# Livestock Watering FACTSHEET

BRITISH COLUMBIA
Ministry of Agriculture and Lands

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# USING WIND ENERGY TO PUMP LIVESTOCK WATER

**This Factsheet outlines the use of wind energy to pump livestock water. Imperial and metric units are used.**

## Introduction to Windmills

The use of mechanical equipment to convert wind energy to pump water goes back many years. By the late nineteenth century there were more than 30,000 windmills operating in Western Europe, many of the Dutch "tower" mill design. In 1854, Daniel Halliday invented the American multiblade windmill using wooden blades. By 1915, Aermotor Company of Chicago had patented the first self-oiling machine, with the open gears enclosed in a water resistant case.

Windmills are classified as vertical or horizontal axis machines depending on the axis of rotation of the rotor. Vertical axis wind- mills can obtain power from all wind directions whereas horizontal axis windmills must be able to rotate into the wind to extract power.

Windmills are also classified as either electrical power generators or water pumpers. Power generators are typically horizontal axis "propeller" type blade designs or vertical axis "egg beater" designs. Power generators typically operate at high rotational speeds with low starting torques, appropriate for generators.

Direct water pumping windmills are characterized by the "old west" style of a multiblade, horizontal axis design set over top of the well (Figure 1). Water pumping requires a high torque to start the pump and this is supplied by the multiblade design.

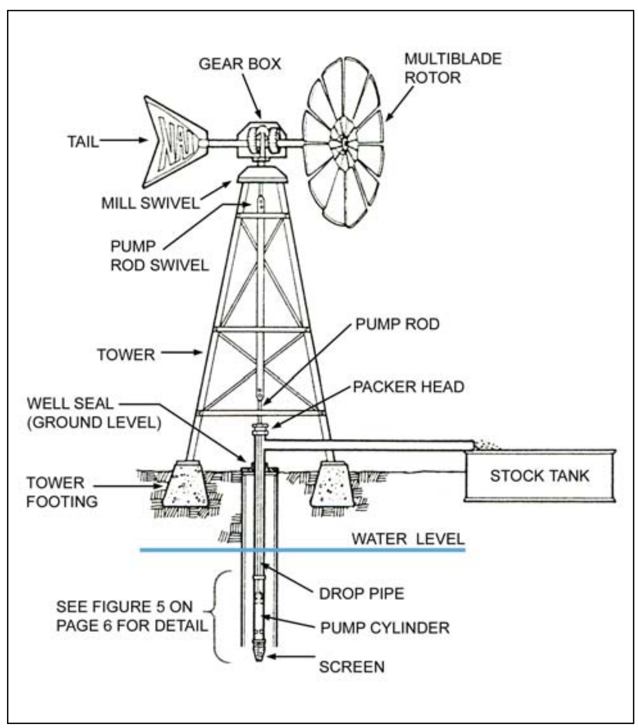



**Figure 1 Components of a Multiblade Windmill For Pumping Water**

## Wind Energy Potential

The energy available in the wind is proportional to the cube of the wind speed: if the wind speed is doubled, there is eight times the available power. A 12 kph wind has eight times the power of a 6 kph wind and a 24 kph wind has sixty-four times the power of a 6 kph wind! There is 73% more energy in a 12 kph wind than in a 10 kph wind ($12^3$ is 1.73 times larger than $10^3$). This is an important characteristic of wind energy. Measurement of the average wind speed of a site is crucial. Generally, winds less than 12 kph are not practical for water pumping.

Wind energy is also affected by the density of the air. Lower density air in summer than winter, or at higher elevations, has less wind energy potential.

**Windmill Power.** The power output of a windmill is dependent on the ***rotor diameter*** and the ***wind speed***. The energy captured by the rotor is proportional to the ***square of the rotor diameter*** (doubled rotor diameter = four times power output) and the ***cube of the wind speed*** (doubled wind speed = eight times power output). The potential output of a multiblade windmill is given by this equation:

$$P = 0.002\ D^2 V^3$$

where: **P** = power in ***watts*** (note: 746 watts = 1 horsepower)
**D** = rotor diameter in ***metres***
**V** = wind speed in ***kilometers per hour***
Assumptions: average air density
overall efficiency = 20% (usual range is 10 – 30%)
(20% = approx rotor 30% x energy conversion 70%)
Note: maximum 59% of wind energy can be extracted (Betz Law)

Tables 1 & 2, next page, provide capacities from this equation and a windmill supplier.

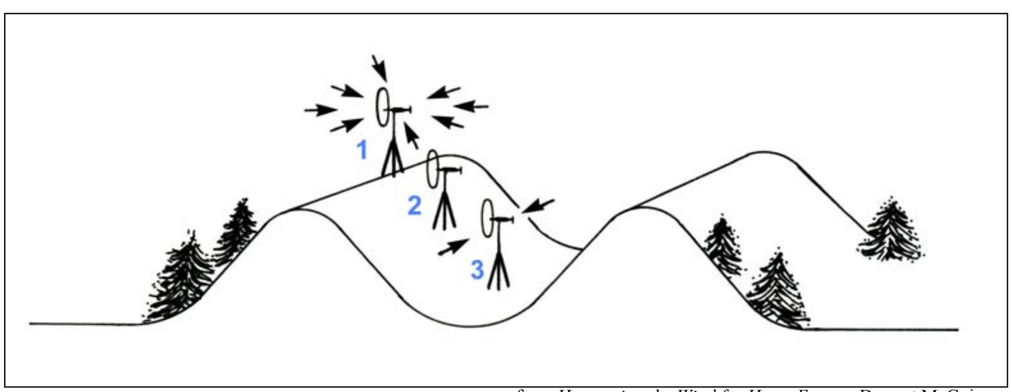
**Site Location.** Site location factors also affect a windmills power output. The terrain affects the wind so windmill location must be considered carefully as illustrated in Figure 2, below.

These site considerations highlight a difficult point in using windpower to pump water – is the water source located at the same site as the most favorable wind site? Water may be in a draw or gulley but the wind is up on the ridge or hilltop. Although windmill designs are available to allow the windmill location offset from the water source, most installations are directly over the source, usually a well. If electrical energy is being generated to power an electrical pump, some separation is possible.

**Site 1 - Ideal (benefits from wind in all directions)**

**Site 2 – Not recommended (wind is usually poor)**

**Site 3 - Good site (wind from two directions only)**




from *Harnessing the Wind for Home Energy*, Dermot McGuigan

**Figure 2 Windmill Site Considerations**

## Table 1 — Estimate of Power Delivered by a Windmill in a 24 kph (15 mph) Wind at 20% Overall Efficiency

| Power | Rotor Diameter (feet / metre) | | | | | |
|---|---|---|---|---|---|---|
| | 6ft 1.8m | 8ft 2.4m | 10ft 3m | 12ft 3.7m | 14ft 4.3m | 16ft 4.9m |
| **horsepower** | 0.12 | 0.21 | 0.33 | 0.50 | 0.70 | 0.85 |
| **watts** | 90 | 160 | 250 | 380 | 510 | 640 |

from $P = 0.002\, D^2 V^3$

## Table 2 — Windmill Lift and Volume Capacities [1] in a 24 kph (15 mph) Wind

**Total Lift (feet and metre) & Volume (USgal per hour and Litre per hour) [2]**

| Pump Cylinder Diameter | Windmill Rotor Diameter (feet / metre) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **6ft / 1.8m** | | **8ft / 2.4m** | | **10ft / 3m** | | **12ft / 3.7m** | | **14ft / 4.3m** | | **16ft / 4.9m** | | **20ft / 6.1m** | |
| inch | ft | USgph | ft | USgph | ft | USgph | ft | USgph | ft | USgph | ft | USgph | ft | USgph |
| cm | m | Lph | m | Lph | m | Lph | m | Lph | m | Lph | m | Lph | m | Lph |
| **1 7/8** | 120 | 115 | 175 | 119 | 260 | 103 | 390 | 121 | 570 | 103 | 920 | 138 | 1200 | 162 |
| **4.76** | 36 | 435 | 53 | 450 | 79 | 390 | 119 | 458 | 174 | 390 | 280 | 522 | 366 | 613 |
| **2** | 95 | 122 | 140 | 135 | 215 | 117 | 320 | 137 | 456 | 118 | 750 | 157 | 1026 | 184 |
| **5.08** | 29 | 462 | 43 | 511 | 66 | 443 | 98 | 519 | 139 | 447 | 229 | 594 | 313 | 696 |
| **2 1/4** | 77 | 165 | 112 | 170 | 170 | 148 | 250 | 174 | 360 | 149 | 590 | 199 | 903 | 232 |
| **5.72** | 24 | 625 | 34 | 643 | 52 | 560 | 76 | 659 | 110 | 564 | 180 | 753 | 275 | 878 |
| **2 1/2** | 65 | 204 | 94 | 210 | 140 | 182 | 210 | 214 | 300 | 184 | 490 | 245 | 896 | 287 |
| **6.35** | 20 | 772 | 29 | 795 | 43 | 689 | 64 | 810 | 92 | 696 | 149 | 927 | 273 | 1086 |
| **2 3/4** | 56 | 247 | 80 | 255 | 120 | 221 | 175 | 259 | 260 | 222 | 425 | 296 | 692 | 347 |
| **6.99** | 17 | 935 | 24 | 965 | 37 | 836 | 53 | 980 | 79 | 840 | 130 | 1120 | 211 | 1313 |
| **3** | 47 | 294 | 68 | 303 | 100 | 263 | 149 | 308 | 220 | 264 | 360 | 353 | 603 | 413 |
| **7.62** | 14 | 1113 | 20 | 1147 | 31 | 995 | 45 | 1166 | 67 | 999 | 110 | 1336 | 184 | 1563 |
| **3 1/4** | 39 | 345 | 55 | 356 | 87 | 308 | 128 | 362 | 186 | 311 | 305 | 414 | 496 | 485 |
| **8.26** | 12 | 1306 | 17 | 1347 | 27 | 1166 | 39 | 1370 | 57 | 1177 | 93 | 1567 | 151 | 1836 |
| **3 1/2** | 34 | 400 | 49 | 412 | 75 | 357 | 111 | 420 | 161 | 360 | 265 | 480 | 390 | 562 |
| **8.89** | 10 | 1514 | 15 | 1559 | 23 | 1351 | 34 | 1590 | 49 | 1363 | 81 | 1817 | 119 | 2127 |
| **3 3/4** | 29 | 459 | 42 | 474 | 65 | 411 | 96 | 482 | 141 | 413 | 230 | 551 | 310 | 646 |
| **9.53** | 9 | 1737 | 13 | 1794 | 20 | 1556 | 29 | 1824 | 43 | 1563 | 70 | 2086 | 95 | 2445 |
| **4** | 27 | 522 | 38 | 539 | 57 | 467 | 85 | 548 | 124 | 470 | 200 | 627 | 252 | 734 |
| **10.16** | 8 | 1976 | 12 | 2040 | 17 | 1768 | 26 | 2074 | 38 | 1779 | 61 | 2373 | 77 | 2778 |

1 – reduce capacities for lower average wind speeds e.g. if wind is reduced from 24kph to 16kph (10mph) – use 62% of above
– based on minimum cylinder stroke setting – lengthening the stroke will increase the volume and reduce the lift

2 – unless otherwise known, assume this hourly output for only 4 to 5 hours in 24 hours

adapted from *Selecting Water-Pumping Windmills*, New Mexico Energy Institute

## Wind Speed Assessment

The accurate assessment of the average wind speed during the period that water pumping is required cannot be over-stressed. In some cases local weather station information may be applicable, however as wind varies widely over short distances actual site wind readings are preferred. A hand held anemometer can be used but will be too close to the ground and requires considerable onsite time to establish meaningful records.

Better results are from a permanent recorder installation. An anemometer can be installed on a simple T.V. antennae tower and when connected to a recorder, wind speeds are continuously monitored, as shown in Figure 3, below. This can then be used to accurately calculate the average wind speed and thereby correctly select the windmill equipment. If needed, adjust site readings to the height of tower to be used using Table 3, next page. Readings should be taken for the period water is required. This wind assessment may have to be contracted from a local company.

**Solar-powered Data Collection of Wind Speed**

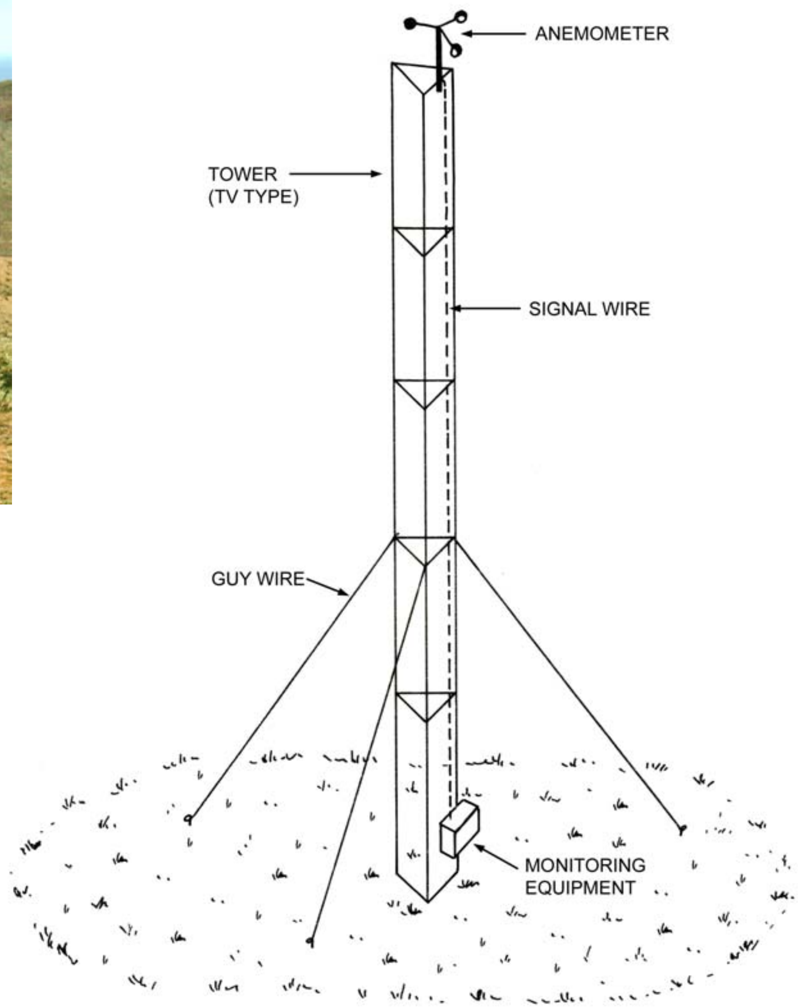


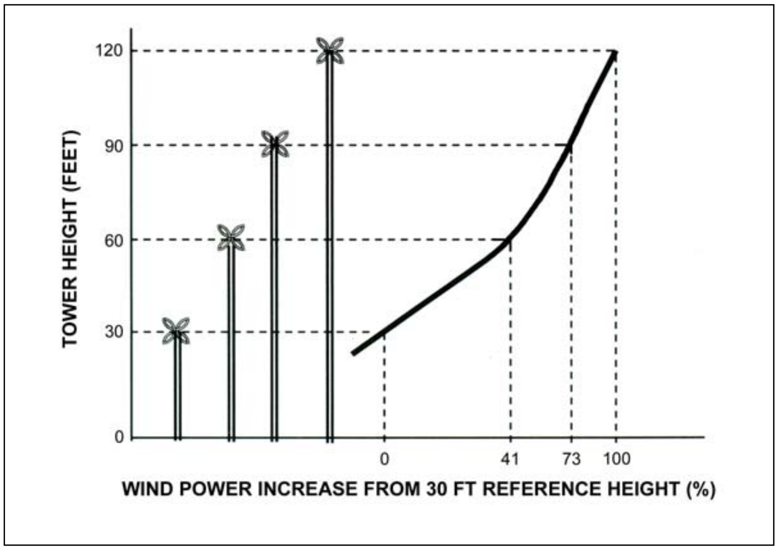

**Figure 3 Wind Speed Monitoring Equipment**

## Tower Height, Wind Speed and Power

Windmills need to be raised in the air a sufficient height to be able to capture undisturbed wind. But as towers are costly, what height is most effective? Consider:

- the windmill wheel must be at least 9m (30 ft) above any obstruction within a 100m (350 ft) radius to give the rotor a free flow of air from all directions
- wind speed generally increases with altitude, meaning more power is available
- therefore, a higher tower can be a cost effective way to increase power

Figure 4 illustrates increasing to a 18m (60ft) from a 9m (30ft) tower has a +41% wind power increase (increased power due to the effect of wind speed "cubed").




from Bergey Windpower Co.

**Figure 4** **Relationship of Tower Height to Available Wind Power**

**The 1/7 Rule.** A method of estimating the wind speed at the elevation of a windmill when it's at a height other than that which the wind speed is measured, is to use the "1/7 Rule". This states that the wind speed increases at the 1/7 power of the height ($H^{1/7}$) above ground, as shown in Table 3. If the wind speed is measured at 20 ft but the windmill will be at 40 ft, Table 3 indicates the speed at 40 ft will be 1.10 times the measured speed at 20 ft (and as the energy potential increases by the cube of the wind speed, a 1.10 wind speed increase = $1.10^3$ = 1.33 energy increase).

**TABLE 3** **THE 1/7 WIND SPEED RULE FOR VARIOUS HEIGHTS OF WINDMILLS**

| Height of Tower (feet and metre) | Height at which Wind was Measured (feet and metre): 15 4.5 | 20 6.1 | 25 7.6 | 30 9.1 | 35 10.7 | 40 12.2 | 45 13.7 | 50 15.2 |
|---|---|---|---|---|---|---|---|---|
| 20 6.1 | 1.04 | 1 | 0.97 | 0.94 | 0.92 | 0.91 | 0.89 | 0.88 |
| 30 9.1 | 1.10 | 1.06 | 1.03 | 1 | 0.98 | 0.96 | 0.94 | 0.93 |
| 40 12.2 | 1.15 | 1.10 | 1.07 | 1.04 | 1.02 | 1 | 0.98 | 0.97 |
| 50 15.2 | 1.19 | 1.14 | 1.10 | 1.08 | 1.05 | 1.03 | 1.02 | 1 |
| 60 18.3 | 1.22 | 1.17 | 1.13 | 1.10 | 1.08 | 1.06 | 1.04 | 1.03 |
| 70 21.3 | 1.25 | 1.20 | 1.16 | 1.13 | 1.10 | 1.08 | 1.07 | 1.05 |
| 80 24.4 | 1.27 | 1.22 | 1.18 | 1.15 | 1.13 | 1.10 | 1.09 | 1.07 |
| 90 27.4 | 1.29 | 1.24 | 1.20 | 1.17 | 1.14 | 1.12 | 1.11 | 1.09 |
| 100 30.5 | 1.31 | 1.26 | 1.22 | 1.19 | 1.16 | 1.14 | 1.12 | 1.10 |

adapted from *Wind Power for the Homeowner,* Donald Marier: (Height / height measured) $^{1/7}$ = Wind Speed / wind speed measured

## Pump Cylinders

Multiblade windmills traditionally pump water by directly operating a pump cylinder with a drive rod. The pump cylinder is submerged in the well attached to the end of the delivery pipe. It is a very simple pump similar to a hand-operated bicycle pump. The drive rod is operated directly by the windmill rotor through the drive gearing which translates the rotating motion to the up and down reciprocating motion. Two one way valves in the pump direct water through the pump as illustrated in Figure 5.

## Windmill Design Variations

The following design improvements made to the standard multiblade water pumping windmill make use of lighter winds or increase the amount of pumping for each cycle.

**Fully Counterbalanced Windmill.** A standard windmill works on the upstroke; pumping water and lifting the weight of the pump rod. A counterbalanced windmill has part of the pump rod weight and one-half the water weight counterbalanced by counterweights. This results in an approximate two-thirds reduction in starting torque allowing the use of lighter winds. Tests have shown 13 times greater volume pumped at wind speeds below 16 kph and one-third greater volume above 16 kph.

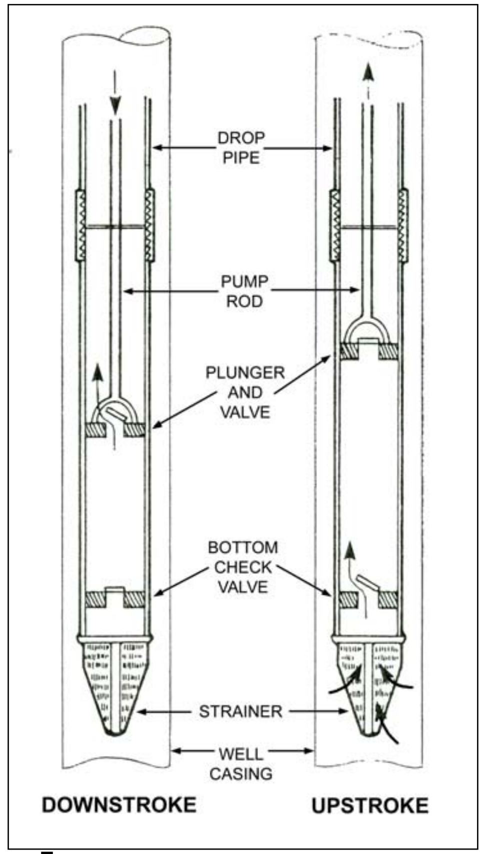



**Figure 5
Operation of a Typical Windmill Pump Cylinder**

**Spring Counterbalanced Windmill.** This design achieves similar results as counterbalancing with weights. Two to four extension springs are attached to the top of the tower and the free ends are connected to the pump rod. Energy is stored in the downstroke to assist in the up stroke and tends to even out the work load. The size and number of springs must be determined to suit the individual windmill.

**Cam-Operated Windmill.** In a cam operated windmill, the lift occurs during more than one-half the cycle (standard designs only lift for one-half the cycle). Using a cam that allows for three-quarters of the cycle lifting and one-quarter return, starting torque is reduced by 60 percent. The windmill will start in light winds, and if combined with counterbalancing, starting torque is reduced by 72 percent.

**Air Lift Pumps.** Air lift water pumps are an alternative to the traditional rod driven cylinder pumps. The windmill operates an air compressor which pumps air down a line set in the well. The end of this air line is attached to the "air lift pump" which is actually a specially formed foot piece attached to the water delivery pipe. This must be submerged in the water a depth equal to 30% to 70% of the required lift measured above the water level. For example, to lift 30m (100 ft) above the water level, the air lift pump must be submerged approximately in the water 27 to 45m (90 to 150 ft).

As air is discharged into this foot piece, the water column in the outlet pipe becomes less dense and is forced up by the denser water on the outside of the outlet pipe. With no moving or wearing components down the well, servicing is simplified. Also this design allows offsetting the windmill site from the water source. The main drawback is the submergence required as many wells will not have the depth of standing water. For more information on air pumps, refer to Factsheet #590.305-2, ***Pumps for Livestock Watering Systems***.

## Selecting a Windmill

Points to consider when selecting a windmill:

1. First of all, a water source is needed, knowing the volume of water to be pumped (livestock requirements) and the lift (from water level to top of tank)
   - if using a well, it should be drilled first to know the lift and volume available
2. Some estimate of available wind must be made, preferably from site readings
   - select a tower height
   - adjust site readings to the tower height using Table 3
3. Choose the combination of cylinder size for volume and rotor diameter for lift
   - use manufacturers tables or Table 2, page 3, for size estimates
   - usually best to choose the largest rotor and smallest cylinder that will fill the need, for easy start in lighter winds and minimized strain on the system
   - as a rule-of-thumb, expect an average of 4 - 5 hours/day of pumping at the specified rate for 24 kph wind unless local conditions are known
4. Other points:
   - windmill pump outlets are normally discharged into an open tank i.e. into the top of the tank - if the outlet is to go into the bottom of the tank or rises above the well head a packer head is installed to seal the drive rod
   - hand pumping can be done on some windmills in emergencies - the hand pump is part of the installation and the operating handle is attached when needed

## Example: Windmill Selection

A ranch requires stock water on rangeland for 80 cows grazing for two months in the spring. A well has been drilled 150 feet deep which produces water from 100 feet deep (i.e. has 50 ft. of storage). The well pump test showed that it will produce 5 USgpm or 300 USgph with a drawdown of 15 feet.

**Calculations**:

- Total lift requirement: the pump will be placed at approximately 140 ft down the well. The pumping lift is taken from the drawdown level which is 100 ft + 15 ft or 115 ft. It has to lift an additional 3 ft above the well head into the stock trough. Allowing 2 ft for pipe losses the total lift is 120 ft (115 + 3 + 2).

- Total daily water requirement: from Factsheet #590.301-1, Table 1, the daily requirement of cows when the air temperature is less than $25^0$ C (spring time) is 12 USgpd/head; for 80 cows = 960 gpd.

- The preferred tower height. Towers range from 22 ft to 40 ft and are selected to ensure the rotor is in undisturbed air as previously discussed. The terrain at the site should be carefully considered when choosing tower height. In this case a 40 foot tower is selected.

- Average wind speed calculation: monitoring the site for the two month period in the spring showed the average wind speed to be 13 mph measured at 15 feet.

- The wind speed at the windmill height. Using Table 3, the 13 mph measured at 15 feet is multiplied by 1.15 for a 40 foot tower = 15 mph wind speed.

**Selection:**

- Windmill selection: refer to manufactures catalogs for windmill capacities for the site conditions of wind speed and water volume and lift or use Table 2 for typical specifications (noting that this table is for 15mph wind speed).

- Use Table 2: As this site has 15 mph wind speed, use Table 2, for estimates:

| | | |
|---|---|---|
| Conditions: | Average wind speed | 15 mph |
| | Well capacity | 300 USgph (max) |
| | Water requirement | 960 USgpd (min) |
| | Daily pump time | assume 5 hours |
| | Hourly pump rate | 960 / 5 = 190 USgph (min) |
| | Total lift | 120 ft |

The best match for these lift and water requirements is
- a 12 ft diameter windmill operating a 2 1/2 inch diameter pump cylinder
- this will produce 214 USgph (more than 190 USgph needed and within the well capacity of 300 USgph)
- at 214 USgph, the 960 USgpd could be pumped in about 4 1/2 hours
- it will lift 210 ft lift (which exceeds the required 120 ft, but the diameter rotor will start easily in light winds)

Note: as Table 2 capacities are for minimum pump stroke settings, a longer stroke setting could be used to increase the pump volume (reducing the hours of pumping per day – an advantage during shorter periods of wind) – this will reduce the lift capacity but it is now greater than required

If extended periods of low winds are expected, water storage should be considered in addition to the storage in the trough(s), as illustrated on page 1. Refer to Factsheet #590.304-7, ***Storage Tanks for Livestock Watering Systems***.

## Other Information

The following publications were used in preparing this Factsheet, or are wind references of note. Refer to them for more information as required.

***Harnessing The Wind for Home Energy***, Dermot McGuigan, 1978

***Selecting Water-Pumping Windmills***, New Mexico Energy Institute, 1978

***Wind Generator Tower Height***, Mick Sagrillo, Home Power #21, 1991

***Wind Power and Other Energy Options***, David R. Inglis, 1978

***Wind Power for the Homeowner***, Donald Marier, 1981

***Wind Power Uses and Potential***, TransAlta Utilities, 1992

Many web sites are available:
- a good "guided tour" on wind energy http://www.windpower.org/composite-85.htm
- animated windmill pump http://www.aermotorwindmill.com/Links/Education/Index.asp
- links to many water pumping sites http://www.internationalwindmill.com/links.htm

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