A Numerical Comparison of Two Approaches to Commercial-Scale Aquaponics

Dr. Mark McMurtry's comparison of the two schools of aquaponics shows that the media-based, "flood/drain" approach outperforms, by a wide margin, the hydroponic raft system.

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NOTE: This document is presented to the aquaculture / aquaponics community as a point of discussion, based on science, design and the interests of increased food security. Comments are solicited in the same spirit.

"In nearly all matters, the human mind has a strong tendency to judge in the light of its own experience, knowledge and prejudices rather in the light of the evidence presented. Thus, new ideas are judged in the light of prevailing beliefs. If the ideas are too revolutionary, that is to say, if they depart too far from the reigning theories and cannot be fitted into the current body of knowledge, they will not be acceptable. When discoveries are made before their time they are almost certain to be ignored or meet with opposition that is too strong to be overcome, so in most instances they may as well not have been made."
W.I. Beveridge. 1957. The Art of Scientific Investigation. Random House, New York, NY

"Most men think that they think but what they are actually doing is rearranging their prejudices." - Bertrand Russell

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Dr. Mark McMurtry is widely acknowledged as creating a science of aquaponics when he was at NC State University in the mid-eighties to early nineties. His method, which he called IAVS, (Integrated AquaVegeculture System), is better known today as *flood-and-drain*. It is favored by backyard practitioners around the world, with a few examples of commercial systems.

Prior to the mid-eighties, aquaponics was merely a sketchy concept of plants growing in fish tanks, originated at The New Alchemy Institute[1]. There had been little, if any research and development. Since then the concept has developed into various forms, methods and sizes, branching off around the world, but

A Profile of Mark McMurtry

In the mid 1980's, Mark was an NCSU grad student initially focusing on International Development, not a scientist. When he learned of the New Alchemy aquaponics concept, he saw opportunity. Over the next few years, he moved into the world of science and engineering and was given the lead role in a team of world-class researchers to support and validate his research which earned him a unique 3-faceted PhD. Over time, as major agri-biz companies came to investigate the invention's patent potential, Mark quickly "open-sourced" the data and rendered it unpatentable. This opened the door for an entire generation of hobbyists and horticulturists to discover what we today call flood-and-drain aquaponics. Today Mark lives off the grid on top of a mountain near Three Forks, Montana.

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[1] http://en.wikipedia.org/wiki/New_Alchemy_Ins

limited to hobbyists, universities and the occasional entrepreneur. Today it is variously described as an “industry” or “movement”. There is clearly positive growth in various regions, as well as occasional setbacks, due to prominent missteps. Yet considering the real and proven value of this technology it is something of a mystery as to why it is not further advanced, creating new economic opportunities and jobs based on locally-grown organic fish and vegetables.

How big is that opportunity? A recent detailed study[2] by Karp Resources indicates that in Louisville, KY, with a population of about 1.2 million, *“Total demand for local foods…is $258 million among consumers and $353 million among commercial buyers.”* This exhaustive survey and analysis clearly puts a target value that can be scaled to other metro areas and begin to figure in to investor spreadsheets.

Two Approaches, One Goal: More Food Faster

Aquaponics is a broad term that covers two approaches, both of which involve converting fish waste to nutrients for plants. There are two distinct paths, or methods, that today’s systems follow. One is the floating raft system by Dr. Rakocy at the Virgin Islands. The other is Dr. McMurtry’s IAVS, which closely mimics a tidal wetland, with plants growing in sand, gravel or other non-soil medium.

Some commercial systems today are beginning to integrate the two methods.

The UVI raft method is a hybrid of traditional hydroponics and aquaculture. In large-scale hydroponic systems, shallow troughs full of water support floating foam panels with plants in net pots, with the roots extending into the water. The water is amended with nutrients (whether purchased or produced by fish waste, or both). The water troughs require their own aeration system. The UVI aquaculture component consists of large tanks, above ground, with water that is recirculated through various filters and plumbing systems to refine the fish waste before its basic nutrients are introduced to the hydroponic ponds. After the water is passed through the ponds, it drains to a sump tank, where it is pumped back to the fish tank.

The IAVS system, by contrast, is far simpler. Fish tanks below ground[3] are adjacent to grow beds (or “biofilters”) containing grow media, such as sand, gravel or any other small mineral particle with high surface area, where the aerobic bacteria population can flourish. The beds are lined with pond liner. The plants are positioned directly into this media without pots, and the fish tank water is flushed across the surface, trickling to a drain that returns to the fish tank. There are no filters, degassing columns, sumps, Styrofoam panels, pots or aeration for the grow beds. Obviously the cost is far lower to implement and to operate, with fewer components to manage or risk failure.

Similarities

As far as similiarites, each system:

- Is considered a form of Recirculating Aquaculture System (RAS).
- Relies on the nitrification process of aerobic bacteria converting fish waste solids and liquids to usable nutrients for plants.

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[2] http://jefferson.ca.uky.edu/sites/jefferson.ca.uky.edu/files/122861902-Demand-Study.pdf

[3] Above ground tanks are also possible.

- Uses fish food as the sole nutrient input.
- Relies on system aeration in various forms to enable microbial growth.
- Is able to produce impressive yields of fish and vegetables.
- Relies on existing technologies of water pumps, plumbing, pond liners, plastic tanks, etc.

System Differences

The UVI system requires more labor, with regular cleaning of its filters and excess waste discarded or used in soil farming. It is far more complex and costly to build and to operate, especially in cold climates. The skill level and potential for equipment failure is also increased. All of these factors add up to a system that is less scalable and more risky for operators and investors. Of course the UVI system is very successful as a producer of fish and vegetables, even compared to traditional hydroponics. However technology evolves toward simplicity. Less efficient systems are eventually modified or abandoned.

The IAVS system demonstrates simplicity, especially the low-tech concept for export to remote areas of the world. It is as close in design to a natural wetland ecosystem as possible. With a single pump, a solar panel and some pond liner it is quite possible to create a low-budget, off-grid system.

Larger "high-tech" commercial IAVS designs build on the original simplicity. Lower development cost allows for creative variations in tank placement and configuration, water heating systems (crucial for tilapia in cold climates) and grow bed construction. Warm water, heated by natural gas, solar or biomass also can serve to heat ambient air in greenhouses far more efficiently than traditional forced air. Advanced sensors and control systems, found in state-of-the-art greenhouses are more affordable with IAVS. Many higher-end solutions exist to enable remote 24/7 monitoring, resulting in greater yield predictability and less risk. Other cutting edge materials include greenhouse components such as glass panel products that generate electricity while allowing light to pass.

The relatively low system cost of IAVS allows for the greenhouse to be included as an integral component of the operation, as they should be. Many of the new aquaponics companies in the upper Midwest do not even use greenhouses, opting for retrofitting of warehouses, with high infrastructure and artificial lighting costs. And the design of a Hawaii greenhouse is not the same as it is in Georgia, Vermont or the high deserts of Afghanistan.

Although the IAVS system has been limited mostly to the small-scale backyard growers around the world, it has been successfully proven on a commercial greenhouse scale at least twice. In the mid-nineties, a public health doctor, Dr. Boone Mora worked with USDA (NRCS) representative Tim Garrett in Eastern North Carolina. They received a $100,000 government grant to develop a 10,000 square foot greenhouse using Dr. McMurtry's method. It operated successfully for 16 months and was documented by Dr. Mora and affirmed by Mr. Garrett as a viable and effective method.[4] It was toured by thousands of curious visitors and its flavorful tomatoes and cucumbers were in extremely high demand at local markets.[5]

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[4] Documentation available from AquaPlanet.

[5] One lesson learned: Maintain limited public access through a controlled environment greenhouse or it will introduce pathogens. Boone Mora is available for further comment.

A better-known example, in Missouri, was started also in the mid-nineties by Tom Speraneo and his family. They operated S&S Aqua Farms as a modest greenhouse operation for about ten years before Tom died in 2004.[6] It received impressive reviews in the horticulture press and was perhaps an inspiration to the early backyard enthusiasts who have been successful in creating even smaller and simpler systems.

The point here is that there is great opportunity for innovation in integrating aquaponics and greenhouses, based on the simplicity of flood/drain IAVS. The resulting yields in a properly designed system can easily go far beyond what amazes us today with even the basic aquaponics systems. This brings up the concept of *system optimization*.

System Optimization

Any engineered system is designed with a goal of optimal results, with greatest results from minimum input, also known as efficiency. Car engines, for example, have been continuously evaluated and updated for over one hundred years with a goal of more power, less fuel at a reasonable price. The difference is that car engines are far easier to engineer for optimal performance than an agricultural biosystem, with so many variables and changing dynamics, including:

- Climate
- Seasons
- Energy costs and methods
- Pathogens & pests
- Human factors
- Untested crop performance

With proper peer-reviewed research and development, we will begin to see real examples of optimized production.

Scalability Factors

A key factor towards encouraging industrial growth is scalability, which, in our opinion, has been lacking in aquaponics. The term is most often used in computing, as in "*capable of being easily expanded or upgraded on demand*" or *"the ability to enhance a system by adding new functionality at minimal effort or cost."* The dominant model of commercial aquaponics, the raft system, in its current design, is far less scalable than the IAVS.

According to Dr. McMurtry, the IAVS method also greatly improves on the yields, and with significantly lower operating costs. This adds further weight to the advantages of IAVS, even with a large margin of error. Without side-by-side comparisons, of course, we can only speculate, based on published numbers. We present this data with a goal of more scientific comparisons in the future.

This is not to dismiss the raft system out of hand, as it will likely continue to prove its value as a specialized enhancement. For example, it is more closely compatible with the existing commercial hydroponic greenhouse industry, which has its own unique efficiencies for producing greens in ponds and NFT systems (nutrient film technology). It appears, however,

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[6] Numerous attempts to contact the Speraneo family have not been successful.

that the raft system needs to continue evolving towards simplicity and modularity to be truly scalable.

Dr. McMurtry's intricate methodologies in measuring the many parameters of an aquaponics system warrant further investigation. We maintain that his work will serve as an industry benchmark, and that additional R&D funding should be applied to replicate and improve on it.

If there are other models that approach this level of detail, in terms of development costs, operating efficiency, production yields, energy consumption, labor costs and nutrition value, we invite comparisons.

The Tables

Dr. McMurtry recently produced an intricately detailed spreadsheet of the numbers comparing the floating raft aquaponics method with IAVS. His numbers show that the two systems are quite distinct in many variables, and that the published volume and depth of parameters of the UVI system does not come close to IAVS. It should be noted that his work at NC State University was supported and reviewed by a world-class ag research team.[7]

The Excel spreadsheet, called *UVI vs IAVS* extends to 250 rows and includes highly detailed calculations, notes and qualifications. We have slightly edited and reformatted the document here for public review and comment.

Dr. McMurtry refers to two variations of IAVS, one low-tech, one high tech. The low-tech design is for remote areas using minimal resources, solar PV to operate the pumps, aeration accomplished by return water splashing.

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[7] See list of supporting scientists at End Notes

Summary of Calculations, IAVS vs UVI Raft System

IAVS Productivity Relative to UVI Performance Data
Dr. Mark McMurtry, Published by AquaPlanet, 2013

Fish Aspects in Red, Plant Aspects in Green

Comparisons based UVI document, by Dr. Rakocy, et al:
http://ag.arizona.edu/azaqua/ista/ista6/ista6web/presentation/p676.pdf

Production Density (Biomass / Composite Area)	
IAVS is	116-fold (times) fish biomass produced per composite area / time
IAVS is	39-fold+ (times) edible plant biomass per composite area / time
Water Use Intensity (Biomass / Total System Volume	
IAVS is	4.8-fold (times) fish biomass produced per total system water volume
IAVS is	14.7-fold edible plant biomass per total system water volume (plus far more nutritious/marketable species)
Water Use Efficiency (Biomass / Annual Total H^2O Usage)	
IAVS is	3.1-fold increase in fish biomass produced per annual total water volume 'used' (incorporated into tissue and 'lost' to evapotranspiration)
IAVS is	9.6-fold increase in edible plant biomass per annual total water volume used (with far higher nutraceutical, vitamin etc content)
Biomass Increase (Production Biomass / Time)	
IAVS is	40%+ increase in fish biomass produced (same or better FCR (same feed) + alternative/supplemental feed options with IAVS)
IAVS is	420%+ increase in edible plant biomass (much higher food-value, botanical-nutrients and market values ($/kg))
IAVS is	600 to 700% increase in total plant biomass (non-edible fraction used as fish feed (direct and/or indirect)
Resource Utilization Efficiency	
IAVS is	103% of mean UVI feed conversion ratio (identical or slightly better FCR - not included in resource use determination below)
IAVS is	<34% UVI electrical power consumption/requirement (or far less - to potentially none in lo-tech, manual IAVS systems)
IAVS is	≈ 10% of UVI equipment costs (or less - ntm land value) - no expensive high-tech (specialized) materials/equipment necessary
IAVS is	≈ 16% of UVI land area or less - more than sufficient production intensity to be highly economic in controlled environmental production facility)
Labor Component	
	30% of (70% less) aquaculture labor (time) - no filter cleaning, sludge disposal 3x daily+ with same (or less) feeding, monitoring, & harvesting demands.
	?% (≈2-fold ?) greater horticulture labor costs (fruit harvesting/grading, staggered production timelines, multi-species crop rotations)
Means (averaging above, equal weighting)	
Above	fish production aspects = 31.3-fold
Above	plant performance aspects = 14.7-fold
Above	resource use (w/o feed or labor) = 18.7% or < 3/16th (an 80%+ decrease in land/water use)
Overall	
	43.4-fold greater productivity generated from (/) 0.1875 resources =
	^^ Under equal performance-factor (aspect, criteria) weighting: ^^^ i.e., 3/16th resource input yielding 43.4 x biomass output / time
	>> (31.3 14.7 / 0.1875 = 245-fold increase in composite (aggregate) resource utilization intensity/efficiency.

<table>
<tr><th colspan="6">Area Usage</th></tr>
<tr><th>COMPONENT</th><th>UNIT</th><th>UVI, High Tech (1:1.45 v:v)</th><th>IAVS Low Tech (1:2 v:v)</th><th>IAVS High Tech (1:1.5 v:v)</th><th>UVI dimensions not stated, area calculated from photos as 12 x 20 m min.</th></tr>
<tr><td>Aquaculture
(all area, not just tanks)</td><td>m^2</td><td>240</td><td>16 to 24 (20)</td><td>12 to 16 (14)</td><td>< (mean used) ||| UVI photograph scale estmate/calculation to right ></td></tr>
<tr><td>Horticulture (tanks only)</td><td>m^2</td><td>214 (+all access areas)</td><td>100 to 200 (150)</td><td>116 to 142 (129)</td><td></td></tr>
<tr><td>Other (access/aisle/perimeter)</td><td>m^2</td><td>640 (plus)</td><td><10% (10)</td><td><20% (27)</td><td>stated as 500 m2 (actual tanks) plus 150% to 200% of aisle/access area</td></tr>
<tr><td>Sludge lagoon aspect</td><td>m^2</td><td>100</td><td>0</td><td>0</td><td>lagoon pits plus adjacent access perimeter area</td></tr>
<tr><td>Total (UVI minimum)</td><td>m^2</td><td>1,200</td><td>120 to 240 (180)</td><td>150 to 190 (170)</td><td>mean area used in subsequent unit area calculations</td></tr>
<tr><td>fish biomass / composite area</td><td>kg/m^2/yr</td><td>1.73</td><td>78</td><td>200.6</td><td></td></tr>
<tr><td>veg biomass (edilble)</td><td>kg/m^2/yr</td><td>3.12</td><td>52</td><td>121</td><td>at 50:50 crop species mix below/avg area</td></tr>
<tr><th colspan="6">System Volumes</th></tr>
<tr><td>Aqua Rearing Tank</td><td>m^3</td><td>31.2</td><td>31.2</td><td>31.2</td><td>all calculations based on constant fish rearing tank volume</td></tr>
<tr><td>Horticulture</td><td>m^3</td><td>45.2</td><td>62.4</td><td>46.8</td><td></td></tr>
<tr><td>Other tanks</td><td>m^3</td><td>33.6</td><td>0</td><td>0</td><td></td></tr>
<tr><td>Total system volume</td><td>m^3</td><td>110</td><td>31.2</td><td>31.2</td><td>the IAVS biofilter volume is **NOT** a water volume</td></tr>
<tr><td>Fish biomass / total system vol.</td><td>m^3</td><td>19</td><td>50</td><td>90</td><td>mean area used in subsequent unit area calculations</td></tr>
<tr><td>Edilble plant biomass / system vol.</td><td>kg/m^3/yr</td><td>34</td><td>250</td><td>500</td><td>at 50:50 crop species mix below/avg area</td></tr>
</table>

Water Use					
COMPONENT	**UNIT**	**UVI, High Tech (1:1.45 v:v)**	**IAVS Low Tech (1:2 v:v)**	**IAVS High Tech (1:1.5 v:v)**	actual UVI flow rates are NOT stated nor readily derivable
Mean Flow Rate	m^3/hr	15 to 23	1.3	2.6	UVI data provided results in differant flow rates for aqua and hort aspects
Water Flow Rate	m^3/d	440	31	62	or less
Water Use (Loss)	m^3/d	1.7	0.5	0.8	
Waste Discharge		YES (substantial)	none	none	
Annual Water Volume	m^3/yr	731	202	316	
Fish biomass / Annual Volume	kg/ m^3	2.84	7.72	8.89	
Plant biomass (edilble)/ Annual Volume	kg/ m^3	5.12	38.61	49.38	50:50 crop mix below/avg area
Equipment (not including greenhouse)					
Rearing Tanks		4	Hole/Pit (1)	Tank/Channel (1)	
Sump Tank		1	none	none	
Base Addition Tank/equipment		1	none	none	automated chemical pH adjustment
Clarifying Tanks		2	none	none	relatively expensive/specialized tank
Filler (Secondary) Tanks		2	none	none	continuous removal of Ch^4, Co^2, H^2S and N^2
Degassing Tank		1	none	none	
Water Pump		1	1	1	
Air Blowers		2	none	1	
Rearing Tank Air Stones		88	none	60	
Hydroponic Tanks		6	Media biofilter	Media biofilter	IAVS biofilters are not tanks and are not a system water volume
Hydroponic Aeration		144	none	none	
Pipe, Valves, Fittings, Air Line		1000+	1	<100	relative feet/pieces in (as) order of magnitude
Regular Nutrient Additions		FE, micronutrients, P?, K?	none	Maybe Vitamin B	varies by/dependent upon elemental composition of feed input(s)
pH Maintained (Aqueous)		7.2 to 7.5	6.3 to 6.9	6.5 to 6.8	

Power Usage (not including heat)					
COMPONENT	UNIT	UVI, High Tech (1:1.45 v:v)	IAVS Low Tech (1:2 v:v)	IAVS High Tech (1:1.5 v:v)	IAVS hi-tech to 2 hr/day ('easily' powered from photovoltaics)
Pumps	HP	0.5	0	0.25	IAVS lo-tech, > manual pump or callabash (bucket)
UVI, Constant Flow	kWh/d	9.0	0	0.37	
Aeration	HP	2.5	0	1	cascade aeration in a IAVS lo-tech system requires no power input
Aeration	kWh/d	44.8	0	17.9	aeration power would need battery storage for nighttime operation
Total	kWh/d	53.7	0	18.3	

Fish Yields					
Live Weight / Tank Volume	kg/m^3/yr	62 to 71	40 to 60	70 to 120	mean (average) rate employed in unit area & volume calculations (above)
Live Weight / Annual Volume	kg/m^3/yr	2.84	7.72	8.89	
FCR (Feed Conversion Ratio, mean)	X:1	1.6 to 2.1 (1.75)	1.2 to 2.8 (1.5)	1.4 to 1.8 (1.7)	lower is better /more efficient conversion of feed to fish biomass
Yield at this scale	kg/year	2,075	1,560	2,808	IAVS yield calculated at mean (average) rate
Horticulture Yields					
Basil (typical for greens)	kg/m^2/yr	23.4	(good but no data)	(good but no data)	Typical yields for greens is 1 lb / sf / month - editor
	kg /yr	5,008			
Okra	kg/m^2/yr	2.67			at 50:50 crop species mix below/avg area
	kg /yr	2,476			
Tomato	kg/m^2/yr	Not applicable	48	96	IAVS at 4 and 8 kg/plt x 4/m2 x 3 crop/yr, respectively
	kg /yr		6,240	12,480	
Cucumber	kg/m^2/yr	Not applicable	72	144	IAVS at 4.5 and 9 kg/plt x 4/m2 x 4 crop/yr, respectively
	kg /yr		9,360	18,720	
This Scale	kg /yr	3,742	7,800	15,600	
Vegetable Species		lettuce, collard, kale, mustard, greens only	ANY / ALL in theory	eggplant, sweet pepper, hot peppers, beans (legumes), peas, cantelope, muskmelon, squashes, beets, chard, others : agroforestry seedling, veg transplants, cut flowers, culinary herbs, medicinal herbs, ornamentals	

Conclusion

As aquaponics continues to develop as a commercial industry, it’s important that these evaluations and standards are discussed publicly. We hope this information will serve as a catalyst for further research and development and help aquaponics prove itself as more than a novelty.

End Notes

IAVS Research Group, North Carolina State University

Investigators and Consultants 1986 to 1992

Principle-Investigator	**Discipline(s):**
Mark R. McMurtry, Ph.D.	Horticultural Science, Integrated Bio-production Systems, Environmental Design, International Development

Co-Investigators:	**Discipline(s):**
Edward A. Estes, Ph.D.	Agricultural and Aquacultural Economics
Blanche C. Haning, Ph.D.	Integrated Pest Management and Plant Pathology
Ronald G. Hodson, Ph.D.	Aquatic Ecosystems and Fisheries Management
Paul V. Nelson, Ph.D.	Botanical Mineral Nutrition & Greenhouse Management
Robert P. Patterson, Ph.D.	Agronomy, Soil Fertility, & Plant Physiology
Douglas C. Sanders, Ph.D.	Horticultural Science and Plant Physiology

Principle Consultants:	**Discipline(s):**
J. Lawrence Apple, P.h.D.	International Development, Plant Pathology
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Stanley W. Buol, Ph.D.	Geomorphology and Mineralogy
JoAnn Burkholder, Ph.D.	Pychology and Aquatic Ecology
James E. Easley, Ph.D.	Aquacultural Economics and Business
Donald Huisingh. Ph.D.	Ecology and Environmental Resource Recovery
Merle H. Jensen, Ph.D.	Agricultural Program Development
Thomas Lossodo, Ph.D.	Recirculatory Aquaculture
L. George Wilson, Ph.D.	Horticultural Science and Extension

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Peter Cooke, Ph.D.	Intensive Aquaculture Systems (Disney World, EPCOT)
R. Jack Downs, Ph.D.	Controlled Environment Agricultural Research
Kevin Fittsimmons, Ph.D.	Intensive and Recirculatory Aquaculture (ERL)
Larry D. King, Ph.D.	Sustainable (Low-input) Agricultural Systems
John Lavine, D.V.M	Veterinary Medicine, Cichlidae spp. specialist
Michael Linker, Ph.D.	Enttomology and Integrated Pest Management
Steve Malvestuto, Ph.D.	Fisheries Assessment and Development
George A. Marlowe, Ph.D.	Horticulture Research and Development (AVRDC)
Robert H. Miller, Ph.D.	Soil Nutrition and Microbial Ecology
Richard A. Neal, Ph.D.	International Aquaculture Development (USAID)
Edward Noga, D.V.M	Veterinary Medicine, Aquatic vertebrates
Glenn W. Patterson, Ph.D.	International Agro-Industries Development (ATI)

James E. Rakocy, Ph.D.	Recirculatory Aquaculture (Univ. of the Virgin Islands)
Pedro A. Sanchez, Ph.D.	Tropical Soils Management
John C. Sager, Ph.D.	Controlled Environmental Life Support Systems (NASA)
Ronald Sneed, Ph.D.	Agricultural Engineering, Irrigation Systems
Kenneth Sorrenson, Ph.D.	Entomology and Greenhouse Pest Management
Carolyn A. Williams, Ph.D.	Vegetable Horticulture and Physiology

Other Technical Resources (partial)**:**	**Field:**
Reed Altman, M.S.	Aquaculture Development (US Peace Corps)
Ray Campbell, Ph.D.	Plant Nutrition and Tissue Analysis (NCDA)
Dale E. Ettel, Ph.D.	Fish Feed Formulation (Purina Mills, Inc.)
Vincent M. Foote, P.D.	Integrated Systems Design
Boone. M. Mora, D.V.M.	Commercial IAVS Demonstration project
Brandy Noon, M.A.	Presentation and Graphics Design
Stephen F. Pekkala, AIA	Architecture and Development Programming
Martin L. Price, Ph.D.	Development Assistance and Networking (ECHO)
Ray Tucker, Ph.D.	Soil Fertility and Analysis (NCDA)