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Case Study:

STANWOOD CENTRALIZED ANAEROBIC DIGESTER EVALUATION OF SITE OPTIONS AND TRANSPORT SYSTEM LAYOUT

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While the information included in this case study may be used to begin a preliminary analysis, a professional engineer and other professionals with experience in pumping manure slurries should be consulted for the design of a particular project.

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EXECUTIVE SUMMARY

Stanwood Bio-Energy Producers, LLC (SBEP) is a group of Stanwood dairy and egg producers conducting a year-long, centralized manure digester feasibility study. This case study provides a preliminary technical evaluation of the manure pipe transport and related site selection portions of this project, including:

- Technical evaluation of three proposed possible sites for the central digester facility.
- General layout of piping from dairies to the central facility.
- Preliminary pumping system analysis including calculation of head losses, and sizing of piping and pumps for each of the three sites.
- Preliminary cost estimate for the piping network.
- Energy use estimate for the piping network

Several pipeline design options with their advantages and points to consider are summarized in Table 1. Recommendations for this project are summarized in Section 8.

Description of the piping system: The proposed piping network would connect seven of the 10 dairies via medium diameter PVC pipe to the central digester facility. Manure slurry would be pumped from underground manure storage tanks on the dairy farms to the digester. After processing in the digester vessel, solids from the digester effluent would be separated, and the liquid portion of the effluent would be pumped back through the pipe network to the individual farm lagoons. This transfer of manure and effluent would occur as frequently as once a day for some of the farms, and less frequently for others. Approximately, 35,000 feet of piping with a maximum pumping distance of approximately 21,000 is required for connecting seven dairies to the piping system.

Central Digester Site Evaluation: Three sites have been considered for siting the central digester facility as shown in Figures 1 and 2. These are:

Site 1: Stubb Road
Site 2: Valde Road adjacent to the railroad
Site 3: Marine Drive

A site located near the physical center of the project area, such as Site 2 on Valde Rd. is preferred considering design simplicity and operational flexibility. Site 1, located at the highest elevation and the extreme eastern part of the project area, is least subject to flooding. Site 3 located on Marine Dr., a major N-S route to the west of the project area, would be best of the three sites to interconnect with the electric utility.

Flooding: While all sites are prone to flooding, Site 1 on Stubb Road is 4 to 10 feet higher in elevation than the other sites under consideration. At all possible digester sites, regardless of location, the potential for flooding should be addressed in the design. This can be accomplished by elevating equipment and materials that are subject to water damage by land fill or by locating on the second floor of a masonry building.

General Layout of Piping: The proposed layout of new piping, shown in Figures 7 to 12, has been arranged to:

- minimize railroad, road and stream crossings,
- parallel roads and existing piping, and
- traverse owner property as much as possible.

A final route for the pipeline has not been decided at this early stage in the design process.

One-Pipe versus Two-pipe Design: A single pipeline could be used for both supply of raw manure to the central digester and return of effluent to the dairies. Alternatively, the system might use two parallel pipes; i.e. separate pipes for return and supply. If Site 2 is selected a third option is possible in which shared return and supply piping is run to the Farms 10 and 11 on the north branch of the pipeline, as shown in Figure 7, with separate return and supply piping to the other dairies on the east and west branches.

Pipe Diameter: PVC pipe with diameters of 8 and10 inches with 8% and 10% solids content has been considered in calculating system curves of head loss versus flow rate (Figures 14 to 25 in Appendix A.) Ten inch diameter should be considered only if shorter pumping times are required, since its cost would be greater than with 8" piping. Reuse of existing 6" irrigation piping was investigated but was not found to be practical.

Pumps: At the central digester, two return pumps are recommended: a high-head pump to serve dairies that are far from the plant and a low-head pump to serve closer dairies. Similarly, two mobile trailer pumps are recommended: one pump to be shared by dairies far from the site and a smaller pump to be shared by closer dairies. In addition, a dedicated return pump should be considered for dairies requiring frequent pumping of large volumes, such as Farms 10 and 11. The additional cost of this option might be offset by lower operation costs. Approximate horsepower required for pumps are shown on the system and pump curves in Appendix A.
.

Energy Use: Energy costs due to pumping are expected to be much lower than labor costs for operating the system on a daily basis. Differences in energy costs for the piping system will not be a major factor in choosing between the three sites. Rather, selecting a site with greater operational flexibility, which will result in lower labor costs, should be prioritized.

Preliminary Cost Estimate: Preliminary cost estimates for several options are included in the Section 7. Estimates range from $1.0 to $1.7 million, depending primarily on the pipe diameter selected and whether a one-pipe, two-pipe system or combination is selected.

Table 1. Summary of Pipeline Design Options

Option		Advantages	To Consider
Site Selection	SITE 1 Stubb Rd.	• Highest elevation (Table 3)	
	SITE 2 Valde Rd.	• Slightly lower cost (Tables 12 to 14) • Combined supply and return pipe option (See below and "Return and Supply Pipe Options" in Section 3) • High-head and low-head pumps back each other up to a greater extent (See "Reliability" in Section 2.) • Least energy use (Table 11)	
	SITE 3 Marine Dr.	• Lowest cost of interconnection with electric utility • Possibly lower trucking costs, if piping is run across the Stillaguamish River to Farm 6. Farm 6 is located at the opposite end of the valley from Site 3.	
Pipe Size	8"	• Lower cost (Tables 12 to 14)	
	10"	• Shorter pumping times (Table 10) • Lower energy costs (Table 11)	• Higher material and initial costs
Return & Supply Pipe	Shared Return and Supply (One-Pipe)	• Least cost option (Table 12 to 14)	• Risk of pathogen transmission • Longer pumping times • More labor required to set valves
	Separate Return and Supply (Two-Pipe)	• Low risk of pathogen transmission (See "Minimization of Pathogen Transmission" in Section 1.) • Greatest flexibility of operation (See "Return and Supply Pipe Options" in Section 3.) • Shorter overall pumping times (Table 10.) • Manual setting of valves in return line only	• Highest cost option
	Separate Return and Supply, Except Shared to Farms 10 and 11 (Combined)	• All advantages of Two-Pipe system • Reduced cost	
Additional Connection	To Farm 1 To Farm 2 To Farm 6	• Lower trucking costs	
Pumps	Dedicated pump for Farms 10 and 11	• For Site 2, shorter overall pumping times due to possibility of pumping simultaneously to multiple locations. • Lower labor costs	

1. GENERAL DESCRIPTION OF OPERATION

For seven of the dairies north of the Stillaguamish River, manure slurry will be pumped from each dairy to the central digester facility. Manure from the other three dairies will be trucked. Two mobile trailer pump(s) can be rotated around the dairies regularly to pump manure from dairies to the central digester. One low-head pump will be shared by dairies close to the plant and another high head pump shared by dairies located at a greater distance. Similarly, digested slurry will be returned to dairies by two central pumps—one high-head and one low-head—located at the digester plant.

Control valves, which may be either gate valves or check valves, depending on design, will be located at all tees off the main pipeline to farms. These will be arranged and operated so that slurry will be allowed to run only from dairy to digester directly with piping to other dairies shut off. Return and supply piping can be shared or separate or a combination of shared and separate, as discussed in Section 3. These options affect the number of valves that must be manually operated.

If a centrally-located site is selected, three independent branches of pipe can be run from this site to the dairies. Some additional piping may be required to ensure all branches are completely independent, as shown in Figure 13. Flexible connections, rather than hard piping with valves, may be used to connect the discharge of the central pump to the appropriate branch when returning digested slurry to a dairy from this site. Sites 1 and 3 do not have the possibility of independent branches.

Minimization of Pathogen Transmission

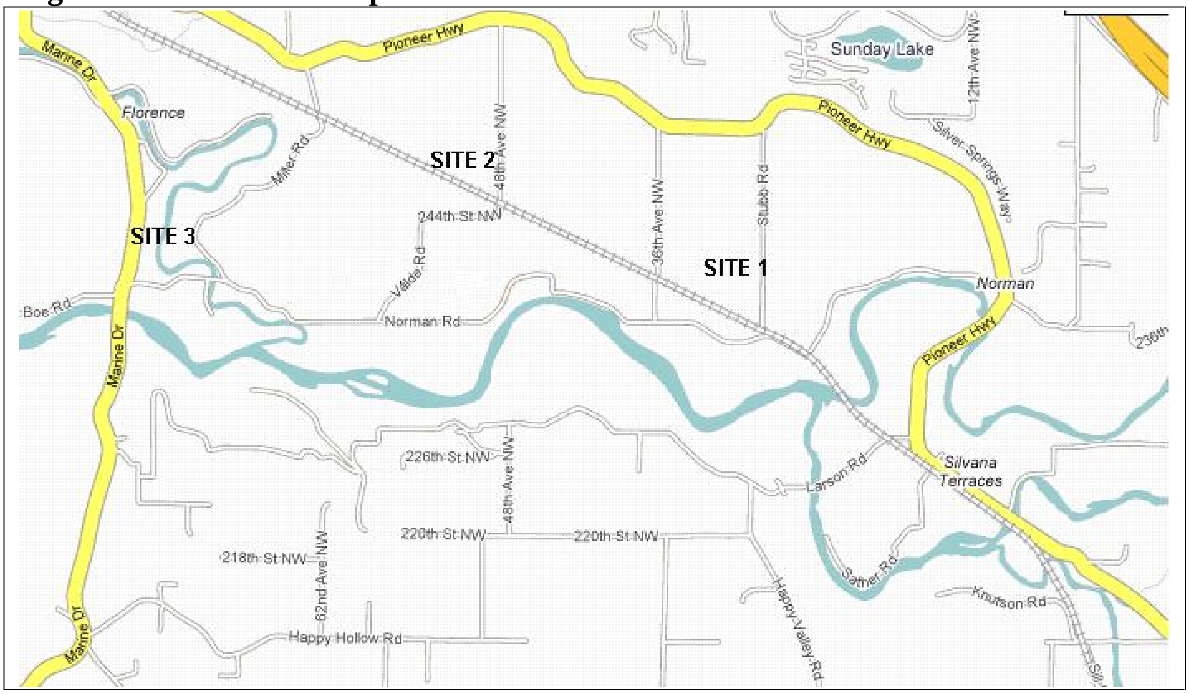
The risk of pathogen transmission is an important consideration when several dairies are connected to a central digester by a shared pipeline. Pathogen transmission can be minimized by the following:

1. *Valve selection*
   Diaphragm valves have no cavities and minimal contact surfaces that can harbor pathogens. In contrast, knife gate valves – which are also suitable for slurry service – contain cavities that may promote contamination. (Refer to Section "Piping and Pipe Route: Selection Valves".)

2. *Back flushing with effluent*
   A single pipeline may be used to both supply manure slurry to the central digester and return effluent back to the dairies. In this case, the risk of pathogen transmission can be minimized by flushing the pipe by immediately returning digested effluent back to the same dairy after delivery of raw manure from that dairy. (Refer to Section "Piping and Pipe Route: Selection Valves: Return and Supply Pipe Options".)

3. *Separate return and supply pipe*
   Alternatively, separate return and supply piping may be used, with the disadvantage of a greater cost of installation. Pathogen transmission in this case is less likely than with shared supply and return piping, since the return piping is never contaminated with raw manure slurry. (Refer to Section "Piping and Pipe Route: Selection Valves: Return and Supply Pipe Options".)

Figure 1. Area Street Map



From MapQuest, www.mapquest.com

2. PROPOSED DIGESTER SITES

Three locations for the central digester plant have been proposed, as shown on the satellite images in Figures 2 to 5. Refer to Figure 1 for a street map of the area, also showing these three sites. These sites are:

Site 1: Stubb Road (aka 28th Ave. NW) just east of Farm 7 and north of the railroad on Farm 7 property
Site 2: A site located near the physical center of the valley, such as on Valde Rd.
Site 3: East of Marine Drive just north of the Stillaguamish River on Farm 3

It should be noted that these sites were chosen to demonstrate three *general* locations for a central digester system, only for the purpose of the initial feasibility inquiry. They are identified as a means of raising issues that would be relevant at these locations or other locations like them. Landowners have not been contacted regarding specific parcel availability or purchase, and final location of the digester may only be located in the general vicinity indicated by these sites, not on the specific plots identified. These sites do not represent specific recommendations by engineering or other consultants.

Piping and pumps for Sites 1, 2 and 3 have been analyzed with system and pump curves for these sites included in Appendix A.

Advantages of each site are described below and summarized in Tables 1 and 2. Manure and effluent pumping factors which influence the location of the central plant include:

- Flooding potential
- Pipeline energy use
- Cost of pipeline installation
- Pipeline operation and maintenance costs (other than energy)
- Pump reliability
- Manure/effluent transportation costs
- Availability of property for sale
- Sale of digester co-products

Flooding Potential

While flooding is possible at all sites, Site 1 is least susceptible to flooding. The existing buildings located on this site also indicate lower flooding potential, since buildings tend to be constructed on high spots. The north side of this building site is at a higher elevation than its south side.

Factors other than elevation affect the potential for flooding. For example, the area just south of the railroad at the intersection of Valde Road has a higher potential for flooding than the north side despite its slightly higher elevation because the railroad acts as a dyke, which causes a floodway just immediately south of it. Florence Road, just north of Site 3, also acts as a dyke reducing flooding on its north side.

The recent flood during November 2006 was the largest in about three years. Marine Drive was closed for two days due to water over the road. Sites 1 and 2 were also flooded, but for less time than Marine Drive. Floods in the mid 1990's were worse. In these, flood waters rose almost up to the elevation of Pioneer Highway at Farm 10 – above the elevation of the 100 year flood plain at an elevation of approximately 24 feet – and behind the protection of the railroad.

Elevations of the three sites and dairies are shown in Table 3. Figure 6 shows elevations of the area relative to the 100 year flood plain. Close-ups of each proposed site in Figures 2 to 5 also show elevation contours in two foot intervals. A topographical map is included in Appendix D. Note there are discrepancies between the flood plain map and the other figures. For example, the flood plain map shows Site 3 on Marine Drive as above the flood plain even though contour maps show this site as at the same elevation as Site 2 on Valde Road, which is below the 100 year flood plain.

Pipeline Energy Use

Estimates of annual energy use to pump manure and effluent through the pipeline are shown in Table 11. A centrally located site such as Site 2 would have lower energy use. Site 1 would use approximately the same energy as Site 3. Regardless, the energy costs at all sites are expected to be low compared to other costs.

Pipeline Initial Costs

The initial cost of the pipeline – including costs of material, labor equipment, and the contractor's overhead and profit – is not significantly affected by location of the digester site. While Sites 1 and 3 would require larger pumps, pump costs including spares are estimated only to be approximately $20,000 more than Site 2. Pipe lengths are very similar for all three sites, with Site 3 requiring some additional piping at the west end of the project area. Site 2 also would require some additional piping to keep all three branches of the pipeline independent, as shown in Figure 13.

The greater potential for flooding may increase the initial cost for Sites 2 and 3 compared to Site 1. Facilities at Sites 2 and 3 may require more fill to raise the elevation of the land and/or a taller masonry building for locating pumps, generator and other sensitive equipment on the second floor. These costs have not been included in the preliminary cost estimate (Tables 12 to 14)

Pipeline Operation and Maintenance Costs

Three independent branches of piping, as would be possible for a centrally located site, such as Site 2, may result in lower pipeline operation costs. Independent branches would enable pumping to or from different dairies simultaneously and so may reduce overall pumping time. In addition, the operator may have greater flexibility in scheduling and carrying out tasks.

Site 1 is less subject to flooding and so may have lower operation and maintenance costs associated with down time and lower risk of damage to digester co-products and equipment.

Pumping System Reliability

As shown in Figures 14 to 25 for a centrally located site, more dairies at an intermediate distance from the site can be served by either the high-head or low-head pump. This will improve reliability since the two pumps back each other up to a greater extent. On the other hand Site 1 will have lower risk of down time and equipment damage due to flooding.

Manure/Effluent Transportation Costs

Site 3 might result in lower costs associated with trucking manure if piping is extended to Farm 6 at the east end of the project area. The other two dairies from which manure will be trucked are both located very close to Site 3 on the west end.

Sale of digester co-products

Site 3 on Marine Drive would have lower interconnection costs to the electric utility. Relatively little additional piping would be required to run piping west beyond Farm 3 to this site. Location of the central facility on Marine Drive may also have transportation advantages for other co-products generated by the digester, such as fertilizer or planting medium.

Table 2. Advantages of Three Proposed Sites

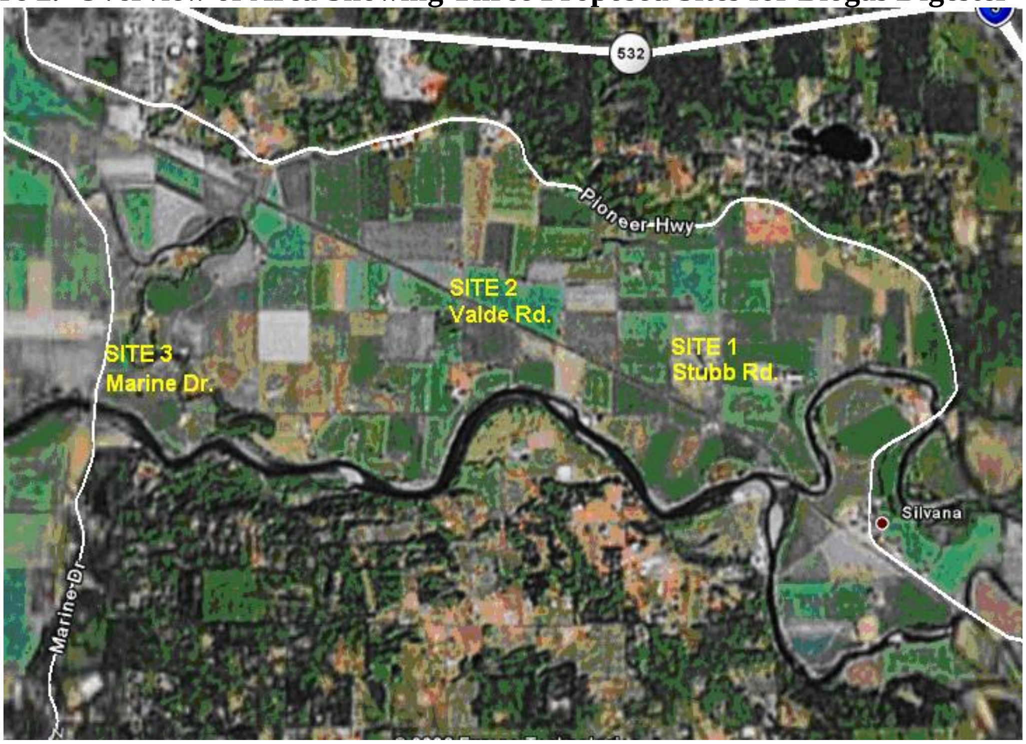
	Advantages
SITE 1 **Stubb Rd.**	• Lowest flooding potential due to higher elevation
SITE 2 **Valde Rd.**	• Enables simultaneous pumping, possibly resulting in lower labor costs • Slightly lower initial cost • Supply and return pipe options • High-head and low-head pumps back each other up to a greater extent, resulting in greater system reliability • Lowest energy use
SITE 3 **Marine Dr.**	• Lowest connection costs to electric utility • Lower manure/effluent trucking costs if piping is run to Farm 6

Table 3. Approximate Elevations of Proposed Digester Sites and Dairies

Facility	Elevation Above Sea Level (feet)	Elevation Relative to Site 1 (feet)	Elevation Relative to Sites 2 & 3 (feet)
Site 1: Stubb Road	26	-	-
Site 2: Valde Rd.	18	-	-
Site 3: Marine Drive	18	-	-
Farm 1*	10	-16	-8
Farm 2*	19	-7	1
Farm 3	18	-8	0
Farm 4	29	3	11
Farm 5	22	-4	4
Farm 6*	31	5	13
Farm 7	29	3	11
Farm 8	21	-5	3
Farm 9	19	-7	1
Farm 10	15	-11	-3
Farm 11	21	-5	3

* Farms 1, 2 and 6 may not be connected to the pipeline system.

Figure 2. Overview of Area Showing Three Proposed Sites for Biogas Digester



From GoogleEarth, www.googleearth.com

Figure 3. Overview of Proposed Site 1 for Central Digester

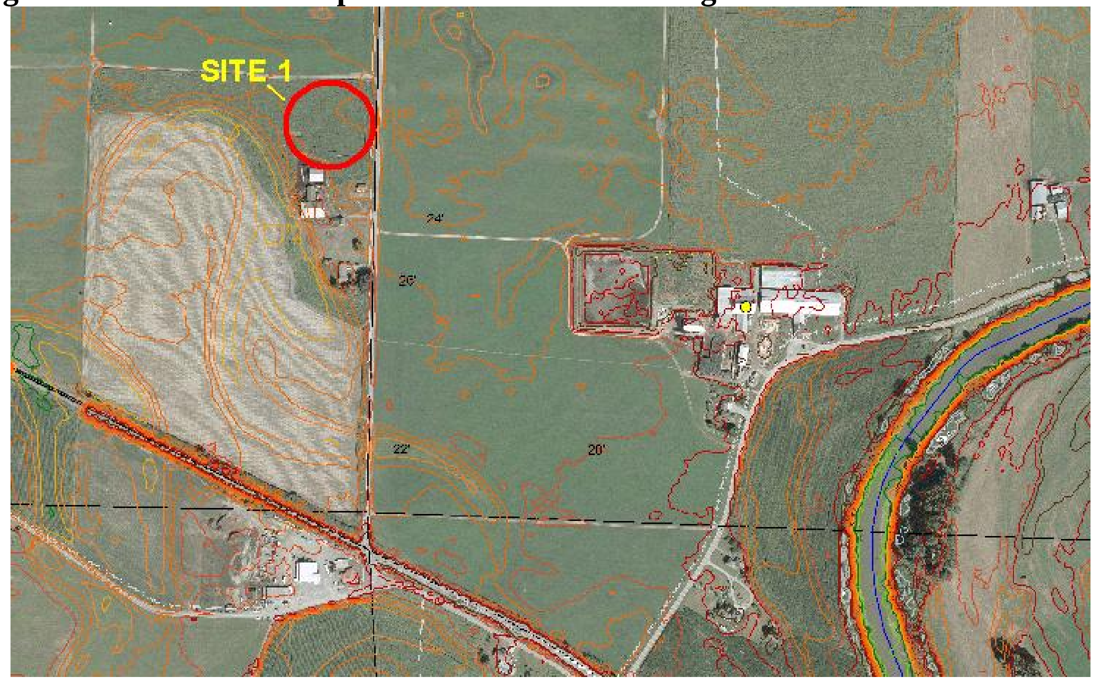


Figure 4. Overview of Central Area and Proposed Site 2 for Central Digester

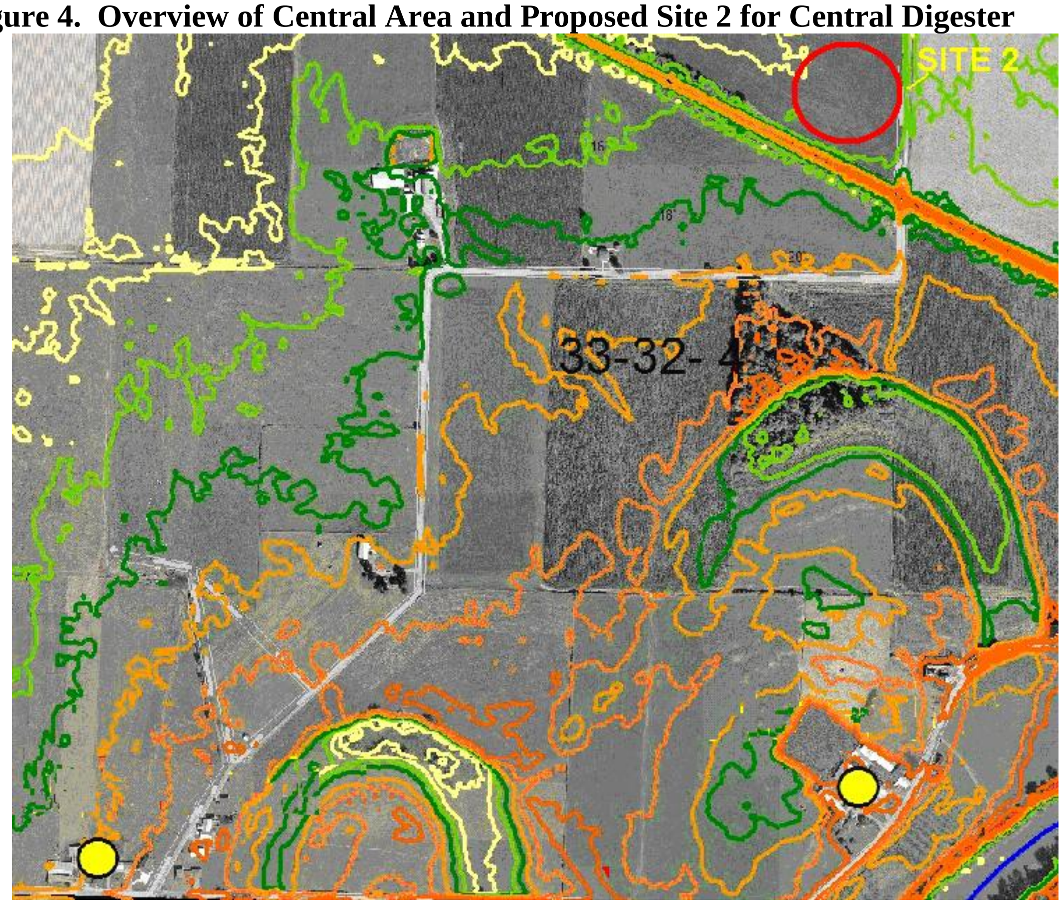


Figure 5. Overview of Proposed Site 3 for Central Digester

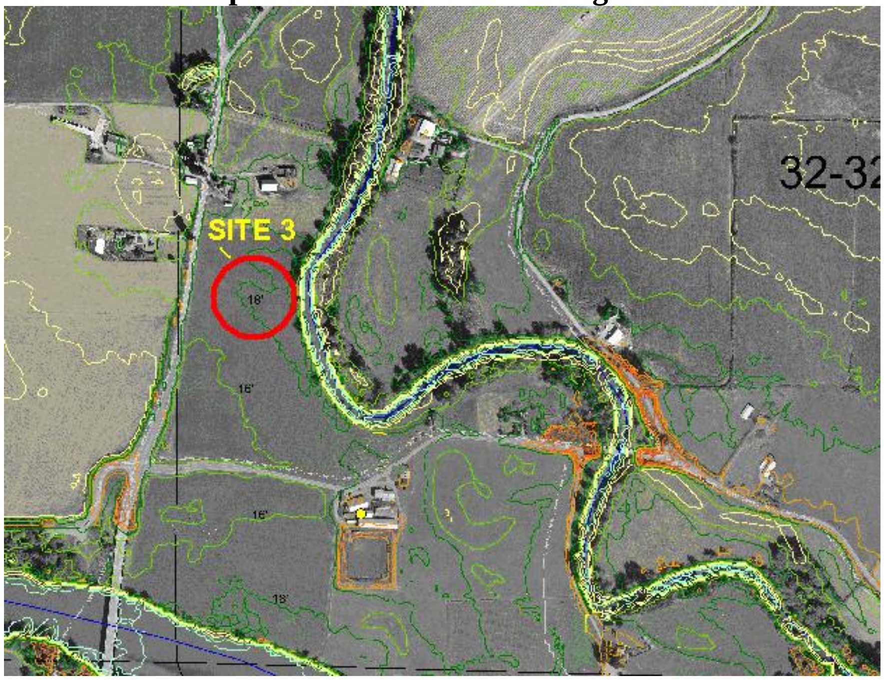
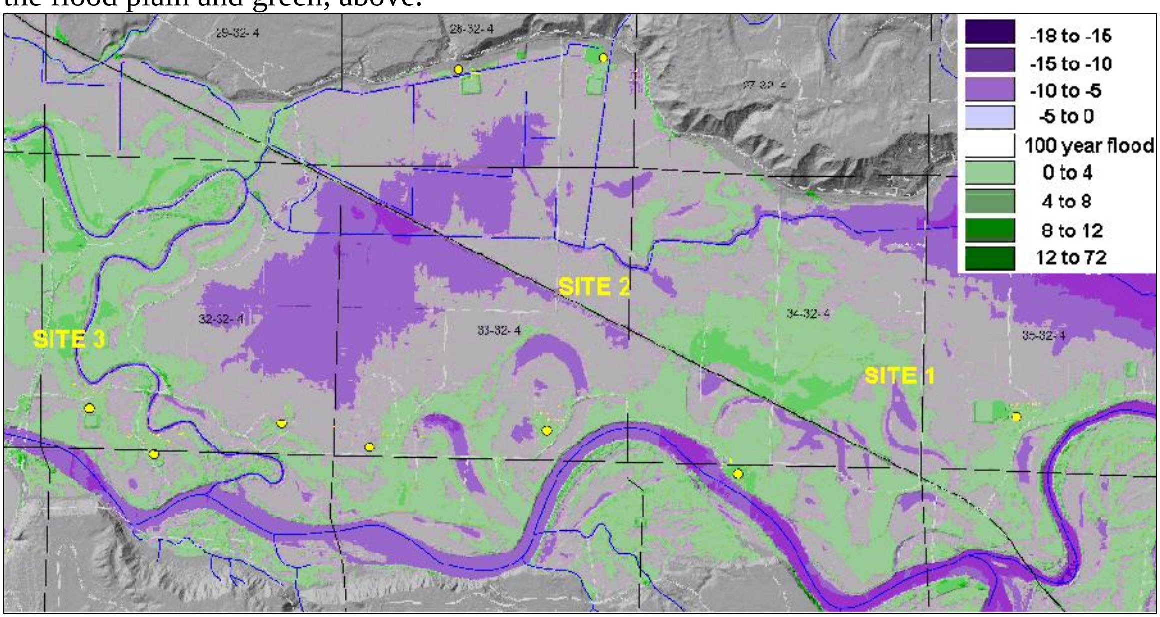


Figure 6. 100-Year Flood Plain

Elevations in feet with respect to the 100 year flood plain. Purple indicates areas below the flood plain and green, above.



3. PIPING AND PIPE ROUTE

An overview of the approximate pipe route proposed for transport of manure from dairies to the digester is shown in Figure 7. Figures 8 to 12 show detail views of pipe routes and identify current property owners by number. The proposed pipe layout has been selected to minimize road, railroad and stream crossings, to follow roads, and to run over property owned by project participants as much as possible. Approximate pipe lengths to each dairy from the three proposed digester sites are summarized in Table 7 for this proposed pipe route.

Manure will likely not be pumped from Farm 2 due to low treatment volumes. Farms 1 and Farm 6 also will likely not be connected to the proposed pipeline due to their locations across the Stillaguamish River. The incremental cost of running piping to Farm 1, Farm 2 and Farm 6 are given in Table 13.

Characteristics of Manure Slurry

Characteristics of manure slurry used in sizing piping and pumps are discussed in Appendix C. In this analysis, it is assumed the manure slurry transported via pipeline will have a solids content of 7% to 8%. This solids content is dilute enough to be easily pumped, yet not too dilute for optimum digester design. Actual total solids content of manure in storage tanks and lagoons currently ranges from approximately 2% to 10%, depending on factors such as season and guttering of rain water. Solids content may be adjusted by dilution with water or diversion of rain water from the manure storage tank.

Crossings and Rights of Way

Table 4 lists road, railroad, and stream crossings and rights of way across property owned by non-participants of the project that would be required for the proposed pipe route shown.

Stream and River Crossings
At least two water bodies must be crossed. The first crossing – the drainage ditch running east-west just south of Farms 10 and 11 – is relatively minor and can be drilled. The second is the Old Stillaguamish Channel to Farm 3 and Site 3. This crossing would preferably be attached to the underside of the county road bridge. If this is not permitted, directional drilling under the channel might be considered.

The pipeline could also be run across the Stillaguamish River to Farm 1 at the west end of the project area and to Farm 6 at the east end. These crossings might be either directionally drilled under the river or attached to county road bridges. For the case of Farm 6, the pipe could also be attached to the railroad bridge. In the proposed route shown in Figure 7 and in the system curves shown in Figures 14 to 25, it has been assumed pipe would be run across the road bridges. With regard to Farm 6, distances are similar if crossing either the railroad bridge or the county road bridge and so from a piping perspective, neither is preferred over the other. The decision between these two routes should be based on right of way or other issues. For both Farms 1 and 6, crossing under the river results in shorter pipe lengths, but making the crossing would likely be significantly more expensive and would not be justified by savings in pipe costs and energy use.

Rights of Way through Non-Participating Property

Right of way through property owned by non-participants is most likely to be granted along roadways by obtaining a franchise with the county. The proposed route crosses three non-participating properties along county roads (Non-Participants 1 to 3.).

If pipe is also run to Farm 6, it could stay on participating property if run over the railroad bridge across the Stillaguamish River. If attached to Pacific Highway county bridge, as assumed in Figure 7, piping along the roadway would cross two additional non-participating properties (Non-Participants 4 and 5).

Railroad Crossings

The railroad must be crossed twice to connect Farms 7, 10 and 11 to the digester pipeline system. There is an underpass at 36th Ave. that is convenient for running pipe between Farm 7 and Farm 4. A crossing at Valde Rd. would be preferable for connecting to Farms 10 and 11. This crossing would be directionally drilled.

Road Crossings

Four and possibly five road crossings will be required under Norman Rd., 36th Ave., Valde Rd. and possibly Miller Rd. Various rights of way along Norman Road will need to be obtained from Snohomish County.

Table 4. Summary of Rights of Way and Crossings*

East to West	1. Road crossing under 36th Ave. 2. Railroad crossing at 36th Ave. attached to underpass 3. Road crossing under Norman Rd. for lateral pipe to Rod storage tank 4. Right-of-way along Norman Road over property owned by Non-Participants NP3, NP9, NP8 and NP1 5. Road crossing under Valde Rd near intersection with Norman Rd. 6. Right-of-way along Norman Road over property owned by Non-Participant NP2 and NP3 property 7. Road crossing either under Miller Rd. or Norman Rd. 8. Stream crossing over Old Stillaguamish Channel attached to bridge
North to South	9. Road crossing under Valde Rd. near intersection with Pioneer Hwy. 10. Railroad crossing at intersection with Valde Rd., directionally drilled.
Additional	To Site 3: 12. Road crossing under Norman Rd. on Farm 3 To Farm 6 (if crossing river on county road bridge): 13. Right-of-way along Norman Road over property owned by Non-Participants NP9 and NP5 14. Stream crossing over Pacific Highway bridge. To Farm 6 (if crossing river on railroad bridge): 13. Stream crossing over railroad bridge.

* Rights of way and crossings required for proposed pipe route shown in Figures 7 to 12

Pipe Size

Pipe diameter should be sized to maintain sufficient velocity to keep solids entrained. Considering that manure slurries typically contain large solids that are prone to settling, a design velocity of 5 or 6 feet per second (fps) is often recommended. A slurry with a more uniform consistency may require velocities of only 3 to 5 fps. In this analyses pipe diameters of 4 to 6 fps have been assumed.

The pipe diameter should either remain constant or should have smooth, gradual transitions between diameters, so the slurry does not experience abrupt changes in velocity. The preliminary analysis outlined in Appendix A indicated that either 8" or 10" diameter pipe may be used. Six inch diameter piping was evaluated and resulted in significantly greater head loss and, since existing 6" diameter irrigation pipe cannot be reused (see Subsection "Reuse of Existing Piping" below), is not recommended.

Advantages of 8" and 10" piping are summarized in Table 5. Ten inch diameter pipe has a higher initial cost, but would result in reduced energy use, as shown in Table 11. The reduction in energy use is not as much as might be expected since higher flow rates are required to maintain a minimum velocity of 4 fps. Perhaps the most important advantage of ten inch diameter pipe is a 40% reduction in pumping times (Table 10). This could result in lower labor costs over the long run that may offset the higher initial cost.

Table 5. Advantages of 8" Versus 10" Diameter Pipe

Pipe Size	Advantages
8" Diameter	• 12-15% lower initial cost (Table 12)
10" Diameter	• 40% shorter pumping times (Table 10) • 11-25% lower energy costs (Table 11)

Pipe Lengths

Overall Length of Piping System

The proposed piping system in which seven dairies are connected requires 33,000 to 36,000 feet of pipe. If Farms 1, 2 and 6 are also connected, approximately 48,000 feet would be required (Table 8).

Pipe Lengths From Dairies to Digester

Pumping requirements for each dairy is primarily determined by its distance from the digester. Approximate pipe lengths from each dairy to the three digester sites are summarized in Table 7. For optimum pumping, both the longest run of pipe and the difference between the longest and shortest runs should be minimized. On both these counts, Site 2 is better than either Site 1 or 3. Note that the total length of the piping system is not the sum of these distances from each dairy to the digester.

The average distance of the dairies from the digester ranges from approximately 8,000 feet to 11,000 feet, depending on the digester site that is selected. The maximum distance ranges from 14,000 to 24,000, depending on the digester site and the dairies that are connected.

Actual distances between the dairies and digester will vary depending on the exact location of the selected site. Lengths given in Table 7 were assumed in calculating the system curves shown in Appendix A.

Pipe Material

Typically PVC pressure pipe rated for 200 psi is used for this type of application, except HDPE is recommended under road, railroad and stream crossings. Any metal components should be coated with asphalt, plastic or epoxy to retard corrosion.

All joints must be sealed so the pipe is water tight. For PVC pipe diameters of about 8 inches or greater, gasketed joints are recommended due to the difficulty of making solvent welded (i.e. primed and glued) joints on large pipe. Both gasketed and solvent-welded joints are designed to be leak-free over a lifespan of a hundred years or more, if properly assembled.

Return and Supply Pipe Options

One-Pipe System
A single pipeline can be used for both supply of raw manure to the central digester and return of effluent to the dairies ("one-pipe system"). This would require manually reversing direction of the valves during supply and return operations.

Two-Pipe System
As a second alternative, two separate pipelines could be installed ("two-pipe system".) Check valves (i.e. one-way valves) could be used as automatic valves in supply piping, but manual valves would still be required in return piping. This is because when supplying slurry to the digester, there is a single destination, the digester. Flow would always pass through the valves in the same direction from any dairy to digester, with reverse flow to other dairies prevented by check valves. In contrast, in return of effluent manual valves must be used to select which dairy is pumped to.

While the initial cost of installing two separate pipelines would be significantly greater, operational costs in the long run may be less if the system requires less paid labor for setting valves and pumping.

Combined System:
If Site 2 is selected, a third "combined system" option is available. In this option, separate supply and return piping would be run in the east and west branches of the pipeline (Figure 7), while a single shared supply and return would be used in the north branch to Farms 10 and 11. In the north branch, valves would need to be set only at the tee between Farms 10 and 11, which is conveniently located between the two farms.

Summary:
Advantages of these options are summarized in Table 6. The primary advantage of a one-pipe system is a much lower initial cost. Both the two-pipe system and the combined system have lower risk of pathogen transmission. A two-pipe system will also give the operator greater flexibility in scheduling tasks since simultaneous pumping is possible.

Using a smaller return pipe with lower flow rates was investigated, since the digested effluent will have a lower solids content. Smaller than 6" diameter piping might be possible but resulted in high head losses. In initial cost estimates, 6" diameter return piping was assumed.

Table 6. Advantages of Return and Supply Pipe Options

Option	Advantages
Shared Return and Supply (One-Pipe)	• Lowest initial cost (Tables 12 and 14)
Separate Return and Supply (Two-Pipe)	• Lower risk of pathogen transmission • Shorter overall pumping times • Less manual setting of valves in return line required.
Separate Return and Supply, Except Shared to Farms 10 and 11 (Combined)	• Lower risk of pathogen transmission • Shorter overall pumping times • Lower initial cost compared to completely separate return & supply • Less manual setting of valves in return line required.

Selection Valves

Selection valves will be required at all tees such that a pathway from one dairy directly to the digester can be isolated. Valves must be arranged to minimize "dead ends" that may compromise flushing of the line during return of fluid from the digester to the dairy and may result in settling of solids. To minimize accumulation, true wyes are recommended over tees.

It is important to consult the manufacturer to ensure that valve type, materials and construction are appropriate for this application. That said, both knife gate valves and diaphragm valves are generally well-suited for transferring abrasive slurries. Both of these valve types have an unobstructed flow path when open. Knife gate valves are particularly suited for use with slurries that may contain solid masses. However, if pathogen transmission is a concern, diaphragm valves are preferred because they have no cavities that can harbor contamination. Ball valves, globe valves and butterfly valves should be used in slurry piping. Use of manually-operated, epoxy-coated steel knife gate valves is assumed in the cost estimate.

Keep in mind that closed valves will prevent isolated sections of piping from naturally draining. This will impact freeze protection requirements if these sections include above-ground portions.

Water hammer[1] due to abruptly closing valves is not a concern, since valves are only operated when the pump is not running.

One-Pipe System
Assuming two-way valves are used (as opposed to three-way valves), two valves are required at each branch from the main pipeline to a dairy.

[1] Water hammer can occur when a valve is turned off abruptly, sending a pressure wave down the pipeline that can damage the piping system.

Two-Pipe System
If separate return and supply piping is installed (two-pipe system), check valves (i.e. one-way valves) can be used instead of manually-operated selection valves in supply piping. Return piping would still require manually opening and closing valves.

Grade Changes

As much as possible the pipeline should be run so that it is level or has a continuous grade (up or down) to the digester. In particular, crests where the pipe comes up to a high point and then back down should be avoided because air tends to get trapped at these high spots and increases the head loss and, if the manure is pumped fast enough, some of the air can move through the pipeline, causing pressure surges. Tri-action valves located at all high points minimizes this condition. Low points also should be avoided due to increased settling of solids. Clean outs could be provided at low points in the pipeline, where feasible, to minimize the downtime in the event that the pipeline plugs up.

Since the valley is relatively flat, maintaining a continuous grade should not be a severe problem, but still should be carefully considered when laying out pipe. To a certain extent, grade changes can be reduced by varying the depth of the pipe trench and by following roads. Crests may be unavoidable in some locations, such as where pipe is attached to the undersides of bridges.

Trenching

Use of a trencher is recommended, rather than excavating a trench. With a trencher, a specified slope between markers can be entered to achieve accurate grades. Trenchers create a cup-shaped bottom, ideal for bedding the pipe. In the cost estimate, it has been assumed separate trenches will be required for return and supply piping.

Freeze Protection

The requirement for freeze protection can be reduced or eliminated if above ground piping is designed to drain completely when not in use. During freezing weather, manure may freeze at the dairies, so pumping in freezing weather would be unlikely to occur. Even if the pipeline is operated in freezing weather, pumping at velocities of 4 to 6 fps, as required to prevent settling, protects against freezing. Therefore, the primary freezing risk is due to slurry standing in piping that does not drain naturally. Note closed selection valves will impact the ability of piping to drain naturally and must be considered in the final design. Freeze protection has <u>not</u> been included in cost estimates.

Reuse of Existing Piping

Reuse of existing 6” piping on Farms 7, 10 and 11 was considered. However, during certain seasons this piping is used for irrigation 24 hours per day, 7 days a week and so would not be available for manure pumping. For this reason, use of the existing piping at these locations for delivery of manure to the digester was not included in the present analysis.

Table 7. Approximate Lengths of Pipe from Each Dairy to the Central Digester

Facility	Approximate Pipe Length from Dairy to Digester Site[1] (feet)		
	SITE 1	SITE 2	SITE 3
Farm 1 [2]	21,900	17,200	5,600
Farm 2 [2]	15,800	11,200	3,700
Farm 3	17,600	12,900	1,300
Farm 4	4,200	7,300	14,600
Farm 5	12,100	7,500	6,700
Farm 6 [2]	5,200	16,700	24,000
Farm 7	2,200	13,700	21,000
Farm 8	8,100	3,400	10,800
Farm 9	14,400	9,700	4,500
Farm 11	16,200	4,700	15,200
Farm 10	17,100	5,600	16,000

1 Overall length of the piping system is not the sum of these distances from each dairy to the digester.
2 Farms 1, 2 and 6 may not be connected to the pipeline system.

Table 8. Overall Lengths of Pipe

Case	Overall Length (feet)
Total excluding Farms 1, 2 and 6:	
Site 1	33,100
Site 2	36,500
Site 3	34,400
Additional Pipe to Connect :	
Farm 1	4,300
Farm 2	1,200
Farm 6	7,500

Figure 7. Overview of Proposed Pipe Route
Approximate route of new piping (yellow) with possible additional piping to Farms 1, 2 and 6, and Site 3 (red).

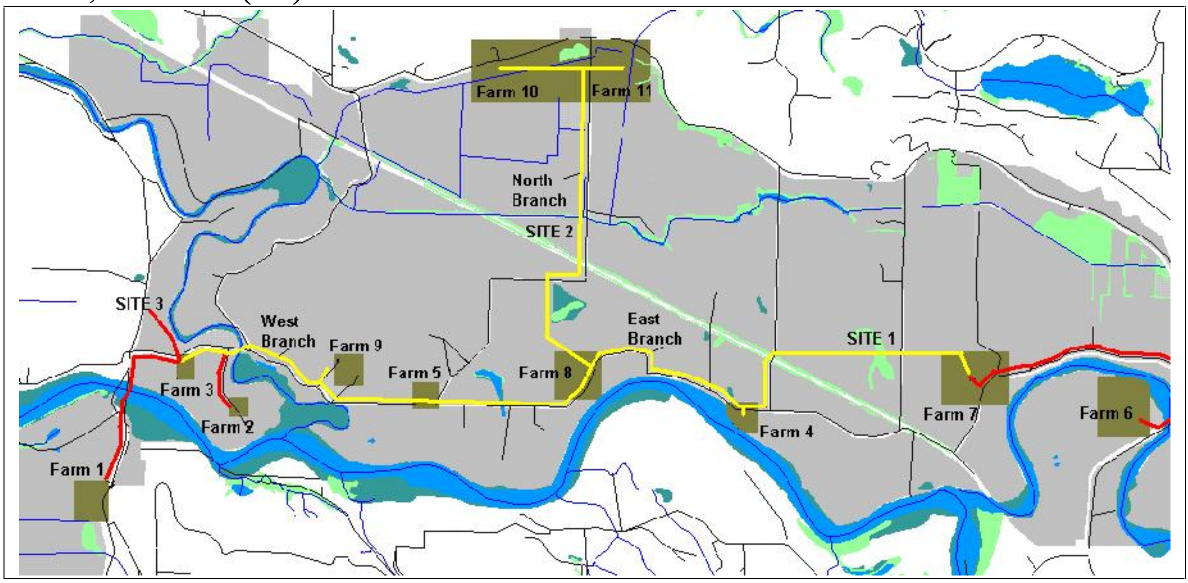


Figure 8. Proposed Pipe Route at West End of Valley
Approximate route of new piping (yellow) with possible additional piping to Site 3 and to Farms 1 and 2 (red). Farm numbers and non-participant (NP) numbers in this figure indicate property ownership, rather than location of facilities.

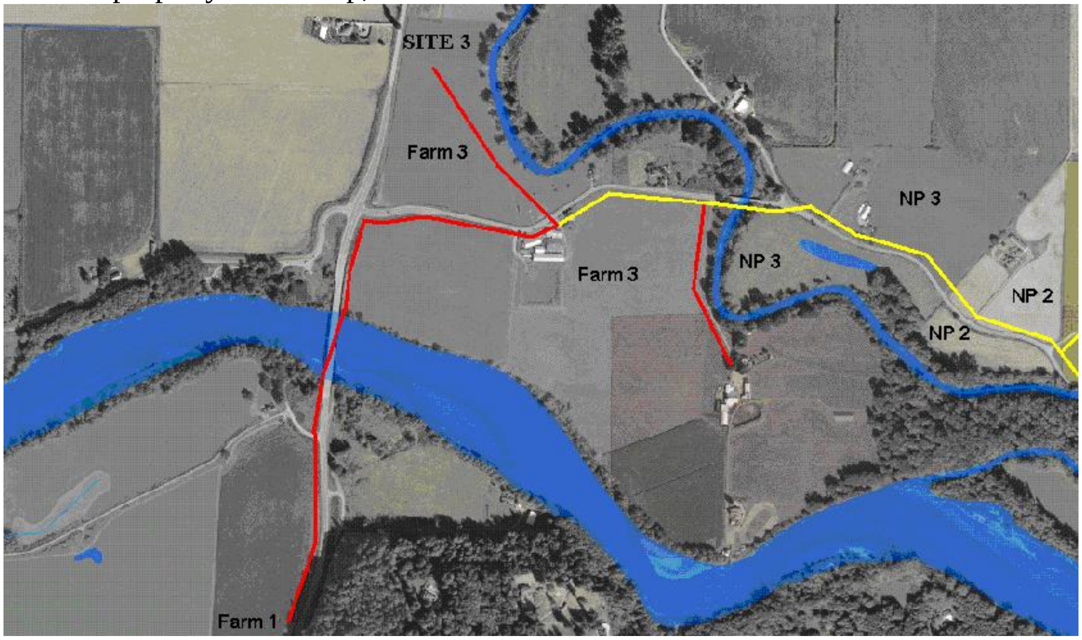


Figure 9. Proposed Pipe Route, Continuing East from Figure 10.
Farm numbers and non-participant (NP) numbers in this figure indicate property ownership, rather than location of facilities.

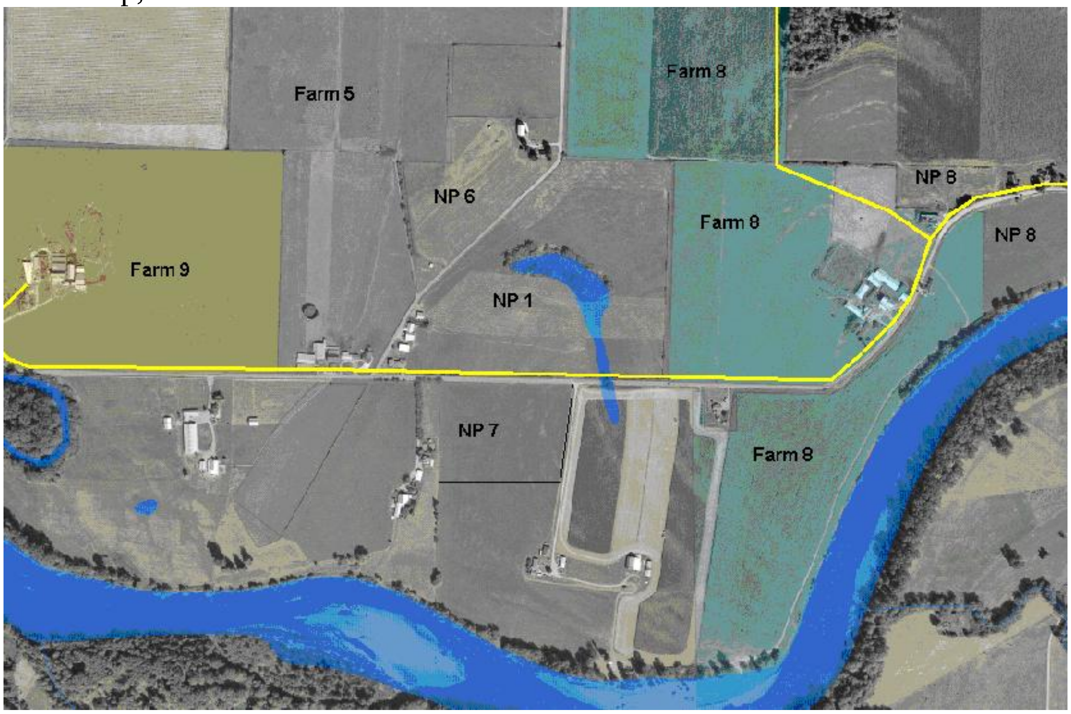


Figure 10. **Proposed Pipe Route, Continuing East from Figure 9**
Farm numbers and non-participant (NP) numbers in this figure indicate property ownership, rather than location of facilities.

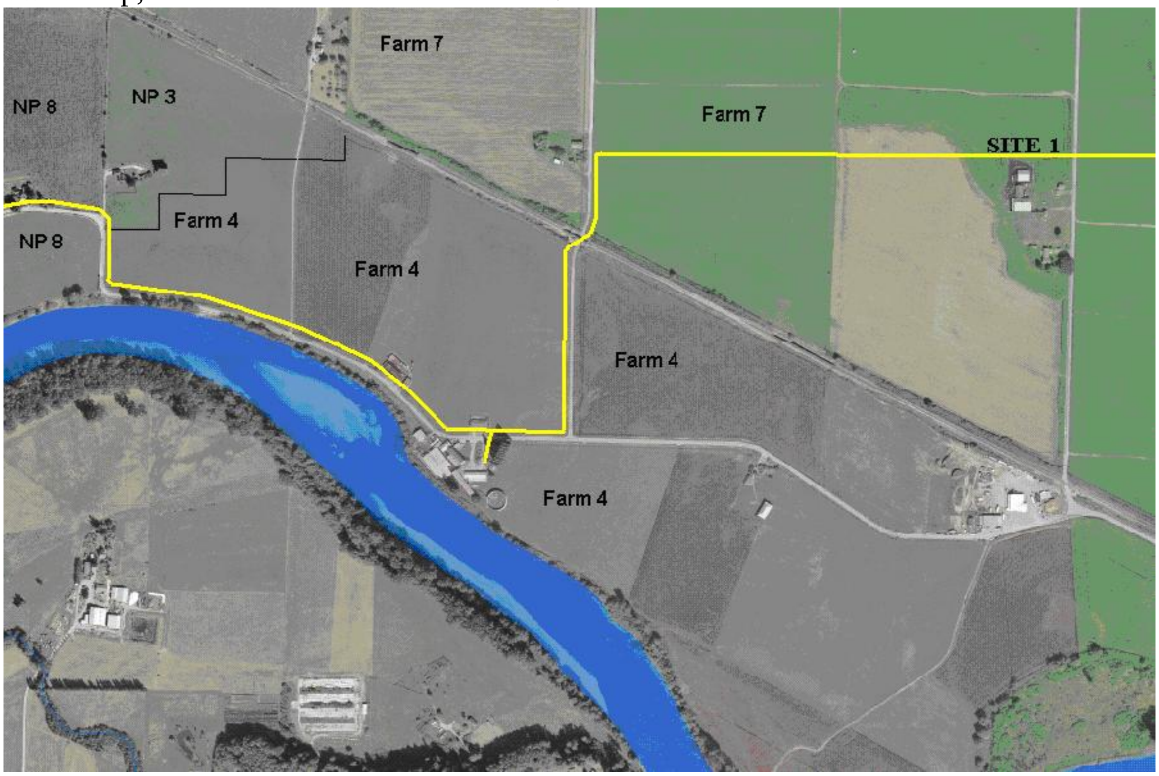


Figure 11. Proposed Pipe Route, Continuing East from Figure 10, East End of Valley
Possible route of piping to Farm 6 is shown in red. Farm numbers and non-participant (NP) numbers in this figure indicate property ownership, rather than location of facilities.

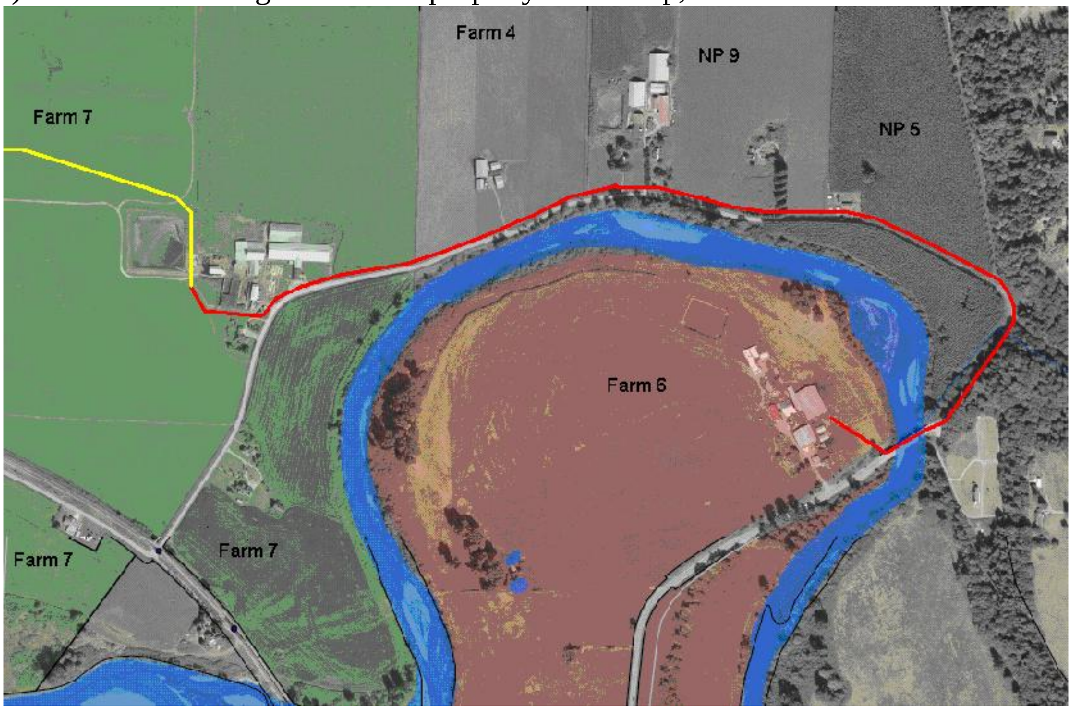


Figure 12. Approximate Pipe Route, Continuing North From Figure 9.
Farm numbers and non-participant (NP) numbers in this figure indicate property ownership, rather than location of facilities.

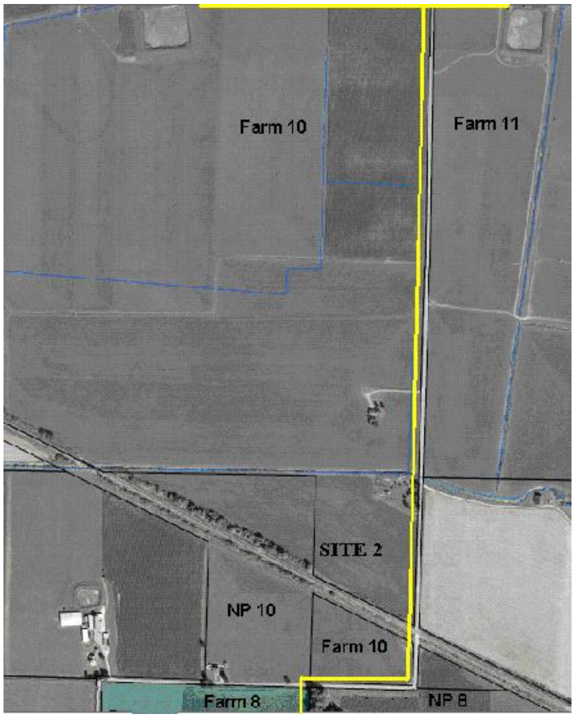


Figure 13. Additional piping for Site 2
Three independent branches possible for Site 2 are indicated in red (north), pink (west) and yellow (east). Note parallel piping required between the central plant (purple) and point A where west and east branches converge.

4. PUMPING REQUIREMENTS

Two sets of pumps must be selected: (1) mobile supply pumps to push manure slurry from the dairies to the digester storage tank and (2) return pumps located at the central digester for return of effluent to the dairies. Head loss varies dramatically depending on which farm is being pumped to or from. One way of meeting this wide range of pumping requirements is to use one high- and one low-head mobile supply pump and one high- and one low-head central pump, for a total of four pumps (2 mobile and 2 permanent). System and pump curves showing head loss versus flow rate, assuming this strategy is used, are included in Appendix A. The method of calculating system curves is also summarized in Appendix A.

In this preliminary analysis, it has been assumed that return and supply pumps will require similar performance characteristics, due to the minimal elevation differences across the area. In the design phase, the difference in solids content between manure slurry and effluent and differences in elevations should be considered.

Information on pumps suitable for pumping manure slurries and general considerations when pumping slurries are contained in Appendix B. Centrifugal pumps are appropriate for this project.   A semi-open or open impeller is less efficient, but is also less prone to plugging and is able to handle semi-solids.

Pumping Volumes

Table 9 shows anticipated annual and daily treatment volumes. Annual treatment volumes were obtained from interviews with dairy owners (Mattocks 2006). Average daily volumes shown equal annual treatment volumes divided by 365. The total peak daily volume is the sum of the estimated peak daily volumes for each farm, which were estimated as the lesser of twice the daily average or the farm's day tank volume.

Daily Pump Times

The maximum daily pumping time is important to estimate to ensure that pumping and all related tasks can be performed within an 8 hour shift. However, estimating the maximum time pumps will operate in a single day over the course of the year is difficult, due to variations with season. Frequency of pumping also varies between the farms. A few farms pump on a daily basis, but most do not.

Rather than attempting to arrive at a realistic value, a very conservative, unrealistic case was examined. In this hypothetical case, all farms supply their peak daily volume of manure slurry to the digester and receive an equal volume of digested effluent in a single day. The peak treatment volume was estimated for each farm as either the total volume if its day tanks or twice its daily average treatment volume (i.e. annual treatment volume divided by 365 days). This scenario was calculated by varying the following parameters:

Site 2 versus either Site 1 or 3, 8” or 10”pipe diameter, separate or shared return piping, and with and without dedicated pumps for Farms 10 and 11. Results for a worst case and a “better” case for both 8” and 10” pipe are summarized in Table 10. The second case is labeled “better” rather than “best” to make clear that it is still conservative and not representative of the best case of a more realistic scenario.

For both pipe sizes, the shortest pumping time is required if separate return and supply piping is installed and if Site 2 is chosen. In the worst case, a single 8” pipe is shared for both return and supply, and the digester is located at either Site 1 or 3. For these scenarios, maximum overall pumping times, not including set-up time, ranges from 3 to 10 hours for 8 inch pipe diameter and 1 to 6 hours for 10” pipe.

Overall pumping time can be reduced by three strategies:

1. Separate return and supply piping enables simultaneous supply and return pumping.
2. If Site 2 is selected, three independent branches of pipe would enable simultaneous pumping.
3. Larger diameter pipe reduces pump times.

Electric versus Diesel Pump at Central Plant

It is assumed the mobile pumps will be diesel powered. The central pumps at the digester plant may be either electric or diesel powered. Using a diesel powered pump station would give flexibility to operate the pump at the best speed for each site. It would also provide the ability to slowly increase the pressure in the pipeline to minimize pressure surges in the system. If electric pumps are used, variable speed drives should be considered.

However, for this project an electric central pump is recommended. If both high- and low-head pumps are installed, operation at varying speeds will likely not be necessary. Also, an electric pump could make use of electricity generated on site.

Dedicated Pump for Farms 10 and 11

An additional pump could be dedicated to Farms 10 and 11 (10 hp estimated for Site 2). Installing dedicated pumps would reduce overall pumping time by enabling simultaneous pumping if a centrally located site is selected. In addition, labor costs due to setting up the pumps and valves would be reduced.

Throttling Valves to Adjust the Pump Operation Point

Throttling valves may be used to adjust a system curve up (higher head, lower flow) to improve the point of operation of the pump to, for example, avoid cavitation or reduce excessive velocity. As much as possible, pumps should be selected to perform well over the range of heads required without the use of throttling valves. It is important that any throttling valves used be located at the point of connection of the mobile pump to the pipe at each dairy so that any plugging can easily be cleaned out.

Pump Manufacturers

There are several manufacturers and suppliers of pumps specifically designed for pumping manure slurries. These include:

- Cornell Pump Company, www.cornellpump.com/ag (503)653-0330
- Daritech, Inc., http://www.daritech.com/page2.html
- Farmer Equipment Co., http://www.farmersequip.com
- Hydro-Engineering, Norwood Young America, MN, www.hydro-eng.com
- Vaughan Chopper Pumps, www.chopperpumps.com
- Volgesang USA, http://vogelsangusa.com

Daritech, Farmer Equipment and Hydro-Engineering all have significant experience pumping manure for dairies. Cornell Pump Company serves both the municipal and agricultural sectors. Cornell Pumps recommend their “Run-Dry” option which keeps the seal faces lubricated with oil to reduce wear issues.

Table 9. Total Day Tank Storage and Anticipated Treatment Volumes (Farms 2 to 11)

Day Tank Storage Volume	544,000 gallons
Annual Treatment Volume	27,740,000 gallons per year
Average Daily Treatment Volume	76,000 gallons per day
Estimated Peak Treatment Volume*	133,400 gallons per day

* The sum of peak treatment volumes for each farm, which were estimated as two times the average or the farm’s total storage tank volume, which ever is less.

Table 10. Conservative Estimates of Daily Pumping Times*

Case		Estimated Pumping Time Average (hours/day)	Estimated Pumping Time Maximum (hours/day)
8”	*Worst case:* 8” Pipe, Site 1 or 3, Shared Return and Supply,	5.0	9.9
	Better Case: 8” Pipe, Site 2, Separate Return and Supply, Dedicated pumps at Farms 10 and 11	1.3	2.6
10”	*Worst case:* 10” Pipe, Site 1 or 3, Shared Return and Supply	3.1	6.1
	Better Case: 10” Pipe, Site 2, Separate Return and Supply, Dedicated pumps at Farms 10 and 11	0.8	1.6

* For the “worst cases”, pumping times include both emptying the treatment volumes given in Table 9 and returning the same volume of effluent for all dairies on a daily basis. For the “better cases”, pumping times do not include returning effluent since it is assumed this can be accomplished at the same time as supply and also do not include pumping from Farms 10 and 11. Since most dairies do not require daily pumping, actual pumping times will generally be much less for all cases.

5. OTHER SYSTEM COMPONENTS

Spare Pump(s)

Wear on pump bearings and seals can be rapid when pumping animal manure waste. The severe pumping conditions can also damage controls and valves. Spare pumps should be readily available. Cost estimates assume spares will be purchased for all four pumps.

To a certain extent, the high- and low-head pumps can back each other up, but only for the dairies that are an intermediate distance to the selected sites. Back up coverage is greatest at a centrally located site. In the system curves in Appendix A, the system curves of dairies that have intercepts with both the high-head and low-head pump curves within the yellow-shaded areas of the figure can be served by either high- or low-head pumps. Cost estimates assume spares will be purchased for all four pumps.

Clean-Outs

Clean-outs should be installed at minimum of approximately every 800 feet. In particular, clean-outs should be installed at all low points, where feasible. To determine the spacing of clean-outs, a local company that performs high pressure water jetting of storm, sewer and septic drainfield piping (Cuz Concrete in Arlington) was contacted to find out the maximum length of their jet hose and get their spacing recommendations. Cuz Concrete typically carries 500 feet of jet hose on their trucks. Thus, jet hose will be able to reach approximately 500 feet on either side of each clean-out, so a spacing of 800 feet will provide redundant coverage for 25% of the pipeline.

Note that clean-out ports are not universally recommended because they introduce edges that can cause settling of large solids. Sizing piping to maintain high velocities and following other guidelines to avoid settling will reduce the need for clean-outs. If a plug occurs and clean-outs are not installed, however, the repair will involve digging up a portion of the pipeline.

Air Venting, Pressure Relief and Vacuum Protection

Tri-action or combination valves serve three functions: air venting, pressure relief and vacuum protection. Combination valves should be provided at all high points in the piping where feasible and where environmentally sound[2].

For safety reasons, bleed-off valves must be provided at all access and cleanout ports to ensure pressure is relieved before a cap is removed. In addition, pressure relief should be installed in any section of piping that can be isolated by valves.

[2] Automatic pressure relief may release untreated manure slurry from the supply line to the environment. Relief valves must be located to minimize negative consequences if this occurs.

Flexible Connections

Flexible connections will be used to connect mobile pumps to piping at each dairy. At Site 2, connection of pump to each branch could be made with flexible connections or valves.

Freeze Protection

Freeze protection may not be required, as discussed in Section 3 above, if pipe is buried below the frost line as much as possible and above-ground sections of pipe are drained when not in use. Note that the ability of piping to drain will be impacted by closed selection valves. If it is decided that freeze protection is required, this may be accomplished by electrically heating above-ground sections and casings for valve stems and access ports in cold weather.

6. ENERGY USE

Annual energy use of pumping manure is relatively small, ranging from $1,000 to $2,500 for a solids content of 8%, as shown in Table 11. Therefore, labor costs and initial costs will be much more important in making site selection and design decisions. Energy use is low because pumps are used only for an *average* of 3 to 4 hours per day over the course of the year for both return and supply pumping.

Site 2 has lower energy costs than the two other sites. Using 10" piping versus 8" piping uses slightly less energy. For all cases, actual energy will vary, primarily depending on pump selection and whether high- or low-pumps are used for dairies located at intermediate distances from the central digester.

Energy was estimated for each case using pump and system curves shown in Appendix A based on the proposed pipe route and assuming the anticipated total annual treatment volumes for each dairy summarized in Table 9. Note that because we are concerned with *annual* energy use, the *daily* pumping times in Table 10 were not used in this energy estimate and none of the assumptions used in those estimates are relevant here.

Table 11. Estimated Energy Use for Supply and Return Pumping

Pipe Diameter	Site	Energy Use (kWh/yr)	Energy Cost* ($/yr)
8" Pipe 8% Solids	Site 1	28,800	$2,304
	Site 2	14,300	$1,144
	Site 3	31,400	$2,512
10" Pipe 8% Solids	Site 1	20,000	$1,600
	Site 2	11,600	$928
	Site 3	20,400	$1,632
8" Pipe 10% Solids	Site 1	53,400	$4,272
	Site 2	37,400	$2,992
	Site 3	75,800	$6,064
10" Pipe 10% Solids	Site 1	36,300	$2,904
	Site 2	24,200	$1,936
	Site 3	45,600	$3,648

* At an energy cost of $0.08/kWh

7. PRELIMINARY COST ESTIMATES

Preliminary cost estimates of piping options for Site 2 are shown in Table 12. Estimates range from $1.0 million to $1.7 million. Incremental costs associated with the other digester sites and for several options are given in Tables 13 and 14.

Table 15 summarizes all elements that are included in initial cost estimates. These unit costs are primarily based on RSMeans (2006) cost data. Trenching costs and pump costs were obtained from vendors. Labor and material costs have been increased by 30% to account for overhead and profit. A contingency of $50,000 has been added to all estimates to account for miscellaneous or unexpected costs.

Estimates do not include costs such as for additional fill material or special building design as may be required to protect the digester facility from flooding. Estimates also do not include costs for obtaining rights of way. It has been assumed that separate trenches will be required for return and supply piping. Linear costs for pipe include the costs of all fittings, such as elbows. The cost of attaching the pipe to the undersides of bridges was roughly estimated by doubling the cost of the pipe for these sections.

Table 12. Preliminary Total and Incremental Cost Estimates, Site 2

Pipe Size	Return Option	Total	Incremental Cost*
8”	Shared	980,000	-
8”	Partial 6” Return	1,405,000	$425,000
8”	Complete 6” Return	1,504,000	$524,000
10”	Shared	1,132,000	$152,000
10”	Partial 6” Return	1,584,000	$604,000
10”	Complete 6” Return	1,678,000	$698,000

* Additional cost compared to the base case of 8” pipe with shared return and supply

Table 13. Estimates of Incremental Cost of Additional Piping*

Pipe Size	Connection	Return Option	Incremental Cost*
8”	To Farm 1	Shared	$92,000
		Separate 6” Return	$153,000
8”	To Farm 2	Shared	$21,000
		Separate 6” Return	$54,000
8”	To Farm 6	Shared	$149,000
		Separate 6” Return	$255,000

* Compared to similar case with 8” pipe in Table 12.

Table 14. Incremental Costs of Other Options

Option	Return Option	Incremental Cost*
Site 2: Dedicated mobile pump for Farms 10 and 11	-	$15,000
Site 1or 3: Larger pumps (including spares)	-	$20,000
Site 1: ~3,000 ft. less piping & trenching compared to Site 2	Shared	-$54,000
	Separate 6" Return	-$92,000

* Compared to similar case with 8" pipe in Table 12.

Table 15. Unit Costs Assumed in Preliminary Cost Estimates

Component		Unit	Installed Unit Cost w/O&P
Initial field stake-out and determination of elevations		Day	$985
PVC pressure-pipe, gasketed (200 psi), including Els	6" 8" 10"	l.f. l.f. l.f.	$11.70 $15.60 $19.50
Trenching	8" 10"	l.f. l.f.	$1.65 $215
Railroad crossing (boring) Road crossings (boring)		l.f. l.f.	$385 $310
Central Pumps: One high and one low pressure electric pumps Material costs Other Costs		ea. Total	$27,000 $30,000
Mobile trailer pumps: One high and one low pressure		. ea	$39,000
Control valves: two-way epoxy-coated steel gate valve	6" & 8" 10"	ea. ea.	$875 $966
Clean-outs		ea.	$400
Tees		ea.	$342
Tri-Action Valves (air venting and pressure relief), epoxy-coated steel		ea. ea.	$400
Flexible connections		ea.	$150
Contingency		Total	$50,000

8. RECOMMENDATIONS

From a piping system design perspective, a centrally-located site is recommended. The possibility of simultaneous pumping at this site will likely reduce labor costs by reducing overall pumping times. A centrally located site will also improve reliability since there is more overlap in the operation ranges of the high- and low-head pumps. The energy use of a centrally-located site is less than that for Sites l or 3, although energy costs are not large at any of the sites evaluated.

If a centrally located site is selected, it is important that any additional piping necessary to create three independent branches of piping. The closer this site is to the point where the three branches of the pipeline converge, as shown in Figure 13, the less additional piping will be required.

Energy use for pumping is expected to be small compared to the labor costs associated with operation of the pipeline. The operational strategy (i.e. order of pumping from each dairy) should be carefully examined to arrive at an estimate of labor costs. A good estimate of labor costs is necessary in evaluating the pay back of certain options that increase first costs, including the installation of a separate return pipeline, installing a dedicated pump for Farms 10 and 11, and additional pipe runs to Farm 2 and Farm 6.

Eight inch diameter piping will have a 12-15% lower installation cost than 10” diameter piping and so based on this preliminary analysis, 8” pipe is recommended for the pipeline system. The additional pumping time required with 8” pipe is not likely to be a problem because most dairies do not require daily pumping even during the rainy season. Energy use is somewhat less with 10” than with 8” piping but the difference is small compared to the additional first cost.

Regardless of location, the potential for flooding should be addressed in the design by elevating equipment and solids handling areas. This can be accomplished by land fill and locating equipment such as the generator, pumps and controls on the second floor of a masonry building.

9. REFERENCES

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APPENDIX A: SYSTEM AND PUMP CURVES

System curves and pump curves – which show the relationship between flow rate (gpm) and total head (ft. H_2O) – are used in sizing piping, selecting pumps and analyzing energy use. In system curves, the total head represents pressure drops due to the fluid moving through the pipe and differences in elevation. In pump curves, the total head represents the pressure the pump is able to provide to counter the pressure drops of the system.

This appendix includes system curves for 8” and 10” PVC pipe. Six inch diameter pipe was also examined, but these curves are not included here due to their very high head losses. For each case, the point of operation is found by the intersection of the pump curves (dashed lines) and system curves (solid lines) on plots of flow versus head loss (Figures 14 to 25). The point of operation must fall within the yellow-shaded areas on these figures to maintain a velocity between 4 and 6 fps.

Because the differences in elevation across the valley are small and distances are long, total head is dominated by friction losses of the manure slurry flowing in the discharge pipe.

Calculating System Curves

Total Head

The total head that a pump must develop to move a fluid through a piping system at a particular flow rate is the sum of the following components:

- static discharge head (equal to the elevation of the surface of the liquid in the discharge tank, or the discharge outlet if open to the air, minus the elevation of the pump datum)
- static suction head (equal to the elevation of the pump datum minus the elevation of the surface of water in the suction bay, i.e. the dairy’s storage tank.)
- velocity head h_v at the discharge nozzle of the pump where

  $$h_v = \frac{V^2}{2g} = 0.0155V^2 \text{ for } V \text{ in [fps] and } h_v \text{ in [feet].}$$
- friction head loss h_f

Velocity head is

$$h_v = \frac{V^2}{2g} = 0.0155V^2 \text{ for V in [fps] and } h_v \text{ in [feet].}$$

For a velocity V of 3 fps, h_v is negligible at 0.1 ft.

These components are all fairly straightforward except for the friction loss, which requires a slightly more detailed calculation.

Calculating Friction Head Loss

To calculate friction losses, we first calculate the friction head loss for clean water, using standard engineering methods outlined in texts such as Roberson and Crowe et al (1985). The result for clean water is then multiplied by the friction loss ratio, which accounts for the greater viscosity of slurries compared to water and the slurry's "non-Newtonian" behavior[3]. (Refer to Appendix C.)

Head loss is calculated by the Darcy-Weisbach equation:

$$h_f = f\,\frac{L}{D}\frac{V^2}{2g}$$

where L is the effective length of pipe (including both suction and discharge lines), V is the velocity, D is the inner diameter of the pipe and f is the friction factor. The friction factor f was found using the explicit Swamee-Jain correlation (instead of the Moody diagram) relating f to the Reynold's number Re and the relative pipe roughness k_s/D:

$$f = \frac{0.25}{\left[\log\left(\frac{k_s}{3.7D} + \frac{5.74}{\mathrm{Re}^{0.9}}\right)\right]^2}$$

The Reynold's number is

$$\mathrm{Re} = \frac{VD^{\circ}}{\text{«}}$$

where for clear water density ρ equals 62.2 lbm/ft^3 and kinematic viscosity μ equals 1.0 centipoise. Absolute pipe roughness k_s for PVC is 6.0 x 10^{-5} inches.

The friction loss due to fittings was assumed to be 5% of the total. Approximate pipe lengths, summarized in Table 7 for the three sites, were taken from electronic "ecw" graphics, which are based on GPS data for the site. These distances were increased by 10% to account for routing to the storage facilities on site, routing around obstacles and low points and accuracy in marking out piping on maps.

Static head differences on the suction and discharge side is 11 feet or less, as shown in Table 3. In this preliminary phase of the analysis, static head difference has been neglected.

[3] In essence, the viscosity of Non-Newtonian fluids varies as fluid velocity changes, in contrast to Newtonian fluids, such as clean water, which have constant viscosity.

Figure 14. Site 1 System and Pump Curves, 8" Pipe, 8% Solids

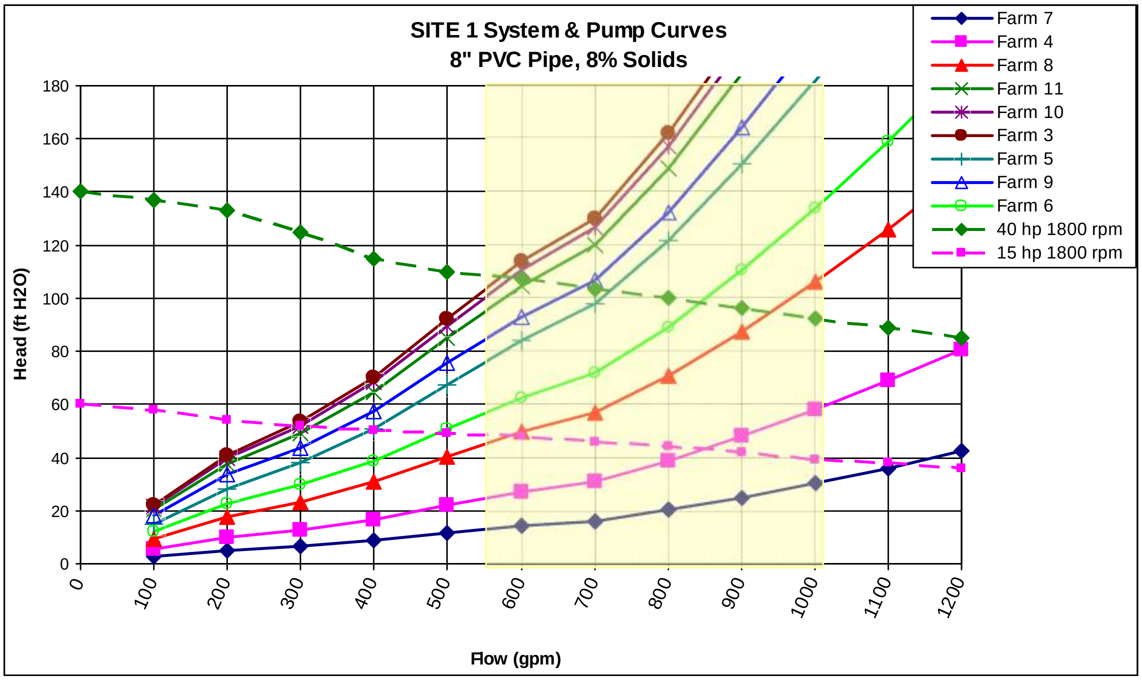

Figure 15. Site 2 System and Pump Curves, 8" Pipe, 8% Solids

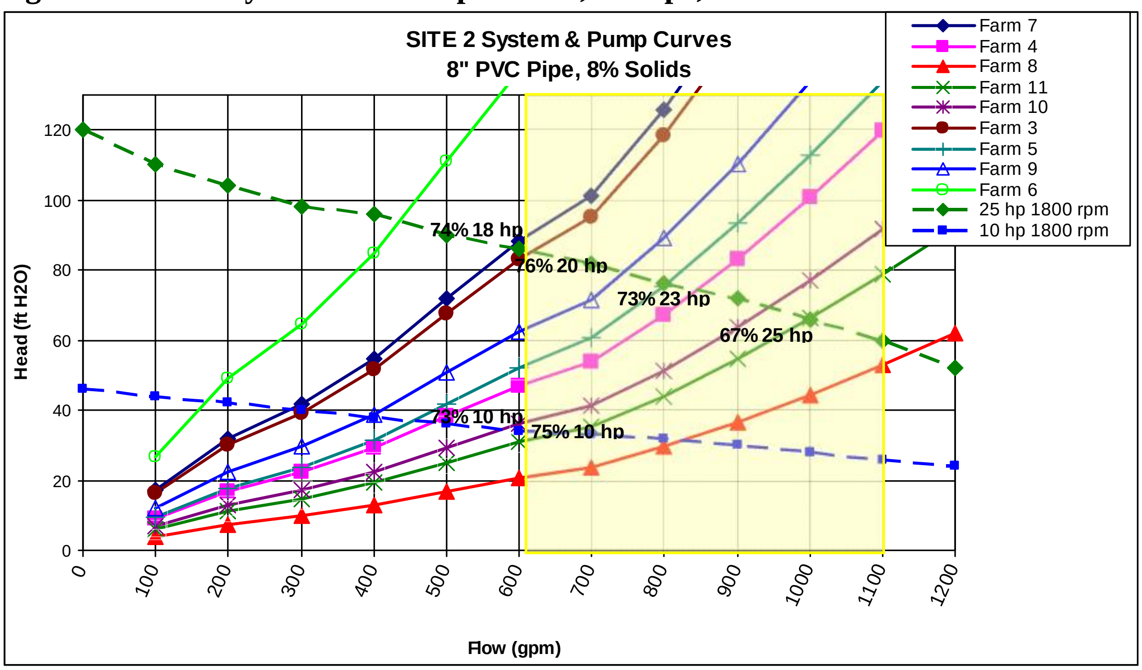

Figure 16. Site 3 System and Pump Curves, 8" Pipe, 8% Solids

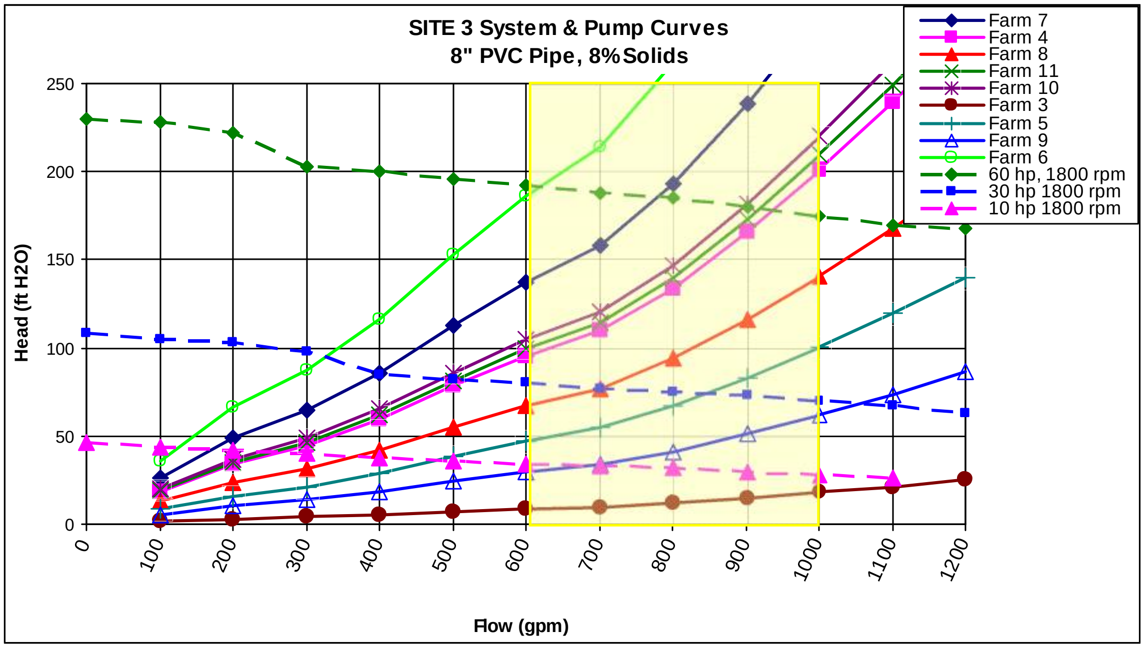

Figure 17. Site 1 System and Pump Curves, 10" Pipe, 8% Solids

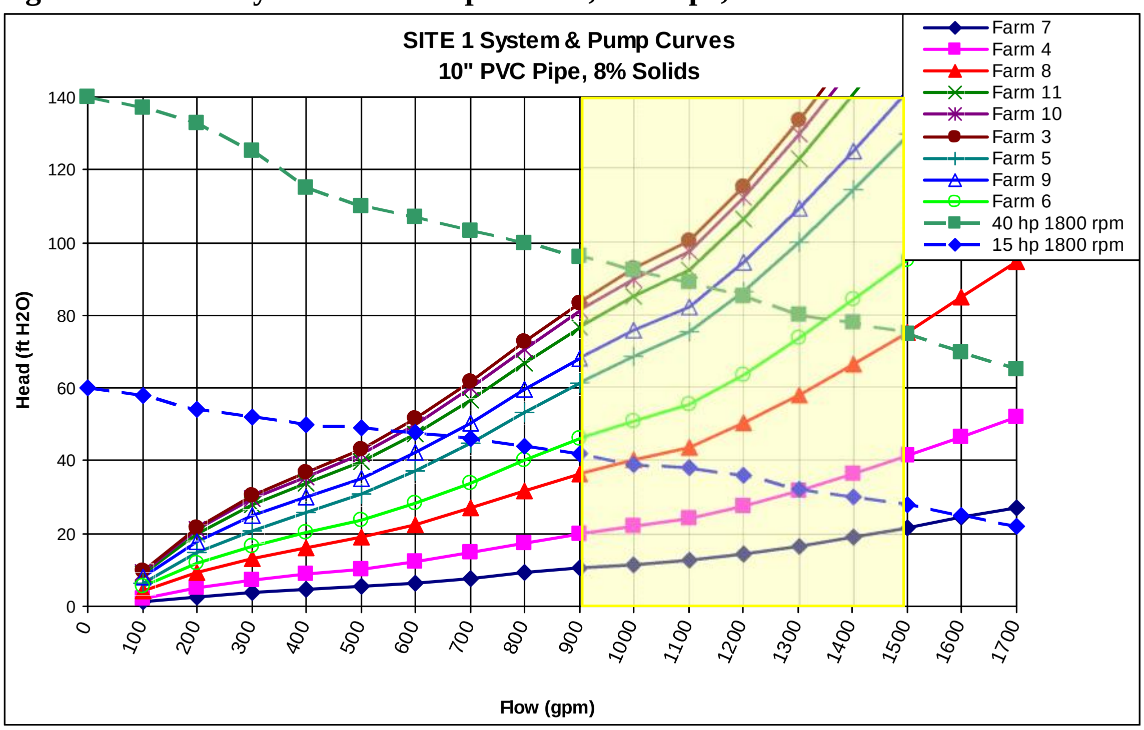

Figure 18. Site 2 System and Pump Curves, 10" Pipe, 8% Solids

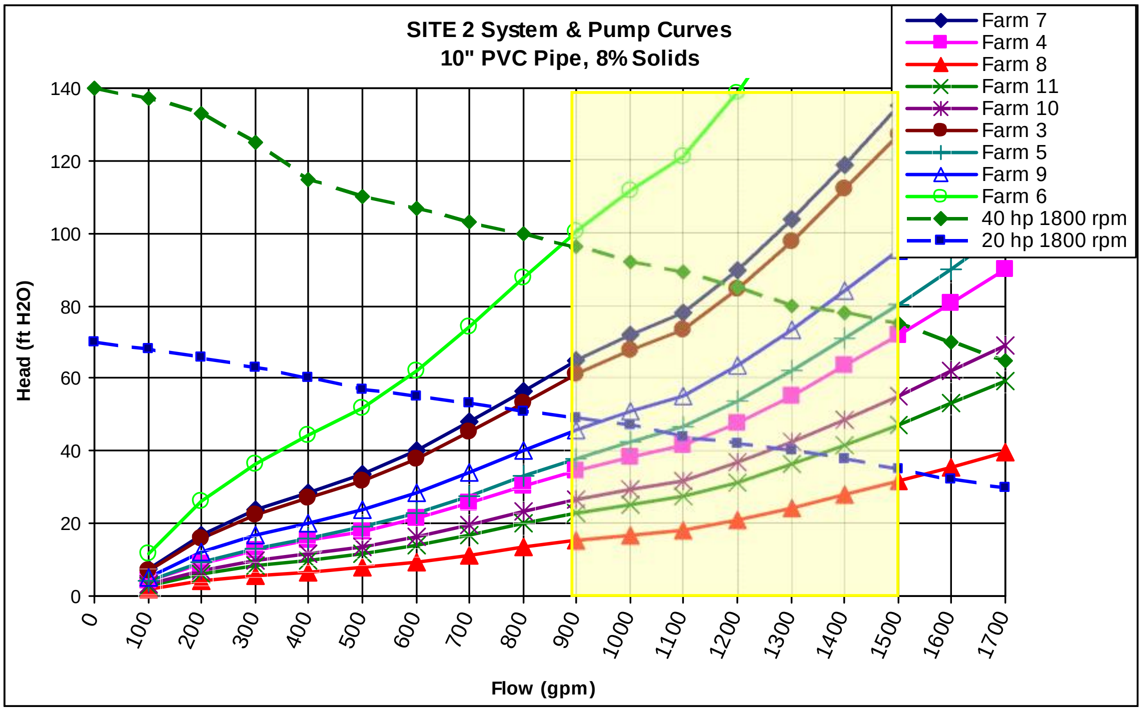

Figure 19. Site 3 System and Pump Curves, 10" Pipe, 8% Solids

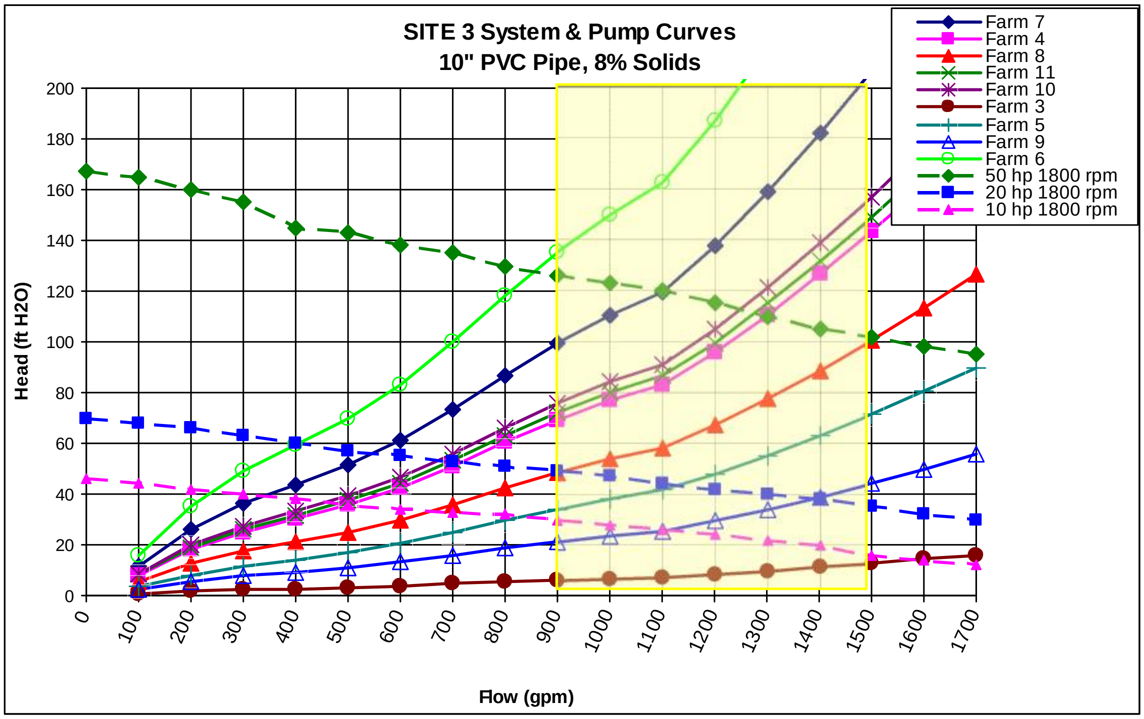

Figure 20. Site 1 System and Pump Curves, 8" Pipe, 10% Solids

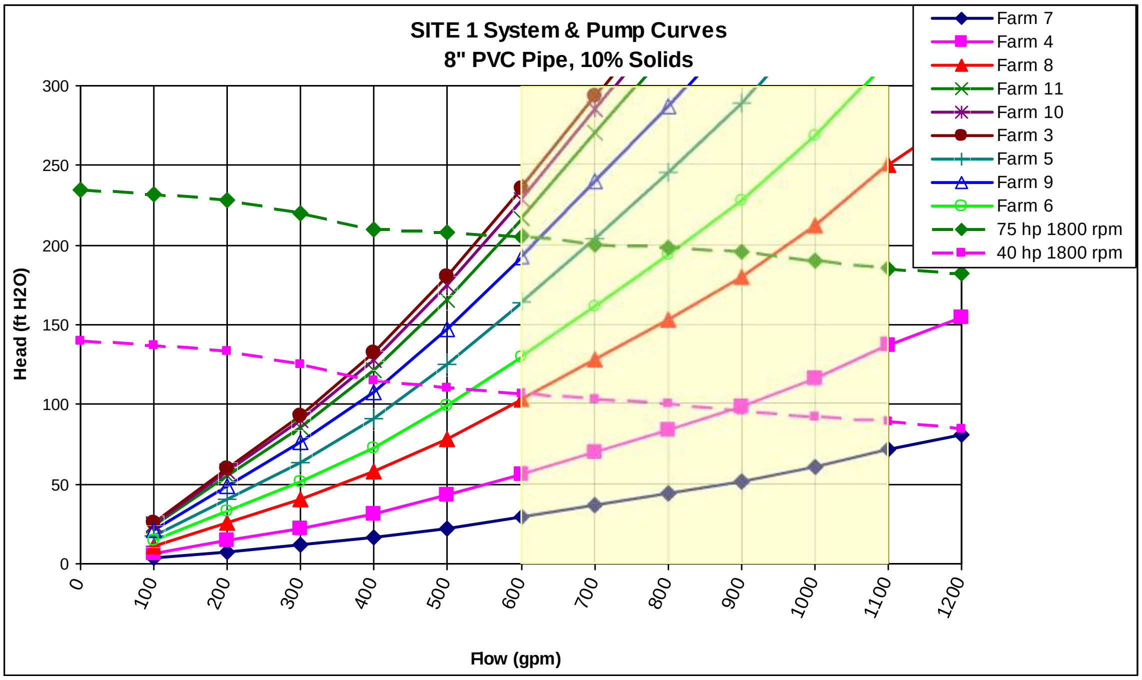

Figure 21. Site 2 System and Pump Curves, 8" Pipe, 10% Solids

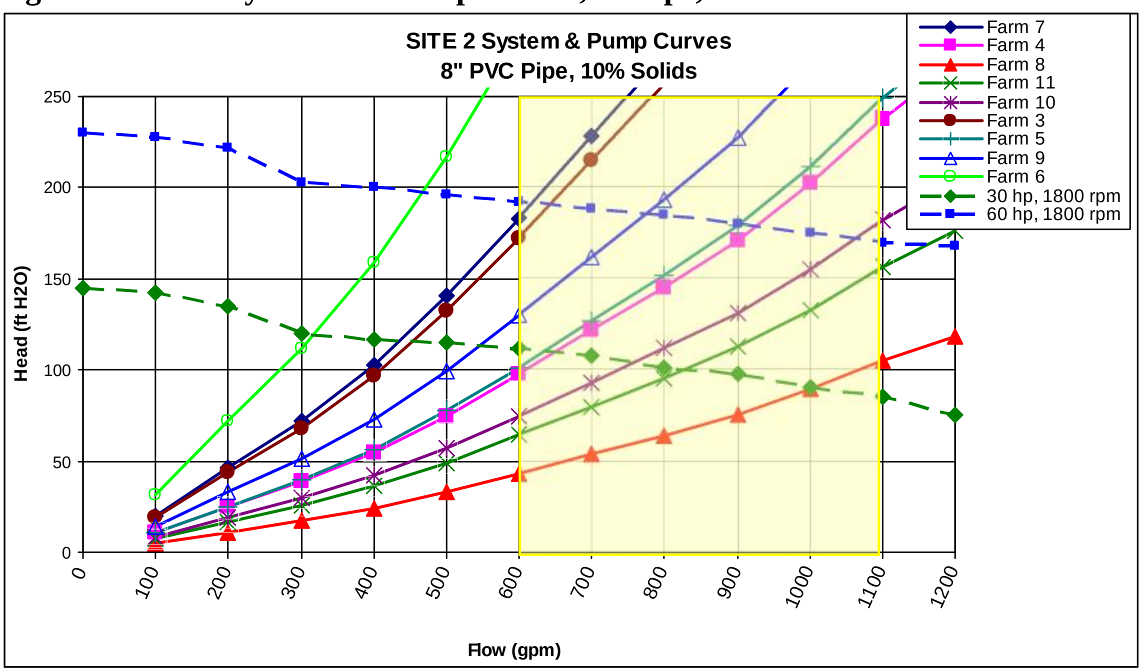

Figure 22. Site 3 System and Pump Curves, 8" Pipe, 10% Solids

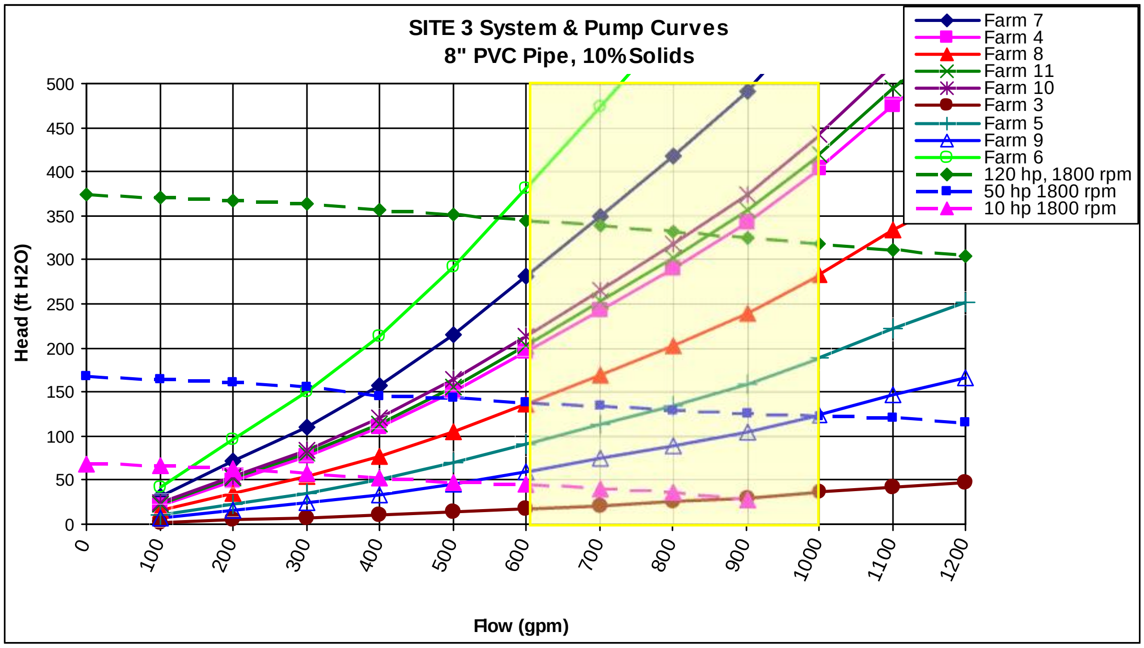

Figure 23. Site 1 System and Pump Curves, 10" Pipe, 10% Solids

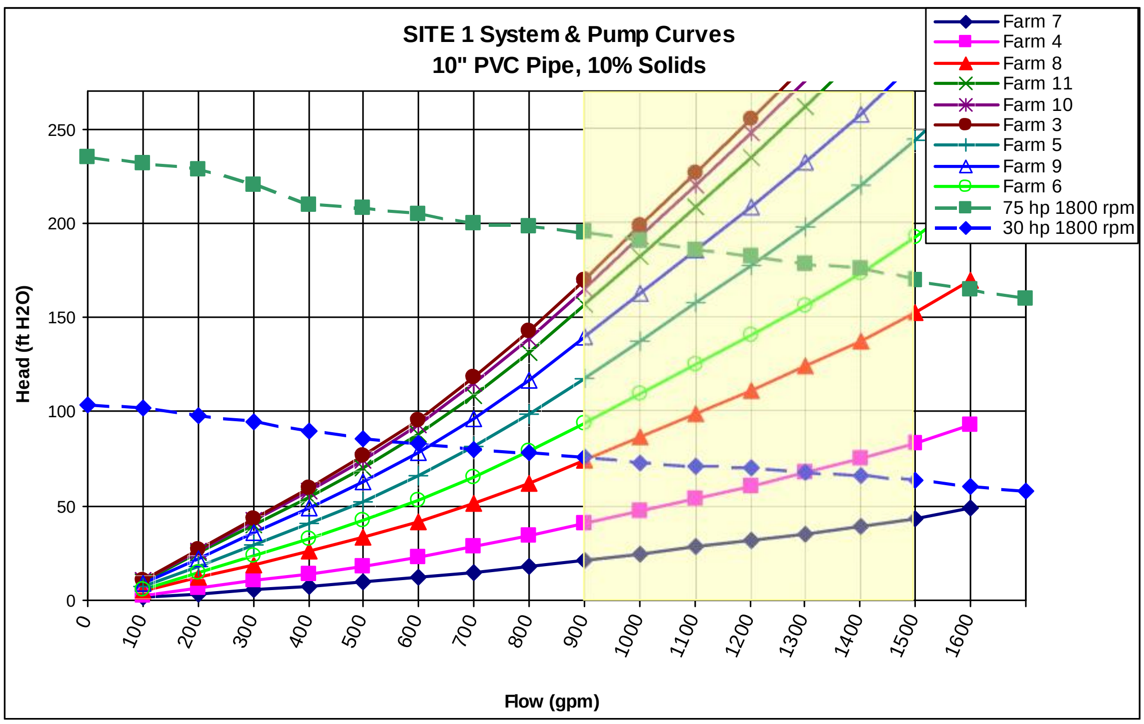

Figure 24. Site 2 System and Pump Curves, 10" Pipe, 10% Solids

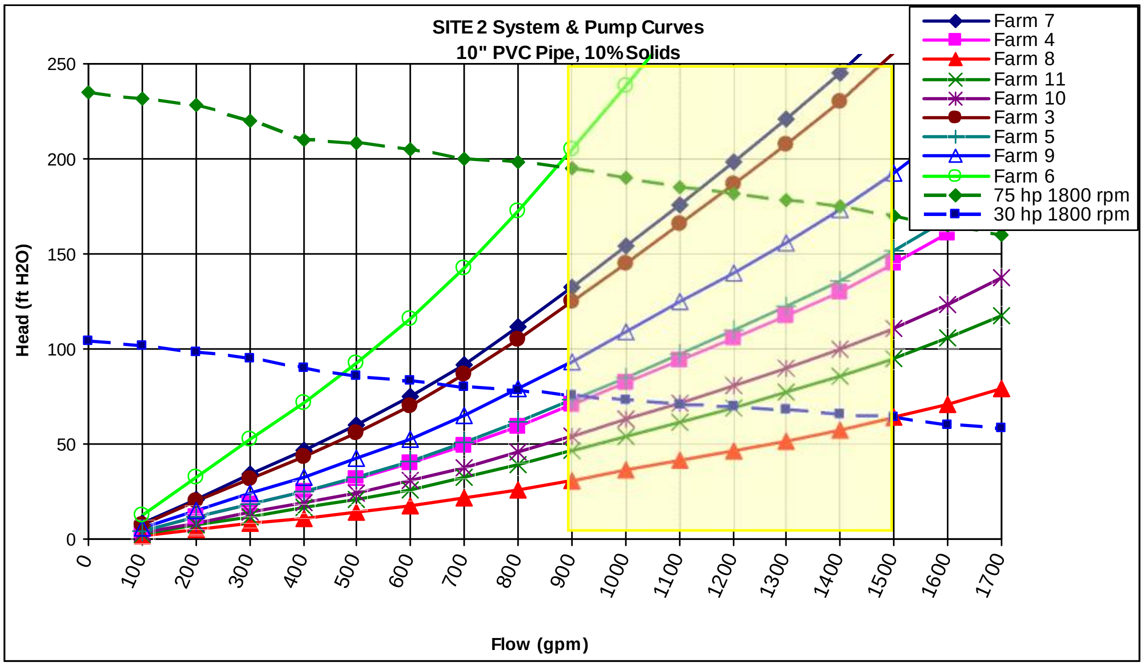

Figure 25. Site 3 System and Pump Curves, 10" Pipe, 10% Solids

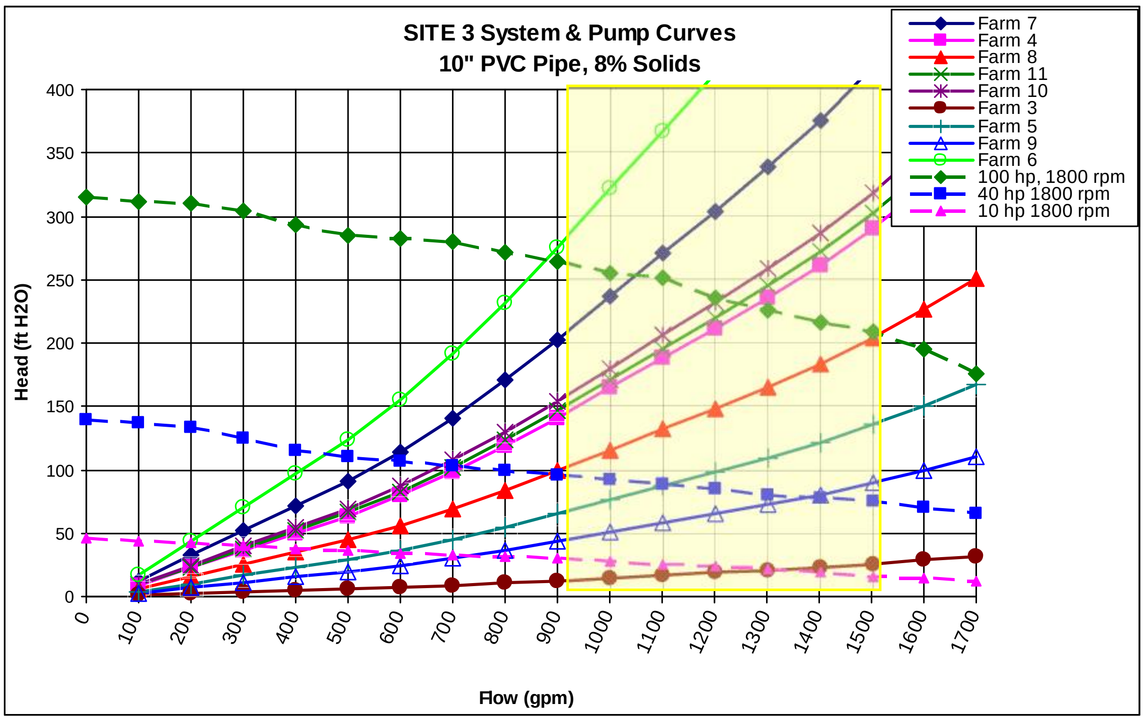

Table 16. Fluid Velocity Given Flow Rate and Inside Pipe Diameter

Flow Rate (gpm)	Velocity (fps)		
	6”	8”	10”
100			
200	2.3		
300	3.4	1.9	
400	4.5	2.6	
500	5.7	3.2	2.0
600	6.8	3.8	2.5
700	7.9	4.5	2.9
800		5.1	3.3
900		5.7	3.7
1,000		6.4	4.1
1,100		7.0	4.5
1,200			4.9
1,300			5.3
1,400			5.7
1,500			6.1
1,600			6.5
1,700			6.9

APPENDIX B: PUMPING SOLIDS IN SUSPENSION

When pumping solids in suspension, it is important to keep the solids entrained in the fluid and to avoid plugging. It is also important to operate the pump near its highest efficiency and to avoid cavitation.

Pump Type

Two general types of pumps are used for transferring manure: centrifugal and displacement. For this project, only centrifugal pumps are appropriate. According to USDA (1999), centrifugal pumps are available for pumping manure slurries having maximum total solids up to 10 to 12% at flow rates of up to 1000 gpm (although distances may be limited at such high solids content). In contrast, displacement pumps (helical screw, piston, air pressure transfer, and diaphragm) have maximum flow rates that are much lower (<300 gpm for helical screw and diaphragm pumps and <150 gpm for piston and pneumatic pumps). Helical screw pumps also have lower maximum solids (4-6%) than required for this application. In addition, with screw pumps the manure must be free from hard or abrasive solids.

Vertical- or inclined-shaft centrifugal pumps have a relatively wide clearance, which helps to avoid plugging. A closed impeller is efficient with liquid waste, but plugging with tough, stringy solids and chunks can be troublesome. A semi-open or open impeller is less efficient, but is also less prone to plugging and is able to handle semi-solids. Although generally inefficient, a sloped and curved semi-open impeller design minimizes flow cavitation and solids plugging. A sharp, hardened chopper-blade attachment at the pump inlet can break up tough materials ahead of the impeller (USDA 1999).

General Guidelines

The guidelines below are based on comments from several manufacturers and consultants with experience pumping manure. In addition, general guidelines for system design when pumping suspended solids are summarized in Colt Industries' "Hydraulic Handbook" (1973). The USDA's "Agricultural Waste Management Field Handbook" (1999) makes recommendations specific to pumping of manure. The following general system design recommendations are based on these two references as applied to this particular project.

Guidelines for improving pumpability and avoiding settling and plugging are:

1. The system should be designed so solids pass through all passages in the piping system, impeller and volute.

2. Manufacturer's recommendations and data should be consulted to ensure that:
   (a) The pump materials and construction are appropriate for the characteristics of the manure slurry to be pumped.

(b) The design velocity is appropriate for the pump characteristics and design.

3. For optimum pump performance and to avoid cavitation, the pump should be selected such that:
   (a) The head is not much lower than the head at peak efficiency.
   (b) The capacity is not much higher than the capacity at peak efficiency.

4. While some dilution will be required for the slurry to flow well, avoid *excessive* dilution of the slurry. Large solids stay entrained better in slurries that are thicker, but at the expense of higher friction losses.

5. Maintain sufficient fluid velocity to keep solids entrained. The optimum velocity will vary depending on characteristics of the manure. Considering that manure slurries typically contain large solids that are prone to settling, a design velocity of 5 or 6 feet per second (fps) is often recommended. A slurry with a more uniform consistency may require velocities of only 3 to 5 fps.

6. Arrange PVC pipe so the bell end is directed toward the supply pump. This way the slurry does not strike the butt end of the inner pipe directly, essentially making a smoother transition over the joint.

7. After transfer of manure slurry, flush the pipeline with clean water or digested effluent.

8. Use variable speed diesel pumps or variable speed drives with electric pumps to give the flexibility to operate the pump at the best speed given the characteristics of the slurry (refer to "Pumps" section below).

9. Consider using chopper pumps and/or grinders to improve the consistency of the slurry and reduce the size of large solids (refer to "Pumps" section).

APPENDIX C: CHARACTERISTICS OF DAIRY WASTE

Manure slurry consists essentially of solids suspended in water. Manure slurry typically contains bedding materials, such as straw, and water used in flushing and washing. It may contain rain water from uncovered concrete slabs if roofs are not guttered. The slurry may also contain sand or grit. Stringy masses of straw and other large solids can cause plugging of pumps and prevent proper seating of valves. Grit and sand increase abrasion of the surfaces of piping, pumps, valves and other components.

The total solids content of the slurry strongly affects friction loss in piping. Solids content of manure slurry typically ranges from approximately 2% to 10%. Table 17 gives total solids of dairy waste typical for herds with moderate to high milk production (USDA 1999). Solids content may be adjusted to a certain extent by, for example, dilution with wash water or diversion of rain water from the manure storage tank. Note in centralized digester systems, there may be a trade off between diluting the slurry so it is pumpable, while still maintaining a solids content that is optimum for the digester.

The increased friction due to the solids content is characterized by the "friction loss ratio" or the ratio of friction loss of the slurry to that of clear water. The friction loss ratio for digested sludge with solids content ranging from 4% to 10% and for pipe diameters from 6" to 10" has been determined experimentally and is shown in Figure 26[4]. In addition to accounting for the greater viscosity of slurries compared to water, the friction loss factor also accounts for the slurry's non-Newtonian behavior[5].

The target total solids content assumed in this analysis is 7% to 8%, which is dilute enough to be easily pumped, yet not too dilute for optimum digester design. Regarding pumpability, notice in Figure 25 that over the range of 3 to 5 fps, the friction loss ratio for pumping a manure slurry that is 8% solids ranges from 1.5 to 1.0. In other words, friction loss is not much more than that when pumping clear water. In contrast, for 10% solids the friction loss ratio ranges from 2.7 to 2.2 for the same range of velocity – or about twice that when pumping 8% solids. A solids content of 10% requires larger pumps, as shown in Figures 14 to 25, and will result in greater pumping energy use, as shown in Table 11.

Manure slurry tends to be acidic, which may affect pump seals and other components. Be sure to discuss this issue with manufacturers to ensure that pump and valve materials are appropriate for this application

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[4] Data for digested sludge is extracted from Colt Industries' "Hydraulic Handbook". Use of data for digested sludge is recommended for designing piping systems for conveyance of manure slurries in the USDA's "Agricultural Waste Management Field Handbook".

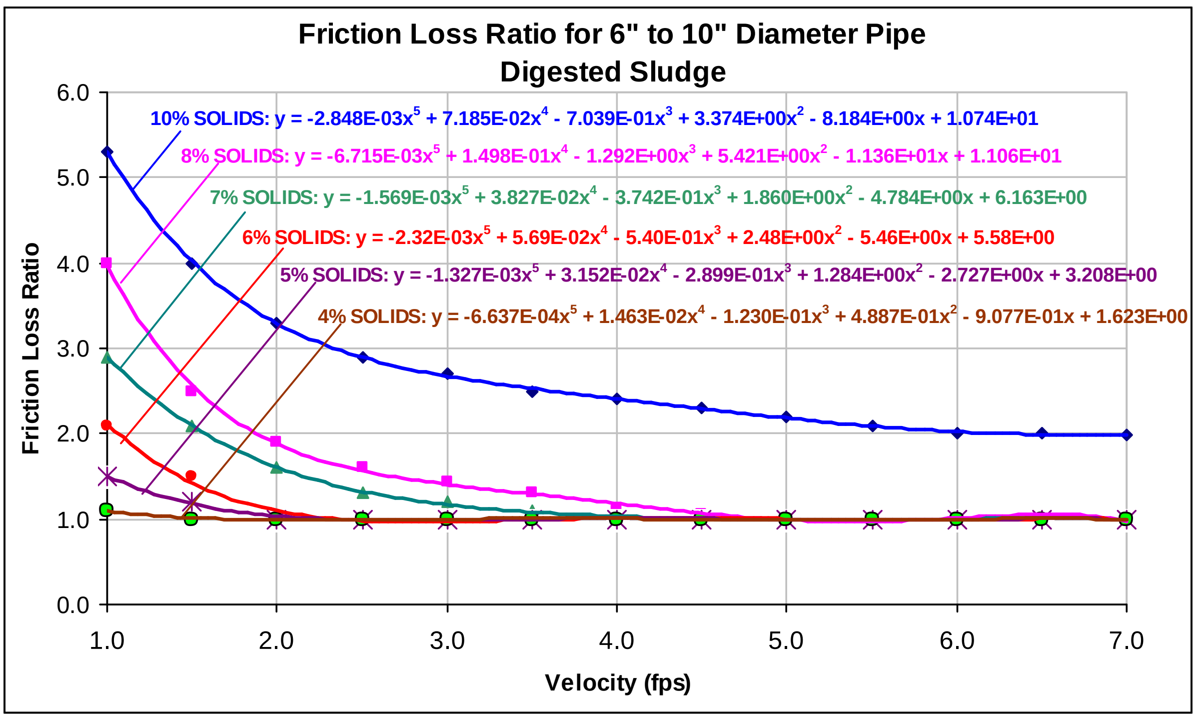
[5] In essence, the viscosity of Non-Newtonian fluids varies as fluid velocity changes, in contrast to Newtonian fluids, such as clean water, which have constant viscosity. The Moody diagram is shown in Figure 10-8 of "Engineering Fluid Mechanics", third edition, by Roberson and Crowe.

Table 17. Typical Total Solids of Dairy Waste

Waste Source	Total Solids (% by weight)
Lactating Cow, As Excreted	12.50
Milk House	0.28
Milk House & Milk Parlor	0.60
Milk House, Milk Parlor & Holding Area. Holding Area scraped and flushed.	1.50
Lagoon, Anaerobic Supernatent*	0.25
Lagoon, Anaerobic Sludge*	10.0
Lagoon, Aerobic Supernatent*	0.05

Source: USDA (1999), Tables 4-3 to 4-7.
* "Supernatent" is taken from the upper layer of a storage lagoon or tank, while "sludge" is taken from the bottom.

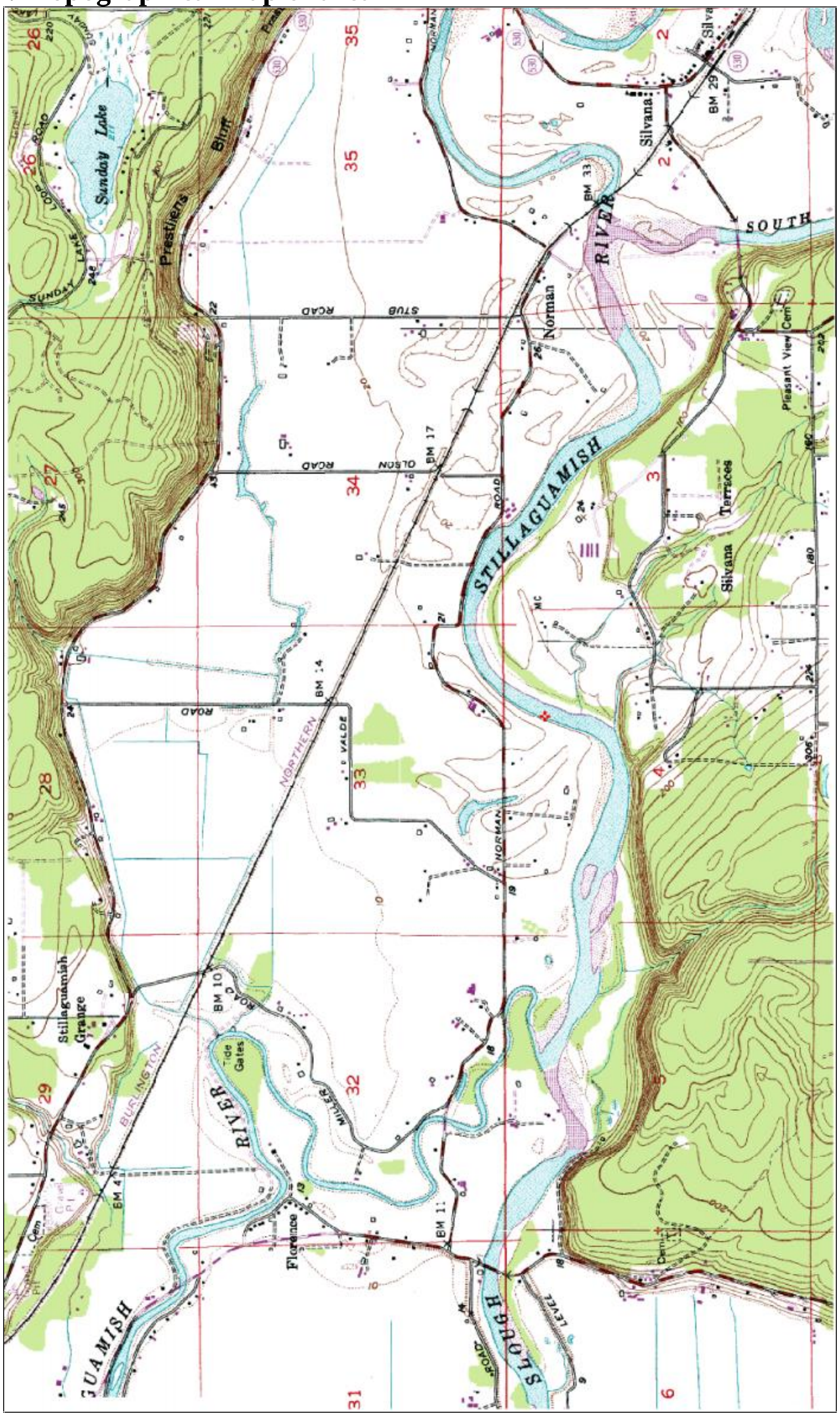
Figure 26. Friction Loss Ratios for Digested Sludge Slurries with 4% to 10% Solids*



* Friction loss ratio is the ratio of the slurry friction loss to that for clean water.
Sources: Adapted from Figure 44 of "Hydraulic Handbook" by Colt Industries and Table 11-1 of "Agricultural Waste Management Field Handbook", U.S. Department of Agriculture, Soil Conservation Service, June 1999, www.wcc.nrcs.usda.gov/awm/awmfh.html.

APPENDIX D: TOPOGRAPHICAL MAP

Figure 27. Topographical map of area



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