New England Water Environment Association
Annual Conference and Exhibit
January 21st – 24th 2018 Boston, MA

Keith J McHale, P.E.
Environment One Corporation

Hydraulics of Pressure Sewer Systems

Flow Characterization of Downhill Pumping

Pressure Sewer System

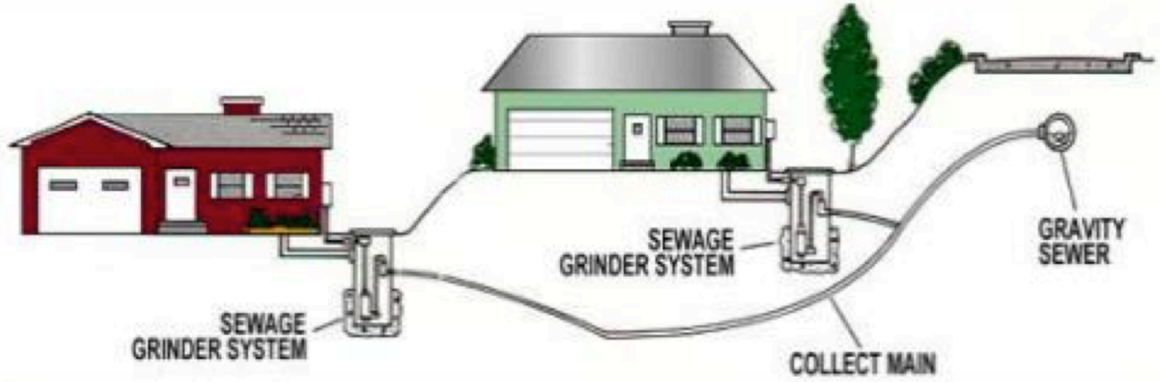
- Wastewater collection systems that use individual residential pumps to convey the flow to a central treatment system, lift station, gravity sewer, or force main
- System consists of
  - Grinder pump
  - Small diameter pressure pipe

The Heart of Pressure Sewers

- Pump basin
- Pumps
  - Progressing cavity (semi-positive displacement)
  - Centrifugal
- Liquid level sensors
- Pump control
- Pump removal guidance

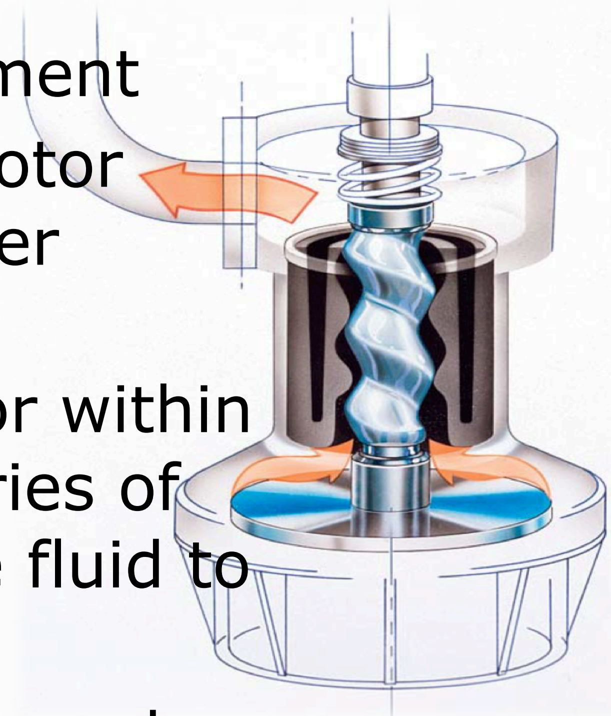
Are Advantages Advantages?

- Key advantage compared to gravity
  - Buried just below the frost line
  - Follows the contours of the land
- Segments of downhill, pumped flow are not uncommon
- Is downhill pumping a problem?

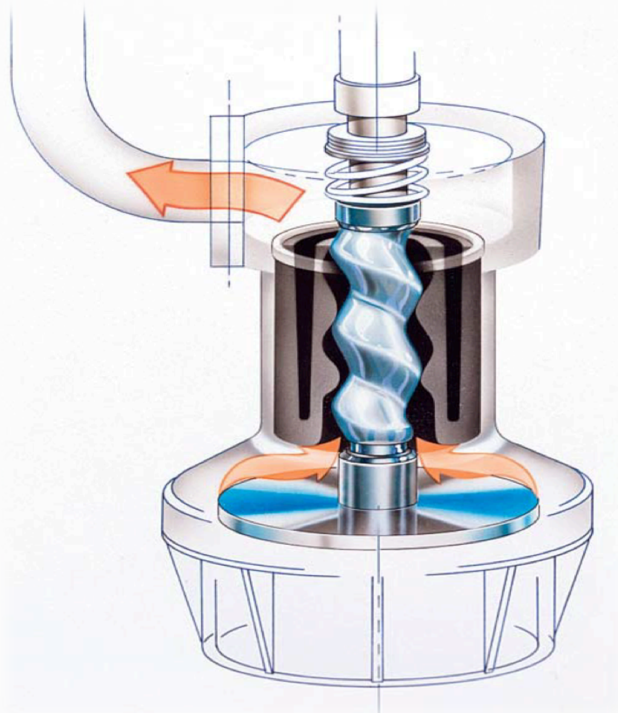


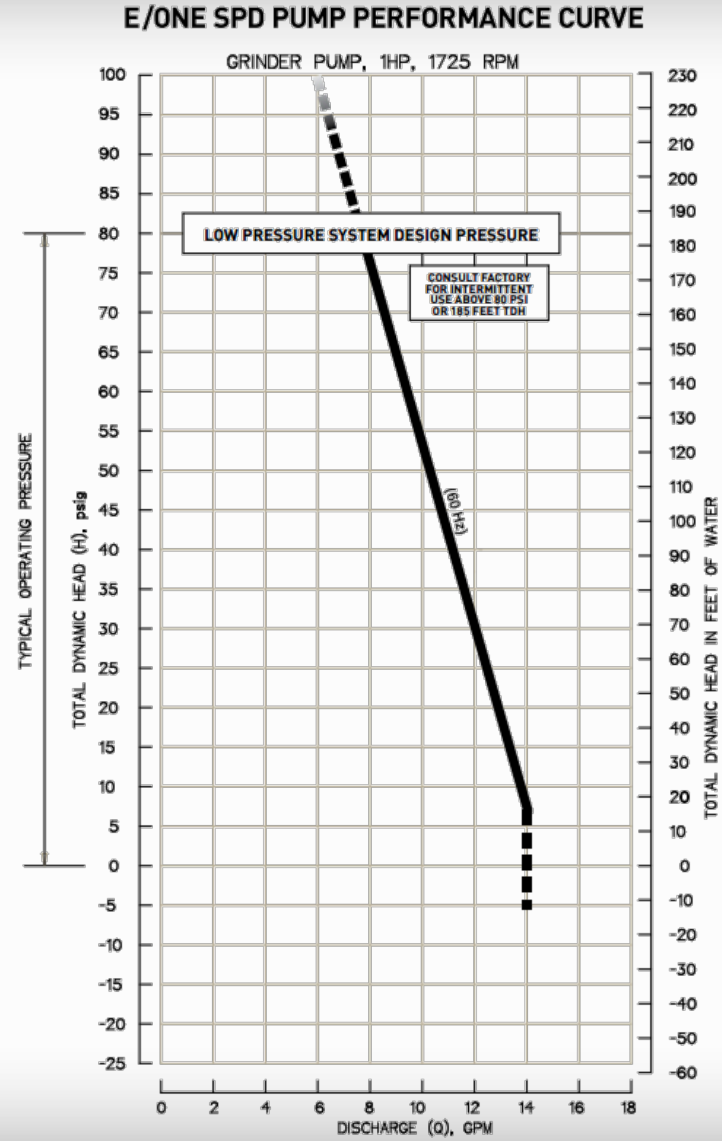
Pump Wet End

- Progressing Cavity
  - Semi-positive displacement
  - Stainless steel helical rotor and stationary elastomer stator
  - The rotation of the rotor within the stator creates a series of cavities that moves the fluid to the discharge
  - Produces a constant flow rate, only marginally effected by system pressure



SPD Pump Characteristics





System Design Methodology

- The Probability Method (aka Sim Ops)
  - Is the preferred design methodology used for systems with near-vertical pressure head – discharge curves (semi-positive displacement pumps)
  - is based on the assumption that each pump that is running will produce a near identical flow rate

Peak Flow Design Basis

- Simultaneous Pump Operation

- Predicts the maximum number of pumps expected to be running simultaneously

Pump Cores Connected	Pumps Operating Simultaneously
1	1
2 – 3	2
4 – 9	3
10 – 18	4
19– 30	5
31– 50	6
51 – 80	7
81 – 113	8
114 – 146	9
147 – 179	10
312 – 344	15
477 – 509	20

Flow Velocity and Friction Loss

Table 5

SDR 21 PVC PIPE

Flow Velocity and Friction Head Loss *vs* Pumps in Simultaneous Operation (C = 150)

	1 1/4 in.		1 1/2 in.		2 in.		2 1/2 in.		3 in.		4 in.		5 in.		6 in.		8 in.		
N	V	H_F	V	H_F	V	H_F	V	H_F	V	H_F	V	H_F	V	H_F	V	H_F	V	H_F	N
1	1.99	1.15	1.52	0.60															1
2	3.99	4.16	3.04	2.15	1.95	0.73													2
3	5.98	8.82	4.56	4.56	2.92	1.54	1.99	0.61											3
4	7.97	15.02	6.08	7.77	3.89	2.63	2.66	1.04	1.79	0.40									4
5					4.87	3.97	3.32	1.57	2.24	0.60									5
6					5.84	5.57	3.99	2.20	2.69	0.85									6
7					6.81	7.41	4.65	2.93	3.14	1.12	1.90	0.33							7
8							5.32	3.75	3.59	1.44	2.17	0.42							8
9							5.98	4.66	4.04	1.79	2.44	0.53							9
10							6.64	5.67	4.49	2.18	2.71	0.64							10
11									4.93	2.60	2.98	0.76	1.95	0.27					11
12									5.38	3.05	3.25	0.90	2.13	0.32					12
13									5.83	3.54	3.52	1.04	2.31	0.37					13
14									6.28	4.06	3.80	1.19	2.48	0.43					14
15											4.07	1.36	2.66	0.48	1.88	0.21			15
16											4.34	1.53	2.84	0.55	2.00	0.23			16
17											4.61	1.71	3.02	0.61	2.13	0.26			17
18											4.88	1.90	3.19	0.68	2.25	0.29			18
19											5.15	2.10	3.37	0.75	2.38	0.32			19
20											5.42	2.31	3.55	0.82	2.50	0.35			20
21											5.69	2.53	3.73	0.90	2.63	0.39			21
22											5.96	2.76	3.90	0.98	2.75	0.42			22
23											6.24	2.99	4.08	1.07	2.88	0.46			23
24													4.26	1.16	3.00	0.49			24
25													4.44	1.25	3.13	0.53			25
26													4.61	1.34	3.25	0.57			26
27													4.79	1.44	3.38	0.61	1.99	0.17	27
28													4.97	1.54	3.50	0.66	2.07	0.18	28
29													5.15	1.64	3.63	0.70	2.14	0.19	29
30													5.32	1.75	3.75	0.75	2.21	0.21	30
31													5.50	1.86	3.88	0.79	2.29	0.22	31
32													5.68	1.97	4.01	0.84	2.36	0.23	32
33													5.86	2.08	4.13	0.89	2.44	0.25	33
34													6.03	2.20	4.26	0.94	2.51	0.26	34
35													6.21	2.32	4.38	0.99	2.58	0.28	35
36															4.51	1.05	2.66	0.29	36
37															4.63	1.10	2.73	0.30	37
38															4.76	1.16	2.81	0.32	38
39															4.88	1.21	2.88	0.34	39
40															5.01	1.27	2.95	0.35	40
41															5.13	1.33	3.03	0.37	41
42															5.26	1.39	3.10	0.39	42
43															5.38	1.45	3.17	0.40	43
44															5.51	1.52	3.25	0.42	44
45															5.63	1.58	3.32	0.44	45
46															5.76	1.65	3.40	0.46	46
47															5.88	1.72	3.47	0.47	47
48															6.01	1.78	3.54	0.49	48
49															6.13	1.85	3.62	0.51	49
50															6.26	1.92	3.69	0.53	50

Head Loss Calculations
From Modified Hazen - Williams Formula

$$H_F = .2083\left[\left(\frac{100}{C}\right)^{1.852} \times \frac{q^{1.852}}{d^{4.8655}}\right]$$

$$V = .3208\,\frac{q}{A}$$

$A = \frac{d^2\pi}{4}$ = cross-sectional flow, sq. in.

C = 150

q = flow in gallons per minute

d = I.D. of pipe in inches = [average O.D. - (2 x min. wall thickness]

N = Number of pumps operating at 11 gpm

V = Flow velocity in ft/sec

H_F = Friction head loss in ft/100 ft of pipe

Table 6

SCHEDULE 40 PVC PIPE

Flow Velocity and Friction Head Loss *vs* Pumps in Simultaneous Operation (C = 150)

	1 1/4 in.		1 1/2 in.		2 in.		2 1/2 in.		3 in.		4 in.		5 in.		6 in.		8 in.		
N	V	H_F	V	H_F	V	H_F	V	H_F	V	H_F	V	H_F	V	H_F	V	H_F	V	H_F	N
1	2.36	1.74	1.73	0.82	1.05	0.24													1
2	4.72	6.28	3.47	2.97	2.10	0.88	1.47	0.37											2
3	7.08	13.31	5.20	6.29	3.15	1.86	2.21	0.79											3
4			6.93	10.71	4.21	3.18	2.95	1.34	1.91	0.46									4
5					5.26	4.80	3.68	2.02	2.39	0.70									5
6					6.31	6.73	4.42	2.83	2.87	0.99									6
7							5.16	3.77	3.34	1.31	1.94	0.35							7
8							5.89	4.83	3.82	1.68	2.22	0.45							8
9							6.63	6.01	4.30	2.09	2.49	0.56							9
10									4.78	2.54	2.77	0.68							10
11									5.25	3.03	3.05	0.81	1.94	0.27					11
12									5.73	3.56	3.33	0.95	2.12	0.32					12
13									6.21	4.13	3.60	1.10	2.29	0.37					13
14											3.88	1.26	2.47	0.42					14
15											4.16	1.43	2.65	0.48					15
16											4.44	1.62	2.82	0.54	1.95	0.22			16
17											4.71	1.81	3.00	0.60	2.08	0.25			17
18											4.99	2.01	3.17	0.67	2.20	0.27			18
19											5.27	2.22	3.35	0.74	2.32	0.30			19
20											5.54	2.44	3.53	0.81	2.44	0.33			20
21											5.82	2.67	3.70	0.89	2.56	0.36			21
22											6.10	2.91	3.88	0.97	2.69	0.40			22
23													4.06	1.05	2.81	0.43			23
24													4.23	1.14	2.93	0.47			24
25													4.41	1.23	3.05	0.50			25
26													4.59	1.32	3.17	0.54			26
27													4.76	1.42	3.30	0.58			27
28													4.94	1.52	3.42	0.62	1.98	0.16	28
29													5.11	1.62	3.54	0.66	2.05	0.17	29
30													5.29	1.72	3.66	0.70	2.12	0.19	30
31													5.47	1.83	3.79	0.75	2.19	0.20	31
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1	1.99	**1.15**	1.52	**0.60**															1
2	3.99	**4.16**	3.04	**2.15**	1.95	**0.73**													2
3	5.98	**8.82**	4.56	**4.56**	2.92	**1.54**	1.99	**0.61**											3
4	7.97	**15.02**	6.08	**7.77**	3.89	**2.63**	2.66	**1.04**	1.79	**0.40**									4
5					4.87	**3.97**	3.32	**1.57**	2.24	**0.60**									5
6					5.84	**5.57**	3.99	**2.20**	2.69	**0.85**									6
7					6.81	**7.41**	4.65	**2.93**	3.14	**1.12**	1.90	**0.33**							7
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12									5.38	**3.05**	3.25	**0.90**	2.13	**0.32**					12
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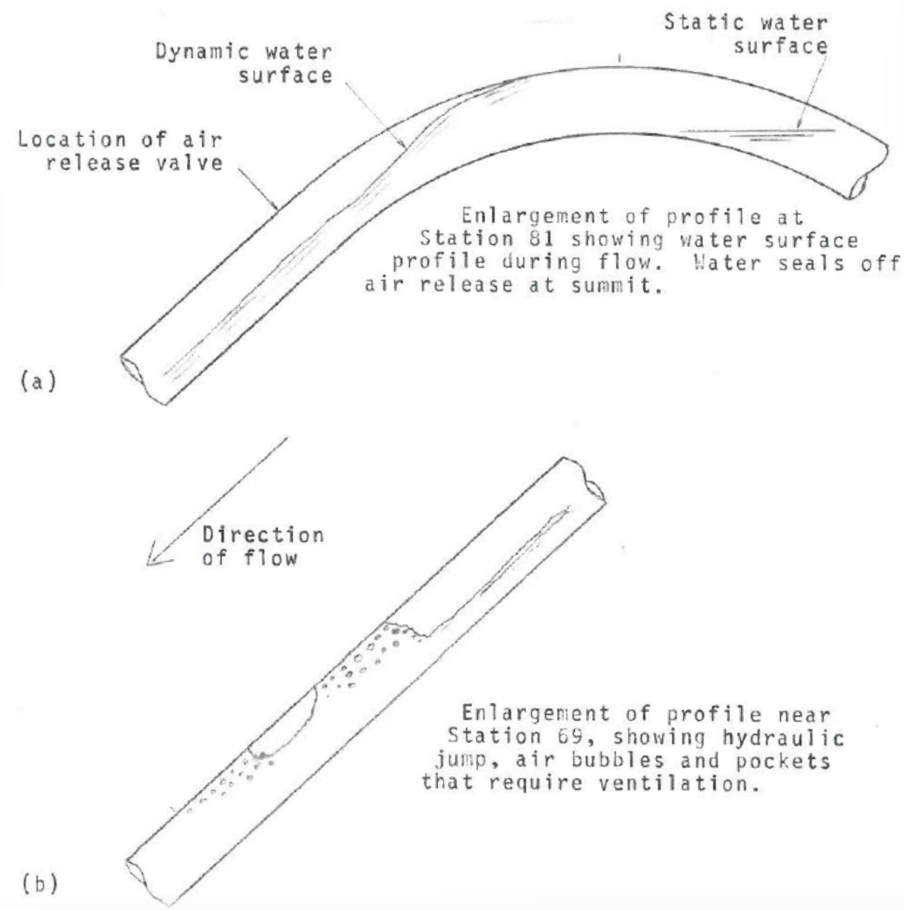
15											4.07	**1.36**	2.66	**0.48**	1.88	**0.21**			15
16											4.34	**1.53**	2.84	**0.55**	2.00	**0.23**			16
17											4.61	**1.71**	3.02	**0.61**	2.13	**0.26**			17
18											4.88	**1.90**	3.19	**0.68**	2.25	**0.29**			18
19											5.15	**2.10**	3.37	**0.75**	2.38	**0.32**			19
20											5.42	**2.31**	3.55	**0.82**	2.50	**0.35**			20

N5 = 19 to 30 connections

N10 = 147 to 179 connections

N20 = 477 to 509 connections

Transitional Pressure Sewers



Bowne, W.C. (1983) *Two Phase Flow in Pressure Sewers and Small Diameter Sewers*

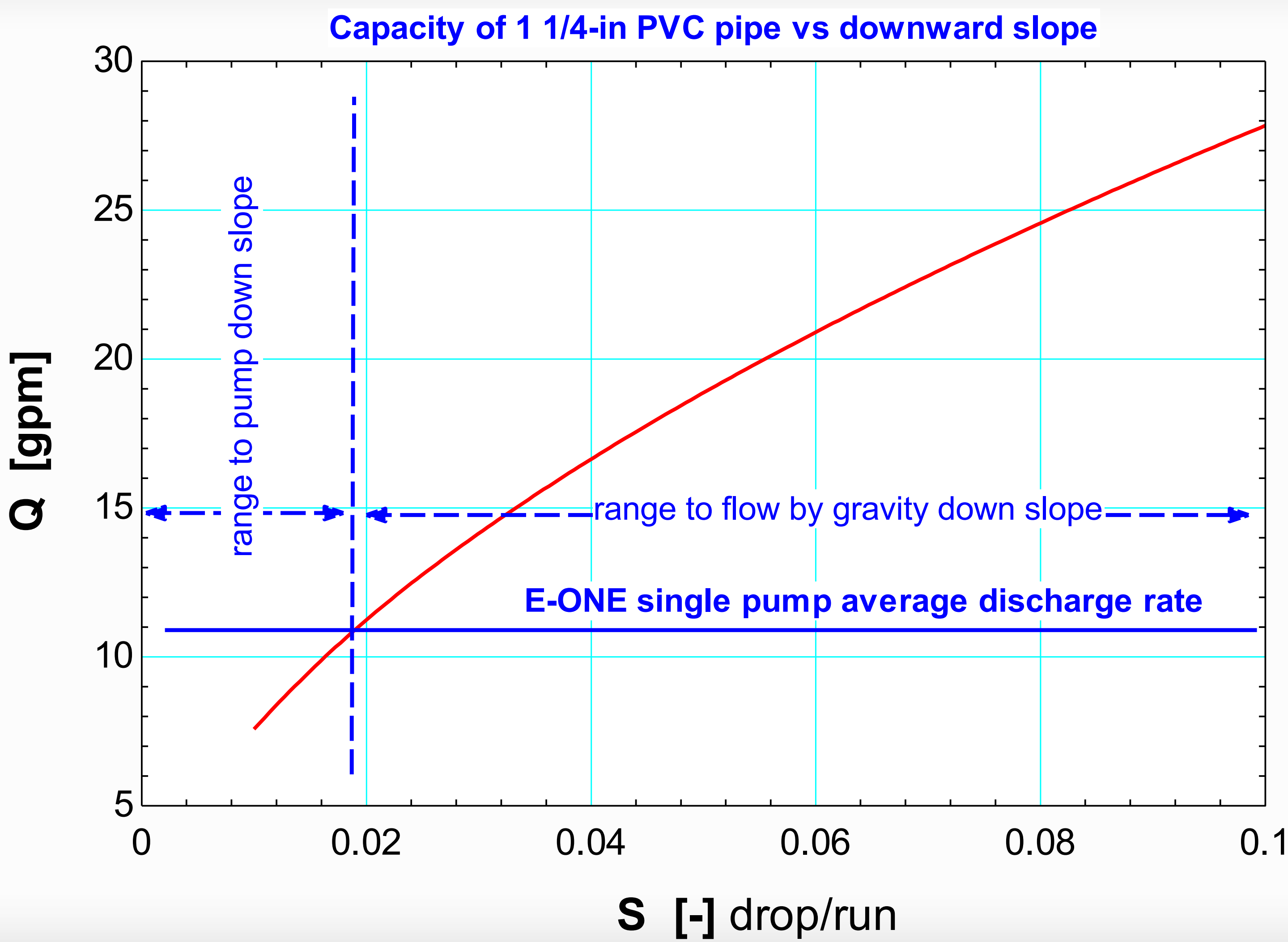
Evaluation of Pressure Sewers

- Hydraulic evaluation completed by E/One and Modern Energy LLC
- Evaluation consisted of
  - a comprehensive theoretical evaluation (table top evaluation)
  - a physical, field demonstration

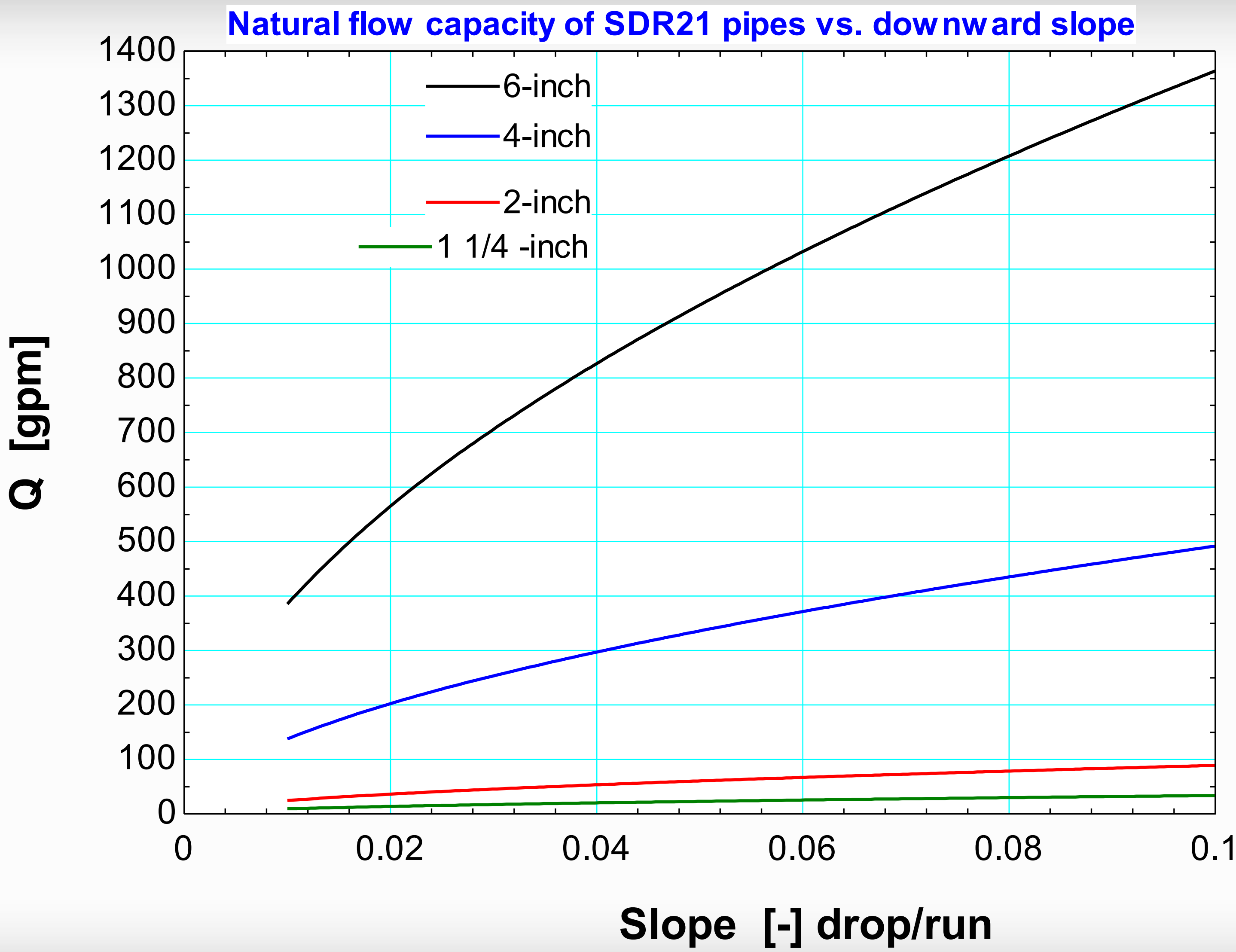
Phase 1: Table-Top Evaluation

- Evaluation Objectives
  - Characteristics of SPD pump
  - Nature of pipe flow: full, partially full
  - Energy of fluid flow
  - Pipe friction and its relation to energy
  - Interaction of pump, pipe, and friction
  - Effect of pipe size, elevation changes, and pipe slope

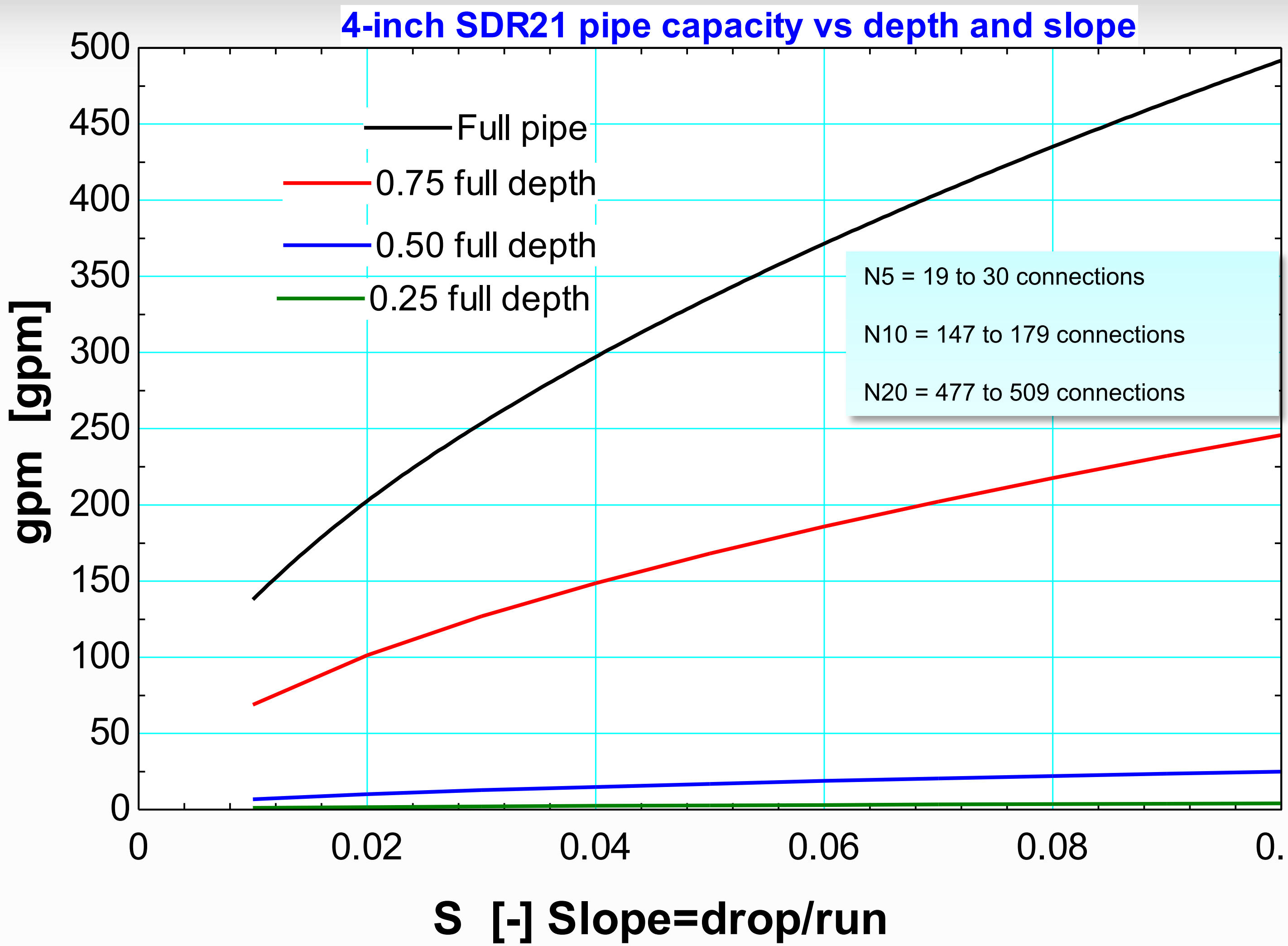
Pipe Capacity vs. Down Slope



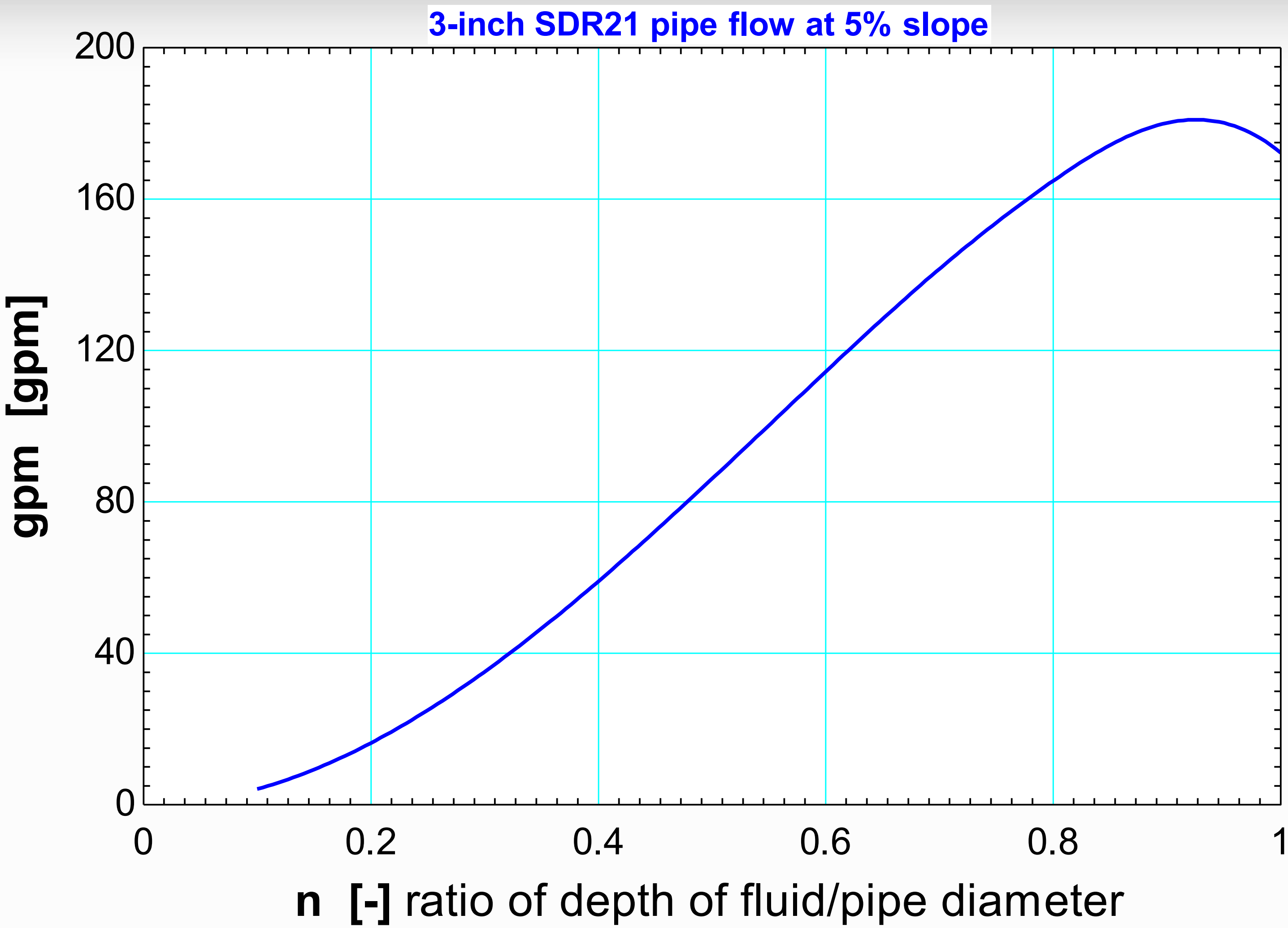
Natural Flow Capacity of Pipe



Natural Flow Capacity: 4-inch



Example: 3-inch @ 5% slope



Conclusions Part I

- Properly vented descending pipe sections allow for free flow
- Design guideline: Pipe diameter on downward pipe sized for 3/4 full depth flow
- Downward pipe with full depth flow yields pressured flow
- In no case should valve throttling or restrictions be used to “make hydraulics work”

Field Apparatus Tests

- Characteristics of the pipe when vented and partially filled with water at various rates
- Pressure versus flow for a range of flows with the vent valve operating and vent valve blocked
- Hill and valley pipe configuration

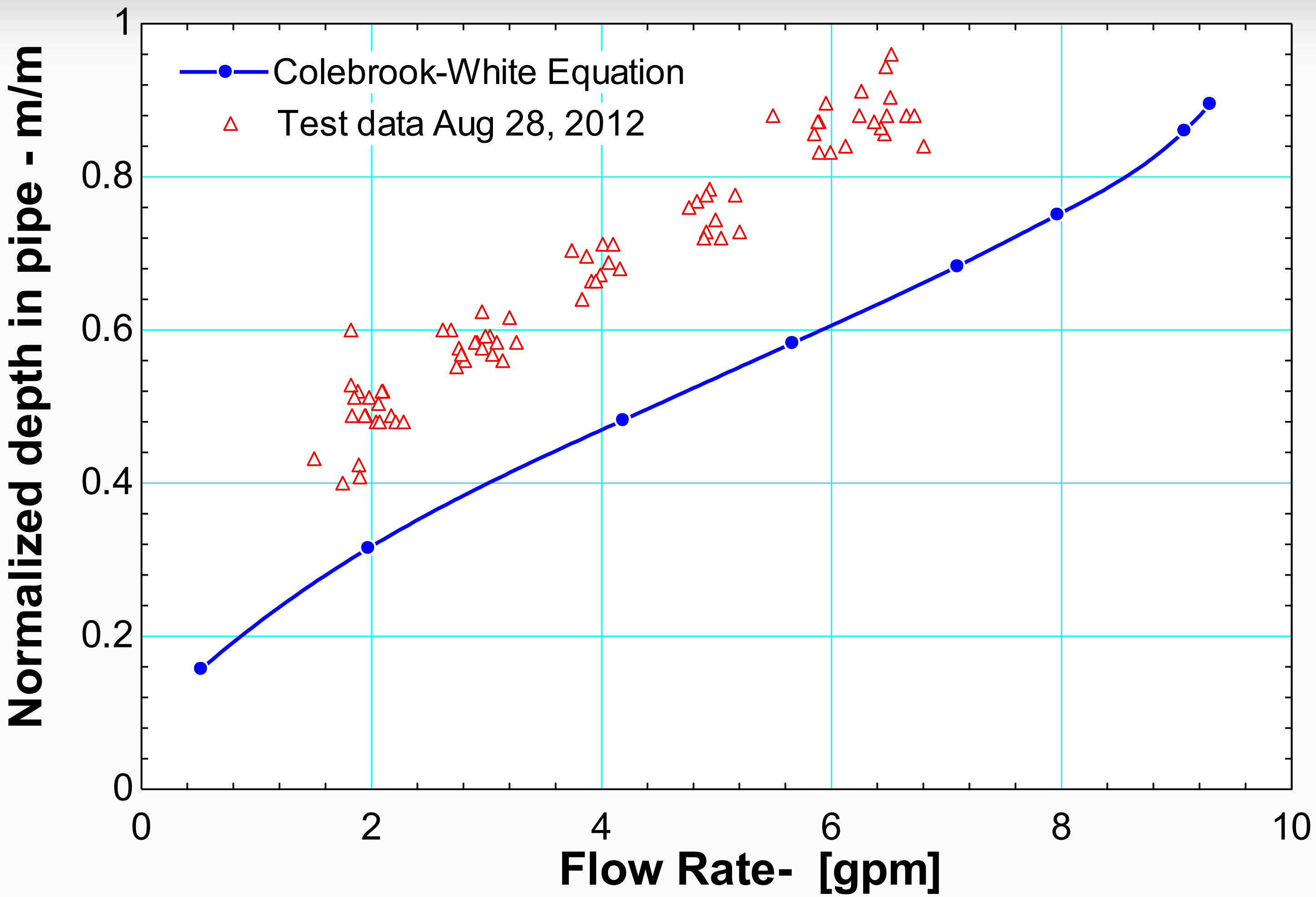
Field Apparatus Test Set-Up

Field Apparatus Test Set-Up

Field Apparatus Test Set-Up

Field Apparatus Test Set-Up

Field Apparatus Test Results



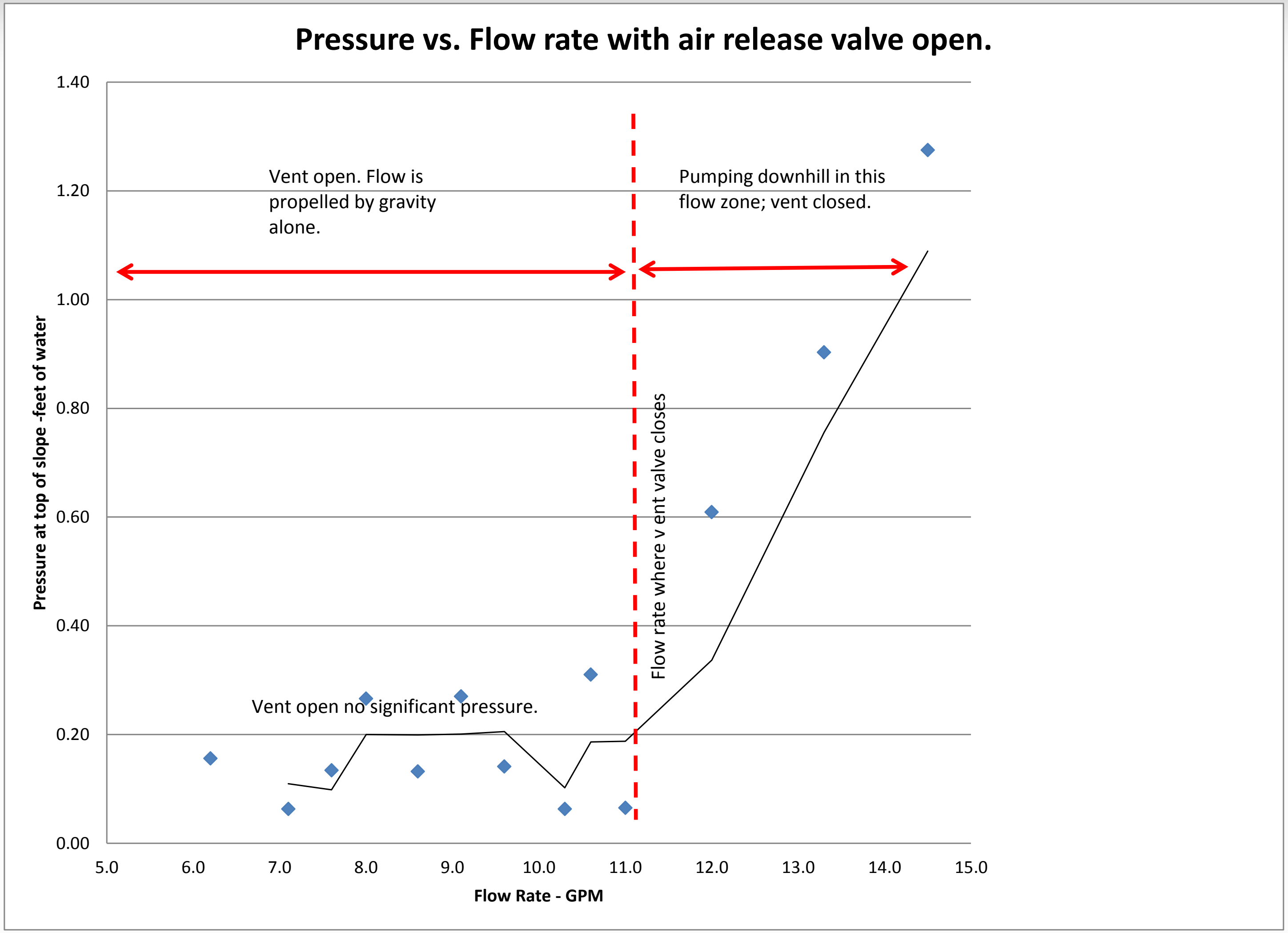
Field Apparatus Test Results

- Wave formation in partially filled pipe
  - Instability of fluid hydraulics?
  - Irregularity in field apparatus?

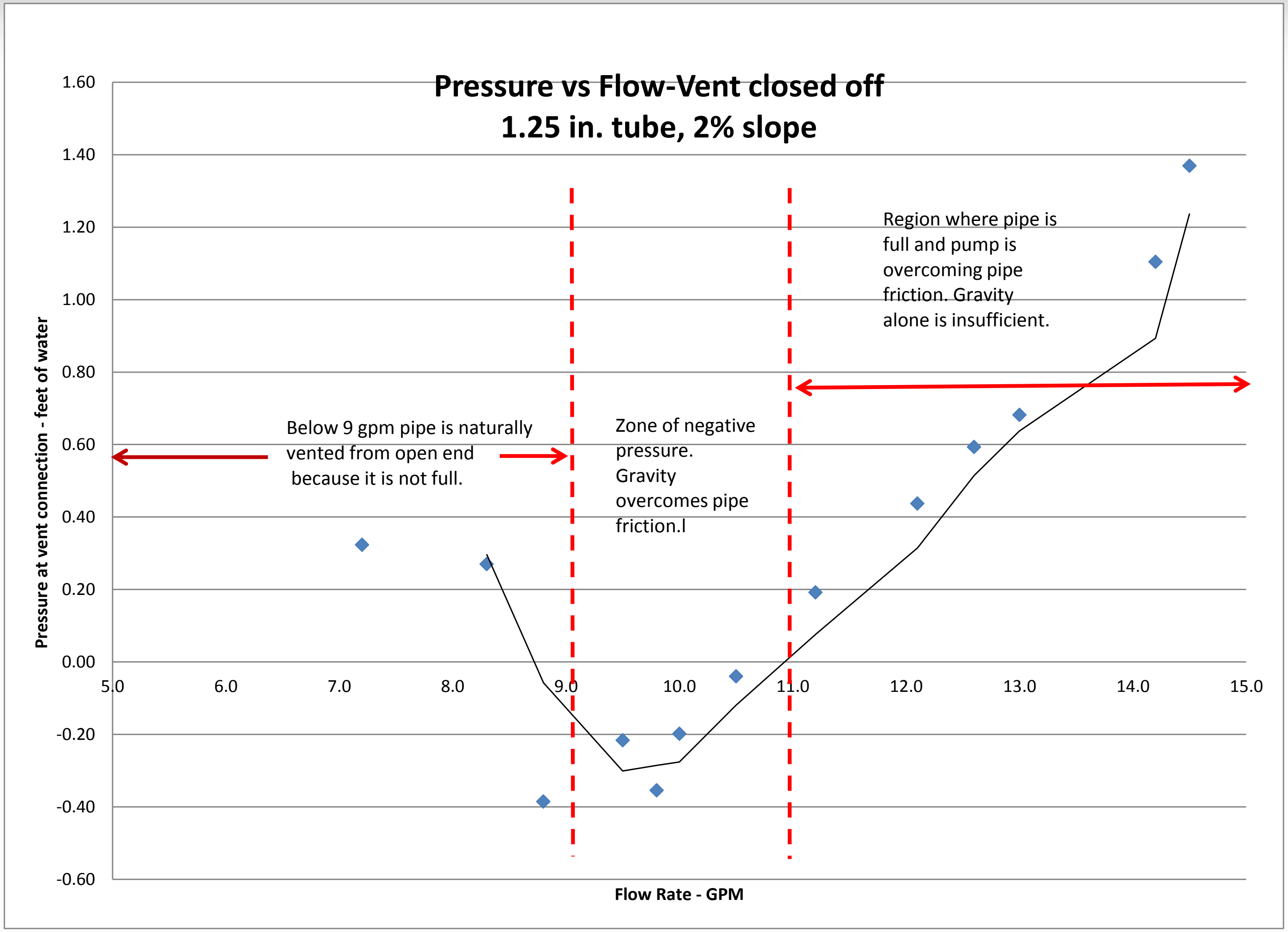
Air Venting Tests

- Test were conducted to demonstrate behavior of fluid under different conditions
  - Vary flow rate in the system with vent shut-off valve open
  - Vary the flow rate in the system with the vent shut-off valve closed
- Flow and pressure at vent connection were recorded

Air Venting Test Results



Air Venting Test Results



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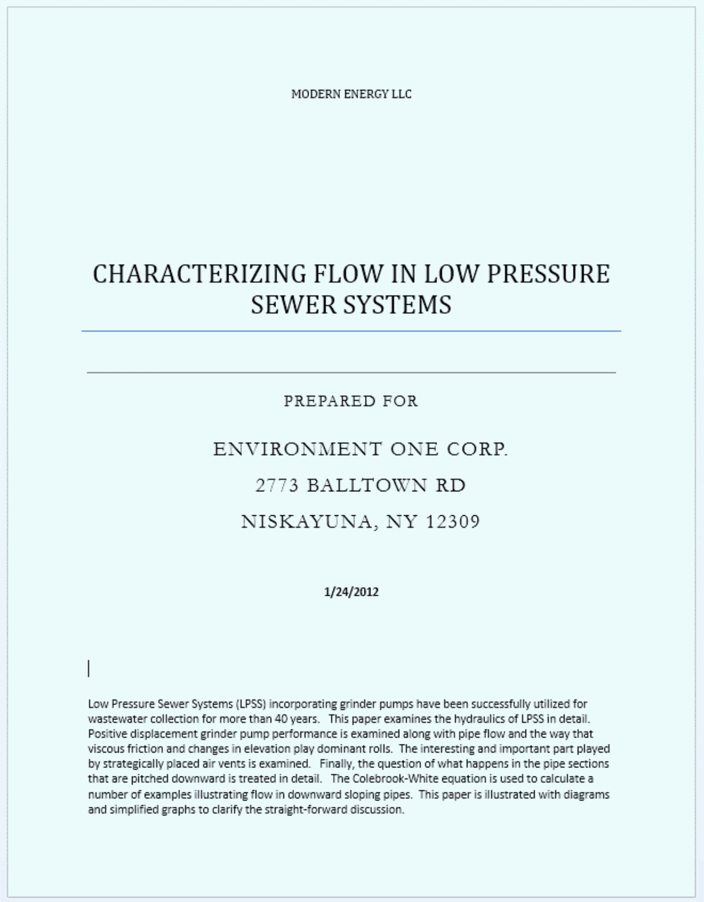
Conclusions Part II

- Flow behavior predicted by the "table-top" evaluation is validated
- Even with an SPD pump, trapped air is not pushed forward through the downward slope
- Air pocket causes a flow resistance
  - The pump curve characteristics favor a SPD pump versus a centrifugal pump
  - Higher friction lost is likely unanticipated
- Air pockets in valleys will behave differently

Acknowledgements

- Modern Energy LLC
  - Ron Amberger,
- Environment One
  - Clark Henry
  - Michael Crowley
  - Skip Murrell

- Paper available on request



MODERN ENERGY LLC

CHARACTERIZING FLOW IN LOW PRESSURE SEWER SYSTEMS

PREPARED FOR

ENVIRONMENT ONE CORP.

2773 BALLTOWN RD

NISKAYUNA, NY 12309

1/24/2012

Low Pressure Sewer Systems (LPSS) incorporating grinder pumps have been successfully utilized for wastewater collection for more than 40 years. This paper examines the hydraulics of LPSS in detail. Positive displacement grinder pump performance is examined along with pipe flow and the way that viscous friction and changes in elevation play dominant rolls. The interesting and important part played by strategically placed air vents is examined. Finally, the question of what happens in the pipe sections that are pitched downward is treated in detail. The Colebrook-White equation is used to calculate a number of examples illustrating flow in downward sloping pipes. This paper is illustrated with diagrams and simplified graphs to clarify the straight-forward discussion.

Thank You

Keith J McHale, P.E.
Environment One Corp.
kmchale@eone.com
Phone: 518-362-6186