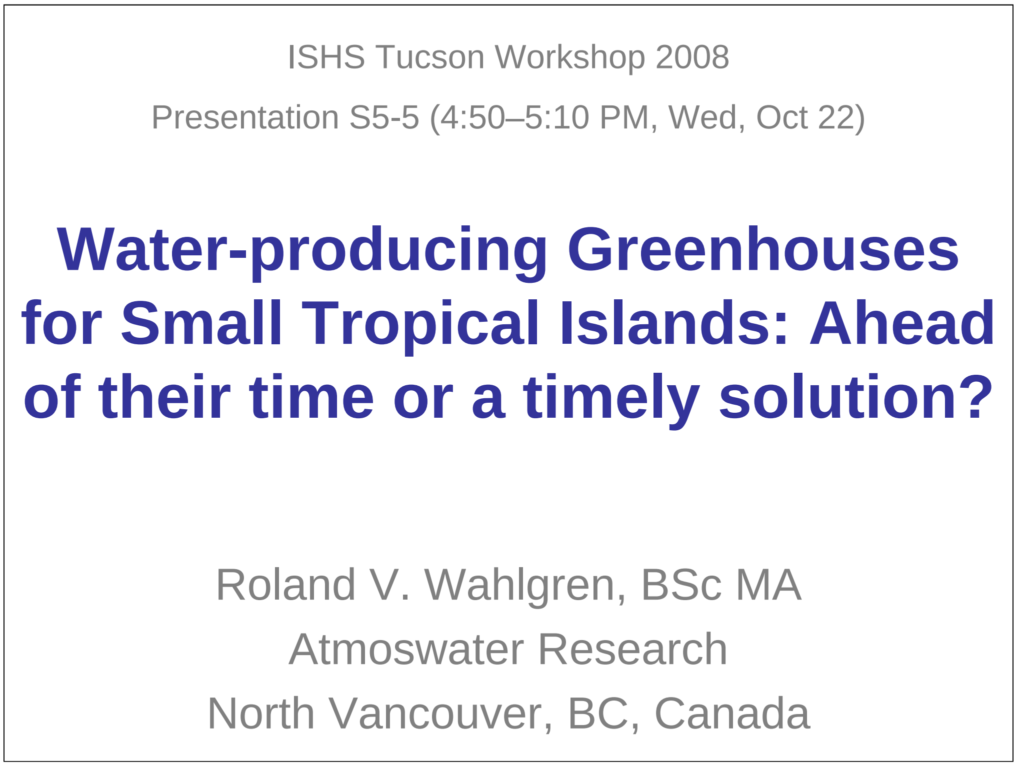


ISHS Tucson Workshop 2008

Presentation S5-5 (4:50–5:10 PM, Wed, Oct 22)

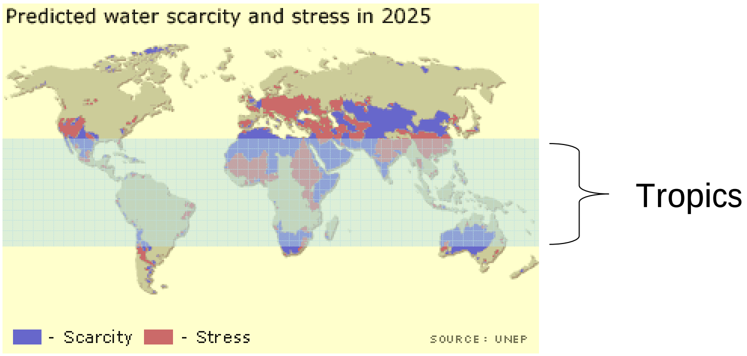
Water-producing Greenhouses for Small Tropical Islands: Ahead of their time or a timely solution?

Roland V. Wahlgren, BSc MA
Atmoswater Research
North Vancouver, BC, Canada

Hi --- I’m Roland Wahlgren. Welcome to my talk in which I’ll explain how to extract water vapour from the air to irrigate plants in a hydroponic greenhouse and produce drinking water.

This talk complements my article in the workshop proceedings. I’ll put a copy of this slide show on my web site.

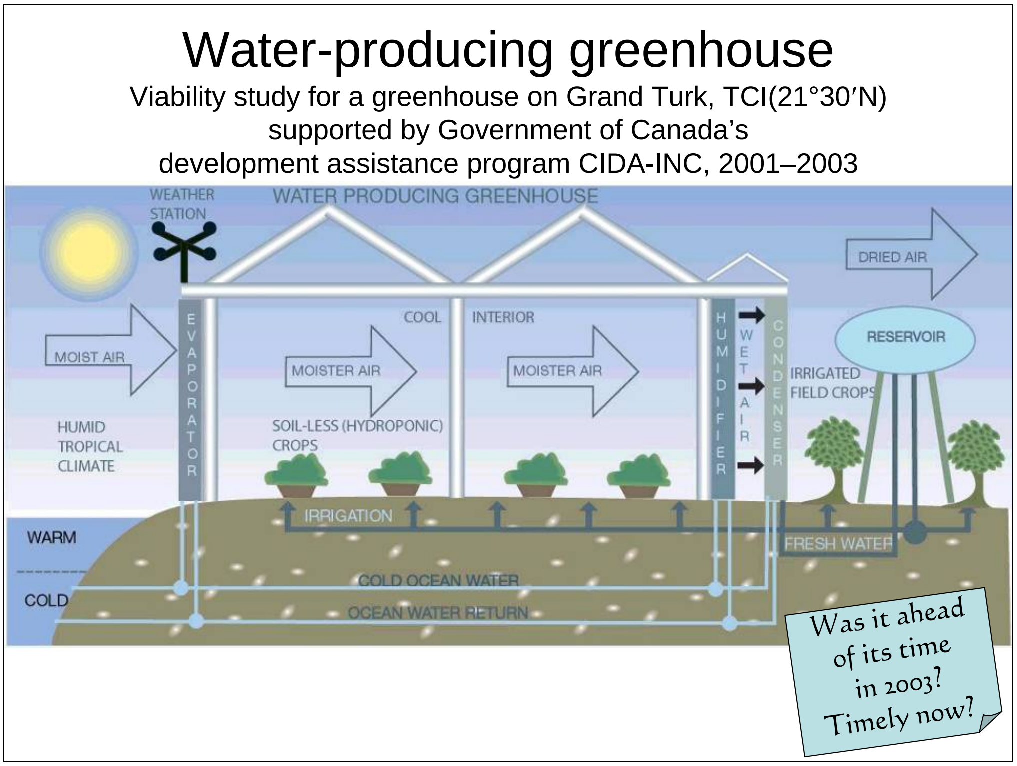
Water security plus food security for arid tropical islands



Tropical water-bottling companies are running out of water sources —
Bob Seaman; Sales Manager, Equipment Express (June 2004)

Our goal is to improve water and food security on arid tropical islands and coastlines between latitudes 30 deg N and 30 deg S.

Clean drinking water is becoming scarcer as you can see from the red and blue regions on the map. The quote at the bottom of the slide emphasizes one practical worry.



Water-producing greenhouse

Viability study for a greenhouse on Grand Turk, TCI(21°30′N)
supported by Government of Canada’s
development assistance program CIDA-INC, 2001–2003

Was it ahead
of its time
in 2003?
Timely now?

Water-producing greenhouses can improve water and food security.

My talk is based on information from a viability study for a Water-producing Greenhouse on the island of Grand Turk, Turks and Caicos Islands (21°North latitude). This study was supported by the Government of Canada during 2001-2003. The work remained unpublished until now.

This greenhouse has a cool interior to grow temperate climate hydroponic crops at sea level in the tropics.

The system produces its own irrigation water by extracting moisture from the ambient air ventilating the greenhouse.

The design was possibly ahead of its time 5 years ago but is now a very timely solution.

Gerhard and Worzel (Columbia U.)
Science, 15 September 1967

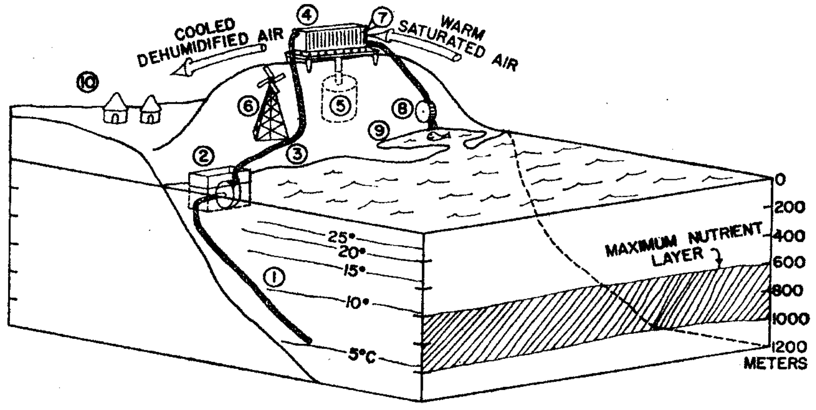
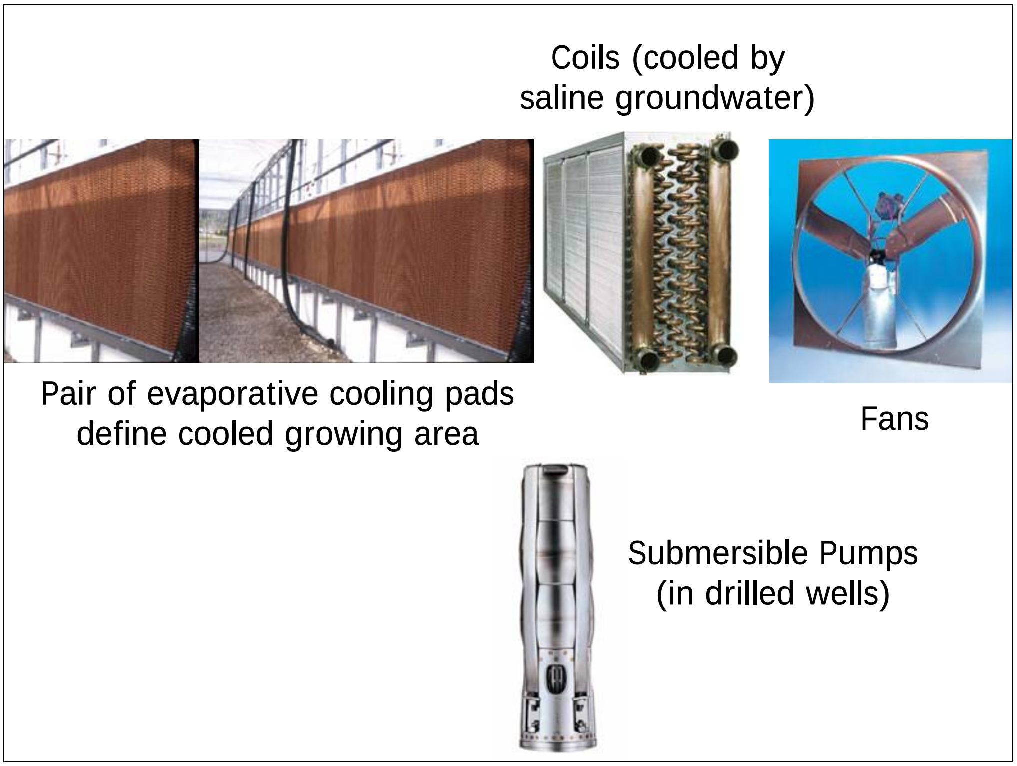


Fig. 2. Proposed water-recovery plant. (1) Large-diameter pipe to deep water; (2) pump; (3) connecting pipe; (4) condenser; (5) freshwater reservoir; (6) windmill electric generator; (7) baffles to direct wind; (8) small turbine to recover water power; (9) lagoon receiving nutrient-rich water for aquiculture; (10) community enjoying cooled dehumidified air.

Nothing under the sun is ever completely new.

This conceptual drawing from 1967 shows how cold, deep ocean water flowing through a dehumidification coil can condense fresh water from the ambient air.



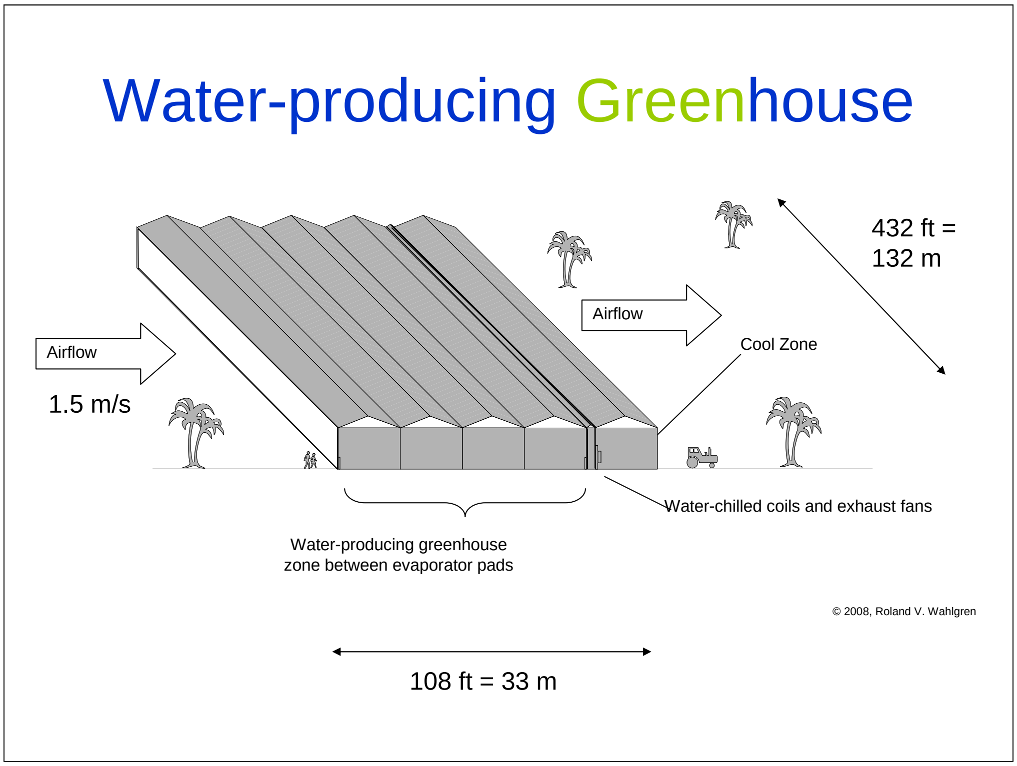
Coils (cooled by saline groundwater)

Pair of evaporative cooling pads define cooled growing area

Fans

Submersible Pumps (in drilled wells)

Here we see a pair of pads defining a cooled growing area. The pads are wetted by saline groundwater pumped up by submersible pumps. The same pumps provide coolant water to the dehumidification coils. Large fans are used to draw air through the system.



Water-producing Greenhouse

This perspective view gives an idea of what a Water-producing Greenhouse would look like.

The fans create an airflow of 1.5 m/s.

The four greenhouse bays to the left contain the growing area between the evaporator pads. The bay on the right is the cool zone, downwind of the fans. The cool zone is where we would grow lettuces and strawberries.

The overall length of the Water-producing Greenhouse is 132 m and the width is 33 m giving a total area of about 1/3 hectare.

Hurricane risk must be considered in the building design as emphasized by the damage caused on Grand Turk by Hurricane Ike in September this year.

Most poly greenhouses are designed to survive Category 1 hurricanes.

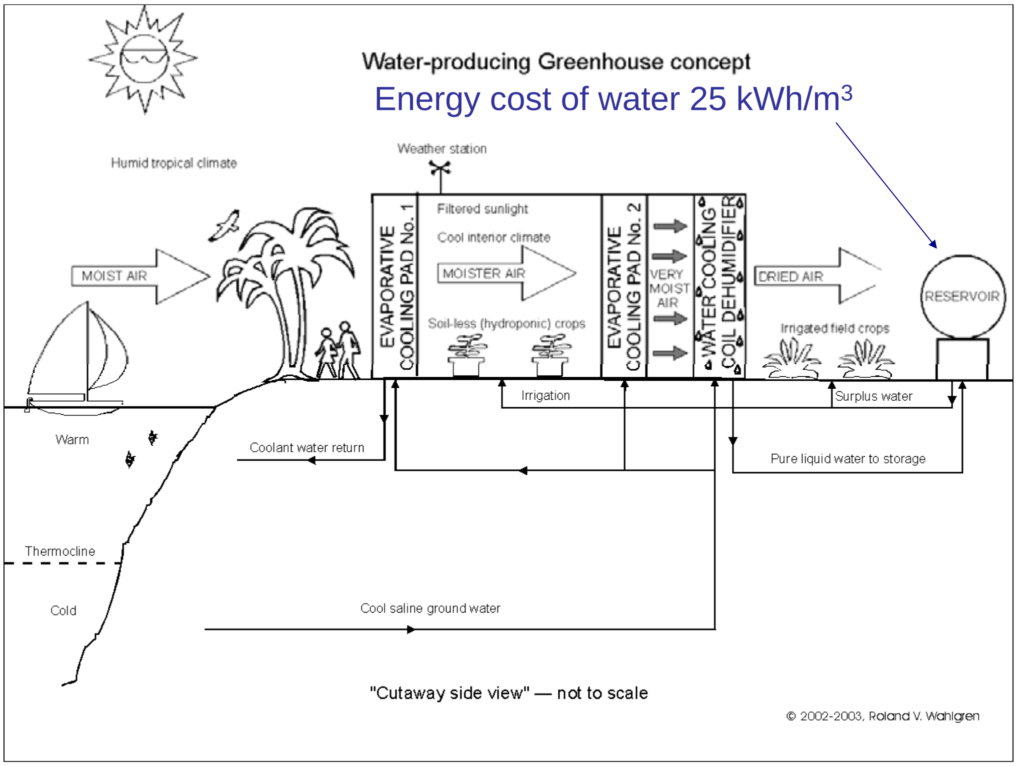
Water-from-air
in Belize City
(17°32′N),
Jan/Feb 2006

Air-cooled compressors
+ Air handling unit

400 kWh/m^3

2500 L/d

We have some experience with water-from-air systems at tropical sites such as Belize (17°North latitude). In 2006 we commissioned a system with air cooled refrigerating compressors that produced 2500 L/d of drinking water. The energy cost of the produced water was 400 kWh/cubic m.



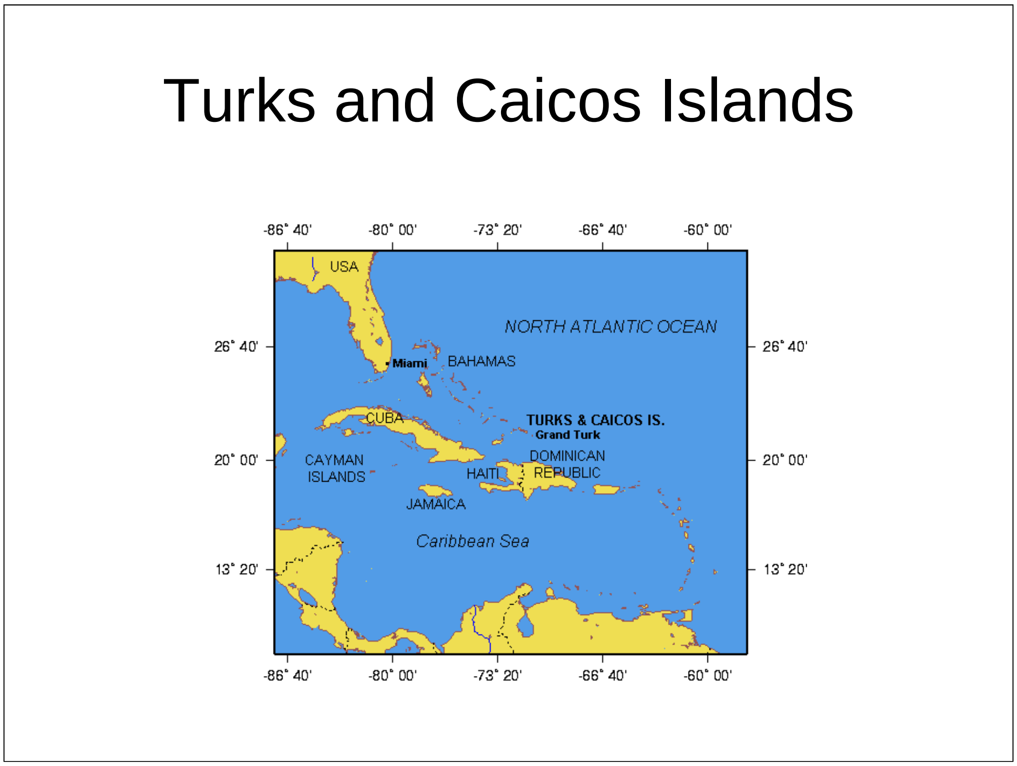
Energy cost of water 25 kWh/m^3

In contrast, the Water-producing Greenhouse would produce potable water at the rate of 200,000 L/d with an energy cost of 25 kWh/cu m. The lower energy cost is possible by avoiding refrigeration technology, using instead natural coolant in the form of 500 m deep saline groundwater or deep cold ocean water.

Here again you see the growing area defined by the evaporator pads over which saline groundwater is trickling. Growing area dry bulb temperature will approximate the wet bulb temperature of the outdoor air.

The dehumidifier coil is collecting fresh water from the moisture in the ventilation air.

Spent water from the coolant coils and evaporator pads is returned to the environment at an appropriate depth so that natural temperature and salinity regimes are not disturbed.

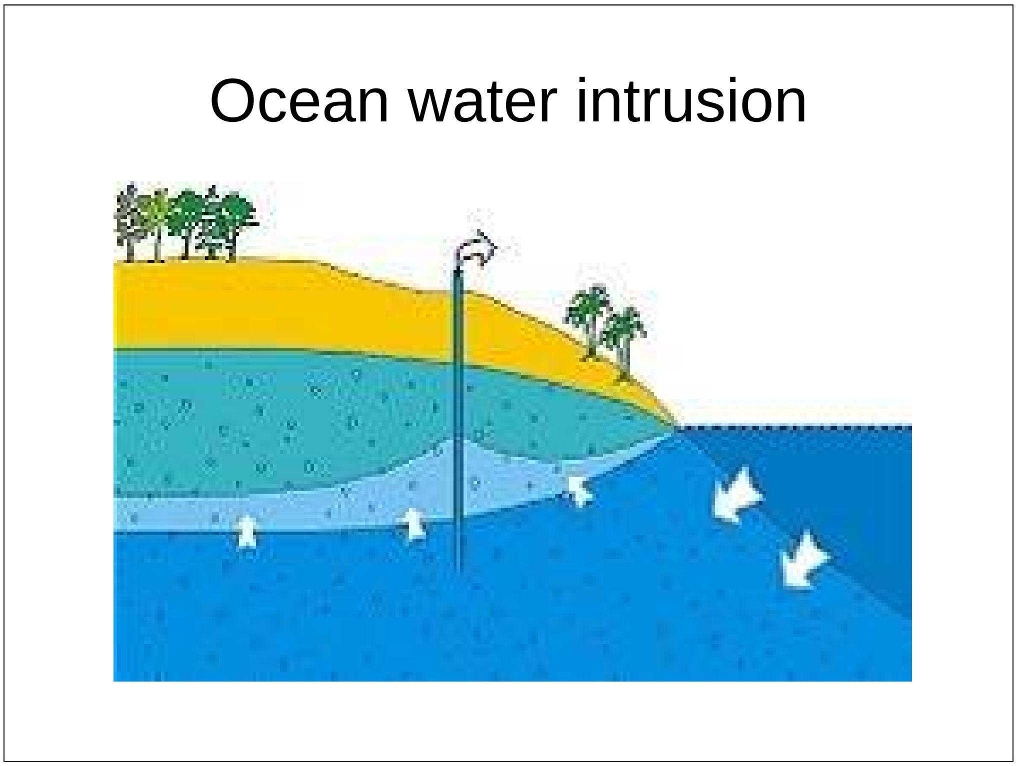


Turks and Caicos Islands

The Turks and Caicos Islands, with a population of 37,000, are a British Overseas Territory situated between the Bahamas and the island of Hispaniola.

Our proposed Water-producing Greenhouse was to be situated on the island of Grand Turk with a population of 3700. Cruise ship visitors total 500,000 per year (about 1400 extra people per day)

Our studies showed that hydroponic irrigation would require less than 10% of the 200,000 L/d daily water production of the Greenhouse. If 190,000 L/d was surplus to irrigation requirements, 50 L/d could be distributed amongst the 3700 residents of Grand Turk. This amount meets personal requirements including drinking, sanitation, bathing, and cooking.



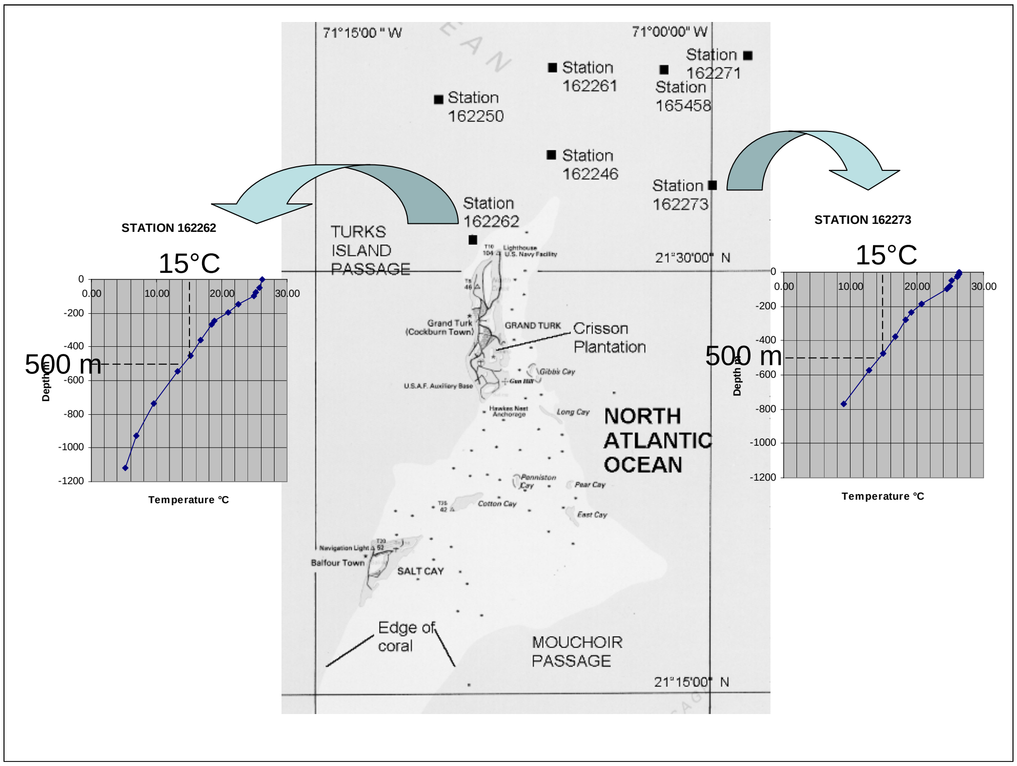
Ocean water intrusion

Many small islands throughout the world consist of carbonate rock which allows ocean water intrusion.

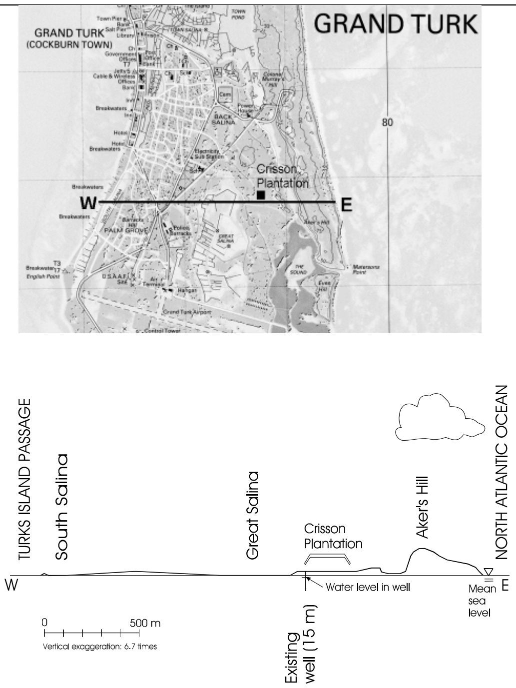
On carbonate islands such as the Bahamas, cold water for air conditioning spaces in hotels and other large buildings is regularly obtained by drilling deep wells, 100’s of metres deep, into saline groundwater. This can be done without disturbing freshwater lenses overlying the saline groundwater.

This is a view from the island of Grand Turk, looking west over the proposed Greenhouse site, known as Crisson Plantation.

An open air hydroponics operation used to occupy part of the site. Irrigation water was obtained from a 15 m deep well into saline groundwater. The salinity was about the same as ocean water. This water was desalinated by reverse osmosis before being applied to the plants.

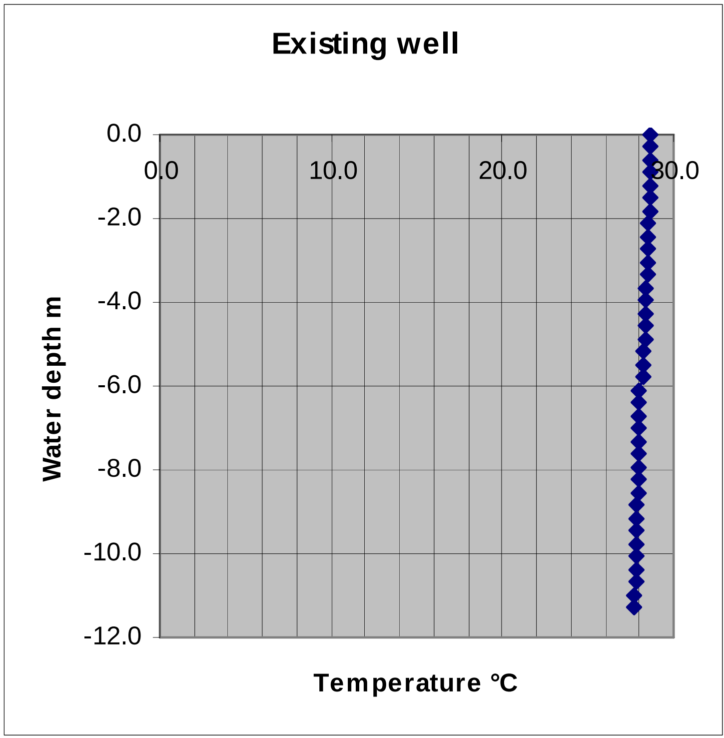


Oceanographic station data revealed that 15 deg C natural coolant water is available at the 500 m depth in the ocean.



We believe that the carbonate geology of the island allows the ocean water to circulate at depth within the bedrock below the proposed site.

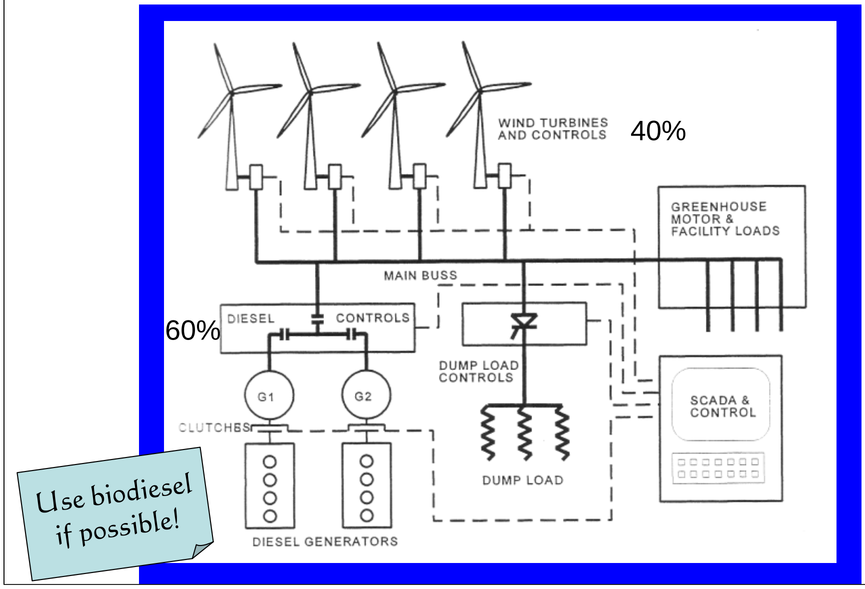
The location of the existing well into saline groundwater is shown just to right of centre in the west-to-east profile view below the map



The existing well's temperature-depth profile showed a definite reverse-geothermal-gradient --- temperature of the saline groundwater decreases with depth.

Our hydrological consultant stated that there is no freshwater lens on Grand Turk.

Autonomous wind-diesel power supply

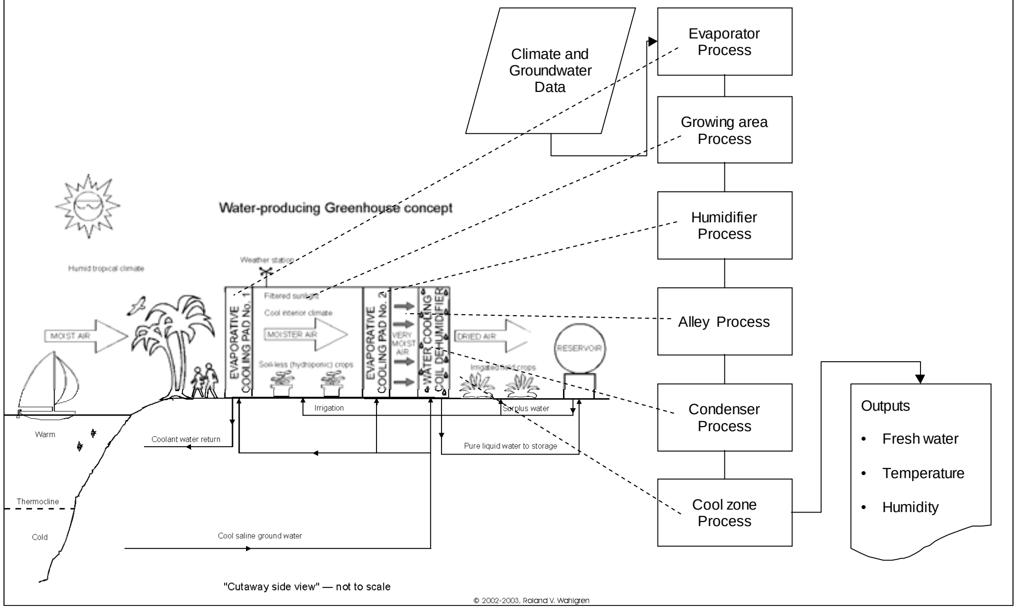


Use biodiesel if possible!

Analyses of the wind data from Grand Turk showed that we could use wind-power 40% of the time, switching to diesel for 60% of the time. Wind-power systems such as the one illustrated here seamlessly switch between wind and diesel to provide uninterrupted power to the Greenhouse system.

To insulate the project from global fluctuations in fossil fuel costs, it may be possible to produce biodiesel from residential and cruise ship food waste. Currently, large cruise ships dock in Grand Turk every second day on the average.

Thermodynamic model



Climate and Groundwater Data

Evaporator Process

Growing area Process

Humidifier Process

Alley Process

Condenser Process

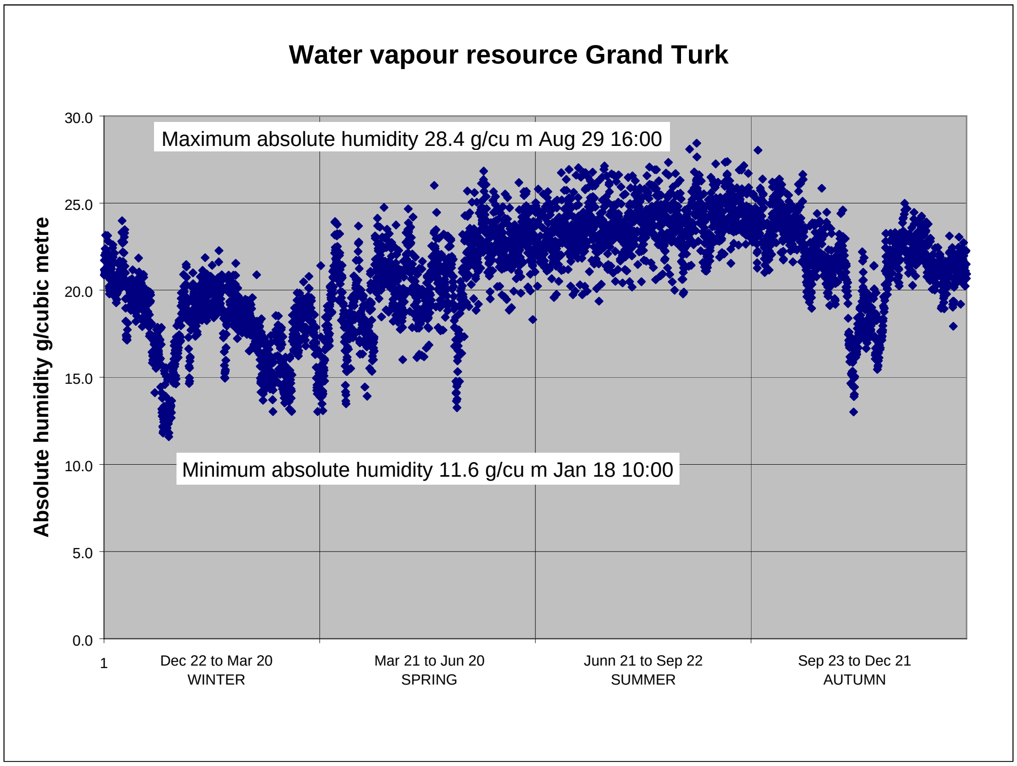
Cool zone Process

Outputs

- Fresh water
- Temperature
- Humidity

A thermodynamic model of the various processes in the Water-producing Greenhouse system let us predict performance through a typical meteorological year.

Two-hourly weather data from Grand Turk allowed us to do refined analyses.



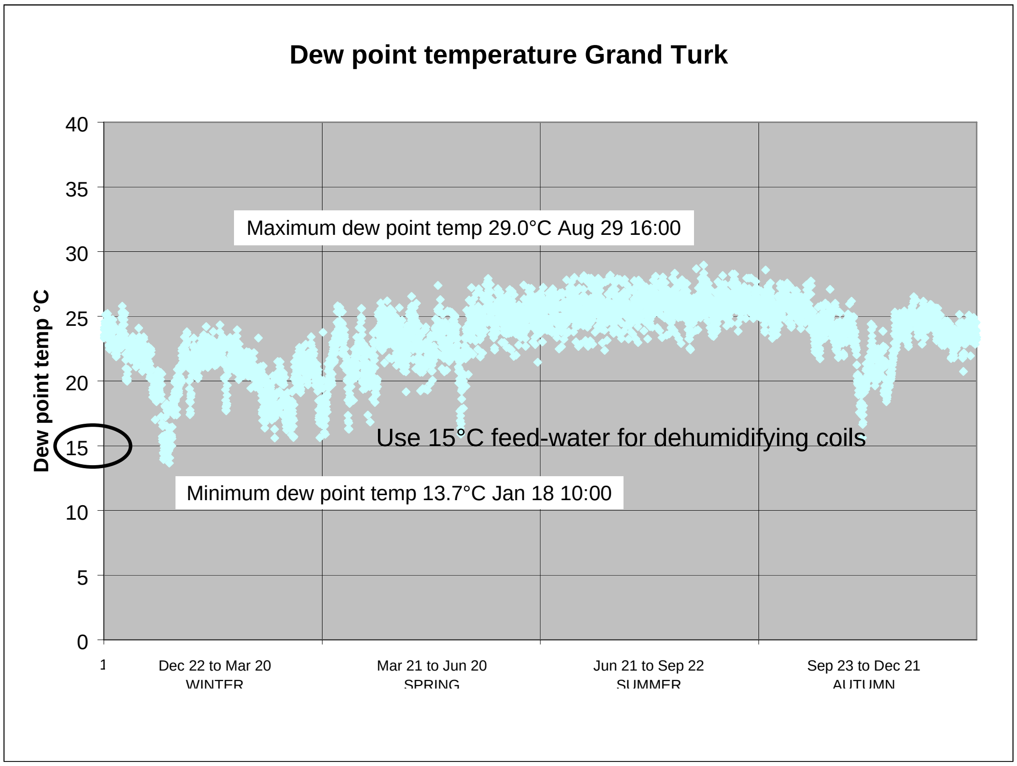
This chart shows seasonal variability of the water vapour resource in the atmosphere above Grand Turk. The warmer summer air contains more moisture than the cooler winter air.

Water-from-air systems are typically 50% efficient at extracting water molecules from the air.

The ventilating air in the Greenhouse comes from the outdoors. The outdoor air contains on the average 20 g of water molecules per cubic metre of air.

For each cubic metre of air flowing through the greenhouse, about 10 g of liquid water is collected. Total airflow is 230 cubic metres per second meaning that 138 L of water is collected each minute, which is 8280 L/h or about 200,000 L/d.

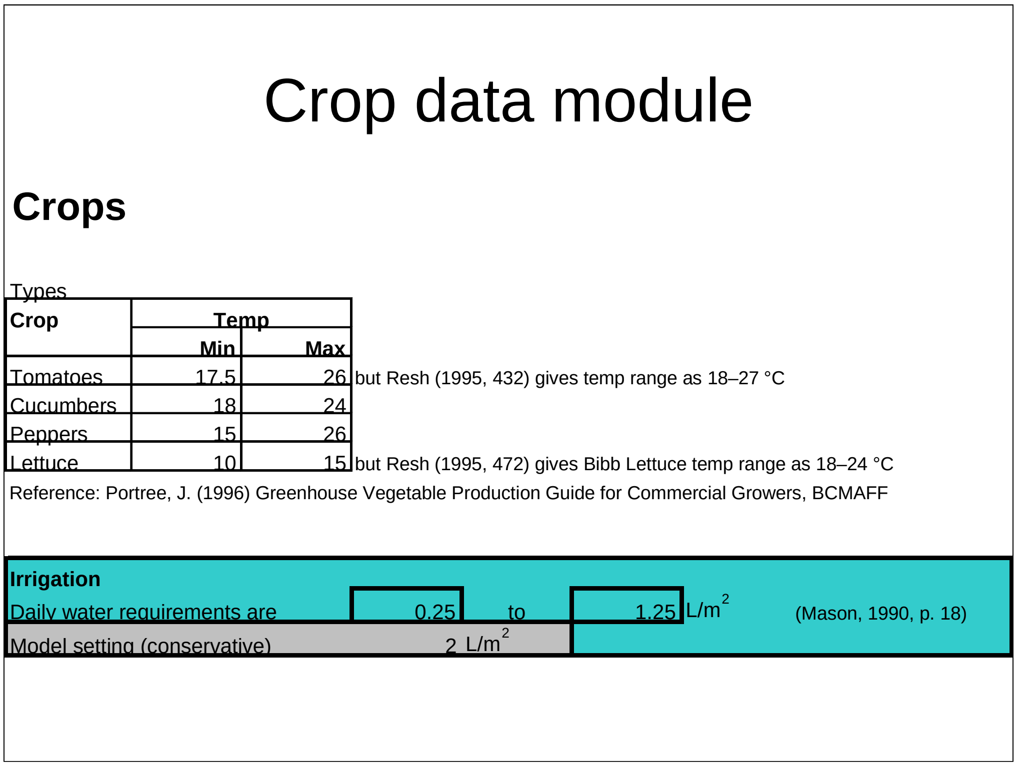
Modeling showed that evaporation from the pads and plants makes a minor, less than 10%, contribution to the water production from the greenhouse system --- more than 90% of the water produced comes from water vapour already in the ambient air flowing through the system.



Dew point temperature is directly related to the amount of water vapour in the air.

Any cooled surface, with surface temperature at or below the dewpoint temperature, will cause water to change phase from gas to liquid --- that is, dew forms on the cooled surface. A reasonable goal for the cooled surface temperature is 15 deg C so that dew collection occurs just about every day of a typical year.

There is a cost-benefit trade-off here --- colder coolant increases capital costs of the system because of the deeper depths involved.



Crop data module

Crops

Types

Crop	Temp		
	Min	Max	
Tomatoes	17.5	26	but Resh (1995, 432) gives temp range as 18–27 °C
Cucumbers	18	24	
Peppers	15	26	
Lettuce	10	15	but Resh (1995, 472) gives Bibb Lettuce temp range as 18–24 °C

Reference: Portree, J. (1996) Greenhouse Vegetable Production Guide for Commercial Growers, BCMAFF

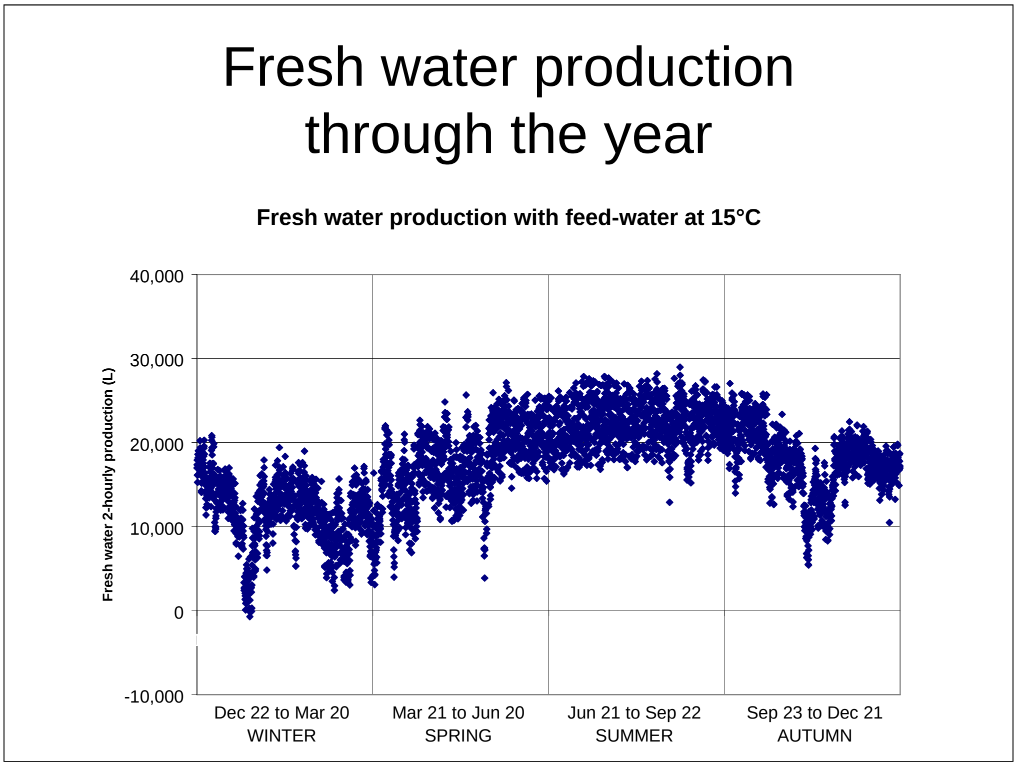
Irrigation

Daily water requirements are 0.25 to 1.25 L/m^2 (Mason, 1990, p. 18)

Model setting (conservative) 2 L/m^2

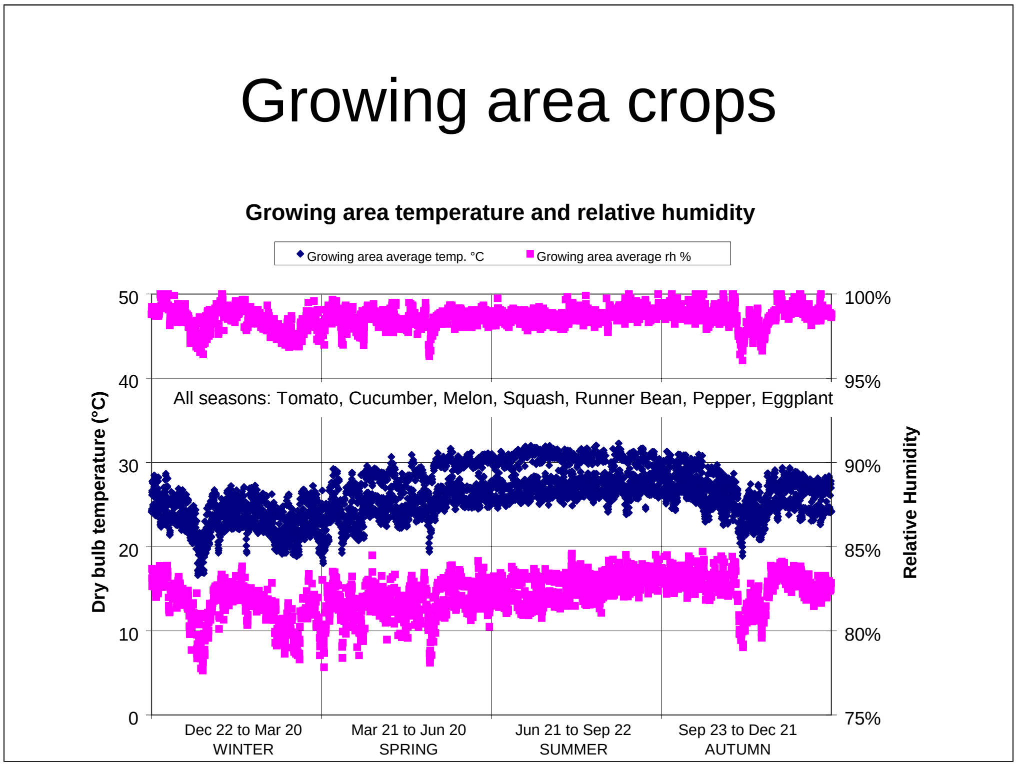
Temperature ranges for typical temperate climate hydroponic crops were checked for compatibility with interior temperature ranges expected for a Water-producing Greenhouse in the tropics.

Although daily water requirements for hydroponically-grown crops are often cited as between 0.25 to 1.25 L/sq m of greenhouse area, we opted to use a value of 2 L/sq m in our thermodynamic model --- to be conservative.



Fresh water production through the year

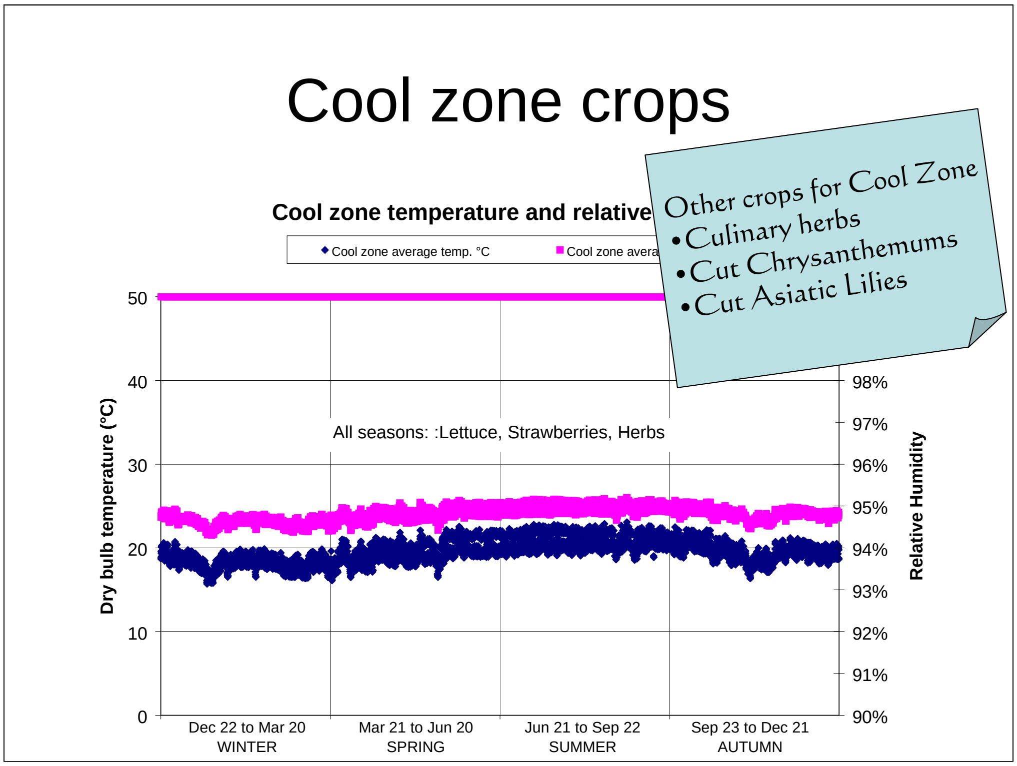
Fresh water production through the year, here shown as 2-hourly values of water produced, shows the same seasonal variability as the water vapour resource. This variability is dealt with by using properly sized reservoirs to store water from periods of high production to be drawn on during periods of low production.



Growing area crops

Temperature is in blue, relative humidity is in pink.

Temperatures in the main growing area between the pads range between 20 to 30 deg C and are suitable for tomatoes, cucumbers, melons, squash, runner beans, peppers, and eggplants.

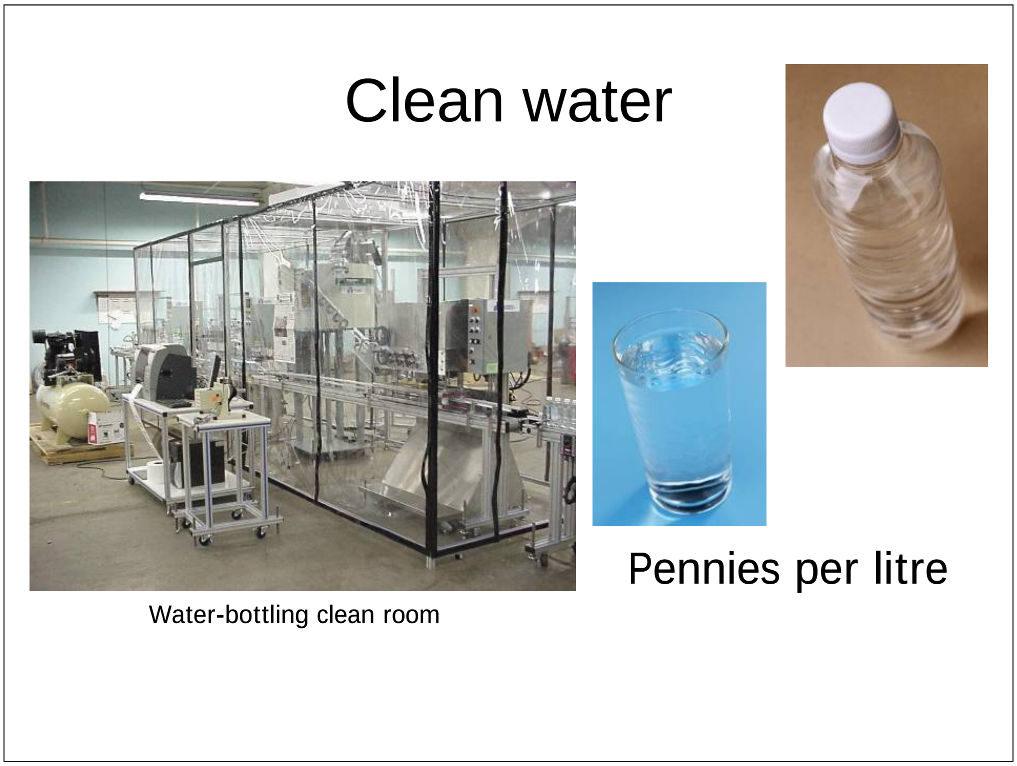


Cool zone crops

Other crops for Cool Zone
- Culinary herbs
- Cut Chrysanthemums
- Cut Asiatic Lilies

Again, temperature is in blue, relative humidity is in pink.

Cool zone temperatures range from about 18 to 22 deg C, suitable for lettuces, strawberries, herbs, and cut flowers.



Clean water

Water-bottling clean room

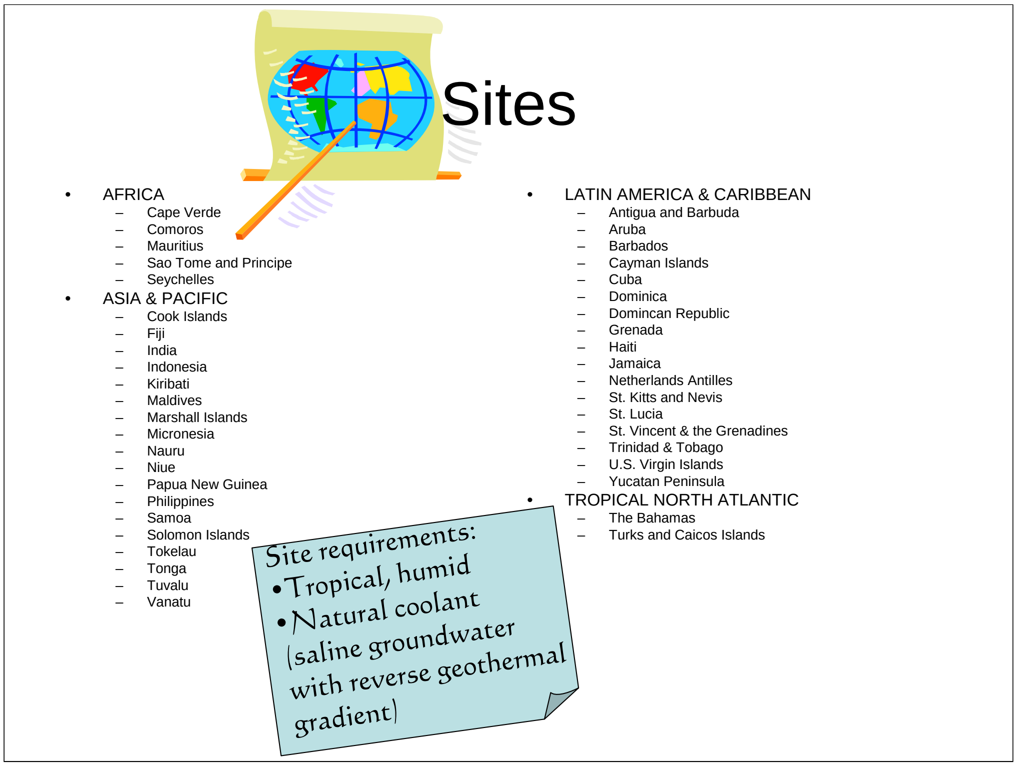
Pennies per litre

Bottled water sales have a dramatic impact on revenues although water bottling might consume only 4% to 18% of the fresh water produced by the greenhouse system. Even though there is some domestic bottled water production in the Turks and Caicos Islands, much of the bottled water is imported from Florida! Therefore it makes sense to bottle some of the water produced from the greenhouse operation for import substitution.

In addition to bottling water for sale, our modeling showed that the water-producing greenhouse operation could donate about 100,000 L/d of fresh water to the community.

Our fresh water would have zero salt content as opposed to the 300 to 500 parts per million typical of water desalinated by the reverse osmosis method.

Water bottling lines are fairly easy to purchase and set up in modules of 25,000 L/d capacity.



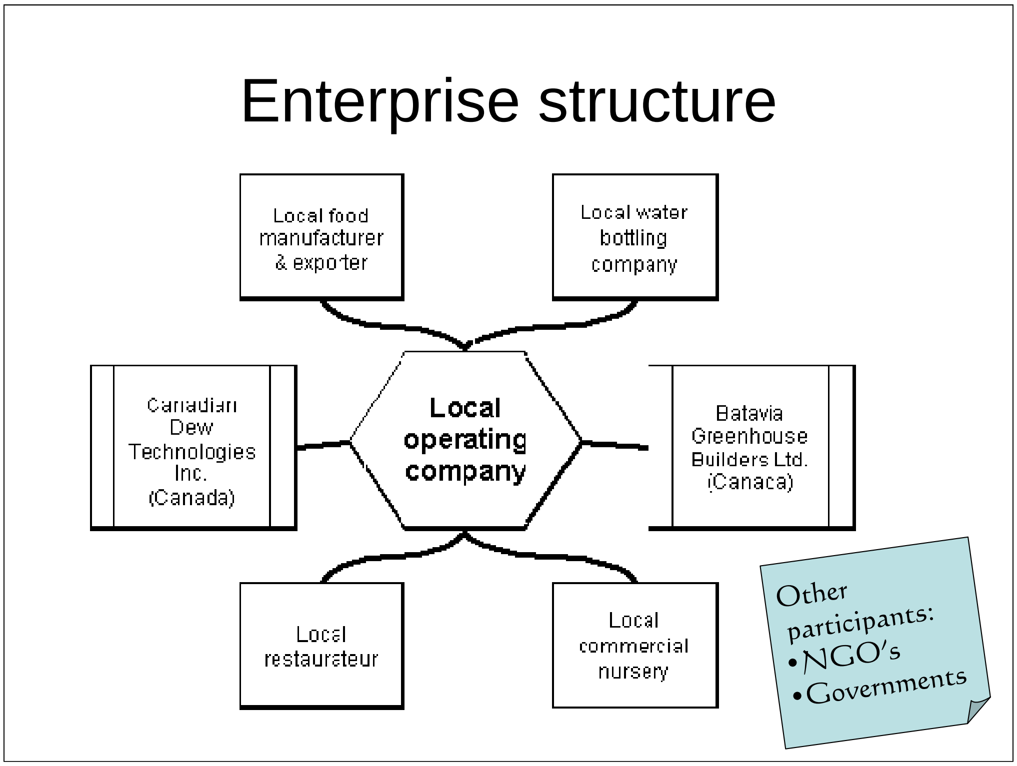
Sites

- AFRICA
  - Cape Verde
  - Comoros
  - Mauritius
  - Sao Tome and Principe
  - Seychelles
- ASIA & PACIFIC
  - Cook Islands
  - Fiji
  - India
  - Indonesia
  - Kiribati
  - Maldives
  - Marshall Islands
  - Micronesia
  - Nauru
  - Niue
  - Papua New Guinea
  - Philippines
  - Samoa
  - Solomon Islands
  - Tokelau
  - Tonga
  - Tuvalu
  - Vanatu
- LATIN AMERICA & CARIBBEAN
  - Antigua and Barbuda
  - Aruba
  - Barbados
  - Cayman Islands
  - Cuba
  - Dominica
  - Domincan Republic
  - Grenada
  - Haiti
  - Jamaica
  - Netherlands Antilles
  - St. Kitts and Nevis
  - St. Lucia
  - St. Vincent & the Grenadines
  - Trinidad & Tobago
  - U.S. Virgin Islands
  - Yucatan Peninsula
- TROPICAL NORTH ATLANTIC
  - The Bahamas
  - Turks and Caicos Islands

Site requirements:
- Tropical, humid
- Natural coolant (saline groundwater with reverse geothermal gradient)

This list includes small islands with carbonate geology and other small islands or continental coasts within a few kilometres of the continental shelf edge (the 200 m depth contour or isobath) --- these are locations with access to deep ocean water natural coolant.

Clearly, there are hundreds of possible Water-producing Greenhouse sites associated with Africa, Asia & Pacific, Latin America and the Caribbean, and the Tropical North Atlantic.



Enterprise structure

Local food manufacturer & exporter

Local water bottling company

Canadian Dew Technologies Inc. (Canada)

Local operating company

Batavia Greenhouse Builders Ltd. (Canada)

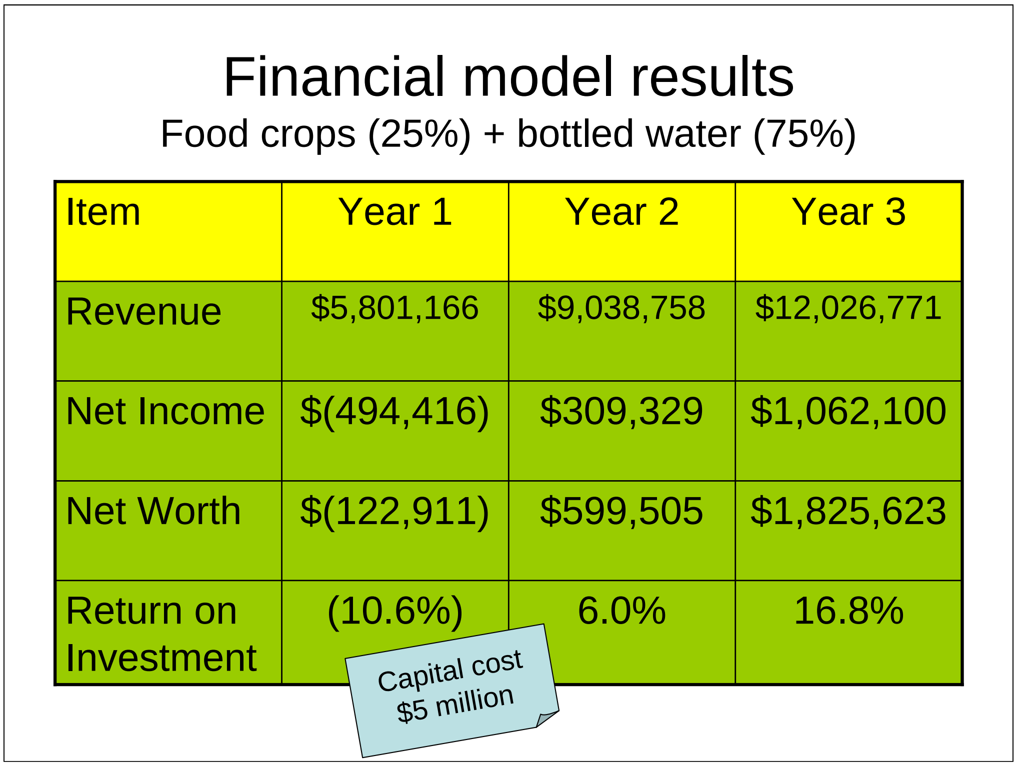
Local restaurateur

Local commercial nursery

Other participants:
- NGO's
- Governments

Business structure can have a considerable influence on whether or not a Water-producing Greenhouse based enterprise is successful. Here is one suggestion for the proposed Grand Turk Greenhouse which emphasizes local involvement but draws on hydroponic and scientific & technical expertise from Canadian firms.

Some projects may be more appropriate for Non Governmental Organization and/or local government participation.



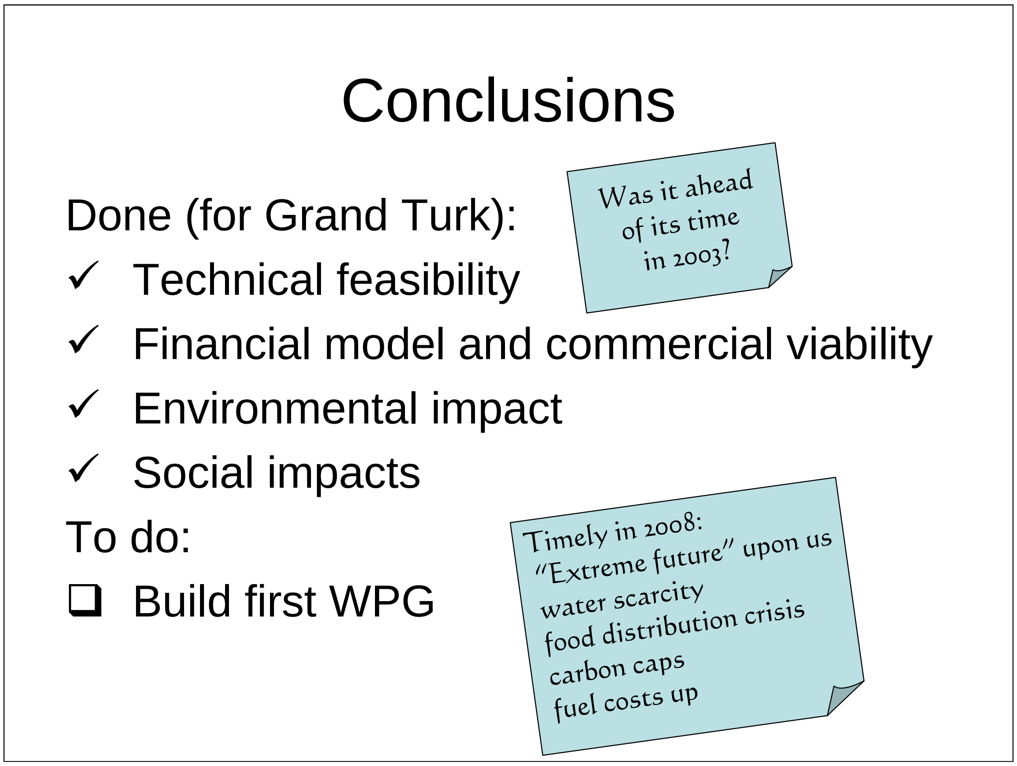
Financial model results

Food crops (25%) + bottled water (75%)

Item	Year 1	Year 2	Year 3
Revenue	$5,801,166	$9,038,758	$12,026,771
Net Income	$(494,416)	$309,329	$1,062,100
Net Worth	$(122,911)	$599,505	$1,825,623
Return on Investment	(10.6%)	6.0%	16.8%

Capital cost
$5 million

With a capital cost of $5 million, food crops contributing 25% of revenue and bottled water contributing 75% of revenue, our financial model projected a 16% to 17% return on investment by the fourth year of operation in Grand Turk.



Conclusions

Done (for Grand Turk):

- ✓ Technical feasibility
- ✓ Financial model and commercial viability
- ✓ Environmental impact
- ✓ Social impacts

To do:

- ☐ Build first WPG

Was it ahead
of its time
in 2003?

Timely in 2008:
"Extreme future" upon us
water scarcity
food distribution crisis
carbon caps
fuel costs up

We've done all the ground work proving project viability.

The previous 5 years of fund-raising efforts generated several discussions with prospects but no actual project startup --- perhaps the proposed project on Grand Turk was ahead of its time.

With the recent hurricane damage to Grand Turk, coupled with a global economic crisis, residents and their government have been reminded about the need for food and water security. Our business contact on Grand Turk said to me a few days ago during a phone call that now may be the best time ever to re-introduce the project.

There are many other small island populations around the globe also wanting greater food and water security. Perhaps the Water-producing Greenhouse is a timely solution.

Thank you!

Please visit…

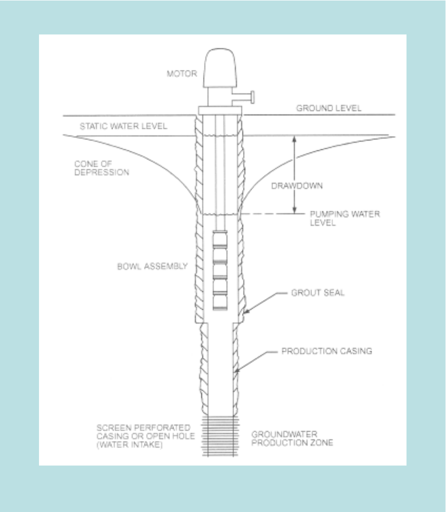
www.atmoswater.com

www.waterplusfood.com

The waterplusfood web site has summaries of our viability study reports.
Thank your for your time and attention. Feel free to contact me after the session.

Now I will take some questions. Thanks again.

Wells



- \$500 / m
- 500 m depth needed to get 15°C feed-water
- Drilling time for four feed-water wells is about 3 months

This is a typical cross-section of a drilled well with a submersible pump.

Environmental needs of selected food plants (after Yuste and Gostincar, 1999)

Species	**Night temp**	**Day temp**	**Maximum biological temp**	**Optimum substrate temp**	**Relative humidity (%)**	**Light intensity (lux)**	**Day length needs**
Tomato	13–16	22–26	26–30	15–20	55–60	10,000–40,000	Day-neutral
Cucumber	18–20	24–28	28–32	20–21	70–90	15,000–40,000	Long-day
Melon	18–21	24–30	30–34	20–22	60–80	—	Long-day
Squash	15–18	24–30	30–34	—	—	—	—
Runner bean	16–18	21–28	28–35	—	—	—	—
Pepper	16–18	22–28	28–32	15–20	65–70	—	Long-day
Eggplant	15–18	22–26	30–32	15–20	65–70	—	Long-day
Lettuce	10–15	15–20	25–30	10–12	60–80	12,000–30,000	Long-day
Strawberry	10–13	18–22	—	12–15	60–70	—	Short-day

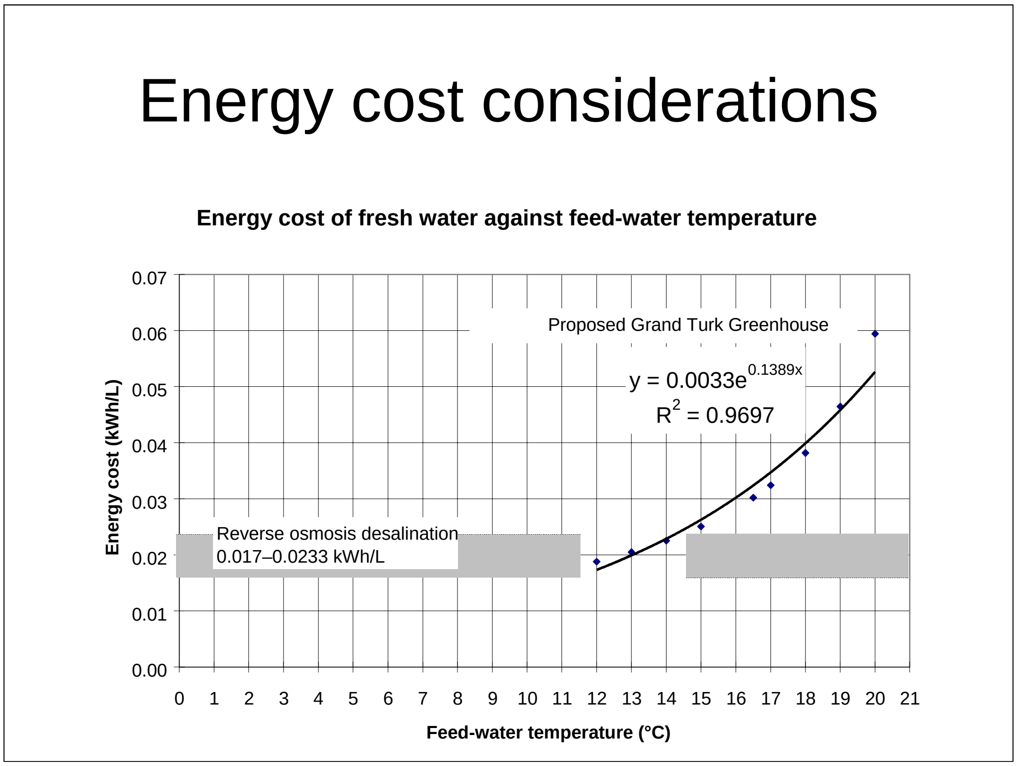
Cool zone

Looking at environmental needs of food plants justified adding a cool zone to the design.

The cool zone is an extra greenhouse bay attached downwind of the fan array.

Rather than just spilling the cool, dehumidified air into the atmosphere, it makes sense to use this resource for crops like lettuces and strawberries which need lower night and day temperatures than can be provided in the main growing zone between the evaporator pads.

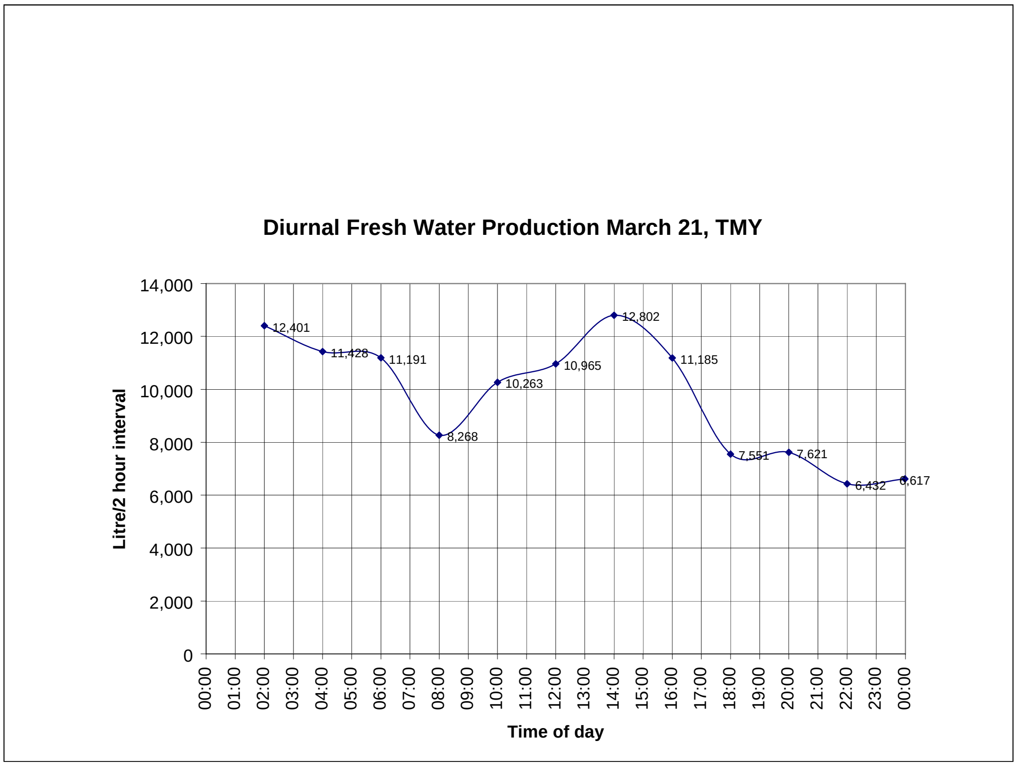
That zone can be cooled only to the wet bulb temperature. In contrast, because sufficient moisture is removed by the water-cooled coils at the fan side of the greenhouse, the air leaving the fans has been cooled several degrees below the wet bulb temperature.



Energy cost considerations

Energy cost of fresh water against feed-water temperature

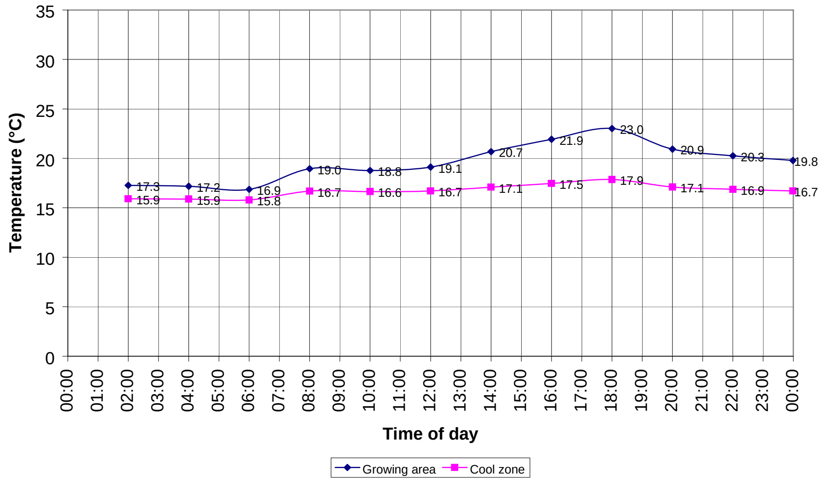
Energy cost of the fresh water produced by the system is lower for colder feed-water temperatures. We can be competitive with reverse osmosis desalination using feed-water temperatures in the 12 to 14 deg C range.



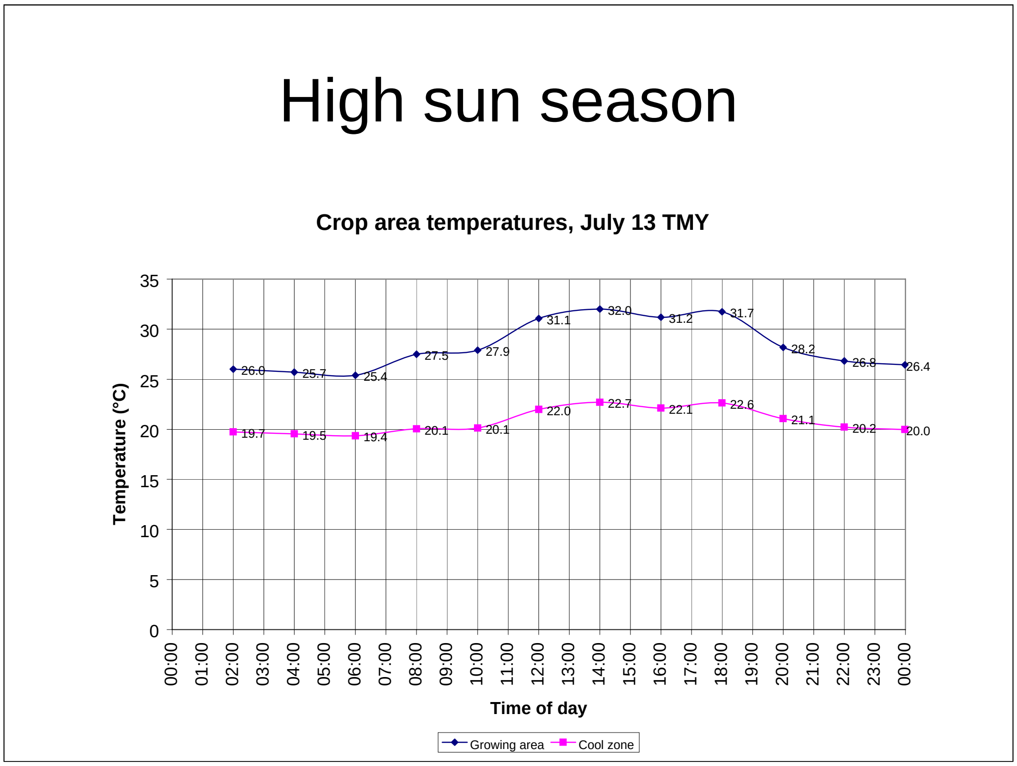
Water production rates will vary throughout a typical day as meteorological conditions change.

Low sun season

Crop area temperatures, Jan 19 TMY

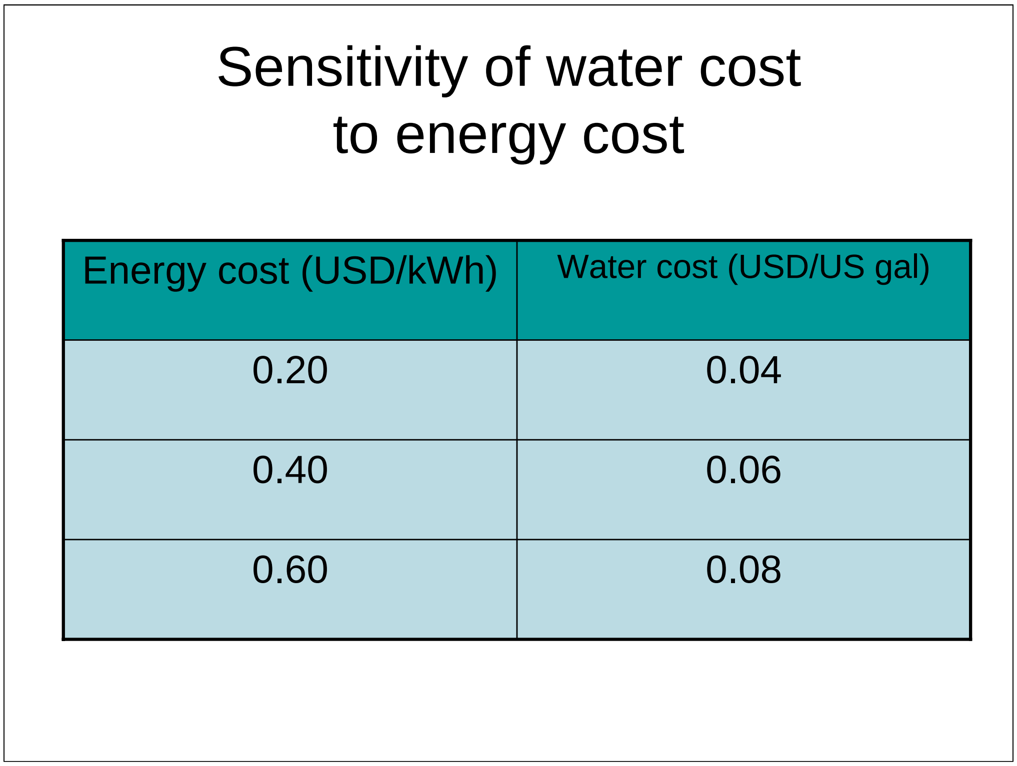


The upper temperature curve is for the main growing area while the lower curve is for the cool zone. During the low sun season, crop area temperatures in both growing areas bottom out during the early morning and peak around 1800 hours.



High sun season

Again, the upper temperature curve is for the main growing area while the lower curve is for the cool zone. During the high sun season, crop area temperatures in both growing areas bottom out during the early morning but now peak throughout the afternoon between 1200 and 1800.



Sensitivity of water cost to energy cost

Energy cost (USD/kWh)	Water cost (USD/US gal)
0.20	0.04
0.40	0.06
0.60	0.08

With rising fossil fuel costs a fact of life it is important to look at the sensitivity of the product water cost to energy cost. Our model showed that if energy costs tripled, water cost would double.