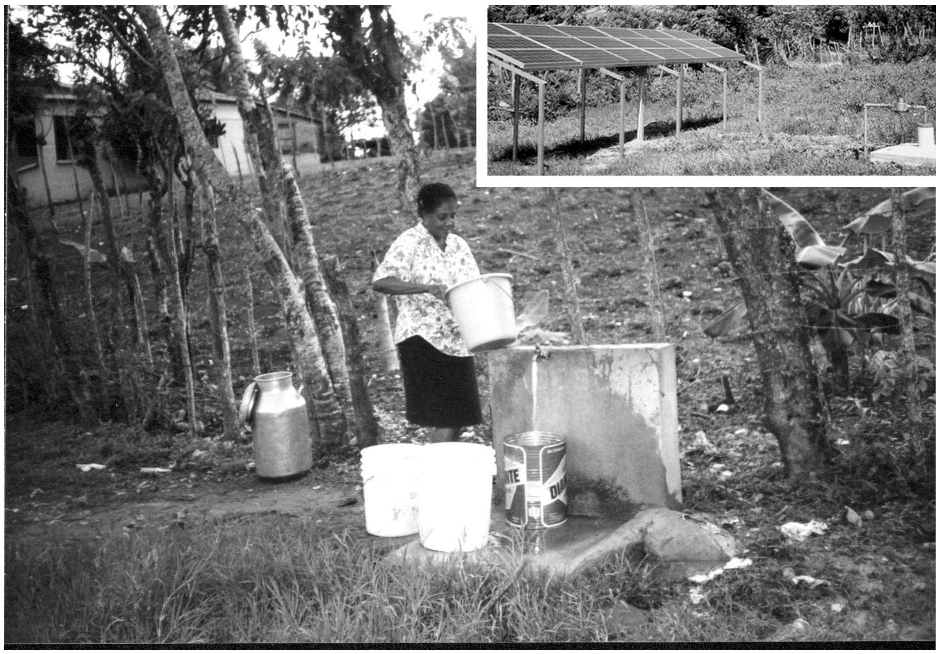
A Case Study and an Emerging Model:
Renewable Energy for Rural Community Water Supply in the Dominican Republic



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Dedication
The authors would like to thanks the families of Arroyo Seco, Bella Vista, Guzman, La Monteada, La Horca and Los Amaceyes for their participation in the water projects detailed in this document and their hard work which has resulted in a significant increase in understanding of how to bring a clean, convenient and reliable water source to more people. In addition, the authors would like to thank the ADESOL team for their patience and perseverance.

Abstract

Enersol, a non-profit organization, initiated renewable energy water pumping activities in the Dominican Republic in 1993. Taking advantage of an infrastructure already established to support the installation, financing and long-term care of stand-alone PV systems, Enersol worked from 1993 through 1998 with its local partner the Association for the Development of Solar Energy (ADESOL) in the development of six community water systems. The goal of the work was to develop a model or models for rural water supply in developing countries which incorporates solar photovoltaic and wind-electric technologies as the energy source and provides improved technical and economic sustainability of the systems. The work was characterized by the following: 1) Use of renewable technologies where conventional solutions such as gravity flow, grid connected electric pumping, or diesel pumping are technically, economically, or socially unfeasible. 2) Strong attention to delivering water at a price as close as possible to its true cost and to increasing cost recovery for capital reinvestment. 3) Opening the door to increased involvement of local, small scale, rural private entrepreneurs in the installation, operation, maintenance, and replacement of water systems.

While renewable energy technologies offer promise to meet rural energy needs such as water supply the infrastructure required to support the new technology is often not present, or the implementing organizations do not have a complete understanding of how to foster it. Conventional models developed for rural water delivery in developing countries do not necessarily favor the entry of renewable energy sources into this area. Enersol's application-based approach provides experience and insight into what infrastructure components can feasibly be developed in order to ensure technical and economic sustainability in renewable energy projects. This has significance also for conventional rural water delivery – an area long marked by extremely poor cost recovery, equally poor coverage, limited technology options, and gross under-capitalization.

The work outlined in this document provides evidence of specific conditions that need to be in place if a renewable energy project is going to succeed. In developing any rural water supply project using renewable energy, there is need for greater attention to: evaluation of level of end-user discomfort around their traditional water source, honest economic and social evaluation of other options, use of increased cost recovery, the introduction of waste reducing technologies that link the cost of water to consumption levels, and the participation of private, local, for-profit entities in the work.

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Introduction

The Perceived Problem

Two of the most pressing issues of rural water supply (indeed, all water supply) for this century will be improved cost recovery and improved conservation of water resource. With estimates of the shortfall in worldwide investment for potable water supply infrastructure ranging up to 180 billion dollars annually, it is clear that any increased coverage and any prospect for improved long term sustainability depends *at least in part* on the development and acceptance of more economically rational schemes for the delivery of water. Conservation of water resource will inevitably become a more prominent feature of water system design, simply by virtue of the facts: a finite supply and an increasing population which combine to form an increasingly difficult equation. Estimates of the world population living under conditions of water stress are now put by some at not 1, but 2 billion, and skyrocketing upward.

Conventional rural water delivery schemes, sadly, are poorly equipped to provide guiding innovation in either of these areas. Largely controlled by political forces either indirectly or directly, and highly dependent on subsidies, they are plagued by an inability to set rational prices independent of the political process, and thus to secure the steady revenue stream essential to providing maintenance to reduce egregious water losses in distribution systems and to procure technology even as basic as simple metering devices. With larger, more urban-oriented water delivery schemes constrained by political considerations, by their very size, and by lack of capital, real path-breaking innovation and guidance for project developers and the populace alike may just emerge from the periphery, the areas abandoned and forgotten, distant from the existing models and too small to warrant political attention.

Enter Solar Photovoltaics

Solar photovoltaic's (PV's) position at the edge of water supply options makes it especially well suited to provide, in small scale, models relevant for water challenges to be faced both today and tomorrow.

PV water is first of all objectively more expensive than other options like conventional electric pumping. Due to the high initial investment its viability benefits directly, and more significantly than other options, from models that can achieve better cost recovery. Secondly, the water demand is more proportional to the up-front cost for a PV water system when compared to other water technologies. Thus it more significantly benefits from models that can reduce waste in the water delivery and consumption. A triangle is completed with the linkage between the two points represented by improved cost recovery and waste reduction. More realistic prices for water, particularly when those prices are on a metered basis, can drive dramatically reduced waste. Reduced waste for its part drives reduced PV power requirements, which in turn lowers system cost, improving cost recovery whatever the price level may be.

This special interplay between PV technology, water conservation, and improved cost recovery that has potential significance for all water supply work. Precisely because it is today more expensive than conventional delivery it puts the bar at a place that more accurately reflects the future for all technologies.

The Case Study

In 1992, Enersol Associates, Inc. initiated a rural water supply program in the Dominican Republic based on the use of renewable energy. Enersol had at the time approximately seven years of experience working in the application of solar electric energy (photovoltaics or PV) for rural home and business electrification. The goal of the water program was fairly simple, to determine if and how renewable energies could provide a clean, convenient and reliable water source for rural communities. Taking advantage of an established supply infrastructure capable of the installation, the financing and the long-term care of PV systems for home and business electrification, Enersol began to tackle another urgent need in rural areas, water supply.

Initially two water projects were completed in an area of the Dominican Republic where both Enersol and its local counterpart, the Association for the Development of Solar Energy (ADESOL in Spanish), had an established presence for over a decade. The decision to initiate these projects "close to home" was based on the desire to constantly monitor their performance and be able to work closely with the community. In 1993, the first project, a PV water pumping system, was installed in the community of Arroyo Seco[1]. This was followed in 1994 by a wind-electric water pumping system in the neighboring community of Bella Vista[2] . Based on the results of the initial projects six additional projects were pursued by Enersol and ADESOL in neighboring as well as distant communities.

These eight systems, which provide daily water service to approximately 1,000 people, have demonstrated the capacity of PV to meet the technical requirements of rural water supply. Before the installation of these systems women and children walked up to four hours a day to collect in many cases poor quality water for their basic household needs. Now they have access to a clean and reliable water source steps from their front doors.

An Emerging Model for Rural Water Supply

PV and wind-electric water pumping systems have been used in many parts of the world in diverse applications and have demonstrated a direct benefit to communities. However, the weak components of these systems, as is the case with more traditional approaches to rural water supply, are project sustainability and cost-recovery. While Enersol's first step was to demonstrate technical viability of renewable energy power sources, the work reaches further out to the issues associated with how to keep systems running over the long-term as well as recovering costs. Enersol has incorporated relatively new elements into their project development model like financing the systems to the community and providing insurance policies in case of technical failure or robbery. These innovations in rural water supply provide insight on how water supply projects with goals of sustainability and cost recovery may be implemented and have aided Enersol with the creation of an emerging model which includes private entrepreneur participation in rural water supply.

The presence of the private sector does not need to mean infringing on the mandate of water delivery agencies or NGOs, or threatening communities' fair and equitable access to water as is often feared, but rather it holds the potential to increase the efficiency of project execution, increase the prospects for long term maintenance, and provide greater capital with which to bring

[1] *Dry stream* in Spanish, which refers to the dry steam bed the community is located around.

[2] In Spanish this means *beautiful view* and refers to the view of the Caribbean sea 5 kilometers away provided by the community's location atop a series of small hills.

water to more communities. The key is that the private sector involvement be in a supporting role to the agency or NGO which is responsible for the water delivery to a given community.

Using private structures for water vending and/or technical service to the water system takes advantage of what is done most efficiently by private means while ultimate control (read: ownership of the capital equipment) can stay in the hands of entities concerned with the larger public good – the community itself, the NGO, or the water agency.

In Part 3 of Section I, the cost of one of the water systems is analyzed using several different ways for defining the scope of the project. By looking at the ascending costs associated with a water project if one counts all of the supporting inputs, it is easy to see that there would be plenty to gain from finding less problematic, less cumbersome ways of delivering the supporting functions, which are a far bigger cost burden than simply acquiring and installing the pumping equipment. In addition to reducing the cost of project implementation Enersol's experience to date is directing the organization's efforts to develop a model that will insure both continued water supply over the long-term and cost recovery so that minimal capital investments benefit a wider rural population. This emerging model will be discussed in Section II.

SECTION I : THE CASE STUDY

This Section begins by documenting (Part 1) and analyzing (Part 2) Enersol's experience from 1993-8 with the development of eight community water systems powered with renewable energy power sources. It then provides an economic analysis (Part 3) to deal with the question of how much these types of systems cost, including initial capital and life cycle costs along with per beneficiary and per liter pumped figures. These costs are compared to actual beneficiary payments and the cost of other sources of water.

Part 1: Eight Community Water Pumping Systems

Community Selection

Enersol and ADESOL based the selection of communities on three initial criteria: (1) that there was no access to the electric grid, (2) that there was a difficult water situation in the community, including no realistic potential to develop a gravity feed system and (3) that there was an adequate renewable energy resource, either solar (>4.5 kWh/m^2 per day) or wind (>6 m/s average), in the community[3]. After the initial screening other factors became important in determining whether projects were implemented or not. These included: (1) the ability to develop a quality water source, in most cases a water well (or bore hole), and (2) a sufficient level of community organization and commitment. In the process of identifying the seven communities where projects were implemented, five additional communities were eliminated from the selection process. In four

[3] In the DR sunlight is abundant in most areas and systems designed for critical months using solar daily insolation of 5 kW/m2 have performed well with no indications of shortages of water. PV water pumping rainfall generally compliment each other. When there is sun there is water pumped by PV, when there is rain PV system production falls off however rainwater can be collected from roofs. A"good" wind resource has been more difficult for Enersol to define. In a report for Winrock International, Global Transition Consulting stated that for a small wind system to make sense economically a minimum of 6 m/s average monthly wind speed is necessary to compete with PV.

of these communities Enersol and ADESOL were unable to continue working because an adequate water source could not be developed. In these cases well drilling was unable to yield water in the vicinity of the community due to the local subterranean geological formation. One community was disqualified due to lack of organization and apparent interest. *This reveals a disqualification probability of almost 50% for communities that make it past the initial project selection criteria, which by itself can be considered a fine filter.* This being said, it is possible to find regions where a significant number of PV water pumping systems could be installed. For example in the DR, Enersol's internal study revealed that communities with the right set of conditions for such systems in the Dominican Republic may be as high as 1,000. In Honduras, however, where Enersol began a water initiative a few years after the work in the DR began, finding suitable communities for renewable energy water supply systems was more difficult. Density of systems in a given area is an issue that needs to be considered carefully by any implementing organization.

The table below provides populations and water access data for the communities selected.

Table 1.1: Communities & Conditions

	Community	**Population**	**Access to Water Prior to RE system**
1.	Arroyo Seco	175	Difficult, approximately 5km to source, 45 minutes on foot.
2.	Bella Vista Arriba [4]	72	Difficult, approximately 3 km to source, 30 minutes on foot.
3.	Bella Vista Abajo	237	Difficult, approximately 1.5 km to source, 15 minutes on foot.
4.	La Monteada	250	Very difficult, + 1 hr. to source.
5.	La Horca	147	Critical, arid area, poor surface water, 2 hrs. to source.
6.	Los Amaceyes	189	Critical, arid area, poor surface water, 2 hrs. to source
7.	Guzman	47	Very difficult, especially in the dry season

System Design and Feasibility

While individual system design characteristics may have varied slightly, Table 1.2 summarizes the design assumptions used.

At this point an important distinction should be made between conventional (electric) water pumping systems and their solar equivalent. In conventional water pumping systems, the main cost component is the pump, and as a result systems are compared on the basis of "dollars per hp of installed (pumping) capacity". However, in PV water systems the major cost component is not the pump but rather the power source (the panels), and cost is expressed and compared on the basis of "dollars per watt of installed power" (supplied). The two terms are linked, but not directly interchangeable. With PV systems, the designer is *always* aware of the amount of energy a system requires, as this will relate directly to the size of the solar array and consequently cost.

[4] Two systems were installed for this community. First a wind-electric system, followed by a PV powered system.

Table 1.2: System Design Assumptions

Parameter	Assumption
Daily water demand	10 gallons (approximately 40 liters) per person per day. Water for household uses only.
Insolation (energy source)[5]	5 kW-hr per m2 per day.
Water storage capacity	3 days minimum.
Distribution system	Limited number of public tap stands. (A mechanism for keeping water consumption at design levels.)
Population growth	2% annually.

In renewable energy water pumping projects the size and feasibility of a particular system is ultimately driven by three parameters: (1) the daily water demand, (2) the vertical distance water is pumped and (3) the available renewable energy resource, solar or wind. In the case of PV systems, when there is a "good"[6] solar resource, system feasibility can be gauged by using what is called the *hydraulic cycle*. This is simply the daily water demand expressed in meters cubed multiplied by the total dynamic head (TDH)[7] of the proposed system expressed in meters. The product of these two quantities produces a value with the units of meters to the fourth. Although in reality meters to the forth is a unit that does not exist, the unit provides a convenient way to express the relative quantity of energy necessary. By calculating the hydraulic cycle, systems with different water demands and TDHs can be *compared in terms of energy demand*. In theory the two following water pumping sites will require approximately the same amount of energy because they have the same hydraulic cycle:

Table 1.3: Hydraulic Cycle Example

Community	**Daily Water Demand** (m3)[8]	**Total Dynamic Head** (m)	**Hydraulic Cycle** (m4)
"A"	5	20	100
"B"	10	10	100

[5] No assumptions were made for design wind velocity, as site specificity is critical in these projects. Enersol and ADESOL felt comfortable using an isolation level 5 kW-hr per m2 per day based on past experience working in this region. Some periods of the year provide a greater solar resource resulting in more water pumped. The months when there is likely to be less insolation available are generally accompanied by rain which reduces demand for water, and therefore there is little reason to worry about water demand in excess of pumping capacity.

[6] See previous footnote on "adequate" solar and wind resources.

[7] Total dynamic head (TDH), expressed in meters, is a quantity which includes both the vertical distance a pump must move water and the friction it must overcome in the water line. To calculate TDH the friction losses are expressed in meters. If a system is designed well TDH is dominated by the vertical distance water travels in a pumping system and friction losses will be minimal. For the rest of the document we refer to TDH not vertical distance water is pumped as TDH is used to calculate the work a pump must do.

[8] 1 m^3 = 265 gallons.

Technical manuals suggest that systems with a hydraulic cycle of up to 2,000 m^4 can be technically and economically feasible. However, our experience and observation indicates that the upper bound of the hydraulic cycle for PV water pumping systems in the communities where Enersol and ADESOL are working is around 1,000 m^4. Assessing the feasibility of wind systems is slightly more complicated due to the variability of wind and the cubed relationship between wind speed and power produced. For these reasons it is difficult to provide a similar “rule of thumb” for wind. However, for the purposes of this paper we will assume that projects where there is an average wind resource of more than 6 m/s and with a hydraulic cycle of less than 1,000 m^4 are feasible.

The table below provides a comparison between the hydraulic cycles of the community water systems implemented. They range from 70 to 665 m^4, with an average value of 270 m^4.

Table 1.4: Hydraulic Cycle Comparison

	Community	**Minimum Daily Water Demand**	**Total Dynamic Head**	**Hydraulic Cycle**
		(m^3)[9]	(m)	(m^4)
1-a.	Arroyo Seco[10]	6.7	61*	409
1-b.	Arroyo Seco	6.7	30.3*	203
2.	Bella Vista Arriba [11]	2.7	68	186
3.	Bella Vista Abajo	9.0	32	288
4.	La Monteada	9.5	70	665
5.	La Horca	5.6	31.5	176
6.	Los Amaceyes	7.2	23.4	168
7.	Guzman	1.8	39	70

* Estimates based on best data available.

The electrical, mechanical and civil works components of the water pumping systems were designed by Enersol and ADESOL technical staff with support from US equipment vendors. In the case of the wind systems, additional technical assistance was required to help estimate the wind resource and system production. Technical assistance was provided in varying degrees by Batelle Laboratories, the US National Renewable Energy Laboratory (NREL), Renewable Energy Group Assistance Entity (REGAE) and wind industry professionals on a volunteer basis. In general pre-

[9] 1 m^3 = 265 gallons.

[10] There was a second PV water pumping system installed at a second well in Arroyo Seco after the initial well was found to provide insufficient water and as a result the pump failed and was replaced.

[11] Two systems were installed for this community. First a wind-electric system, followed by a PV powered system.

existing wind data was scarce and unreliable and Enersol found that the wind resource was difficult to estimate. Another difficulty that arose while doing the system designs in the Dominican Republic was the limited availability of product information in-country for either PV or wind technologies and also their associated pumps.

Product Delivery Chain

In general the acquisition of the power source, the PV modules, was not difficult, as in-country purchase and regular importation had been going on since the mid-1980s. There were a number of distributors and module manufactures from which to choose.

The situation with *solar* pumps and controllers was much different. PV water pumping systems are distinguished from conventional systems in that the vast majority use pumps specifically designed for PV, and generally do not use off-the shelf conventional pumps.[12] In 1992, when Enersol initiated its water pumping activities, almost no *solar* pumps were available in the Dominican Republic. One business in the capital city of Santo Domingo carried pumps from one manufacturer, but maintained virtually no stock, requiring special orders. To facilitate the first installation in Arroyo Seco it was easier, and cheaper, for Enersol personnel to order the solar pump in the US and carry the PV pump into the country. Procurement for the PV water pumping systems that followed was done in a more formal manner. The pumps were ordered or donated by US equipment suppliers and shipped to the country. ADESOL and Enersol were responsible for actually importing the equipment to the local airport. Import duties varied between 20-40% of the pump's value, which is calculated as cost paid plus freight. Although inconvenient and costly on a per unit basis, importation of pumps and controllers was never a major cause of delay in system installation. Currently the situation has improved slightly. There are few distributors in the DR that keep PV pumps in stock on a limited basis however much of the equipment is still special ordered.

The procurement of the first wind system for Bella Vista Abajo, in 1993, was more difficult. While wind-mechanical water pumpers have been used in the Dominican Republic for decades, wind-electric generators are virtually unknown. Given the lack of experience in the Dominican Republic with wind-electric turbines, Enersol decided to import a wind-electric water pumping system almost in its entirety, including the tower, the electrical cable and the guy wires. Although these are components that Enersol and ADESOL would now attempt to procure locally, for a first round project Enersol considered it important to make sure all the specified components were available. The actual importation of the equipment was difficult and time consuming due to the unfamiliarity of the customs officials with this product.

Procurement of the second wind system for Guzman, done years later in 1998, was simplified by the presence of a USAID supported wind and micro-hydro program, the REGAE. The REGAE purchased multiple machines, imported them and made them available to local businesses and organizations on a financed basis. ADESOL, with the assistance of Global Transition Consulting (GTC), was able to acquire one of these machines. Therefore import was not necessary to acquire the equipment, only shipment to the community on the north coast of the island.

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[12] This point definitely warrants further discussion, but is beyond the scope of this paper. In brief, solar pumps are designed to optimize the influx of solar energy and as such can be run at a variety of speeds, which correlate to variable solar resource throughout the day. They are designed to not suffer great losses in efficiency under these conditions as would conventional pumps. Most solar pumping designs eliminate battery banks to reduce cost, improve reliability and maximize system efficiency.

In all cases, except for the wind system in Guzman, equipment was purchased using foundation grants and USAID funding.

Installation

The installation of the water pumping systems and the construction of the civil works was initially led by Enersol in collaboration with ADESOL. Subsequent installations provided the opportunity for ADESOL to take over the bulk of the responsibility while Enersol provided technical assistance primarily in the feasibility studies and system designs. Installations provided intense periods of learning for both organizations as well as for local solar technicians. In total four solar vendors, representatives or owners of small solar businesses, from distinct regions of the country participated in the water pumping system installations. One of these PV vendors was influential in selecting two of the most recent communities where projects were implemented. The table below lists the equipment installed in each community.

Table 1.5: Summary of Systems Installed

	Community System	**Date Installed**	**Wind Turbine**	**PV Module**	**Rated Watts**	**Number of Units**	**Watts Installed**	**Pump/Motor**	**Controller**
1-a.	Arroyo Seco,	Aug-93	--	Siemens M75	48	18	864	AY MacDonald	None
1-b.	Arroyo Seco,	July-96	--	Siemens M75	48	16	768	Grundfos SP2A-1.5	SA-1500
2-a.	Bella Vista Abajo *Wind*	Apr-94	Bergey 1.5 kW	--	"1,500"[13]	1	"1,500"	Franklin 2hp, 230Volt	BWC PCU
2-b.	Bella Vista Abajo *PV*	Oct-96	--	ASE 050	48	20	960	Grundfos SP2A-1.5	SA-1500
3.	Bella Vista Arriba	Jan-97	--	Solar Jack	50	18	900	Solar Jack SCS10-230	Solar Jack PCB8-120B
4.	La Monteada	Sep-97	--	ASE 050	48	32	1,536	Grundfos SP2A-1.5	SA-1500
5.	Los Amaceyes	Mar-98	--	Siemens M50, M75	16 x 50W 5 x 48W	21	1,040	Grundfos SP2A-1.5	SA-1500
6.	La Horca	Nov-97	--	ASE 050	48	12	576	Grundfos SP2A-1.5	SA-1500
7.	Guzmán	May-98	Windseaker 500	--	"500"	1	"500"[14]	SolarJack SDS-D-288	None

The first system installed in Arroyo Seco in 1993 suffered a pump failure due to low well water conditions, essentially the low water level mechanism did not protect the pump and it burned out. A second well was drilled where the recharge rate was much greater and a new pump was installed in 1996.

[13] The Bergey Wind Machine is rated at 1,500 W at 12.5 m/s (28 mph). At 5m/s and 6m/s it produces approximately 100W and 300W respectively. The Windseaker similarly has a rated power output at a wind speed much higher than the average wind speed where is it located. Rated powers of PV arrays and wind turbines can not easily be compared.

[14] Se previous note.

In Bella Vista the initial water pumping system was a wind-electric turbine. After monitoring it's performance for over two years Enersol and ADESOL decided to drill a second well and add a PV water pumping system to augment the production of water, which had been insufficient to meet the community demand.

Enersol acquired a drilling rig in 1995 from a Rotary Club donation to allow ADESOL to provide the well drilling service to communities. This was seen as an essential piece so that ADESOL could insure quality drilling and a lower cost option. In addition, as an NGO, ADESOL could use the drilling rig to provide a revenue stream to support the organization's operating costs. All wells drilled from 1995 on were done by ADESOL's drilling team.

Community Involvement

The initial two community projects, Arroyo Seco (PV) and Bella Vista (wind-electric), were implemented in areas where Enersol and ADESOL had maintained a high level of activity for over a decade. Both organizations were well known in the communities and PV technology was something that had been part of people's daily lives for almost a decade, primarily through PV used for domestic lighting. This provided some margin of goodwill and trust for experimentation on the two initial water pumping systems. Since Enersol did not know what the outcome of the installations would be, emphasis was placed on insuring careful work and then closely monitoring performance.

Although ADESOL maintained ownership of the water pumping equipment (the pump) and the power source (the modules), the community was deeply involved in the project. With ADESOL's help, a water board was formed in each community, family water tariffs were set, funds were raised in the community (approximately 20-30US$ per household) to support the purchase of the distribution system materials and community members donated their labor for the construction of the civil works and the installation of the water pumping system. The community development was done by Enersol and ADESOL jointly, drawing on the grassroots experience of their personnel and their perspectives as neighbors to or members of these communities.

In the subsequent projects installed from 1996 through 1998, Enersol stepped back from field implementation work in the Dominican Republic and ADESOL took the primary role in working with individual communities in the projects. ADESOL's engineer was in charge of system design, project development and installation and also was integrally involved in the community development aspects of the project. The engineer was supported by a rural promoter. ADESOL indicates that the process of community development was definitely the most time consuming aspect in the project implementation. This is in agreement with Enersol's experience, in which a substantial amount of time was spent on community development issues such as the development of a water committee.

ADESOL's general approach to project development once a community had been selected is summarized below.

1) Visit community to evaluate feasibility of a project., initial screening..
2) Perform studies necessary to help determine project feasibility (population, topographic, etc.)
3) Meet with community to discuss conditions of a possible project.
4) Wait for a community decision to take on project.

5) Hold workshop to assist community in the formation of a water board.
6) Develop water well (bore hole).
7) Develop civil works (tank and distribution system).
8) Install PV system with local solar technician support.
9) Inaugurate water system.
10) Post-installation technical assistance and supervision of monthly payment collection.

In the process of implementing the seven community systems, one potential community was disqualified due to lack of community interest and participation (step 3 above) and four were disqualified due to inability to develop a water source (step 6).

Post inauguration responsibilities of the communities vary slightly from community to community. In general the community is responsible for daily system operation, maintenance of the civil works and collection of monthly payments. To date monthly collections can be classified into two distinct types: insurance policy only (1.25 – 2.50 US$/month) and financed payments (2.50 – 6.25$/month). These will be discussed in more depth below.

Monthly Tariffs

In all cases the payments are made on a per household flat tariff, non-metered basis, except Guzman solidarity group with one group payment which is discussed separately below.

The payment systems can be grouped into two categories, (1) insurance policy only, (2) finance payment and insurance policy. In the case of the first group, money for the project was donated to ADESOL who then lends equipment indefinitely to a community. The community pays a monthly fee to ADESOL which provides for a type of insurance policy on the water pumping system (pump,. controller and panels). If the pumping system fails, ADESOL is responsible for the repair or replacement of necessary components. This arrangement is in response to the acknowledged difficulty for small communities to consistently collect fees and set aside money for equipment failure. ADESOL serves as a safe haven for these accumulated resources. Communities with arrangements of this nature are Arroyo Seco, Bella Vista Abajo, Bella Vista Arriba and La Monteada. These were the initial water projects Enersol and ADESOL implemented with testing the technology rather than cost recovery as the primary concern. Table 1.6 below indicates the level of payment made by these communities.

The Monteada payment is larger than the others for two reasons. First the system is larger, both the PV array and the civil works infrastructure is larger, even on a per capita basis. This is due to a relatively high total dynamic head (pumping distance) and sprawling community layout. Second, both Enersol and ADESOL felt comfortable enough with the performance of the previous systems, so insisted on a higher tariff in La Monteada. The initial systems enjoyed a “grandfather” clause in the sense that their tariff stayed lower that what was necessary to cover the insurance policy due to the “research” benefit their systems provided Enersol and ADESOL.

Table 1.6 Lent Pumping Equipment with Insurance Policy

Community	Monthly Payment (US$)[15]
Arroyo Seco[16]	No data
Bella Vista Abajo	US$1.25
Bella Vista Arriba	US$1.25
La Monteada	US$2.50

The second group of systems are distinguished from the first because they were partially financed to the communities by ADESOL. This was Enersol's first attempt to finance a water system to a community. The monthly payments that the communities make to ADESOL cover the insurance policy that is described above, as well as a payment toward covering the capital investment of the project. In theory this recovered capital can be used to seed additional projects in other communities. As in the initial projects the funding for these projects was donated to ADESOL. The table below indicates the monthly payment.

Table 1.7 Insurance Policy with Partially Financed Pumping Equipment

Community	Monthly Payment (US$)[17]
La Horca	$2.50
Los Amaceyes	$2.50

In Los Amaceyes the initial monthly tariff was set at over $US 3.00, but was later reduced since the water from the aquifer is somewhat mineralized, causing a reduced willingness to pay. Water delivered there by the PV system is not considered suitable for drinking or cooking. The monthly payments made by La Horca and Los Amaceyes over a 5 year period are expected to cover an estimated 30-50% of the initial capital investment in the PV water pumping equipment.

The only project not mentioned yet is the Guzmán wind-water pumping system. The Guzmán project had a history different from the others and due to its importance for the development of a cost recovery model more detail regarding the project is provided. It was the site of a proposed community wide water pumping project in November 1996. Given the lack of readily available water, interest in the project was high. However, the community members were unable to agree as a whole to pay a monthly fee that covered the capital costs of a water system. The tariff had been proposed at a higher level to see if a community could cover the full cost of a system, and to reflect the difficulty in gaining access to the location . Guzman is an isolated community 10 miles off the main highway over unimproved dirt roads. After repeated meetings between community members and ADESOL/Enersol staff, the project was abandoned.

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[15] This was calculated using an exchange rate of 1US$ = 16 $RD (Dominican Pesos), which was representative of the exchange rate when this data was collected in March 1999.

[16] No data was available for Arroyo Seco. The system, after 3 years of service, was being removed in 1999 due to the arrival of the electric line. Previous monthly tariffs were similar to those in the Bella Vistas.

[17] This was calculated using an exchange rate of 1US$ = 16 $RD (Dominican Pesos), which was representative of the exchange rate when this data was collected in March 1999.

On the initiative of some of the disillusioned community members, a small nucleus of families formed that were committed to paying the true cost of a simple water system. As the group grew, a commission of them approached ADESOL anew. In the end 10 families made a firm commitment to pay as a group a monthly fee of approximately $70 for a reliable water supply. Each family would have a water bill of US$7; in the event one family did not fulfill their commitment the other families would be responsible for covering the shortfall. This project is an example of the solidarity group model for rural water supply.

A small water system was finished in March 1998, providing roughly 250 gallons of water daily to a single communal tap. The system is currently powered by 4 mid-sized solar panels though initially a 300 watt wind turbine was installed. The water is pumped from a 60 foot deep well and is raised another 100 feet to height of the community. The water pumped is slightly salty, but this did not deter the group – so great is the need. While not very suitable for direct drinking, it is used for cooking, bathing, and clothes washing without problem. The community members still must go to a traditional source for drinking water, but the overall amount of water needed is greatly reduced. Drinking water is only a small portion of total domestic use of water.

Since completion, the solidarity group has not failed to honor their payment commitment. As a result ADESOL has had substantial incentive to maintain the system and provide service in the event repairs are needed. A number of repairs have in fact been needed on the wind-electric system and they were handled without problem.

Payments

ADESOL currently requires that communities make payments in their offices and will cutoff water supply when payment is not made on time. This has helped ease the time commitment associated with collecting payments.

Technical performance

A full list of the technical difficulties experienced with the systems are contained in Appendix B. A summary of the status of the systems when inspected in 1999 is provided in Table 1.8.

Table 1.8 : Status of Water Pumping Systems in 1999

	Community	**Status**
1.	Arroyo Seco	Water service 1993-9, second well in 1996 to replace dry well. Alternative type of PV pumping system installed. Removed (99) with arrival of electricity.
2.	Bella Vista Arriba	In service. Arrival of the electric line in the near future.
3.	Bella Vista Abajo	Initial wind system ('94) was complemented by PV system in ('97) since water pumped by wind turbine was below demand. Second well drilled. Wind system out of service due to dry well conditions which burned out pump.
4.	La Monteada	In service.
5.	La Horca	In service.
6.	Los Amaceyes	In service but mineralized water.
7.	Guzman	Many complications with the wind system, it was replaced with a PV system which was in service.

The PV systems provided roughly the quantity of water for which they were designed. There was more difficulty with the water production from the wind machines in that it was highly variable and in neither case was the production sufficient to meet demand.

Wells, in general, were a source of difficulty. In total they were problematic in four of the seven communities due to quality of water: in two (brackish) and in two (wells drying up). When added to the four communities which were disqualified from the selection process due to the inability to develop an adequate water supply, it is evident that water wells (bore holes) are a weak point in these systems.

Part 2: Observations and Water Program Suggestions

Although Enersol and ADESOL had a number of years of experience working with PV, the application of renewable energy to community water supply posed an entirely new set of design and project parameters. The water systems installed and studied here were some of the first in the Dominican Republic; due to the pilot nature of projects, challenges and obstacles were expected. Those encountered are listed below. The obstacles, although frustrating, provided rich experience and insight into what works, what does not and what might possibly work. In turn the obstacles were the basis of learning about what works and what does not, this is expanded upon below.

Observations and Notable Obstacles

The issues highlighted below are listed not in order of importance but in the order in which they arose in the project development process.

<u>Community selection</u>: Identifying communities with the necessary conditions for project development proved more difficult than anticipated. It is deceptively hard to find communities where there is an intersection of the design criteria of no electricity, no realistic potential for gravity flow supply, an undeveloped but available groundwater resource, and interest on the part of the community in a water project reflected in a willingness to pay.

<u>Quality water well development</u>: Developing a quality water source, technically speaking, was one of the most challenging aspects of the projects for the following reasons:

- The business of water well drilling is notoriously corrupt and dishonest. In an attempt to provide cheaper wells ADESOL acquired a donated drilling rig. It was an effective way to develop low cost wells in communities, but the drilling rig took time to learn how to use and manage.
- A water well could not be developed due to the geological conditions. This occurred in four communities where all other conditions were promising for project development. The projects had to be abandoned.
- The water well developed produced slightly brackish water due to the conditions of the local aquifer. In two communities were projects were implemented, the community accepted slightly brackish water. However, they do not use the water for drinking.
- The water well level fluctuated and affected pump operation. Two wells ran low and pumps consequently burned out. An additional well began to fill with sediment which burnt out the pump.

<u>Design</u>: Technical materials to aid in system design were hard to find locally, this was even more so for materials in Spanish which were practically non-existent. The multiple module water pumping systems were significantly more complicated to design than the single module solar home systems with which Enersol, ADESOL and the local technicians had much experience.

<u>Wind Resource assessment (Bella Vista Abajo and Guzman)</u>: The wind systems added a degree of difficulty with the need for assessment of the wind resource and site selection. Almost no information was available locally. What was available was unreliable and potentially misleading. This made predicting performance almost impossible. In both cases, the initial systems did not produce enough water and systems needed to be modified by adding PV capacity. Wind resource assessment is extremely site specific and regional or general wind data alone is not sufficient to make informed turbine siting decisions.

Equipment availability: PV pumps and controllers as well as wind-turbines were basically not available in the country at the beginning of Enersol's water pumping initiative. Availability has increased in the Dominican Republic as have links to US distributors. However, there is still a limited stock of pumps in country.

Installation: A set of skills was needed for the installation of pumps, controllers and multi-module systems in addition to what local technicians previously had for single module installations. For wind systems, installations were more difficult as well as labor and time intensive. Also new skills, like tower climbing, needed to be developed. Experts from the US wind industry assisted in the wind installations. For the construction of the civil works further skills were required, in some cases local craftsmen were hired.

Technical problems related to system operation: Technical problems with the PV systems either required a minor repair that a local technician could handle or a system component replacement. In general the PV systems reported significantly fewer technical problems and maintenance demands than wind systems. See Appendix for a list of the technical problems reported.

High cost and time commitment associated with community development: While there is no question of the importance of community involvement in the development of a water project, some activities produce more results than others, and some can even be counterproductive or divisive to the community. Members of both the Enersol and ADESOL staff spend large amounts of time building community relations and helping the community develop the necessary human and administrative infrastructure to maintain system service in long-term.

Need to be clear about tariffs from the start: There is a tendency of community members to commit to more than they really are willing to provide in order to win the project, or appease the project workers. They have a realistic basis to expect that they will not be expected afterwards to honor their commitment.

Funding organization's time table: It was challenging to pace water system development, given the number of hurdles, to funding organization's time lines and constraints. This is an issue that should be addressed at the outset by all stakeholders.

Water Program Suggestions

The experience and knowledge gained from these eight systems is ample regarding technical aspects, community development and planning for system sustainability. Many of the findings parallel what has been learned by other water organizations and support common knowledge regarding community water supply projects. For example: community development can be the most time consuming portion of a project; local community involvement and "buy-in" is necessary for success of the project; regular payments for water service are crucial for the system long term survival; and community members are capable of making regular payments *however* the level of payment and the conditions must be clear and agreed upon before the project begins.

Below some suggestions are made for the development of future renewable energy powered community water supply projects. The issues below were influential in the development of distinct water system delivery models which are discussed in Section II.

Community identification : Identifying communities that meet project development criteria is time consuming and up to 50% of the communities which make it through the initial screening may not make it through the entire project development process. The initial screening is also a relatively fine filter. For either technology an appropriate density of opportunities need to be identified to allow for sufficient infrastructure development to support the systems.

Water source: Water well development proved to be one of the largest hurdles in project development. Providing funds for various well drillings as well as for technical assistance from experienced water well drillers increases the possibility of developing a quality water source.

Technology choice: Absent unusual wind resource over a large enough area to justify a large number of systems, PV is a more reliable, lower cost option than wind. The experience in the Dominican Republic indicated that PV requires less technical knowledge and maintenance or repairs and also enjoys more opportunities for replication than wind.

Realistic time lines and budgets: Community water systems take time to implement well. Project development, regardless of model, requires much more effort than simply installing the equipment. The design and installation of the renewable energy (RE) system is the more straight forward part of project development. The difficult areas, and those that require time, center around community participation and development of payment of financing model. Personnel and project development budgets must plan for a realistic time frame.

Reputation of technology: The reputation a technology has in a community is important to community acceptance of the project.

New local practices: A water supply system can introduce new procedures or ideas into a community which might not be congruous with local practices and experience to date. For example monthly payments for water service, need to conserve water and access to financing and insurance policies. In addition, while exposure has greatly increased over the last few decades, in some areas there is not a realization of the link between water quality and health.

Mobile and flexible installations: Communities change and are dynamic. Therefore the conditions that make a RE system favorable can change within a period of years. An implementing organization, private or public, must be able to a) remove a water pumping system and install it in another, more suitable community when conditions are no longer favorable or b) increase the size of the system if community growth is beyond what was projected. This flexibility must be inherent in both the physical installation and the financing model used.

Challenging design: Some things to keep in mind, which make design more difficult than is often touted by manufactures and industry representatives are: (1) the sometimes questionable reliability of manufacture product information, (2) the lack of technical information in local languages, (3) the difficulty in obtaining precise site conditions (for example, total dynamic head and well characteristics), and (4) inability to put a large safety factor on design (ie. overdesign) due to the high penalty imposed by the high initial cost of the systems.

Standardization of equipment and materials: Equipment and material selection is limited in the Dominican Republic (DR) as is technical assistance to fix pumps and controllers. It is difficult for local suppliers to keep adequate stock due to the many possible combinations of pumps and motors. It may be best to try to use similar pumps and controllers in all systems, even if they are not optimal for all locations, so that at least one replacement set can be kept in stock which can serve many systems. Materials such as UV resistant tie wraps, flexible-metal fiber re-inforced drop pipe and locking-rust-resistant screws are all materials that are difficult to find yet can make a big difference in system sustainability. Implementing organizations and installers should find ways to have these materials available, perhaps by purchasing in bulk and importing.

Price of water service: It is difficult to predict the willingness of a community, or a group of individuals within a community, to pay for water, with surprises sometimes running in both directions. The notion that water can be and should be provided free is endemic in many communities, a result of water policies of the national government. However there are currents that move in an opposing direction and illustrate a clear demonstrated willingness to pay for water.

Inclusion of women: Women are emerging as important figures in system long-term care and management. In at least half of the communities a woman plays a fundamental role keeping the system running and collecting monthly payments.

Clear communication with the community: As with almost any community based development project, maintaining clear communication between the community members and the implementing entities from the very beginning is essential.

Part 3 : Economic Analysis

One of the most frequently asked questions about the water pumping systems Enersol and ADESOL installed is: "*How much did they cost?*" This is a surprisingly hard question to answer in a clear way. This confusion is partially based on the lack of precision in book-keeping at the community level, however more fundamentally it has to do with the difficulty in defining *cost*. In this section we analyze the cost of a representative PV water pumping system in four ways: 1)the initial capital cost or cash outlay, 2)the life cycle cost (LCC), 3)the cost on a per beneficiary basis and 4)the cost on a per volume, say meter cubed, basis. While the immediate concern for any organization implementing a project will be with the initial cash outlay, to fairly compare a renewable energy system with more conventional pumping systems, a LCC analysis must be performed. This is simply because in a renewable energy water pumping system the majority of the cost of the system lies in the power system. After this initial investment, fuel for the system is essentially free. Once the LCC is established, the cost per beneficiary over the project lifetime can easily be calculated. This can prove useful to planners in government and development organizations alike. Finally it is insightful to calculate the cost on a per volume basis because this can be compared to other current options for water supply, many of which are ultimately purchased on a per volume basis.

Initial Cost

The initial cost of a system refers to the actual cash outlay associated with installing a water pumping system. At this point it is important to distinguish how a cash outlay might vary for different situations and organizations as well as depending on how cost is defined. There are two broad distinctions we would like to make. First between subsidized and non-subsidized systems. A subsidy can be in the form of donated time, donated materials, and equipment at cost below list price, for example. Some non-government organizations (NGOs) and government agencies may enjoy these cost reducing measures, but by including them the real cost of the system is obscured. The second broad distinction is which components of the project are included in the cost, for example the pumping equipment and power supply, the civil works and/or the technical assistance. Project cost can multiply various times depending which components are included in the final sum. To demonstrate exactly how much cost can vary, depending on what is included, we have defined five possible categories and have analyzed the cost of what we considered an "average" PV water pumping system of the six installed. Bella Vista Abajo[18] was the community system chosen as it reflects an average system in terms of daily water demand, system size and cost.

In the case of the Bella Vista Abajo water pumping system, the cost was subsidized by Enersol and ADESOL through both time donations and acquisition of lower than list price equipment. The cost of the civil works was also heavily subsidized by the community, who donated labor and some materials. A local market price for Bella Vista was calculated by estimating cost if component subsidies were removed and donated components were paid for. The five possible *initial costs* are defined in the table below and approximate costs for the Bella Vista system are provided.

[18] More project specifics are available in Section 2.

Table 4.1 : Various Costs of the Bella Vista Abajo PV Water Pumping System

Cost Category[19]	**Cost (US$)**	**Cost/Watt ($/W)**
Subsidized Costs		
"Subsidized *Equipment* Cost" : Subsidized PV water pumping system.	$ 11,500	$ 12
"Subsidized *System* Cost" : Subsidized PV water pumping system with civil works	$ 12,300	$ 13
Local Market Cost (Non-Subsidized)		
"*Equipment* Cost" : Local market price for PV water pumping system	$ 15,000	$ 16
"*System* Cost" : Local market price for PV water pumping system and civil works	$ 22,500	$ 23
" *Project* Cost" : Local market price for PV water pumping system, civil works and technical assistance	$ 40,000	$ 42

While the figures above are estimates they serve two purposes. First, the numbers clearly demonstrate how the "*cost*" of a water pumping system can vary simply depending on what is included in the sum. The *equipment cost* went up 30% from the subsidized to the local market price case, the *system cost* is almost 50% more than *equipment cost* in the non-subsidized case, and when technical assistance is included for the *project cost* the *system* cost doubles. Second, when a full range of costs are included, as in the *local market project cost,* the initial cost of a RE water pumping system can be daunting. *However,* renewable energy technologies *always* urge the application of a life cycle cost analysis since the initial capital investment is high compared to the associated long-term costs. This is done in the following section and the results are intriguing.

Life Cycle Cost

A Life Cycle Cost (LCC) model was developed to include the initial, operating and replacement costs of the PV water systems over the expected project life. Although solar modules can be expected to work for 20-30 years, a ten year life cycle was used due to the multitude of variable factors that can affect a system's appropriateness for a specific community, for example, the existence of electrical service, the size of the population served, and the quality of the well. When these conditions change, it may be necessary to move the PV water pumping system, or modify it. In addition to the initial costs discussed in the section above, the LCC analysis also assumes these additional costs:

- A contract is given to a local solar company to maintain the system.
- The community has an insurance policy on pump/controller (provided by NGO).
- A community member is paid to perform civil works repairs.
- The pump and the controller are replaced after 7 years.
- ADESOL charges an annual fee for on-going technical assistance and administration. (For "Project Cost" only.)

[19] Note that all costs include the installation of the system. In the subsidized costs the installation may have been done on a pro-bono basis. For the cost that reflect local market prices, the cost paying a technician and a supervisor to install the system is included.

In addition, a 2% growth rate in the community and 95% availability of the system are assumed. The financial parameters used in the LCC are the following:

Table 4.2 : Financial Parameters

Return of equity	30%
Percentage borrowed	100%
Commercial interest rate	20%
Inflation rate	12%
Year of analysis	20

The analysis performed for the Bella Vista Abajo system is used as the example below as it best represents an "average" system in terms of size, water production and cost. For this analysis the subsidized cases outlined in the Initial Cost section were disregarded. The initial costs of the Bella Vista "Equipment", "System" and "Project" were affected over the 10 year life cycle as is demonstrated in table 4.3 below.

The LCC analysis is highly sensitive to the inputs and for that reason is to be regarded as a tool to provide rough estimates. In Appendix A an example of the analysis is included. The "Long-term Cost Component" is higher for the "Project" analysis due to the inclusion of the cost of both on-going technical assistance and administration.

Table 4.3 : LCC for the Bella Vista Water Pumping System

Cost Category (all costs in US$)	**Initial Cost**	**Long-term Cost Component**	**Life Cycle Cost**	**LCC/Watt ($/W)**
Local Market Cost (Non-Subsidized)				
"***Equipment***" Local market price for PV water pumping system.	$ 15,000 (75%)	$ 4,500 (25%)	$ 19,500 (100%)	$ 20
"***System***" Local market price for PV water pumping system and civil works.	$ 22,500 (85%)	$ 4,500 (15%)	$ 27,000 (100%)	$ 23
" ***Project***" Local market price for PV water pumping system, civil works and technical assistance.	$ 40,000 (85%)	$6,250 (15%)	$46,250 (100%)	$ 42

As is generally the case with renewable energy projects, the majority of the cost of the Bella Vista system, over the course of its lifetime, is up-front. What is an encouraging result of this analysis is that even when a solid program is contemplated to maintain the system functioning over its lifetime[20], the incremental cost represents only 15-25% of the total LCC. That is to say that quality long-term system care of a system is only a fraction of the initial investment made. *However,* it is generally just this marginal amount, paid out over years, that is the historic cause for failure of rural water supply systems. For this reason Enersol is developing models for rural water supply which

[20] A 10 year life cycle is used. Although systems can function technically for a longer period of time, the dynamic nature of communities adds uncertainty. It is assumed that modules are sold for 1.5$/W after 10 years.

have components for cost recovery and plan for long-term care of system; one depends on the other.

In the case of wind, initial equipment costs can be lower as compared to PV for the amount of water pumped. However Enersol's experience is that even when "good" wind resource exists, long-term costs are significantly higher due to more frequent component replacement, increased maintenance demands and need to use another energy source for low wind periods.

Cost per Beneficiary

Having the LCC in hand, the cost of water supply can be analyzed on a per beneficiary basis *over the life cycle* of the project. In the case of Bella Vista Abajo, with a current population of 237 and an assumed 2% annual growth rate over the ten year life cycle, the LCCs per beneficiary resulted in the figures in table 4.4.

That is to say, that an investment of 163$ on a per beneficiary basis can provide for the implementation of a community PV water project that will supply water over the course of 10 years. This includes the annual "service" fees which insures that the system continues to function over its life cycle, as discussed in the section above this on-going long-term cost represents only 15-25% of the per beneficiary cost.

Table 4.4 : Bella Vista cost per Beneficiary Over System Lifetime

Cost Category	**Cost per Person**
Local Market Cost (Non-Subsidized)	(US$)
"***Equipment***" Local market price for PV water pumping system.	$ 69
"***System***" Local market price for PV water pumping system and civil works.	$ 95
" ***Project***" Local market price for PV water pumping system, civil works and technical assistance.	$ 163

Cost of Water Pumped

Again taking Bella Vista Abajo as an example for analysis, the costs per gallon over the 10 year life cycle are in table 4.5 below.

This analysis is sensitive to its many input variables, and in this document the results are intended only to provide a plausible range of water costs. Examples of the analysis are included in the Appendix A.

Table 4.5 : Cost of Water Pumped from Bella Vista System Over Lifetime

Cost Category	**Cost per gallon**
Local Market Cost (Non-Subsidized)	(cents)
"***Equipment***" Local market price for PV water pumping system.	0.57 cents
"***System***" Local market price for PV water pumping system and civil works.	0.79 cents
"***Project***" Local market price for PV water pumping system, civil works and technical assistance.	1.36 cents

Cost of Current Water Sources

Part of gauging a community's willingness and capacity to pay for a new water service is examining what they currently pay for water. One of the apparent barriers to developing a model for rural water supply that integrates end-user payments into the long-term strategy is the perception that many people in rural areas currently do not pay for water either because the water is collected from a natural source like a spring or river, or because water is supplied free of cost by the government. In the first case, families do pay for water, although not using currency but through the time and energy of family members, generally women and children, allocated to collect water. This labor is frequently not highly valued, so putting a price on monthly water service that offsets a family's time spent collecting water may not in fact be an easy selling point to some heads of household. However Enersol has observed that convenience is valued, perhaps even more than the impact an improved water service can have on health

While there is a widespread perception that water is "free" in rural areas Enersol conducted an informal study that reveled that in the Dominican Republic people are increasingly paying for water and that the cost on a per volume basis is sometimes surprisingly high.

In most communities, water was drawn from a traditional surface source, located usually 30 minutes to one hour walking distance. In a few cases, water was drawn by hand from a well in the vicinity. In four communities, families received water brought by a private truck and delivered to a 55 gallon drum for US$1.30 to US$1.40, about 2.5 cents per gallon. Discounted at 15% over a ten year period this represents a cost of 1.4 cents per gallon, which is still competitive with the "Project" cost per gallon above. In one case the local government delivered water by truck, but with service that was described as "very deficient".

In only five of the communities surveyed was there evidence of families purchasing water in the standard 5 gallon dispensing bottles, and even among those five communities the percentage of those purchasing 5 gallon bottles was small (approximately 5-15%). However, this is a significant change from the recent past, where it was impossible to even obtain such water outside Santo Domingo and Santiago, the two largest cities. Water in a 5 gallon bottle costs 94 cents, or about 24 cents per gallon (13.2 cents when discounted at 15% over 10 years). A family will typically use two

5 gallon bottles per week, which implies monthly expenditure for water of about eight US dollars. This water consumption would always be supplemented by water drawn from the traditional community source. This is orders of magnitude higher than the cost per gallon in the Bella Vista analysis above.

Surprisingly, the sale of water in small plastic bags was greatly expanded from just a few years ago. The sale of these 8 ounce units was reported in six communities. Often the main purchasers were local school children using a one peso coin to quench their thirst after class rather than buy a sweet. The cost of water in 8 ounce packets is about 6 cents, or 48 cents per gallon!

It is difficult to discern from the above precisely how much a family could and would comfortably pay for a reliable supply of high quality water. But it is clear that the landscape is changing. There appears to be a modestly higher awareness of the health risks posed by contaminated water, and a willingness to pay for clean water in at least some cases.

SECTION II : AN EMERGING MODEL FOR PV POWERED RURAL WATER SUPPLY

While strong arguments can be made on various levels for the affordability and efficiency of supplying a clean, convenient and reliable water source in rural areas with renewable energies, and including the opportunity for cost-recovery, whether this really happens depends on some key factors, including:

1) The absence or presence of other easily accessible water sources, even those of acknowledged low quality.
2) The proximity of the community to highly subsidized water projects (in neighboring areas), which can distort perceptions of the fair value of water.
3) The willingness to pay for water.
4) The model used to implement the project.

Various approaches exist. As documented in the previous section of this paper, Enersol initiated its work utilizing a 'simple NGO' model in order to better understand the technologies and potential range for cost recovery in rural areas. In the this model, the NGO procures (often at favorable prices), installs the systems and works to strengthen the community to help manage the system. The NGO also collects revenues from beneficiary families for maintenance and for part of the capital replacement. Although valuable, this type of model is more for implementing a few projects rather than for a large program with significant impact in the rural country-side. This is primarily for two reasons:

1) Limits on NGO capacity to efficiently manage a large number of labor intensive interventions.
2) Drain on capital: while cost recovery has been improved in progressing from the initial to the later systems, it is still short of the mark.

Enersol's experience has resulted in the desire to develop a model, or models, which are efficient in implementation and management, leverage limited capital and provide for a long-term water supply solution. Cost recovery is seen as a key element that can bring together these goals.

In moving towards higher levels of cost recovery the question emerges of what distinguishes the NGO intervention from that of a commercial activity, and indeed what might be the commercial potential. Given the newness of increased cost recovery for rural water users, there are several roles for the presence of an NGO, even in a case of full cost recovery and commercial viability. These roles cover technical, financial, and social considerations that would be unfilled by a straight commercial enterprise.

Roles for the NGO

A. <u>Risk taker</u>. Even in a full cost recovery model the beneficiary community is not in a position to advance the resources up front to install a water system. Rural water systems of any sort are not precisely a magnet for private capital. Private sources of capital usually seek to avoid risk, or seek high return in exchange for accepting it. The NGO can be and is in this respect the risk taker, providing the system in the expectation that the revenue will be generated to pay for it over time.

B. <u>Advocate</u>. Unlike a private water delivery enterprise, the NGO can be seen as an honest broker, seeking to defend the interests of the community. Together with the community, the NGO determines a fair price to place on the water delivered, not in search of a profit but in search of economic sustainability. It also serves as the intermediary between private interests that legitimately may participate in a water delivery system and the community, for example the *colmado*, *pulperia*, or *bodega* (a small country store) at the dispensing point or a private small enterprise that installs and provides repairs to the pumping equipment on behalf of the NGO and the community.

C. Technical assistance and long-term management of the revenue stream. In a full cost recovery model, the revenue stream is sufficient to cover not just O&M, but also replacement of capital equipment as it wears out. Capital replacement means saving up sometimes thousands of dollars over years to be able to replace a pump when it breaks down, for example. While in many cases communities have managed their own resources, there are also undeniably many cases of communities, particularly smaller ones, where management of financial resources is highly problematic. In these instances an NGO is better equipped than a community to do this, and is more logically the entity to do so. The NGO provides initially to a community a functioning system of capital equipment. The community pays towards the value of the equipment over time. As the pieces wear out, the NGO relies on the money received from the community to pay for replacement of the equipment that it originally provided.

D. Funding/investment channel. An NGO is far better positioned to attract resources that can be invested in small rural community water systems than either the community directly, or a for profit enterprise. With mandates to work in poor rural areas and experience in doing so, NGOs command trust that funds will be used to execute projects consistent with the needs of the beneficiary communities.

Pitfalls for the NGO

Non-profits organizations have long been involved in rural supply in the Dominican Republic and have a fairly high degree of credibility in the areas where they operate. Non-profits are not generally structured like a service delivery business however, and they are not always well equipped to respond to the needs of the community for on-going support. They also have not generally in the past expected to recover their costs from the end users, relying mostly on grants from outside donors. Non-profits have every incentive to finish their projects, make their evaluation, and move on to the next proposal. Their beneficiary count does not increase for giving continued support to a group already served. Even where there is a sincere wish to provide long term support to a community, the desires of funders dictates that new activities be found; funders are generally reluctant to cover indefinite support.

However, non-profits can provide long term support if the community in question is capable of paying the cost of the support. In this instance, the non-profit operates much like a cooperative – sustained by its revenues but with a mission driven not by profit motives but rather to provide service.

Options for NGO participation

The first option mentioned above is for the NGO to run the water intervention much the way it might run a low cost community dispensary (*botiquin*), providing the system with in-house resources and managing the revenues created. Enersol is experimenting with two alternatives to this initial approach. The first is that of water system financing. In this model either all or portions of a project are financed to a community. The second is a metered-service system where the NGO retains some control and management responsibility, but where a substantial portion of the revenues generated go to the private local entities running the water dipensing and the technical maintenance.

Financed systems

The finance approach over time relieves the NGO of a significant portion of cost of executing a water project. However, this ultimately leaves the community in possession of a system which it is often poorly equipped to maintain or manage. Without some external entity to provide the discipline for accumulation of a capital replacement fund, eventually the community is at risk of finding itself facing an expensive replacement or repair. With a financed system there is no means by which an NGO can obligate a community to pay for system insurance, especially once the community has completed the financing. Yet it is the very insurance that is a bedrock requirement for long-term sustainability. While more attractive than the 'simple NGO' model, financing is perhaps more suitable for private systems for a single family or organization as opposed to an entire community.

Flat fees, Metered-service and private participation with an NGO and the community

The key aspect of the flat fee system commonly used for rural community water supply is that it is simply that: a flat rate where each family pays the same amount for water service regardless of family income on one side and family consumption on the other. This tautological description is necessary to remind us of the feature so obvious as to seem at times invisible to analysis. Because of their widespread use, the flat fee has achieved the appearance of and acceptance as a logical system when actually it is an irrational and anti-environmental aberration that exists only for two reasons:

1. water resource allocation has not historically been under the pressure that it is today, and
2. easy alternatives to a flat rate at the rural level up until now have not been widely known.

A willingness to pay study for a rural community can generate a number which corresponds to a single flat fee that the majority of families in a community would accept for a given level of water service. This is always a trade-off game however: if broad acceptance of the fee is desired it must be set at an extremely low level. If the fee is positioned higher, the number of families willing to accept it goes down, even as revenue may for a time go up. At whatever service level the flat fee system is hostage to the community members who least can afford it or least want to pay. And in attempting to achieve any sort of sustainability through a more realistic price level, it becomes a crude instrument indeed, neither fair to those who cannot afford the price, nor fair for those who would pay the price but use disproportionately large quantities of water.

For these reasons, another model that Enersol is experimenting with is a metered-service system operated by either token, card swipe, or direct sale dispensing from the tap at small general stores. This approach tackles in a very direct way the challenge of periodically collecting adequate fees for maintenance and capital replacement, and at the same time responds to the problem of wasting water. As mentioned, in PV water pumping systems, the cost varies very closely with the number of gallons pumped. This fact gives a powerful incentive to find ways to promote conservation and reduce waste of water. Providing water to rural consumers on a per unit consumed basis dramatically changes behavior patterns.

Under this model a local merchant participates, selling tokens (or cards) or directly selling the water at a tap-stand with a standard timed switch (run by PV electricity) that allows her just by hitting a button to measure out exact amounts without leaving the counter. In either case the merchant receives a portion of the revenues to cover her efforts, but she does not determine price. Pricing would be determined by an external body for example, an NGO with a community water board. A local PV technician also participates, providing maintenance and service, again for a portion of the revenue.

The beauty and inherent fairness of a meter pay system is that each family gets to set its own fee according to how much it wants to use and according to its ability to pay. Only such a system adequately reflects the range of incomes and consumption patterns in a given user group. If the individual consumption of water were inelastic, this would not be a fair arrangement, but that is not the case. Standard engineering texts show up to 50 fold difference in water consumption – all to meet the same basic set of needs. In the most difficult case, if the resources of a family are extremely limited, the basic amount of water needed for drinking and cooking can be obtained at a near microscopic outlay, and the remainder of the of their water would be covered from the traditional source.

Challenges for meter-pay

Meter-pay is not an easy concept to advance in Latin America, and many people working with rural potable water supply dismiss it out of hand. There is often initial hostility to the idea of metering when speaking rural residents, though this can be overcome, often powerfully, by presenting metering in the context of fairness, elimination of abuse of the water supply by wealthiest few (who often use highly disproportionate amounts of water for their larger houses and their economic activities), and the reduction of waste by careless individuals who leave taps open and thus jeopardize the service of everyone. Though development workers are often dismayed at the extent of water waste and abuses of the system and can easily conclude that nobody cares, that is a mistake. Many rural residents are acutely aware of inequitable apportionment of the water and of damaging waste, and respond very positively to the idea of tackling these problems.

Many people will cite the expense of metering units as an insurmountable obstacle for rural water systems. What is often overlooked is the cost of providing unmetered systems. With metering demonstrably able to show reductions in waste exceeding 50% of the total water, the cost of metering can justifiably balanced against the savings in reducing the size of water system by half.

It is also difficult to imagine how metered systems can be monitored and managed at the rural level. New technology is changing that obstacle however. With card swipe metered water and electricity systems enjoying success in Africa, the cost of simple integrated circuitry declining, and the rapidly expanding acceptance of debited cards as an improvement on cash for making even the smallest of transactions, the potential for metering is being vastly widened. Card swipe technology is now available for both urban and rural water supply, and for both individual house connections and for public tap-stands. Issues of equity and access for all, previously intellectual stumbling blocks when talking of metering, are easily addressed by card swipe systems. "Lifeline tariffs" can be built into cards to provide certain sustaining amounts of water for free or at low cost while charging more for additional consumption.

Beating the bugaboo of community participation

Models incorporating some form of meter-pay model hold the promise of a new, community-helping alternative for collecting the needed revenue for a water system: a method that is (beneficially) impersonal, independent, consistent, and impartial. Many NGOs struggle in project development and implementation with the precarious dependence on a small number of active and resourceful individuals without whom it would often be impossible to imagine the success of a project. Collection of revenues falls disproportionately on the shoulders of these key individuals, and it is not gratifying work. Having to act in the role of bill collector among friends and neighbors and dealing constantly with those members of the community who attempt to avoid payment demoralizes and discourages the community activists – they eventually resign their positions of responsibility or seek to lessen their involvement in the system administration. Or worse, the temptation to use the money for personal purposes, coupled with poor controls, overcomes initial goodwill, and key community members whose co-operation is necessary for the success of a project find themselves ensnarled in a moral and financial mess.

Meter pay can enhance community participation by liberating its best members from the thankless task of fee collections and providing a more independent and consistent revenue stream needed to enable the community to focus on maintenance, repair, and sustainability. In this way, far from being counter to community participation, meter-pay technology can help the community to manage some of the most challenging and problematic elements of water system operation and maintenance.

The potential realm for meter-pay water delivery

The potential for a simple meter-pay water dispensing model are enormous. Small rural water systems everywhere chronically deal with not having a good way to raise money for basic maintenance, much less for recovery of capital costs for replacement of worn out equipment. This applies to gravity fed systems or ones using electric pumping, and to public taps or individual connections. Flat fee systems often do function adequately in the beginning, but their long term track record is uneven at best. The scope of this problem is huge and vastly underreported.

Conclusion

The work conducted by Enersol from 1993 to 1998 in the development of community water systems that are powered by renewable energy sources, most notably solar PV and wind-electric, provided immense learning opportunities. At this stage, Enersol and its local partner the Solar Energy Development Association (ADESOL) have a high level of confidence in solar photovoltaics (PV) technology for the delivery of reliable water from a deep well source, given that local services are available to support the technology in case of mechanical or other problems which inevitably arise in any water supply system. Establishing the credibility within the organizations and in the country for this application was a crucial first step in the development of models for wider project implementation.

Evaluating the cost of the systems, so that they can be compared with current water sources and other alternatives for water supply, was a challenge for two reasons. First, the scope of the water system must be defined. That is to say, a decision needs to be made as to which components of the project are included in the analysis. For example does the system include merely the water pumping equipment, or also the water distribution network or also the technical assistance and project management costs? Enersol found an almost four fold increase in the “initial cost” of a system depending on which project components were included. This indicates that the up-front cost of implementing a PV water pumping systems is much larger than the mere cost of the water pumping equipment, and therefore organizations should plan budgets accordingly. Secondly, the use of renewable energy power sources demands an evaluation on a life cycle cost basis. When a life cycle cost (LCC) assessment was performed, the long-term operating costs represented only 15-25% of total system cost. *However*, it is generally just this marginal amount, paid out over years, that is the historic cause for failure of rural water supply systems. For this reason Enersol is developing models for rural water supply which have components for cost recovery and plan for long-term care of the system; one depends on the other. The LCC analysis also provided an evaluation of the cost of the water service on a per beneficiary and per unit of water cost; both were favorable from a planning and competitive market perspective.

Neither of the findings above is revolutionary, in many ways the experience confirms what other organizations have found related to renewable energy power sources as well as rural water supply. One conclusion that Enersol did make, which departs somewhat from other reports, concerns the viability of small wind systems for community water supply. Absent unusual wind resource over a large enough area to justify a significant number of systems, PV is a more reliable, lower cost option than wind. The experience in the Dominican Republic indicated that PV requires less technical knowledge and maintenance or repairs and also enjoys more opportunities for replication than wind.

Enersol’s work did point to a number of issues which previously have not been highlighted, but are crucial to the development of a regional renewable energy water supply initiative. Among others:

1. <u>Community section</u>: Finding an area with a significant number of communities with the characteristics and conditions to support a PV water pumping system is essential yet sometimes challenging.
2. <u>Water source development</u>: Even when communities have the desired conditions for a PV water pumping system, water source development can present an impassable barrier. (In

Enersol's experience 50% of communities that made it through the initial filter did not have the subterranean characteristics necessary to develop a water well.)

3. Hurdles in system design and installation: a) Lack of technical materials locally and in local language. b) Technicians and local engineers need to be trained in multi-panel system and water pump design and installation. c) Some standardization of systems locally could assist in the availability of equipment as well as replacement parts. d) Installations need to be somewhat mobile to respond to changing local conditions.

4. Most significant time commitment was work with the community. Budgets and time lines need to reflect a range of realistic factors, the most significant being developing a working relationship with the community and building the necessary infrastructure (mechanical and human) to provide for long-term service.

The work described in the Case Study section of this document represents the necessary stepping stones for both Enersol and ADESOL in the development of a viable model for rural water supply which incorporates the goals of long-term water supply (ie. sustainability), recovery of some percentage of the initial investment and ability to leverage limited capital. Once Enersol had acquired confidence in the PV technology, systems were financed to communities. Monthly payments were made by community members on a flat fee basis to pay back part of the capital investment and to pay for an insurance policy arrangement with ADESOL for their system. This payment scheme represents the recuperation of a significant percentage of the entire project cost.

The learning that occurred from the financed systems encouraged Enersol to pursue the development of a pay-for-service, or metered, model. This approach tackles in a very direct way the challenge of periodically collecting adequate fees for maintenance and capital replacement, and at the same time responds to the problem of wasting water. As mentioned, in PV water pumping systems, the cost varies quite closely with the number of gallons pumped. This fact gives a powerful incentive to find ways to promote conservation and reduce waste of water. Providing water to rural consumers on a per unit consumed basis dramatically changes behavior patterns. Models incorporating some form of meter-pay model hold the promise of a new, community-helping alternative for collecting the needed revenue for a water system: a method that is (beneficially) impersonal, independent, consistent, and impartial.

The development of a model which is more sustainable in financial and environmental terms, and capable of cost-recovery has the potential to better serve people in rural areas while dovetailing with international trends towards more economically rational delivery schemes and increased participation of the private sector. There is however considerable confusion and hostility by many to the notion of private participation in the delivery of essential services. Enersol is focusing on finding ways in which the benefits of small scale, local, for-profit enterprises (accountability, efficiency, reliability) can be harnessed to water delivery activities while minimizing the risks associated with for-profit presence (monopolistic pricing, narrow radius of service). This work is not being pursued by others in the Dominican Republic, and models which successfully incorporate both non-profit and for-profit are urgently needed to assure skeptical non-government organizations and government entities that such collaboration is not only possible, but essential to long term viability of water systems and best use of limited resources.

Appendix A: Reported Technical Problems

Table A.1: Reported Failures in 6 PV Water Pumping Systems

Component Failure	Cause	Impact/Action
DC Pump burned out (1994)	Low water level in well. Poor mechanism for detection and pump shut off.	Replaced with AC pump and developed second well with better recharge rate.
DC Pump burned out. Different manufacture than first. (1999)	Low water level in well. Mechanism for detection failed or was not installed properly.	System out of order. Electric line recently arrived in community.
Module broke (1998)	Perhaps a coconut hit module during high wind storm or child with rock.	Module still functioning. Need to monitor performance as it could affect entire string of modules.
Two modules with water intrusion (1997 or 8)	Poor fabrication.	It was recommended to ADESOL that they remove the modules and seek replacement under manufacturer's warrantee.
Drop cable connection broke. (1998)	Pump installed with PVC tubing which had weak connection between lengths. When ADESOL was working on system, pump fell off.	Pump reviewed and appears to work fine. Will be re-installed. Flexible drop pipe re-inforced with metal fiber is suggested for future installations.

Table A.2: Reported Failures in 2 Wind-Electric Water Pumping Systems

Component Failure	Cause	Impact/Action
Controller battery low.	Low wind speed for a number of days left battery in controller low on a number of occasions.	When wind resource picked up the controller did not function, no water was pumped. A small PV panel was added to keep controller battery always at optimal charge. In addition a switch was added to controller to prevent trickle charge out of battery when system is not in use.
Controller components failed (1994 and 5)	Low battery voltage lead to failure of two components in the controller.	Replaced components. Had to order from USA.
Winch cable for furling wind machine broke 2 times.	Rusted from exposure to salty air (ocean is 5 km away) and strained by over tightening.	Replacement which required climbing the wind tower.
Wind machine did not pump sufficient water to meet demand.	Lower than estimated wind speed at location.	Machine raised higher. Minimal impact on production. PV system installed to augment production for community.
Pump burned out.	Sedimentation in well.	Pump removed and local technicians attempted to repair. They could not, pump will need to be replaced.
Controller failed to function between battery bank and pump.	Problems with voltage settings and compatibility with wind charger.	After attempting to use at least 2 different controllers, the system was left with no controller.
Machine did not pump sufficient water.	Wind speed lower than estimated or electrical output lower than manufacture specifications.	Replaced with larger machine and then a PV systems.

Appendix B. Sample of Economic Analysis

Life Cycle Cost **PROJECT: Bella Vista Abajo, Puerto Plata, Dominican Republic**

CASE: "Equipment"

Financial Assumptions:		Calculated:		Other Assumptions:	
30%	Required return on equity	20%	Nominal discount rate	2.0%	Community Growth Rate
100%	Percentage borrowed	7.1%	Real discount rate	1,984	Water pumped daily (5kwh/m2) [Gal]
20%	Commercial interest rate	7.1%	Real discount rate for fuel	95%	Availability of System
12%	Inflation rate			$ 680	Annual O&M, Replacement/Sevice Fee
12%	Inflation rate of gas fuel			960	Number of Watts installed
0%	Income tax				
10	years in analysis				

Summary:

Total LCC:	$19,472	Initial $/W:	15.7	Monthly Payment:	$ 162
Investment per Person:	$ 69	10 yr. care $/W:	4.6	Per Person Min:	$ 0.57
Cost per gallon (cents):	0.31	Final $/W:	20.3	Per Person Max:	$ 0.68

*Annual Service Fee:	
Maintaince Contract Solar Company:	$ 150
Community Member Paid for Repairs	$ 75
Civil Works Repairs	$ 75
Pump/controller replacement/7 yrs	$ 380
TOTAL	$ 680

Note: Monthly Payment assumes TNP/20 years/12 months

Note: For the "Project" Case and additional $320 is added to the Annual Service Fee to cover ADESOL's technical assistance and project management services.

	Year	PV System			Population	Investment per person	Water Pumped (m^3)	cost (US$/$m^3$)
		Cost	Present Value	Total PV				
Initial Cost:	0	$ 15,068	$ 15,068	$ 15,068	237	$ 64		
Annual Service Fees:	1	$ 680	$ 635	$ 15,703	242	$ 65	2,606	6.02
	2	$ 680	$ 592	$ 16,295	247	$ 66	5,212	3.12
	3	$ 680	$ 553	$ 16,848	252	$ 67	7,818	2.16
	4	$ 680	$ 516	$ 17,364	257	$ 68	10,424	1.66
	5	$ 680	$ 482	$ 17,846	262	$ 68	13,030	1.37
	6	$ 680	$ 449	$ 18,295	267	$ 69	15,636	1.16
	7	$ 680	$ 420	$ 18,715	272	$ 69	18,242	1.03
	8	$ 680	$ 392	$ 19,106	278	$ 69	20,848	0.92
	9	$ 680	$ 365	$ 19,472	283	$ 69	23,454	0.82
	10	$ 680	$ 341	$ 19,813	289	$ 69	26,060	0.77
	11	$ 680	$ 318	$ 20,131	295	$ 68	28,666	0.71
	12	$ 680	$ 297	$ 20,428	301	$ 68	31,272	0.66
	13	$ 680	$ 277	$ 20,705	307	$ 68	33,879	0.61
	14	$ 680	$ 259	$ 20,964	313	$ 67	36,484	0.58
	15	$ 680	$ 242	$ 21,206	319	$ 66	39,091	0.21
	16	$ 680	$ 225	$ 21,431	325	$ 66	41,697	0.55
	17	$ 680	$ 210	$ 21,642	332	$ 65	44,303	0.50
	18	$ 680	$ 196	$ 21,838	338	$ 65	46,909	0.48
	19	$ 680	$ 183	$ 22,022	345	$ 64	49,515	0.45