Water System Design Considerations for Modern Dairies

JOSEPH G. MARTIN—Consulting Engineer, 6024 SW 89th Terr., Gainesville, FL 32608 Tel: 352-371-4655

JOSEPH P. HARNER—Biological and Agricultural Engineering, Kansas State University, Manhattan, Kansas

JOHN F. SMITH—Animal Sciences and Industry, Kansas State University, Manhattan, Kansas

Introduction

Site selection for modern dairy production facilities is dependent on numerous criteria. One of these criteria is an adequate water supply. The facility must have the potential to develop or obtain a water supply of sufficient quantity and quality to serve the anticipated present and future production needs (Hoehne et al., 1994). Minimum water requirement for meeting the intake water needs of lactating cows, milk parlor usage and other needs of a functioning dairy seem to range from 40 to 50 gallons per cow per day (gal/cow/dy) (Allen el al., 1974; Bailey et al., 1993; Beede, 1992; MWPS-7, 1997). Water usage can increase to 100 gal/cow/dy if a wash pen is used. The following figures suggest if a wash pen is not used, then 1 acre-foot of water is annually required per 15 cows. Therefore, it is critical adequate water rights be obtained during the initial phase of planning, expanding or remodeling of dairy. Generally, adequate water rights are obtained but due to lack of planning, the water supply cannot be delivered in quantities necessary to meet the dairy demands. Poor planning has also resulted in some dairies not having adequate water supplies to address heat abatement issues.

Water Supply

Groundwater is probably the water source of choice if it is of sufficient quantity and quality (Hoehne et al, 1994). A secondary well provides a back-up in the event of failure of the primary well. If a single well is used, a storage tank with a minimum of a two- to three-day water supply is recommended. Some dairies are purchasing water. Hoehne et al. (1994) state it is their "opinion that water supplied by rural water districts should not be the primary water source for modern dairies." Dairies purchasing water from a rural water district must also have a storage tank to handle outages. These dairies also must work with the rural water district to ensure their system can handle the demands of the dairy facility. Hoehne et al. (1994) recommended surface water supplies have a minimum of two-year storage capacity. Reservoirs must be large enough to store the anticipated water used plus losses due to evaporation, seepage and other inherent losses. Surface water supplies will probably require treatment prior to usage. Minimum treatments would control bacteria and reduce sediment.

Demand vs Usage

There are two water issues to address during the planning of a dairy. The demand is maximum water used during a given time period and is normal measured in gallons per minute (gpm). The water system must be able to meet the maximum amount of water used during a single 1- to 5-minute interval during the day. There will also be seasonal demands. A water supply may be adequate during the winter but insufficient during the summer when heat abatement equipment is utilized. On a modern dairy, the maximum demand generally will occur during the summer when the milk parlor equipment is being cleaned. This is the time period when there is a percentage of the cows drinking water, sprinkler or mister may be on and milk parlor and equipment lines are cleaned.

The second factor to consider is the usage. Usage is the total amount of water used during a day. It is important to consider all present water requirements as well as future water needs. Modern dairies need to consider the drinking water requirements of heifers, dry cows and lactating cows, cleaning of milk parlor, usage at hospital facilities, water requirements of restrooms, truck wash water, etc.

In the housing area approximately 69 percent of the water is used for drinking with the remainder being used for sprinkler systems. However, the minimum demand by the watering troughs for a 1,000-cow dairy is 30 gpm, while the sprinkler demand is 125 gpm assuming all of the cows are cooled simultaneously.

Types of Water Lines

A water line or pipe transfers water between two points, and other factors beyond just the demand and usage must be considered. Equivalent pipe length, pipe diameter, pipe location, and piping losses must be considered. There are three basic types of water lines to consider, however, each water line must be able to supply the demand requirements. These include the main, distribution and branch water lines.

The main line carries the water from the well or storage tank into a dairy complex. Proper sizing of the main pipe is critical because it must be able to deliver the demand

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of the entire dairy. Water distribution problems arise when future expansion is planned but the main water line is sized only to meet the current needs. Unless a second water line is going to be installed, the main water line must initially be sized to meet the demands of the final dairy size.

Distribution lines carry water from a main line junction to specific buildings or areas. Examples include to freestall housing area, milk parlor or office complex. It is recommended to size the distribution lines in freestall housing areas based on the demands of the watering and sprinkler systems. Generally, this water line is undersized because adding sprinklers for cow cooling is an after thought and not planned. Therefore in the future when a cooling system is added, even though the initial plan was never to install one, the water lines cannot meet the demands of the sprinkler and watering system. The demand to meet the needs of the sprinkler system is 3 to 4 times greater than the demand of the watering troughs.

The third line type is the branch line which carries water from the distribution line to the end use. Examples include the waterers, sprinklers, plate coolers, wash machine or milk parlor platform. Normally, these water lines are probably adequately sized. The difficulty occurs when a branch line becomes a distribution line. For example, a branch line to a watering trough is tapped into for the sprinkler system. The other difficulty occurs when a branch line needs to be added but installation requires placement of lines under concrete. Often in this scenario, the line is added above ground and then lack of maintenance, draining lines that may freeze, becomes a problem.

Pipe Losses

Water pipes need to be able to supply water to the end usage based on the peak flow rates. The plumbing system must be able to overcome losses incurred as water moves through the pipes. Pressure losses occur due to pipe friction, elevation differences between the pump source and point of use and velocity losses due to water movement. Friction losses are due to water flowing through pipes, fittings and valves. Often friction losses through fittings and valves are based on the equivalent feet of straight pipe (MWPS-30). Table 1 shows different fittings and their equivalent straight pipe length. The water velocity and inside surface roughness affect the friction losses. To reduce excess friction losses, normally the system is designed to limit pipe velocity to 5 fps or less. Water hammering will result when velocities exceed 5 fps. Table 2 shows the flow rate in gpm through various size pipes based on 4, 5 and 7.5 fps flow velocities. It is recommended to use the column showing 4 fps for the main and distribution lines. Branch lines can be sized based on the 5 fps velocities. Table 2b shows the capacity of different size pumps based on the total head at which a pump must operate against. Pipes should be selected based on the following guidelines (MWPS-7): 1. Limit the pressure loss to 5 psi when moving water from the pressure tank to building (this would be the losses in the main and distribution lines); 2. Limit the pressure losses in the branch lines to less than 5 psi; 3. Limit the pressure losses in the main line to less than 1 psi per 100 feet of pipe; and 4. Use a maximum water velocity of 4 fps to prevent water hammering.

Water Usage

Water usage on a dairy will vary significantly amongst dairies. Zuagg (1989) studied five dairies and found water usage varied from 80 to 240 gallons per lactating cow per day. Dairies raising replacement heifers and using calf barns utilized more than 200 gallons per lactating cow per day. Wiersma (Zaugg, 1989) reported water usage on Arizona dairies in 1975 at 91.5 gallons per cow per day. Zuagg (1989) also indicated the Arizona Department of Water Resources adopted 105 gallons per lactating cow per day and 20 gallons per nonlactating cow per day as the maximum water usages for dairies by the end of 2000. Table 3 summarizes the daily water usage on the five dairies in the Zuagg (1989) study. In South Flordia, dairies applying for a consumptive use permit to use 40 gallons per cow per day for drinking and 130 gallons per cow per day for flush water (Bray et. al., 1994).

Drinking Water Requirements

Lactating milk cows will drink from 30 to 50 gallons of water per day. A summary of daily water requirements for different type of dairy cattle is shown in Table 4. Data collected during the study comparing the impact of dietary fiber (Dado and Allen, 1995) indicates a cow will drink about 1.5 gallon of water per trip to a watering trough at a rate 1.3 gpm. They also found a cow will spend about 12 to 16 minutes per day drinking water. Their measured free water intakes were lower than most studies. However using this data, a cow makes about 24 trips per day if she drinks 40 gallons per day and 1.5 gallons per visit. Assuming a 12 foot watering trough and 6 cows present, the minimum water flow rate would be 8 gpm. A group of 100 cows spends approximately 40 hours of time per day at watering troughs. Even though cows spend only about 2½% of their time at the water trough, adequate water space recommendations per cow are to provide 2 feet of tank perimeter or 1 watering space per 15 to 20 cows (MWPS, 1997). Reinemann and Springman (1992) determine the drinking water requirements based on 4.5 to 5 pounds of water per pound of milk. They recommend the peak flow to waterers at 0.5 to 1 gpm per 10 cows. Dairies using a parlor more than 18 hours per day can probably use a 0.5 gpm per 10 cows peak flow rate, whereas dairies using a parlor less than 12 hours per day should use 1 gpm per 10 cows.

Martin (2000) estimates peak flow rate for larger dairies based on 10 gpm times the number of waterers in one group plus 10 gpm on all remaining lactating groups. If the facility houses heifers and dry cows, then peak flow rates for these groups may be based on daily consumption (gallons) divided by 1,440 minutes per day), to estimate the flow rate (gpm).

Wash Pen

The wash pen is a significant user of water on a dairy. Wiersma (1988) indicates 15 to 20 gallons per cow per milking may be used in the wash pen. Zaugg (1991) found on five dairies in Arizona the wash pen used from 19 to 93 gal/cow/day. The average value was 50 gal/cow/day. The water usage in a wash pen can equal the drinking water requirements. However, the demand will be much higher because a group of cows must be washed in a relatively short period of time.

Milk Equipment and Parlors

Many dairies have reduced water usage in the milk parlor by changing udder prep procedures. Dairies using hand operated wash hoses or automatic prep systems will utilize between 1 and 4 gallons per cow per milking. Water usage can be reduced to less than ½ gallon per day when using low water techniques such as single service towels. If cow towels are being used, water usage by the wash machine must be considered. Larger amounts of water are required for spray pens. Ludington and Sobel (1992) reported in a case study hot water usage dropped from 3.4 gallons per cow per day to 0.69 gallons per cow per day when changing from udder washing to dry prepping with pre and post dip.

Factors influencing the water usage in cleaning milking system include pipeline diameter, air injector settling, number of cycles per milking, etc. Automatic clean-in-place systems require from 100 to 300 gallons per milking for large parlors with weigh jars. Milk equipment suppliers should be able to provide an estimate of water requirements for cleaning the type of system being installed.

Water usage for bulk tank cleaning can be estimated by dividing a bulk tank size by 20 (Reinemann and Springman, 1992). The amount of water required is 3 to 5 percent of the tank volume with automatic washing systems. Water utilized in cleaning the milk equipment and bulk tank is not potable but may be stored and reused for flushing the cow platform and holding pens.

Reinemann and Springman (1992) recommends sizing the water requirements of plate coolers based on 1 to 2 pounds of water per pound of milk. Water usage may be less than 1 to 1 if no attempts are made to control water and milk flow. Spencer (1992) also notes water usage with pre cooler may be twice as much as the milk production while obtaining 30 to 50 percent of the cooling requirements.

Fresh or clean water is required when flushing the parlor platform and holding pen. Water can be recycled from the plate cooler to perform this task. Weeks (1992) reported about 7.5 gallons of water per cow were required per day for flushing the milk parlor and holding pen. However, the milk parlor was only used less than 8 hours per day. Some data suggest an adequate flush can be obtained using 1.5 gallons per sqare foot per flush. Assuming 30 cows per milk stanchion per milking, with each stanchion being 40 square feet (2.5 feet by 16 feet—rapid exit space included) along with 15 square feet per cow in the holding pen would result in 2.75 gallons per cow per flush or frequency of milking. Therefore, it is recommended for planning the water requirements for flushing the milk parlor be based on 5 to 7.5 gallons per cow per day. Basing the demand on delivering the water during a 3-minute flush cycle, the water demand can be estimated by multiplying the number of lactating cows by 1 gpm. A 1,000 cow dairy would have a water demand for flushing the platform and holding pen of 1,000 gpm. This demand does not have to be included in the water distribution system if recycled water from the milk equipment room is utilized. Another method to reduce the water demand is to provide a storage tower. In this case the demand can be based on the available time to fill the tank. If 4 hours are available, then the demand reduces from 1,000 to 10 gpm.

Sprinkler Systems

Sprinkler systems are used to wet the cow's back and can be used in the holding pen and along the feed lane. Bray et. al. (1994) reported water usage for low pressure systems ranging from 18.6 to 56 gallons per cow per day. They reported a study by Montoya (1992) found 23 percent of the water was evaporated and 15 percent of the total water applied evaporated from the cow's body. This rate of evaporation equaled about 1.1 gallon per cow per hour.

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Bray and Bucklin (1995) recommend applying 0.05 inches per cycle when sprinkling cows. This converts to 0.03 gallons per square foot of wetted area. A cow will have about 12 square feet of wet area based on 2 feet along the feed line and 6 feet for cow length. Sprinkler systems generally operate based on 3 minutes on and then 12 minutes off. This will vary among regions and system design. The demand of the sprinkler system can be estimated by the number of cows being cooled multiplied by 0.1 gpm/cow. The water usage can be estimated by multiplying the number of cows by 0.3 gal/cow/cycle or 1 to 2 gallons per cow per hour. Therefore, if 1,000 cows are being cooled simultaneously, the demand would be 100 gpm and the water usage would be 300 gallons. Table 6 provides a summary of water usage and demand rates for low pressure sprinkler systems based on length of feed line. Pipe size can be reduced by locating the water line serving the sprinkler system in the middle rather than at one end. Plumbing becomes expensive with trying to meet the water demands on long feed lines due to the increase in pipe size necessary to carry the water demand.

Sprinkler systems can be operated either simultaneously or sequenced. A simultaneous system cools all of the cows at once and places the most demand on a system. The system basically comes on for the set time interval and is off until the next cycle occurs. The 1,000 cow example mentioned earlier has a demand of 100 gpm. A sequenced system results in using controllers to sequence the sprinklers on between different pens. For example, using a four-row 1,000 cow freestall, the sprinkler system in each quadrant of the building would come on at different times. This results in significant cost savings because the demand on the water system is reduced from 100 gpm to 25 gpm. The water usage is still 300 gallons but it can be delivered over a 12-minute interval rather than 3 minutes. Additional controllers are required with sequencing systems and management must be available to operate these systems. It is much easier to switch from a simultaneous to sequence system than vice versa. Therefore, initial planning requires careful consideration.

High pressure systems using misters require different types of planning. Bray et.al. (1994) reported high pressure fog ring systems use between 1.5 to 2 gallons per hour with water usage a function of pressure. For planning purposes, dairies can estimate the water demand of high pressure systems based on 0.03 gpm per fan. The system demand is based on the total number of fans being installed with misters multiplied by 0.03 gpm/fan. Assuming 1 fan per 5 cows, the system demand for a 1,000 dairy would equal 6 gpm. However, in many regions a sprinkler system is still needed along the feed line to adequately cool cows.

Dairies in the southwest United States use evaporative cooling under shade or cattle shade coolers. Armstrong and Welchert (1994) reported water usage for these systems from 0.2 to 2 gpm. One fan will serve 13 to 15 cows. The daily water usage with a shade cooler can be estimated by multiplying the number of cows times 0.1 gpm times the minutes per day of operation. The water demand can be estimated by multiplying the total number of shade cooler unit fans by 1.5 gpm. Using the 1,000 cow example and 12 hours of operation per day, the daily water usage would equal 72,000 gallons of water and the demand would be 100 gpm.

Holding pen sprinkler systems should be sized based on providing 0.01 gallons of water per square foot of area (gal/sq.ft.). Table 8 shows the water requirements for different size holding pens and the required flow rate of the water system. The flow rate is based on a cycle of 1 minute on and 6 minutes off. The time the sprinkler nozzles are on may be reduced if the udder of the cow is getting wet.

Summary

Modern dairy facilities will use between 50 to 200 gallons of water per cow per day depending on the operation. Proper planning requires obtaining adequate quantities and qualities of water to meet the present and future water requirements. It is important during the planning phase to consider the water demands of the dairy and design accordingly. When in doubt or uncertain, it is better to err by installing larger pipe so that management changes may be made in the future.

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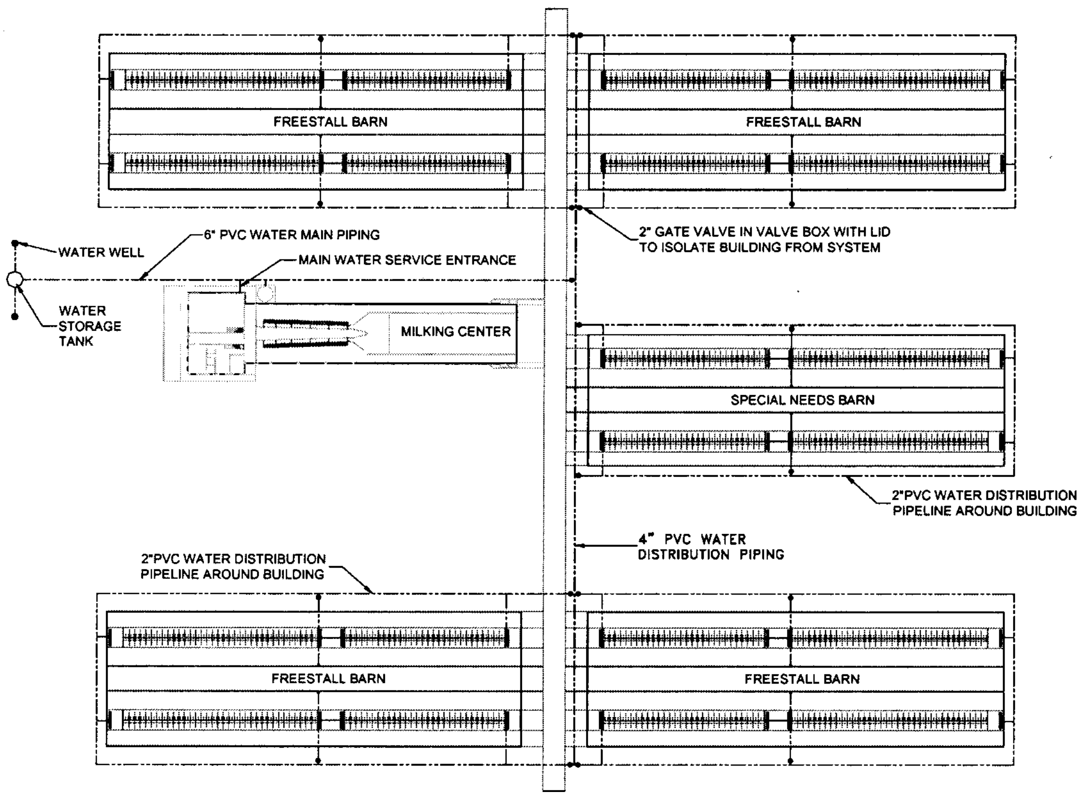
Design of a Water System



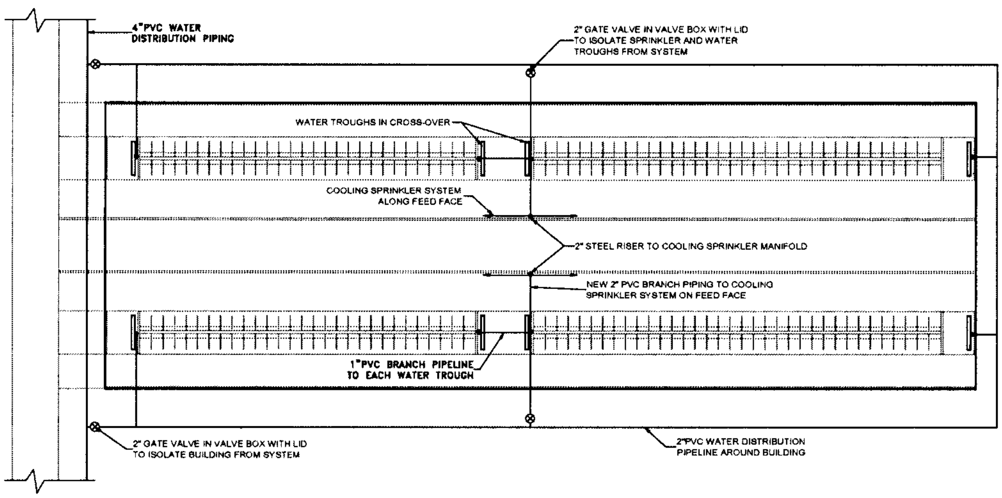


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Table 1. Effect of friction associated with pipe fittings and valves.

Fitting Type	Pressure loss (psi)	Equivalent pipe length (ft)
90° long sweep elbow	0.05	14
90° standard elbow	0.8	20
45° elbow	0.03	8
Gate valve, wide open	0.02	5
Gate valve, half open	0.41	130
Flow meter	0.14	32

Table 2. Estimated flow rate of various pump capacity operating against different pressure losses.

	Estimated Flow Rate (gpm) Based on Pump Size (hp)					
Pump Size	Average Feet of Head					
(horsepower)	20	40	60	80	100	120
10	1,485	743	495	371	297	248
20	2,970	1,485	990	743	594	495
30	4,455	2,228	1,485	1,114	891	743
40	5,940	2,970	1,980	1,485	1,188	990
50	7,425	3,713	2,475	1,856	1,485	1,238
75	11,138	5,569	3,713	2,784	2,228	1,856
100	14,850	7,425	4,950	3,713	2,970	2,475

Table 2b. Recommended maximum flow rate through pipe using different flow velocity. Water hammering may occur at velocities greater than 5 fps and require special fittings.

Nominal Pipe Diameter (inches)	Flow velocity through pipe (feet per second)		
	4	5	7.5
0.5	2	3	5
0.75	6	7	10
1	10	12	20
1.25	15	20	30
1.5	20	30	40
2	40	50	70
2.5	60	80	120
3	90	110	160
4	160	200	300
6	350	440	660
8	630	780	1,200
10	980	1,200	1,800
12	1,400	1,800	2,600
16	2,500	3,100	4,700
24	5,600	7,000	10,500

Table 4. Estimate of drinking water requirements for different dairy animal types (MWPS, 1999).

Animal Type	Water Usage (gallon/day/head)
Calves (1 to 1.5 gal/100 lbs)	6 to 10
Heifers	10 to 15
Dry Cows	20 to 30
Lactating Cows	25 to 50

Table 5. Estimate of water usage (gallons) and demand (gpm) for low pressure system located along a feed line.

Length of Feed Line (ft)	Water Usage per Cycle(gal)*	Water Demand (gpm)
100	20	7
200	40	13
400	75	25
600	110	38
800	150	50
1,000	190	62

*Based on wetted distance from feed line of 6 ft and 0.05 inches of water/cycle/sq.ft and 3 minute on cycle.

Table 6. Sprinkler nozzle requirements based on holding pen capacity.

Holding Pen Capacity	Typical Pen Size (feet by feet)	Water Required (Gallons/Cycle)	Minimum Flow Rate (gpm)*
80	24 by 50	40	14
100	32 by 48	50	16
120	32 by 56	60	20
160	32 by 75	80	30
200	32 by 96	100	40
300	32 by 144	150	50
400	32 by 192	200	75
500	32 by 240	250	100

*Flow rate based on a 3 minute on cycle with 12 minutes off.

**Assumes nozzles have an 8 foot spray diameter and 0.5 gpm capacity.

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Table 3. Summary of daily water usage on five dairies in southwestern United States (Zaugg, 1989).

	Dairy Identification and Milking Frequency				
	A(3X)	B(3X)	C(2X)	D(2X)	E(3X)
Daily Water Usage					
Total Gallons per Lactating Cow*	186	101	95	72	182
Udder Wash per Lactating Cow	93	49	19	24	65
Drinking					
Early Lactation	34	31	30	29	35
Late Lactation	27	28			25
Dry Cow	16	13			17
Close-up		16			17
Calves (hutches or barns)		3	2	2	25**
2-6 months		3	4	4	5
7-15 months					10
16-22 months					11
Cooling					
Shade Evaporative Cooler		15			16
Shade Misters			4.5		
Fence Line Misters			2.5	1.4	
Holding Pen Sprayer		2	2	2.3	
Exit Sprayer	2.1			0.8	
Parlor Evaporative Cooler	1.4	0.5		0.1	5.4
Parlor					
Hot Water	0.8	0.3	0.7	0.8	0.9
Cold Water	5.9	2	1		
Drop Hoses	1.8			2.5	2.1
Wash Hoses	3.3		6		6.5
Vacuum Pump	6.5				5

*Total water usage divided by the number of lactating cows.
*Includes cleaning and sanitizing wire cages, concrete floors and alleys.

Table 7. Estimate of daily water requirements and demand for 1,000 lactating cows.				
	Percent of Lactating Cows	Daily Usage (gal./day)	1,000 Lactating Cows (gal./day)	Minimum well(s) capacity based on 20 hours pumping (gal./min.)
Drinking Water				
Lactating Cows	92	40 gal/cow	36,800	31 gpm
Dry Cows	25	30 gal/cow	7,500	7 gpm
Calves/Heifers	115	15 gal/cow	17,250	15 gpm
Sick/Lame Cows	8	30 gal/cow	2,400	2 gpm
Milk Parlor				
Plate Cooler		1.5 lb water per lb milk	14,400	12 gpm
Wash Water	100	5 gal/cow	5,000	4 gpm
Flush Water	100	25 gal/cow	25,000	21 gpm
Employees	1 FTE/80 cows	50 gal/employee	600	0.5 gpm
Sprinkler System*	4 cycle/hr	1 gal/cy/cow	96,000	80 gpm
Special Needs				
Special Needs Parlor	8	15 gal/cow	1,200	1 gpm
Holding Pen	3x milking	3 gal/cow/milking	9,000	8 gpm
Minimum pumping capacity from the well into a storage tank				185 gpm

*assumes the times are sequenced such that no more than 4 groups are being sprinkled at a time using a 3 minute on and 12 minute off cycle.