island, Florida is located at 24°34’12”N 81°44’15”W
- Approx. 1 square mile of land
- Population = 4,000 (est)
- Approx. 1,855 housing units
- Sewer utility on Stock Island is owned and operated by Key West Resort Utilities Corporation



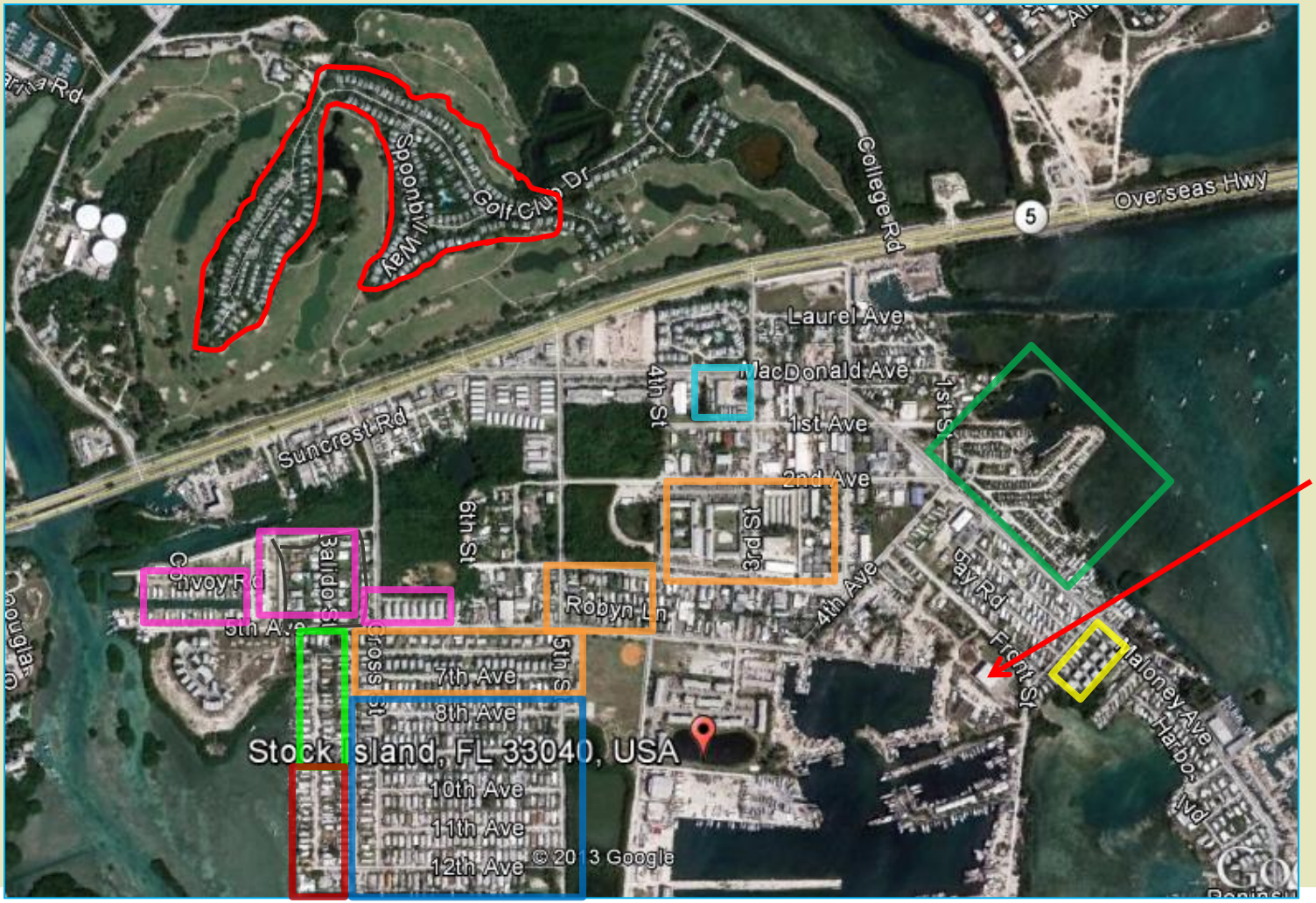
Stock Island

Key West

Why KWRU Was Chosen for this Study

- Ideal candidate for comparative evaluation
- Two different collection systems operated by same utility
  - Conventional gravity sewers w/ multiple lift stations
  - Vacuum sewer system
- Both systems are similar in size (# connections)
- Both systems have been in operation for 10+ years
- Good operating records available from the utility

Conventional Gravity Sewer System (9 L.S.)



WWTP

Why Stock Island Was Chosen for This Study

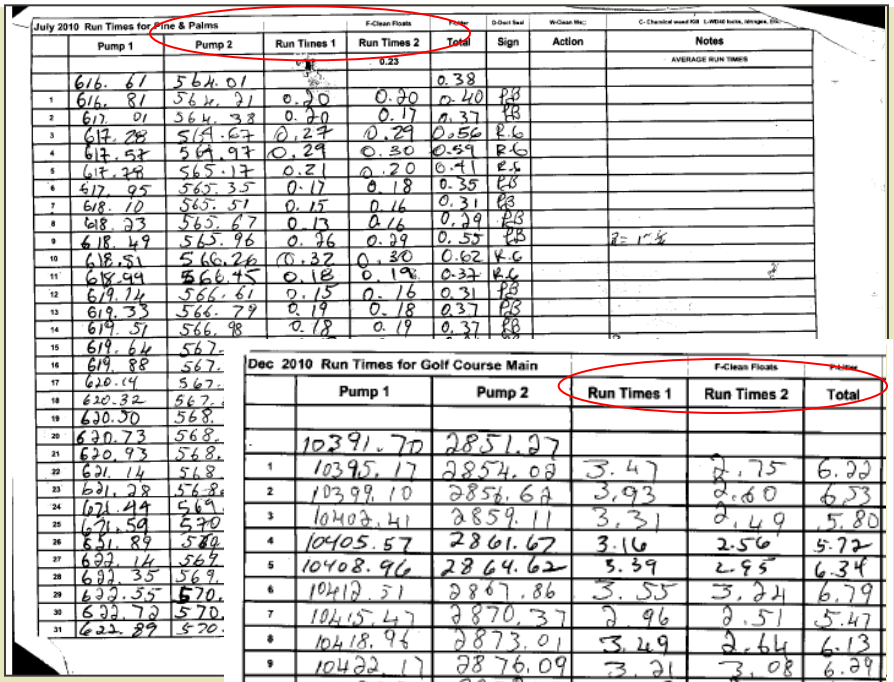
- Sewer lateral inspection requirements for new connections has reduced observed inflow/infiltration into the Stock Island collection system
- KWRU routinely conducts salinity monitoring in its system to detect where potential I/I problems may exist and can be remedied
- Salinities > 2-3 ppt will usually indicate a significant I/I problem

Key West Resort Utility – Stock Island, FL

Parameter	Gravity	Vacuum
System type in operation	Yes	Yes
# Pump Stations	3 large 6 small	1
Operational 10+ years?	Yes	Yes
# ERC's	928	1,309
Power records	Yes	Yes

Methodology

- Lift Station Pump Information
- Lift Station Pump Run Times
- Vacuum Station Pump Run Times
- 3-year Data Period Used
- Actual Data Records:
  - January 2010 thru April/May 2012
- Data Extrapolation:
  - 2nd half of 2012



July 2010 Run Times for Pine & Palms

	Pump 1	Pump 2	Run Times 1	Run Times 2	Total	Sign	Action	Notes
				0.23				AVERAGE RUN TIMES
	616.61	564.01			0.38			
1	616.81	564.21	0.20	0.20	0.40	PB		
2	617.01	564.38	0.20	0.17	0.37	PB		
3	617.28	564.67	0.27	0.29	0.56	R.G		
4	617.57	564.97	0.29	0.30	0.59	R.G		
5	617.78	565.17	0.21	0.20	0.41	R.G		
6	617.95	565.35	0.17	0.18	0.35	PB		
7	618.10	565.51	0.15	0.16	0.31	PB		
8	618.23	565.67	0.13	0.16	0.29	PB		
9	618.49	565.96	0.26	0.29	0.55	PB		
10	618.81	566.26	0.32	0.30	0.62	R.G		
11	618.99	566.45	0.18	0.19	0.37	R.G		
12	619.14	566.61	0.15	0.16	0.31	PB		
13	619.33	566.79	0.19	0.18	0.37	PB		
14	619.51	566.98	0.18	0.19	0.37	PB		
15	619.64	567.						
16	619.88	567.						
17	620.14	567.						
18	620.32	567.						
19	620.50	568.						
20	620.73	568.						
21	620.93	568.						
22	621.14	568.						
23	621.28	568.						
24	621.44	569.						
25	621.59	570						
26	621.89	570						
27	622.14	569						
28	622.35	569.						
29	622.55	570.						
30	622.72	570.						
31	622.89	570.						

Dec 2010 Run Times for Golf Course Main

	Pump 1	Pump 2	Run Times 1	Run Times 2	Total
	10391.70	2851.27			
1	10395.17	2854.02	3.47	2.75	6.22
2	10399.10	2856.62	3.93	2.60	6.53
3	10402.41	2859.11	3.31	2.49	5.80
4	10405.57	2861.67	3.16	2.56	5.72
5	10408.96	2864.62	3.39	2.95	6.34
6	10412.51	2867.86	3.55	3.24	6.79
7	10415.47	2870.37	2.96	2.51	5.47
8	10418.96	2873.01	3.49	2.64	6.13
9	10422.17	2876.09	3.21	3.08	6.29
10	10425.76	2878.79	3.59	2.70	6.29
11	10428.58	2881.04	2.82	3.25	6.07
12	10431.40	2883.81	2.82	2.77	5.59
13	10434.89	2886.59	3.49	2.98	6.47
14	10437.88	2889.38	2.99	2.79	5.78
15	10440.68	2891.80	2.80	2.42	5.22
16	10443.34	2894.47	2.66	2.67	5.33
17	10446.17	2897.40	2.83	2.93	5.76
18	10448.60	2899.35	2.43	1.95	4.38
19	10451.60	2901.94	3.00	2.59	5.59
20	10455.73	2904.99	4.13	3.05	7.18
21	10458.93	2907.40	3.20	2.41	5.61
22	10462.11	2910.18	3.18	2.78	5.96
23	10465.08	2912.57	2.97	2.39	5.36
24	10468.30	2915.36	3.22	2.79	6.01
25	10471.35	2917.93	3.05	2.57	5.62
26	10475.05	2920.83	4.70	2.90	7.60
27	10478.64	2923.59	3.59	2.76	6.35
28	10482.63	2926.57	4.01	2.98	6.99
29	10486.68	2929.94	4.05	3.37	7.42
30	10491.26	2934.11	4.58	4.17	8.75
31	10496.53	2938.68	5.26	4.57	9.85

Typical Power Bill

KEYS ENERGY SERVICES
Powering Paradise Since 1943

Account Number 6636391-00

Name KW RESORT UTILITY CORP

Service Address 6630 FRONT ST Pine & Palms

Meter Number	Read Dates Present	Read Dates Previous	Billing Days	Meter Readings Code	Meter Readings Present	Meter Readings Previous	Multiplier	Usage	Units	Power Factor
ELECTRIC: 0000055353	12/07/2010	11/12/2010	25	RE	06650	06645	1	5	kWh	
ELECTRIC: 0000055353	12/07/2010	11/12/2010	25	RE	0		1	0.00	kW	
ELECTRIC: 0000057022	12/13/2010	12/07/2010	6	MR	00018	00000	1	18	kWh	
ELECTRIC: 0000057022	12/13/2010	12/07/2010	6	MR	57		1	0.57	kW	

All payments are due upon receipt. Payments received after 2:00 p.m. will be processed the next business day. A 5% penalty will be assessed on current amounts not paid by the "Past Due On" date. **Any unpaid previous balance on your bill may cause immediate disconnection of service.**

Billing Summary	
Previous Balance as of 11-18-10	8.30
Payments & Adjustments	-8.30
Balance Forward as of 12-20-10	.00
Current Charges as of 12-20-10	11.67
Total Amount Due	11.67

PREVIOUS BALANCE	8.30
PAYMENT 12/03/2010	-8.30
BALANCE FORWARD	**0.00**

	RATE	USAGE	CHARGES
CUSTOMER CHARGE			7.32
ENERGY CHARGE	0.138300	23	3.18
POWER ADJUSTMENT	-0.001000	23	-0.02
GROSS RECEIPTS TAX			0.27
LOCAL OPTION TAX			0.16
STATE ENERGY TAX			0.11
SALES TAX			0.65
CURRENT CHARGES			**11.67**
TOTAL AMOUNT DUE			**11.67**

RECEIVED DEC 29 2010 By

CONSUMPTION HISTORY			
Read Date	Days	Electric Use (kWh)	Avg. (kWh) Usage per Day
12-13-10	31	23	0.74
11-12-10	29	1	0.03
10-14-10	30	716	23.87
09-14-10	32	140	4.38
08-13-10	29	95	3.28
07-15-10	30	88	2.93
06-15-10	32	95	2.97
05-14-10	30	89	2.97
04-14-10	30	91	3.03
03-15-10	31	105	3.39
02-12-10	30	101	3.37
01-13-10	33	120	3.64
12-11-09	30	128	4.27

If you have any questions, please call Keys Energy Services at (305) 295-1000, or visit our website: www.KeysEnergy.com

Bill Type	Account Type	Bill Date	Past Due On	Total Amount Due	Payment Type
REGULAR	COM SM 210	12/20/2010	01/17/2011	11.67	PAYMENT DUE UPON RECEIPT

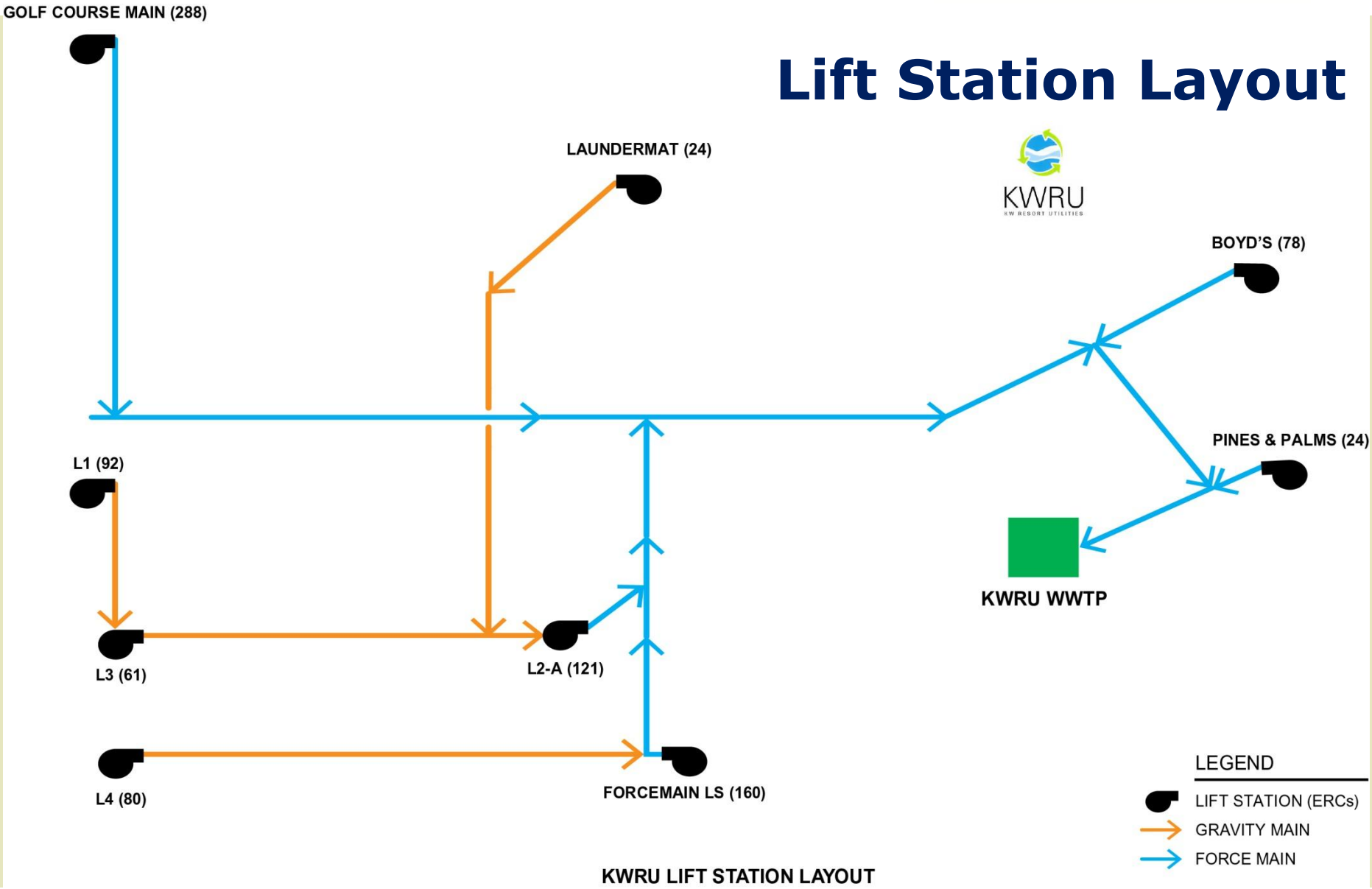
MESSAGE: WISHING YOU A BRIGHT HOLIDAY SEASON, AND A PROSPEROUS NEW YEAR! HAPPY HOLIDAYS FROM KEYS ENERGY SERVICES!

Lift Station Information

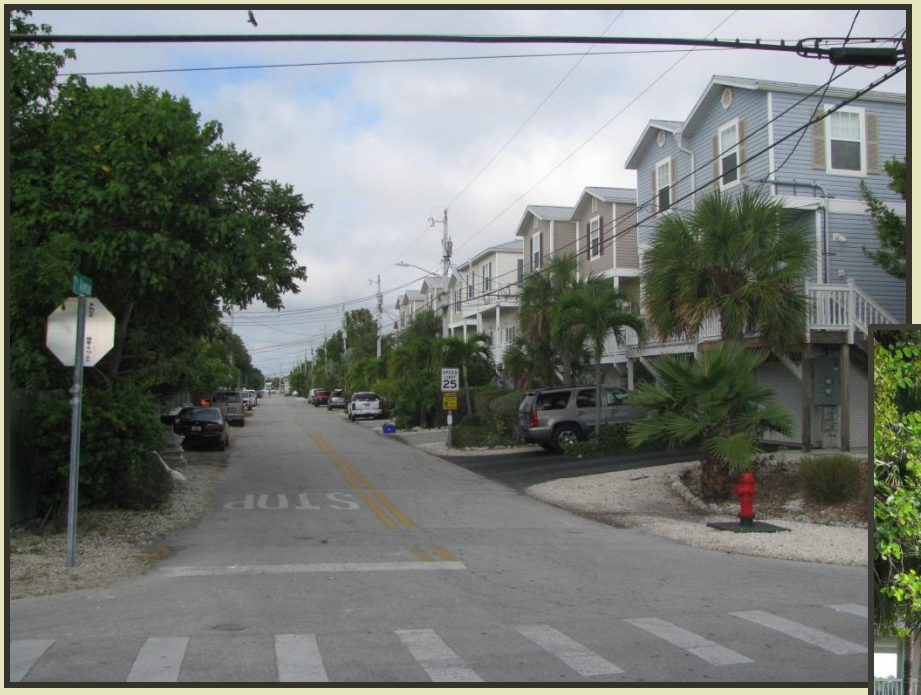
- # pumps (duplex, triplex station)
- Voltage
- Full load amperage
- Annualized run times
- Power usage (calculated)
- Power costs (calculated)
- Based on $0.1383 kW/hr costs in the Keys

# Pumps	Voltage	Pump #1 Amps	Pump #2 Amps	Total kW Usage	Annualized Pump Run Time (hrs)	Annual Power Cost	Monthly Average Power Cost
2	230	22.6	20.8	9.982	5,351	$7,387	$616

Lift Station Layout



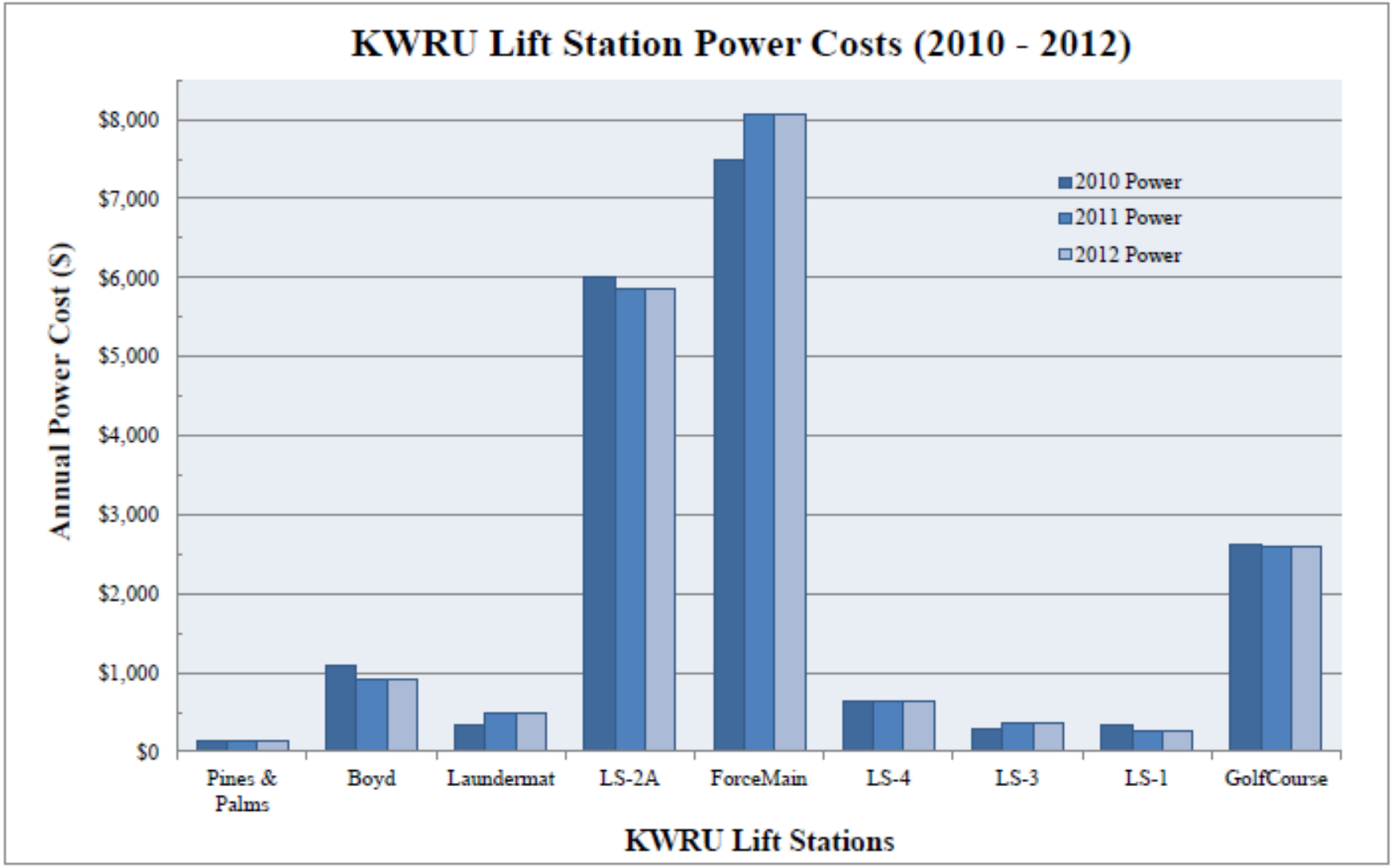
Typical KWRU Residential Connections



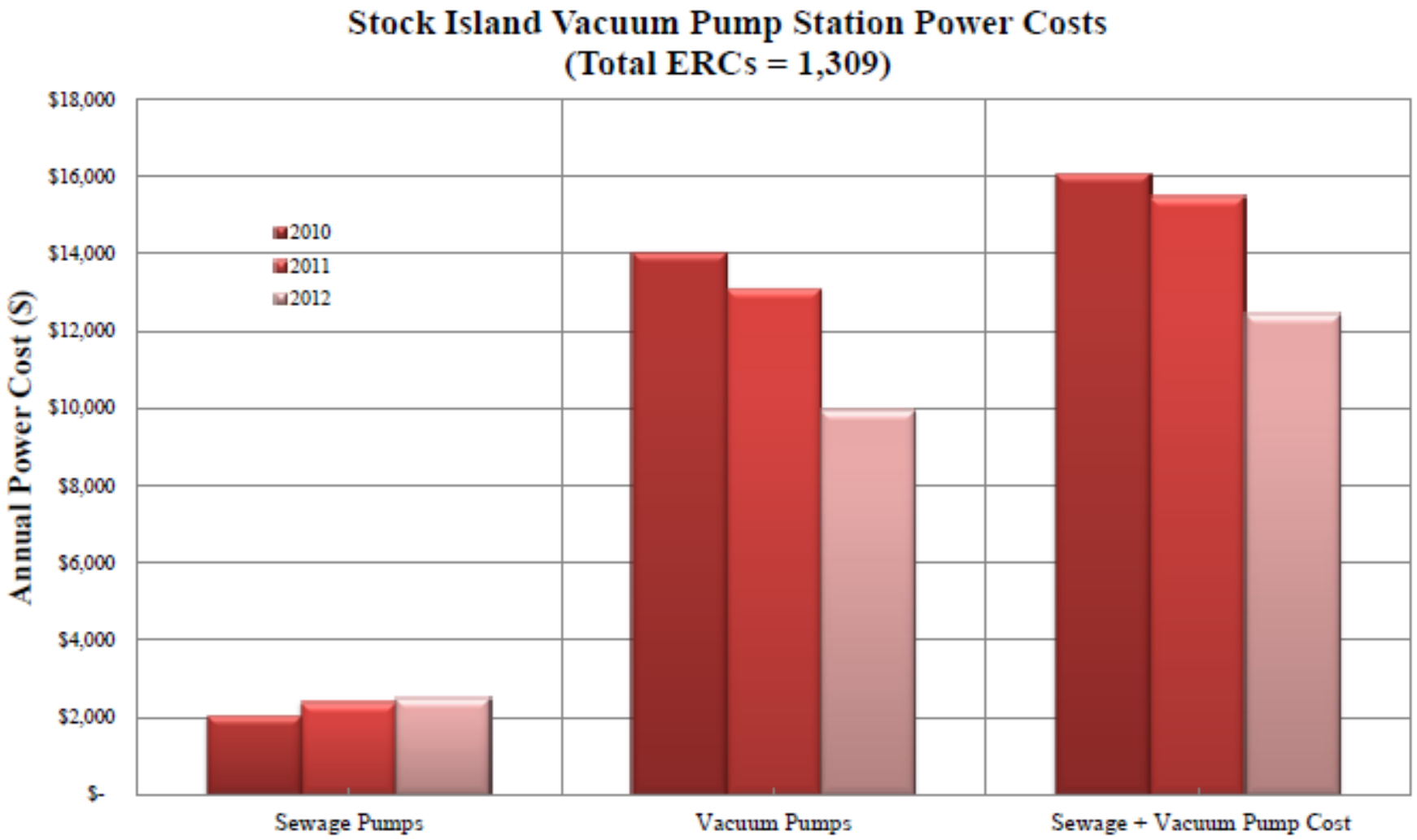
KWRU System Connections

KWRU Lift Station Name	Equivalent Residential Connections (ERCs)
Laundermat	24
Pines & Palms	24
LS-3	61
Boyd	78
LS-4	80
LS-1	92
LS-2A	121 (298)
ForceMain	160 (240)
GolfCourse	288
TOTAL	**928**

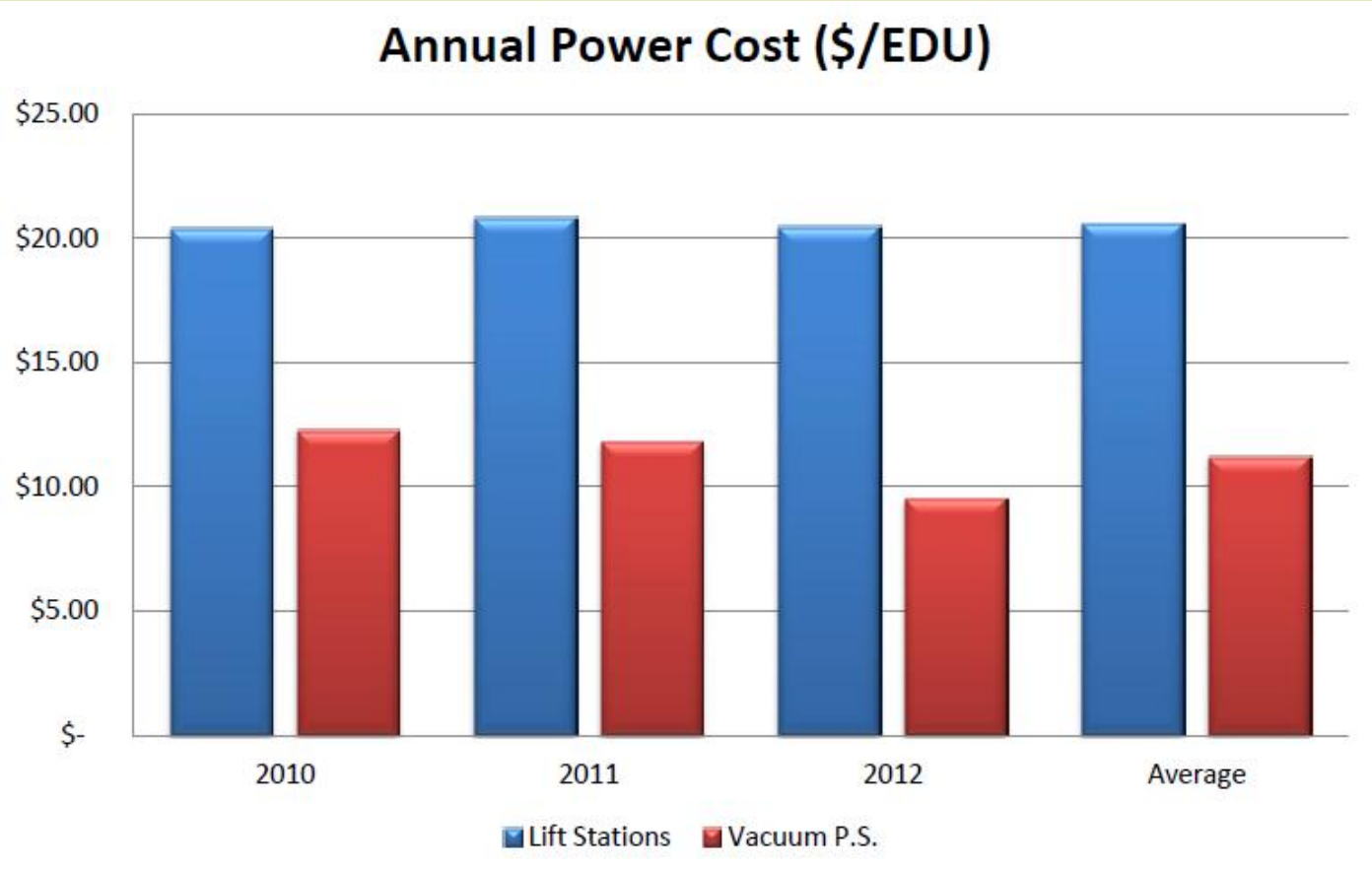
Lift Station Power Costs



VPS Power Costs



Cost Comparison Results

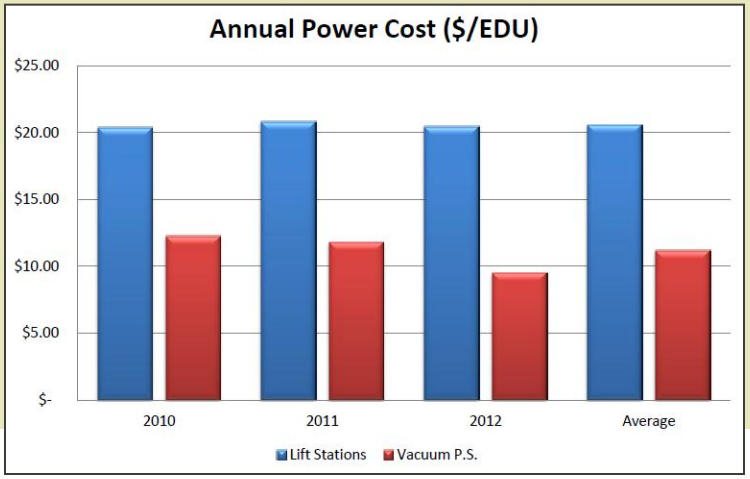


VPS Power Cost = $11.21/ERC
(based on 1,309 ERCs)

L.S. Power Cost = $20.57/ERC
(based on 928 ERCs)

Cost Comparison Results

Parameter	WEF MOP No. FD-12 Published Results	KWRU Vacuum Pump Station
Monthly Power Costs ($/kWh/EDU)	$1.66 - $3.34/EDU	$1.71/EDU
Power Rate	$0.10/kWh	$0.1383/kWh
Installation Date(s)	1970 – 2001	2002



Results

Stock Island Gravity System

- Multiple small lift stations w/ only 2 large stations in the system
- Most gravity systems have multiple large stations (5-10)

Results – Stock Island VPS

- Located adjacent to WWTP; meaning less power consumption required for sewage pumps
- Average runtime is 3.28 hrs/day for sewage pumps (Sept 2010)
- Sewage pump flow (VPS) accounted for approx. 162,400 gals of treated flow (approx. 50% of the total system flow – 330,000 gpd through the WWTP)

Conclusions

- Vacuum sewers are more energy efficient when compared with conventional gravity sewer systems for similar service areas

- Results compare favorably with WEF Manual results
- Possible federal and/or state program financial incentives for energy conservation

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- Chris Johnson, Key West Resort Utilities Corp.
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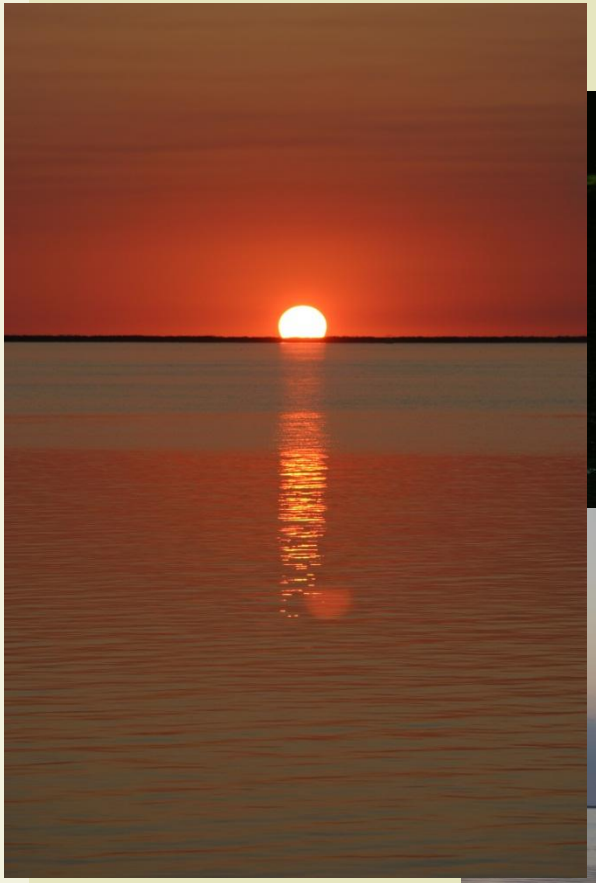
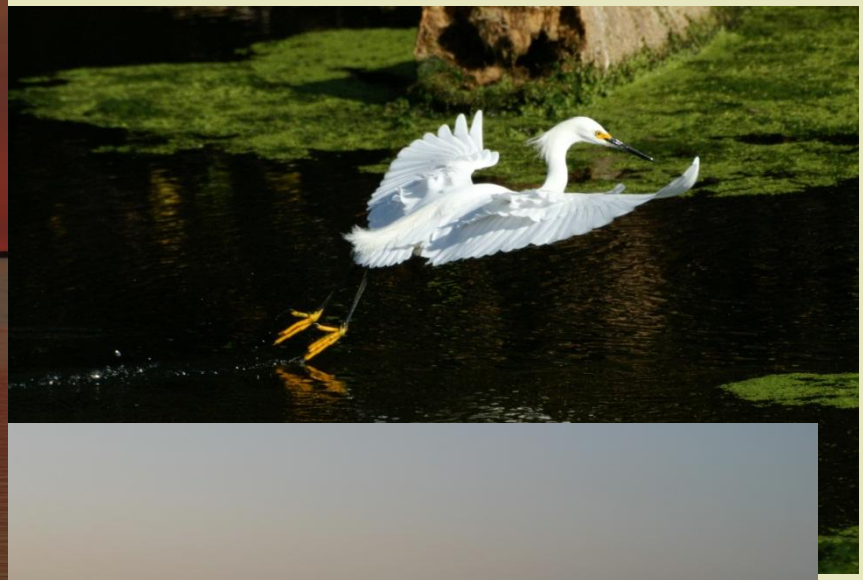
Q&A





Follow up Q&A

Log on to www.cenews.com/webcast to find answers to more questions.

Thank you!