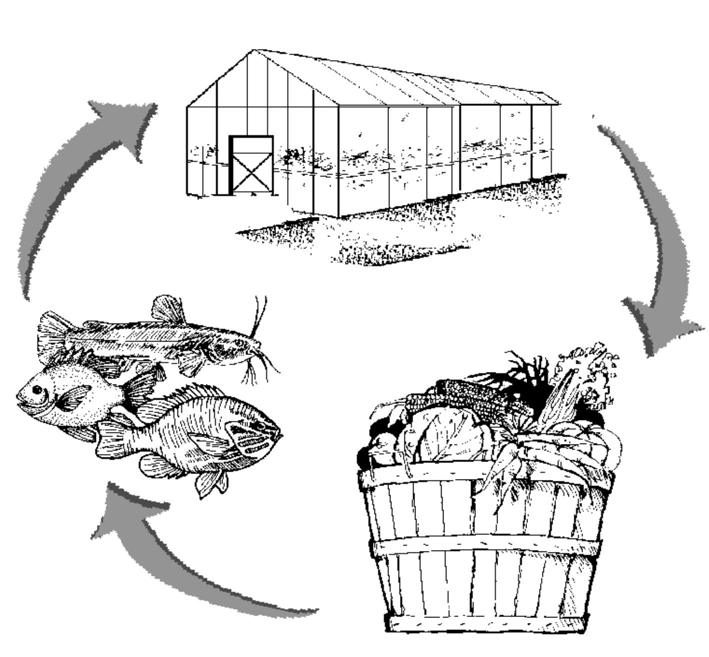
AQUAPONICS - INTEGRATION OF HYDROPONICS WITH AQUACULTURE

HORTICULTURE SYSTEMS GUIDE

ATTRA is the national sustainable agriculture information center funded by the USDA's Rural Business -- Cooperative Service.

Abstract: *Aquaponics is a bio-integrated system that links recirculating aquaculture with hydroponic vegetable, flower, or herb production. Recent advances by researchers and growers alike have turned aquaponics into a working model of sustainable food production. This publication provides an overview of aquaponics with brief profiles of working units around the country. An extensive list of resources point the reader to print and web-based educational materials for further technical assistance.*

By Steve Diver, NCAT Agriculture Specialist
February 2000



Aquaponics, also known as the integration of hydroponics with aquaculture, is gaining increased attention as a bio-integrated food production system.

Aquaponics helps production agriculture meet its goals of sustainability by following certain principles:

- The *waste products* of one system *serve as food or fuel* for a second biological system
- The *integration* of fish and plants is a type of *polyculture* that increases *diversity* and thereby enhances system *stability*
- *Biological water filtration* removes nutrients from water *before it leaves the system*
- Sale of greenhouse products *generates income* which supports the *local economy*

Contents

In aquaponics, nutrient wastes from fish tanks are used to fertilize hydroponic production beds via irrigation water. This is good for the fish because plant roots and associated rhizosphere bacteria remove nutrients from the water. These nutrients — generated from fish manure, algae, and decomposing fish feed — are contaminants that would otherwise build up to toxic levels in the fish tanks, but instead serve as liquid fertilizer to hydroponically grown plants. In turn, the hydroponic beds function as a biofilter so the water can then be recirculated back into the fish tanks. The bacteria living in the gravel and in association with the plant roots play a critical role in nutrient cycling; without these microorganisms the whole system would stop functioning. Greenhouse growers are taking note of aquaponics for several reasons:

- Hydroponic growers view fish-manured irrigation water as a source of organic fertilizer that enables plants to grow well.
- Fish farmers view hydroponics as a biofiltration method to facilitate intensive recirculating aquaculture.
- Greenhouse growers view aquaponics as a way to introduce organic hydroponic produce into the market place, since the only fertility input is fish feed and all of the nutrients pass through a biological process.
- Food-producing greenhouses — yielding two products from one production unit — are naturally appealing for niche marketing and green labeling.
- In arid regions where water is scarce, aquaponics is an appropriate technology that allows food production with re-used water
- Aquaponics is a working model of sustainable food production wherein plant and animal agriculture are integrated, and recycling of nutrients and water filtration are linked.
- In addition to commercial application, aquaponics has become a popular training aid on integrated bio-systems with vocational agriculture programs and high school biology classes.

The technology associated with aquaponics is complex. It requires the ability to simultaneously manage the production and marketing of two different agricultural products. Until the 1980s, most attempts at integrated hydroponics and aquaculture had limited success. However, innovations in the 1980s and 90s have transformed this technology into a viable modern food production system. This publication will not attempt to summarize the production details associated with aquaponics, but rather it will point to key innovators and published resources for further information.

Highlighted below are profiles of several aquaponic greenhouses as models and examples of commercial systems. Most of these operations can provide technical assistance and/or offer classes or opportunities to visit their greenhouses. Please refer to articles in the **Suggested Reading** list and to the resource listings in the bibliography for more complete descriptions and technical details.

The North Carolina State University System

In the 1980's Mark McMurtry (former graduate student) and Doug Sanders (professor) at North Carolina State University developed an aqua-vegeculture system based on tilapia fish tanks sunken below the greenhouse floor. Effluent from the fish tanks was trickle-irrigated onto sand-cultured hydroponic vegetable beds located at ground level. The nutrients in the irrigation water fed tomato and cucumber crops, and the plants and sand beds served as a biofilter. After draining from the beds, the water recirculated back into the fish tanks. The only fertility input to the system was fish feed (32% protein).

Some findings and highlights of McMurtry's research:

- Benefits of integrating aquaculture and vegetable production are:
  1. conservation of water resources and plant nutrients
  2. intensive production of fish protein
  3. reduced operating costs relative to either system in isolation
- Water consumption in integrated systems including tilapia production is less than 1% of that required in pond culture to produce equivalent yields.
- Such low-water-use symbiotic systems are applicable to the needs of arid or semi-arid regions where fish and fresh vegetables are in high demand.
- Organic vine-ripened, pesticide-free produce and "fresh-daily" fish can bring premium prices, particularly during winter months in urban areas.
- Biofilters (sand beds with vegetables) that are alternately flooded and drained with nutrient-laden fish tank water are called reciprocating biofilters.
- Reciprocating biofilters provide advantages of uniform distribution of nutrient-laden water within the filtration medium during the flood cycle and improved aeration from atmosphere exchange with each dewatering which

benefits both nitrifying bacteria and plant roots.

- Dissolved and suspended organic materials accumulate rapidly in aquaculture systems and must be removed for efficient fish production.
- Previous integrated fish-vegetable systems removed suspended solids from the water by sedimentation in clarifiers prior to plant application. Removal of the solid wastes resulted in insufficient residual nutrients for good plant growth; acceptable fruit yields had previously only been achieved with substantial supplementation of plant nutrients.
- Aqueous nitrate concentrations in recirculating aquaculture can be adequately regulated when fish and vegetable production are linked via reciprocating biofilters.
- Tomatoes may have also assimilated N in organic amino acid forms. In 1950 Gosh and Burris (*Utilization of nitrogenous compounds by plants. Soil Science*, 70: 187-203) found that tomatoes utilize alanine, glutamic acid, histidine, and leucine as effectively as inorganic N sources.
- Research to determine the optimum ratio of fish tank to biofilter volume ratio on fish growth rate and water quality found that stocking density of fish and plants can vary depending on desired goal. Essentially, fish stocking density and feed rates are adjusted to optimize water quality as influenced by plant growth rate.

See the *Bibliography on Aquaponics* in the appendix for a listing of publications and articles that resulted from the North Carolina research.

Dr. Sanders explained that aqua-vegeculture research at NCSU has been discontinued because the technology had evolved to the point where it is ready for grower application. A packet of articles that summarize NCSU's work on this technology is available on request, contact:

Department of Horticultural Sciences
North Carolina State University
Box 7609
Raleigh, NC 27695-7609
919-515-3283

The Speraneo System

Tom and Paula Speraneo — owners of a small greenhouse operation near West Plains, Missouri — modified the North Carolina State method and raise tilapia in above-ground tanks inside a solar greenhouse. The effluent from the tanks is used to fertigate gravel-cultured vegetables in raised benches. In addition, the Speraneos manipulated the watering cycle and use selected tilapia hybrids adapted to cooler water temperatures. They also developed a unique blend of microbes which they sell as an inoculant to *start* new fish tanks.

The Speraneos grow fresh basil, tomatoes, cucumbers, mixed salad greens, and an assortment of vegetable, herb, and ornamental bedding plants in their greenhouse. Tom estimates they produce 45 to 70 pounds of produce for every pound of tilapia. This is a significant improvement over the North Carolina system, which was getting a produce-to-fish ratio of 2 to 1. Thus, the primary income in a Speraneo-style aquaponic system comes from greenhouse produce. Fish are a secondary marketable product.

In the early 1990's, Tom and Paula were raising basil which they sold for $12 a pound to gourmet restaurants four hours away in St. Louis, Missouri. However, after passage of NAFTA, imports of basil from Mexico resulted in a market crash to $4 per pound, so they dropped the St. Louis market. Now the Speraneos grow a diversity of vegetable and herbs, selling locally at a farmers market combined with direct sales out of their greenhouse.

Interest in the Speraneo system has resulted in over 10,000 visitors to their small farm in Missouri, including agriculture researchers and government officials from dozens of foreign countries. To handle the numerous inquiries and requests for assistance, the Speraneos assembled a resource packet that features a design manual with technical specifications for an S & S Aqua Farm-style aquaponic system. The packet also includes a 10-minute video documenting the S& S Aqua Farm greenhouse, and a listing of supplies. Response from growers to a practical design manual like this has been tremendous. The Speraneos have assisted over 130 aquaponic greenhouses get successfully established. The resource packet, which sells for $200, is available through:

> Attn: Tom and Paula Speraneo
> S & S Aqua Farm
> 8386 County Rd. 8820
> West Plains, MO 65775
> 417-256-5124
> snsaquasys@townsqr.com
> http://www.townsqr.com/snsaqua

The University of the Virgin Islands System

Dr. James Rakocy at the University of the Virgin Islands developed an aquaponic system that relies on rain water catchment, rotating mechanical biofilters, and floating polystyrene panels that hold the plants. This differs dramatically from the Speraneo and NC State models in which the vegetable beds themselves serve as the biofilter for cleaning effluent water. Rakocy raises tomatoes and leafy vegetables. Like Mark McMurtry, Dr. Rakocy sees integrated water reuse systems as a viable solution to self-sufficient food production in developing countries and other locations (such as the Carribean) where fresh water is scarce.

Rakocy has published a series of research reports as well as Extension bulletin on integrated fish-vegetable production. In addition, he hosts an aquaponics short course through the University of the Virgin Islands. See the *Bibliography on Aquaponics* in the appendix for a selection of articles and papers by Rackocy.
Contact:

> Dr. James Rakocy
> University of the Virgin Islands
> Agriculture Experiment Station
> RR 2, Box 10,000
> Kingshill, St. Croix
> U.S. Virgin Islands 00850
> 340-692-4020
> jrakocy@uvi.edu
> http://rps.uvi.edu/AES/Aquaculture/aquaponics.html

The Freshwater Institute System

The Freshwater Institute is a non-profit organization in Shepherdstown, West Virginia, that specializes in aquaculture research and education. Fresh spring water is an abundant resource in the Appalachian region. However, protection of spring water quality as it relates to aquaculture effluent is viewed as a vital component of this technology.

For years, the Institute has specialized in cold-water aquaculture systems raising trout and arctic charr. The Institute helps Appalachian farmers set up two types of cold-water systems: (a) an indoor, high-tech recirculating tank method and (b) an outdoor, low-tech gravity fed tank method. Treatment of aquaculture effluent prior to its return to the natural stream flow led to collaborative research with scientists at the USDA-ARS Appalachian Fruit Research Station in Kearneysville, WV, on integrated hydroponic-fish culture systems. Trials at the Institute's greenhouses showed that nitrogen, phosphorus, and other nutrients in aquaculture effluent can be effectively removed by plants grown in NFT hydroponic or constructed wetland systems.

More recently, the Institute implemented an aquaponic demonstration program based on a Sperraneo-style gravel-cultured system. Hydroponic crops include basil, lettuce, and wetland plants. Tilapia is raised as a warm-water fish species. In addition to providing technical assistance to farmers, the Institute provides educational training materials to high school biology & agriculture teachers. The Institute offers 5–6 aquaponic workshops a year, each lasting 1–3 days long.

The Freshwater Institute Natural Gas Powered Aquaponic System - Design Manual is a 37-page aquaponic design manual published by The Freshwater Institute in 1997. Included are diagrams and photos, details on greenhouse layout and aquaponic production, parts list with suppliers and cost, estimated operating expense, and further informational resources. This design manual is the most detailed instruction manual available to the public at low cost. To cover the cost of shipping and handling, $5.00 is requested. Contact:

The Freshwater Institute
P.O. Box 1746
Shepherdstown, WV 25443
304-876-2815
304-870-2208 Fax
Attn: Mr. Marten Jenkins, Mr. Larry Selzer
m.jenkins@freshwaterinstitute.org
http://www.conservationfund.org/conservation/freshwater/index.html

The Cabbage Hill Farm System

Cabbage Hill Farm is a private non-profit foundation located about 30 miles north of New York City. The foundation is dedicated to the preservation of rare breeds of historic farm animals and the practice of sustainable agriculture and aquaponic greenhouse production techniques.

Tilapia fish and leaf lettuce are the main products of the Cabbage Hill Farm system, though basil and watercress are also grown in smaller quantities. In addition to hydroponics, water passes through a constructed reed bed outside the greenhouse for additional nutrient removal.

The Cabbage Hill Farm web site contains an introductory manual on aquaponics. It provides a nice introduction to aquaponics and highlights features of the Cabbage Hill Farm system.

Aquaponics — Preserving the Future is a video film documenting the research and demonstration of aquaponics at Cabbage Hill Farms. Cost is $18.00 (tax included).

Cabbage Hill Farm
115 Crow Hill Road
Mount Kisco, NY 10549
914-241-2658
914-241-8264 Fax
Contact: Annie Farrell
veglady@aol.com
http://www.cabbagehillfarm.org/home.html

The New Alchemy Institute

The New Alchemy Institute in East Falmouth, Massachusetts, conducted research on integrated aquaculture systems during the 1970s and 1980s. Although the Institute closed in 1991, New Alchemy publications on greenhouse production and aquaponics provide historical insight to the emerging bioshelter (ecosystem greenhouses) concept and are still a valuable resource. The Green Center, formed by a group of former New Alchemists, is again making these publications available for sale. Contact:

The Green Center
237 Hatchville Rd.
East Falmouth, MA 02536
508-564-6301
http://www.fuzzylu.com/greencenter/home.htm

Especially see:

The Potential for Commercial Food-Producing Greenhouses in the Northeast: A Review of the Literature. Research Report No. 5.
By Norman L. Marshall. March 1987.
http://www.fuzzylu.com/greencenter/rr/rr005.htm

Miscellaneous Systems

Instead of locating the fish and vegetable components in separate containers inside a greenhouse, fish production can be located in outdoor tanks or adjacent buildings. The effluent simply needs to be delivered to hydroponic vegetable beds.

In warm climates, hydroponic vegetable beds may be located outside. As an example, the Center for Regenerative Studies at California State Polytechnic University-Pomona implemented an outdoor integrated bio-system that links: (a) a pond containing treated sewage wastewater stocked with tilapia and carp; (b) water hyacinth — an aquatic plant very efficient at sucking up nutrients — covering 50% of the water surface area; the plant biomass generated by water hyacinth is used as feedstock for compost heaps; (c) nearby vegetable gardens irrigated with nutrient-laden pond water.

In addition to locating the fish and vegetable components in separate containers, fish and plants can be placed in the same container to function as a polyculture. For example, plants sit on top of floating polystyrene panels with their roots hanging down into the water that fish swim around in. Models include the Rackocy system, solar-algae ponds (see literature by Zweig and Kleinholz), and the solar-aquatic ponds, or Living Machines, made popular by John Todd at Ocean Arks International.

Economic Considerations and Related ATTRA Publications

Due to the technical nature of aquaponics and the expense associated with greenhouse production, prospective growers are advised to seek technical assistance from greenhouse advisors **and** to visit a working aquaponic operation. Building and equipping a commercial-sized greenhouse can cost $10,000-$30,000, with the aquacultural components an added expense.

For general information and supplies associated with greenhouse production, see the ATTRA publications titled *Organic Greenhouse Vegetable Production* and *Hydroponic Vegetable Production.* A complementary publication is *Integrated Pest Management for Greenhouse Crops*.

Evaluating an Aquaponics Enterprise

1) Aquaponics is one method of greenhouse production. The first step is to evaluate the feasibility of a greenhouse business in your market location.

2) Do not try to re-invent the wheel. Successful aquaponic operations exist because innovators have implemented technological modifications for many years. As a starting point, pick one of the existing models and duplicate it insofar as possible.

3) Read some literature to help you become familiar with this sort of enterprise. The **Suggested Reading** list below can provide quick background reading. The **Bibliography on Aquaponics** in the Appendix can be consulted for in-depth research.

4) Visit an aquaponic greenhouse. An on-site greenhouse tour can save you weeks or months of time trying to visualize how these operations work. Keep in mind that aquaponic growers are busy people who've worked hard to learn this business. If you offer to pay a fee for their time and expertise —just like you would pay for any professional's time — it can help you get through the front door.

5) Attend seminars on aquaponics, aquaculture, and hydroponics.

6) Purchase videos and design manuals. The Freshwater Institute's design manual at $5 is a good starter — so is The Cabbage Hill video for $18. To play around on a small-scale and get firsthand experience with this technology, the Desktop Aquaponics Booklet from Nelson/Pade Multimedia is available at $15. If you are ready to go commercial, the Speraneo design manual is available at $200.

7) If you want to shorten the time and risk involved getting started, consider hiring a consultant. A few consultants with expertise in aquaponics are listed in the **Consultants Section** below.

Suggested Reading:

Dinda, Kara. 1997. Hydroponics & aquaculture working together: A case study. The Growing Edge. September-October. p. 56-59.

McMurtry, M.R., et al. 1993. Yield of tomato irrigated with recirculating aquacultural water. Journal of Production Agriculture. Vol. 6, No. 3. (July–September). p. 428–432.

Modeland, Vern. 1993. Aquafarming on a budget. BackHome. Summer. p. 28–31.

Smith, John Wesley. 1993. The genius of simplicity. The Growing Edge. Vol. 5, No. 2. (Fall). p. 40–44, 70.

Rakocy, James E., Thomas M. Losordo, and Michael P. Masser. 1992. Recirculating Aquaculture Tank Production Systems: Integrating Fish and Plant Culture. SRAC Publication No. 454. Southern Region Aquaculture Center, Mississippi State University. 6 p.

Rackocy, James. 1999. The status of aquaponics, Part I. Aquaculture Magazine. July-August. p. 83-88.

Rackocy, James. 1999. The status of aquaponics, Part II. Aquaculture Magazine. September–October. p. 64–70.

Watkins, Gordon. 1999. Inslee fish farm: A family run aquaponic operation produces chives and fish. The Growing Edge. Vol. 10, No. 5. (May–June). p. 35–40.

Watkins, Gordon. 1998. Integrating aquaculture and hydroponics on the small farm. The Growing Edge. Vol. 9, No. 5. (May–June) p. 17–21, 23.

Yarrow, David. 1998. A food production revolution: Missouri aquafarmers discover huge benefits in trace elements integrated with hydroponics. Remineralize the Earth. Spring–Fall, No. 12–13. p. 38–43.

Resources

E-mail Sites for Aquaponics–Hydroponics—Aquaculture

Aquaponic Lists:

Tom and Paula Speraneo of S & S Aqua Farm in Missouri host an Aquaponics List on the Internet. It is also available in digest format. The Aquaponics List has become a prominent source of up-to-date information and resource sharing on all aspects of aquaponics: hydroponics, aquaculture, fish species, supplies, practical solutions, and resources.

Send message to:
aquaponics-request@townsqr.com
In the body of the message, type:
subscribe *YOUR NAME*

Hydroponic Lists:

SoilLess email list
http://www.aquamist.com/soilless/index.html
A hydroponics newsletter and email listserv managed by Aquamist.

Hydro Newsletter
http://www.mayhillpress.com/archives.html
These are the archives of the Hydro1 Newsletter from Mayhill Press.

To subscribe, mailto:
bsaffell@mayhillpress.com
In the subject line, type:
subscribe hydro1

Aquaculture Lists:

Aqua-L Mailing List Archives
http://www.ifmt.nf.ca/aqua-l.archive/
Includes instructions on how to subscribe.

Aquatic-Plant Mailing List Archives
http://www.actwin.com/fish/aquatic-plants/index.cgi
Includes instructions on how to subscribe.

Publications and Magazines:

Desktop Aquaponics Booklet

This booklet provides information, directions, diagrams, photos and drawings on how to establish a home aquaponic system. It shows how to turn any aquarium or hydroponic grow bed into a unique, aquaponic eco-system. Includes:

- four primary system designs
- adapting an existing aquarium
- adapting an existing hydroponic grow bed
- set up instructions, picutres and diagrams
- plant and fish selection
- growing medium selection
- operation and maintenance

Price: $14.95 through Nelson/Pade Multimedia, the publisher of *Aquaponics Journal*:

Nelson/Pade Multimedia
P.O. Box 1848
Mariposa, CA 95338
209-742-6869
209-742-4402 Fax
info@aquaponics.com
http://www.aquaponics.com/

Aquaponics Journal
See address listed above
http://www.aquaponics.com/

Aquaponics Journal is a bi-monthly trade magazine for hydroponic gardeners and fish culturists who combine these two technologies to create a new growing method called aquaponics. Subscription: $49/year for 6 issues per year; back issues $10 each.

The Growing Edge Magazine
New Moon Publishing
P.O. Box 1027
Corvallis, OR 97339
800-888-6785
541-757-0028 Fax
tom_alexander@growingedge.com
http://www.growingedge.com

The Growing Edge is a bi-monthly trade magazine on high-tech gardening systems like hydroponics, bioponics, aquaponics, and ecologically-based pest management. Subscription: $27/year for 6 issues per year; back issues $5 each.

Practical Hydroponics & Greenhouses
http://www.hydroponics.com.au

Aquaponic Consultants

Fisheries Technology Associates, Inc.
P.O. Box 80
Fort Collins, CO 80522-0080
970-225-0150
970-225-0150 Fax
info@ftai.com
http://www.ftai.com/consult.htm

Gordon Creaser
5431 Bracken Ct
Winter Park, FL 32792
407-671-5075
407-671-5628 Fax

Myles Harston
Ringer Foods — Aquaculture Division
Box 40
Gridley, IL 61744
309-747-2152
309-747-2243 Fax

S&S Aqua Farms
8386 County Rd. 8820
West Plains, MO 65775
417-256-5124
snsaquasys@townsqr.com
http://www.townsqr.com/snsaqua
Attn: Tom and Paula Speraneo

National Agricultural Library:

Aquaculture resources available through the Alternative Farming Systems Information Center at the National Agricultural Library include:

Perschbacher, Peter W., et al. 1993. Recirculation-Aeration: Bibliography for Aquaculture. USDA-ARS, National Agricultural Library Bibliographies and Literature of Agriculture. BLA-124. 78 p.

Aquaculture Resources
http://www.nal.usda.gov/afsic/afsaqua.htm
afsaqua@nal.usda.gov

- Aquaculture-related Internet Sites and Documents
- Directory of Aquaculture Associations
- Directory of Primary Extension Specialists For Aquaculture
- Directory of State Aquaculture Coordinators and Contacts
- United States Joint Subcommittee on Aquaculture

Aquaculture-Related Internet Sites and Documents
National Agricultural Library
http://www.nal.usda.gov/afsic/aqua/aquasite.htm

This is an extensive resource on aquaculture from the National Agricultural Library. It features aquaculture-related web sites organized alphabetically; employment/careers; FAQ's; graphics and images; aquaculture-related publications and topics; and U.S. federal government agencies.

Contact:

AFSIC, NAL, ARS, USDA
10301 Baltimore Ave., Room 304
Beltsville, MD 20705-2351
301-504-6559
301-504-6409 Fax
http://www.nal.usda.gov/afsic/index.html

Aquaponics on the Web

Recirculating Aquaculture Tank Production Systems: Integrating Fish and
Plant Culture
Southern Regional Aquaculture Center, Publication No.454
http://agpublications.tamu.edu/pubs/efish/454fs.pdf

This is the Rakocy Agricultural Extension Service publication on aquaponics. It is perhaps the *only* Extension Service fact sheet on this topic.

A Prototype Recirculating Aquaculture-Hydroponic System
By Donald Johnson and George Wardlow
University of Arkansas, Department of Agricultural and Extension Education AgriScience Project
http://www.uark.edu/depts/aeedhp/agscience/aquaart.pdf

This web download is a 10-page reprint of an article the authors originally published in *Journal of Agricultural Mechanization* (November 7, 1997). It describes a low cost (less than $600) recirculating aquaculture-hydroponic system suitable for use in laboratory settings. Included is a materials list and approximate cost of materials to set up a 350-gallon aquaponic unit.

Farming the Water
By Linda Weimer
http://www.jhu.edu/~jhumag/694web/farming.html

This is a 4-page web article, originally appearing in the June 1994 issue of John Hopkins University magazine. It highlights the Bioshelters aquaponic greenhouse operation in Amherst, Massachussetts.

Raising Tropical Food Fish in Small Greenhouse Promises Profits for Texans
Marty Baker's Tilapia/Greenhouse Project
Agricultural Research and Extension Center at Overton, Texas.
http://overton.tamu.edu/htmsub/tilapia.html

This is a 3-page web article that features the integration of tilapia fish to greenhouse transplant production in Texas.

Eutrophic Aquaculture-Hydroponics Systems in Integrated Wastewater Treatment
Department of Biosystems and Agricultural Engineering, University of Minnesota
http://www.bae.umn.edu/annrpt/1996/research/waste10.html

Abstract of paper in Proceedings of the Internet Conference on Integrated Bio-Systems

The Freshwater Institute
Shepherdstown, West Virginia
http://www.conservationfund.org/conservation/freshwater/index.html

The Freshwater Institute is a nationally recognized program in Shepherdstown, West Virginia, that works toward sustainable solutions to environmental and conservation challenges. The main focus of the Freshwater Institute's programs is the conservation and efficient use of water resources through the development of cost effective, efficient, and sustainable aquaculture technologies. The Freshwater Institute's web page contains an excellent set of publications and design manuals for recirculating and aquaponics, developed primarily for high school aquaculture learning labs in West Virginia and Alabama.

The following publications can be found by following web links to *Education and Outreach* & *Aquaculture in the Classroom*:

Computer Monitoring and Control Technology
The Freshwater Institute
http://www.conservationfund.org/conservation/freshwater/pdffiles/cmc98.pd

Suggested Management Guidelines for an Integrated Recycle Aquaculture - Hydroponic System
The Freshwater Institute
http://www.conservationfund.org/conservation/freshwater/pdffiles/grobedom.pdf

Linking Hydroponics to a 880-Gallon Recycle Fish Rearing System
The Freshwater Institute
http://www.conservationfund.org/conservation/freshwater/pdffiles/igrobed.pdf

Operator's Manual for 880-Gallon Recycle System
The Freshwater Institute
http://www.conservationfund.org/conservation/freshwater/pdffiles/800man.pdf

880-Gallon Recycle Aquaculture System Installation Guide
The Freshwater Institute
http://www.conservationfund.org/conservation/freshwater/pdffiles/sysiman.pdf

Why Use Aquaculture as an Educational Tool?
The Freshwater Institute
http://www.conservationfund.org/conservation/freshwater/pdffiles/whyaqua.pdf

In addition, a series of very informative lesson plans on aquaculture from The Freshwater Institute can be found on the ReadiSkills web site.
http://www.cesd.wvu.edu/readiskills/

The complete set of aquaculture lesson plans costs $275

Module I: Determining the importance of aquaculture
Module II: Establishing a recirculating system for aquaculture production
Module III: Exploring the biology of aquaculture
Module IV: Using principles of microbiology
Module V: Managing water
Module VI: Reproducing fish
Module VII: Rearing fish

S&S Aqua Farm
http://www.townsqr.com/snsaqua

Cabbage Hill Farm
http://www.cabbagehillfarm.org/home.html

ADM Aquaculture and Hydroponics
http://www.admworld.com/about/overview/aqua.htm

Mineral County Vocational Technical Center – Aquaponics Project
http://168.216.197.6/aqua.htm

University of the Virgin Islands – Aquaponics
http://rps.uvi.edu/AES/Aquaculture/aquaponics.html

Aquaponics Technology Center
http://www.aquaponics.com/atclinkshtml.html

Aquaponics from Global Aquatics
http://www.aquatic-technologies.com/aquaponics.htm

Aquaponics Journal
http://www.aquaponics.com/

The Growing Edge Magazine
http://www.growingedge.com

EcoGenics
http://www.dabney.com/ecogenics/

Aquaculture on the Web

Regional Aquaculture Centers sponsored by the Extension Service:

Northeastern Regional Aquaculture Center
http://www.umassd.edu/specialprograms/nrac/

North Central Regional Aquaculture Center (NCRAC)
http://ag.ansc.purdue.edu/aquanic/ncrac/index.htm

Southern Regional Aquaculture Center
http://www.msstate.edu/dept/srac/

Western Regional Aquaculture Center
http://www.fish.washington.edu/wrac/newsletter.html

Center for Tropical and Subtropical Aquaculture
http://library.kcc.hawaii.edu/CTSA/

Aquaculture Network Information Center
http://www.aquanic.org/

Fisheries Publications at Texas A&M
http://agpublications.tamu.edu/pubs/efish/

Southern Regional Aquaculture Center publications at Texas A&M
http://agpublications.tamu.edu/pubs/efish/srac.htm

Aquaculture Magazine's Product Guide
http://www.aquaculturemag.com/products/product.html

US Tilapia Market & Price Update
http://www.fishfarming.com/usmarket.html

Aquaculture Journal from Elsevier
http://www.elsevier.com/locate/aquaculture

An international journal devoted to research on the exploration, improvement and management of all aquatic food resources, both plants and animals. This website provides Table of Contents and Abstracts for back issues to 1990.

Aqua-Vegeculture Systems: Mineral Content and Yield of Bush Bean, Cucumber, and Tomato Cultivated in Sand and Irrigated with Recirculating Aquaculture Water.
By M. R. McMurtry, P.V. Nelson and D.C. Sanders
Department of Horticultural Science, North Carolina State University
In: Rodales' International Ag-Sieve, Vol. 1, No. 3
http://fadr.msu.ru/rodale/agsieve/txt/vol1/3/art7.html

Integrated Bio-Systems on the Web

Integrated Bio-Systems in Zero Emissions Applications
Proceedings of the Internet Conference on Integrated Bio-Systems
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Sustainable Aquaculture and Aquatic Feeds
By Ronald Hardy
Aquaculture Magazine
http://www.aquaculturemag.com/html/hardy.html

Wastewater-fed Aquaculture: State of the Art article by Peter Edwards
AARM Newsletter, A Quarterly Newsletter of the Aquaculture and Aquatic Resources Management Program. Vol. 4, No. 1, January 1999.
Asian Institute of Technology (AIT)
http://www.agri-aqua.ait.ac.th/scripts/aqua/newsletters/detail.cfm?ID=233

Wastewater-Fed Aquaculture Systems: Status and Prospects publication by
Peter Edwards
Aquaculture and Aquatic Resources Management Program, Asian Institute of Technology (AIT)
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Volume IV, Number 5, 1992
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Integrated Bio-System at The Center for Regenerative Studies, California State Polytechnic University in Pomona, California
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Ecological Engineering journal from Elsevier
http://www.elsevier.com/locate/ecoleng

Ecological engineering has been defined as the design of ecosystems for the mutual benefit of humans and nature. Specific topics covered in the journal include: ecotechnology; synthetic ecology; bioengineering; sustainable agroecology; habitat reconstruction; restoration ecology; ecosystem conservation; ecosystem rehabilitation; stream and river restoration; wetland restoration and construction; reclamation ecology; non-renewable resource conservation.

Wastewater-fed Aquaculture in Temperate Climates - Nutrient recycling with Daphnia and Fish
Abstract at the 4th International Conference on Ecological Engineering for Wastewater Treatment — Managing the Wastewater Resource June 7-11, 1999 - Aas Norway
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Sustainable Urban Biodegradable Waste Utilization Modules
http://www.fishace.demon.co.uk/subwum.htm

The electronic version of **Aquaponics-Integrating Hydroponics with Aquaculture** is located at:
http://www.attra.org/attra-pub/aquaponic.html

By Steve Diver,
NCAT Agriculture Specialist

February 2000

Appendix:

Bibliography on Aquaponics

The following bibliography contains the bulk of articles on aquaponics published in the agricultural literature; a notable exception are those articles that have appeared in the recent Aquaponics Journal. Many of these publications will only be available through a land-grant university library, the Inter-Library Loan service at local libraries, or through a document delivery service. Nevertheless, they are provided here as an important time saver to those seeking technical and popular information on this topic.

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