INSTITUTIONAL CONSTRAINTS

to

INNOVATIVE TECHNOLOGY FOR MUNICIPAL WASTEWATER TREATMENT

A Greater Boston Case Study

By Krag Unsoeld

Submitted to the Department of Urban Studies & Planning
in Partial Fulfillment of the Requirements
of the Degree of
Master in City Planning

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Signature of Author ____________________
Department of Urban Studies and Planning
May 22, 1989

Certified by ____________________
John E. Ehrenfeld
Senior Coordinator, MIT Hazardous Waste Program
Thesis Supervisor

Accepted by ____________________
Donald A. Schon
Chairperson of MCP Committee

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ABSTRACT

Since the approval of the 1972 amendments to the Clean Water Act, it has been an explicit federal policy to encourage the use of alternative technologies. In 1977, Congress approved amendments implementing the innovative and alternative (I/A) technology program, which offered a financial incentive for using I/A technology, as well as providing funds for the research and testing of different proposals. I/A technology, by definition, must offer the potential to reduce costs or energy demand, to recycle water or other wastewater resources, or to eliminate pollutant discharge. Despite these advantages, however, innovative technologies are still generally rejected in favor of conventional methods. What are the institutional constraints facing innovative wastewater treatment technology?

This research involved three major components. The first task was to establish the appropriateness of using constructed wetlands as an innovative approach to wastewater treatment. Second, was examining the feasibility for using wetland processes for wastewater treatment in Greater Boston. This work was incorporated into a summary proposal for "solar aquatics" in Greater Boston comparing this approach to a conventional system in terms of cost, effectiveness, and miscellaneous other considerations, such as chemical toxicity and the potential for reuse of water. This proposal was circulated with personnel from the Massachusetts Water Resources Authority, the Department of Environmental Quality Engineering, and the Environmental Protection Agency. The third phase of the project was doing taped interviews with these agency personnel to obtain their responses to the proposal. The interview transcripts was used as data for doing qualitative social research to develop an understanding of the constraints facing solar aquatics in this particular case.

The analysis developed from this study examines the roles played by analytical categories, such as the professional identity of engineers, the public accountability of agency personnel, fear of bearing the liability for a failed project, and simply not wanting to risk pursuing a technology about which relatively little is known, in influencing the ultimate decisions as to whether or not to use innovative treatment. Some of these constraints, it was concluded, are an appropriate way of mitigating risk. However, these constraints are often inappropriately applied as a barrier to fully considering the advantages of innovative treatment technologies.

The research concludes by suggesting a process that could be used to facilitate greater use of innovative wastewater treatment technology. The process is based on the analysis that there are different goals to be achieved in treating wastewater, and these differences are reflected in the needs of different groups. For instance, farmers can use sewage plant effluent as irrigation, and solar aquatics can combine treatment with aquaculture. Similarly, environmentalists find that the final effluent from a process like solar aquatics can be used for efforts to restore wetlands and for water quality enhancement projects. Rather than simply disposing of a waste product, wastewater management can thus be regarded as a way of utilizing a valuable resource.

The process suggested is one that would incorporate all of these different perspectives concerning what do about wastewater, and how best to accomplish that, into a consensus-based policy making forum. In this way, all important considerations would be discussed, debated, and agreed upon by all parties that would be affected by the project: commercial and residential ratepayers, environmentalists, parties with a reason to want to reuse the resource, and so forth. The applicability of this proposal emerged not only from discussions with agency personnel, but also from examples that exist of using this type of forum for making policy decisions, often involving the use of natural resources.

Wastewater planners would be well-advised to consider some option like this consensus-based policy forum now for facilitating the development of advantageous innovative technologies, since the federal I/A program has been terminated. What incentives there were before are now gone. The best way to develop appropriate technology appears to be to originate the major proposals of what technology to use in a process that considers all aspects of the issue, and not just the technical engineering considerations.

This research is clearly not definitive in terms of the desireable approach to designing the process and so forth, but it offers some important insights into the nature of the constraints facing innovative technology for municipal wastewater treatment and what kind of process should be considered to overcome some of these.

Thesis Supervisor: Dr. John R. Ehrenfeld
Title: Senior Coordinator, MIT Hazardous Substance Management Program

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INTRODUCTION

The municipal wastewater treatment industry is in the process of going through a major transition in terms of the incentives provided to encourage the use of innovative and alternative (I/A) wastewater treatment technologies. This is an important issue for planners working for municipal sewage districts. The Clean Water Act, particularly as amended in 1977, was part of an effort by Congress to encourage the use of I/A wastewater technologies. This effort has resulted in a predominantly no-win contest for innovative proposals pitted against conventional wastewater treatment technologies. Now that the incentives for developing innovative projects through the federal construction grants program are being phased out the contest will most likely become even more one-sided against innovative technologies.

I am puzzled by this situation, especially when I learned about the use of constructed wetlands, and one version of this approach called "solar aquatics", which appear to be very promising in terms of overall cost, effectiveness, ease of operations, as well as other advantages. Why is it so difficult for a promising development like this to gain acceptance and approval within the wastewater treatment community? What are the institutional constraints within the agencies that regulate and operate a municipal sewer district that lead them to use conventional methods even when there are advantages to going with innovative technologies? These are the main questions for my research which is a qualitative case study of a proposal for an innovative technology in Greater Boston. This introduction explains the project in greater detail and presents the methodology.

MUNICIPAL WASTEWATER TREATMENT PLANTS IN THE U.S.

The debate of what to do with the polluted waters of the United States intensified with the approval of the 1972 amendments to the Federal Water Pollution Control Act (Public Law 92-500). This new law, which became known as the Clean Water Act (CWA), proclaimed the goal "to restore and maintain the chemical, physical, and biological integrity of the nation's waters," in which all communities and states were expected to participate. The CWA set an ambitious schedule of "zero discharge" -- meaning the elimination of the discharge of all pollutants to water by July 1, 1985.

A process was implemented for identifying and regulating all discharges of pollutants into the nation's waterways. This included a policy of issuing national pollution discharge elimination system (NPDES) permits which required stringent levels of waste treatment. The subjects of these permits were any identifiable operation discharging a certain amount of effluent. Publicly owned wastewater treatment facilities are one of the grantees of these permits.

These municipal wastewater treatment facilities are in the forefront of efforts to restore and preserve U.S. water quality. More than 7,000 plants are responsible for processing and treating approximately 30 billion gallons of raw sewage generated every day in the United States. However, some serious questions have been raised concerning how well they perform this task.

A report released in 1980 by the United States General Accounting Office (GAO 1980), the investigative, research arm of Congress, summarized their findings and recommendations based on a study of the performance of wastewater treatment plants. In a random sample of 242 plants in 10 states, 87 percent of the plants were in violation of their NPDES permits. Thirty-one percent of the sample were considered to be in serious violation, meaning that noncompliance was found during four consecutive months and exceeded the NPDES permit discharge limits by more than 50 percent.

Why weren´t wastewater treatment plants working as they are intended?

The report cited five major categories into which the reasons for the permit violations fell:

-- Design deficiencies -- problems with the actual design of the treatment facility keeping it from operating with full compliance.

-- Equipment deficiencies -- plant equipment which may have met minimum design standards, only to be determined to be lacking in performance, durability, and/or reliability during operation.

-- Operations and maintenance deficiencies -- plants were often understaffed with unqualified personnel. Some budgets were also inadequate to maintain and properly operate the facilities.

-- Infiltration/inflow overloads -- caused by groundwater entering sewer pipes, or combined storm and sanitary sewers, and often resulted in plant overloading and insufficient treatment.

-- Industrial waste overload -- caused when industrial waste contains toxics and/or high organic loads for which the treatment process was poorly designed.

In 1983, the GAO claimed that 3,400 (about half) of the nation's major wastewater treatment plants had been out of out of compliance with their discharge permits for a period of at least six months out of the previous year. Further, they submitted, one-quarter, or 1,760 of them, had been discharging at least 50 percent more of the pollutants limited by their NPDES permits for four months or longer. They had not examined the situation for the nation's smaller plants (Oppenheimer 1988, p. 16).

A similar study, conducted in 1984 by the Conservation Foundation, a non-profit research organization, concluded that more than 100 million U.S. citizens were served by treatment facilities that did not conform to their NPDES permits (Klockenbrink 1988).

A conclusion that could be drawn from statistics like these[1] is that something is seriously wrong with pursuing the goal of the CWA. As standards become more stringent, both the capital, and operating and maintenance costs increase (Reed et al. 1988). More trained operators are required as the equipment and process becomes technically more complex as more is learned, either about the character of the pollutants being treated, or about shortcomings of the process.

The U.S. Environmental Protection Agency (EPA) estimates that at least $79 billion will be needed to construct new facilities or bring the existing ones into compliance with their discharge permits (Klockenbrink

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[1] GAO has done no more recent study on this matter. The most recent figures along these lines that I found were not so specific, but still revealing. In 1988, over 40 percent of the nation's sewage facilities were said to have public-health and water-quality problems. About 150 communities still dump raw sewage directly into bays, lakes, and coastal waters (Marx 1988, p. 37).

1988). This assessment comes at a time when the federal government's construction grants and loan program is being phased out. This evolving regulatory climate will be discussed in Chapter One below.

INNOVATIONS IN WASTEWATER TREATMENT TECHNOLOGIES

New technologies are beginning to emerge in the field of wastewater treatment and management. The procedures that most interest me can best be described as "nature-mimicking" in that they try to incorporate the natural logic of ecological processes into an operation that will effectively eliminate the assorted health and pollutant effects of wastewater.

In their recent book, Natural Systems for Waste Management & Treatment, environmental engineers Sherwood Reed, E. Joe Middlebrooks and Ronald W. Crites, differentiate the emerging systems from the ones that are more conventionally employed. All wastewater treatment facilities do use some natural process -- physical, biological, or chemical. However, they contend that the old style generally requires an extensive array of complex, energy-intensive machinery and equipment to sustain the treatment process. The new "natural" approach, such as using wetlands for wastewater treatment and renewal, effectively incorporates ecological processes so that the system becomes self-sustaining. It is also less costly both to construct and operate.

Ironically enough, this new approach is also the oldest. Wetlands, otherwise known as swamps, bogs, marshes, and so forth, are the oldest waste treatment "facilities" around. Communities and scientists discovered that wetlands can be used for processing their wastewater. Natural marshes can provide advanced levels of treatment (Kadlec 1987, Best 1987). But these marshes, once thought of as wastelands, are now more fully understood in terms of their vital environmental functions (Nichols 1988). Under the CWA and other laws and regulations, wetlands have now obtained a protected status. Even the discharge of distilled water quality effluent is impermissible in many instances.

This new protected status has led to the development of what can be referred to as "designer marshes." Communities wishing to use wetland processes for wastewater treatment and renewal, are now designing and constructing their own wetland. This approach avoids the restrictions placed on wastewater discharge into natural wetlands, and also allows for the optimization of the treatment function of the wetland.

The benefits to this innovative approach are beginning to be recognized. Chapters Two and Three will discuss this topic further. A recent report by the Tennessee Valley Authority (Steiner et al. 1988) cited the potential advantages as follows:

1. relatively low capital and operating costs;
2. effectiveness in removing pollutants from wastewater able to meet secondary and advanced treatment standards;
3. flexibility in receiving organic and hydraulic load variations;
4. operational and maintenance simplicity;
5. solids are not separated to cause sludge -- they are deposited in the wetland so that it also serves as a sludge disposal unit at no extra cost; and
6. the possibility to create or restore habitat for wildlife species.

INSTITUTIONAL CONSTRAINTS TO INNOVATIONS

Constructed wetlands must go through the same approval process as other technologies when they are considered for wastewater treatment in Massachusetts. First, a community or agency must submit a proposal. Next the Massachusetts Department of Environmental Quality Engineering (DEQE) and the Environmental Protection Agency (EPA) must approve the plan by granting the necessary permits and construction grants if these are available. In this process, developing technologies encounter certain patterns within the institutions making decisions concerning their future. These patterns reflect what is often described as the inflexible nature of institutions which generally inhibit innovations and change (Foster & Southgate 1983). Understanding institutional constraints is important for planners since these constraints can often be the source of rejection for the technology despite its technical, scientific, and economic feasibility and benefit.

By definition, an institution is an organization or establishment for the accomplishment of a particular object, often one for some public purpose. It is also an organized pattern of group behavior -- a well-established and accepted practice that has become a fundamental part of a culture. Institutional thus refers to either the formal aspects of an organizational structure, or else of the less tangible, but analytically important, established processes within that structure. These implicit institutional norms are ones that can most affect the behavior of individuals. An important norm or convention discussed in this study is the professional training as an engineer. This plays a significant role in standardizing and conventionalizing responses to innovative technology.

SCOPE AND METHODOLOGY OF THIS THESIS

The thesis that I researched is that institutions inappropriately constrain the use of innovative technologies. To develop insights into this hypothesis I conducted a qualitative case study. Rather than reading the literature on this subject and conducting secondary analysis, I simulated the process of agencies deciding on a wastewater treatment technology by eliciting authentic agency responses to a specific proposal for an innovative technology.

The case study used is based on a proposal to adopt "solar aquatics" in Greater Boston. I selected Greater Boston, meaning the 43 communities having sewer services provided by the Massachusetts Water Resources Authority (MWRA), since I wanted to investigate the behavior of large-scale public agencies. Solar aquatics is one form of simulated wetland that offers advantages for a densely populated region in a cold climate.

The research methodology consists of several parts. The first task was to familiarize myself with the wastewater treatment industry and to learn enough about constructed wetlands to know that this innovative approach truly merits serious consideration by wastewater treatment agencies. This required extensive research into the literature that has emerged during the last two decades on the subject. The appropriateness of using constructed wetlands is discussed in Chapter Two.

The second task was to assess the feasibility of using solar aquatics in Greater Boston. This portion of my work was assisted by Ecological Engineering Associates in Falmouth, Massachusetts, the developer of solar aquatics. A discussion of the advantages of this approach and how it can be used in Greater Boston is presented in Chapter Three. The findings of Chapters Two and Three were assimilated into the proposal that was circulated to personnel with MWRA, DEQE, and EPA with whom interviews were conducted. The proposal is included as Appendix A.

The third task was to conduct interviews with the personnel who had been given copies of the proposal. These interviews were taped and later transcribed to serve as a basis for the analysis that I developed of institutional constraints facing solar aquatics in Greater Boston. The methodology that I was using to develop this analysis is known as "grounded theory" (see Glaser and Strauss 1967; Lofland and Lofland 1984). It was necessary to use grounded theory since I found that most of the literature on institutional constraints to innovative wastewater technology was descriptive in nature (see Chapter Four).

Grounded theory is a type of qualitative social research that uses either participant observation or intensive interviews to acquire data in the form of field notes and transcripts that is then used for developing a theory to explain the problem being researched. "The grounded theory method stresses discovery and theory development rather than logical deductive reasoning which relies on prior theoretical frameworks" (Charmaz, p. 110). As explained by Glaser and Strauss (1967), theory is "discovered" in the data from the research and so the methodology is appropriate for theory development rather than simply verification. The process involves inductive reasoning rather than a logico-deductive process.

During my analysis of interviews conducted with agency personnel, I looked for themes and categories (see Chapter Five) to help me explain the responses that were generated. The theory that I formulated concerns the apparent polarity between what I observed as an individual's personal values and beliefs and that same person's professional identity. This tension is clearly present in an individual's tendency to be risk averse thus inhibiting the selection of innovative proposals. I also found that public accountability and professional credibility play an important role in helping to explain the constraints that were present within the agencies I studied. These and other findings are presented in Chapter Six along with policy recommendations that could be used to assist the adoption of innovative wastewater treatment technologies.

My project is a case study involving a specific innovative technology for wastewater treatment, specific agencies, and a limited set of interview subjects so it is hard to generalize the theory that I developed. Nevertheless, this theory could prove instructive for planners working on projects using innovative technology where the decision makers are predominantly engineers, particularly if it is a municipal wastewater treatment project. The findings of this study could also be used to help guide additional research on institutional constraints and for studies that do theory verification.

CHAPTER ONE - HISTORICAL CONTEXT
The Changing Regulatory Environment

The risks to public health and the environment have long been important factors in the planning and implementing of water resource management policies. For instance, the ancient Greeks had this to say:

> Water is easily polluted by the use of any kind of drug. It therefore needs the protection of a law, as follows: Whoever willingly (or: purposely) pollutes water shall be obliged, in addition to paying an indemnity, to purify the spring or receptacle of the water, using whatever method of purification is prescribed by ordinance, at all times and to everyone.
> --Plato, Law 845

As the world's population has increased, problems presented by human fecal contamination have been magnified. Without a doubt, every nation has been afflicted at one time or another with the ravages of diseases borne by fecal contamination. Among these are intestinal parasites -- such as worms -- infectious diarrheal diseases, infectious hepatitis, poliomyelitis, cholera and typhoid. When the Revolutionary War occurred in 1776, the resident population of Boston was 2,700, down from 8,000 in 1701. A large part of this drop can be attributed to the ravages of waterborne diseases (KE, 1979). Wastewater policy developed as part of an effort to prevent these epidemics.

The 1972 amendments to the Federal Water Pollution Control Act (FWPCA) were another important step in this process. This law (Public Law 92-500), known as the Clean Water Act (CWA), declared as its objective "to restore and maintain the chemical, physical, and biological integrity of the nation's waters." One major thrust of the legislation was to standardize the level of treatment being provided by municipal wastewater plants. A goal was set to attain secondary treatment standards for all wastewater facilities by July 1, 1977, and for using the "best practicable waste treatment technology over the life of the works" by July 1, 1983. Stringent standards were also set for all other discharges, such as industrial, but I will restrict my focus to wastewater treatment measures.

Standards set forth in the CWA were intended to push the nation forward to "zero discharge" of pollutants into our waterways by July 1, 1985. This constituted a "technology-forcing" approach, in that the goal was to require use of equipment that otherwise might not have occurred. Mandating the use of technology was technically reasonable under the CWA since the necessary techniques were already available to turn all point sources of water pollution discharge into distilled drinking water. The major inhibiting factor was the cost.

The National Commission on Water Quality was established under the CWA to examine the costs of implementing the act. It estimated that the capital costs of achieving the zero discharge goal was $600 billion, in addition to substantial operating costs (Stewert & Krier, 1978, p. 516). In order to help financially, Congress created the construction grants program. This program served two purposes: to shift the primary burden of funding wastewater treatment plants into the federal purse, and to encourage the development of alternative technologies for wastewater treatment.

<u>Incentives to Innovate</u>

According to Sections 202(a) and 201(g)(2) of the CWA, EPA was authorized to award grants for 75 percent of the cost of wastewater treatment facilities constructed by municipalities, provided that "alternative waste management techniques have been studied and evaluated" by the grantee. Alternative systems were ones that would reclaim or reuse wastewater, productively recycle wastewater components, recover energy, or eliminate the discharge of pollutants. This approach reflected congressional desire to restrict the costs of the clean water program, and to place itself firmly on record for supporting alternative technology.

In 1977, Congress once more acted in response to the continued opposition by communities and engineers to adopting alternative strategies for wastewater treatment. New amendments to the CWA (P.L. 95-217) were approved, establishing a difference between alternative and innovative technologies. **Alternative technologies** were defined as proven methods of wastewater treatment that were not conventionally chosen by municipalities and their contracted consulting engineering firms. Alternative means of treating effluent included land treatment, aquifer recharge, aquaculture, silviculture, direct reuse (non potable), horticulture, revegetation of disturbed land, containment ponds, treatment and storage prior to land application, and preapplication treatment.

Innovative technologies were defined as methods of wastewater treatment not fully proven under the circumstances of their intended use. Due to this unproven characteristic, innovative technologies are considered more risky than either alternative or conventional techniques. According to the EPA:

> Innovative Technologies can come about as:
> * New process and equipment inventions
> * Improvement and modification of old or known processes
> * New or unique combination of known processes and techniques
> * Greater integration and use of natural processes
> * Maximum use of physical surroundings and

environmental conditions (EPA March 1980)

In addition to the increased risk factor, innovative technology must also advance the state-of-the-art in any of the following areas:

* Cost Reduction
* Recycling, Reclamation, or Reuse of Water
* Energy and Resource Conservation
* Improved Joint Industrial/Municipal Treatment
* Elimination or Confined Disposal of Pollutant Discharge (EPA August 1984)

Congress wished to encourage the adoption of both of innovative and alternative technologies. The development and diffusion of new systems was considered as being fully in the public's interests. Section 201(g)(5) of the CWA now required recipients of construction grants to fully study and evaluate both innovative and alternative treatment processes and techniques when designing wastewater facilities. But to overcome the persistent reluctance to use these systems, Congress decided to create positive incentive for communities and consulting engineers to adopt new technologies. This was done by creating the innovative and alternative (I/A) technologies program.

Under the I/A program, qualifying communities could receive increased grant assistance for the construction of innovative and alternative wastewater treatment facilities. An 85 percent grant was provided for I/A construction, whereas conventional ones received a 75 percent award. The difference in funding came from a special fund set aside annually from each state's total construction grant allocation. The required set-aside amount was two percent for the first two years, rising to three percent in the third year of the program. Each year, at least one half of one percent of the grants allocation (part of the funds set aside) had to be used for innovative technology.

The 1981 amendments to the CWA were used to strengthen the congressional commitment to the use of I/A technologies. The difference of an I/A grant compared to a conventional one was raised to 20 percent, and the set-aside program was increased to a minimum of four percent and a maximum of up to seven and one half percent, according to the discretion of each state.

To further reduce reluctance in trying innovative methods, part of the construction grants funding was to pay for the modification or replacement of I/A projects that failed to perform during the first two years of operation. This was intended to serve as a 100 percent insurance program so that there was basically no risk on the part of the community opting for the innovative technology, and none for the consulting engineer firm which designed the process unless gross liability could be established. The I/A program also included a commitment of funds for field testing projects to evaluate emerging technologies before funds were committed to a full scale operation.

This I/A program was described by state regulatory officials as being a carrot and stick approach. The carrot was offered to the communities and engineers in terms of the increased allotment they would receive for I/A projects. The stick was directed at the state to encourage them to see that they enforced the requirement to use the I/A set-aside for its intended purpose. If the money was not used to fund I/A, then it reverted back to the federal government for reallocation among the states that had already spent all of their I/A funds. Certain states -- for instance, Connecticut and New Hampshire -- resisted federal direction to pursue I/A projects. They thus lost money every time funds were reallocated.

This is the way that the construction grants program has operated for the past 12 years. Under these auspices the I/A program invested $4.4 billion in 2,700 I/A facilities. State and local governments invested an additional $1 billion in these projects. Alternative technology accounted for $3.3 billion of the federal funds for a total of 2,100 projects. The innovation investment share was $1.1 billion for 600 projects (EPA Oct. 1988).

Grants to State Revolving Fund Loans

The regulatory situation for I/A projects changed dramatically in 1987. While striving for federal reductions of the budget deficit, Congress passed legislation as part of the 1987 amendments to the CWA which officially terminated the construction grants program. The deadline for this to occur is 1990. Federal dollars will continue to be allocated but they will be used as capitalization for creating state funds for loans to communities needing treatment facilities. In 1994, EPA will have allocated all the money for these loan funds. Loans made by the states will have to be paid back by the communities. Congress believed that these state revolving funds (SRFs) will effectively meet the funding needs for constructing new or upgrading old wastewater treatment facilities.

But the importance of this policy shift cannot be understated. In addition to eliminating the grants funds, all of the I/A incentives that were discussed above will also be terminated. The states did not want the federal government specifying the types of projects for which they could make loans, so Congress complied with this position. The states will determine if they want to continue to prioritize I/A technologies.

In addition, the gross negligence standard for establishing the liability of contracting engineers when an I/A project fails will be changed back to ordinary negligence. It will be far easier for a community to succeed in pressing for damages from an engineer who developed its project. Communities will be under no strictures to pursue innovative approaches to wastewater treatment, and engineers will have every reason in the world to be reluctant to design methods that are not time-tested and proven effective.

The 1987 CWA amendments will also be instrumental in placing wastewater treatment plants under stricter enforcement of water quality standards. This is a result of the continued concern over the presence of toxic substances in our waters despite some appreciable gains made in industrial pretreatment technologies, and in terms of the implementation of technology-based controls, i.e., best available technology. The source of much toxic pollution is wastewater treatment facilities. States are required to prepare water quality studies that will categorize waterbodies as to whether or not they will meet water quality standards through the implementation of technology-based regulations. This new approach will result in chemical-specific limits and whole-effluent toxicity limits being established for wastewater treatment plants.

The result of these changes is the subject of current debate among many EPA staff, treatment plant operators, and consultants. It's likely that the costs of treatment will escalate as more stringent water quality standards are applied to sewage treatment. Yet at the same time, the federal incentives for developing I/A technology -- originally sought out as a lower cost, less complex, energy savings, multiple-use option -- will have evaporated. Given this new context, what will the future be for the development of innovative and alternative technologies? What are the institutional constraints to its development? How can these constraints best be overcome?

To answer these questions, I will begin by reviewing the developments of a particular form of innovative technology -- constructed wetlands. I will review the literature surrounding this approach, examine the problems of it for an area such as Greater Boston, and then present the case that can be made for solar aquatics. Solar aquatics is one approach to simulating the natural processes inherent to wetlands in a smaller area, and in such a way that the process is able to occur all winter in a cold climate.

CHAPTER TWO - AN INNOVATION TAKES ROOT
Constructed Wetlands for Municipal Wastewater Treatment

Whenever a new wastewater treatment technology is developing, certain issues must examined when assessing its appropriateness. Many of these issues are going to be site specific design factors. This is especially true when considering constructed wetlands. Everything from the character of the wastewater to the topography of the site and the indigenous vegetation must be considered. However, there are certain general areas of concern that must be fully taken into account.

Foremost among these is the effectiveness of the process. Does it perform the desired function in terms of removing the pollutants that are present? Do some pollutants ultimately slip through the system? What is the ultimate disposition of toxic substances, such as heavy metals?

Another important factor is reliability. What are the possible upsets that can occur to the system? How easy are they to rectify? How will it perform under different organic loading or hydraulic loading? What is the projected life of a project of the type considered?

It is important to consider the appropriateness of the system to the overall environment. Does it present any possibility of degrading the natural environment? How about the social environment? Are there public health risks? Does it create any nuisance effects, such as odor or mosquito problems?

Finally, it is important to ask whether the project is operable. Is it cost-effective for the community? Will the necessary operators be readily available?

This chapter will examine the use of constructed wetlands for wastewater treatment in light of these questions.

CONSTRUCTED WETLANDS FOR WASTEWATER TREATMENT

The definition used for "constructed wetlands" in this thesis will be the same one as used by the Tennessee Valley Authority (Steiner et al. 1988). For them a constructed wetland is an engineered and constructed complex of saturated substrates, emergent and submergent vegetation, animal life, and open water that simulates natural wetlands. It has been discovered that these simulated wetlands can be quite effective in reducing the pollutants in municipally generated wastewater.

Wetlands have long been used for the treatment of municipal sewage. However, until recently this use was largely inadvertent. The wetland (a.k.a. swamp, bog, etc.) was regarded as worthless property that was only fit for dumping or filling. Wastes, including fecal wastes, were commonly dumped in the wetlands, but nobody was really interested in what happened to it then, just so long as it was out of sight.

Over the last 20 years, however, the importance of aquatic plants in removing organic chemicals from aquatic environments has grown. This research initially began in Europe at the Max Plank Institute in Germany. In the United States, researchers have studied the possible application of wetland and aquatic ecology for the treatment of wastewater at the National Aeronautics and Space Administration (NASA) National Space Technologies Lab, Walt Disney's EPCOT Center, the Tennessee Valley Authority and various universities, among others. Research has focussed on the use of floating aquatic plants (i.e., water hyacinth [*Eichornia crassipes*] and duckweed [*Lemna, Spirodela,* and *Wolfia* sp.]) and rooted aquatic plants (i.e., bulrush, cattails, canna lily, pickerel weed and arrowhead).

Research has developed two major types of wetland approach for wastewater treatment. One uses emergent vegetation and the other submergent. Wetlands using emergent vegetation, such as bulrush and cattails, can be divided into subgroups. These are either a free water surface system (FWS) or else a subsurface flow system (SFS). The FWS approach directs wastewater through shallow channels or basins where the plants are rooted. An SFS is essentially a horizontal trickling filter using a rock, sand or soil medium. This is also occasionally referred to as a Root-Zone-Method (RZM).

The approach to wetlands using submergent vegetation depends upon floating aquatic plants rather than ones rooted in a substrate. Water hyacinth, pennywort and duckweed are the primary varieties used. There does not have to be any substrate as used by the emergent plant systems. Depending upon project specific considerations regarding climate, wastewater planners will have to make a determination as to which approach would be most appropriate for their needs.

As more is being learned about the natural processes of wetlands, more varieties of plants and other forms of aquatic life are being integrated into the wetland facilities that are designed and operated. For instance, you can place water hyacinth in the channels or basins in a FWS system. For our purposes in this thesis, it is not necessary to completely separate between the various aquatic treatment approaches. Therefore, in the text that follows, the terms constructed wetland and aquatic plant systems will often be used interchangeably

What appears to be a fairly innocuous discovery -- that wetlands can be used for treating waste -- has steadily gained adherents in the scientific community. As B.C. Wolverton, a NASA research scientist commented in a recent paper:

> The integration of emergent aquatic plants with microbial filters has produced one of the most promising wastewater treatment technologies since development of the trickling filter process in 1893. This process, a lateral flow system containing rooted aquatic plants with microbial communities on rocks serving as a trickling filter, represents a different biological process. Once the micro-organisms are established on the rocks and plant roots, a symbiotic relationship develops between them which enhances the wastewater treating capability of both processes. (Wolverton, 1987, p. 10)

Initially, research focussed on the use of monoculture systems for wastewater treatment. However, as more has become understood regarding the complex and symbiotic relationships in the aquatic system, referred to by Wolverton, greater integration has been made in terms of the diversity of microbial, plant, and animal life in the nature-mimicking ecosystems that have been developed. New discoveries have also been made in terms of the potential spinoffs of this form of wastewater treatment. For instance, Cornell University has developed the potential for both the aquaculture of saleable plants, as well as the anaerobic digestion of the biomass generated to fuel the generation of power to operate their facility. These functions can both reduce the operating costs and generate revenue to fund the system. We will examine some of these potentials in the case studies presented below.

Effectiveness of wetlands in cleaning effluent: Three of the best sources for reviewing the effectiveness of constructed wetlands for pollutant removal are EPA's Design Manual -- Constructed Wetlands and Aquatic Plant Systems for Municipal Wastewater Treatment, Reed, et al., Natural Systems for Waste Management & Treatment, and Reddy and Smith (Eds.), Aquatic Plants for Water Treatment and Resource Recover.

When assessing the effectiveness of aquatic wastewater treatment it is first important to note the general factors which result in the removal of pollutants from the waste stream. There are basically three categories: 1) physical, 2) chemical, and 3) biological. Each of these has a number of different mechanisms whereby it occurs. Physical removal processes include sedimentation, filtration, adsorption, and volatilization. Chemical refers to precipitation, hydrolysis reaction, oxidation-reduction, and photochemical reactions. Biological effects are caused by bacterial metabolism, plant metabolism, plant absorbtion, and natural die-off. Depending upon what forms of pollutants are expected in the wastewater, a particular removal process will be required to be planned for and designed into the treatment works [Tchobanoglous, 1987].

What has been learned in researching aquatic plant systems is that the plants themselves provide very little in terms of treatment value. Rather it is the microbial bacteria, suspended, benthic, and plant-supported, that reduce the levels of contaminants in wastewater. For instance, they have a primary effect in the reduction of colloidal solids, biochemical oxygen demand, nitrogen, and refractory organics. Plant metabolism and absorption provide secondary effects for the process of removing nitrogen, phosphorus, heavy metals, refractory organics, and certain bacteria and viruses.

How effective are these processes in treating wastewater? This was precisely the question being asked by the Tennessee Valley Authority (TVA) in 1986 when considering a tri-city project to demonstrate the use of constructed wetlands for municipal wastewater treatment. But there was a shortage of available data, both in terms of treatment process design and assessment. However, a project which had been built by the Pennsylvania Department of Environmental Resources in Iselin, PA, provided data for them to analyze. Table-2a provides a summary of this data. It is accompanied by a list of typical water quality characteristics and effluent standards.

Table-2a Performance Data for Constructed Wetland in Iselin, PA
(March 1983 through September 1985) (Watson, et al., 1987, 266-7)

Season	Biochemical Oxygen Demand		Total Suspended Solids		Ammonia Nitrogen	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
	mg/L					
Winter	230	8.5 (96)*	180	21 (88)	13	5.8 (54)
Summer	288	6.5 (98)	170	18 (90)	16	1.2 (93)
Total	260	7.4 (97)	180	19 (89)	14	3.3 (77)

Season	Total Phosphorus		Fecal Coliforms	
	Influent	Effluent	Influent	Effluent
			colonies/100 mL	
Winter	12	3.9 (68)	1,200,000	240 (100)
Summer	16	1.6 (90)	2,600,000	23 (100)
Total	15	2.6 (82)	1,800,000	150 (100)

* Numbers in parentheses are percent reduction.

Typical Water Quality Characteristics and Effluent Requirements

Level of Treatment	Value, mg/L BOD	SS	N*	P**
Untreated wastewater	220	220	30	8
Primary	150	80	25	7
Advanced primary	80	50	20	6
Secondary	≤30	≤30	20	6
Advanced secondary	≤10	≤10	18	5
Tertiary	≤5	≤5	≤1	≤1

* Total (org. N, NH_3, NO_2, NO_3 expressed as N).
** Total (org. P, PO_4^{3} expressed as P).

The Iselin facility was a fairly small operation. It was designed for a capacity of 45.4 m^3/d (12,000 gpd). The treatment process entailed four separate components: an aerated basin, a cattail marsh, a stabilizing pond, and a reed canary grass meadow. The initial basin was effective primarily for BOD reduction. The marsh component generally provided the most treatment for the pollutant parameters regulated in the NPDES permit. The pond provided removal of primarily ammonia nitrogen. And meadow application was used for the final polishing of the effluent. When all four of these elements were taken together, the conclusion was that "the marsh/pond/meadow system is capable of consistently meeting EPA's secondary treatment standards and even more stringent standards" (Watson et al. 1987, p. 269).

Secondary treatment is defined as an 30-day average of ≥ 85 percent removal of both BOD_5 (five-day biochemical oxygen demand) and suspended solids. The 30-day average measurement for both must be ≤ 30 mg\L and the seven-day average must be ≤ 45 mg\L. The Iselin facility was able to attain these standards during both the summer and winter, although the winter time removals were less than for the summer. This was particularly the case for the ammonia nitrogen and phosphorus.

Table-2b shows the outcome of treatment at selected pilot-scale constructed wetland projects. Although the influent concentrations are not shown in this table, the expected levels of concentration for municipal wastewater allow us to conclude that the treatment which is being provided is advanced secondary. The accompanying text in the source from which this table was drawn (Reed et al. 1987) describes the process whereby the contaminants are removed and also indicates some of the influent concentrations. For instance, the Listowel, Ontario project occasionally received levels of suspended solids as high as 406 mg/L.

It is important to note that the removal of NH_4 and NO_3, a process referred to as nitrification-denitrification, is generally considered a costly process. The ammonium is converted to nitrate which is

Table-2b (Reed, et al., p. 171)	Effluent Concentration, mg/L					
Location	BOD	SS	NH_4	NO_3	TN	TP
Listowel, Ontario	10	8	6	0.2	8.9	0.6*
Arcata, CA	<20	<8	<10	0.7	11.6	6.1
Santee, CA	<30	<8	<5	<0.2	-	-
Vermontville, MI	-	-	2	1.2	6.2	2.1 *

* Alum treatment provided prior to the wetland component.

BOD_5 - Biochemical Oxygen Demand   SS - Suspended Solids
NH_4 - Ammonium NO_3 - Nitrate
TN - Total Nitrogen   TP - Total Phosphorus

subsequently converted to nitrogen gas. This process is generally only performed where the receiving water-course is used as a source for public water supply and the dilution factor is insufficient to reduce the nitrate concentration to less than 10 mg/L.

Removal of synthetic organic compounds and heavy metals: The resistance of synthetic organic compounds to conventional wastewater treatment procedures has been a growing sense of concern for everyone concerned about the condition of the nation's waters. The 1987 Water Quality Act, an amendment to the Clean Water Act (PL 92-500), will have the effect of placing publicly owned treatment works (POTWs) under stricter effluent limitations. For the first time, many POTWs may face either chemical specific permit limits for toxics or whole effluent toxicity limits under the National Pollutant Discharge Elimination Service permit system.

Can wetlands cope with these new standards? Table-2c below shows the extent to which trace organics are removed by a water hyacinth system for wastewater treatment. This table demonstrates that constructed wetlands using water hyacinths can effectively remove trace organics from the municipal wastestream.

Other studies have found that wetlands can be similarly effective at removing heavy metals without the large capital investment and high operating and maintenance costs of advanced processes such as chemical precipitation, electrolysis, reverse osmosis and ion exchange. A constructed wetland at Santee, California was tested for metal removal. As part of the test the influent wastewater was spiked with copper, zinc and cadmium. With hydraulic retention times of 5.5 days, 99, 97, and 99 percent of these metals were removed respectively (Gersberg et al. 1984, pp. 639-645). Scientists attribute this to a precipitation-adsorption process. Plant uptake accounted for less than one percent of the metals involved.

Table-2c Trace Organic Removal in Pilot-Scale Water Hyacinth Basins*
(Reed et al., 1987, p. 136)

	Concentration, ug/L	
Parameter	Untreated Wastewater	Hyacinth Effluent
Benzene	2.0	Not Detected
Toulene	6.3	Not Detected
Ethylbenzene	3.3	Not Detected
Chlorobenzene	1.1	Not Detected
Chloroform	4.7	0.3
Chlorodibromomethane	5.7	Not Detected
1,1,1-Trichloroethylene	4.4	Not Detected
Tetrachloroethylene	4.7	0.4
Phenol	6.2	1.2
Butylbenzyl phthalate	2.1	0.4
Diethyl phthalate	0.8	0.2
Isophorone	0.3	0.1
Naphthalane	0.7	0.1
1,4-Dichlorobenzene	1.1	Not Detected

*4.5 day detention time, 76 m^3/d flow, 3 sets of 2 basins each in parallel, plant density 10-25 k/m^2 (net weight).

The ultimate fate of these metals is not necessarily decided by the wetland, however. The question still remains as to what to do with them at such time as when the plants are harvested, the sludge is dredged out, or something else along these lines. What many facilities have done is design the wetland system so that it combines the sludge disposal with the wastewater treatment. The facility becomes the repository for the toxic residuals from the treatment process.

Cost of Constructed Wetlands: The economic costs of constructed wetlands will depend on such things as the hydraulic loading rate and detention time for the project. These, in turn, are directly linked to the characteristics of the wastewater and the desired effluent quality. For these reasons it is impossible to calculate the costs of a project without having the specific site and specifications with which to work. However, some costs can be estimated based on the experience of other similar projects.

Capital costs will be determined by the value of the land which is necessary and the amount of construction that will be needed. Table-2d lists the costs of four specific cases of where constructed wetlands were used and compares them to the average cost of conventional secondary treatment.

Table-2d Cost Summary of 4 Wetland Projects v. Conventional Treatment
(Crites & Mingee, 1987, p. 886)

Location	System type	Design flow, m^3/d	Area, ha	Construction costs $ millions	Unit cost, $/$m^3$/d
Cannon Beach, OR	Existing wetland	3,440	6.5	0.58	170
Gustine, CA	Created Marsh	3,785	10	0.88	230
Incline Village, NV	Created and existing wetland	8,100	49	3.3	410
Iron Bridge Plant, Orlando, FL	Hyacinth system	30,280	12	3.3	110
Typical Secondary	Activated sludge	3,785	--	3-3.8	800-1,000

Note: The conversion factor for m^3/day to gpd is 264. The reason for the variance in unit costs for constructed wetlands is due to other requirements. Incline Village's costs also included habitat improvement and complete containment of the applied effluent. Dollars are for June 1986.

This table shows that there is a significant advantage in terms of capital costs by going with a constructed wetland over the conventional treatment process. Table-2e provides additional comparisons between a constructed wetland system and conventional treatment. The cases cited are ones where official estimates were made regarding each system during a facility siting process.

Table-2e Cost Comparison Between Conventional and Wetland Treatment

Location	Conventional	Wetland Treatment (WT)	Comment
Houghton, LA	$1.2 million	$400,000	WT provides better quality
Benton, KY	$2.5 - $3 million	$260,000	1 mgd capacity; better qual.
Arcata, CA	$3.5 - $7 million	$514,600	2.3 mgd; wildlife/bird refuge
San Diego, CA	$3.5 million	$2.8 million	Water hyacinth system
Hornsby Bend, TX	$3.5 - $7 million	$1.2 million	Water hya. w/ greenhouse

Note: The costs cited are capital costs only. They do not include the O&M, such as energy, chemicals and equipment, which can be very significant for conventional treatment. The estimates also do not include the revenue from some of the wetland projects, such as digesting the San Diego water hyacinth for marketable methane. (EPA Sept. 1988; Steiner et al. 1988)

The above tables provide evidence that constructed wetlands can be less costly than the conventional approach to wastewater treatment in terms of the initial investment. This cost advantage is also the case in terms of the operations and maintenance expenditures. Constructed wetlands simply use far less mechanical equipment, and therefore save both in terms of repairs and replacement, as well as energy costs. Then there is also the savings from not having to purchase the chemicals that are used in conventional treatment.

In 1986, a survey by Kentucky Division of Water personnel estimated that it would be appropriate for 64 of their communities needing new, upgraded, or replacement plants to use constructed wetlands for that purpose. If this is extrapolated nationwide, the estimated total capital cost savings for small publicly owned treatment facilities alone would be over $2 billion. Steiner et al, concluded that this approach would thus provide "an economically viable approach to cleaning up our Nation's waters (p. 3)."

Land space required: One factor that has limited the use of constructed wetlands to predominantly small, rural communities is the larger amount of land that is required when compared to a conventional treatment system. A standard estimate is that about 26 acres are required for processing every 1 million gallons per day of wastewater. A rough estimate of the space required for the city the size of Detroit is 10 square miles (Goldstein 1988).

The following table summarizes the estimated land requirements for different innovative approaches to treatment. Slow rate (SR) and rapid infiltration systems are nondischarging systems. These are land treatment methods since the effluent is directed into the ground rather than into surface waters. These approaches can be used for groundwater recharge or land reclamation projects. Overland flow (OF) involves land application, but the effluent generally drains into surface waters. The following area requirements have been estimated using the following

Table-2f Land Area Estimates for 4000 m^3/day Systems

Treatment system	Area, ha		
	North	Mid-Atlantic	South
Pond systems			
Oxidation	NA*	NA	12.8
Facultative	67.2	43.6	20.4
Controlled discharge	65.2	65.2	65.2
Partial-mix aerated	20.4	15.3	11.6
Hyacinth, secondary	NA	NA	38.0
Hyacinth, advanced secondary	NA	NA	4.0#
Hyacinth, tertiary	NA	NA	22.8#*
Constructed wetland	26.3	26.3	26.3
Slow rate	134.0	102.0	72.0
Overland flow	92.0	69.0	47.0
Rapid infiltration	6.0	6.0	6.0

* NA = not applicable (Reed et al. 1987, p. 20)

\# Includes allowance for primary treatment.

** Includes a 20-ha facultative pond.

standards: The community wastewater flow is 4000 m^3/day (1.06 million gal/day); 5 months storage capacity is needed for OF and SR in a cold climate; 3 months is required in the mid-Atlantic states; and no storage in the southern states. The land required for the storage and any pre-treatment options that would be required are also factored into this table.

Climatic concerns: Table-2f reflects some of the difficulties with operating these natural treatment systems in colder climates. As EPA has observed (EPA Sept. 1987):

> In natural systems, dormant vegetation, the slow reaction rate for soil or aquatic microbes at low temperatures, and/or the presence of an ice cover, may reduce both physical and biological activity, and thus affect system performance on a seasonal basis.

For this reason it is often necessary to increase detention time, which in turn demands more land for the project. However, research and operations in Ontario, Canada has resulted in a significant amount being learned about the use of constructed wetlands in cold climates. In Table-2f you can see that constructed wetlands do not require additional acreage for the more northerly climates. Engineering criteria have been developed for year-round operation of these systems in cold climates [Reed et al., 1985; Herskowitz, 1986].

Overall wetland considerations: In general, research and experience has indicated that constructed wetlands are far less technical to operate than conventional systems. It is perhaps this aspect that separates this treatment approach the most from the conventional method. In summary of the merits and drawbacks of using constructed wetlands, NASA's Wolverton concluded (Wolverton 1987, p. 148):

> Advantages of the artificial marsh treatment process over mechanical systems are: 1) less costly to in-

> stall in most locations; 2) lower operational and maintenance costs; 3) non-technical personnel can operate and maintain; 4) more flexibility and less susceptibility to shockloading; 5) less energy required to operate; and 6) greater reliability. The major disadvantage of the artificial marsh process is the increased land area required.

So the situation in which this leaves one when considering an innovative wetland-type approach for an area such as Greater Boston is wondering if the land requirement will allow the project to proceed. Can the amount of land needed be reduced sufficiently to find room, or alternately, can we find sufficient land available for constructed wetlands? That issue will be discussed in the next chapter as we review the research and experience surrounding the development of solar aquatics.

CHAPTER THREE - SOLAR AQUATICS
Adapting Wetland Ecology to Fit Greater Boston

For this research project it was necessary to develop a way in which the natural processes of wetlands could be reasonably considered as being viable for use in the sewer system for Greater Boston, currently operated by the Massachusetts Water Resources Authority (MWRA). To do this I turned for assistance from Ecological Engineering Associates (EEA), of Falmouth, Massachusetts. EEA is responsible for developing the concept of the solar aquatics wastewater treatment process. This was the approach to natural wastewater treatment that seemed to be most feasible for Greater Boston. It is the approach that uses the least land of all the passive treatment methods, and it is able to function year-round in a cold climate.

Pilot projects for solar aquatics have been conducted in Harwich, Massachusetts for treating septage, and in Warren, Vermont at the Sugarbush ski resort for treating the wastestream of the resort community. Another pilot study is in the process of being started in Providence, Rhode Island. After describing the solar aquatics process in general, the results of these projects will be reviewed.

Solar Aquatics Explained

Solar aquatics, as the name implies, is a treatment process that occurs in and around water while using energy derived directly from the sun. Wetland processes are simulated inside of greenhouses. In taking this approach, wetland processes can be expedited and condensed through careful ecological engineering, reducing the amount of land that is required, and also allowing year-round operation in a cold climate.

Some of the pioneering work in using greenhouses occurred at the New Alchemy Institute in East Falmouth, Massachusetts. Their work has developed the potential for using greenhouses -- known to them as "arks" or "bioshelters" -- for fish farming, hydroponics, and gardening. It was within these bioshelters that New Alchemy more fully developed the understanding that in a natural ecosystem there is no such thing as waste; everything is continually recycled as part of the energy/nutrient process (Barnhart 1979).

The use of greenhouses for enhancing aquatic systems of wastewater treatment is not unprecedented. Experiments regarding this were conducted at the University of Wisconsin, Oshkosh (Spangler et al. 1976). The city of Austin, Texas has used a greenhouse structure to allow its Hornsby Bend Hyacinth Facility to operate without having winter freezing as a recurring problem (EPA Sept. 1988, pp. 71-74).

Solar aquatics at Sugarbush: The attached diagram (see Appendix A) shows how the inside of the greenhouse at the Sugarbush ski resort in Vermont is laid out as, and what phases of treatment occur at the different points of the simulated stream as it moves through the system. The detention time in the facility is five days.

The following tables summarize the results of the solar aquatics project at Sugarbush. The facility is small and operates with a hydraulic load of only 3,000 gpd. But the organic loading is adjusted daily to simulate the conditions of a full-scale facility. All surges in the effluent entering the main facility are duplicated in the greenhouse to match the present population of residents, skiers, and vacationers. An important factor to notice about this project is that the greatest organic loading occurs during the winter ski season. This is also a period during which the temperature can be lower than $0^{o}F$.

TABLE-3a DATA SUMMARY, SUGARBUSH SKI RESORT PILOT SOLAR AQUATICS PLANT [EEA, 1988a]

Sampling Period	5-1-87 to 11-24-87	12-22-87 to 3-31-88	2-3-88 to 3-31-88	4-1-88 to 5-15-88	7-28-88 to 10-31-88
Type of Pretreatment:	aerated lagoon	none (raw sewage)	none	none	none
Parameters (mg/L)					
BOD influent	32.04	293.96		79.80	118.73
effluent	11.45	24.68		1.72	2.10
(% reduction)	(66.00)	(91.60)		(97.84)	(98.20)
TSS influent	48.36	192.35		73.67	122.95
effluent	18.55	10.86		8.83	1.66
(% reduction)	(62.00)	(94.35)		(88.00)	(98.60)
NH_3-N influent	10.99		41.52	7.77	16.45
effluent	0.95		5.01	0.08	0.38
(% reduction)	(91.00)		(87.95)	(98.97)	(97.90)
NO_3-N influent	2.12		0.72	0.32	0.24
effluent	13.43		11.87	8.51	11.90
TKN influent	16.19		79.25	27.73	31.84
effluent	3.38		7.54	1.55	0.99
(% reduction)	(80.00)		(90.40)	(94.40)	(96.90)
TDP influent	2.39	*		*	2.70
effluent	1.08	*		*	1.29
(% reduction)	(55.00)				(52.20)
Dissolved oxygen in effluent					1.65
pH value of effluent					7.17

* No phosphorus data is available for this period due to the accidental introduction of aluminum sulfate from the main treatment plant into the pilot facility.

The environmental statutes in Vermont specify that water discharges can result in "no significant alteration of the biota." So the discharge from the Sugarbush plant had to conform to the waters of Rice Brook, considered a high mountain stream. The standards are set assuming 10:1 dilution. The in-stream (background) levels are:

TDP	0.015	mg/L
NO_3-N	2.0	mg/L
TKN	3.0	mg/L
NH_3-N	1.04	mg/L (summer) 2.2 mg/L (winter) 1.49 mg/L (spring)
BOD	2.0	mg/L

The effluent standards for the facility can be derived from the background measurements by multiplying by 10. The data show that this project was capable of performing within the effluent standards specified on most occasions. However, this was never the case for phosphorus or BOD during the winter months. According to state officials, the effluent levels of phosphorus could be no more than 0.1 mg/L. Because this is a pilot project operating alongside a conventional treatment plant, the effluent of both was mixed together and then treated with aluminum sulfate to precipitate out the phosphorus. This allowed it to meet the standards, but it seems logical to ask whether there are any toxic effects due to any trace aluminum that might be introduced into the brook.

The following is a description of the solar aquatics process from the EEA report on the Sugarbush project:

> The treatment process occurs in four stages over approximately five days.
>
> 1. Aeration, Bioaugmentation and BOD Reduction -- In the first day air is diffused into the effluent as it enters the first raceway. At the point of entry, the waste stream is augmented with seven strains of bacteria which, in the presence of air, break soluble organic chemicals down int carbon dioxide and water and degrade proteins, fats and starches into compounds that can be metabolized by other microorganisms downstream.
>
> 2. Nitrification and Initial Nitrogen Removal -- In the first and second days, nitrifying bacteria, algae and higher plants begin to metabolize nutrients in the waste stream. Ammonia is broken down into nitrates. Nitrites, ammonia and soluble orthophosphates are metabolized directly by the green algae and higher plants. Snails and other zooplankton begin the process of sludge digestion.
>
> 3. Nutrient Removal, Reduction of Suspended Solids and Nitrate Uptake -- In the third and fourth days, higher plants on the surface with their root masses reaching down into the water column take nitrates from the wastestream. Very large populations of grazing zooplankton inhabit the extensive surface area of the roots where the water is filtered and

> these animals digest suspended solids.
>
> 4. Pathogen Destruction, Filtration and Denitrification -- In the fourth and fifth days as the water passes through the marsh biofilter, solids are filtered in the sand and stone substrate, nitrates are reduced to nitrogen gas and water, and certain pathogenic bacteria are destroyed by the action of several marsh plants including bulrush, rush reed and cattail. (EEA 1988a)

EEA cites the advantages of this approach as: 1) no addition of toxic chemicals to the water, 2) limited land use, 3) very little sludge is produced, 4) lower capital cost, 5) competitive operating cost, 6) effective removal of nutrients and toxic materials, 7) positive earning potential growing fish and plants that can be sold, and 8) an attractive physical plant.

Solar aquatics in Harwich: The test facility that was operated in Harwich, Massachusetts uses the same basic principles as Sugarbush although the arrangement is different. The operation was performed on a temporary basis, so there was no greenhouse constructed. It operated during the spring and summer of 1988. Treatment was provided for the supernatant from a lagoon into which septage had been dumped.

Instead of channels for a simulated streamflow, Harwich uses 21 translucent cylinders approximately five feet high and five feet in diameter, and one constructed marsh. The influent was eventually pumped through the system at a rate of 1200 gallons per day. The wastewater would remain in each tank for about 12 hours, thus providing for an overall retention time of 10 days in the tanks and marsh.

The same basic steps of bioaugmentation, nitrification-denitrification, nutrient removal, and pathogen destruction occurred as at Sugarbush. Tanks 1 to 10 form an artificial river through which the influent was pumped. Aeration was provided to reduce BOD and enhance the growth of selected bacteria. Algae and higher plants began to metabolize nutrients.

A constructed marsh, approximately 116 feet long, 14 to 20 inches wide at the top tapering to a point, and 15 inches deep, provided treatment after the first 10 tanks. Solids were filtered out in the sand and stone substrate, nitrates were reduced to nitrogen gas and water, and pathogenic bacteria were reduced. Tanks 11 to 21 polished the effluent, to remove the remaining nutrients, reduce coliforms, and result in very high quality water by Tank 21.

The following table (next page) provides a summary of the results from this project. The tests were performed by the Barnstable County Health and Environmental Department.

These data show that the system provided very advanced treatment from its outset. The system designers and operators stated that this is the only case in the U.S. of an operation treating septage to tertiary standards with no chemicals being used. Although the additional data are not provided, the system demonstrated that even when a hard frost destroyed the system's ability to perform advanced treatment, the removal of BOD and the TSS remained at secondary levels. Ammonia also continued to be removed at a rate in excess of 99 percent.

Projected costs and land requirements of solar aquatics: As with other wetland treatment systems, the cost of solar aquatics will depend very heavily on the acquisition of the land needed. Solar aquatics requires less land than other wetland projects, but it still needs more than conventional treatment. One estimate for the land required for

Table-3b Solar Aquatic Data -- The Harwich Plant

Influent

DATE	BOD5 mg/L	DATE	AMMONIA mg/L	NITRATE mg/L	TKN mg/L	PHOSPH. mg/L	TDP mg/L	TSS mg/L
6-22	5030	6-22	57.1	2.15	112.0	22.8	22.0	800
6-29	2303	6-28	59.3	1.83	123.0	24.4	19.1	600
		7-5	72.7	1.35	120.0	17.6	15.2	400
7-13	1473	7-11	69.7	1.64	124.0	24.8	19.6	200
7-20	1832	7-18	79.3	1.65	172.0	28.3	22.7	667
7-27	1447	7-25	66.7	1.88	149.0	29.3	22.7	300
		8-2	69.2	3.52	151.0	26.6	19.7	357
8-12	1013	8-9	78.8	2.70	223.0	35.5	31.1	1250
8-17	1278	8-15	73.5	2.51	166.0	28.5	22.8	500
8-24	1700	8-22	92.4	1.90	166.0	29.3	24.2	5333
9-2	1464	8-31	73.3	1.45	133.0	26.5	20.5	400
9-8	2100	9-7	71.9	1.56	114.0	25.3	18.8	300

Effluent

DATE	BOD5 mg/L	DATE	AMMONIA mg/L	NITRATE mg/L	TKN mg/L	PHOSPH. mg/L	TDP mg/L	TSS mg/L
6-15	2.1	6-15	0.17	0.18	0.47	0.04	--	--
6-22	9.6	6-22	0.19	0.61	1.82	0.064	0.02	20
6-29	5.7	6-28	0.03	0.47	1.21	0.06	0.02	5
		7-5	0.13	0.42	0.43	0.02	0.01	5
7-13	3.4	7-11	0.11	0.65	0.96	0.14	0.05	5
7-20	3.1	7-18	0.07	0.57	1.16	0.09	0.06	5
7-27	4.7	7-25	0.08	0.61	1.07	0.10	0.06	5
		8-2	0.22	1.20	3.78	0.83	0.68	5
8-12	4.2	8-9	0.09	3.63	4.87	1.37	1.19	10
8-17	6.0	8-15	0.11	1.12	3.39	0.82	0.67	5
8-24	4.9	8-22	0.18	0.96	3.03	0.71	0.63	4
9-2	1.8	8-31	0.05	0.82	3.51	2.26	2.18	3.3
9-8	5.8	9-7	0.18	3.83	4.09	4.74	4.50	6.7

Percent Reduction

DATE	BOD5 mg/L	DATE	AMMONIA mg/L	NITRATE mg/L	TKN	PHOSPH. mg/L	TDP mg/L	TSS mg/L
6-22	99.81%	6-22	99.67%	98.38%		99.72%	99.91%	97.50%
6-29	99.75	6-28	99.95	99.02		99.75	99.90	99.17
		7-5	99.82	99.64		99.89	99.93	98.75
7-13	99.77	7-11	99.84	99.23		99.44	99.74	97.50
7-20	99.83	7-18	99.91	99.33		99.68	99.74	99.25
7-27	99.68	7-25	99.88	99.28		99.66	99.74	98.33
		8-2	99.68	97.50		96.88	96.55	98.60
8-12	99.59	8-9	99.89	97.82		96.14	96.17	99.20
8-17	99.23	8-15	99.85	97.96		97.12	97.06	99.00
8-24	99.71	8-22	99.81	98.17		97.58	97.40	99.92
9-2	99.88	8-31	99.93	97.36		91.47	89.37	99.18
9-8	99.72	9-7	99.75	96.41		81.26	76.06	97.77

solar aquatics offered by Ecological Engineering Associates (EEA), is two acres for 1 mgd capacity. This includes land for employee parking, administration, etc. (Peterson 1989). EEA recently submitted a proposal for a 13 million gallons per day solar aquatics project in Columbia, MO, which estimated a need for 10 acres of land (Barnett 1988). Thus, as the project gets larger, there are some added efficiencies in land use.

EEA estimates unit costs of 2 cents per gallon for construction, operation and maintenance in year One of a 20-year service contract for a 100,000 gpd facility. A facility of from 100,000 gpd to 1 mgd would have a stable cost of 1.4 cents per gallon, plus or minus .4 cents. These costs are based on estimated construction needs, plus the O & M costs for an extended aeration system, which closely parallel solar aquatics (Peterson 1989).

An important advantage of solar aquatics is the revenue potential from some of the plants and fish that can be produced under aquaculture management of the system. A 50,000 gpd EEA project to be located in Providence, RI is estimated to have operating expenses of $25,000/year. Revenue from sales of cut flowers, decorative plants, medicinal herbs and fish, however, are projected to be as much as $112,000 each year (Meadows 1988).

<u>The Application of Solar Aquatics in Greater Boston</u>: From the above data, the resources in the bibliography, and interviews a proposal was developed for integrating solar aquatics into the MWRA system. The following is taken from the proposal that was circulated as the basis for the subsequent interviews that were conducted:

Solar Aquatics In Boston

The specific location considered for solar aquatics in Greater Boston is in the Middle Charles River Basin. This is one of the regions considered in the EMMA plan for a satellite treatment facility. Among the advantages cited in favor of this location was maintaining water in the basin of its origin in order to make it available for reuse. For the purpose of this study, an advanced waste treatment (AWT) project using solar aquatics will be compared to a conventional AWT operation. The community of Framingham is the selected case. Framingham has been selected since it is one of the furthest outlying communities in the MWRA system.

The following table summarizes the estimated wastewater flows for Framingham, and the expected land, capital investment, and operating costs of the two approaches. Although the estimates are made as if there will be a single facility for all of Framingham, there may be advantages to going with smaller scale projects requiring even less transport and pumping capacity. The purpose of this study is not so much a site specific proposal, but rather to assess the institutional constraints to an innovative technology.

Estimated Wastewater Flow, Framingham (Maguire 1984)

1990		2010	
Ave.	Peak	Ave.	Peak
6.86 mgd	15.97 mgd	7.72 mgd	18.00 mgd

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Solar Aquatics Project Approach:

Land required: 12 - 36 acres (Peterson 1989; Barnett 1988)

Construction/engineering: $2.6 to 3.6 million (Peterson 1989; EPA 1988)

Operating expenses: $900,000/year (Meadows 1988)

Conventional AWT Facility:

Land required: 5 - 10 acres (Montgomery Engineers 1985; Hammer 1986)

Construction/engineering: $32 million (including 35% engineering and contingencies)(Kennedy Engineers 1979)

Operating expenses: $2.6 million to $4.5 million/year (Middleton 1977)

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CHAPTER FOUR -- INSTITUTIONAL CONSTRAINTS
A Review of the Literature

Now that the case has been established of how to integrate solar aquatics into the wastewater treatment system in Greater Boston, it is time to examine the literature concerning institutional constraints to innovative wastewater technologies. This chapter provides a review, and some of my comments, on this literature.

In reviewing the literature on institutional constraints as they relate to wastewater management, I discovered that virtually all of the studies were descriptive in nature. The absence of analytical studies from which a theoretical framework for explaining the institutional constraints to innovative technology can develop is puzzling. One paper does offer a summary of this conceptualization:

> ...I do wish to argue that there needs to be an appropriate model for the social and behavioral sciences that can be used to guide research in this area. And I would encourage research ... to try to find a guiding model that will help make some sense out of these descriptive, research projects. (Bruvold 1984, p. 1756)

In marked contrast, another author concludes:

> the task of defining and describing the institutions themselves is an exercise in complexity. Every level of government -- in its laws and policies, as well as the pressure groups to which it is subject ... -- impacts upon the institutional process.... Since the definition itself is so complex, there is no simple way to describe impacts ..., either for analytical purposes or for practical goals. (Lohman 1982, p. 53)

In other words, Lohman is saying, the only way to examine institutional affects is on a case-by-case basis. But this does not have to be the case if there is an integrating theory applicable to the issue being studied. One goal of grounded theory is to see if a one can discover a theory from the data collected during the research, which helps to explain the findings. Some helpful insights were gained from the literature concerning institutional constraints, but perhaps the greatest benefit from these readings was seeing what questions were not being asked by other researchers.

Wastewater Management: This literature review regarding constraints to innovative wastewater technology includes many articles for wastewater reuse or reclamation, and not specifically treatment. Wastewater reuse, however, is one method of treatment and was also a primary objective of the Clean Water Act's Innovative and Alternative Technology Program. As presented in Chapter Three, solar aquatics is a technology well-suited for various kinds of reuse, such as aquaculture, groundwater recharge, and land reclamation projects. This literature was helpful for developing an understanding of various legal issues, regulatory requirements, and agency dynamics facing innovative wastewater treatment technologies.

One thesis of the literature can be summarized as: "(I)nstitutions tend to be static and creatures of habit. As a technology begins to be adopted, institutional constraints are expected" (Forster & Southgate 1983, p. 42). These constraints were cited as emerging in several ways. First, there are formal laws and rules with which to be in compliance. Second, there are public attitudes that arise in response to public projects like wastewater treatment facilities. These are seen as being shaped by historical precedents and cultural influences. Finally, there is the nature of the institutions that dominate the wastewater management field. In discussing the nature of the institution, authors tended to focus on what procedures were used by the organizations and agencies, or on the individuals who worked within those procedures. There was no attempt made to inquire as to how institutions affect the actions of individuals.

Some articles examine institutional constraints only as environmental laws and regulations with which state and local governments and businesses must comply (Rusincovitch 1985; Vlatas 1981; Zeitzew 1981). This legal approach was not critical in my research. There are clearly issues concerning the consistency of regulations and their enforcement at different levels of government, but on the whole federal law explicitly approved and even favored innovative technologies, and state statutes are no different for innovative technology than for conventional.

One author (Lohman 1982, p. 41) attempts to integrate the interaction of "<u>structure</u>...that which is written -- an observable, quantifiable law or bodily creation of law" and "<u>process</u>...the amorphous gathering of all those diverse elements that meet in an actor or agency designated to act for the structure" into what she terms "<u>meld</u>...the interaction of the static structure and the fluid forces of society and personality that make up process." According to Lohman, "Where structure is law and process is institutional activity, meld -- the area in which structure and process merge or conflict -- is the institution."

I found this approach more intriguing for examining institutions than simply viewing the legal structure as the constraint, but it is still not completely satisfactory for the purposes of my research. The main problem is that it is too relativistic. The final sentence in the above paragraph seems to say that the institution is where individual actors, whether persons or agencies, through their decision making, either support or oppose the laws. There was no attempt to find factors that interconnect agencies and levels of government, and which also affect individual responses to innovative technology.

An article by Kurt Wehbring (1981) uses a case study approach to examine institutional considerations. Using nine cases of water reuse projects[1] in the southwestern U.S., he developed helpful categories in which obstacles to water reuse projects can be expected. These are:

1) Competing uses for water: If water will be reused rather than discharged into a river, this raises issues with the existing water rights of people downstream.

2) EPA grant requirements: The innovative technologies for water reuse require significantly more studies and documentation for funding approval than if a conventional system is used.

3) Neighborhood opposition to treatment facility site: This is the obstacle that has become known as "not in my back yard" or NIMBY.

4) Urban growth issue: There is often opposition to sewer treatment plans based on the concern that it might allow for more growth in an area where people are opposed to this.

5) Inter-agency conflicts: Described by Wehbring as "a fact of life in public decision making (p. 1794)" these are cases where the needs and priorities of agencies conflict. For instance, a board of health might raise concerns over a plan approved by a sewer district due to a lower threshold for tolerance of health risks. A budget agency might veto a project if it felt that going with a more reliable technology was preferable.

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[1] These projects included industrial cooling, agriculture, landscaping, marsh and wetlands habitat enhancement, and mining.

6) Public health concern: Whenever new methods of dealing with wastewater are suggested, this issue invariably arises.

Another article combining four case studies of wetland wastewater treatment in the western U.S. observes about wetland projects: "The state of the art is making rapid advances. Hopefully, this will be accompanied by an increased level of acceptance by practitioners in the field of wastewater treatment and reuse" (Demgen 1984, p. 579). The primary obstacles that faced the four projects studied were cited as:

* Early on in the process, there is a lack of delineation of specific goals and requirements.
* Inappropriate design suggestions.
* Political competition among equivalent entities.
* Lack of consistency among staff at federal and state levels.
* Wastewater wetlands are still viewed as an unproven technology.
* A willingness to persevere, educate, and negotiate is essential. (p. 587)

Not all the articles suggest ways of breaking down institutional barriers. The ones that do generally agree on the need for increased public involvement. This view is based largely on the perspective that public sentiments tend to affect agencies; if there is public support, the agency is more likely to move ahead with a project than when there is not. According to Forster and Southgate:

> The existence of these institutional barriers inhibit the growth of land application. Institutions frustrate efforts to change and can be expected to construct barriers to change. An important issue is how to build public acceptance that will accommodate an emerging technology like land application. A host of methods are available to build public acceptance. They include public involvement in the decision making process, clarification of incentives for land application, resolution of odor, health, and environmental problems, establishment of advisory groups, aggressive educational programs, and responsible management of land application. (1983, p. 42)

The incentives they refer to as being needed are basically the economic justification of using the emerging method for treatment. If people can be convinced that it is less costly, then there will be more interest in fully exploring it as an option.

A similar set of recommendations emerged from the discussion during a session on political and institutional constraints at the 1983 Workshop on Utilization of Municipal Wastewater and Sludge on Land (Davis & White 1983). Key factors to the acceptance of a new technology cited were:

1) Independent Resource Personnel: The involvement of these "objective evaluators" is important to assure the credibility of a proposed project.

2) Early and Continuing Public Involvement in Decision Making: This should occur before decision and not after. This is deemed important in order to gain public support.

3) Education: This is cited as an important part of any public agency action. It entails communicating with all of the parties potentially affected by a project.

4) Involve Local Elected Officials and Opinion Leaders: This is another way of gaining support from everyone who might be able to affect the project.

5) Communication: This must be kept completely forthright and honest. There can be no grounds for the accusation that approval was granted due to important information being withheld.

Reports by EPA, GAO, and KSG: Three other studies merit attention. These are the General Accounting Office's 1984 report critiquing the Innovative Technology Program, EPA's Report To Congress On The Effectiveness Of The Innovative And Alternative Wastewater Treatment Technology

Program[1], and a case study prepared by Harvard's Kennedy School of Government (KSG) on the innovative treatment facility in Arcata, California[2].

The EPA makes these conclusions concerning the effectiveness of its program to encourage the dispersion of innovative and alternative (I/A) technologies:

* I/A technologies are not a State priority; state program focus is on conventional wastewater treatment technologies.
* I/A projects are not being proposed by the local municipality or community's consulting engineers... (EPA Oct.1988)

In its report, EPA did not ask why these conclusions are still true after 12 years of program operation. But it seems clear that the risk aversion associated with engineering conservatism that had been a target to overcome through the I/A program is still very much a factor in the development of wastewater treatment systems.

The GAO report finds that: "The (I/A) program does not provide sufficient incentives for consulting engineers and states to take the risk or incur the additional cost of developing innovative projects" (GAO Aug. 1984, cover summary). The report found that the institutional barriers, including engineering and community reluctance and risk aversion, were practically untouched through the I/A program's operation.

GAO studied 70 projects around the nation which received the bonus

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[1] A draft copy of the executive summary of this report was provided by EPA since they felt that this would not be changed. The full report is still in preparation since there is still a debate as to what to recommend for the future now that the I/A program has been suspended.

[2] This report, obtained from Dr. Robert Gearheart, professor of environmental engineering at Humboldt State University, is a draft that is awaiting completion.

federal allotment for being innovative. This represented 40 percent of the 175 innovative projects approved nationwide at the time of the study. Through interviews with communities and project engineers, GAO found that 53 of the 70 cases studied would have used the innovative technology regardless of the federal incentive program. The reasons for this are that the innovative technology offered clearly a more cost-effective or easier to operate approach. GAO expresses the concern that this raised serious doubts as to whether the I/A program offers sufficient incentives to overcome the engineering conservatism. In order to overcome risk aversion, particularly on the part of engineering firms, they recommend that additional payments be provided to engineers because:

> Engineers frequently told us they would not accept the risk or cost of designing an innovative wastewater treatment plant without some additional compensation. Generally, consultants are not paid for their extra time or the risk in designing an innovative process. (p. 24)

The GAO report also found that "states have also contributed to the barriers by continuing to apply very conservative standards which raise the cost and effort required to successfully construct an innovative project" (p. 29).

The KSG case study on Arcata provided a more comprehensive case study of the process of gaining approval for an innovative wastewater treatment project than any other which was available. It describes the five year administrative, legal, and political struggle waged by the city of Arcata to convince the Northcoast Regional Water Quality Control Board of California that Arcata did not have to participate in a regional sewage plant project. Arcata wanted to develop a low-cost, reliable sewage treatment project integrated with providing a dependable water supply for rearing salmon. The final proposal developed for this purpose included an upgrade of Arcata's existing treatment works, construction of 50 acres of wetlands into which water from the oxidation ponds would be discharged, and the development of a public park and bird sanctuary.

Scientific analyses conducted determined that Arcata's treatment approach would provide quality effluent. Tests performed also showed that the treated effluent would enhance the waters of Humboldt Bay. In constructing the marshes and lake to be used for fish raising, the project would also recover the land that had formerly been a county landfill. The problem with this proposal, for both the Regional Water Board and later the State Water Resources Control Board, was that it would have violated the state's stringent "no-bay-discharge" policy. State and regional regulator's favored the significantly more expensive regional project proposing to use the Pacific Ocean as the ultimate outfall.

Arcatans began to resent what they felt was the bureaucratic inertia on the part of the state regulators. "No amount of data would have made any difference, because they had already invested a lot of planning time and money into this regional system. So it wasn't a question of how logical your arguments are, or how legitimate the assumptions are," stated environmental and sanitary engineer Bob Gearheart.

Political pressure mounted for the state to review the "no-discharge" bays and estuaries policy. The state legislature began to act on a bill to lay the groundwork for the explicit approval of Arcata's proposal. More of the cities in the proposed regional treatment system got angry at the projected expense of that project and requested approval for individual treatment facilities. In May of 1979, the state water board backed down and granted approval to the Arcata project. In doing so, they ruled that the educational and research aspects of the marsh, along with the fish raising operation, would "enhance" Humboldt Bay.

Sam Pennisi, who serves on the Arcata city council, described the city's battle:

> "We had everything to lose...but I would say we had an ethos. We had an outlook that values consistency in policy, innovation.... We believed in experimentation, in the value of research. We believed in risk-taking.... I think politically we were able to pull this thing off just because we believed in what we were doing. It's a bit like Don Quixote. You don't care how big the windmills are. You can take a windmill down with a bulldozer quickly or with a pocketknife slowly."

Effects of Literature on Research: As I mentioned at the beginning of this chapter, this literature did provide some guidance in terms of thinking how to approach my interviews. For instance, one important finding from the GAO report (1984) is that cost-effective innovative technologies are acceptable. But these cases were generally ones where the community that opted for the innovative technology basically had no other option. This was often the case due to it being a small community that did not rank very highly on the state's priority list, and thus stood little chance of qualifying for a share of the state's federal funding allotment. Other times it was a community that had a particular need, such as to eliminate chlorine treatment from its process due to water toxicity problems. Another reason was some overarching consideration such a water shortage demanding that sewage plant effluent be used to supplement public drinking water supplies.

Another finding from the readings was that "institutions tend to be static" (Forster & Southgate). This is an important consideration for researching institutional constraints but the authors made no attempt to propose any theory that explain why this is the case. Instead, they looked at the structural aspects of specific agencies, which they viewed as being institutions, without attempting to ask what the similarities were between different agencies as well as the persons who work for them. I wanted my research to develop an understanding of what common factors there are to all elements of the wastewater technology selection process.

The issue of a technology conflicting with state regulations was also important to consider. My sense was that there are stringent regulations covering untreated wastewater released into natural wetlands, but I was not aware of any requirements that would affect only innovative projects. I wanted to verify this, however, by asking questions concerning regulatory and legal considerations that solar aquatics would encounter.

Finally, the Arcata study pointed out that an activist approach on the part of a local government and its citizens could prevail in gaining approval for an innovative project. But this does not occur without significant expense all the way around. This is not uncommon in resolving an adversarial dispute involving a public issue. Is there any way in which an agreement could be reached more easily and with less cost?

Against this background, it is now time to examine the results of interviews with agency personnel regarding the proposal to integrate solar aquatics into the municipal wastewater treatment system in Greater Boston.

CHAPTER FIVE -- INTERVIEW ANALYSIS
Summary of the Results from MWRA, DEQE, and EPA

In conducting this research project I used three types of interviews. The first was a series of interviews with people who have been active in the field of wastewater treatment for an extended period of time. They are noted for their expertise in some aspect of wastewater treatment in Greater Boston or in the use of innovative and alternative technologies for wastewater treatment. This series of 15 interviews included operators of both conventional and innovative wastewater treatment facilities, personnel with EPA's Office of Municipal Pollution Control in Washington, D.C., researchers for the National Science Foundation, principals with Ecological Engineering Associates, environmental engineers with the U.S. Army Cold Regions Research and Engineering Lab in Hanover, New Hampshire, and personnel from various state agencies. In this chapter I discuss how these interviews helped me formulate issues for my research, and what initial insights I developed into my topic. Field notes were made of these contacts.

The second set of interviews involved the summary proposal I prepared for integrating solar aquatics into the Greater Boston municipal wastewater system. These interviews, ranging from 30 minutes to 1 hour and 10 minutes in length, were conducted after the subjects read the proposal. The interview was designed to elicit three categories of response: personal, professional, and agency. Although it is possible to argue that personal and professional are one and the same, and an agency is merely an aggregation of individuals, background interviews and the initial discussions with agency personnel regarding the solar aquatics proposal demonstrated that there are important dynamics present between these three categories. I believe that these distinctions are therefore important. This will be explained more fully in the following discussion.

These interviews were tape recorded and transcribed for data analysis. My subjects included five personnel from the MWRA, five from the DEQE, and one from the EPA's Region One Boston headquarters. These subjects were assured that their names would remain confidential.

The third set of interviews involved the frequent telephone calls that I made during the course of my research and analysis. These were to ask technical questions, to clarify something that I had been told, or to follow up on an idea that I was developing. Some of these phonecalls were repeat contacts to people with whom I had met; others were pre-interview contacts; and some were sole contacts. I did not always keep a strict accounting of these calls, nor of the content of them.

In this chapter, I will present a summary of my findings based on the interviews that I conducted. I organize the data that I collected in my field notes and transcripts according to distinct themes that are represented and that provide a basis for my discussion of the institutional constraints facing solar aquatics. In the following discussion, I combine the third set of telephone contacts with the initial round of general background contacts, and present the intensive interviews with the agency personnel in two groupings: first, the municipal sewer district operating agency, i.e., MWRA, and, second, the regulatory branches of government, i.e., both DEQE and EPA.

The Background Interviews and Miscellaneous Phonecalls

Background interviews are an important part of qualitative research.

They occur during the phase referred to as "getting in" (Lofland and Lofland). These are random and unstructured interviews that are performed to gain information on both the topic and the site for the research being contemplated. From the background interviews a set of factors began to emerge that seemed likely to pose institutional constraints for an innovative technology proposal. These factors, or categories, helped me to formulate an understanding of my research topic. I will summarize the major categories of analysis that emerged from these contacts below. They are not presented in order of importance.

Timing: One of the first factors that emerged in discussing the use of solar aquatics in Greater Boston was the importance of timing. An innovative technology will have no chance of being seriously considered if the agency which could potentially use it is operating under pressure to "accomplish a mission." MWRA's mission was said to be the construction and restoration of interceptor pipes and pumping stations to transport wastewater to the secondary treatment plant under construction on Deer Island. With this sort of workload -- a workload that was inherited from its predecessor, MDC, Greater Boston sewage planners had very little else on their minds.

Another aspect of the timing issue was where the consideration of a project fits into the process used to conduct an agency's business. I was warned that the solar aquatics proposal I was considering too closely resembled a decision to perform satellite treatment rather than relying on the single centralized facility on Dear Island. One of the first decisions made by MWRA was to use centralized treatment. Solar aquatics thus seemed like it was rehashing an issue that was already resolved.

In response to this concern, I deliberately placed the solar aquatics proposal in the future when the Deer Island facility no longer meets the needs of Greater Boston. Agency personnel with whom I spoke agreed that this was appropriate since eventually the agency would have to deal with the issue of additional facilities, and thus what kind of facilities to develop.

Risk Aversion: There were two major ways in which risk aversion was expressed. First was the agency concern over the wise use of public funds and maintaining its credibility. Second was the caution exhibited by professional engineers when they are working on a project. This latter involves both private consulting engineers who are hired to do a facility plan, and engineers employed by and possibly making decisions for the agency. I will discuss this second form of risk aversion below under the heading **Engineering Conservatism**.

Much of the risk aversion on the part of the agency was discussed as a desire to be fiscally responsible. In fact, many of the obstacles to innovative technologies in this regard are deliberately planned to impede what might be considered "rash" decision making. For example, administrative and budget procedures are created to ensure that public funds get spent wisely and prudently. These same policies prevent an agency from getting "egg in its face" by actively working for an innovative idea that ends up failing miserably. These administrative "safeguards" certainly favor agencies' use of technologies that are time-tested and proven.

Engineering Conservatism: Engineers are involved in technology selection in two ways: as the consulting engineers who usually prepare a facility plan, and as employees for agencies. The role played by engineers is generally very conservative in terms of selecting innovative technology[1]. Although engineering conservatism is one manifestation of risk aversion, it is important to separate it from that category. Engineering conservatism assumed almost an identity of its own when being discussed during interviews. This was a curious phenomenon raising questions concerning the implications of professional identity and the effects which the profession has on the success of innovative proposals.

Engineers and wastewater treatment facility operators interviewed expressed a strong desire to be "in control" of the process. Conventional treatment provides this through the assorted valves, gauges, and tanks. If treatment standards are not being met in terms of fecal coliforms, then an extra dose of chlorine can be added at the end. If it is phosphorus levels that are a concern, then phosphorus can be precipitated out using aluminum sulfate. Engineers expressed doubts as to whether this same degree of control would be present if the system was "natural" as in a wetland.

Engineering conservatism is simply a product of their tendency to be strongly risk averse. Engineers are not willing to take risks that might jeopardize their professional reputation by proposing a technology that is less known or less used than the conventional approach. It was generally agreed that it is tough to overcome this tendency to avoid risk so much a part of engineering. Advocates of innovative wastewater treatment systems maintained that risk aversion was just as true for engineers

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[1] It is important to recall that the Innovative and Alternative Technology Program under the 1977 amendments to the Clean Water Act was largely an attempt to overcome this conservatism on the part of engineers.

working for agencies as it is for professional consulting engineers.

<u>**Land space available**</u>: One of the major constraints mentioned by those I interviewed working with municipal wastewater treatment was the availability and proper permitting of land. A "passive" treatment approach, which simulated wetlands clearly is, requires more land. This makes it difficult to acquire the necessary acreage, particularly in a densely populated region like Greater Boston with high land values. Many efforts to develop satellite treatment facilities in the past were scuttled due to political opposition from the communities being looked at as possible sites.

There were two other considerations regarding land that were mentioned during my discussions. It was observed that the more time passes, the more benefits are perceived in going with smaller scale, decentralized treatment facilities. This is largely due to the increasing scarcity of land, and the growing recognition of some of the fundamental shortcomings of centralized treatment[1].

The other opinion was that because of the frequently hostile community response to siting considerations, it could be an advantage to use community-based facilities since then no one could reasonably object to having a treatment plant put "in my backyard" since everyone would have one. This approach would be aided if solar aquatics did not possess significant economies of scale so there would be no reputed savings from centralizing the treatment process. This was seen as a way of providing

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[1] For example, the threat of massive spills, such as the one in 1979 at the "model" plant for San Jose and Santa Clara, CA, which spilled billions of gallons into the San Francisco Bay (Marx 1988). Decentralized treatment facilities have also been cited in numerous studies as being less expensive (KE 1979; EMMA 1976; USACE 1974).

community ownership to their problems.

State-Generated Regulations: Personnel at the Sugarbush treatment facilities, both the conventional and greenhouse, raised the issue of the effects of state regulations. The Vermont effluent regulations state there can be "no significant alteration of the biota" due to treatment plant discharges. Since solar aquatics at Sugarbush did not reduce phosphorus to the 0.1 mg/L required in their permit, the effluent had to be treated with aluminum sulfate before the final discharge. This process raises major questions, however, as to which is worse: increased phosphorus in a virtually lifeless mountain stream, or the trace aluminum residues that would be introduced into the watershed instead? The additional phosphorus was generally assessed by environmental engineers to whom I spoke as not constituting a genuine threat in terms of severe algae blooms and eutrophication, whereas aluminum is considered highly toxic to all life.

Market Forces: Market forces were also discussed in terms of how they affect various actors in the wastewater treatment industry. A major obstacle for innovative technologies was seen as there being no powerful interest group that will directly benefit from the economics of implementing the idea. Even if the public at large would benefit from the innovative technology, this would be diffused as a small amount of benefit for a large number of people. On the side of the status quo there are powerful vested interest groups supporting conventional technologies: consultants, contractors, equipment suppliers, operators, and so forth. This is the classic market entry question that economists and businesses often confront.

Entry to the market might be gained if the cost of the conventional approach became high enough to force municipal sewerage officials into contemplating cheaper innovative options. In terms of calculating a cost advantage it is important to factor in the reactions of the potential lenders in the bond market. An innovative technology approach must include a risk premium on top of the going rate of interest in order to attract investors.

Public Accountability and Professional Credibility: Concern over one's accountability or credibility seemed to permeate many of the categories already mentioned. For instance, credibility was cited as a strong factor in inducing risk aversion so characteristic of engineering conservatism. Consulting engineers, for example, need to maintain a good reputation in order to continue to attract contracts for their business. This is one disincentive for them when it comes to pioneering unconventional sewage treatment techniques. They want to avoid the stigma of being associated with a failed project. If they are licensed Professional Engineers[1], it is also possible for them to lose their credential if an individual or community files a complaint against them. Complaints are generally associated with failed projects.

Public officials are concerned about their job's accountability. They need to demonstrate to the public that they are spending public funds prudently. In order to preserve this image they are wary of getting behind sewage treatment options that are relatively new or untried.

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1 Professional Engineers (P.E.s) become certified with a state after meeting a minimum set of criteria and by taking a special licensing exam. It is a position of professional distinction and is a requirement for some types of job.

This is true for both elected and appointed officials.

Guidance From Background Interviews: After this first set of interviews, I was prepared to approach the next phase of my research. My proposal for solar aquatics in Greater Boston was placed in the future so that it did not conflict with the MWRA's current agenda. The issue of risk aversion, both within agencies and as exhibited by engineers, emerged as an important issue to pursue with agency personnel. This was done through asking questions about the effects of one's professional identity and public accountability on one's willingness to select an innovative wastewater treatment technology proposal.

THE INTENSIVE INTERVIEWS

In presenting the intensive interviews that I conducted it is important to distinguish between the two types of agency I researched: service provider and regulatory. By service provider I refer to the MWRA, which provides wastewater treatment for its member communities. A fee is collected to pay for this service. This fee might be incorporated into property taxes, but it is a fee nonetheless levied on the recipient of the service provided.

Regulatory agencies, on the other hand, refer to DEQE and EPA, which have a responsibility to monitor and control municipal wastewater treatment services. It can be argued that regulatory agencies are in fact providing a service in terms of public protection. By setting and enforcing effluent standards for municipal wastewater treatment facilities the regulatory agencies are protecting public health and the environment. It can also be argued that this same service carries over into the agencies' licensing and approving projects.

Nevertheless, I found distinct differences in the responses from the two types of agency and feel that it is important to separate their presentation. I will occasionally make references to the differences between responses from the two types of agency.

MWRA -- Service Provider

In general, the MWRA is different from DEQE and EPA in that it is a recently formed agency. MWRA was created by an act of the Massachusetts legislature in December of 1984, and was brought into being during 1985. It was given the "mission" to do successfully what the Metropolitan District Commission, its predecessor, was unable to do. Namely, provide secondary treatment for the wastewater being generated in Greater Boston and to solve the problem of the combined sewer overflows[1] (CSOs). This "special mission" status affected both the time available -- there was not only a sense of wanting to get the job done, but also a court order to require it -- and the pressing sense of public accountability. This will be discussed further below.

In conducting the interviews, I asked questions focussing on four areas in which constraints to innovative proposals could occur: personal, professional, agency, and regulatory/legal[2] (see Appendix B). I used this approach since these were the categories I wished to explore

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[1] Combined sewer overflows are a problem created by combining the sanitary and storm sewers. When a heavy rain occurs, the influx of storm water overloads the system and causes the mixture of untreated sewage and storm water to pour out of the emergency outfall pipes into the surface waters. Some consultants maintained that this is the single most critical aspect of water quality concerns in Boston Harbor, far more so than secondary treatment.

[2] A copy of the outline used to conduct interviews is included as Appendix C.

after performing the background interviews. These four areas are not easy to separate, however, since both professional training and agency priorities can affect personal responses and vice versa. I thus organize and present my findings from these interviews according to categories similar to the ones used for the background interviews.

The interviews were conducted with personnel selected from three different segments of the agency. My method of subject selection was what´s know as a "snowball" sample, meaning I first approached my initial contacts who referred me other subjects whom they thought would be helpful. Through this process I selected people who were involved in project planning and development, and long-term planning. This same process was used for DEQE.

At MWRA, two of my subjects were from the Capital Planning Group, the most long range planning division of the agency; two were with the Program Management Division, a section that recently incorporated the earlier engineering and project management divisions; and one interviewee was with the Sewerage Division and was a manager for an extension sewer project. Two of these subjects were certified Professional Engineers. The minimum level of engineering training by any of these five was a BS in civil engineering. One subject had more recently received an MBA after eight years of work for a consulting engineering firm. Only one woman who was interviewed.

Personal Risk Aversion: Interviews were used to help me probe for an individual´s reaction to the proposal. The responses provided an indication of whether or not the subjects were risk averse or risk taking in their attitude toward innovative technology. The connection that I made concerning risk aversion was that it appeared to be associated with a respondent's professional training as an engineer.

Of these five interviews I elicited only one response that initially seemed unaffected by the subject's membership in the engineering profession. This person's first response to the question of how she responded to solar aquatics was, "Well, I read your (proposal) and I thought it was very exciting." But this reaction was tempered almost immediately. Technical questions regarding the effectiveness of the proposal were raised, then the respondent continued:

> "So these are all questions that have been answered in terms of traditional technologies....these are things we know about, and a lot of times in engineering, the devil that you do know is preferable to the devil you don't. That is because engineers are very aware of their responsibility to the public, and they are trained that way -- engineers are registered with the state, ...they are liable for anything...that's practiced. So there's a barrier...in terms of creativity for engineers. They may be thinking, I may be thinking, 'Gosh, this would be wonderful! I think we should try it!' But I still have that special responsibility to pick something that's reasonably predictable, that the future effects of are reasonably well-known."

In this quote the respondent refers to engineers as being extremely cautious. Having stated this she then expressed the constraints that this approach places on members of the profession, including herself. I believe this statement expressed a conflict between the desires of the individual and the operating norms of the engineering profession. An individual might want to pursue an idea further, but the exigencies of the profession and agency can prevent this.

This conflict was also illustrated in the other interviews. Each one of the respondents had something good to say about the proposal, but invariably predicated that support on actually finding out more about the effectiveness of the idea. At a personal level they seemed to be attracted by the idea, but at a professional level they needed more information to assure themselves that it would not be too much of a risk. When I use the term "personal" I am referring to that individual's "lifeworld" meaning all of their assorted experiences, beliefs, and values that have developed over the years. "Professional", on the other hand, refers to the particular set of experiences that are directly linked to an individual's professional identity. In my study, professional refers to membership in the engineering profession. The engineers who were the subjects for my interviews were also personnel for public agencies.

The polarity between personal and professional as I defined them was most noticeable when respondents used the third person when referring to engineers. For example, "You're going to get the engineers in the authority not wanting to face it (using solar aquatics) because it's not something that they are personally familiar with." Third person references like this were used even though the respondents were all trained as engineers and generally working in some engineering capacity. Individuals appeared to be both distinguishing themselves from and resigning themselves to the profession.

The person whom I observed as being most skeptical of the proposal used the first person[1] form of reference when speaking of what engineers felt was necessary before proceeding with a project. I viewed this as reflecting a personal ownership of this attitude. This person had apparently internalized risk aversion to a greater extent than the others

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[1] In the quote cited above the first person was also used, but this was done to exemplify the conflict posed by the profession on her personal ideas.

and spoke in terms of "I" or "we" without using it to set himself apart from the engineering perspective. This use of the first person may be associated with the age and his length of professional experience, since this person was the most senior of the respondents and also a Professional Engineer.

At one point he said, "My overall feeling is...it's (the proposal's) a little naive...When you have my background, you probably wouldn't be doing this (i.e., proposing solar aquatics)." I felt that he was basically saying that anyone with his professional engineering background couldn't possibly support solar aquatics.

Even this subject was not immune to the conflict between the personal and professional, however. At one point he said that solar aquatics, which he referred to as "ecotechnology", was "almost an ideal". None the less, he made it very clear that, "I'd rather do things in tanks than wetlands, you know. You can control them." This need to feel "in control" of the process was a common assertion on the part of engineers in order to avoid risk.

Agency Risk Aversion: The need for the agency to be careful about venturing into innovative treatment technologies was another common element in responses to questions. When I say agency, I am referring to what the individuals whom I interviewed defined as being their agency's likely response. It is hard to separate the individual and the agency risk aversions, since an individual could be speaking as much for her or himself in answering questions as for the agency. I have attempted to distinguish between personal and agency by noting the choice of subject in the statement, i.e., first or third person, and by the justification that is offered for the aversion to risk. The grounds used to justify agency caution were generally ones involving public accountability.

Perhaps the biggest reason for the agency not to use an innovative technology can be summed up by the old maxim, "If it ain't broke, don't fix it." For instance, one respondent said, "Why should an agency bother to engage in what someone might consider...a risky technology if conventional technology is adequate?" Another respondent characterized this attitude, what she termed "institutional resistance" to innovative technologies, as being based on "the unwillingness to take certain kinds of risks." She was also not willing to necessarily criticize this approach. It's "a very powerful way in which the community is protected from unscrupulous vendors....that weighs very heavily on senior people" within the agency.

One of the main elements of public responsibility was spending the public's money wisely. For instance, one subject averred that it was MWRA's responsibility to "<u>not</u> make mistakes (with public funds), to decrease the liability, the financial liability, (and this generally causes) agencies to go with the proven technologies." Not taking unnecessary risks was stated as the best way to ensure that the public funds were spent wisely. This is where the issue of reliability affected the agency.

All of the people at MWRA who I spoke to were in agreement that the agency would need more information than what was in my proposal for them to act. They felt that it was their responsibility to get this before they could proceed further in the process. According to one: "I think in general (solar aquatics) appears to be a technology that has some merit." But, "obviously before the agency took the next step in terms of endorsing or proceeding with the proposal, they would need more information than is presented here." The additional information that he was referring to was technical information that is commonly sought by the engineering community for a new wastewater treatment technology: scale-up factors, loading rates, reliability, work history, potential impacts, and so forth.

This consideration was emphasized by another subject:

> "We (at the MWRA) have...a history of a treatment facility that never worked very well,...was never maintained very well. It had a bad track record. We have a tough job turning that around....we only have one chance to do this right, and so we're looking for good solid technology that we can count on -- that we know will be reliable, operable, and will meet our effluent limits."

The best way to procure the necessary information about a new technology was mentioned by one subject as following the existing review process. Solar aquatics should be one option that was considered alongside all others. In his words,

> "I look at things in terms of the established facilities planning and environmental review procedures, 'cause I have to live with those, so I say to myself is this something that should be considered in that program and I think that it is -- it should be considered as seriously as conventional or any other procedure .... then I reserve judgement for the...findings of those reports."

My impression during these interviews was that the people at MWRA felt they had a public responsibility to fulfill in terms of doing good work. Agency risk aversion, as expressed by in the interviews, was affected by the engineering profession in the same ways that individual risk aversion was. Both were largely based on a need for ensuring the technical reliability a technology before supporting it. In other words, the conservatism of the engineering profession was integrated into the decision process for both the individuals and the agency for which they worked.

Time Constraints: The importance of assuring technical reliability clearly raises the issue of time. Will there be enough time to perform all the necessary research for an innovative technology before the system has to be constructed and operating? Timing was thus very much a factor in the issues of technical reliability and overcoming risk aversion. As one person stated:

> "Timing is important to us. If we had the time to go through all of these studies, then it (solar aquatics) would be a real viable solution. Usually, we're attacking problems...that are emergencies. And if we look at conventional wastewater treatment and we can get a wastewater treatment facility built within a few years, and we look at an alternative treatment that would require a few years just to test the alternative, just to test the reliability, the effectiveness of it, and then we would have to go and implement it during another few years, that may be enough reason to throw out that alternative."

What is mentioned in this quote that is significant is the way that MWRA is usually confronting problems that are seen as emergencies. This is in large part due to the legacy of unsolved issues they acquired from the MDC. The person making the quote felt that once all the present interceptor projects were completed, and the Deer Island facility was up and operating, there would be a greater chance of doing long term planning. Once they had complied with the court order, they could turn to the task of developing long term plans that might more reasonably be expected to include innovative technologies.

Role of the Public: It is important to distinguish the two different roles which the public has in the selection of wastewater treatment technologies: one is passive, the other active. The passive role, which has already been mentioned above, is the responsibility that the agency has to fulfill for the public. The active role is what occurs when public participation is included in the wastewater management process. This is increasingly being done, in part due to statutory requirements, including provisions of the Clean Water Act, and in part due to public demand to be heard for issues involving plant siting, and waste treatment and disposal.

One subject commented:

> "...if we became a project proponent, it would be our job to sell this idea to the recipient community....You know, around the Greater Boston area, there's a real mix of people who are interested in newer technologies, and...people who want something that's tried and true. So what our job is to try to balance that and try to come to them with a proposal that ... meets both of those kinds of needs....I think that a little bit innovative ...has some potential degree of success. It's when you get out on the edge that people get skittish about it, because...you are dealing with wastewater, (and) there is a public health risk."

Concern about the public response was expressed in all the MWRA interviews. The public was generally cited as having an important and legitimate role to be played in the selection of treatment technology. This was different from the cases of DEQE and EPA, as will be seen below, since their job is more one of technical enforcement of water quality and effluent standards and regulations. MWRA appeared to be more publicly responsive.

There were two major types of public response that MWRA personnel were aware of: ratepayer motivated and not-in-my-back-yard or NIMBY. The former is one that has previously not been much of an issue in Boston but was thought to become increasingly important since MWRA rates are rising dramatically. The latter is the typical response to siting virtually any facility dealing with any form of waste treatment or disposal. It was generally agreed that it was appropriate to deal with both public responses by incorporating public participation as early and as often as possible in the process of planning, designing, and implementing projects. One interviewee commented:

> "I think we have an obligation to open these topics (technology selection and siting) up to the public and get their input, regardless of what the public's reaction is going to be. I think that they should have their say and...have it early, and that they should be part of the process. ...I understand that many people in the community are not technically sophisticated enough to perhaps evaluate things and in the end they'll be saying, 'Well, your engineers will have to make that specific decision.' But I still think that they have to know regardless of the reaction that they have -- whether it's supportive, whether it's the NIMBY reaction, or whether it's the...god, you're wasting my money reaction."

Two reasons mentioned in the interviews for seeking this sort of public involvement were the need to enlist public support for a project before opposition had a chance to consolidate, and to demonstrate to the public that MWRA was fulfilling its public responsibility. This latter reason was considered to be important to help overcome the legacy of incompetence left by the MDC.

Role of the Consulting Engineer: The issue of engineering conservatism recurs when considering the important role played by consulting engineer firms during the course of planning, designing, and constructing wastewater treatment facilities. I have already presented some of the effects of professional risk aversion on the parts of individuals and agencies. This story is perhaps even more the case when it comes to considering the professional engineering community.

The consulting engineers are generally not going to be very familiar with innovative technologies. This is in spite of the efforts of the EPA through its research and design programs, and policy of technology transfer, to help develop improved innovative approaches to wastewater treatment. As was said in one interview:

> "...much of what we do is influenced by the consultants that work for us. We go to a consultant and we ask him (or her) to come up with alternatives and we basically listen to whatever he (or she) has to say. If (she or) he doesn't come up with solar aquatics as an alternative, we're not going to question (her or) him on why he (or she) didn't. We sort of leave the expertise to them and it's whatever their expertise is that influences the design. And I don't think that there are too many civil engineering firms, AE (architecture engineering) firms, out there that are getting into a lot of the alternative technologies. They push what they know best for obvious reasons. They're going to be doing the work, they want to be able to do it right..., and be able to cost it out in order to make money. ... they know what they've been doing, and when you throw something new at them, they get scared."

The most senior of the respondents commented:

> "People are willing to listen to...engineers, (and) consultants --the people who design these systems. They tend to be conservative...because their reputation is a stake. You couldn't get a bonafide registered engineer to (support solar aquatics without proof it will work)....You know, engineering is that way, it's built around experience and there's no shortcuts."

This comment raises an interesting issue since it seems to indicate the complete deference of this agency engineer to consulting engineers. This can perhaps be explained by the fact that the person speaking personally regards himself as an engineer first and foremost. He is conceding nothing to private engineers since he agrees with them fully.

From this discussion regarding the role of consulting engineers in wastewater treatment, I realized that my research demanded that I contact some members of this community. This was done and the results of these contacts will be discussed in Chapter Six along with the conclusions from these interviews.

Innovations at MWRA: The future prospects of solar aquatics were summarized by the MBA degree holder: "It obviously would take...some agencies or institutions that are willing to take a little bit of risk to get something like this started -- and to set an example for the rest of the engineering community." Has MWRA ever taken a risk.

Innovative approaches, including new technologies, are not unknown at MWRA. During the interviews several examples were cited of methods that had been selected by MWRA that are clearly not conventional[1]. It was generally agreed that options like these were made possible because of the relative youth of the agency. "I just think that we're much more open-minded and...we're not prejudiced by a long relationship with the status quo," one subject commented.

MWRA's willingness to try unconventional approaches was also attributed to the court-imposed mandate to get the job done. MWRA administrators are apparently more willing to use an unconventional technique in meeting its goals if it seems reasonable that this will aid that effort and work effectively. Both of the innovative techniques referred to above offer space saving and cost reduction advantages at Deer Island.

The factor that was cited as offering the best chance for MWRA's selection of solar aquatics over conventional treatment was the difference in cost. If the difference is as much as in my proposal then it was generally agreed that this was a good reason for the agency to choose this approach. This was seen as being especially true in light of the

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[1] To name a couple: Stacked clarifiers, or settling basins, previously used only in Japan, were selected for Deer Island in order to save space. Anaerobic selection, which is a biological treatment step occurring before the aeration basins and is done to eliminate what's known as sludge bulking, or rising. This is a patented process that was developed very recently.

increased responsibility for funding the construction costs shifting onto the individual communities. This is occurring as a result of the changes in the federal construction grants program.

Finally, when evaluating the prospects for innovative technology, the role of the individual cannot be underestimated. This point was emphasized in two interviews:

> "I think...individuals affect the process more than anything else. More than the regs do, and all of that.... If you've got a guy... that thinks one way and it's not the way that you're thinking, then your project is going to be held up because of that one guy, regardless of what the regs say. I can see comparing an institution to a group of people, and I think they're basically the same thing. An institution is a group of people, but I'm saying the prejudices are individual -- they're more important than group prejudices. You'll get one person that can really make something like this fly, and you can get one person that can really kill something like this."

and:

> "...so while there are people...who would like to be leaders ... at a lower level, it takes a very strong leader at a higher level to actually get people to support this and to not be afraid ... of ... risks. So...when you look at...MWRA you (also) want to look at its top leadership, you want to look at the top leadership of DEQE (and) the EOEA (Executive Office of Environmental Affairs)."

These comments exemplify the perspective that what is needed in order to successfully adopt innovative technology is "political will." Individuals can obstruct and delay a proposal that they personally do not like, or they can really open the doors for its consideration.

Regulatory/Legal Considerations: Regulations and laws cited as being important when considering an innovative project are the same ones that apply to all projects. Basically, the facility must conform to all effluent standards and permits, load allocations under the anti-degradation statutes, toxicity limits, land use requirements and permits, and taking the proposal through the permitting process of the regulatory agencies.

The other regulatory factor cited in the interviews as being important was the previously cited shift of responsibility for funding the construction of wastewater treatment facilities to the community level as the construction grants program is phased out.

DEQE AND EPA

The sample interviews of regulatory personnel included five with DEQE and one with EPA. I included personnel from as many of the sections of DEQE's Division of Water Pollution Control as possible that would be involved in the process of reviewing proposals for wastewater treatment facilities. The ones I included were: the Technical Services Branch located at the lab in Westborough, the Surface Water Permit Section, the Boston Harbor Program, Construction Grants/Innovative and Alternative Technology Program, and the Residuals Program. Two other people who worked at the Technical Services Branch reviewed the proposal, but could not participate in an interview. They submitted written responses.

At EPA I interviewed someone from the Technical Assistance Section who was also the Northeast coordinator for the Innovative and Alternative Program. All six of the subjects had masters degrees in engineering -- four environmental, one sanitary, and one who didn't specify. Each one has spent at least 10 years with their particular agency.

Responses to my questions overwhelmingly reflected the technical orientation of the regulatory personnel. It was more difficult to get the subjects in these interviews to state directly what they personally felt about solar aquatics. They generally qualified their opinions by making them contingent on the technical reliability of the technology.

One difference in the innovative technology roles played by DEQE and EPA is that EPA, up to this time, monitors DEQE to ensure that communities fully consider innovative and alternative wastewater treatment options[1]. DEQE, on the other hand, sets state water quality and effluent standards, and reviews and approves treatment projects which the communities and their consulting engineers bring forward. As expressed in one interview:

> "Aside from issuing the permit and deciding what the limits have to be, DEQE also has to approve the plans for the treatment, they have to approve whatever the technology is going to be in specific plans. ...that's a little bit different than ... what EPA does when it issues a permit. They're just concerned with what the limits are and it's up to the applicant to...meet the limits.... We, by law, have to approve the plans for the treatment, and... permit... the facility, not just what's coming out of the pipe."

The interviews in these two agencies were conducted in the same fashion as for MWRA. Some of the questions were changed to reflect the different roles played by them in the process. For instance, rather than asking if they would choose to propose solar aquatics as a form of treatment for a facility that they would operate, I now asked if they would approve this facility if it were brought to them by the MWRA. I also tried to be more specific about some of the risks associated with the conventional approach that were absent with solar aquatics. Specifically, I asked if the possible toxic effects of trihalomethanes (THMs), one of the possible consequences of chlorination during treatment, posed a

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1 This role will change now that there is no longer going to be a federal grants program. The role will become more one of technology transfer although it has not fully been spelled out. In the words of one EPA official in DC., "We're still trying to figure out how to dispose of the carcass," i.e., the innovative and alternative technology program.

sufficient enough concern for them to be more interested in a method using no chemicals.

The data from these interviews will be presented in the same way as was done for the MWRA. Many of the regulatory personnel responses are the same as they were for the sewer service provider interviews. Where there are differences that are worthy of note I will present them as such.

Personal Risk Aversion: As stated above, there was a general reluctance during these interviews for the subjects to express their personal reactions without qualifying them. The reactions that were discernable were:

* one very skeptical of the benefits that were presented in the summary proposal;
* one in favor in principle, but in need of more technical data;
* one generally in favor of more "natural" systems, but wanting to see them as supplements to more conventional treatment practices;
* two that it was their's and the department's responsibility to fully consider all innovative proposals that were placed before them; and
* one who didn't express any reaction, but did say that he couldn't support something unproven over time.

The common theme in every one of these interviews was that it was too risky without a lot more evidence to really be able to make a decision in favor of supporting solar aquatics. As one subject said:

> "I personally like innovative treatment, and I'm personally ... very much interested in the New Alchemy Institute down on the Cape and what they're doing...(But) I looked at it from a technological point of view, and I know personally from being a fan

> of this type of thing, it's not quite as proven a technology, ... these numbers are not quite as representative of the process as...they're sort of put forth to be....It's purely technical; it's nothing institutional."

This question of technical reliability was raised over and over by all of the respondents to say that the project seemed too risky. In doing this, the respondents commonly used the first person "I" or "we" when discussing what they felt had to be done. More often than not, the collective "we" appeared to be meaning more the agency than the engineering profession. The following are some of the quotes that illustrate this:

> "From what I know of the proposal, no, I couldn't say to go with that. I know what you can do with a conventional treatment plant -- nitrification, phosphorus removal -- we know that can be built and meet water quality standards for the facility that is being designed and will be constructed out there. Based on what I see in here, I would need a much larger...documentation before I could say, yes, this looks like a viable option."

> "Unfortunately..., the reality is that I would probably go with the time-tested method.... Reliability -- we're supposed to prove the reliability...here, and...if the thing doesn't work after (we approved it) then it reflects on us."

These quotes reflect a difference between DEQE and MWRA since the individuals are counterposing themselves with the agency and its needs or purposes, rather than those of the engineering profession as occurred with MWRA personnel. This difference is possibly due to differences in the agencies' ages and the duration for which individuals had been employed. At MWRA, four of the five people with whom I spoke were with the agency for less than one and one half years, the longest for four years or the life of the organization. This could mean that they were less bonded to the agency and more closely affiliated with being engineers.

There was one interviewee at DEQE who used the first person in referring to himself as an engineer. He said:

> "I think that the engineers in our agency are probably not unlike a lot of engineers nationally in that we´d like to see things demonstrated properly.... I think that we don´t just take a lot of information from...other sources. We like to see direct applications and...some real good demonstrations (in the) field."

This person was the eldest of the interview subjects, with the longest duration spent in the engineering profession. He was not a certified professional engineer. At other times he used the first person to refer to the agency´s obligations.

Another difference between the regulatory and provider agencies was the general attitude toward innovative technology. It became evident in the DEQE/EPA interviews that the regulators were conscious of the requirement that they fully consider all technologies in the course of a project. This was different from MWRA, where the sentiment seemed to be more: we need something that will work and we needed it yesterday.

An exchange at the start of one of the DEQE interviews went like this:

> Question: What was your personal response to this proposal for solar aquatics?
> Answer: Personally, as I/A technology, I have to be open-minded to all innovative technology.
> Question: Is that because of what you feel and believe as an individual, or is it because of your agency role?
> Answer: As part of the, you know, as an individual, and...as a professional. Open-minded and objective to innovative technologies.

Another DEQE representative stated:

> "First of all, I don´t think it should be the department´s position to be opposed to any innovative technology. We certainly want to look to the best of our abilities at all innovative technologies, because we think it has a future. The big institutional problem I see with it is being able to properly evaluate new technology as it comes on board."

The latter quote signifies that the commitment to consider innovative projects clearly does not dilute the commitment to first convince themselves of the reliability of the innovation. The implications of this will be raised in the discussion of the time constraints.

The final element of risk taking which I questioned DEQE and EPA officials about was use of chemicals in the treatment process. I pressed them with questions concerning the possible toxic effects of THMs and other chemical residues from conventional treatment as compared to the relatively uncertain, but chemical-free, innovative technology. The answers to this questioning conveyed to me the same "devil you know" philosophy that was voiced in one of the MWRA interviews.

One response was to discount the importance of the question by raising the specter of unreliability. For instance, one person said, "I guess you can focus on the risks of the existing technology, but then, on the other hand, ...you can't be assured of the removal of a lot of pollutants (using solar aquatics)."

Another response to this line of questioning was simply to deny its relevance. It was dismissed as comparing "apples and oranges." For instance, after having been asked whether an innovative system that did not require additional steps to avoid some of the possible toxicological effects of using chemicals was preferable to the conventional method, one person responded:

> "You mentioned dechlorination; that's not required at all of our facilities yet, okay? So I don't think that is a particularly fair issue to put on the table. The key ingredient here is that we know that with most of the technology that is out there we can, at a minimum, meet secondary treatment limits.... We don't know that, particularly with an innovative system, because it's never been demonstrated. So, there is a certain degree of certainty with conventional systems that you don't have

with an innovative and alternative system."

When these people were pressed further on this issue about whether or not THMs could even be removed effectively once they were present in the water, they did agree that there was no guarantee of their removal through the existing techniques[1]. One response to this consideration was, "But, you know, (chuckle) a lot of these things are uncertain."

Agency Risk Aversion: Since it was so difficult to separate personal risk aversion from agency aversion to risk, much of the agency's has already been illustrated in the preceding discussion regarding the individual. A few more quotes, however, are noteworthy. The single feature that was the most evident in discussion regarding an agency's desire to avoid risks was that there was a process that was established and should be followed to ensure this. I ascribe this attitude in part to what emerged from my interviews as the regulatory attitude towards the public. I will come back to this below while discussing the public's role.

The agencies' approach was perhaps best summed up when someone at DEQE said:

> "...our main emphasis is...that we're not opposed to innovative technology, but we have to prove that they can work before we put something...into the ground....The key ingredient here is can it function and do the job, number one, and number two, can it be operated an maintained over the long term. And with innovative technology, when it is something new, that has to be evaluated up front."

Another person at DEQE commented:

"The Division of Water Pollution Control, in reviewing plans

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[1] As stated in a textbook on this subject: "The preferred approach to control of trihalomethanes is prevention rather than removal after formation (Hammer, 1986, p. 271)."

and so forth, (has) learned by experience to take a conservative approach, because you get burned every now and then .... (I)t is our responsibility...to worry...two or three years down the line if the thing collapses or doesn't operate right. We have to be sort of forced to be more conservative than someone who doesn't have that vested interest or isn't responsible for running it.... Reliability -- we're supposed to prove the reliability, proven technology, here....(I)f the thing doesn't work afterwards then it reflects on us."

The EPA employee in turn emphasized the role of EPA as "to take as much of the risk out of the innovative system to try to get it to work before we...go about funding it." These quotes represent the same concerns over agency credibility and liability and over the prudent use of funds that were raised by MWRA officials.

Time Constraints: I mentioned above that the process of "proving" a new technology presented problems for innovations. During the interviews it was acknowledged that this approval process would take more time for an innovative technology than it would for a conventional proposal. At the same time, this additional time was justified on the technical grounds that were referred to above. One respondent said:

> "Once a proposal comes in then we handle each one based upon its merits.... Granted, there is probably a lot of information on a wetland type system..., and that would be evaluated based on its merits, okay? It just takes a matter of time to properly evaluate is what I am saying. We are just simply not as used to innovative systems as we are conventional systems, and that's the bottom line. And that's why it takes longer. We have to familiarize ourselves with that type of system and properly evaluate it."

When I pointed out during an interview that this approach invariably handicapped the progress of an innovative proposal, the response was this:

> "The regulations that are in place are designed to ensure the proper review of treatment procedures. There are two ways you can look at this: first, it slows down the implementation of innovative techniques, and second, it provides for public

protection."

Based on this response, and others like it, it seemed that public protection is primary in the minds of the regulatory officials to whom I spoke. Public protection, that is, from the known dangers of the conventional pollutants in wastewater -- eutrophication, environmental pollution, and disease -- but not necessarily from the toxic effects that can be a consequence of conventional treatment.

The other way in which time constraints are felt at an agency are in terms of an individual's workload. Employees at DEQE and EPA were generally working with a large backlog of tasks to be completed. This affects the willingness/ability to consider innovative proposals. As one person commented:

> "Whether an individual would be more willing or less willing (to consider solar aquatics) is based upon his (or her) present workload....And certainly more work can be put out if it's a conventional system (proposed) that they're already familiar with than an innovative system."

This person went on to describe the pressure worked under at DEQE:

> "It's very extreme, and therefore you constantly have many projects on the back burner (during the approval process), some which you know the technology already, but it's on the back burner simply because you can't keep up with the workload....I think a person with a lot of knowledge and background in a particular area is more willing, even if subconsciously, to attack something that he (or she) already knows, because he (or she) knows there isn't going to be as much time involved with evaluating that process as there would be an innovative process."

For this reason, it is more likely to get approval for a conventional system than an innovative one. Many wastewater treatment projects are operating under externally imposed deadlines, both regulatory and court-ordered, and so this creates a situation where a community could choose to proceed with a conventional technology on efficacy grounds alone.

<u>Role of the Public</u>: Whereas MWRA personnel stressed the importance of the role played by public acceptance of their projects, DEQE and EPA employees usually had to be prompted before stating what role they felt the public had in determining what technology should be used. The interviews revealed for me an important distinction in the way the different types of agencies related to the public. The MWRA was concerned about the public's response since they were in a fee-collecting stance with the public, whereas DEQE and EPA were in a relationship that I describe as essentially paternalistic. Their purpose was to "protect" the public in a way that they knew best how to do; protection both in terms of guarding public funds and public health. Many of the procedures that were an important part of the agencies' function embodied this paternalistic relationship.

<u>Role of the Consulting Engineer</u>: The DEQE and EPA interviews presented the same picture of the critical role played by consulting engineers in the design of wastewater treatment projects as MWRA. One person commented:

> "You know, I think that probably the first place one has to go if one was trying to push this kind of technology...is to get the consulting firms to agree that this is a viable option. They're the ones that do the first cut analysis."

They also expressed the same difficulty in expecting engineers to propose innovative systems. In the words of a DEQE employee:

> "I think many consulting firms don't...want to spend the time to evaluate innovative technologies.... The reason I'm throwing that out these is that the reason they're in the consulting business is to make money, to make profit....(M)any consulting firms will be reluctant to take a project like (solar aquatics) where a number of variables have to be considered before the project ever really is put into the ground.... I think in terms

> of volume and profits from a consulting standpoint it's much easier to latch onto conventional technology than it would be an innovative technology."

These interviewees, especially the I/A Coordinators, were more concerned about the effects that were going to be felt by communities after the phase-out of the federal construction grants program, including the I/A program. They all felt that this will result in negative impacts on the future of innovative technologies since it will increase the risk burden on both the communities and consultants.

Innovations at DEQE and EPA: Officials at DEQE expressed their commitment to innovative projects, as discussed earlier, but emphasized the importance of going through the proper channels when proposing an innovative technology. For instance, the solar aquatics pilot in Harwich was cited as an example of a project where the innovator, in this case Ecological Engineering Associates (EEA), did themselves a disservice by not getting approval to operate the facility. Not following the proper channels resulted in DEQE taking enforcement action against both the Town of Harwich and EEA and levying fines of $6,000 and $5,000 respectively. EEA personnel expressed their reluctance to have to go through what they felt was unnecessary red tape in order to run a pilot project to which the town had already agreed. I was unable to discuss this perspective in detail to develop any suggestions as to what they could or could not do to avoid having an innovative technology encounter the sorts of regulatory actions they did. Is there any way to expedite the process while maintaining the public protection purpose behind the regulations? This is the subject of another study.

Some of the innovative projects that are being worked on or are approved include both sludge disposal and wastewater treatment efforts. Using reeds (phragmites) to dewater sludge is being studied for the town of Ipswich. The town of Salisbury is using marsh application of secondary treated effluent to provide advanced wastewater treatment. Another example is the town of Yarmouth, on Cape Cod, which is located next door to Harwich. This facility is to treat septage and uses, among other things, oxidation ditches for nitrification and denitrification followed by land application in beds of reed canarygrass (Giggey et al., March 1989).

These innovative projects are generally prompted by some factor specific to that project. For instance, Yarmouth wanted to find an affordable way of treating septage that will avoid groundwater contamination. Salisbury wanted to find a treatment process that avoids using chlorination in order to preserve the shellfish beds in the ocean where the effluent was being discharged. Ipswich, and others like it, was simply looking for a less costly approach.

Regulatory and Legal Considerations: The greatest concern voiced by the regulatory officials was the impact of phasing out the innovative and alternative (I/A) technology program, which was part of construction grants funding. The phasing out will make it far more difficult to come up with the funding to run the extensive tests and pilot studies that are considered necessary before adopting an innovative technology. The states could develop their own sources of funding to replace the ones being lost at the federal level, but this has not happened in Massachusetts. The Technical Services Branch at DEQE said that they had the same funding for research and development work now as they did five years ago.

The result is that they initiate half as many projects.

In addition to funding, the increased burden of proof on defendants in liability suits surrounding failed projects was also discussed. Under the I/A program federal funds paid for the modification and replacement (M/R) of an I/A project that failed during its first two years of operation, unless there was evidence of gross negligence. With the change, if a community decides that a failed project was an engineering firm's fault, they need only to establish their claim in the courts on the basis of simple negligence. This was cited as yet another disincentive for consultants to become innovative.

Follow-up Interviews With Consulting Engineers: After conducting the above interviews, I concluded that it was important to include some of the perspective represented by professional consulting engineers since they play such a critical role in the development and choice of technologies. To do this I contacted senior engineers with the firms Lombardo Group of Dames and Moore, and Wright Pierce Engineering. Both of these firms have done work with innovative technologies. Lombardo is renowned for its pursuit of innovative projects, and Wright Pierce has been contracted by EEA to conduct a solar aquatics pilot project in Harwich. I decided that the person's to whom I spoke would provide good insights into both why engineers in general resist innovative technologies, and why they have chosen to pursue them to the extent they have.

Both of the engineers I spoke to expressed the benefits of the engineering conservatism. They felt that it was a responsibility of engineers to propose systems that they were certain would work. Innovative systems were victims of being "too young." Solar aquatics, which both were familiar with, was an idea that was still on the "relative fringe" of "technological viability." The way to bring it inside of what is considered the appropriate window of risk, it would have to be fully evaluated in a fashion that the engineering community considers objective, correct, and thorough. "Then we are professionals, not dreamers," declared the Lombardo representative.

If the project can be established as being effective, and if the economics are as indicated in some of the preliminary research, then these two engineers were certain that solar aquatics, just like other technologies gaining entry into a market, would be used more regularly. "You don´t take risks unless you have to or you feel that it will benefit you." Use of innovative technologies would be enhanced by strong political will and leadership to go with this sort of option, having the community doing the choosing in a situation where action is imperative but they have relatively few other options, and a fundamental commitment to projects with a low impact on the environment.

The engineer from Lombardo also commented that it was unfortunate that the federal incentives for innovative technology had been abandoned. He attributed some of his interest in this type of technology to his good fortune to have begun practicing during a time in which there was fertile ground for innovative technologies and projects. He felt that it was now going to be more difficult to interest other engineers, but he also believed that time could favor innovations. "People don´t count (costs) correctly, right now. If people know how to count, and if these systems can be demonstrated effective, then these ideas will catch hold."

The engineer from Wright Pierce summed up his thoughts by stating, "You're talking about taking a step into the unknown. The question is how big of a step, and who's going to pay for it."

Summary of Interview Findings: The intensive interviews raised some important considerations for developing a theory of institutional constraints. Perhaps most fundamental was the tension that I observed between what I labelled the personal and professional responses. The personal responses are ones based on the multifarious life experiences of an individual that have resulted in the development of particular values, beliefs, and principles. Professional, on the other hand, is the limited set of experiences directly related to one's identity acquired through training and work as an engineer, and, in my case, through working for an agency. I observed personal responses as being more open to considering solar aquatics than professional ones.

Another important finding was the effect of the perceived role of the public. MWRA felt that the public had more of a legitimate role in the planning process since if the public did not like what was proposed they always had the option to challenge it in court. MWRA was more willing to integrate the public into the process. DEQE, on the other hand, perceived its role more as one of being the enlightened protector of the public. There was less of a role for the public in this since they lacked the necessary expertise.

With these considerations, and the others discussed in this chapter, I was ready to develop conclusions regarding the fate of solar aquatics in Greater Boston.

CHAPTER SIX -- CONCLUSION BASED ON FINDINGS
The Future of Solar Aquatics in Greater Boston

In this chapter I present conclusions derived from my research regarding solar aquatics in Greater Boston. Specifically, are there institutional constraints to innovative technologies for wastewater treatment? What have I learned in my research?

Institutional Constraints: Are institutions refractory to innovative proposals? The answer to this is an unequivocal yes. Every person with whom I spoke agreed that it is far more difficult to get an innovative technology proposed, much less have it approved, than it was for a conventional technology. The reasons for this is broken into categories below: individual considerations, agency considerations, and system considerations. As each constraint is summarized, a brief comment is provided of what could be done to counter it. These are prescriptions based on my research and personal beliefs. Not all will seem feasible, nor will everyone agree with them, but I think they are important considerations to make if only as contrasts to the current situation. After reviewing these conclusions, I will complete this chapter by tying the most important ones together into a proposal of how to change the institutional process for selecting wastewater treatment technology in Greater Boston so that it would not be inappropriately biased against solar aquatics.

Individual Considerations

1) Personal likes and dislikes: This element of reactions to innovative technology proposals is perhaps the most unpredictable and most difficult to analyze. In my analysis of the interviews I did not try to ask why people personally felt the way they did about solar aquatics, but

I did observe that the personal reaction was affected by their professional identity.

Some of the interviewees did comment on the possibility that an innovative proposal could succeed or be defeated through the actions of a single person depending upon the level of decision making responsibility or political clout that individual happens to command. For instance, having people high in the agency supportive of solar aquatics will set a general tone and make it more likely that other people working in the agency will be supportive. This is attributable to the role played by agency leadership. One way to effectively deal with this type of constraint within an agency is to have a clearly enunciated policy of supporting innovative technologies, and have administrators who enforce this through their actions.

Personal likes and dislikes are also present with the general public. These negative attitudes concerning solar aquatics can be countered through public education campaigns, pilot projects that are open to visitors, having respected experts in the field endorse the technology, the dissemination of independent research on the use of this approach, and lobbying public officials as part of an effort to elicit their support.

2) **Professional considerations**: Individual´s personal feelings certainly affect their response to an idea, but these in turn are clearly tempered through their professional and agency standing. Every one of the interviewees expressed this conflict between personal and professional belief systems. Although they may have personally approved of the concept represented by solar aquatics, they felt obligated to toe the

line professionally to first establish its "effectiveness" and "reliability." **Risk aversion** was thus closely linked to **identity** as a professional. An individual did not want to jeopardize his or her identity, either as a private consultant or as a government regulator, by becoming associated with a project failure.

This element of constraints facing solar aquatics was one of the most prevalent since it affected not only individuals, but also agencies and consulting engineers. It is probably the most challenging constraint in terms of figuring out ways of countering it. The engineering community is incredibly steeped in its tradition of what works and what does not, and it will not change these attitudes easily. This is particularly so when even a cursory risk-reward analysis will demonstrate that there is <u>no</u> reward in terms of increased earnings. Two ways to attempt to resolve this is to increase the reward for innovative projects (a government subsidy of some sort) or to redefine the roles and responsibilities of designing and implementing a project. The latter would be to make failures reflect less heavily on the individuals who were involved.

Another way to approach this problem would be to change the content of the professional education of an engineer so that it includes coverage of innovative technology. This could lead to more active consideration of innovative systems by practicing individual engineers.

This issue of professional constraints on an individual's affective and creative character is a topic that needs more research. Questions need to be raised regarding how to place an individual in control over his or her choices, such as selecting a technology. Based on sociological literature on institutional effects on individuals, it appears that the role of reflection will play a vital part of being able to guide an individual in overcoming these constraints. Institutional conventions affecting individuals can be so endemic as to be unobserved by those affected (Douglas 1986). Self-awareness is thus critical as a first step to obtaining individual control.

Agency Considerations

1) **Procedural:** There can be no denying that the agency process, ostensibly intended to treat all projects even-handedly, is stacked against innovative technologies at both the provider and regulatory levels. MWRA does not design its own proposals, but rather leaves that up to the consulting engineering (CE) firms. DEQE and EPA insist on proof of the "reliability" of a technology. CE firms are generally not willing to select an innovative approach because of the greater risk involved, and "reliability" is something that can only be proved over time. If a proposal is innovative, then it clearly hasn´t had time in which to prove itself and will thus face a heavier burden of proof than an older, more established technology.

One element of the process of planning for sewage treatment facilities that seems almost universal for the provider agencies is their rushing to fit the development of virtually an entire project into the last possible moment. MWRA, for example, finds itself working under emergency deadlines that have been imposed by the courts because its predecessor dragged its feet for so long. Decision making is thus reduced to emergency response, and counts heavily against the serious consideration of innovative technologies.

One way to respond to the problem of always dealing with issues as if they were an emergency is for agencies to begin proactive decision making. Agencies need to place more priority on long range planning for the development of innovative technologies, especially those offering clear advantages over conventional treatment. Financial incentives and regulatory inducements can be used to encourage this action on the part of the agencies. Additional financial resources would also clearly help in allowing agencies to plan further ahead.

2) **Public accountability**: The public accountability issue affected MWRA differently than it did DEQE and EPA. MWRA personnel, sewer providers, were more in touch with the opinions and reactions of the rate-paying public than those at EPA and DEQE. Interviews at MWRA mentioned the need to consider what the public affairs division could do in terms of "selling" an idea to the public, but this concern was never voiced at DEQE or EPA. The latter agencies perceived their job as more paternalistic in that it was to "protect" the public.

This is an important distinction since it demonstrates the different ways in which agencies respond to the public. From my interviews it appears that providers, those agencies that exchange a specific service for a fee, are more likely to prioritize public involvement. MWRA personnel expressed this as an important way of avoiding some of the otherwise virtually inevitable objections and the filing of law suits. All the agencies shared a commitment to public accountability, but they defined what that meant differently.

Public accountability raised by agencies generally had to do with ensuring that a system works technically and that it will not endanger public health and the environment. This concern was a top priority for

DEQE. Agencies also raised concern over how public funds are used, i.e., whether or not it was going to be wasted. MWRA emphasized this concern more than the regulatory bodies did. Whether it was to ensure appropriate use of public funds or to protect health and the environment, public accountability was one reason on the part of the agencies to be risk averse.

One way of treating the current dilemma posed by the notion of public accountability would incorporate a **redefinition** of the **public's interest**. This redefinition could entail two major changes: one would be to have the public participate more in the planning process; the other would be to change the definition of what is appropriate for wastewater treatment to accomplish.

The MWRA has begun to incorporate greater public participation into its decision making process. Interviewees at MWRA stated that this was a good thing for them to be doing. These comments reflect the view that it is in the public's interest to help agencies make decisions concerning what kinds of treatment plants to develop. This approach is consistent with the main proposal that I have developed as a result of my research. This proposal is to more fully integrate public participation into the process of deciding what wastewater treatment technologies to adopt.

The process that I have in mind is similar to one involving multi-party, consensus-based committees to develop public policies (see: PDN Nov. 1988, Mar. 1989). As many of the parties that are affected by a potential policy are brought together to conduct a process of joint fact-finding, to brainstorm proposals to meet the agreed upon ends, to package these proposals into various options, and to reach consensus on the option that best suits all parties. This proposal is then submitted to the government for implementation.

In the case studied of solar aquatics for wastewater treatment, the parties needing to participate in this sort of policy forum would be everyone with any stake in wastewater. This includes ratepayers, environmentalists, public officials, and any group possibly having an interest in reuse of the water (e.g., farmers, industries needing water for cooling). This type of process is going to become more appropriate for planning wastewater treatment systems as these processes become more contentious, such as was the case in Arcata, California. Another example of wastewater conflict is in Columbia, Missouri (Elley 1989). Contributing factors to this type of conflict discussed in my interviews are more stringent federal and state water quality requirements being put into effect, and the responsibility for funding entire projects shifts to the local level.

As far as the type of treatment to encourage for the public good, this should become a non-chemical, cost-effective treatment technology more conducive to water reuse projects. The engineers with whom I spoke virtually all agreed that reuse would become the priority of the future in terms of wastewater management, especially as the population and water demand continue to grow. Public accountability, or upholding the public's best interests, which would continue to be an agency's obligation, would now mean ensuring public protection, but also integrating public involvement in striving for an optimal treatment procedure to which all parties could agree.

3) Risk aversion: Risk aversion for the agencies is closely linked to the effects the engineering profession, and the "standards" of reliability used in assessing proposals, have on the agencies. I use quotes for "standards" since there is no official working definition of what reliability means. I was told at DEQE there are memos providing guidance on this subject somewhere in the files, but did not have an opportunity to review them. Asking individuals to define a standard of reliability they use resulted in a range of times for a pilot study of a minimum of nine months to "five to ten years". The longest time requirement was from an individual who also expressed his reluctance to accept studies done elsewhere when evaluating a technology.

Agency risk aversion is closely associated with agencies' adoption of professional engineering methodology in terms of being certain that a proposal is going to work properly. When considering constraints facing innovative technologies, this in and of itself can be an appropriate constraint. It is appropriate to assess fully the risks of a proposal before it is adopted in order to guard against negative impacts and wasted public funds. The approach used by agencies -- bench testing, establishing the theory of how a treatment works, running a pilot project, and evaluating all possible impacts that the project might have -- is a legitimate approach.

But this appropriate barrier to unwise projects can be inappropriately applied. An example is when it is used as an excuse or justification for conventional technology even though there are serious questions as to the appropriateness of this approach while innovative technology must be proven fully "reliable." In a situation like this, conventional technology is accepted as "given" and not subjected to the same standard of inquiry.

This uneven application of the technical reliability constraint was reflected by DEQE and EPA officials totally discounting the risks of trihalomethanes and other toxic consequences of using chemicals as part of the wastewater treatment process. The grounds for this dismissal was that conventional treatment effectively removes the conventional pollutants and was thus less risky than solar aquatics. This narrowly based conclusion is not justified, however, as one of the interviewees made clear when he explained that chlorine residues from treatment plant effluents was the leading cause of water-borne toxics in many areas of Massachusetts. The standard of needing to prove technical effectiveness seemed to inhibit unfairly the consideration of solar aquatics in this case.

These constraints posed by agency risk aversion could be lessened through the use of the consensus-based public decision making process described above. Through this process, agencies and the communities responsible for providing wastewater services would be expected to seek a wastewater treatment process that is most cost-effective, causes the least impact to the environment, is most energy efficient, and could be used for water reuse projects. These are basically the same goals as expressed by the Clean Water Act, but I am recommending a different process for achieving them.

Part of this process would involve the recognition that risks would be taken and some projects might fail. This is a necessary part of learning in the face of uncertainty. A reasonable goal is to mitigate possible losses from project failures without being overly restrictive, as is generally the case now, by limiting proposals to an existing technology even though there are clear advantages of going with an innovative system.

4) **Inconsistent or nonexistent political support:** The issue of political will is an issue when considering what the obstacles are facing solar aquatics. Political support is indicated by the expression of broad public opinion or by the stated goals and priorities of elected or appointed political officials. These two types of support tend to go together. It is not easy to say which one, if either, must precede the other, but both are key factors contributing to an overall political "climate" encouraging the adoption of innovative technologies. The issue of political support will probably become more critical for innovative projects now that the financial incentives of I/A program have been abandoned.

The creation of the political climate to support solar aquatics is of fundamental importance since it affects all levels of the consideration of a project -- within agencies, among the general public, and with consulting engineers. The engineer with the Lombardo Group credited the political climate when he was getting started as having been what interested him in pursuing innovative technologies. Successfully redeveloping this supportive environment requires political leaders who recognize the importance of considering innovative technologies and of incorporating more public participation into the process of designing and approving municipal wastewater treatment facilities.

When a project is being considered, technical experts, political officials, ratepayers, environmentalists, and groups desiring water reuse could work together to devise the proposal of what treatment process and technology to use. This process would provide an opportunity to forge disparate perspectives into a more cohesive expression of political will.

5) Agency resources, budget and crew: Two resources of which the agencies are often short are personnel and money. At DEQE, for example, individual workers, I was told, are overloaded due to the shortage of staff. Because their schedules are so tight, the people who do permits and grants are much more interested in having proposals brought before them about which they are already familiar rather than innovative ones. If an agency like MWRA working under a strict timetable knows that this is the case at DEQE, then this will encourage them to propose a conventional plant for the relative ease in getting it approved.

Money can also pay for some of the research and development efforts necessary for developing new technology. This task is complicated since the agency does not want to pay for the development of a technology that some other party might later claim as its own. But the agency certainly needs funds with which to run the necessary independent tests and monitoring of a technology before approving it. Budget constraints on developing innovative technologies will increase with the termination of the federal I/A grants program, which paid for field testing emerging technologies.

A way of coping with these factors is to provide the appropriate agencies with more money. This is not easy, however, in the present climate of government cutbacks. Every opportunity needs to be taken to educate the public and lawmakers about the critical needs of well-funded, safe sewer operations.

Budgetary constraints are a double-edged sword in that they could become one of the key incentives for seriously considering innovative technologies, such as solar aquatics, if they are as inexpensive as indicated. If funds become as short as is feared by agencies, then a higher value will be placed on keeping a project as inexpensive as possible; communities may become more willing to risk the uncertainty of the innovative technology to afford necessary wastewater treatment. Existing examples of alternative technology being used are predominately cases of seeking ways of decreasing the costs of complying with clean water standards.

<u>System Considerations</u>

There are three factors that warrant consideration at the societal level: risk, reward, and the market economy. The basic issue is how to provide sufficient incentives for the decision makers to ensure that they select a socially optimum technology. In the scenario incorporating public participation, like I have recommended above, the final decision makers are the appropriate government body, but the recommended proposal is reached by all parties affected by the project.

1) Risk factors: There are two basic risks assumed by the developers of a new technology: research and development (R&D) and personal liability. R&D will be discussed down below under the heading **Market considerations**. Liability, on grounds of negligence in the event of project failure or an injury due to the project, was cited as one of the key considerations that induces engineers to be conservative about new technologies. This conservatism will likely be heightened as contractor liability can be established on simple rather than gross negligence grounds. Engineers will face a greater possibility of having to pay damages or to replace a facility that they built, but which did not work the way it was intended.

One way to overcome the constraint posed by the threat of liability is to modify the role of the consulting engineer. The way this would work in my scenario is to redefine the responsibility of the consultant so that their function is exclusively one of providing technical information to a public/community group that chooses the technology.

2) **Reward factors**: Reward means different things to a public agency than it does to a private contractor. The interviews discussed contractors' needs to make a profit since monetary return is the basis for their reward. Reward for public agencies, on the other hand, is far more complex. Agencies or their personnel do not personally earn a higher return by cutting costs for a project, i.e., going with a conventional, well-used treatment process, rather than innovating. Public accountability places agencies in a situation where there is a greater potential for acting in a public needs-based rather than personal reward fashion. Acting in this fashion, of course, depends on the degree to which the public pays attention to their actions, and the de facto influence the public can wield to ensure accountability.

3) **Market factors**: Finally, market factors are necessary to consider when dealing with institutional constraints. Economic theory covers constraints by discussing the issues of market entry for a new producer. Market institutions generally are seen as initially resisting the change but gradually growing to accept it as they get to know it. For instance, W. Gordon, in Institutional Economics, the Changing System

(1980), says, "Institutions tend to be static, inherited from the past, dictatorial, and creatures of habit. They inhibit change. However, new institutions evolve as society re-evaluates its rules and norms in light of new technology" (in: Forster & Southgate 1983, p. 30).

This perspective is a bit simplistic, however, since it fails to consider the control over the market that can be exercised by actors with a vested interest in the status quo. Many of the equipment suppliers, contractors, and operators, to name a few, will fiercely resist changing technologies. It would be an interesting study to see what degree of market concentration exists for wastewater treatment supplies, and what the potential impact is of these consolidated firms on communities and design firms that did not play by their rules. For now, suffice it to say that this could be one factor in discouraging the adoption of innovative technologies.

Another market consideration is the inherent risks of performing R&D work for innovative technologies. There is no guarantee of a financial return on this type of investment, a major factor in discouraging private engineers from doing R&D of innovative technologies intensively. They do not want to embark on projects that require extensive evaluation and documentation to ensure their effectiveness. One way to rectify this is to shift R&D cost fully onto the public since they are the ones who will benefit most from innovations. This would be feasible if engineering work is taken over by public entities which have sufficient funds for the work. Short of that, there are other options, too.

The Technical Services Branch of DEQE already does some R&D, although this activity is restricted by the shortage of funds. They previously relied upon the EPA for a large portion of R&D funding. Now they are forced to turn to new sources. One of the most productive source for them is the state universities. Students and professors, alike, are interested in working on research projects in the areas that need it as part of their learning process.

Another approach, mentioned in GAO's August 1984 report "EPA's Innovative Technology Program for Waste Water Treatment Needs Better Controls", would be to establish a demonstration project for innovative technologies. Rather than having random and/or repetitive development of innovative technology, this program would select promising technologies for communities willing to accept them. The program would pay for the construction and start-up of the facility, and then to evaluate it's operations and results. This could allay some of the suspicion and doubt expressed by the engineering community by proving the reliability and feasibility of the new technologies.

A PROPOSAL FOR A RESTRUCTURED PROCESS

Solar Aquatics In Greater Boston: Analyzing the data from my research provided some important insights regarding institutional constraints to solar aquatics in Greater Boston. My research was a qualitative case study, supplemented by background interviews and reading, which taught me a great deal about institutional constraints. Based on my research, the proposal that I make for a process of selecting wastewater treatment technology is well grounded. The following scenario is my design for a way that I have concluded wastewater treatment planning can optimally be carried out in the future:

General considerations: Make it an explicit public policy, supported at all levels, to pursue the socially optimum method of wastewater management. Responsibility for planning and implementation of projects is in hands of communities, within the parameters specified by federal and state regulators. A public entity is created to either provide technical assistance to communities or to perform model project development work for use by private consultants.

Planning & development phase: Project development is handled by a group representing all parties interested and affected by the project. This process is similar to "negotiated rulemaking," a process increasingly used by agencies in developing regulations as part of an effort to make regulations as non-controversial as possible for easy implementation. This form of consensus-based process uses techniques similar to those used in alternative dispute resolution (see Susskind & Cruikshank 1987), except that it occurs before any dispute arises. The forum of open dialogue between the participating parties lets them arrive at what is termed "bounded ambiguity"[1], meaning that they are in accord as to what the desired results are from the project, the range of options to choose from, and which one is preferable in meeting the particular needs of the community. The ultimate decision of what technology to recommend that meets their desired ends is made by way of a consensus of all parties. This recommendation is them submitted to the proper government body for action. The public agency or government body is also represen-

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[1] This term is used in an MIT Urban Studies and Planning doctoral dissertation by Connie Ozawa discussing the benefits of using negotiations in considering technical and scientific information (PDN March 1989). EPA and other federal agencies use negotiated rulemaking to develop regulations that are subsequently published in the Federal Register (PDN March 1989).

ted in this process so they have a stake in the formal adoption of the consensus agreement.

During this process, the technical resources -- whether from a public entity or private firm -- fully cooperate in terms of sharing their particular expertise, but they are not responsible for the final consideration of community values leading to the ultimate decision. This approach is intended to allow communities, engineers, and interest groups to cooperate in way that most reduces the risks of having uncertainty and risk aversion dissuade decision makers from choosing an optimal technology for serving the public's overall needs.

Implementation and operations phase: Once a process has been chosen, it is always possible for it not to work. This is sometimes due to operator inattention or neglect, but it can also result from a basic flaw in the design or construction of a facility. What happens then? In the scenario that I am sketching the community will have to be responsible for correcting the situation. Ideally, there should be a federal program to help finance this. Alternately, the state should think about generalizing these costs of plant failures. This could be justified on the grounds that all communities and individuals do benefit from learning that a particular technology or method does not work.

This proposal represents a chance of overcoming the inappropriate types of constraints facing innovative wastewater treatment technology. By taking actions recommended in this scenario, a situation will hopefully be created where institutional constraints are no longer the obstacle they are now. By making it a priority to fully integrate public participation into the process of evaluating considerations involving every aspect of selecting wastewater treatment technology, the result should be steady progress toward the development of an optimal wastewater management approach.

CHAPTER SEVEN -- AN EPILOGUE
Theoretical Implications

In conclusion, I will discuss some of the theoretical implications that I believe are relevant to my analysis. The implications involve understanding the relationship between an individual's actions and her or his cognitive structure, or worldview. The analysis of the tension or conflict between what individuals indicated as their interest, i.e., pursuing an innovative idea, versus what they actually would choose, i.e., proceeding with the conventional approach, offers insights into this dynamic.

Sociological theory is a starting point for an explanation of why interviewees would make statements such as, "Unfortunately, I think, you know, the reality is that I would probably go with the time-tested method (emphasis added)." In other words, even though his personal creative and affective inclination was to select solar aquatics, the professional category dominated so he could not choose that.

One theory which illustrates this subjugation of an individual's will to a social entity is Max Weber's theory of bureaucratization as explained in The Theory of Social and Economic Organizations:

> Weber...saw bureaucracy as an efficient, `rational' way of dealing with problems, necessary to a modern state and to the end of feudalism and yet prospectively tyrannical because of its inflexible ritualism, its insistence on rules for everything. (Wallace & Wolf, p. 50)

At the same time as Weber described bureaucracies as necessary aspects of social development, he also feared the implications of what he termed the "rational-purposive" action of these structures. When the bureaucratic organizational structure was fully linked to rational-purposive action, Weber believed that the result would be sentencing people to the "iron cage" of modernity.

Rational-purposive action, what Weber saw as the cognitive convention for bureaucracy, is instrumental thinking such as that pursued by the engineering profession. Weber believed that rationalization along these lines was "a process in which the original ethical and religious-cultural motivations are dissolved into a `pure utilitarianism´" (Pusey 1987, p. 53). Individuals would perform tasks dictated to them by their training and the structure within which they worked. Weber did not know when or if the bounds of this iron cage would ever be transcended.

Analyzing the evidence of an inherent conflict between the individual and the professional for the engineers I spoke to who worked for agencies, evoked Weber´s grim assessment of modern culture. What they spoke of as important in the professional sense were "precedence", "documentation", and "reliability", all things that are handed to them from the past by their profession. There seemed little room for their creative initiative. If these engineers are as bound by institutions as Weber believed was the case, what is the most effective way to break out of this cycle of "rationalization" and the "iron cage"?

I believe that the prescriptions for public participation referred to in Chapter Six are a good place to begin to answer this question. I base this on what I observed in conducting research, and its reflection of the theory of communicative rationality as formulated by Jurgen Habermas[1]. Communicative rationality is a theory put forth as one way of regaining creative and reflective human control over the technical pro-

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[1] For a good overview of Habermas´s work see Bernstein 1976, 1985 and Pusey 1987.

cesses of society.

Habermas´s theory is based on the distinction between what he argues are two separate and distinct forms of rationality: instrumental (rational-purposive) rationality, as developed by Weber, and communicative rationality, that allows the free and non-coercive debate of values and ideas.

As Habermas states:

> Rationalization (of communicative action) means extirpating those relations of force that are inconspicuously set in the very structures of communication and that prevent conscious settlement of conflicts, and consensual regulation of conflicts by means of interpsychic as well as interpersonal communication. Rationalization means overcoming such systematically distorted communications in which the action-supporting consensus concerning the reciprocally raised validity claims -- especially consensus concerning the truthfulness of intentional expressions and the rightness of underlying norms -- can be sustained in appearance only, that is counterfactually. (Bernstein 1985, p. 21)

Habermas argues that it is important to integrate communicative rationality into modern social and political institutions "which, on the one hand, would represent the normative anchoring of the system in the life-world, and on the other, would protect the communicative structures of the life-world themselves, and secure a rational and democratic control of the system by the life-world" (Wellmer 1985, p. 58). System and life-world are presented as the two poles from which sociological analysis is standardly conducted: "systems theory (which) diminishes the significance of the role of social actors ... (and) the other pole ... (which) gives primacy to the creative role of social actors, and the ways in which they construct, negotiate, and recommend the social meanings of their world" (Bernstein 1985, p. 22).

For Habermas, the "system" is dominated by technical-purposive rationality, and "life-world" is where communicative rationality must be exercised. Through the concomitant development of these two forms of rationality, Habermas would like to be able to overcome the institutional constraints found in Weber's iron cage. To do so requires initiating free and open debate over the choices made concerning the direction of the rational-purposive system that we are all part of.

I contend that communicative rationality, the unrestricted exchange of information, is possible in the public participation recommended above for wastewater treatment planning. It is in this context of dialogue, inquiry, reflection, and consensus-based decision making that individuals can be in as direct control as possible over the decisions that are being made which affect them. For instance, this sort of integrative policy-making forum was used successfully in Hawaii to develop a management plan for the state's freshwater resource (Unsoeld 1988). Small farmers, plantation owners, the tourist and hotel industries, local and state governments, native Hawaiians, and environmentalists all had a hand in developing the policy. No assumptions about what was needed or desirable were allowed to go unchallenged during the course of policy development. Agreement was reached concerning the objectives of the water code, what the ways were to achieve this, and which option was the most preferred by all parties.

For wastewater treatment, this sort of policy forum would mean learning fully the implications and consequences of the conventionally accepted technology. It would mean being able to compare these elements of risk to the possibility or concern that an innovative technology would not work as effectively as the conventional method. These considerations would be made while also coming to an agreement on what the agreed upon function for the technology would be. Would it be part of a traditional wastewater disposal system, or would there be greater benefit to trying to reclaim the water as a resource to be used for another purpose?

If this approach is used, it will be one way to return rationality, in the very broad sense of the word, to control over decisions that are currently the purview of the technical and instrumental side of our thinking and acting. Beginning to devise and working to implement policies that do this is clearly a way to begin to break down institutional barriers to innovative wastewater treatment technologies, such as solar aquatics.

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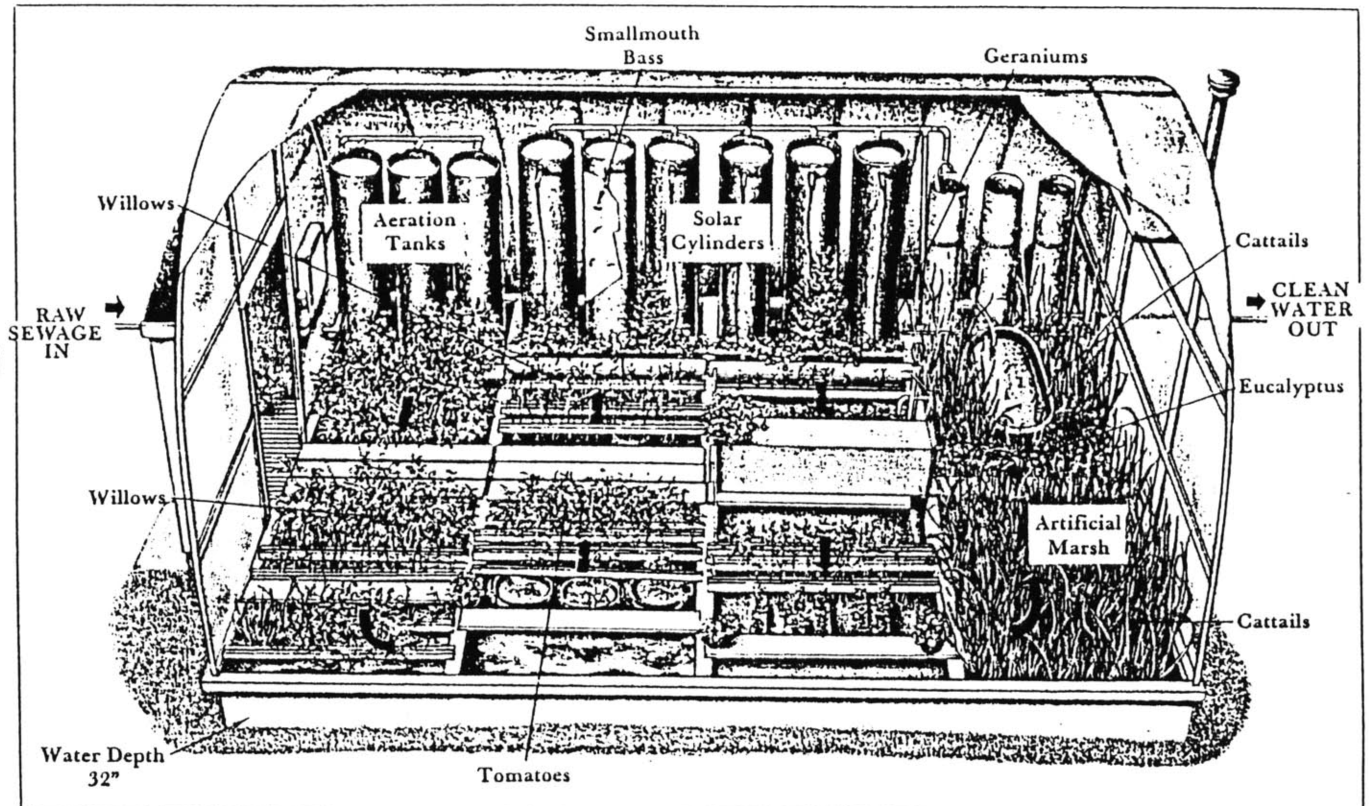
Appendix A

SOLAR AQUATICS DIAGRAM

The solar-aquatic treatment plant at Sugarbush: raw sewage flows through aeration cylinders where light, air and bacteria digest organic components and break down ammonia. It then enters the plant-filled raceways where algae takes up nitrate, phosphate and other nutrients. Shrimp eat the algae and fish eat the shrimp. Snails live throughout the system, cleaning up sludge. Plants are chosen for their ability to take up toxic substances, their ability to kill pathogenic bacteria or for their commercial value.



source: Meadows

SOLAR AQUATICS

in

GREATER BOSTON

"A Research Project"

Contact: Krag Unsoeld
Telephone: (617) 489-2113
or (617) 495-1684

Date: March 15, 1989

This project is an attempt to investigate institutional constraints to innovative proposals within public agencies. The particular case being studied is the use of an innovative technology, solar aquatics, for wastewater treatment in Greater Boston. Please read this proposal so that you can respond to questions in a subsequent interview.

Appendix B

Introduction and Summary: The Massachusetts Water Resources Authority has decided to work for the implementation of an innovative wastewater treatment facility some time in the future. The Deer Island treatment plant no longer meets all of MWRA's needs and they have decided to pursue a community-based treatment system. Because of mounting public concerns over trace organics and toxic substances in the nation's waterways, municipal wastewater facilities will be expected to perform advanced levels of waste treatment.

The main question is: What kind of technology should be approved? One option is the conventional approach used by most sewer districts in the nation. The other is "solar aquatics," a newly developed method of simulating natural wetland processes in a controlled fashion so they can be used for treating municipal wastewater. This paper provides a brief overview of the two different approaches. Framingham was selected as the location, but this could easily be changed. The important factor is your reaction to the proposal for an innovative, and relatively lesser known proposal, over the conventional approach.

For Framingham (18 mgd, peak load), the two options can be summarized like this:

	Solar Aquatics Project	Conventional AWT Facility
Land required:	12 - 36 acres	5 - 10 acres
Construction expenses:	$2.6 to 3.6 million	$32 million
Operating expenses:	$900,000/year	$2.6 million to $4.5 million/year

From these estimates, solar aquatics appears economically superior. However, it is an innovative technology without an extensive working history. Public agencies are often reluctant to take what is perceived as too great of a risk. This project is intended as a case study of constraints to institutional risk taking.

Appropriateness for Use of Constructed Wetlands for Wastewater Treatment

Solar aquatics is one type of constructed wetland that is used for the treatment and polishing of wastewater. A constructed wetland, as defined by the Tennessee Valley Authority (TVA), is an engineered and constructed complex of saturated substrates, emergent and submergent vegetation, animal life, and open water that simulates natural wetlands for the purification of municipal effluent. Solar aquatics simulates the wetland processes inside of a greenhouse. This allows year-round operation in cold climates. It also enables wetland processes to occur in an area little bigger that that required by conventional facilities. Constructed wetlands have acquired a more significant history than solar aquatics at this time, but the ecological processes of the systems are essentially the same. The following tables summarize the effectiveness of wetland projects.

Table 1. Performance Data for Constructed Wetland in Iselin, PA
(March 1983 through September 1985) (Watson, et al., 1987, 266-7)

Season	Biochemical Oxygen Demand Influent	Biochemical Oxygen Demand Effluent	Total Suspended Solids Influent	Total Suspended Solids Effluent	Ammonia Nitrogen Influent	Ammonia Nitrogen Effluent
	mg/L					
Winter	230	8.5 (96)*	180	21 (88)	13	5.8 (54)
Summer	288	6.5 (98)	170	18 (90)	16	1.2 (93)
Total	260	7.4 (97)	180	19 (89)	14	3.3 (77)

Season	Total Phosphorus Influent	Total Phosphorus Effluent	Fecal Coliforms Influent	Fecal Coliforms Effluent
			colonies/100 mL	
Winter	12	3.9 (68)	1,200,000	240 (100)
Summer	16	1.6 (90)	2,600,000	23 (100)
Total	15	2.6 (82)	1,800,000	150 (100)

* Numbers in parentheses are percent reduction.

Tables 1 & 2 show that constructed wetlands perform well at secondary and advanced secondary levels of effectiveness. Table 3 (see below) summarizes data from an operating solar aquatics project.

Table 2 Performance of Pilot-Scale Constructed Wetland Systems

(Reed, et al., 1987, 171)

	Effluent Concentration, mg/L					
Location	BOD_5	SS	NH_4	NO_3	TN	TP
Listowel, Ontario	10	8	6	0.2	8.9	0.6*
Arcata, California	<20	<8	<10	0.7	11.6	.1
Santee, California	<30	<8	<5	<0.2	-	-
Vermontville, Michigan	-	-	2	1.2	6.2	.1

* Alum treatment provided prior to the wetland component.

BOD_5 - Biochemical Oxygen Demand SS - Suspended Solids
NH_4 - Ammonium NO_3 - Nitrate
TN - Total Nitrogen TP - Total Phosphorus

TABLE 3 -- DATA SUMMARY, SUGARBUSH SKI RESORT PILOT SOLAR AQUATICS PLANT

(EEA, 1988a)

Sampling Period		5-1-87 to 11-24-87	12-22-87 to 3-31-88	2-3-88 to 3-31-88	4-1-88 to 5-15-88	7-28-88 to 10-31-88
Type of Pretreatment:		aerated lagoon	none (raw sewage)	none	none	none
Parameters (mg/L)						
BOD	influent	32.04	293.96		79.80	118.73
	effluent	11.45	24.68		1.72	2.10
	(% reduction)	(66.00)	(91.60)		(97.84)	(98.20)
TSS	influent	48.36	192.35		73.67	122.95
	effluent	18.55	10.86		8.83	1.66
	(% reduction)	(62.00)	(94.35)		(88.00)	(98.60)
NH_3-N	influent	10.99		41.52	7.77	16.45
	effluent	0.95		5.01	0.08	0.38
	(% reduction)	(91.00)		(87.95)	(98.97)	(97.90)
NO_3-N	influent	2.12		0.72	0.32	0.24
	effluent	13.43		11.87	8.51	11.90
TKN	influent	16.19		79.25	27.73	31.84
	effluent	3.38		7.54	1.55	0.99
	(% reduction)	(80.00)		(90.40)	(94.40)	(96.90)
TDP	influent	2.39	*		*	2.70
	effluent	1.08	*		*	1.29
	(% reduction)	(55.00)				(52.20)
Dissolved/ Oxygen	(effluent)					1.65
pH values/	(effluent)					7.17

* No phosphorus data is available for this period due to the accidental introduction of aluminum sulfate from the main treatment plant into the pilot facility.

Solar Aquatics at Sugarbush

The data in Table 3 are from Sugarbush ski resort in Vermont. The solar aquatics facility works alongside a conventional plant. It is a small facility, 3,000 gallons per day average, but the loading is regulated to simulate a full scale treatment plant. An important thing to notice about this project is that the greatest organic loading occurs during the winter ski season. Because of the location, this means that the major loading for the facility occurs when temperatures are around 0°F.

Solar Aquatics in Harwich, Massachusetts

A project using the same processes as at Sugarbush was successfully operated in Harwich to treat septage. This project was conducted as a pilot before receiving state approval to proceed with a full scale operation. At its conclusion the project treated 1,200 gallons of septage per day. Table 4 shows the percentage reduction in some of the parameters that was obtained. It is important to note that loading varied but was always significantly higher than would be the case for raw sewage. The maximum recorded loading of certain parameters are as follows:

BOD_5	5,030	mg/L
ammonia	92.4	mg/L
TKN	223	mg/L
Phosp.	35.5	mg/L
TSS	5,333	mg/L
TDP	31.1	mg/L

Table 4: Solar Aquatic Data -- The Harwich Plant (EEA, 1988b)

			Percent Reduction				
DATE	BOD5	DATE	AMMONIA	TOT.KJELDAHL NITROGEN	PHOSPH.	T.DIS.PHOS.	T.SUS.SOL.
6-22	99.81%	6-22	99.67%	98.38%	99.72%	99.91%	97.50%
6-29	99.75	6-28	99.95	99.02	99.75	99.90	99.17
		7-5	99.82	99.64	99.89	99.93	98.75
7-13	99.77	7-11	99.84	99.23	99.44	99.74	97.50
7-20	99.83	7-18	99.91	99.33	99.68	99.74	99.25
7-27	99.68	7-25	99.88	99.28	99.66	99.74	98.33
		8-2	99.68	97.50	96.88	96.55	98.60
8-12	99.59	8-9	99.89	97.82	96.14	96.17	99.20
8-17	99.23	8-15	99.85	97.96	97.12	97.06	99.00
8-24	99.71	8-22	99.81	98.17	97.58	97.40	99.92
9-2	99.88	8-31	99.93	97.36	91.47	89.37	99.18
9-8	99.72	9-7	99.75	96.41	81.26	76.06	97.77

Wetlands, Trace Organics and Heavy Metals

Synthetic organic compounds have long been known to resist conventional wastewater treatment. The 1987 amendments to the Clean Water Act (PL 92-500) will lead to stricter effluent limitations for wastewater treatment facilities. Many publicly owned treatment works will, for the first time, face national pollution discharge elimination system permits with chemical specific limits for toxics or whole effluent toxicity limits. Table 5 summarizes the results for the removal of trace organics in a water hyacinth system in California.

Table 5 -- Trace Organic Removal in Pilot-Scale Water Hyacinth Basins*
(Reed, et al., 1987, 136)

	Concentration, ug/L	
Parameter	Untreated Wastewater	Hyacinth Effluent
Benzene	2.0	Not Detected
Toluene	6.3	Not Detected
Ethylbenzene	3.3	Not Detected
Chlorobenzene	1.1	Not Detected
Chloroform	4.7	0.3
Chlorodibromomethane	5.7	Not Detected
1,1,1-Trichloroethane	4.4	Not Detected
Tetrachloroethylene	4.7	0.4
Phenol	6.2	1.2
Butylbenzyl phthalate	2.1	0.4
Diethyl phthalate	0.8	0.2
Isophorone	0.3	0.1
Naphthalene	0.7	0.1
1,4-Dichlorobenzene	1.1	Not Detected

* 4.5 day detention time, 76 m^3/d flow, 3 sets of 2 basins each in parallel, plant density 10-25 k/m^2 (net weight).

A constructed wetland at Santee, California was tested for metal removal. The wastewater influent was spiked with copper, zinc and cadmium. With a hydraulic retention time of 5.5 days, 99, 97 and 99 percent, respectively, of these three chemicals was removed. Scientists attribute this primarily to precipitation and adsorption.

Expected Costs of Proceeding With Constructed Wetland Wastewater Projects

The economics of constructed wetlands will depend on such things as the hydraulic loading rate and detention time for the project. Capital costs will be determined by the value of the necessary land and the amount of construction needed. Table 6 lists the costs of four cases of using constructed wetlands as compared to a conventional secondary process.

Table 8 -- Cost Summary of 4 Wetland Projects v. Conventional Treatment

(Crites & Mingee, 1987, 886)

Location	System type	Design flow, m^3/d	Area, ha	Construction costs $ millions	Unit cost, $\$/m^3/d$
Cannon Beach, OR	Existing wetland	3,440	6.5	0.58	170
Gustine, CA	Created Marsh	3,785	10	0.88	230
Incline Village, NV	Created and existing wetland	8,100	49	3.3	410
Iron Bridge Plant, Orlando, FL	Hyacinth system	30,280	12	3.3	110
Typical Secondary	Activated sludge	3,785	--	3-3.8	800-1,000

Note: The conversion factor for m^3/day to gpd is 264. The reason for the variance in unit costs for constructed wetlands is due to other requirements. Incline Village's costs also included habitat improvement and complete containment of the applied effluent. Dollars are for June 1986; ENR CCI = 4290.

Table 9 (compiled from newspapers and various articles) offers some additional cost comparisons between wetland approaches and conventional methods.

Table 9 -- Cost Comparison Between Conventional and Wetland Treatment

Location	Conventional System	Wetland Treatment (WT)	Comment
Houghton, LA	$1.2 million	$400,000	WT provides better quality
Benton, KY	$2.5 - $3 million	$260,000	1 mgd capacity; better qual.
Arcata, CA	$3.5 - $7 million	$514,600	2.3 mgd; wildlife/bird refuge
San Diego, CA	$3.5 million	$2.8 million	Water hyacinth system
Hornsby Bend, TX	$3.5 - $7 million	$1.2 million	Water hyacinth w/ green house

Note: The costs cited are capital costs only. They do not include the O & M, such as energy, chemicals and equipment, which can be very significant for conventional treatment. The estimates also do not include the revenue from some of the wetland projects, such as digesting the San Diego water hyacinth for marketable methane.

Projected Costs for Solar Aquatics

As with other wetland treatment systems, the cost of solar aquatics will depend very heavily on the acquisition of the land needed. Solar aquatics requires less land than other wetland projects, but it still needs more than conventional treatment. One estimate for the land required for solar aquatics offered by Ecological Engineering Associates (EEA), is two acres per 1 mgd capacity. This includes land for employee parking, administration, etc. (Peterson). EEA recently submitted a proposal for a 13 million gallons per day solar aquatics project in Columbia, MO, which estimated a need for 10 acres of land (Barnett). Thus, as the project gets larger, there are some added efficiencies in land use.

EEA estimates unit costs of 2 cents per gallon for construction, operation and maintenance in year One of a 20-year service contract for a 100,000 gpd facility. A facility of from 100,000 gpd to 1 mgd would have a stable cost of 1.4 cents per gallon, plus or minus .4 cents. These costs are based on estimated construction needs, plus the O & M costs for an extended aeration system, which closely parallel solar aquatics (Peterson).

An important advantage of solar aquatics is the revenue potential from some of the plants and fish that can be produced under aquaculture management of the system. A 50,000 gpd EEA project to be located in Providence, RI is estimated to have operating expenses of $25,000/year. Revenue from sales of cut flowers, decorative plants, medicinal herbs and fish, however, are projected to be as much as $112,000 each year (Meadows).

Solar Aquatics In Boston

The specific location considered for solar aquatics in Greater Boston is in the Middle Charles River Basin. This is one of the regions considered in the EMMA plan for a satellite treatment facility. Among the advantages cited in favor of this location was maintaining water in the basin of its origin in order to make it available for reuse. For the purpose of this study, an advanced waste treatment (AWT) project using solar aquatics will be compared to a conventional AWT operation.

The community of Framingham is the selected case. Framingham has been selected since it is the furthest outlying community in the MWRA system.

The following table summarizes the estimated wastewater flows for Framingham, and the expected land, capital investment, and operating costs of the two approaches. Although the estimates are made as if there will be a single facility for all of Framingham, there may be advantages to going with smaller scale projects requiring even less transport and pumping capacity.

Estimated Wastewater Flow, Framingham (Maguire, B-25)

1990		2010	
Ave.	Peak	Ave.	Peak
6.86 mgd	15.97 mgd	7.72 mgd	18.00 mgd

****

Solar Aquatics Project Approach:

Land required:	12 - 36 acres (Peterson, Barnett)
Construction/engineering:	$2.6 to 3.6 million (Peterson; EPA, 73)
Operating expenses:	$900,000/year (Meadows, 46)

Conventional AWT Facility:

Land required:	5 - 10 acres (Montgomery Engineers, 662; Hammer, 404)
Construction/engineering:	$32 million (including 35% engineering and contingencies)(Kennedy Engineers, 2.123)
Operating expenses:	$2.6 million to $4.5 million/year (Middleton, 3-32)

****

The above estimates indicate that the solar aquatics in Framingham represents a much more cost-effective approach than conventional AWT. Capital costs are as much as ten times less for solar aquatics and operating costs are less than half what they would be for an equivalent AWT facility. The primary drawback to this approach is the land requirement. No estimates on land cost are presently available and they will vary from site to site. However, this concern is outweighed by the other costs and the additional advantages that are offered by solar aquatics.

Included among the advantages for using solar aquatics are as follows:

** No use of potentially toxic chemicals (e.g., Cl_2, $Al_2(SO_4)_3$).

** Very little sludge from the process.

** Positive earning potential: The operation can be combined with aquaculture and hydroponics to rear fish and plants that can be sold, or else used to produce biomass for the production of methane gas.

** The potential for water quality and wildlife area enhancement: Many of the wetland projects for municipal wastewater treatment have been combined with wildlife refuge/bird sanctuary development.

APPENDIX -- How does solar aquatics work?

Summary of the Sugarbush Solar Aquatics Treatment Process

The treatment process occurs in four stages over about five days time. The process uses a stream flow model.

1) Aeration, Bioaugmentation and BOD Reduction -- Aeration begins at the start and continues throughout the process. Seven strains of bacteria are added to the wastestream which break soluble organic chemicals down into carbon dioxide and water, and degrade proteins, fats and starches into compounds that can be metabolized by other microorganisms further downstream in the process.

2. Nitrification and Initial Nitrogen Removal -- During first and second days nutrients in wastestream begin to be metabolized by nitrifying bacteria, algae and higher plants. Ammonia is broken into nitrates. Green algae and higher plants directly metabolize nitrites, ammonia and soluble orthophosphates. Snails and zooplankton begin to digest sludge.

3. Nutrient Removal, Reduction of Suspended Solids and Nitrate Uptake -- During third and fourth days, root masses of higher plants (e.g., willows and eucalyptus) remove nitrates directly from the wastestream. Zooplankton inhabit the root masses and digest suspended solids as they pass through.

4. Pathogen Destruction, Filtration and Denitrification -- During the fourth and fifth days an artificial marsh with sand and stone substrate serves as a biofilter to remove solids. Nitrates are reduced to nitrogen gas and water. Certain pathogenic bacteria are destroyed by the action of marsh plants such as bulrush, cattail and rush reed.

Solar Aquatics in Harwich, Massachusetts

A similar project has been operated at Harwich to treat septage. This project has been able to provide advanced wastewater treatment without the addition of any chemicals. In stead of an artificial stream bed, this project uses an initial settling lagoon, 21 translucent cylinders (current technology allows these to be six ft. deep and six ft. in diameter), and a constructed marsh that is 14" to 20" wide at the top, and 15" deep, tapering to a point. This arrangement for the biological processes that occur in the wetland allows the process to be more land efficient. There is even the possibility of stacking the tanks to save space.

> According to an Ecological Engineering Associates progress report: this "system provided tertiary treated effluent from the outset .... (T)he system...remove(d) Volatile Organic Compounds such as very high concentrations of toluene, methylene chloride, and 1,1,1-trichloroethane. The analyses were performed by the Barnstable County Health and Environmental Department. In their report dated Nov. 9, 1988, they say: "... that despite influent water having up to several thousand micrograms per liter (ppb) of total VOCs, the effluent was invariably very low in VOC concentration. In no effluent sample was a Maximum Containment Level (MCL) exceeded."

INTERVIEW GUIDE

Remember, the focus of questioning is the selection of the innovative technology -- solar aquatics -- over the conventional treatment approach.

Personal Data: What is your official position within the agency?

How long have you held this position?

Briefly, what is your professional background and training?

What role do you have in agency decision making? (Seniority, area)

Reaction to Solar Aquatics Prop.: How did you feel after reading this proposal? What is your response to the solar aquatics proposal?

If you had the authority would you personally select the solar aquatics approach?

What factors influence your response?

(Cost?)

(Effectiveness?)

(Concern over public response?)

(Perceived risky nature of the proposal?)

(Need for a pilot project? How long? What scale?)

Considerations Within the Agency: Regardless of your personal response to the solar aquatics proposal, what in your opinion are the overall chances of its approval within the agency?

Are there particular people or branches of the agency who are likely to support or oppose such a proposal?

Let's start with the probable supporters -- who are they and why do you believe they would take this position? (Personal experience, training)

Now the opponents -- who are they and why do you believe that they are unlikely to support this innovative proposal? (Personal experience, training)

What is your experience with how this agency has responded to innovative technologies proposals? (Example?)

Has your agency ever taken the lead in developing a new approach or technology? (Example?)

Do you feel that it is a legitimate function of DEQE and its research arm to actively develop innovative approaches? Why or why not? (Regulatory dictates? Precedent? Leave that to the private sector?)

I'm fascinated by the dynamic between the private consulting engineers and the public municipal sewer agencies. Can you characterize that relationship for me? Who takes the lead in technological development? Why?
(funding problems, lack of expertise)

There are some notable cases of municipal wastewater treatment plant failures; does fear of public ridicule direct your agency to be cautious? (agency face saving)

Legal & Regulatory Considerations: Do you perceive any legal or regulatory issues in adopting a proposal like solar aquatics?

(CWA I/A provision)

Are these legislative or administrative in nature?

Interagency Considerations: What are the interagency considerations for adoption of this proposal?