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Batavia Greenhouse Builders Ltd.

Technical Feasibility Study

Grand Turk Solar Desalination Greenhouse for Water + Food ™ —2nd ed.

(revised September 2002)

Abstract

Deliverable 1 of the CIDA INC Contribution Agreement with Batavia Greenhouse Builders Ltd. for the Viability Study—Solar Desalination Greenhouse—Turks and Caicos Islands is this Technical Feasibility Report.

Our Greenhouse for subtropical Grand Turk uses 27 exhaust fans to force air at 1.52 m/s (300 ft per minute) through a 3,500 m^2 (0.87 acre) greenhouse. There is one air change every minute. Cool (15°C; 59°F), salty (36 ‰) groundwater, from four wells 400–500 m (1,300–1,650 ft) deep, is pumped through 27 condensers. Total flow is 256 L/s (4,050 US gal per minute) The aluminum-finned copper-nickel condenser tubes (total face area 2700 ft^2) are colder than dew-point. Airflow moisture (11–28 g/m^3) turns into pure fresh water droplets collected in a reservoir for crop irrigation. Thermodynamic modeling shows that any crop mix among tomatoes, cucumbers, melons, squash, runner beans, peppers, and eggplants, would use less than 5% of the 200 m^3 (52,800 US gal) fresh water produced daily by the greenhouse. About 190 m^3 (50,200 US gal) fresh water is pumped each day to storage tanks. This surplus water is allocated according to demand for drinking, beverage manufacturing, food-processing, livestock, and irrigation of nursery stock.

The salty groundwater is returned, unchanged in salinity, to the environment via the Great Salina just west of the proposed Greenhouse site at Crisson Plantation.

Evaporative cooling pads soaked with saltwater from the condenser maintain a year-round temperate summer climate inside four main growing zones in the greenhouse so that a variety of high-value vegetables and fruits can be grown and sold. A special feature of our design is a fifth 840 m^2 (0.21 acre) zone, the cool zone. Although not used for water production, it maintains coolness for lettuce and strawberries.

Modeled energy consumption is just over 5200 kWh daily, based on a power requirement of about 220 kW. Fresh water energy cost of 25.1 kWh/m^3 is slightly higher than for reverse osmosis—but our water would be pure with no dissolved solids. Cooling efficiency of the simulated greenhouse space has a coefficient of performance (COP) ranging from 2 to 17 depending on weather conditions—better performance than electrically powered refrigeration or air-conditioning.

Approximate capital cost with wind-diesel power supply would be CAD 4.2 million (USD 2.7 million) with 3 to 4 years payback for the power installation. By postponing power autonomy and connecting to the Grand Turk power grid, capital cost is reduced to CAD 3 million (USD 2 million) but annual energy costs will continue at a rate of CAD 1 million (USD 650,0000).

The Greenhouse is shown, through extensive tests of the design by a thermodynamic model, to be technically feasible. The Greenhouse could produce commercial volumes of water, vegetables, and fruit for Grand Turk residents and tourists.

Approved by CIDA INC July 11, 2002. Technical Feasibility Study Team: Roland V. Wahlgren*, Atmoswater Research, 2116 Grand Boulevard, North Vancouver, BC, V7L 3Y7; Bob Crocker, Site Specific Structures, 3785 - 202 Street, Langley, BC, V3A 1R9; and Aar Koeman, Batavia Greenhouse Builders Ltd., P.O. Box 948, Aldergrove, BC, V4W 2V1.

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Grand Turk Solar Desalination Greenhouse for Water + Food ™

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Grand Turk Solar Desalination Greenhouse for Water + Food™

1 Description

This report is addressed to the Canadian International Development Agency Industrial Cooperation Program (CIDA INC) as ***Deliverable 1 of the Contribution Agreement with Batavia Greenhouse Builders Ltd. for the Viability Study — Solar Desalination Greenhouse — Turks and Caicos Islands.***

A Solar Desalination Greenhouse (SDG, Fig. 1-1) comprises a system of producing fresh water and food along arid subtropical or tropical coastlines by:

1. Bringing ocean water into a greenhouse and encouraging evaporation of pure water molecules into the air inside the building;
2. Cooling the greenhouse space by evaporative cooling;
3. Condensing pure fresh water out of the greenhouse air by means of a condenser array cooled by a flow of cold ocean water pumped from depths of 100's of metres; and
4. Irrigating the greenhouse crop with condensed fresh water.

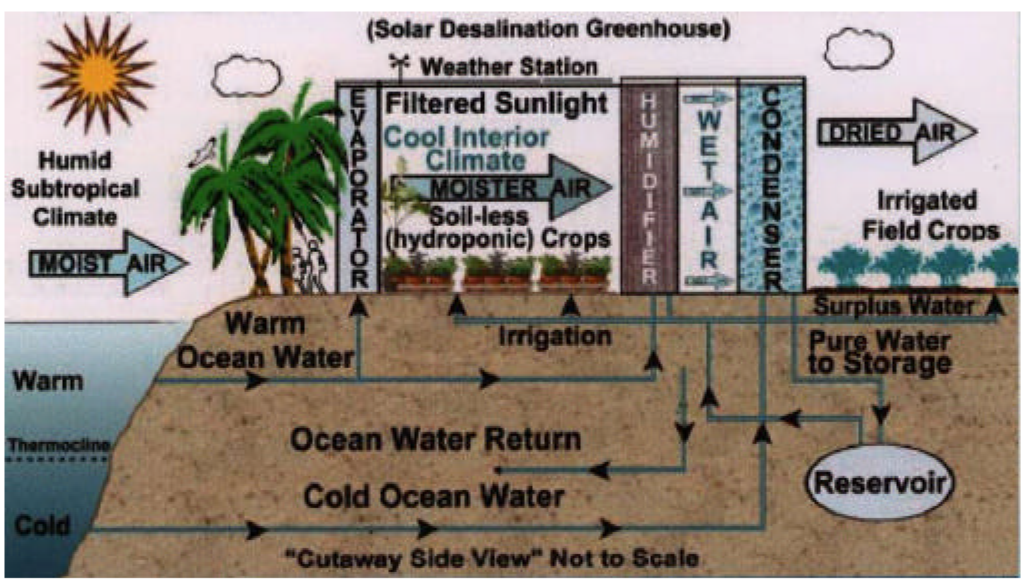

Fig. 1-1. Components of a solar desalination greenhouse

Unlike other desalination methods such as distillation, reverse-osmosis, and electrolysis; water desalination by humidifying air followed by dehumidifying (HD process) is not energy intensive. Energy intensive methods require production of large volumes (1000's of m^3 per day) of fresh water to be economical (Bourouni et al., 2001). SDGs, such as our design, producing 100's of m^3, are appropriate for regions where demand is lower and decentralized. The lower energy demands mean that renewable energy such as wind and solar can be used for the power supply. Bourouni remarked that the HD process operates at atmospheric pressure so that the equipment is not subjected to the wear and tear imposed by methods dependent on high pressures to accomplish their task of producing fresh water. Another important advantage of the HD process is that the processed ocean water is returned with only a minor change in its salinity. Other desalination methods are notorious for producing high-salinity brine that is costly to dispose properly.

Disadvantages of solar desalination are that installations require large areas of land and capital costs tend to be high (Chaibi, 2000). Chaibi observed these negative factors are offset by lower operation and maintenance costs compared to other desalination techniques.

Solar distillation designs having real utility date back to 1872, according to Chaibi (2000) and Goosen et al. (2000). The two papers mentioned that Las Salinas, Chile, was the site of a 4459 m^2 water surface area installation producing 23 m^3/day. For 36 years it provided water for a mining operation. Both papers go on to describe research through the 20^{th} century. Chaibi cited a 1961 paper co-authored by F. Trombe, of Trombe Wall fame in passive solar-heating design, as presenting the idea of combining solar distillation with a greenhouse.

The concept of using deep, cold ocean water as a coolant resource for condensing moisture out of air for fresh water supply in the US Virgin Islands was described by Gerard and Worzel (1967). Rajvanshi (1981) outlined a similar design.

Indoor air temperatures in greenhouses and other agricultural buildings may be lowered by using evaporative cooling created by air flowing through wetted pads (Bucklin, 1993; Strobel *et al*., 1999). Evaporative cooling from thin films of water on cellulose fibre pads is a low energy cost alternative to mechanical air-conditioning in climatic regions with a sufficient difference between air temperature and the wet bulb temperature. Fan-and-pad systems were promoted as a means of providing cooled water for commercial aquaculture fish tanks (Baird et al., 1993). Evaporative cooling is seen as an environmentally friendly technology that uses much less electricity than mechanical cooling and so reduces emissions of pollutants associated with global warming, corrosion, and smog (Brown, 2000).

Our design uses two wetted pads each serving entirely different purposes. The first pad, called the evaporator defines the windward edge of the crop area and cools this space. The fresh water evaporated from the saline water flowing through the pad enters the air stream. The second pad, called the humidifier defines the leeward edge of the crop area. Without this arrangement, the air inside the greenhouse would become too hot for temperate climate crop production. The humidifier also insulates the condenser from the growing area environment. Evaporation from the humidifier saturates the air flowing into the condenser so that water production is maximized.

Commercial greenhouses are often kept cooler by using specific polyethylene film covers that partially filter out the solar spectrum not essential for photosynthesis.

We are aware of two solar desalination greenhouse designs operated with apparent success by Seawater Greenhouse, United Kingdom. The first was a small prototype, 12m by 36m by 4m average height, on Tenerife, Canary Islands during the mid-1990's (Paton and Davies, 1996; Raoueche et al., 1996; Raoueche and Bailey, 1997). Development was funded by the European Commission and involved participants from the UK, Portugal, and Greece. Land and facilities were provided by Instituto Tecnológico y de Energías Renovables S.A. (ITER) in Tenerife. Deep, cold ocean water in the condenser was simulated by refrigeration.

Although the first greenhouse ceased operation after three years, a second Seawater Greenhouse, 45m by 18m, producing 800 litres of fresh water per day is now operating in Abu Dhabi growing cucumbers, tomatoes, salad plants, and flowers (Pearce, 2002). Interestingly, the University of Arizona Environmental Research Laboratory conducted a two-hectare greenhouse project in Abu Dhabi in 1972 (Resh, 1995, pp. 289–292). They used sand culture with desalinated seawater to grow vegetables in large greenhouses. In this project, the greenhouse was not itself capable of desalination but at least one major design element foreshadowed current designs of solar desalination greenhouses. For example, seawater rather than fresh water was used on evaporative cooling pads to cool the growing space. Exhaust fans forced air to flow through the pads. The fans were located centrally and air was exhausted through roof vents. Many vegetable crops were grown commercially during the project.

1.1 Project site

Grand Turk (Fig. 1-2), with limited natural fresh water sources and a population of 2000 that must import almost all its food, could be an ideal location for a solar desalination greenhouse. Although the sea surface temperatures are warm, the island is surrounded by ocean water that is deep and cold. Depths range to 1800 m within a short distance of land. The porous limestone-dominated bedrock allows ocean water to flow right through the island at depth. This can be accessed by drilling wells so the Greenhouse can be located almost anywhere on the island. It need not be located on high value land close to the coast. There is no need to contemplate constructing a pipeline across the sensitive coral platform surrounding the island.

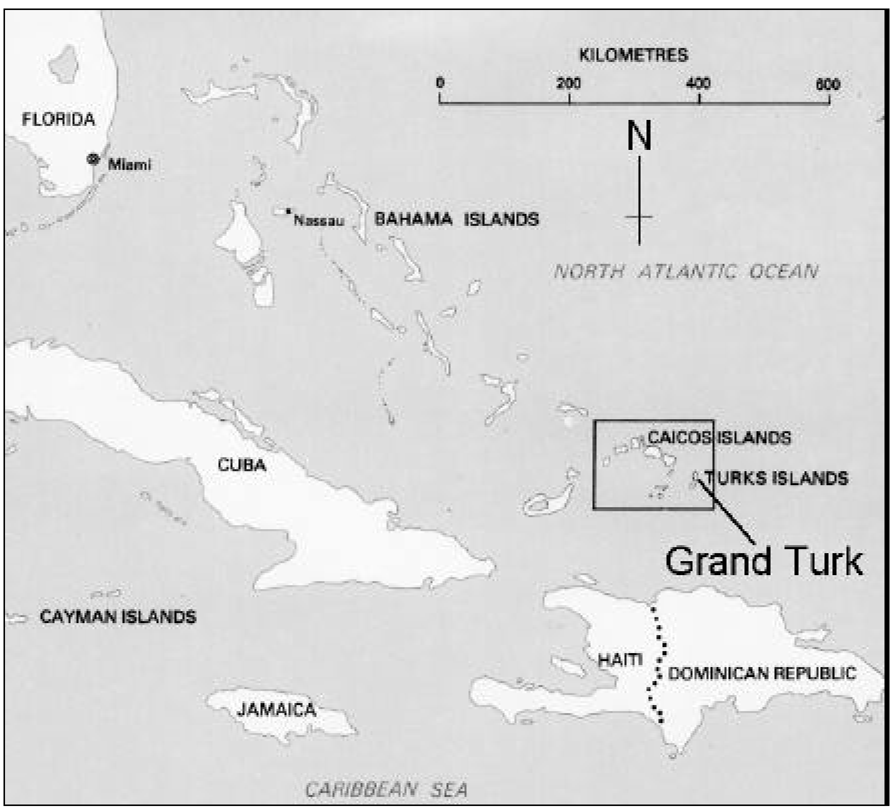

Fig. 1-2. Geographical location of Grand Turk in the Turks and Caicos Islands (base map by Directorate of Overseas Surveys, UK, 1984).

Deliverable 4 — *Details for borehole undertaking*, has already been submitted to CIDA. The report has been approved. It included information relevant to the present report because the saline feedwater for operation of the greenhouse is accessible inland on Grand Turk.

1.2 Project team

The Technical Feasibility Study (TFS) team of Bob Crocker, Aar Koeman, and Roland Wahlgren developed an environmentally sound system of ocean water desalination, integrated with vegetable, fruit, and ornamental plant production in a greenhouse setting. The study was based on conditions at the Crisson Plantation site (Fig. 1-3) on Grand Turk, Turks & Caicos Islands, BWI. Bob Crocker is Principal of Site Specific Structures, Aar Koeman is Managing Director of Batavia Greenhouse Builders Ltd., and Roland Wahlgren is Principal of Atmoswater Research. They developed the Greenhouse design during September 2001 to March 2002 by integrating public domain solar desalination systems information with horticultural knowledge and expertise in greenhouse design, construction, and operation.

The TFS team retained a Canadian wind/solar power consultant to explore properly the possibility of using alternatives to Grand Turk's grid power. This is supplied by fossil fuel fired generators. Batavia contracted Malcolm A. Lodge, P. Eng., Island Technologies Inc., Charlottetown, PEI, to do consulting engineering for assessment of technical and economic feasibility of wind/solar - diesel electrical power generation for a Solar Desalination Greenhouse on Grand Turk Island. Malcolm Lodge visited Grand Turk March 4–10, 2002.

A week's visit was made to Grand Turk in March 2002 by Roland Wahlgren. This resulted in finding an archive of 2-hourly meteorological observations, improved understanding of the proposed site, developing business and technical relationships within local government and the private sector, and information on construction and capital costs.

The structural facility and mechanical equipment design developed by us is technically feasible for fresh water and food production on Grand Turk and uses components that are available readily to the Canadian greenhouse industry. Our 3500 m^2 Greenhouse could manufacture 200,000 litres of fresh water per day, twenty times the 10,000 L/day needed for greenhouse crop irrigation. The excess water can profitably be used for drinking water, value-added products, or irrigation of field crops.

Fig. 1-3. The project site, Crisson Plantation, is shown in this view westward from one of the small hills at the site's eastern boundary (Photo by Roland V. Wahlgren).

2 Methodology

The TFS Team met weekly throughout the study period. These were usually 2-hour long meetings on Friday mornings in the boardroom of Batavia Greenhouse Builders Ltd. The meetings addressed:

- Greenhouse structure, dimensions, internal layout, and orientation on site;
- Components such as polyethylene film, evaporative cooling pads, condensers, fans, and pumps;
- Sources of components and their costs;
- Crop selection and irrigation;
- Fluid flow and air flow;
- Power supply requirements and energy costs; and
- Thermodynamic model development.

A visit to Grand Turk, March 9–16, 2002 by Roland Wahlgren involved:

- Discussions with Seamus Day, our advisor on Grand Turk;
- Meeting and discussions with Malcolm Lodge, wind power consultant, at the proposed Greenhouse site;
- Detailed photography and video of the Crisson Plantation site;
- Understanding preferred siting and orientation of Greenhouse structure;
- Background research on climate and physical geography in the Victoria Library, Grand Turk;
- Discussions with Brian Riggs, of the Turks and Caicos Museum. These furthered understanding of Grand Turk's physical environment (geology, geomorphology, climate, oceanography, ecology) in which the proposed Greenhouse would operate;
- Preliminary evaluation and collection of long-term 2-hourly meteorological observations collected by local amateur meteorologist Robert D. G. Laing;
- Discussion with Mark Day, Director, Environment and Coastal Resources about returning to a salina the ocean water that has circulated in the Greenhouse condenser and the evaporator pads. This would save the capital cost of injection wells;
- Discussing with Nicholas Turner the previous use of the site in the 1980's as a hydroponic farm. Mr. Turner was manager of the farm at the time;
- Discussions about the saline groundwater temperature regime. Paul Day, Managing Director of Columbus Foods Limited was particularly helpful in trying to find information on this topic. Through contacting some key long-

term residents of island, he discounted rumors of "deep" boreholes having been drilled at the old Pan-Am base and at the radar dome;

- Discussions about cost of borehole drilling (Ezekiel Hall, Halltech; Paul Day, Columbus Foods); and

- Discussions about capital costs for construction with Paul Day who introduced us to Johnston International Limited, building and civil engineering contractors based in the TCI.

Fig. 2-1. Remnants of the 1980's hydroponics farm at Crisson Plantation (Photo by Roland V. Wahlgren).

2.1 Thermodynamic modeling

Performance of the Solar Desalination Greenhouse is directly related to climatic and oceanographic conditions at the site. A thermodynamic model was developed to simulate Greenhouse operation and quantify temperature, humidity, water production, and power consumption. The model also served as a framework for testing and storing information and ideas evolving from the TFS meetings.

The first versions of the thermodynamic model relied on monthly averages of air temperatures and relative humidity archived at *Washington Post*'s Historical Weather Data web site. Our liaison on Grand Turk had discovered that the Turks and Caicos Civil Aviation service could not make their records available to us. Air pressure was assumed to be standard sea level pressure adjusted for the 5 m elevation of the site. During the visit to Grand Turk in March, meteorological data for one complete year with synoptic observations, taken at two hourly intervals, was acquired from the computer-archived records of an amateur meteorologist whose home is near the proposed Greenhouse site. This increased accuracy of the model and allowed analysis of diurnal trends of various parameters.

Related synoptic observations of wind speed and direction, and precipitation were also available from the amateur meteorologist. Synoptic observations of solar radiation and cloud cover were not available. Values of solar radiation could be simulated empirically.

Seasonal ocean water temperature data with temperature/depth profiles were found archived on the USA's National Oceanographic Data Center website. This information was from positions close to the proposed site. Seasonal observations included only April and July.

2.2 Site data

Crisson Plantation was decided upon as the site location. Meteorological and oceanographic data was located.

2.3 Simulation

The simulation model was run with nominal Greenhouse design parameters using data converted to thermodynamic model format. Climatic conditions were reconstructed within the model.

2.4 Forecasts

Key outputs and inputs were identified as the model responded to the data.

2.5 Crop models

The model revealed the range of internal climates that are achievable. This was correlated to requirements for various crop types so that an assessment could be made of crops that would thrive in the available conditions.

2.6 Design

Ways of improving and optimizing the process were investigated. For example, it is possible to increase water production by adjusting the dimensions and specifications of internal components of the Greenhouse. These choices were balanced with capital costs and the resulting Greenhouse microclimate.

2.7 Optimization

The simulation model outputs were analyzed to establish the optimum fixed design choice values and operator controllable parameters. Feed-water temperature was the critical design choice. The model was run with a range of feed-water temperatures to evaluate the optimum temperature and corresponding well drilling depth. This provided a range of choices with associated costs and benefits.

2.8 Results

The products of the technical feasibility study were:

- Graphs and tables of the values for water production, with respect to the ambient temperature, internal and exhaust air temperatures, and humidity;
- Water output with volume projections;
- Outline drawings of the Greenhouse structure and layout;
- Pump, fan, and control requirements;
- Power supply specification and energy consumption estimates; and
- Estimated capital cost.