Chapter 9
System Design Procedures

CHAPTER 9 SYSTEM DESIGN PROCEDURES

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FIGURES

CHAPTER 9

SYSTEM DESIGN PROCEDURES

9.1 GENERAL

There are three major categories of system designs associated with stockwater pipelines. They are:

1. Gravity flow pipeline
2. Pumped pipeline
3. Lateral pipeline pressurized from a mainline.

Sometimes the system types are combined on one job. For instance, water may be pumped to a large storage tank on a hill and then a gravity pipeline will exit from the storage tank. The design approach in such a case is to perform the hydraulic calculations separately for each calculation category.

Example No. 1 illustrates system design for a very simple, low pressure gravity pipeline leading from a spring. Example No. 2 illustrates an automatic pumped pressure system which incorporates one lateral. Example number 3 represents a manually operated pumped system that incorporates a gravity segment and a lateral. Between these examples, most computational procedures you will encounter are illustrated.

Appendix A contains master copies of the worksheets used in these examples. These worksheets are for your convenience. Use them only if they will aid in the computations.

Computer programs can be used to aid in computations. Appendix B illustrates the use of currently available programs.

9.2 EXAMPLE 1, LOW PRESSURE GRAVITY SYSTEM

Figure 9.1 illustrates the profile for a very low Pressure system. The pipeline originates at a spring box and terminates at a stock tank. An overflow is built into the stock tank. There is not a float valve at the tank and the entire spring flow goes to the tank. A gate-type valve could be installed at the spring box to throttle the flow or shut it off when water is not wanted. A valve at the tank allows drainage of the pipeline during non-use. The pipeline is buried below the frost line.

There is little design involved in this installation. Size of pipe is the minimum dictated by the standards. Missouri NRCS standards state the following:

Pipe size shall be no smaller than:

- 1-1/4 inch nominal diameter for grades over 1.0 percent
- 1-1/2 inch nominal diameter for grades from 0.5 to 1.0
- 2 inch nominal diameter for grades from 0.2 to 0.5 percent

Figure 9.2 shows the calculations that were made. The slope of each segment is calculated and pipe size is based on the slope. Pressure rated PVC pipe was selected due to its availability and low cost. The pressure rating of the pipe is 160 psi, which is normally the lowest pressure rated PVC pipe commonly available in the desired sizes. Since the available head is so low, it is obvious that pressure rating of the pipe will not be exceeded. In this case it would not be necessary to calculate pressures. We did though, and the maximum static pressure when the gate valve is shut off is 21.6 psi.

It is important in this installation to install the vent and air valve at the locations shown. If they were not installed, this system would almost certainly air lock.

Figure 9.1
LOW HEAD GRAVITY SYSTEM

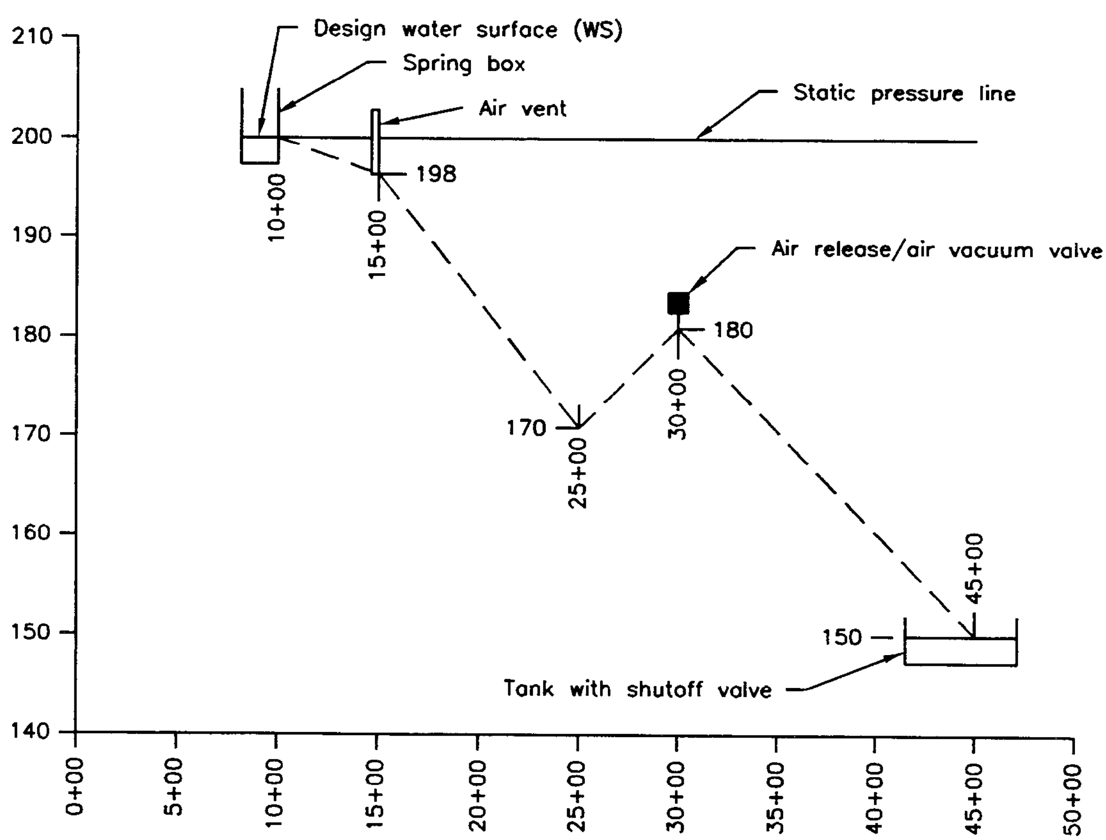

Figure 9.2

LOW PRESSURE GRAVITY SYSTEM COMPUTATIONS

USDA-NRCS

MO-ENG-106
07-97
File Code - Coop Folder

GRAVITY STOCKWATER PIPELINE
HYDRAULIC COMPUTATION WORKSHEET

Land user Example No. 1
Job description South Pasture Pipeline
Farm No. 532 Tract No. 3 Field No 2 County Gallatin
Designer V. Tech Date 11/8/90 Checked by JCD Date 11/10/90

Water surface elevation (WS) 200
Critical point along pipeline (CP): Station ------- Elevation ____________
Clearance Head(CH) at critical point: _____________ ft x .433= ____________psi
Minimum required HGL at CP = CP elevation + CH ft =
______________+____________=______________
Estimated pipeline entrance losses (EL) = ___________________ft
Starting HGL elevation = WS - EL = ______________-______________=___________________

Free flow
Hydraulic calc's
not required

(1) Station	(2) Reach Length (ft)	(3) Pipe Elevation	(4) Design Flow Rate (gpm)	(5) Nominal Pipe Diameter (in)	(6) Pipe Type	(7) Pipe Pressure Rating (psi)	(8) Friction Factor H_f/100ft (ft/100)	(9) Reach Total H_f (ft) (2) x (8)	(10) HGL Elev (from start HGL)	(11) Max Pressure on Pipe (psi) WS-(3)	Comments (slope %)
10+00		200									at source
	500			2	PVC SDR 26						
15+00		198									0.40%
	1000			1 1/4	PVC SDR 26						
25+00		170									2.80%
	500			1 1/4	PVC SDR 26						
30+00		180									2.00%
	1500			1 1/4	PVC SDR 26						
45+00		150								21.6	2.00%
											21.6 psi<
											160 psi
											∴ ok

9.3 EXAMPLE 2, PUMPED AUTOMATIC PRESSURE PIPELINE

Example number 2 covers the elements that must be determined in a typical automatic pumped system, as illustrated in Figure 9.3. Figure 9.4 shows the automatic pump pipeline calculations. Figure 9.5 illustrates a lateral pipeline profile. Figure 9.6 is the computations for lateral "A".

9.3.1 Pumped Automatic Pressure System Computations

After plotting the profile, determine where the most critical point (CP) in the pipeline is located. This is usually, but not always, the highest point in any part of the line. The criteria for selecting the critical point is to find where the hydraulic grade line (HGL) will pass closest to the profile. This is sometimes a trial and error determination. In other words, select a critical point and then compute the hydraulic grade line. Plot the HGL on the profile and see how close it passes to all high points.

We want the HGL to pass within a certain clearance head (CH) above the ground line. The CH value will depend on the type of engineering survey made to determine the ground profile and the type of air valves installed in the pipe. See Glossary for definition of terms. In this case a CH value of 25 feet was selected.

A 30 psi pressure range between pump cut-in and cut-out is used. In a flowing pipeline, when the pressure is near cut-in, the flow will be less than when the pressure is near cut-out. We calculate the hydraulic grade line at the average of the cut-in/cut-out pressures so the average flow rate will be equal or greater than the design flow rate.

It is important that the cut-in pressure be high enough that flow will clear the high point even when the pressure at the pump is at or near cut-in. We also need to make sure that the design flow rate will clear the high point. For this reason we must check both the clearance of cut-in pressure head and of the hydraulic grade line.

Minimum cut-in pressure head is equal to the critical point elevation plus clearance head. The hydraulic grade line is computed starting at the clearance head point and then working backward to the pump. Pipe friction loss data is obtained from tables in Chapter 5.

In some cases it may be desirable to provide minimum acceptable flow rate at pump cut in pressure. In this situation pump cut-in pressure would have to be raised to a level equal to critical point elevation plus clearance head plus friction loss at minimum acceptable flow rate. Keep in mind this may increase pump and pipe pressure requirements and thus would increase installation and operating costs.

At the pump, an additional loss is added for the losses in the plumbing at the well. These losses can be estimated using Figure 5.1 in Chapter 5, or by making special detailed computations. In most cases estimates based on Figure 5.1 will be adequate.

If the calculated hydraulic grade line at the pump is lower than the cut-in head plus 1/2 of the pressure range head, then the HGL is raised until the start is halfway between cut-in and cut-out pressure.

The greatest pressure at any point in the pipeline is when the flow stops in the pipeline and the pump runs the pressure up to cut-out pressure and stops. Static pressure everywhere in the pipeline is then computed from cut-out OFF pressure.

Compute maximum pressure at all stations. If pressure at any point in the line is greater than the rating of the pipe, use a higher pressure rated pipe in the appropriate location and redo the HGL computations.

Total dynamic head (TDH) at the pump is computed by taking the difference in HGL at the pump and the drawdown water surface in the well or other water source. The drawdown water surface is the lowest water surface during pumping.

Figure 9.4 illustrates example computations.

9.3.2 Lateral Computations

The OFF pressure and HGL at the mainline takeoff point are used in computations at the start of the lateral. Figure 9.5 illustrates a profile and Figure 9.6 is computations for this type of installation.

It may not be necessary to actually compute the HGL on a lateral of this nature. It is sometimes obvious that the HGL will clear the critical head point and that pipe pressure rating will not be exceeded.

Figure 9.3
PUMPED AUTOMATIC PRESSURE SYSTEM

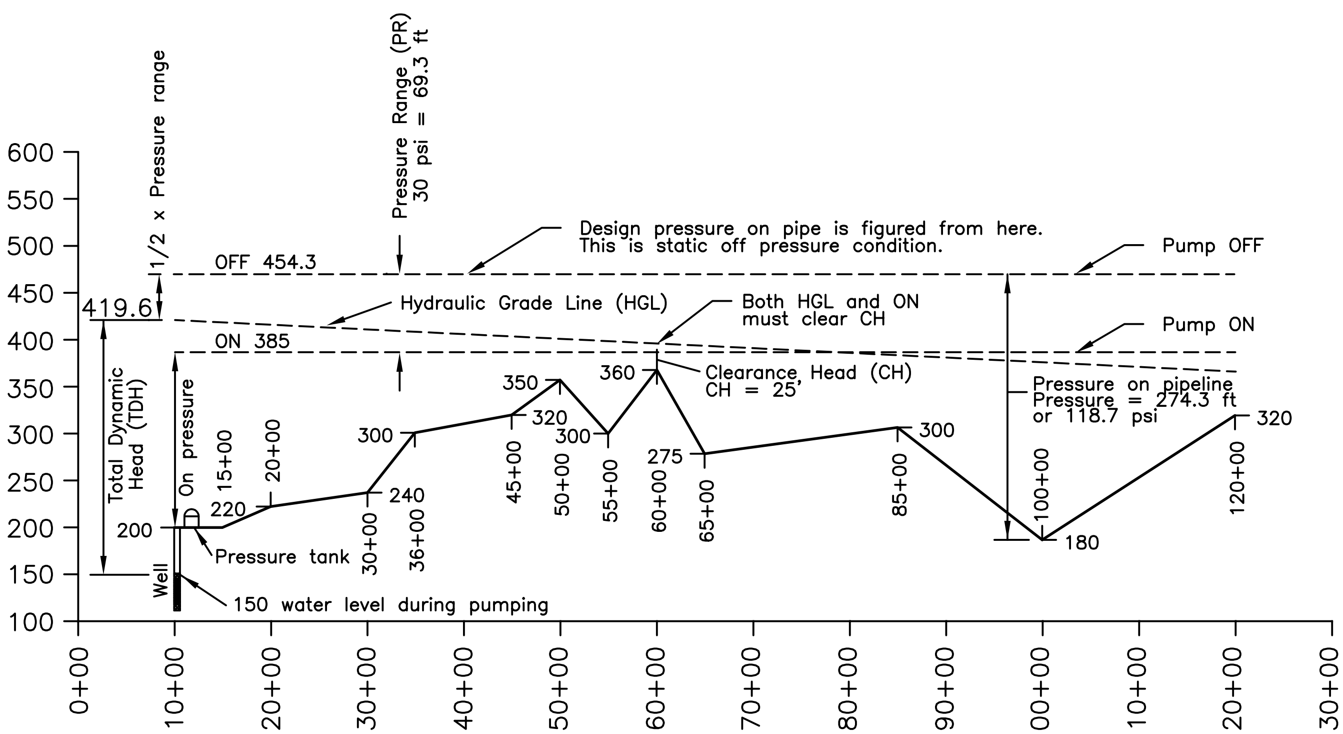

Figure 9.4
AUTOMATIC PRESSURE COMPUTATIONS

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MO-ENG-104
07-97
File Code - Coop Folder

AUTOMATIC PRESSURE STOCKWATER PIPELINE HYDRAULIC COMPUTATION WORKSHEET

Land user Example No. 2
Job description West pasture
Farm No. 532 Tract No. 3 Field No. 3 County Gallatin
Designer V. Tech Date 11/8/90 Checked by JCD Date 11/10/90

Water surface elevation during pumping (WS) 150
Critical point along profile (CP): Station 60+00 Elevation 360-
Clearance Head (CH) at critical point: 25 ft x .433 = 10.8 psi
Cut in/Cut out pressure range (PR): 30 psi x 2.31 + 69.3 ft
Losses in plumbing at pump (PL): 4 ft
Minimum ON elevation = CP elevation + CH ft = 360 + 25 = 385
ON elevation based on HGL = HGLpump + PL - (PR ft/2) = 413.6 + 4 - (69.3 /2)- 382.9
ON elevation used (greatest elevation of above alternatives): 385
OFF elevation used = ON elevation + PR ft = 385 + 693 = 454.3
Total Dynamic Head (TDH) = OFF elev - (PR ft/2) - WS = 454.3 - (69.3 /2) - 150 = 269.6 ft
Pump HP = __________HP (Select from pump curves)

(1) Station	(2) Reach Length (ft)	(3) Pipe Elevation	(4) Design Flow Rate (gpm)	(5) Nominal Pipe Diameter (in)	(6) Pipe Type	(7) Pipe Pressure Rating (psi)	(8) Friction Factor H_f/100ft (ft/100)	(9) Reach Total H_f (ft) (2) x (8)	(10) HGL Elev (from start HGL)	(11) Max Pressure on Pipe (psi) WS-(3)	Comments (slope %)
10+00		200							413.6	110.1	
	500		8	1.25	PVC SDR 26	160	0.572	2.86			
15+00		200							410.7	110.1	
	500		8	1.25	PVC SDR 26	160	0.572	2.86			
20+00		220							407.9	101.5	
	1000		8	1.25	PVC SDR 26	160	0.572	5.72			
30+00		240							402.2	92.8	
	600		8	1.25	PVC SDR 26	160	0.572	3.43			
36+00		300							348.7	66.8	
	900		8	1.25	PVC SDR 26	160	0.572	5.15			
45+00		320							393.6	58.2	
	500		8	1.25	PVC SDR 26	160	0.572	2.86			

continued on next page

(1) Station	(2) Reach Length (ft)	(3) Pipe Elevation	(4) Design Flow Rate (gpm)	(5) Nominal Pipe Diameter (in)	(6) Pipe Type	(7) Pipe Pressure Rating (psi)	(8) Friction Factor H_f/100ft (ft/100)	(9) Reach Total H_f (ft) (2) x (8)	(10) HGL Elev (from start HGL)	(11) Max Pressure on Pipe (psi) WS-(3)	Comments (slope %)
50+00		350							390.7	45.2	
	500		8	1.25	PVC SDR 26	160	0.572	2.86			
55+00		300							387.9	66.8	
	500		8	1.25	PVC SDR 26	160	0.572	2.86			Critical Point
60+00		360							385	40.8	
	500		8	1.25	PVC SDR 26	160	0.336	2.86			
65+00		275							382.1	77.6	
	2000		6	1.25	PVC SDR 26	160	0.336	6.72			
85+00		300							376.4	66.8	
	1500		6	1.25	PVC SDR 26	160	0.336	5.04			
100+00		180							370.4	118.9	
	2000		6	1.25	PVC SDR 26	160	0.336	6.72			
120+00		320							363.7	58.2	

Figure 9.5
LATERAL PROFILE

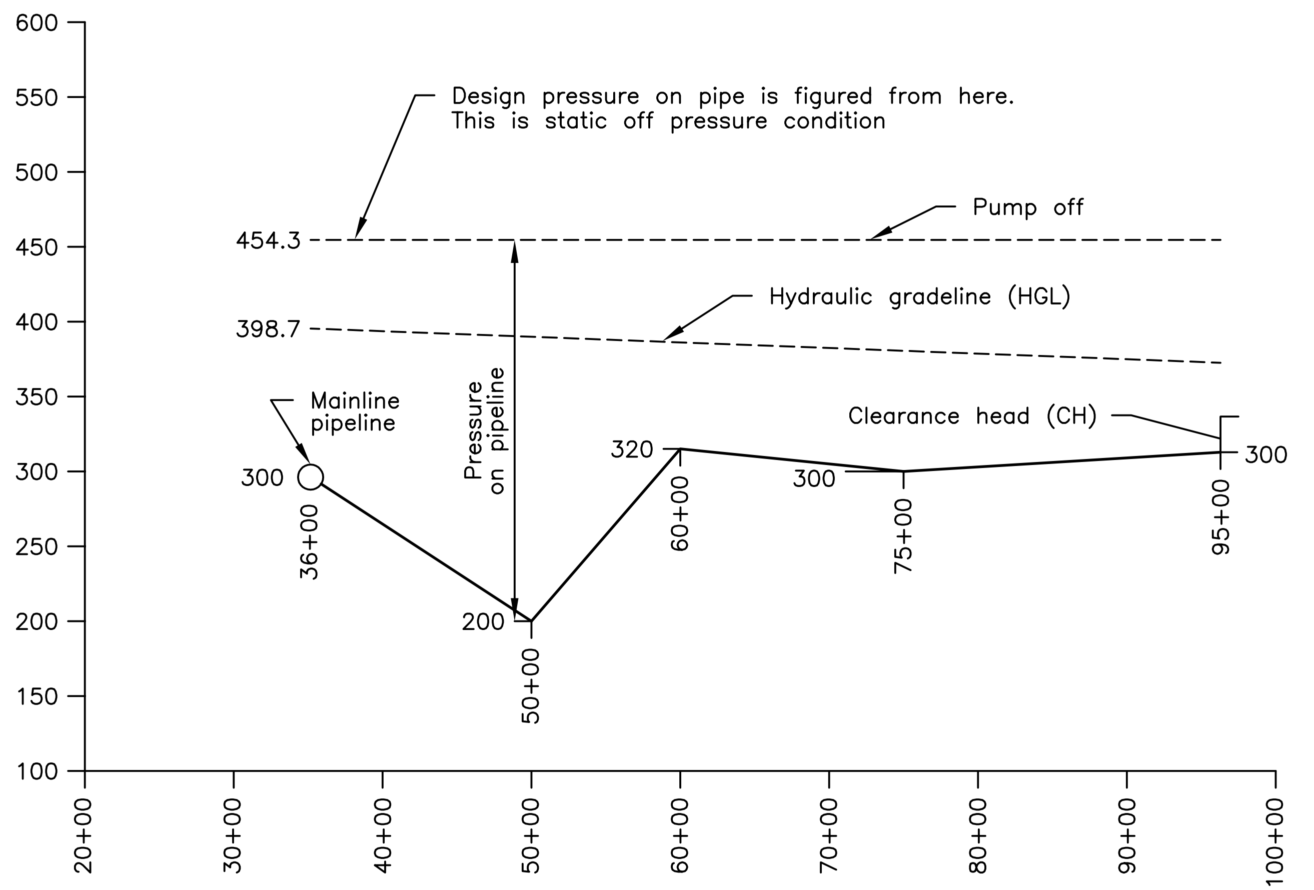

Figure 9.6
LATERAL COMPUTATIONS

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MO-ENG-107
07-97
File Code - Coop Folder

LATERAL STOCKWATER PIPELINE
HYDRAULIC COMPUTATION WORKSHEET

Land user Example No. 2 (Lateral A)
Job Description West pasture
Farm No. 532 Track No. 3 Field No. 3 County Gallatin
Designer V. Tech Date 11/8/90 Checked by JCD Date 11/10/90

HGL at mainline 398.7
Pump OFF elevation (Automatic pressure sysem only) 454.3
Flow in lateral - OFF elevation (manual, timed or gravity) -------
Critical point along lateral (CP): Station 95+00 Elevation 310.0
Clearance Head (CH) at critical point: 25 ft x .433 = 10.8 psi
Minimum required HGL at CP=CP elevation + CH ft = 310 + 25 = 335

(1) Station	(2) Reach Length (ft)	(3) Pipe Elevation	(4) Design Flow Rate (gpm)	(5) Nominal Pipe Diameter (in)	(6) Pipe Type	(7) Pipe Pressure Rating (psi)	(8) Friction Factor H_f/100ft (ft/100)	(9) Reach Total H_f (ft) (2) x (8)	(10) HGL Elev (from start HGL)	(11) Max Pressure on Pipe (psi) WS-(3)	Comments (slope %)
36+00		300			PVC				398.7	77.5	at main
	1400		8	1.25	SDR 26	160	0.572	8.01			
50+00		200			PVC				390.7	118.8	
	1000		8	1.25	SDR 26	160	0.572	5.72			
60+00		320			PVC				385	66.8	
	1500		6	1.25	SDR 26	160	0.336	5.04			
75+00		300			PVC				379.9	75.5	
	2000		6	1.25	SDR 26	160	0.336	6.72			
95+00		310								71.1	373.2>
											335 ∴ ok

9.4 EXAMPLE 3, TIMER OR MANUALLY OPERATED PRESSURE SYSTEM

Example number 3 covers elements that must be determined in a typical pumped pressurized, manually or timer operated system. In the example system, a storage tank is installed at the system high point. The pipe beyond the storage tank exits from the tank as a gravity pipeline. The plumbing at the storage tank is set up so water will flow back into the supply line when the pump is off.

Figure 9.7 illustrates the pipeline profile. Figure 9.8 illustrates details of the storage tank plumbing. Figure 9.9 shows pump calculations. Figure 9.10 shows computations for gravity flow portion of the pipeline. Figure 9.11 contains hydraulic computations for lateral "A".

9.4.1 Timer or Manually Operated Pumped System Computations

After plotting the profile, determine where the highest point in the pipeline is located. This is where the outlet storage tank will be located. The outlet storage tank must have an overflow capable of handling the design flow over extended periods of time. Plot the HGL on the profile and see how close it passes to all high points.

We want the HGL to pass within a certain clearance head (CH) above the ground line. The CH value will depend on the type of engineering survey used to determine the ground profile and the type of air valves installed in the pipe. See Chapters 4 and 6 for more explanation. In this case we selected a CH value of 25 feet.

Hydraulic grade line is computed starting at the clearance head point and working backward to the pump. Pipe friction loss data is obtained from tables in Chapter 5.

At the pump, an additional loss is added for losses in the plumbing at the pump. These losses can be estimated using Figure 5.1 in Chapter 5 or by making special detailed computations. In most cases estimates based on Figure 5.1 will be adequate.

The greatest pressure on any point in the pipeline is the head measured between the HGL and the pipe. Compute maximum pressure at all stations. If pressure at any point in the line is greater than the pressure rating of the pipe, use a higher pressure rated pipe in the appropriate location and redo the HGL computations.

Total dynamic head (TDH) at the pump is computed by taking the difference between HGL at the pump and the drawdown water surface in the well.

Figure 9.8 illustrates storage tank plumbing and Figure 9.9 shows an example of pumped system computations.

Figure 9.7
TIMER OR MANUALLY OPERATED SYSTEM

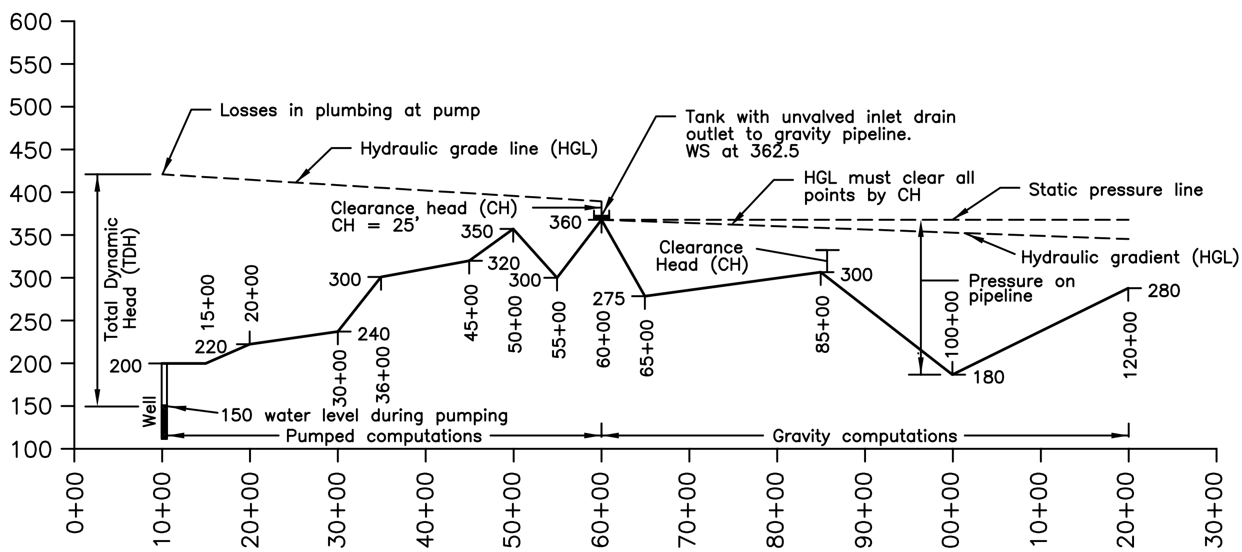

Figure 9.8
STORAGE TANK PLUMBING

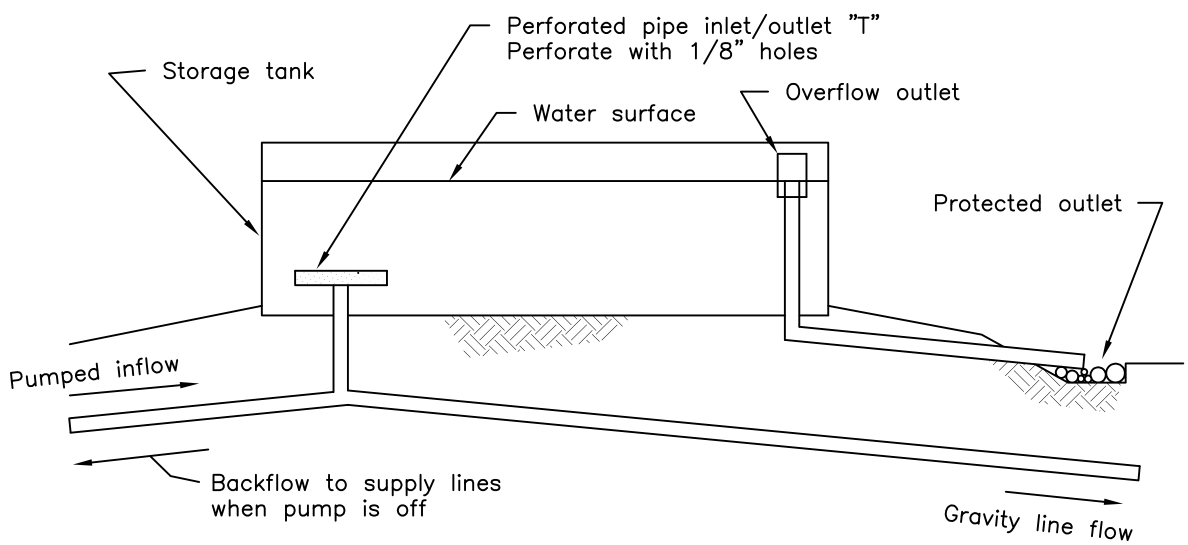

Figure 9.9
TIMER OR MANUALLY OPERATED
PUMP SYSTEM COMPUTATIONS

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MO-ENG-105
07-97
File Code - COOP Folder

MANUAL OR TIMER OPERATED STOCKWATER PIPELINE PUMPED SEGMENT HYDRAULIC COMPUTATION WORKSHEET

Land user Example No. 3 *(Sheet 1 of 3)*
Job description West pasture
Farm No. 532 Tract No. 3 Field No. 3 County Gallatin
Designer V. Tech Date 11/8/90 Checked by JCD Date 11/10/90

Water surface elevation during pumping (WS) 150
Pumped segment end station critical point (CP): Station 60+00 Elevation 360
Clearance Head (CH) at critical point: 25 ft x .433 = 10.8 psi
Losses in plumbing at pump (PL): 4 ft
HGL at CP = CP elevation + CH ft = 360 + 25 = 385
HGLpump = HGL from profile = PL = 413.6 + 4 = 417.6
Total Dynamic Head (TDH) = HGLpump - WS= 417.6 - 150 = 267.6 ft
Pump HP ________________HP (Select from pump curves)

(1) Station	(2) Reach Length (ft)	(3) Pipe Elevation	(4) Design Flow Rate (gpm)	(5) Nominal Pipe Diameter (in)	(6) Pipe Type	(7) Pipe Pressure Rating (psi)	(8) Friction Factor H_f/100ft (ft/100)	(9) Reach Total H_f (ft) (2) x (8)	(10) HGL Elev (from start HGL)	(11) Max Pressure on Pipe (psi) WS-(3)	Comments (slope %)
10+00		200			PVC				413.6	92.5	at pump
	500		8	1.25	SDR 26	160	0.572	2.86			
15+00		200			PVC				410.7	91.2	
	500		8	1.25	SDR 26	160	0.572	2.86			
20+00		220			PVC				407.9	81.4	
	1000		8	1.25	SDR 26	160	0.572	5.72			
30+00		240			PVC				402.2	70.2	
	600		8	1.25	SDR 26	160	0.572	3.43			
36+00		300			PVC				398.7	42.7	
	900		8	1.25	SDR 26	160	0.572	5.15			
45+00		320			PVC				383.6	31.9	
	500		8	1.25	SDR 26	160	0.572	2.86			
50+00		350			PVC				390.7	17.6	
	500		8	1.25	SDR 26	160	0.572	2.86			
55+00		300			PVC				387.9	38.1	
	500		8	1.25	SDR 26	160	0.572	2.86			Critical
60+00		360							385	10.8	Point
(1)											

9.4.2 Gravity Line Computations

As in previous examples, a critical point is selected. The computed hydraulic grade line must clear the CP plus CH.

Water surface (WS) in the storage tank is used as a starting point for hydraulic computations. Friction loss is subtracted from WS to compute HGL. Figure 9.10 shows computations that were preformed for this example.

Figure 9.10
GRAVITY FLOW COMPUTATIONS

USDA-NRCS

MO-ENG-106
07-97
File Code - Coop Folder

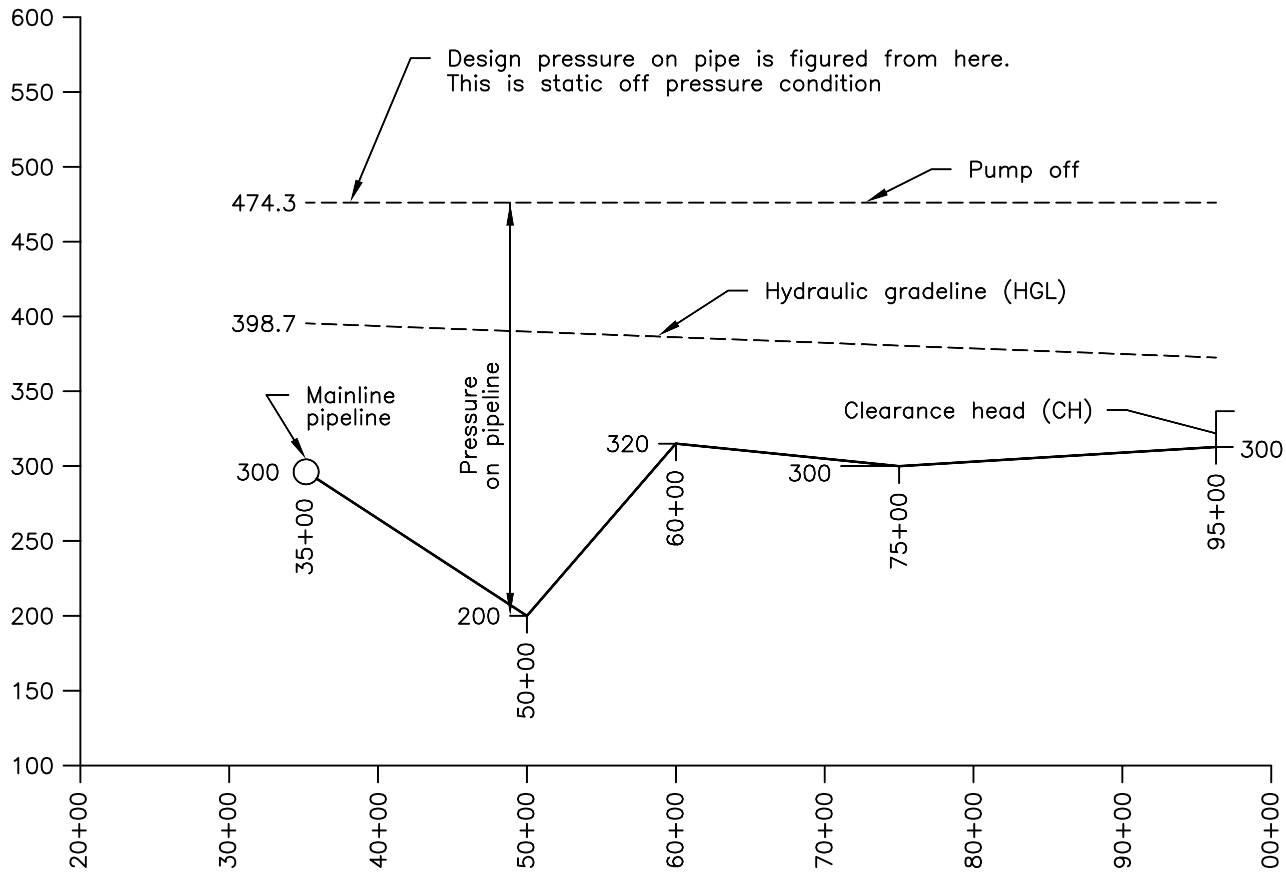
GRAVITY STOCKWATER PIPELINE HYDRAULIC COMPUTATION WORKSHEET

Land user Example No. 3 (Gravity Extension) *(Sheet 2 of 3)*
Job description West pasture
Farm No. 532 Tract No. 3 Field No 3 County Gallatin
Designer V. Tech Date 11/8/90 Checked by JCD Date 11/10/90

Water surface elevation (WS) 362.5 (Intake at sta 60+00)
Critical point along pipeline (CP): Station 85+00 Elevation 300
Clearance Head(CH) at critical point: 25 ft x .433= 10.8 psi
Minimum required HGL at CP = CP elevation + CH ft = 300 + 25 = 325
Estimated pipeline entrance losses (EL) = ____________ft
Starting HGL elevation = WS - EL = 362 - 1.0 = 361.5

(1) Station	(2) Reach Length (ft)	(3) Pipe Elevation	(4) Design Flow Rate (gpm)	(5) Nominal Pipe Diameter (in)	(6) Pipe Type	(7) Pipe Pressure Rating (psi)	(8) Friction Factor H_f/100ft (ft/100)	(9) Reach Total H_f (ft) (2) x (8)	(10) HGL Elev (from start HGL)	(11) Max Pressure on Pipe (psi) WS-(3)	Comments (slope %)
60+00		360							361.5	1.1	at source
	500		8	1.25	PVC SDR 26	160	0.572	2.86			
65+00		275							358.6	37.9	
	2000		6	1.25	PVC SDR 26	160	0.336	6.72			Critical
85+00		300							351.9	27.1	Point
	1500		6	1.25	PVC SDR 26	160	0.336	5.04			
100+00		180							346.9	79	
	2000		6	1.25	PVC SDR 26	160	0.336	6.72			
120+00		280							340.2	35.7	

Figure 9.11
GRAVITY FLOW LATERAL PROFILE



It sometimes may not be necessary to actually compute HGL on a lateral of this nature. It will often be obvious that HGL will clear the critical head point.

Figure 9.12
GRAVITY FLOW LATERAL COMPUTATIONS

USDA - NRCS

MO-ENG-107
07-97
File Code - Coop Folder

LATERAL STOCKWATER PIPELINE
HYDRAULIC COMPUTATION WORKSHEET

Land user Example No. 2 (Lateral A)
Job Description West pasture
Farm No. 532 Track No. 3 Field No. 3 County Gallatin
Designer V. Tech Date 11/8/90 Checked by JCD Date 11/10/90

HGL at mainline 398.7
Pump OFF elevation (Automatic pressure sysem only) ________
Flow in lateral - OFF elevation (manual, timed or gravity) -------
Critical point along lateral (CP): Station 95+00 Elevation 310.0
Clearance Head (CH) at critical point: 25 ft x .433 = 10.8 psi
Minimum required HGL at CP=CP elevation + CH ft = 310 + 25 = 335

(1) Station	(2) Reach Length (ft)	(3) Pipe Elevation	(4) Design Flow Rate (gpm)	(5) Nominal Pipe Diameter (in)	(6) Pipe Type	(7) Pipe Pressure Rating (psi)	(8) Friction Factor H_f/100ft (ft/100)	(9) Reach Total H_f (ft) (2) x (8)	(10) HGL Elev (from start HGL)	(11) Max Pressure on Pipe (psi) WS-(3)	Comments (slope %)
36+00		300							398.7	77.5	at main
	1400		8	1.25	PVC SDR 26	160	0.572	8.01			
50+00		200							390.7	118.8	
	1000		8	1.25	PVC SDR 26	160	0.572	5.72			
60+00		320							385	66.8	
	1500		6	1.25	PVC SDR 26	160	0.336	5.04			
75+00		300							379.9	75.5	
	2000		6	1.25	PVC SDR 26	160	0.336	6.72			
95+00		310								71.1	373.2>
											335 ok

Figure 9.13
PRESSURE REDUCER VALVE INSTALLATION

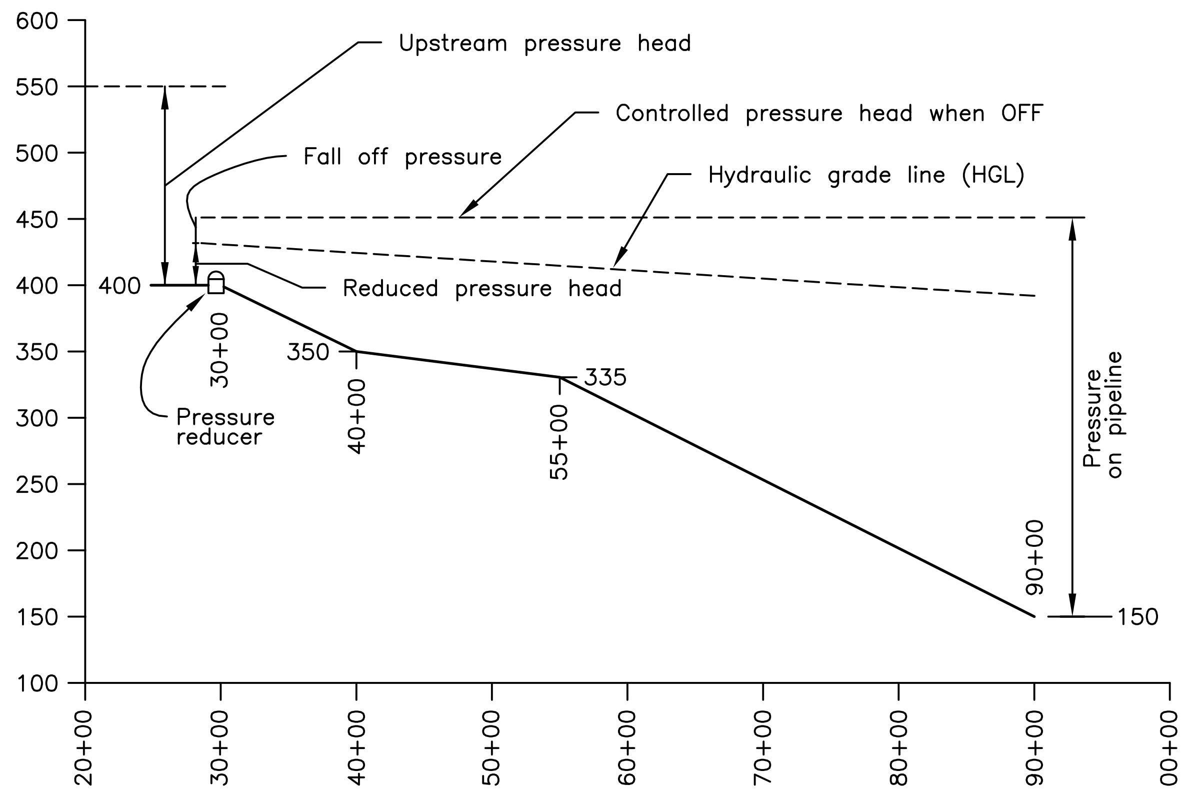


Figure 9.14
PRESSURE REDUCER VALVE SYSTEM COMPUTATIONS

USDA - NRCS

MO-ENG-107
07-97
File Code - Coop Folder

LATERAL STOCKWATER PIPELINE
HYDRAULIC COMPUTATION WORKSHEET

Land user Example No. 4 (Pressure Reducer)
Job Description North pasture
Farm No. 532 Track No. 3 Field No. 4 County Gallatin
Designer V. Tech Date 11/8/90 Checked by JCD Date 11/10/90

HGL at mainline 450
Pump OFF elevation (Automatic pressure sysem only) _________
Flow in lateral - OFF elevation (manual, timed or gravity) ______
Critical point along lateral (CP): Station ______ Elevation ____
Clearance Head (CH) at critical point: _________ ft x .433 = ________ psi
Minimum required HGL at CP=CP elevation + CH ft = + _____ = ____

From Manufacturer - Fall Off = 4.0 psi at receiving valve 4.0 psi x 2.31 = 9.2 ft 450-9.2 = 440.8

(1) Station	(2) Reach Length (ft)	(3) Pipe Elevation	(4) Design Flow Rate (gpm)	(5) Nominal Pipe Diameter (in)	(6) Pipe Type	(7) Pipe Pressure Rating (psi)	(8) Friction Factor H_f/100ft (ft/100)	(9) Reach Total H_f (ft) (2) x (8)	(10) HGL Elev (from start HGL)	(11) Max Pressure on Pipe (psi) WS-(3)	Comments (Slope %)
30+00		400							440.8	21.7	at main
	1000		10	1 1/4	PVC SDR 26	160	0.865	8.65			
40+00		350							432.2	43.3	
	1500		10	1 1/4	PVC SDR 26	160	0.865	13			
55+00		335							419.2	49.8	
	4500		10	1 1/4	PVC SDR 26	160	0.865	38.9			
90+00		150							380.3	129.9	
											129.9< 160 ∴ ok