Understanding and preventing frost damage

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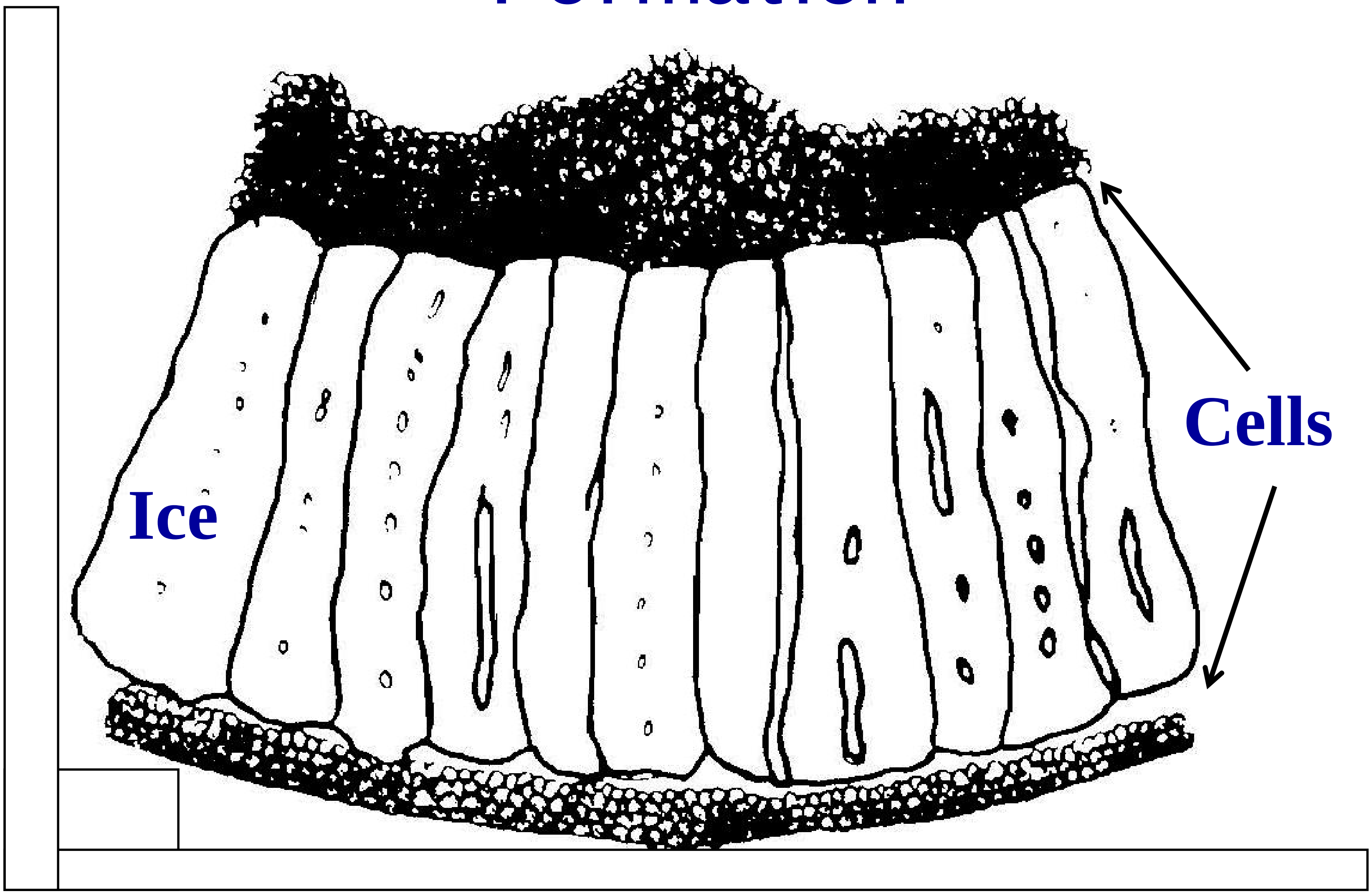
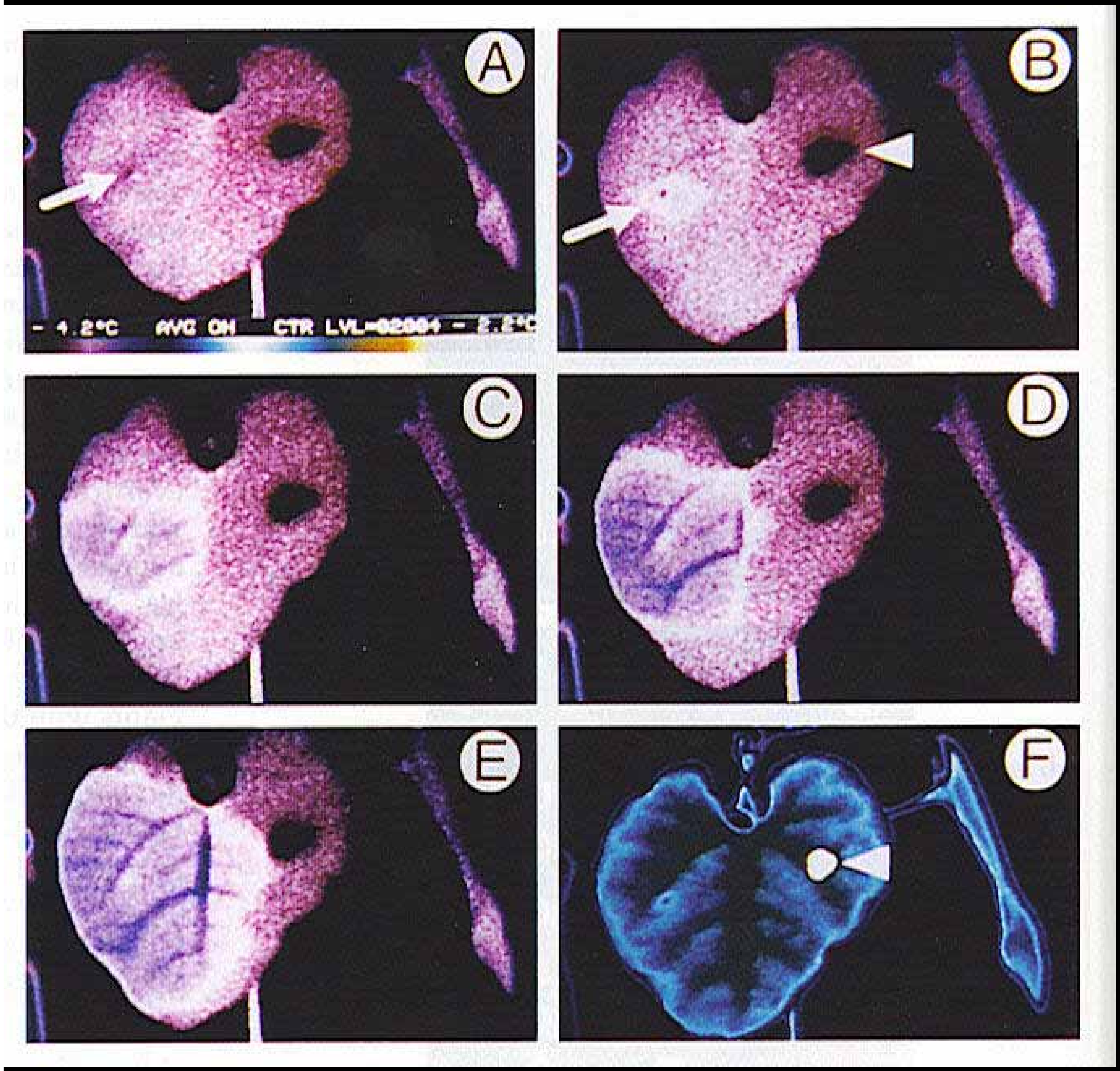
Intercellular Ice Crystal Formation



Prillieux (1869) cited by Levitt (1980)

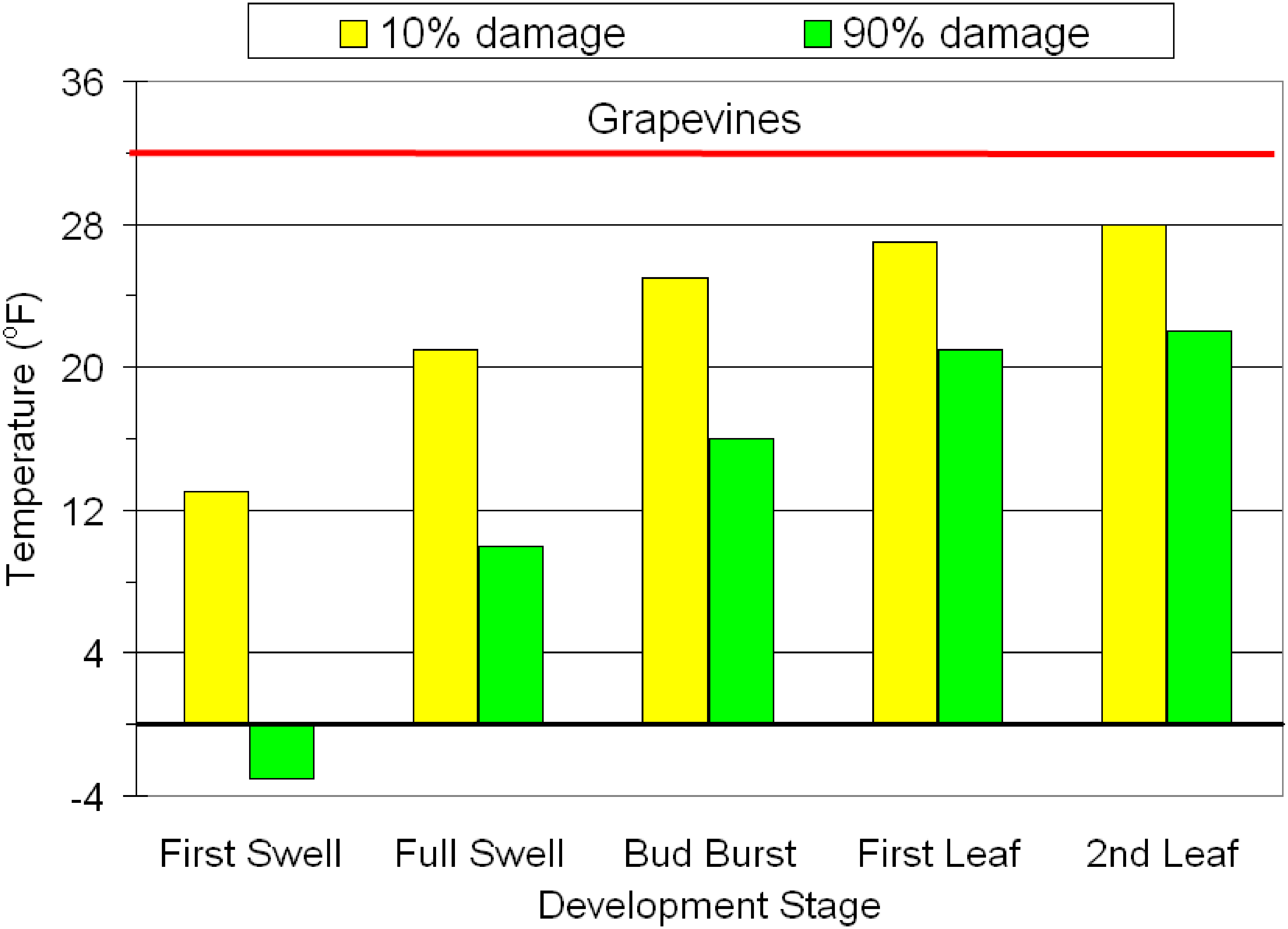
INA Bacteria

- **Water Freezes below the Melting Point (0^{o}C or 32^{o}F)**
- **In the temperature range for Frost Damage (-5 to 0^{o}C or 23 to 32^{o}F), INA bacteria cause 99% of Ice Nucleation**



In A, water with *P. syringae* placed at arrow and deionized water at black spot. Black spot is colder because of evaporation. Ice forms first at the bacteria and propagates through the leaf (B-E). Two minutes after exothermic response dissappates, the deionized water freezes.

Wisniewski, Lindow and Ashworth (1997)



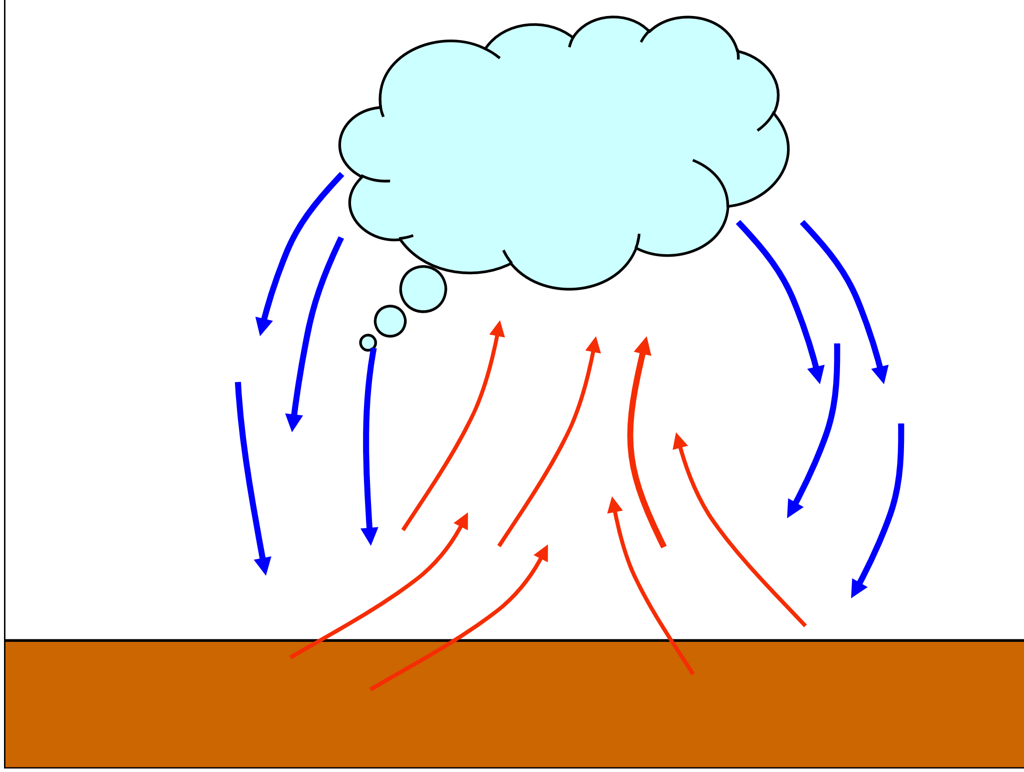
E. L. Proebsting, V. P. Brummund and W. J. Clore. Washington State University, Prosser.

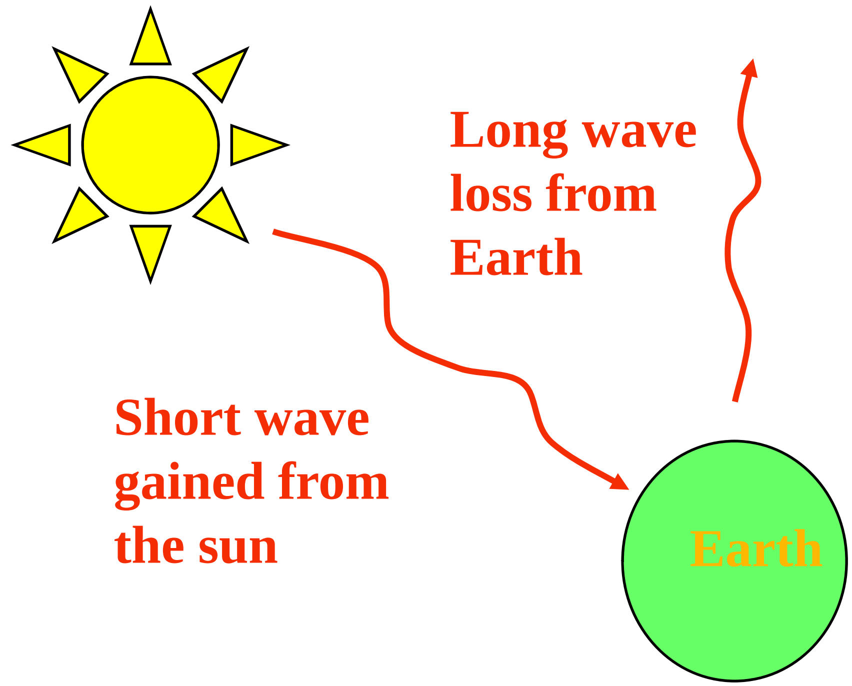
Methods of Heat Transfer

Conduction- from molecule to molecule

Convection - by movement of heated air

Radiation - energy passing from one object to another without a connecting medium

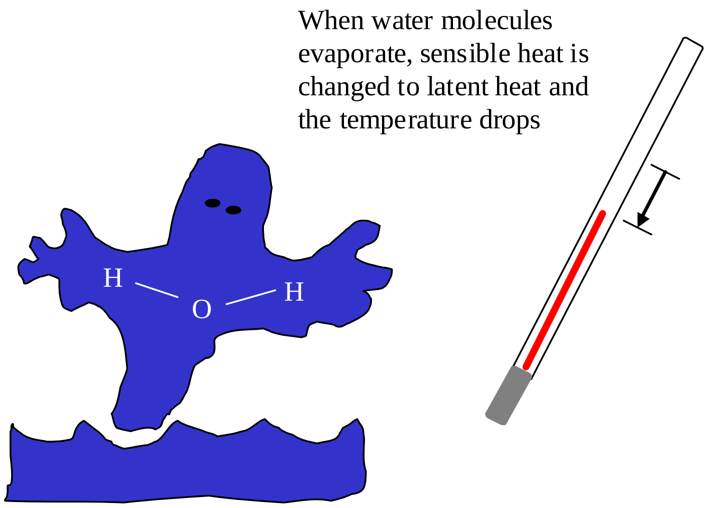


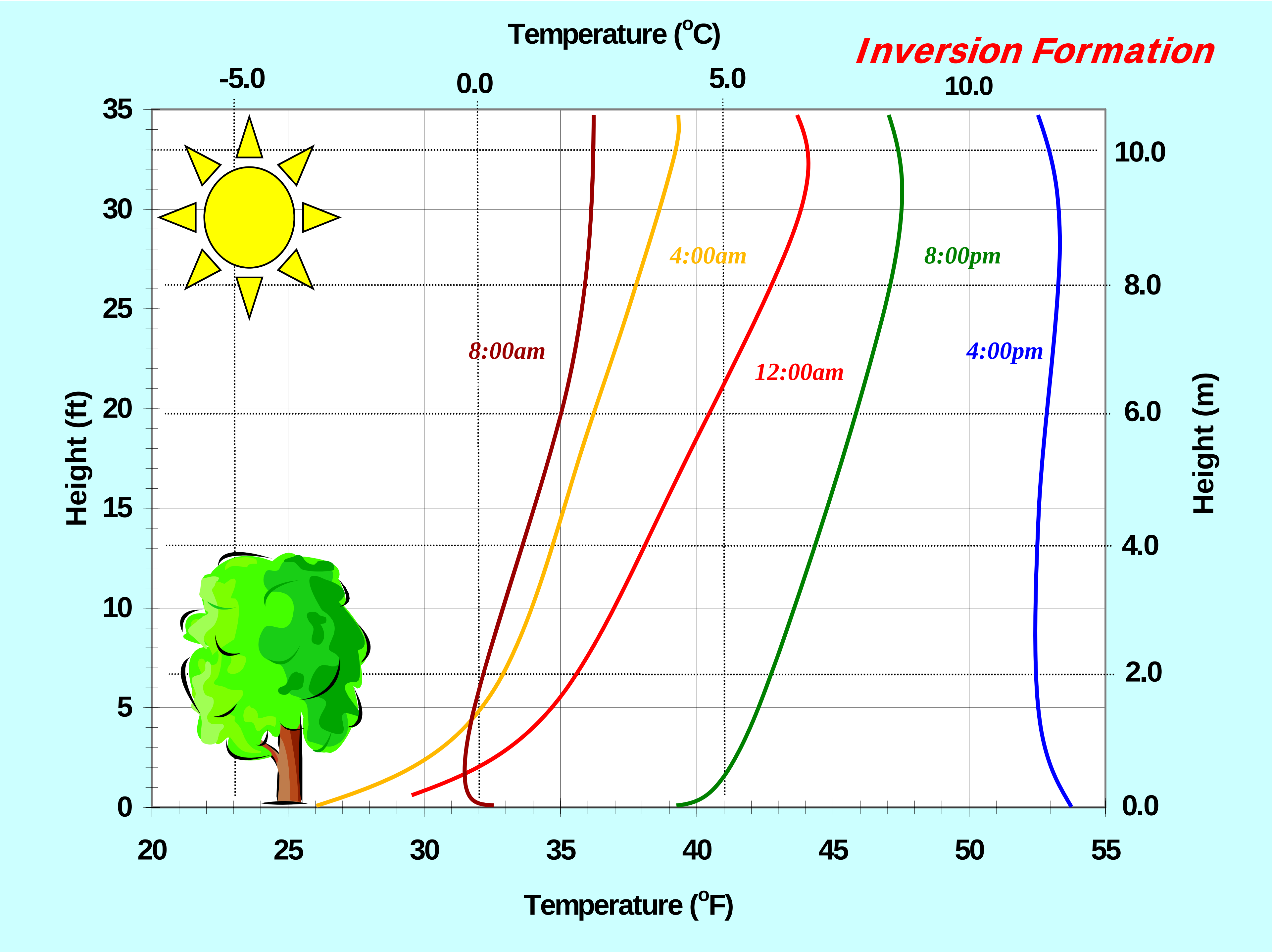


Methods of Heat Transfer

Latent Heat - Chemical Heat

Energy is released to the environment as liquid water cools and freezes. Energy is removed from the environment if liquid water evaporates!




Inversion Formation
Temperature (°C)
-5.0
0.0
5.0
10.0
35
30
25
20
15
10
5
0
Height (ft)
10.0
8.0
6.0
4.0
2.0
0.0
Height (m)
8:00am
4:00am
12:00am
8:00pm
4:00pm
20
25
30
35
40
45
50
55
Temperature (°F)

Passive Protection

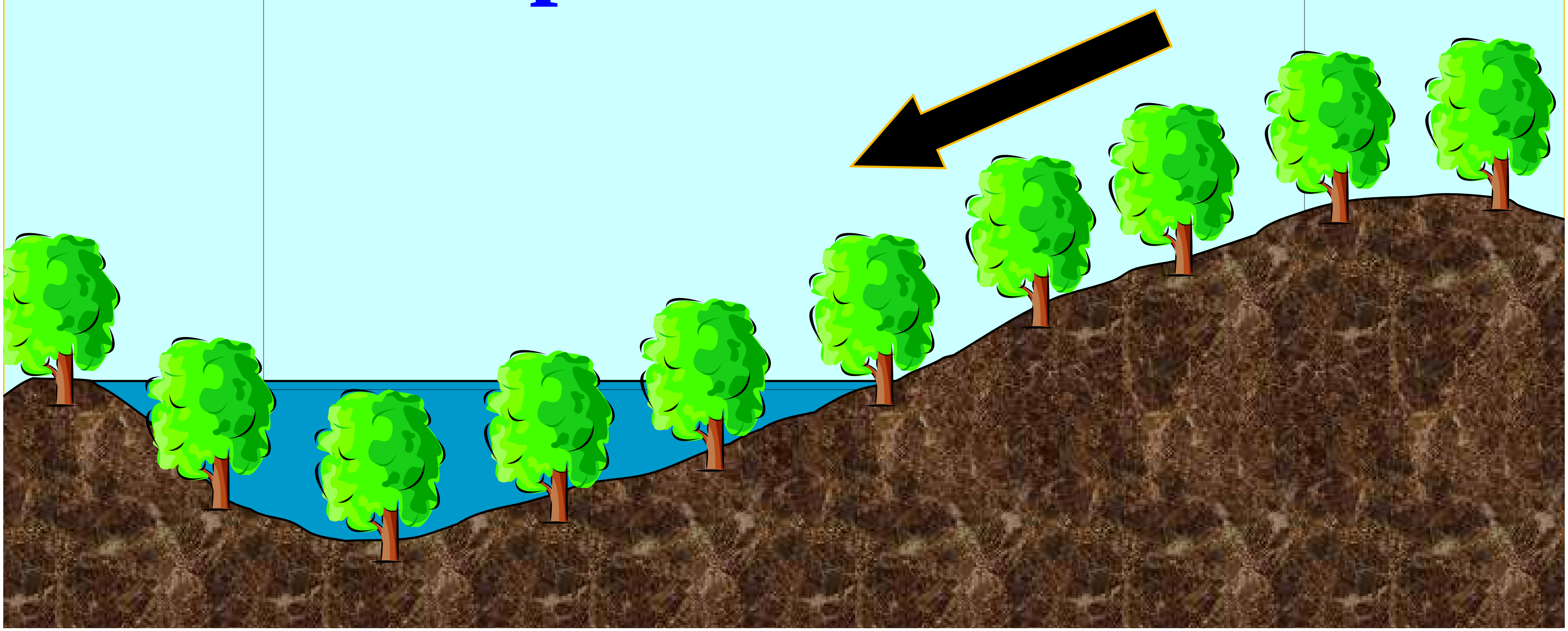
- **Bacteria Control**
- **Site Selection**
- **Soil Water Content**
- **Ground Cover**

Control of INA Bacteria

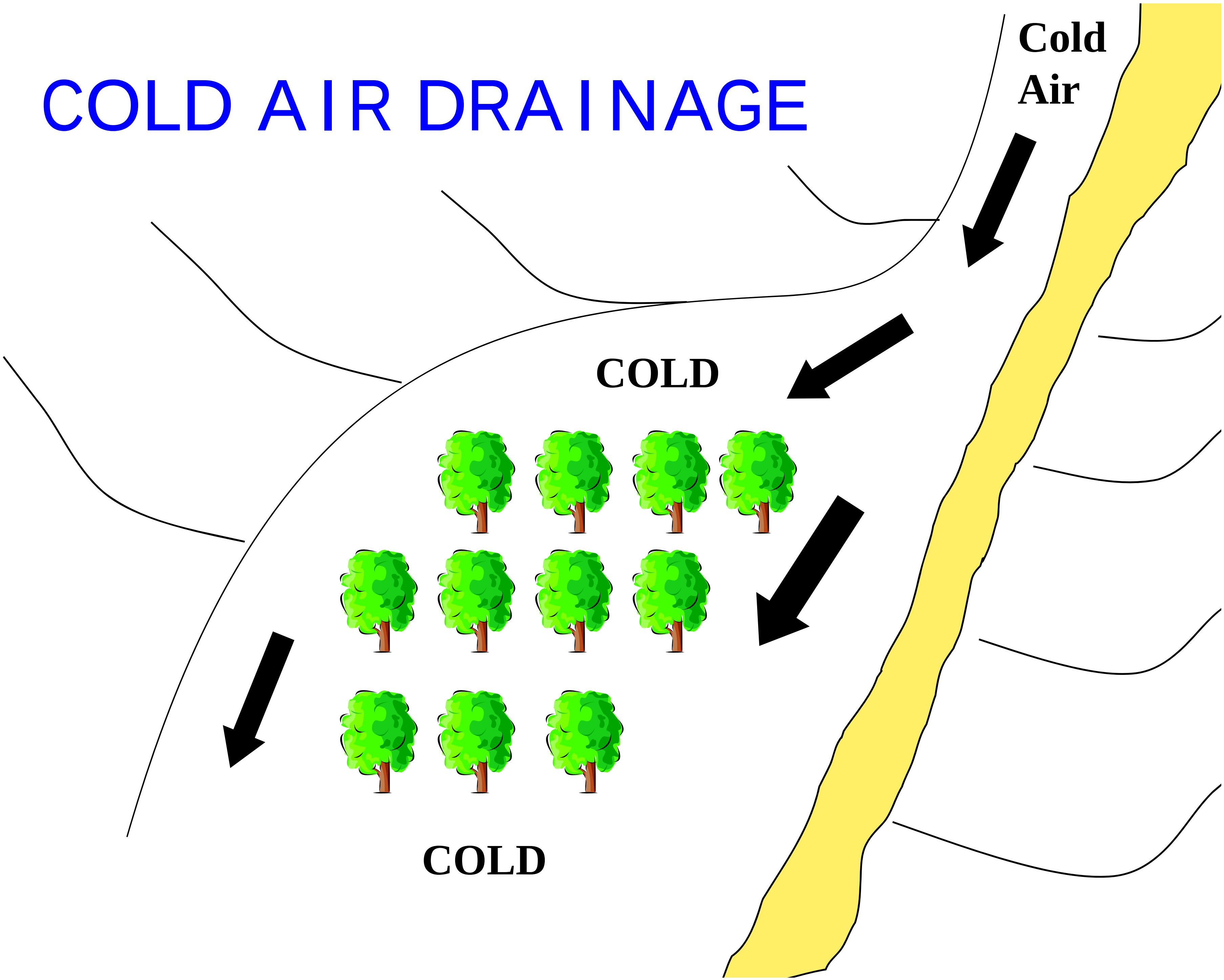
- Kill the Bacteria
- Competitive Bacteria
- Remove Ground Cover

Site Selection

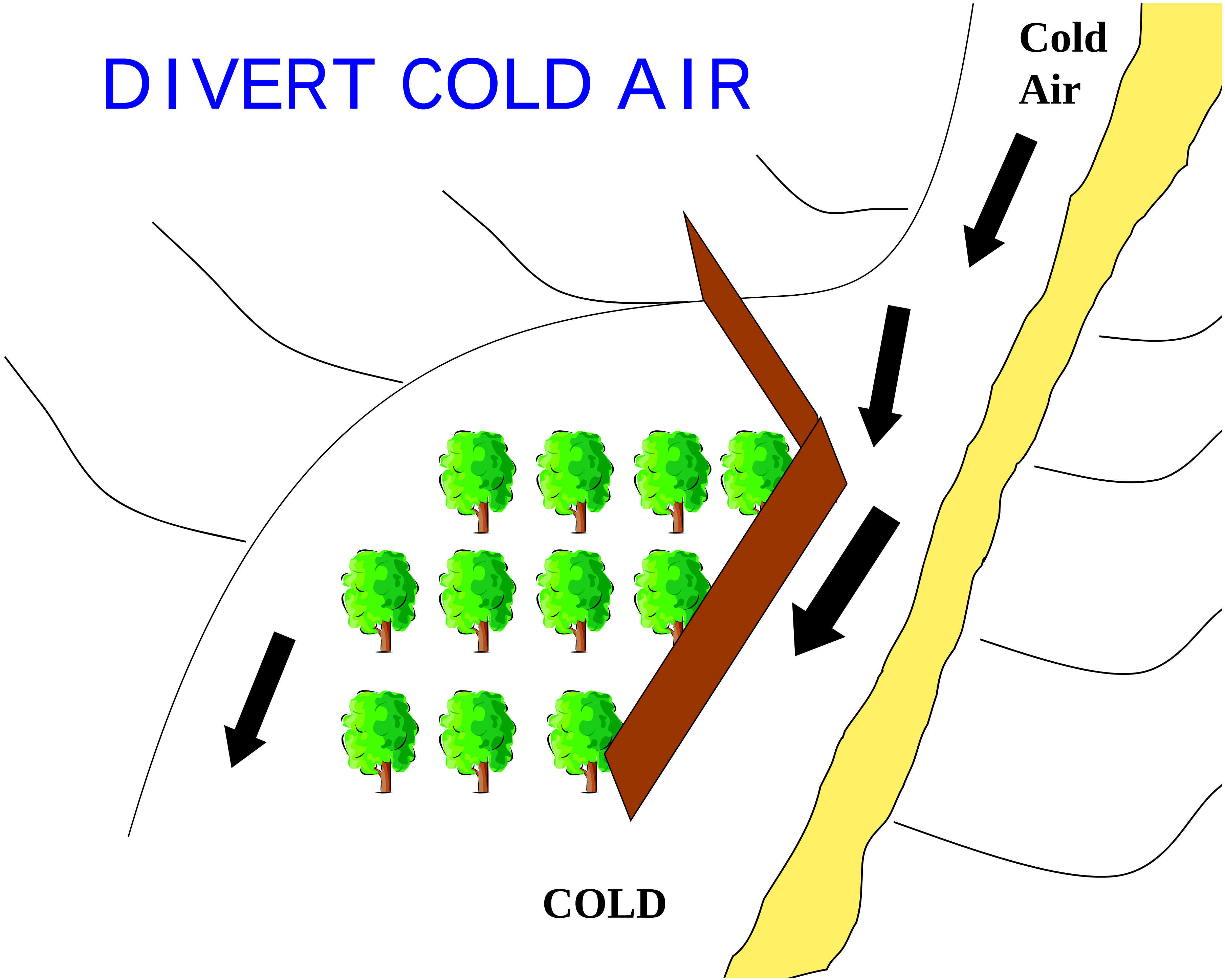
Cold Air Drains to Low Spots



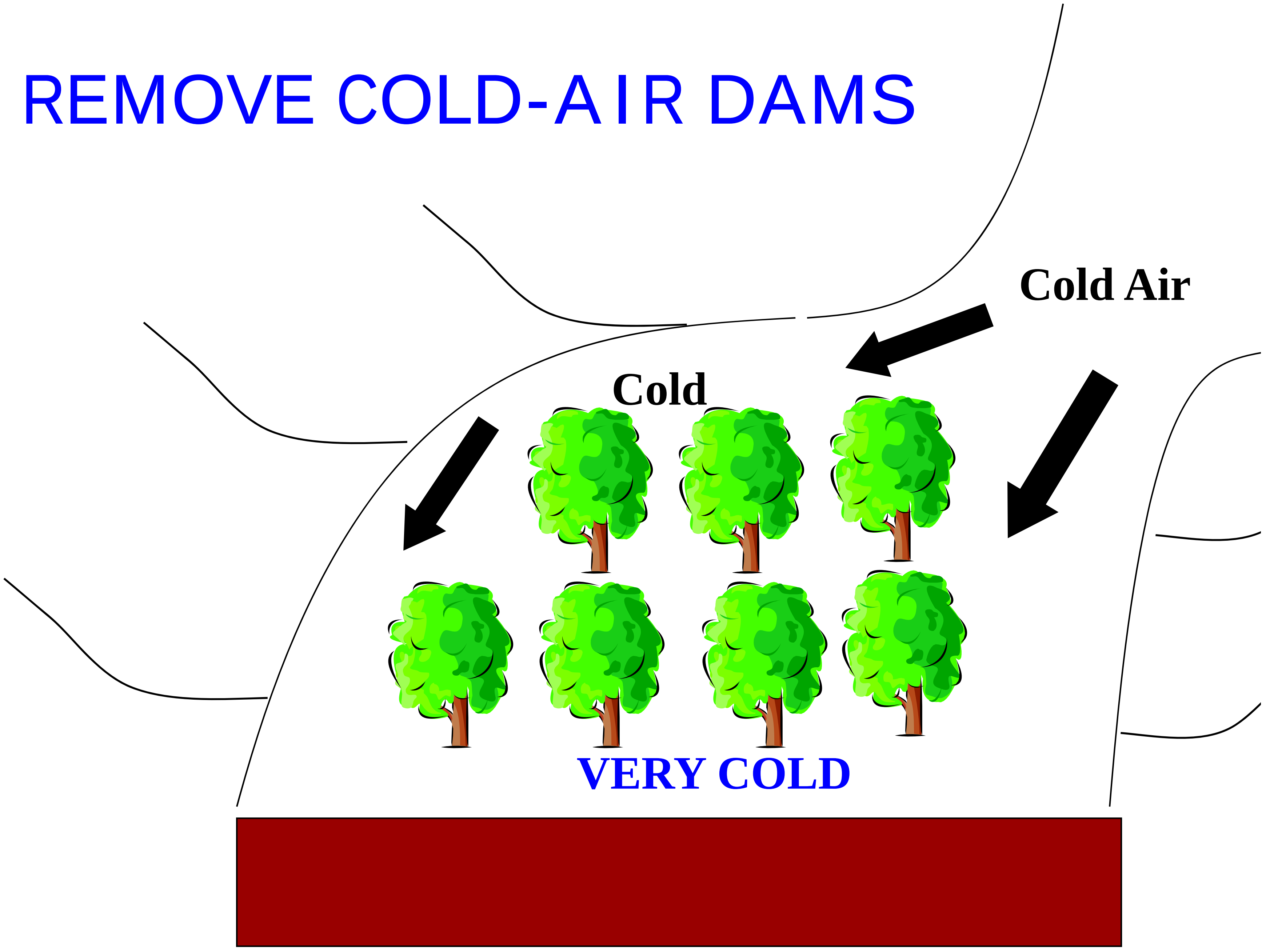
COLD AIR DRAINAGE



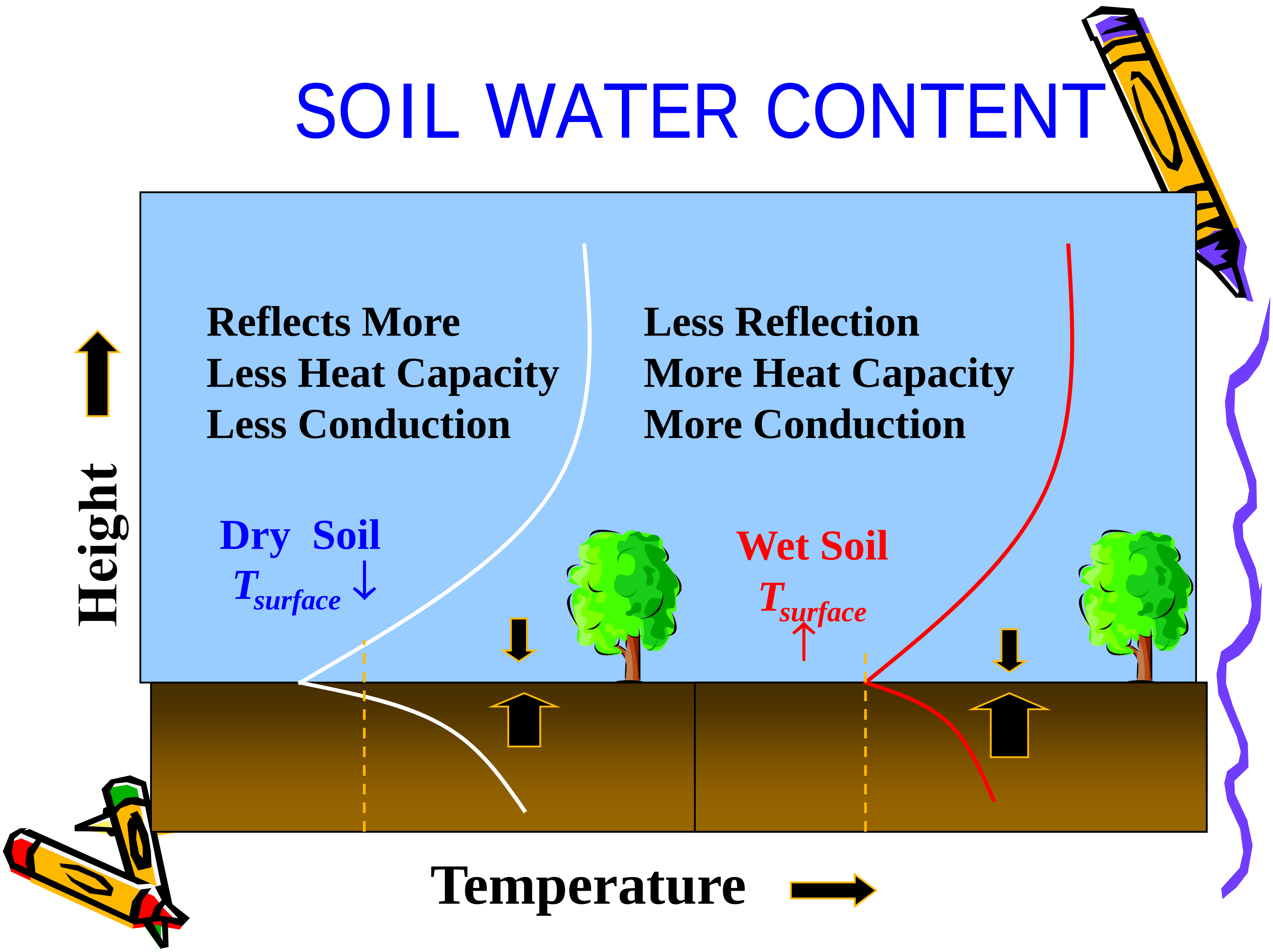
DIVERT COLD AIR

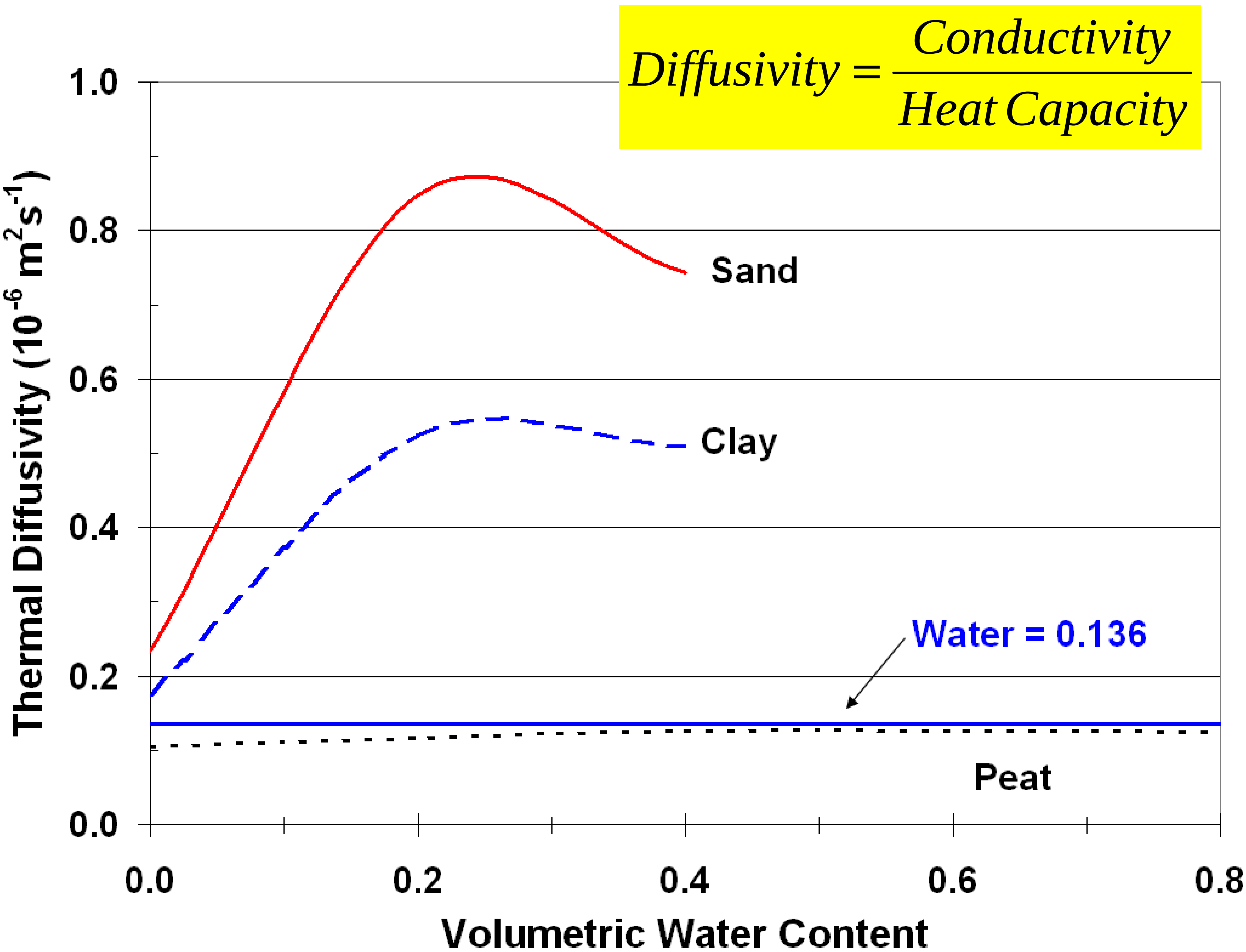


REMOVE COLD-AIR DAMS



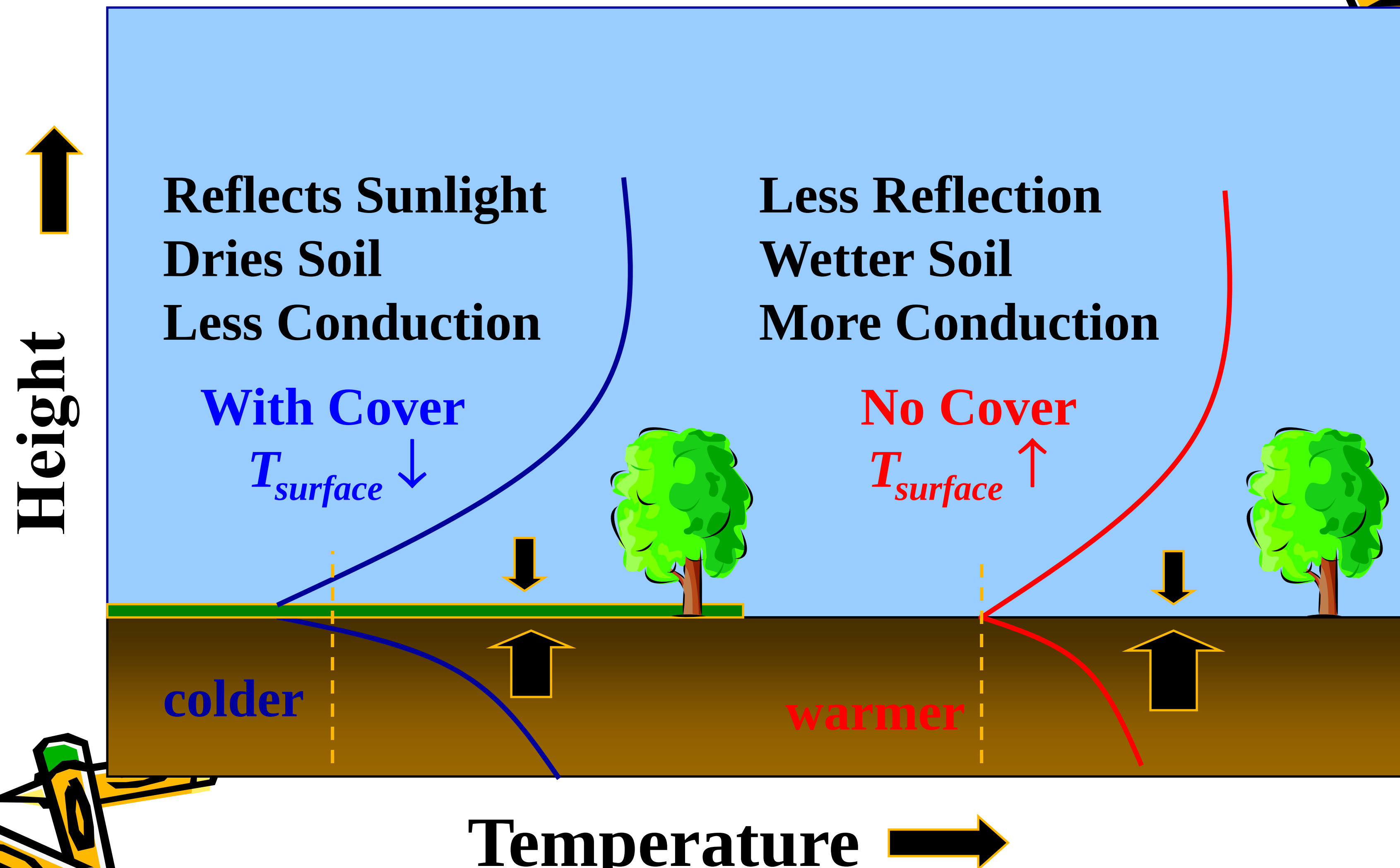
SOIL WATER CONTENT





$$Diffusivity = \frac{Conductivity}{Heat\ Capacity}$$
Sand
Clay
Water = 0.136
Peat
Thermal Diffusivity (10^{-6} $m^2 s^{-1}$)
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
Volumetric Water Content

COVER CROP



Height
Reflects Sunlight
Dries Soil
Less Conduction
With Cover
$T_{surface}$ ↓
Less Reflection
Wetter Soil
More Conduction
No Cover
$T_{surface}$ ↑
colder
warmer
Temperature

Active Protection

- Sprinklers
- Heaters
- Surface Water
- Wind Machines
- Helicopters

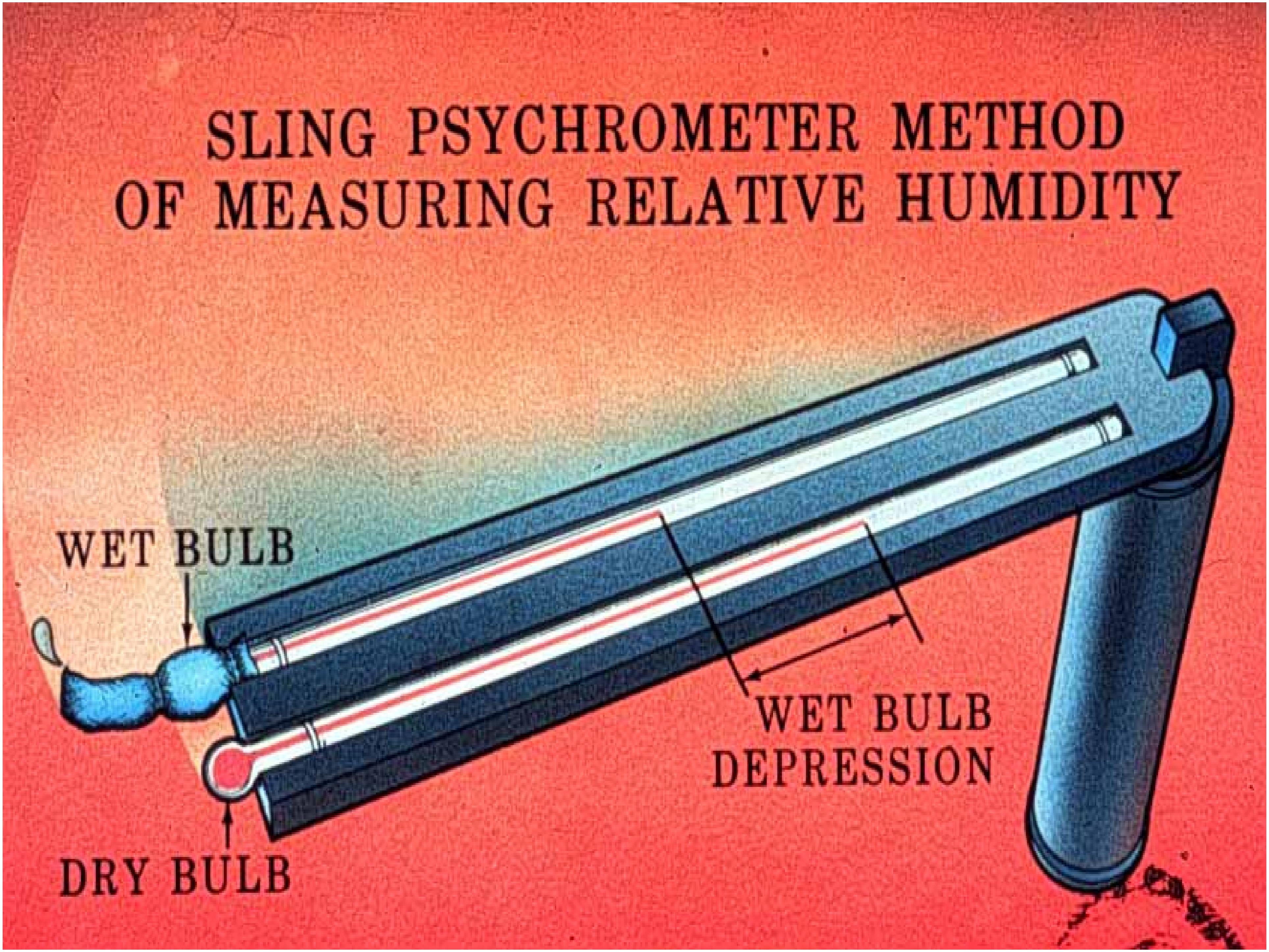
Sprinklers

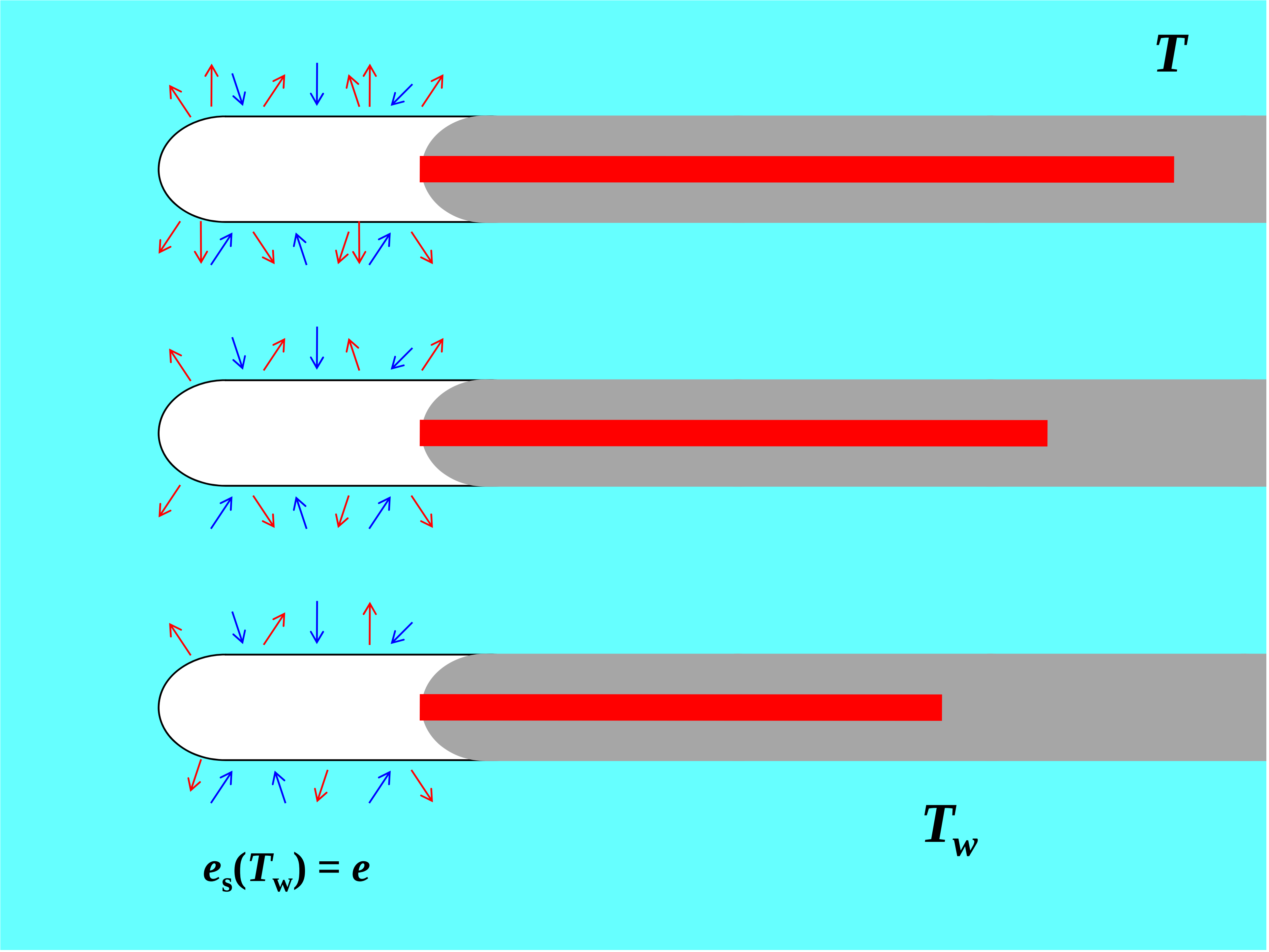
- **Heat from freezing water**
- **More energy from freezing than lost to evaporation**
  - **Dew pt ↓& Wind Spd↑ ⇒Evap↑**
- **Start & stop based on T_{wet}**
  - $T_{wet} > T_{crit}$

Energy Exchange

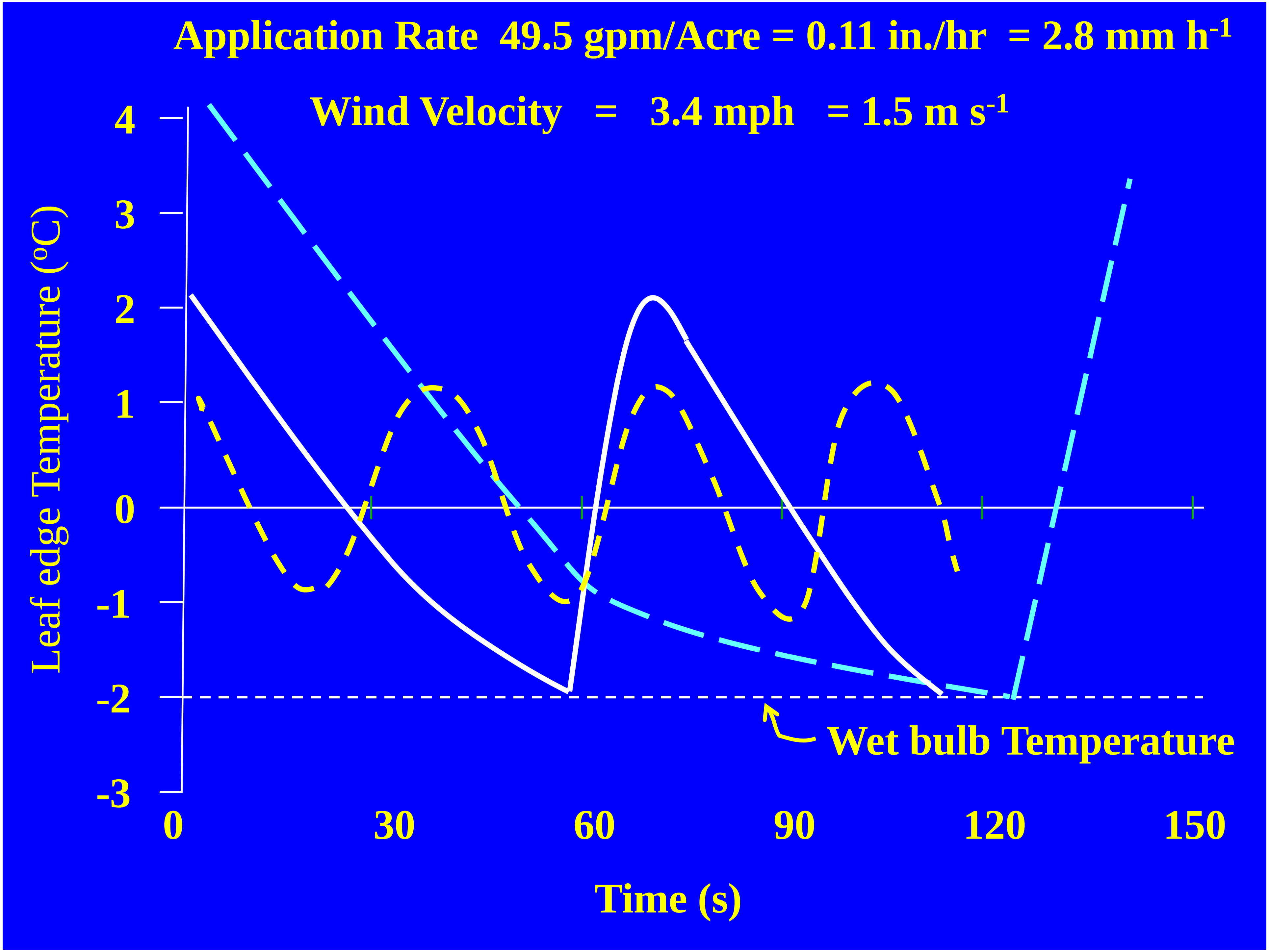
Process	cal g^{-1}
20^{o}C to 0^{o}C (68^{o}F to 32^{o}F)	20
Freezing at 0^{o}C (32^{o}F)	80
Evaporation	-597


Cool and Freeze 6 × Evaporation.
Ice should be clear and dripping wet


SLING PSYCHROMETER METHOD
OF MEASURING RELATIVE HUMIDITY
WET BULB
WET BULB
DEPRESSION
DRY BULB



T
T_w
e_s(T_w) = e



Application Rate 49.5 gpm/Acre = 0.11 in./hr = 2.8 mm h-1
Wind Velocity = 3.4 mph = 1.5 m s-1
Leaf edge Temperature (oC)
4
3
2
1
0
-1
-2
-3
0
30
60
90
120
150
Time (s)
Wet bulb Temperature

Typical Impact Sprinkler Application Rates Wine Grapes

T_{min}	Wind Speed	30 s	60 s
°F	mph	gpm A^{-1}	gpm A^{-1}
28.9	0.0-1.1	36.0	45.0
26.1	0.0-1.1	49.5	58.5
23.0	0.0-1.1	67.5	76.5
28.9	2.0-3.1	45.0	54.0
26.1	2.0-3.1	58.5	67.5
23.0	2.0-3.1	81.0	90.0

Sprinklers

Impact

Targeted

Targeted Vs Impact

Sprinklers	gpm A^{-1}
Targeted	15.0
Impact	55.1

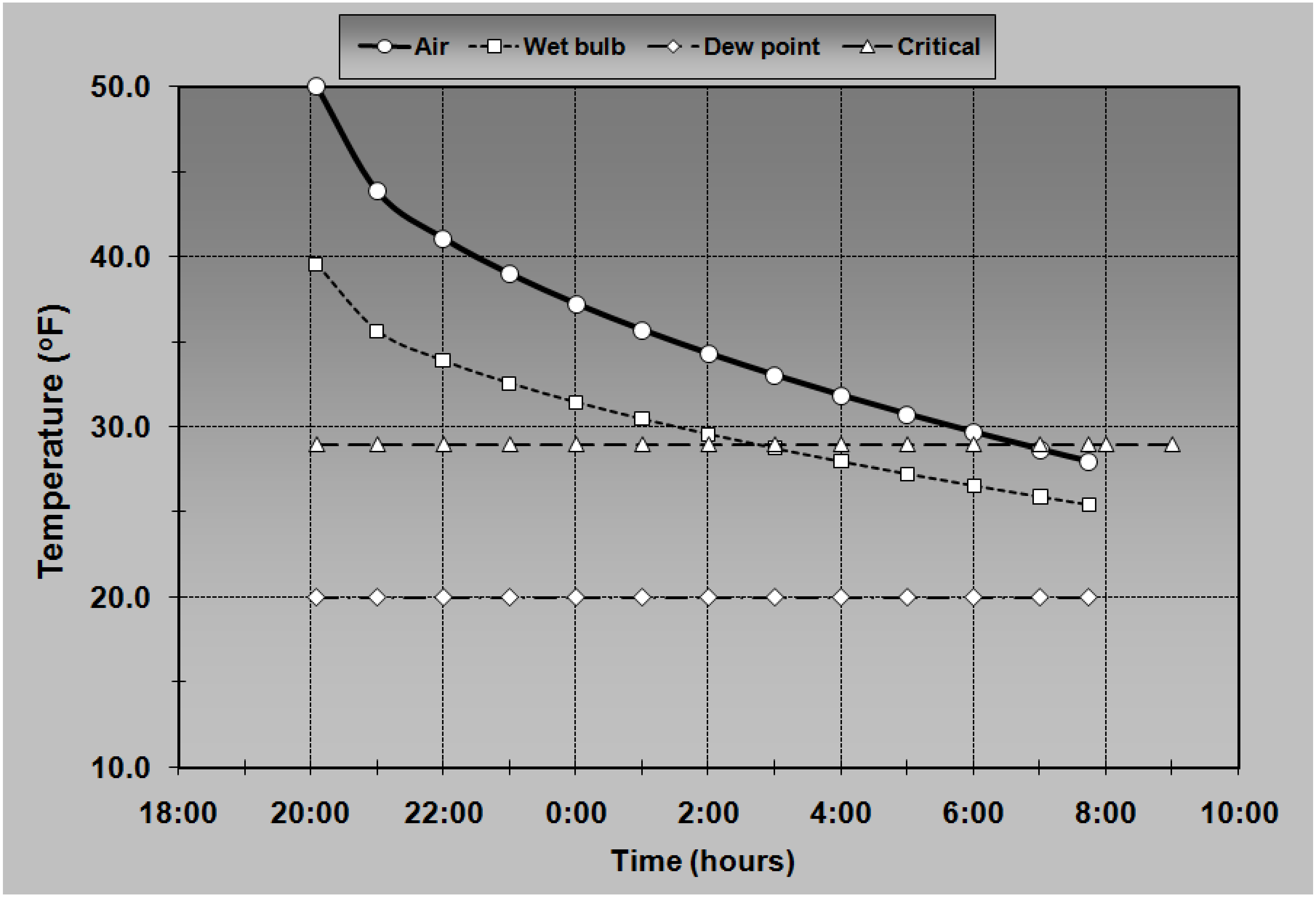
Equal protection at 21.6^{o}F (-5.8^{o}C)

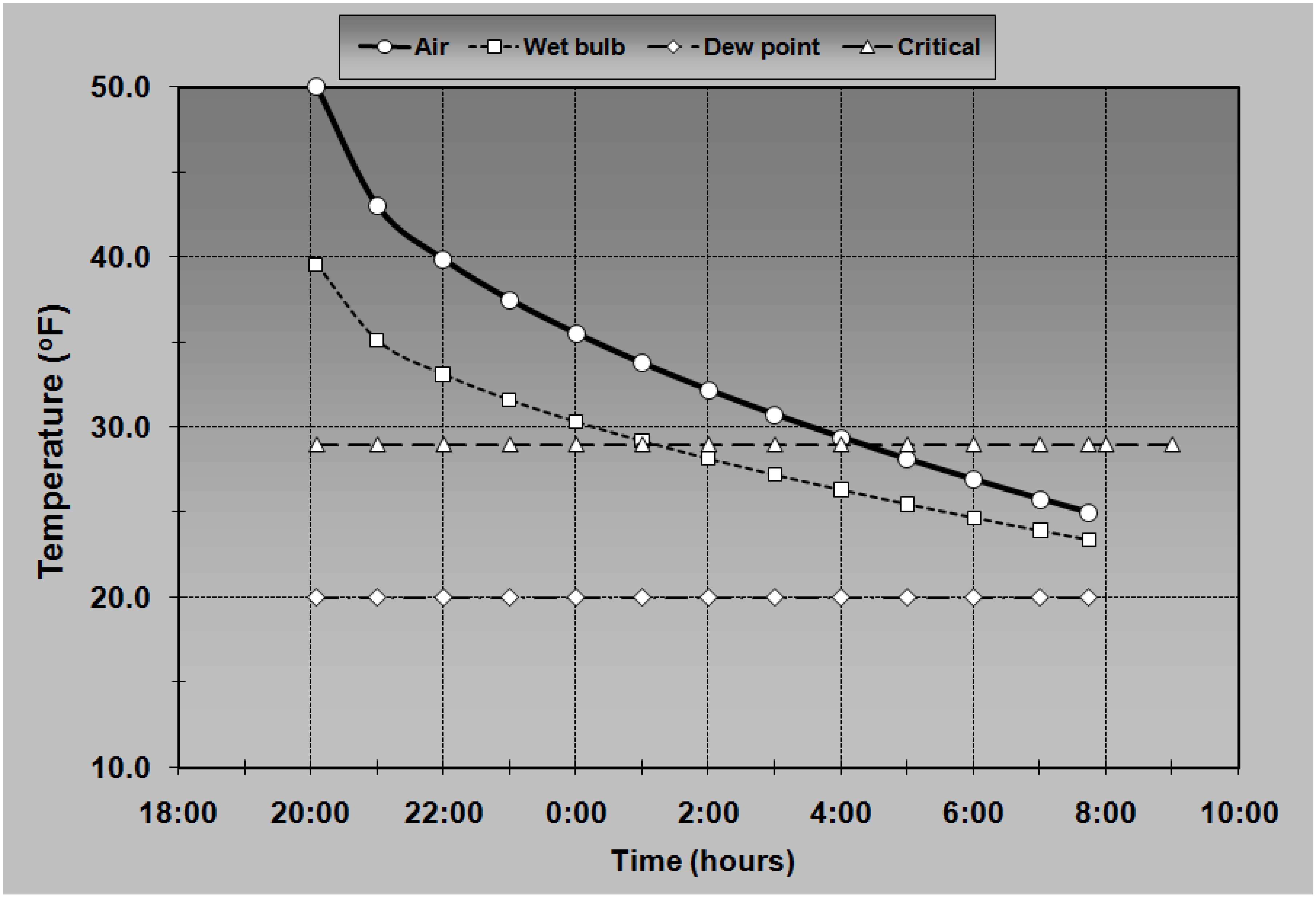
Higher cost and more labor to keep the sprinklers properly oriented.

Fetzer (near Monton)

Starting and Stopping

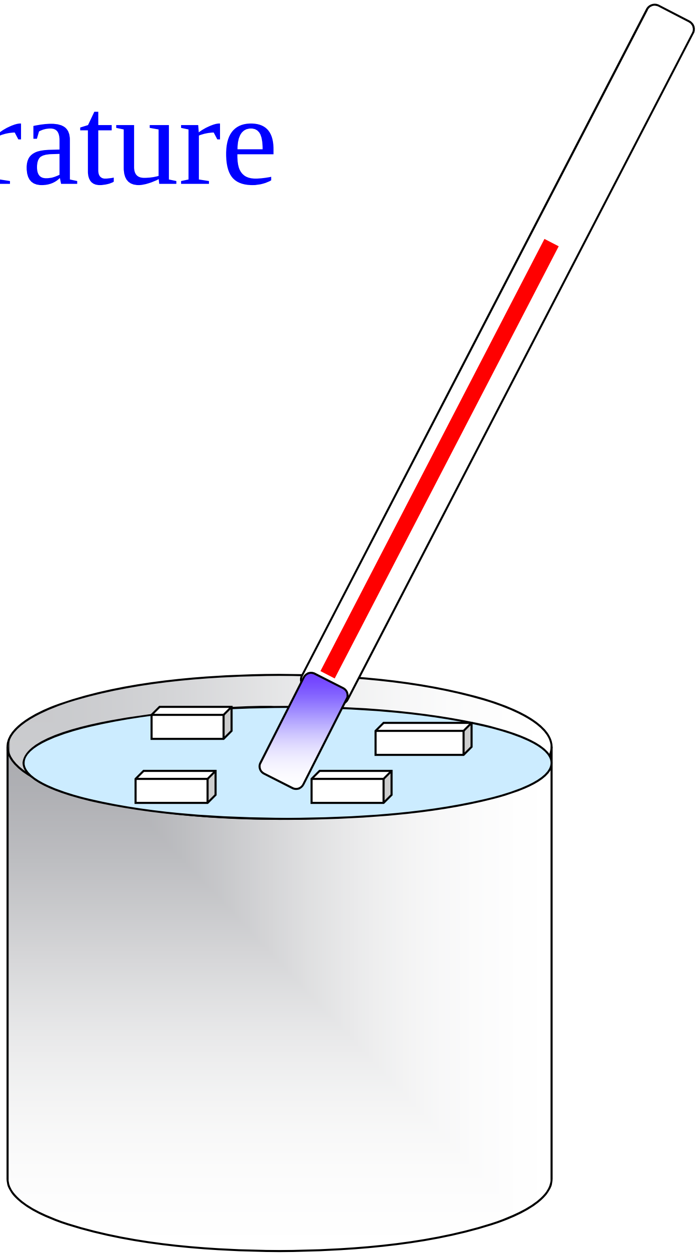
Start and stop when the wet-bulb temperature is higher than the critical damage temperature


Air
Wet bulb
Dew point
Critical
50.0
40.0
30.0
20.0
10.0
Temperature (°F)
18:00
20:00
22:00
0:00
2:00
4:00
6:00
8:00
10:00
Time (hours)


Air
Wet bulb
Dew point
Critical
50.0
40.0
30.0
20.0
10.0
Temperature (°F)
18:00
20:00
22:00
0:00
2:00
4:00
6:00
8:00
10:00
Time (hours)

Dew point Temperature

Slowly add ice cubes to the water to lower the can temperature. Stir the water with a thermometer while adding the ice cubes to insure the same can and water temperature. When condensation occurs, note the dew point temperature.



Select a wet-bulb equal to the critical damage temperature and select the start and stop air temperature corresponding to the dew-point.

Dew-point	Wet-bulb Temperature (^oF)					
^oF	**23.0**	**24.8**	**26.6**	**28.4**	**30.2**	**32.0**
32.0						32.0
30.2					30.2	33.3
28.4				28.4	31.3	34.3
26.6			26.6	29.5	32.4	35.4
24.8		24.8	27.5	30.4	33.4	36.3
23.0	23.0	25.7	28.6	31.3	34.3	37.2
21.2	23.9	26.6	29.3	32.2	35.2	38.1
19.4	24.6	27.3	30.2	33.1	36.0	39.0
17.6	25.5	28.2	30.9	33.8	36.7	39.7
15.8	26.1	28.9	31.6	34.5	37.4	40.5

SURFACE IRRIGATION

- Flood or Furrow
- Heat is released as the Water Cools
- Avoid freezing

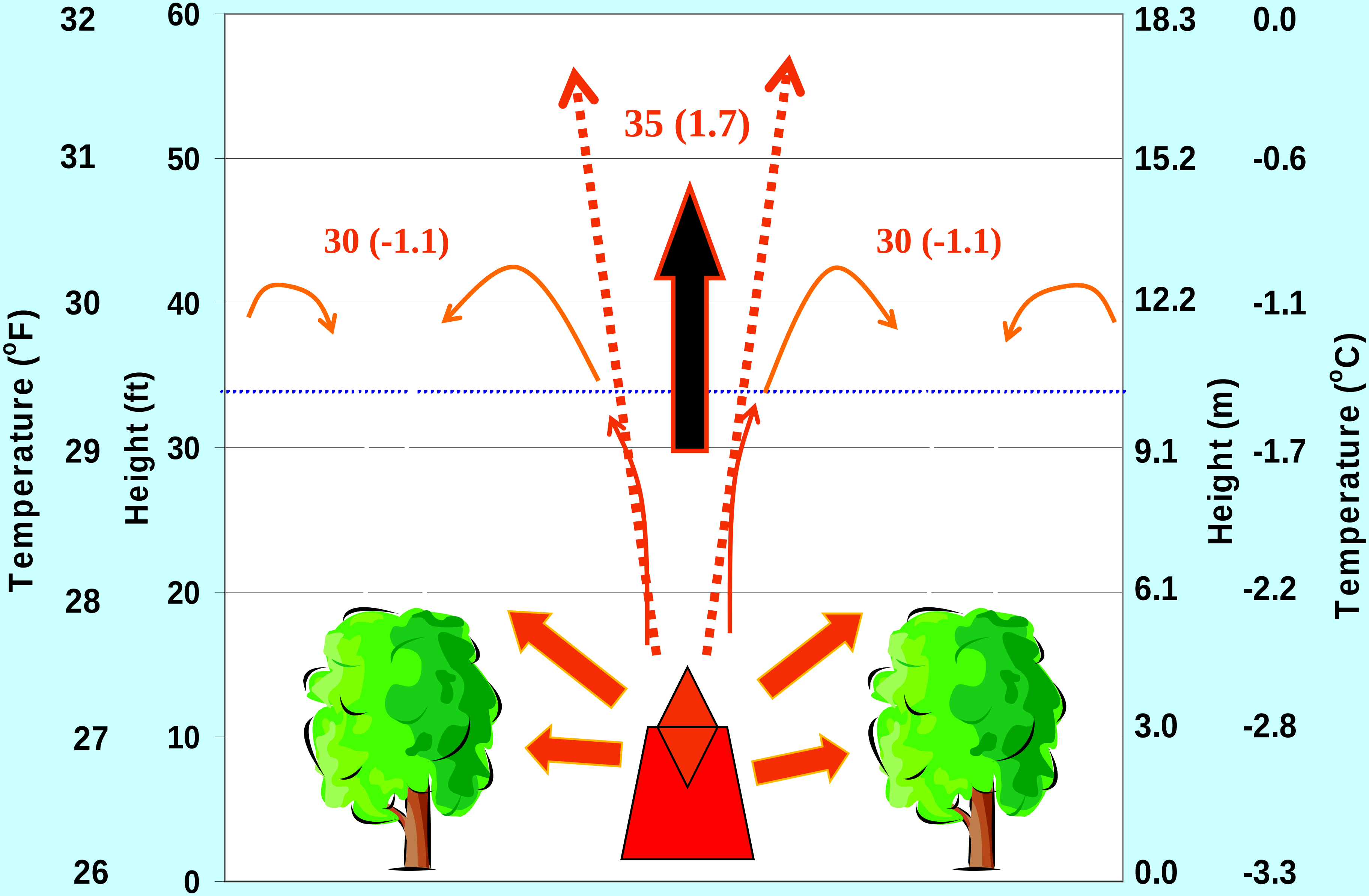
SURFACE IRRIGATION

- **Start early enough**
- **Do not reuse cold water**
- **Run water near tree skirts**
- **Maximize the area**
- **Good flow rate**

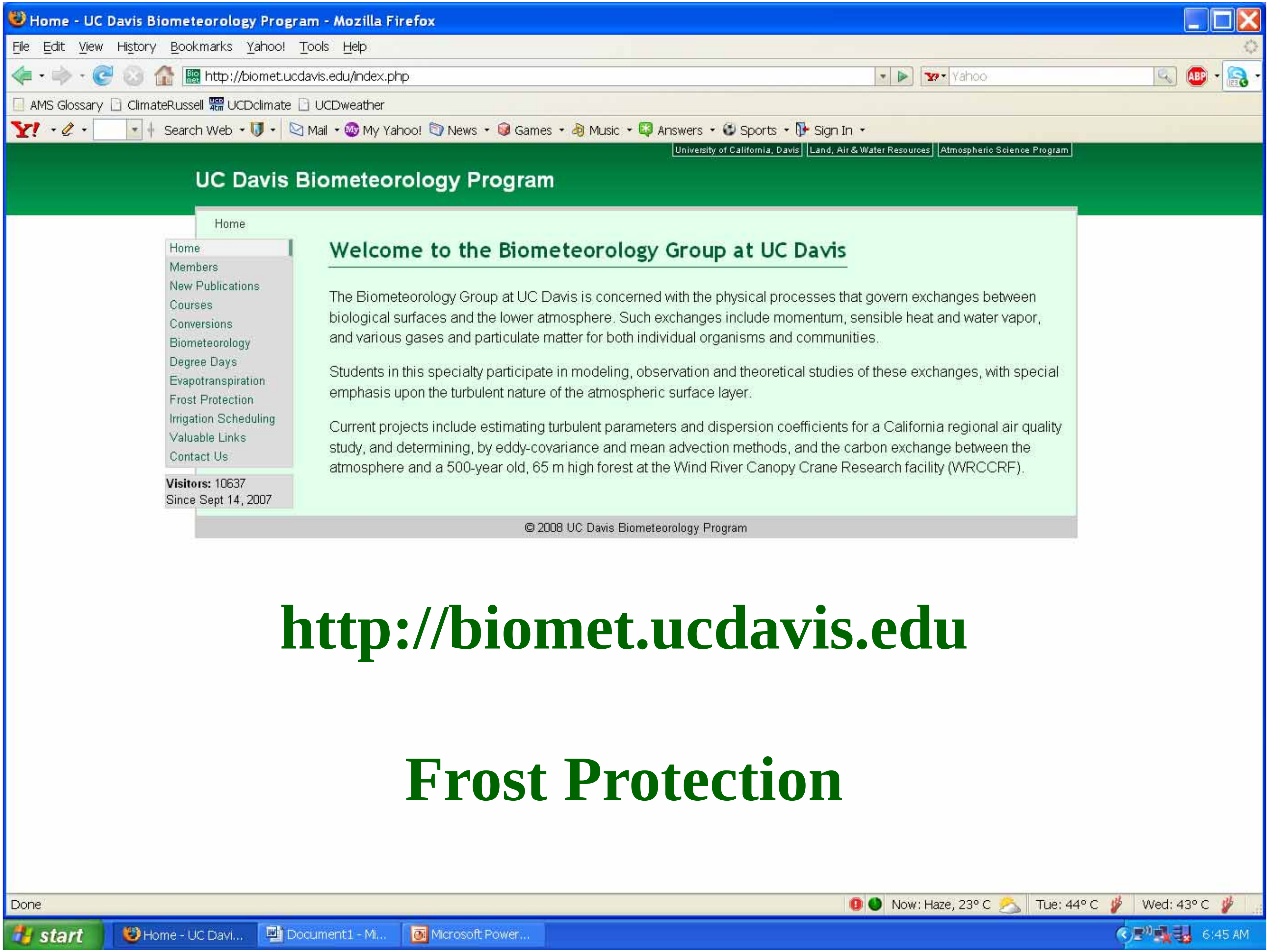
Heaters

- Radiation
- Heats the air
- Convective currents

Heaters



Temperature (°F)
32
31
30
29
28
27
26
Height (ft)
60
50
40
30
20
10
0
35 (1.7)
30 (-1.1)
30 (-1.1)
Height (m)
18.3
15.2
12.2
9.1
6.1
3.0
0.0
Temperature (°C)
0.0
-0.6
-1.1
-1.7
-2.2
-2.8
-3.3



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Frost Protection

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Frost Protection

When to Turn Sprinklers On and Off for Frost Protection

FP001 Quick Answer—This quick answer provides information on using a psychrometer or temperature and dew point data to determine when to start and start sprinklers for frost protection.

Predicting Temperature Trends during Freeze Nights

FP002 Quick Answer—This quick answer gives a method for predicting the change in temperature during a calm, radiation freeze night.

A Simple Method to Measure the Dew Point Temperature

FP003 Quick Answer—This quick answer provides information on how to measure the dew point for use in estimating minimum temperature and for starting and stopping sprinklers for frost protection.

Sprinkler Application Rates for Freeze Protection

FP004 Quick Answer—This quick answer provides information on the sprinkler application (precipitation) rates needed to protect crops from freezing.

Principles of Frost Protection

FP005 Quick Answer—This quick answer provides information on the general principles of well-known frost protection methods. A PDF file of the WEB page can be uploaded from this Quick Answer. In addition, a shorter version is available.

Programs for Estimating Frost Night Minimum Temperatures and Temperature Trends (new 7 Mar 2007)

The FFST Excel application programs FFST_E.xls and FFST_M.xls are available from this link. The FFST application helps users to determine an empirical equation for estimating minimum temperatures during radiation frost nights. Note that the program will provide good estimates if there is little or no wind, no significant cold air

The End

Thanks

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