DEVELOPMENT OF A DECISION SUPPORT SYSTEM FOR SUSTAINABLE IMPLEMENTATION OF RURAL GRAVITY FLOW WATER SYSTEMS

By

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This thesis, "DEVELOPMENT OF A DECISION SUPPORT SYSTEM FOR SUSTAINABLE IMPLEMENTATION OF RURAL GRAVITY FLOW WATER SYSTEMS," is hereby approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE IN ENVIRONMENTAL ENGINEERING.

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ABSTRACT

Rural water scarcity is a serious issue facing many of the world's population. Gravity flow water systems provide a cost efficient means of providing those in need of improved water with a sustainable service. This manuscript presents software to be used by organizations, individuals, and institutions involved in managing and developing gravity flow water supply systems. Five software modules were developed with the Visual Basic for Applicaions programming language for use in a Mirocsoft Excel program. This software is aimed at water supply system project managers who at present may not have the proper tools, ability, or time to complete the engineering calculations required. Current tools and methods used by engineers addressing rural water systems are discussed. A clear need is demonstrated for a tool specifically tailored to address the unique challenges of development of rural water systems. It is hoped that the software package ***GOODwater*** can fill this void. The program consists of different modules which assist the project manager during the various life stages of a project. Menus and navigation are intuitive to use and simple to learn. Once an organization sets up a ***GOODwater*** template, users can quickly enter information about the proposed system and generate standardized reports. A module is provided to help in assessing the suitability of different sites for a gravity flow water system. Once a site is chosen, detailed topographical information can be entered into the design module. This module creates a system design optimized for least capital cost using a simple genetic algorithm. Budgets and schedules can also be prepared in the subsequent modules of the software. Finally the ***GOODwater*** software evaluates the overall sustainability of the project. A case study was presented in which the ***GOODwater*** software was applied to the communities of Guaranal and Quita Sueño in the Dominican Republic, where the author had lived for two years.

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LIST OF ACRONYMS

AVPL	Agua Para La Vida
CPVC	Chlorinated Polyvinyl Chloride
DSS	Decision Support System
EPA	United States Environmental Protection Agency
ESW	Engineers for a Sustainable World
EWB	Engineers Without Borders
GA	Genetic Algorithm
GFWS	Gravity Flow Water System
GFWS	Gravity Flow Water System
HDP	High Density Polyethylene
Lpcd	Liters per-capita daily
MIP	Masters International Program
MTU	Michigan Technological University
PVC	polyvinyl chloride
UN	United Nations
UNDP	United Nations Development Program
VBA	Visual Basic for Applications
WHO	World Health Organization
WRI	World Resources Institute

1 INTRODUCTION

This work outlines the development of a decision support system (**DSS**) designed to assist in the sustainable completion of rural gravity flow water systems. Chapter 1 presents the motivation for the research detailed within this manuscript. The main argument of this text, which is that a DSS can assist in sustainable implementation of rural gravity flow water projects, is consequently outlined. The development of the DSS software, named ***GOODwater***, is then explained. The intended audience for the software ***GOODwater*** is also summarized. Finally, this chapter concludes with a discussion of expected benefits for ***GOODwater*** users.

1.1 MOTIVATION FOR RESEARCH

The work described within this document was completed between the years 2004 and 2008. During that time the author was a graduate student of Michigan Technological University (**MTU**) (Houghton, Michigan), as well as a United States Peace Corps Volunteer serving in the Dominican Republic. The Peace Corps is an international development agency of the United States government which places trained professionals throughout the developing world in order to provide technical assistance to communities and organizations. Michigan Technological University's cooperation with the Peace Corps stems in part from the university's Civil and Environmental Engineering department's Master's International Program (**MIP**). This program engages students in one year of graduate studies at the university, and assists in placement with the Peace Corps in engineering positions in developing countries worldwide. Students of the program have worked in water supply and treatment, wastewater treatment, water resources management, solid waste management, and other technical fields throughout the world (Mihelcic 2004). One of the stated goals of the MTU-MIP involves incorporating environmental, social, and economic issues into engineering projects through a sustainable framework. Presenting students with extensive overseas field work during their education provides an opportunity for students to learn through experience. The program also generates new research which directly addresses concerns of developing nations (Mihelcic et al. 2006).

As a member of the MTU-MI program, the author was assigned by the Peace Corps to work as a water and sanitation engineer in the Dominican Republic. Located in the western Caribbean, the Dominican Republic shares the island of Hispaniola with Haiti. With a GDP per capita of $US 3,877 in 2006, and an estimated 9.2 million inhabitants, the Dominican Republic is a developing nation in which the Peace Corps has maintained a presence since 1962. In 2002, an estimated 19 percent of the population, around 1,748,000 Dominicans, lacked access to an improved water source (Economist Intelligence Unit 2007).

In this context the author began working in the communities of Guaranal and Quita Sueño, near the town of Altamira, in the north of the country. Working with local leaders and a community water board, a gravity flow water system bringing water to over 150 homes was constructed between 2005 and 2007. For the second half of 2007 the author also served as a technical coordinator for Peace Corps water and sanitation efforts in the Dominican Republic. This role entailed diagnosing problems, providing advice, and assessing the feasibility of different water project throughout the country.

During the lifespan of the water project in the Dominican Republic the author served many different roles. Acting as engineer, foreman, accountant, health trainer, and community organizer for the project, the author became well-informed about many dissimilar aspects of water system implementation, management and operations. Through this work the author became conscious of a lack of tools designed to assist managers of rural water projects. During his time in the Dominican Republic, the author searched for, combined, and created various tools to assist in different stages of the Guaranal and Quita Sueño water system. Upon return to the United States further research into the tools and methodology of rural gravity fed water systems was conducted. This manuscript is a refinement of those investigations.

1.2 THESIS OBJECTIVE AND FORM

The main hypothesis proposed by this document is that there exists a lack of proper managerial tools to assist in the decision making processes involved in the selection, design, planning, construction, and maintenance of small-scale gravity flow water systems (**GFWS**). As defined within the scope of this work, a GFWS is a network of pipes, storage tanks, user connections, and other associated infrastructure which transmit water to small, usually rural, communities using the force of gravity to move water through pipes. Research of currently available technologies pertaining to GFWS was conducted and a need for future development in this area was identified. To meet this need, a software program titled ***GOODwater*** was developed by the author to aid organizations, individuals, and communities interested in rural water projects throughout the world. This software provides assistance in making critical decisions necessary throughout the lifecycle of gravity flow water systems projects.

This manuscript is divided into six main chapters:

CHAPTER 1: INTRODUCTION	The origin of the research is discussed, and the main hypothesis is presented. Development of the software ***GOODwater*** is summarized. Anticipated users of ***GOODwater*** are discussed, along with the intended benefits for using the developed software
CHAPTER 2: IDENTIFICAION OF NEED	Current strategies and resources available to those implementing rural water projects are analyzed. Commercial and non-commercial software packages and design tools are compared with the special needs associated with working in rural areas of developing nations. Decision support systems are described and examples from similar applications are presented.
CHAPTER 3: METHODOLOGY	The methodology necessary for sustainable implementation of rural water systems is presented. Social, environmental, and economic concerns for gravity flow water systems are discussed for each lifecycle stage. A description of the ***GOODwater*** software is offered. Layout and use of the software are detailed. The different modules of ***GOODwater*** are explained to the reader.
CHAPTER 4: APPLICATION OF THE DSS	An application of the decision support system is provided. ***GOODwater*** is applied in the communities of Guaranal and Quita Sueño, and the results are presented.
CHAPTER 5: CONCLUSIONS	Conclusions drawn from this work and recommendations for future study are presented.
CHAPETER 6: LIST OF REFERENCES	A list of references used in this manuscript is provided.

1.3 DEVELOPMENT OF *GOODwater*

The main product of this research is the development of the ***GOODwater*** software. ***GOODwater*** is a decision support system developed to assist in implementation of gravity flow water projects. As such, the software enables the user to make informed decisions about the best course of action for a given project. ***GOODwater*** attempts to aid project supervisors in finding the optimal level of service, while minimizing costs and maximizing the long-term system sustainability.

GOODwater is a spreadsheet program written for use in the commercial software Microsoft Excel®. Microsoft Excel® is a common spreadsheet program available on many computers. The spreadsheet capabilities of Microsoft Excel® enable the user to organize, calculate and analyze data gathered from the project site. ***GOODwater*** makes use of macros, routines written in the Visual Basic for Applications (**VBA**) programming language. ***GOODwater*** is a 5.17 MB file that can be downloaded from the MTU website: http://www.d80.mtu.edu/Resources.html. On this same website, the instructions and help files included within the ***GOODwater*** program can also be found. The ***GOODwater*** software is designed to be easy to use and require little computer experience from the user. The program as written is currently available only in English, though other languages would broaden the applicability of the software.

GOODwater is a software program which provides assistance in five main aspects of a project's lifecycle:

1) Site assessment
2) System design
3) Planning and budgeting

4) Project implementation
5) Project Evaluation

The program is divided into five modules, one for each stage of a project's lifecycle. Each module can be used individually; however the software is designed to assist the user throughout the entire life of a project. The program also includes introduction, options, and help menus. For each stage of a project, ***GOODwater*** has three main subsections. The first subsection is a checklist of actions to be completed by the user. These actions often need to be performed with community members in the location where the project is to be completed. Examples of important actions are conducting a community census, pricing materials, and organizing labor. The next subsection is an area in which the user enters data gathered from the suggested actions. At this time the user also selects options about how the intended system is to be completed. Finally, each module produces a report from the data and selections of the second section. The reports generated for each module include summaries of the different findings calculated by ***GOODwater*** for each module.

1.4 TARGET AUDIENCE FOR *GOODwater*

The ***GOODwater*** software was developed to be used by organizations, communities, and individuals involved rural water projects. ***GOODwater*** assists decision making in small-scale gravity flow systems. Rainwater harvesting, groundwater wells, pump projects, and other system are not dealt with by the software. Worldwide there are many organizations addressing rural water issues. Engineers Without Borders (**EWB-USA**), Engineers for a Sustainable World (**ESW**), Water for People, and the

Millennium Water Alliance all are some of the many institutions dedicated to international engineering projects (McConville and Mihelcic 2007). Additionally, government programs such the Peace Corps are involved in assisting communities to deal with water scarcity. For instance, in 2000, the Peace Corps was involved in water and sanitation projects in 15 countries, with a total of 491 volunteers addressing various water related problems. Construction of water systems, hygiene education, watershed management, community organization, and other areas are all addressed by Peace Corps volunteers (Peace Corps Center for Field Assistance and Applied Research 2001). Though there is much work being done to address water scarcity globally, a sustainable approach is needed if long term success is to be expected. ***GOODwater*** was created to assist these and other organizations in their efforts to combat water scarcity in a sustainable manner.

1.5 BENEFITS OF ***GOODwater***

By using the ***GOODwater*** software, project supervisors are able to make informed decisions throughout a water project's lifecycle. This translates into both direct and indirect benefits for the end user of a water system. Often project managers must balance the demand for a high level of services, economically efficient production, and timely delivery. ***GOODwater*** assists in finding the desired equilibrium between these competing forces. The software also maintains a focus on the sustainability of the project. ***GOODwater*** incorporates the economic, social, and environmental considerations which affect the long and short term survival of rural water projects into the decision making framework.

Throughout the lifespan of a project, proper management of limited time and resouces is important. Organizations and institutions often work on multiple projects simultaneously, thus limiting the amount of time focused on a given system. Also, the specialized knowledge needed during the various stages of a project can come at high prices. By helping to organize and calculate many of the variables involved in water systems, the ***GOODwater*** user can dedicate valuable time where it is most needed. The reports and summaries generated by the software also assist in timely presentation of project details to those funding, overseeing, and executing the project. Often the limiting factors in development of rural water systems are the capital costs involved. ***GOODwater*** provides the system designer with the opportunity to minimize these costs. Given a specific set of boundary conditions necessary for a community's water system, the ***GOODwater*** software will create a design which provides a pre-designated level of service at minimum costs. By producing a design with low capital costs, scarce monetary resources can be efficiently managed. People need a minimum level of service to meet their daily living needs, and ***GOODwater*** allows a project designer to create a water system with a designated level of service. Through different options found within the software, users can set flow rates, connection types, pipe sizes and other variables to ensure proper water delivery to all users. Computations are processed by the computer, eliminating mathematical errors which can accumulate when working with large sets of data, such as topographical survey points. These features allow for maintained quality control (Batteson et al. 1998).

Sustainability is a concept which integrates the economic, social, and environmental concerns of the all stakeholders for a project. By ensuring that the different needs of these groups are addressed, the long-term viability of a project can be increased. The ***GOODwater*** software provides suggestions of actions to be taken which can improve the sustainability of the water system. By completing these actions, different stakeholders are drawn into the project and their opinions and interests are considered. The software also presents a diagnosis of the expected sustainability for each stage of the project, and for the project as a whole, through the report generated during the evaluation stage (Mihelcic et al. 2003).

2 IDENTIFICATION OF NEED

In the United Nations *Human Development Report: 2006*, the Secretary General of the UN stated that "access to safe water is a fundamental human need and, therefore, a basic human right." Worldwide, water scarcity affects health, education, economic growth, and continued development of large numbers of the world's poor, particularly those living in rural areas, and ensuring their right to water has become a global concern. As the international community increasingly responds to what has been labeled a "global water crisis" by the United Nations, different technologies have developed to assist in the implementation of water and sanitation projects (Watkins 2006). This chapter outlines the current global water situation and details approaches used to combat water deficiencies. Gravity flow water systems, a common choice for resolution of rural water scarcity, are described. A survey was conducted of water system managers, and the results from that survey are presented. Current resources available to assist in water supply projects are presented. Both computer and non-computer based resources are discussed and reviewed.

2.1 RURAL WATER SUPPLY AS A GLOBAL ISSUE

Throughout the previous decades, and continuing today, international organizations such as the United Nations, the World Bank, and the World Health Organization have placed water and sanitation on the forefront of their agendas. Studies by the World Health Organization and UNICEF have stated as recently as 2002 that over 1.1 billion people, or roughly one-sixth of the global population, lack access to an improved water source (United Nations 2002; World Health Organization and UNICEF 2000). In the United Nations publication, *Water Rights and Wrongs, a Young Peoples*

Summary of the United Nations Development Report, the effect of water scarcity on children is highlighted. The booklet notes that each year approximately 5 billion cases of diarrhea cause 1.8 million deaths, the majority of these being children under the age of five (United Nations Development Programme and Peace Child International 2006).

The *Global Water Supply and Sanitation Assessment: 2000* noted that of those families lacking an improved water source, the majority live in rural communities (World Health Organization and UNICEF 2000). At the turn of the century the general assembly of the United Nations passed the *Millennium Declaration*, which outlined the Millennium Development Goals and called for 50% reduction of number of people who cannot reach or purchase safe water by 2015 (United Nations 2000). In recent reports from the United Nations on the progress towards these goals, targets for safe drinking water were within reach; however progress in rural areas had fallen behind that of urban sectors (United Nations 2005, 2006). The World Resources Institute noted that rural areas are home to three fourths of the worlds poor. These areas typically see less investment in their development then urban areas. Also, rural areas are often less empowered politically, and lack adequate representation (World Resources Institute in collaboration with United Nations Development Programme, United Nations Environment Programme, and World Bank 2005). Though progress is being made overall, the rural poor face the greatest water scarcity issues, and receive the least amount of assistance. Rural poor are burdened economically, socially, and environmentally by lack of adequate access to clean water (United Nations 2006).

In an attempt to alleviate water scarcity, various governmental and non-governmental organizations have utilized diverse approaches. Table 2.1 shows different water supply technologies and how the WHO classifies them. A lack of an improved water source can lead to disease contracted through drinking contaminated water and disease contracted due to lack of water for washing and personal hygiene (World Health

Organization and UNICEF 2000). Due to the large scope of water supply options as a research area, and the personal experiences of the author, only water delivered by gravity though pipe networks to household connections and tap stands will be addressed within this work.

Table 2.1 Water Supply Schems And Their WHO Classificaion

IMPROVED	NON-IMPROVED
Household Connection *	Unprotected Well
Public Standpipe *	Unprotected Spring
Borehole	Vendor-Provided Water
Protected Dug Well	Bottled Water
Protected Spring	Tanker Truck provision of Water
Rainwater Collection	

*Technologies addressed in this manuscript
(World Health Organization and UNICEF 2000).

2.2 GFWS AS A SOLUTION TO RURAL WATER SCARCITY

The main focus of this manuscript is on water systems using the force of gravity to propel water through a network of pipes to tap stands and household connections. A GFWS consists of many different components all working together to deliver water to users. Figure 2.1 shows a typical layout for a GFWS, with many of the standard components. These components consist of intakes, various tanks, water lines, and user connections. The intake is a structure built to move water into the system. These are typically built near springs or small streams.

As water moves from the intake towards users it passes through a network of pipes. Conduction lines often carry water to a central tank, and distribution lines then carry that water to users. Pipes made from plastics such as polyvinyl chloride (**PVC**), chlorinated polyvinyl chloride (**CPVC**) and high-density polyethylene (**HDPE)** are common, as well as cast iron, spun iron, steel, asbestos-cement, and pre-stressed cement. Different types of tanks may be installed in a GFWS. These include, but are not limited to, sedimentation tanks, break pressure tanks, and reservoir tanks. Intake works, tanks, tapstands and other components are often made using simple masonry techniques. Brick, stone, block, ferro-cement, and reinforced concrete are common construction materials. Community members receive water by user connections. Connections can take the form of public tap stands, individual tap stands, and domestic connections, as well as other less commonly used installations such as wash stations or communal bathing areas. Elements such as system cleanouts, air release valves, and suspended crossings may also be installed in a given system (Longland 1998; Jordan 1984).

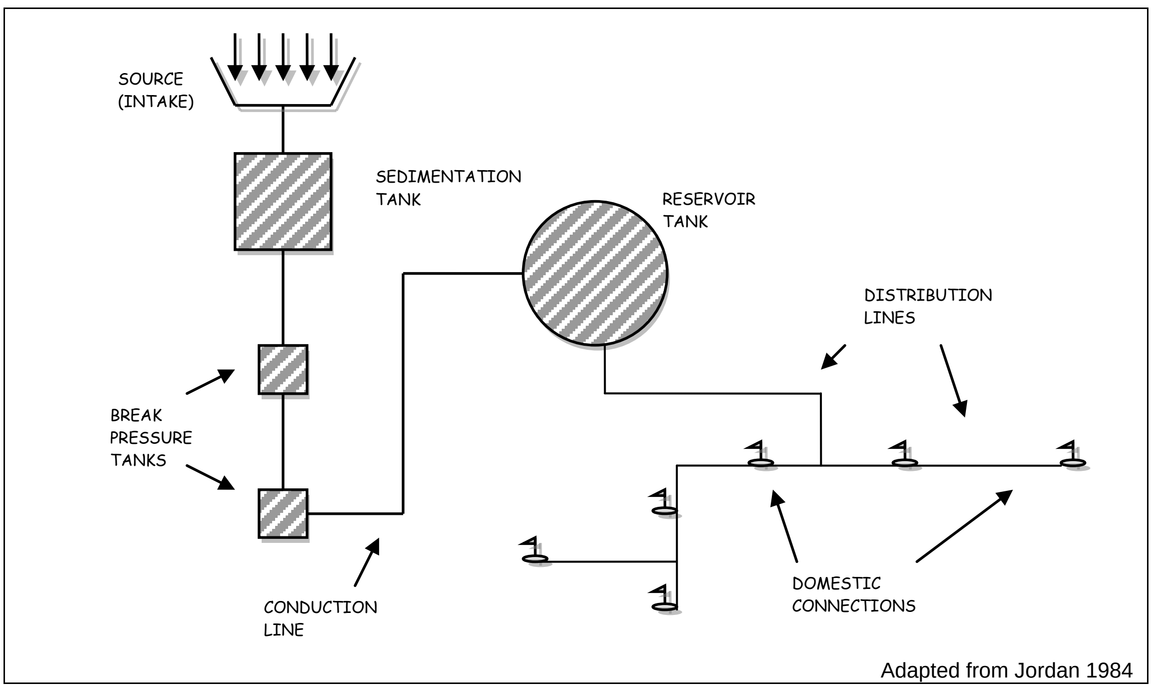

Figure 2.1 A Typical GFWS Layout.

Rural GFWS projects are susceptible to unique constraints imposed by working in remote locations throughout the developing world. Local availability is often a determining factor in materials selection. Tools and equipment may also be limited or beyond the budget of some projects, necessitating the use of locally-available resources. Labor is often supplied by the community in which the system is being installed. This labor is frequently unskilled labor, though masons, plumbers and other skilled workers may be present. Transportation of materials, labor, and supplies can be a significant issue in rural GFWS projects. Appropriate planning should be completed to ensure that needed materials, transport, and labor be obtained where needed (Deverill et al. 2002). Funding availability limits the size of projects and can decide who obtains water and who does not. By avoiding complex and costly technologies such as mechanized pumps, initial capital costs as well as long term maintenance costs can be minimized. Involvement of the local populace throughout the project helps to ensure that knowledgeable individuals remain to maintain the system (Corcos and Vial 2004).

Worldwide, many organizations and institutions are involved in GFWS projects. From large groups working in many locations across the globe to individual communities working to improve their water supply without assistance, a variety of implementation schemes are utilized. Several groups interact with communities through field workers, extension agents, or volunteers. These individuals often visit communities, plan projects, implement these projects, and then leave the area (Bolt and Fonseca 2001). Many times a group of local leaders will be elected or chosen to form a water board. By sharing costs, ownership, and decision making responsibilities between communities and external agencies, water systems have been shown to benefit a broader cross-section of populations, as well as providing better service (Lockwood 2004). Non-technical aspects such as local political influences and gender roles can also be incorporated into a project. The amount of community involvement, as well as consideration of non-technical variables, in projects varies with different organizations and the methodologies they utilize during a project's lifespan (Brikké and Rojas 2001).

Water supply projects are large undertakings, and can be broken up into individual life stages. Classification and naming for each stage can vary between organizations, though a general flow is common in most projects. Figure 2.2 presents the typical life cycle for a project. The process begins with a study of possible sites and the feasibility of completing a project there. Once site selection is completed, detailed information is gathered and a design is generated. An action plan is created detailing how the project will move forward. The project is then implemented. Finally, operation and maintenance are planned and an evaluation of the project is completed. The cycle then hopefully begins again.

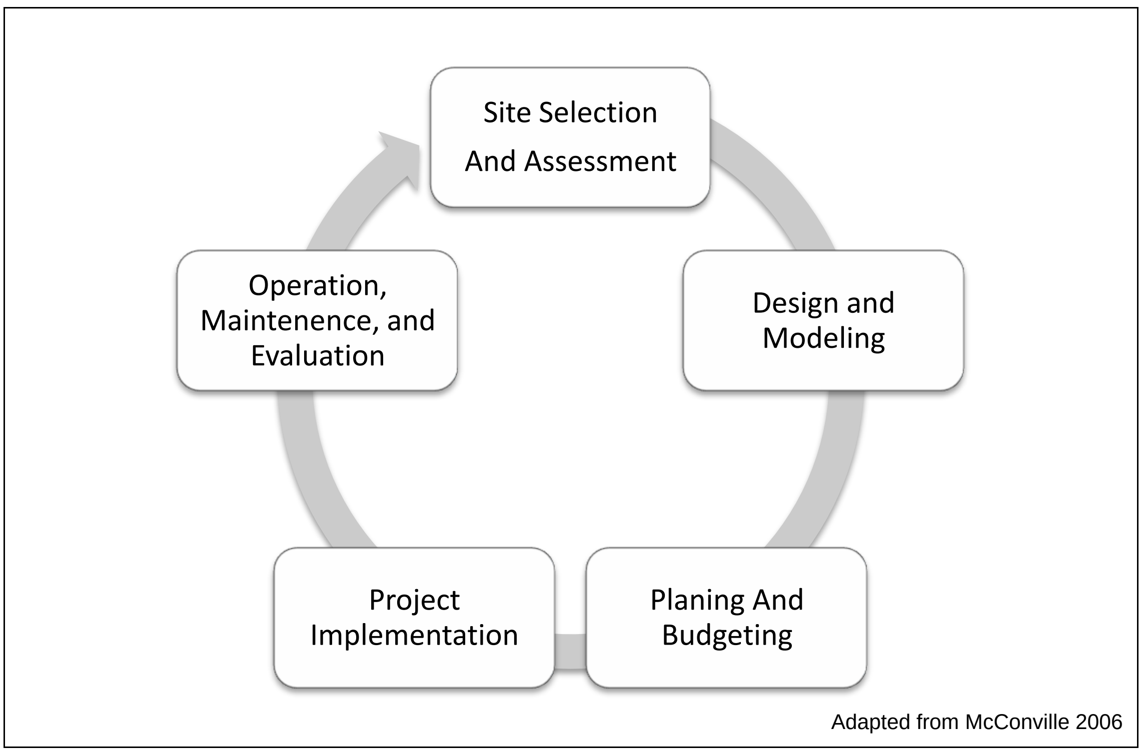

Figure 2.2 Project Lifecycle Diagram

A water supply pipe network is a complex hydraulic system, and requires specialized knowledge in order to create a functioning product. A GFWS is normally constructed according to designs created by engineers or technicians. To complete these designs, detailed information needs to be gathered from the proposed site. Topography, stream and/or spring flows, population data, and other information need to be available to the engineer (Peace Corps 1983). Once this information is compilied, the engineer applies specific criteria and design standards to generate the plans to be used during construction. These designs consist of plans for placement and sizing of system components. The amount of water to be supplied to a community should be calculated according to current population and forecasted growth (Batteson, Davey, and Shaw 1998). Water sources need to be selected and their intake structures planned. The need for reservoir and break pressure tanks, and their volume and placement must to be determined. Conduction and distribution pipelines need to be sized according to their respective distances, flows, elevations, and losses of pressure due to friction (Jordan 1984). Worldwide, groups, organizations, and individuals generate designs for GFWS's using different methods, resources and criteria.

2.3 SURVEY OF WATER PROJECT SUPERVISORS

In March of 2007, a survey was conducted of water system designers and project managers. This survey was intended to provide a viewpoint from which current resources for water supply project design and implementation could be assessed. Surveys were distributed throughout the world via email, as well as conducted in person by the author in the Dominican Republic. Survey questions dealt with specific design criteria and methodology used in water system implementation.

From the author's experience in the Dominican Republic, a clear need existed for technologies to assist in implementation of GFWS's. In order to assess the universality of this need, the GFWS Design Survey was created. Figure 2.3 provides a copy of the survey sent out to the water project managers. The completed surveys are also provided in Appendix A. The aim of the survey was to determine what types of projects were being completed throughout the world, and what tools were being used to assists those implementing such projects. Different organizations employ different methodologies and standard practices in their projects and these differences needed to be clarified. In order for any tool being developed to be usable beyond the immediate environment in which it is created, an understanding of possible applications was required. An attempt was made to discover the needs of water system designers and managers. It was hoped that common practices or problems encountered during implementation would be exposed.

The GFWS Design Survey was conducted during the spring of 2007. Dr. James R. Mihelcic, co-coordinator of the MTU-MI engineering program, distributed the survey to 10 members of the program; of those 8 responded. Current and former members of the program who worked with gravity fed water systems were surveyed. These respondents worked on projects in the Dominican Republic, East Timor, Honduras, Madagascar, and Panama while serving as Peace Corps Volunteers. Following standard Peace Corps practices the volunteers worked with project partners from host county organizations, and thus their experiences differed greatly. Two associates of the author from the Dominican Republic were surveyed as well. These individuals were involved in implementation of water systems in rural areas and worked with Dominican organizations not affiliated with the Peace Corps. In total, the survey respondents have been involved in over 123 water projects worldwide. Table 2.2 provides a summary of those surveyed. Thoes surveyed do not represent a ramdom selection of water project managers worldwide, as all respondents were either Peace Corps volunteers or associates of the autor in the

Dominican Republic. The resulting survey data is therefore not an unbiased indication of the typical water project managers.

- Gravity Fed Water System Design Survey –

Your Name: **Date:**

1. *General Project Information*

How many projects were you involved in? (And where) 4 Projects – Dominican Republic

What was your role in these projects?

2. *Specific Design Criteria*

What kind of topographical survey was performed? (GPS, Abbney level, a mix, other, etc.)

What kind of source was used?

How many gallons did you design you system to carry per person per day? (or per house)

What formulas did you use to calculate the flow rates within the system? (List whatever you can here

What kind of storage tank was built? (And with what materials)

What type of connection did the users receive?

What was the source for all these design criteria that you used? (i.e. Local government regulations, Peace Corps suggestions, what it says in Jordan and so on, …)

3. *Specific Design Methodology*

How did you go about designing your system? (Paper and Pencil, using an excel spreadsheet, a program such as EPANET, and so on)

How did you decide on the tube sizes that you needed? (i.e. graphically, with a program, solved simultaneous differential equations, and so on)

Did you use a computer in any part of the design process, and if so for what and with what programs?

What were the limitations to the design method you used? (Could there be any improvements you can think of?)

Please email this survey to Stephen Good at [redacted]. Thank you very much!

Figure 2.3 GFWS System Design Survey

The questions included in the survey were intended to provide a snapshot of criteria and methodology used in different regions. The survey begins by asking the respondents where they worked, how many projects they were involved in, and what their role was in these projects. Specific design criteria were treated next. Questions involving the type of topographical survey preformed, kind of water sources utilized, tank constriction material, and nature of service connection were intended to provide information about the type of systems designed. The service level used to design the system, in liters per capita daily (**Lpcd**) was investigated. The source of the criteria and formulas used in designing the system were also asked. The specific methodology employed by each respondent to design these systems was also investigated. The survey asked each respondent the manner utilized to produce a system design. The tools used by each respondent to generate such a design, and the limitations of these tools were also investigated.

Table 2.2 GFWS Design Survey Respondents

Projects Region	AFRICA	ASIA	LATIN AMERICA
Number of Respondents	1	1	8
MTU-MI Affiliated Respondents	1	1	6
Non MTU-MI Affiliation	0	0	2
Number of Water Projects per Region	6	3	114+

Recipients of the GFWS Design Survey. Members of the MTU-MI program throughout the world were surveyed, as well as associates of the author in the Dominican Republic

The results of the GFWS Design Survey provide insight into common practices and problems facing water system project managers. A summary of the responses from the surveys are presented in Table 2.3. In all of the surveys, multiple leadership roles were assumed by the respondents. Tasks including feasibility assessment, surveying, design, organizing, purchasing, construction, maintenance, and watershed management were assumed by respondents. This multiplicity of roles was described by both the Peace Corps Volunteers and those working for government agencies and non-governmental organizations. Throughout the responses, similar survey tools were employed. These were limited to: Abney Levels, Altimeters, Global Positioning Units, and Measuring Tapes. Most respondents reported using spring or stream sources, with only one utilizing bore wells. Of those that replied, an average of 90 Lpcd was allotted. This coincides with international statistics such as the WHO's figure of 100 Lpcd, their stated service level to promote optimal health (Howard and Bartram 2003). All respondents utilized brick, block, or reinforced concrete to construct storage tanks. A mix of public and private tapstands was reported, with only one respondent installing domestic connections. The respondents implemented projects in vastly different areas and situations, yet very similar responses were received as to construction practices.

The survey demonstrates similar methodologies were employed by respondents while creating designs for water systems. The majority of the respondents utilized Thomas Jordan's *A Handbook of Gravity Flow Water systems*, as a source for their design criteria (Jordan 1984). Many also employed location-specific Peace Corps standards, such as the Peace Corps publication: *Rural Aqueducts and Community Development in the Dominican Republic* (Peace Corps 2000). A number of respondents reported using criteria provided by local government institutions, such as the Instituto Nacional de Aguas Potables y Alcantarillados (**INAPA**), in the Dominican Republic. A large majority reported that they used computers during their projects. Microsoft Excel® was noted as a common tool utilized, though other software such as EPANET and AutoCAD were also employed. However, many that employed computer software stated that they created their designs by hand calculations, graphically, and by trial and error. This suggests that there is indeed a lack of resources available to assist in the design of rural water system projects.

Table 2.3 GFWS Design Survey Results Summary

	#	Roles Assumed	Survey Tools Used	Source Type	Gpcd	Design Formula	Storage Tank Type	Connection Type	Design Criteria	Design Tools	Design Methodology
Respondent 1	6	Surveying, Design, Organizing, Purchasing, Construction	Abbney Level	Spring	17	Bernoulli	Reinforced Concrete	Public Tap Stands	Jordan, Peace Corps	Excel	Trial and Error
Respondent 2	4	Surveying, Design, Organizing, Construction	Abbney Level, Measuring Tape	Spring	25	Iterative Process	Concrete Block	Private Tap Stands	Jordan, Peace Corps	Excel	Hand Calculations
Respondent 3	2	Surveying, Design, Organizing, Construction	Abbney Level	Spring	Most Possible	Hazen Williams	Concrete Block	Domestic Connection	Local Regulations, Jordan, Peace Corps	Paper and Pencil	Hand Calculations
Respondent 4	6	Design Organizing	Abbney Level, GPS Units	Spring, Stream	20-25	Software	Brick Masonry	Private Tap Stands	Local Regulations, Peace Corps	Excel	Computer Software
Respondent 5	78	Feasibility, Design, Construction, Maintenance, Watershed management	Altimeter, Measuring Tape	Spring, Stream	18	Hazen Williams	Concrete Block	Public and Private Tap Stands	Local Regulations	Paper and Pencil	Hand Calculations
Respondent 6	-	Surveying, Design, Organizing	Abbney Level, Altimeter, GPS Units	Spring, Stream	25-35	Hazen Williams	Brick Masonry	Public and Private Tap Stands	Peace Corps	Excel, Paper and Pencil	Graphically
Respondent 7	2	Design, Organizing, Construction	Abbney Level	Spring	14	Head Loss Tables	Concrete Block	Private Tap Stands	Jordan, Peace Corps	Excel, Paper and Pencil	Graphically
Respondent 8	18	Surveying, Design, Organizing, Purchasing, Construction	Abbney Level	Spring, Stream	30	Hazen Williams	Reinforced Concrete	Private Tap Stands	Peace Corps	AutoCAD, Excel	Computer Software
Respondent 9	3	Design, Organizing, Construction	GPS Units	Bore Well	8	Software	Reinforced Concrete	Public Tap Stands	Local Regulations	EPANET, Excel	Computer Software
Respondent 10	4	Design	Abbney Level, Altimeter, GPS Units	Spring	-	-	Reinforced Concrete	Private Tap Stands	Jordan, Peace Corps	Paper and Pencil	Hand Calculations

2.4 CURRENT RESOUCES FOR GFWS IMPLEMENTAION

Development of water supplies has a long history and many tools have been created to address the problem. Traditional resources used in water supply are presented to the reader. Decision support resources for water supply project management are also outlined. A group of computer-based tools are discussed, as well as their specific applicability to GFWS.

2.4.1 Traditional Resources

Much of the specialized knowledge required in design, construction, and operation of GFWSs has been documented. Classic texts such as Thomas Jordan's *A Handbook of Gravity-Flow water Systems* are valuable resources for engineers working on GFWSs. As Cairncross notes, "water-supply systems are built in only a limited number of ways and with a limited range of materials, and in general the solutions in appropriate textbooks and manuals will suffice." Specific countries or organizations often have their own manuals and guides to ensure that systems adhere to local regulations (Cairncross 1992). The *Rural Aqueducts and Community Development in the Dominican* manual is an example of such a work (Peace Corps 2000). The spread of the World Wide Web has increased the availability of the literature devoted to water systems, and a simple Internet search can locate resources quickly and economically.

Though much information is available to the GFWS engineer, design calculations are often still completed manually. The survey data in Section 2.3 provides evidence of this. In selection of pipe diameters to be used in a GFWS, engineers working by hand must either solve a system of equations, graphically plot the losses in each section of pipe, or use an iterative procedure to ascertain a suitable combination of pipe sizes and lengths. All of these procedures are time consuming, and become increasingly unwieldy with larger systems. With these methods it is difficult to obtain the optimum configuration of diameters and pipe lengths, thus leading to exaggerated capital costs. In response to these issues and others, several computer software programs have been developed for use by engineers designing water systems.

2.4.2 Decision Support as a Resource

Decision support systems are interactive tools which enable users to make informed decisions about unstructured problems. These systems typically contain a database of information about a problem, a model of how the studied problem functions, and a user interface. Figure 2.4 shows the components of a typical DSS (Walsh 1993). Dispute exists over what applications qualify as decision tools. Keefer and Kahkonan (2004), who conducted a study of decision analysis applications, noted that "an application generally had to explicitly analyze alternatives for a decision problem using judgmental probabilities and/or subjectively assessed utility/value functions." Various tools have been developed to address problems pertinent to the water sector. Some examples of tools which assist in making informed decisions, though not necessarily full decision tools are: 'Cost-Benefit Analysis,' 'Multi-criteria Analysis,' 'Life Cycle Analysis,' 'Materials Flux Analysis,' and 'Environmental Impact Assessments' (Barnes and Ashbolt 2006). Consideration for the sustainability of solutions has been integrated into some DSS's. Churchill and Baetz (1999), for instance, incorporated sustainable design rules to assist in development of community growth into their DSS. By considering the economic, environmental, and social aspects of a problem and incorporating this information into a DSS, water systems can be created in such a manner as to remain functioning over the long term. Use of appropriate technologies and incorporation of stakeholder opinions as decisions are made can improve system performance (Barnes and Ashbolt 2006). Resources developed to address rural water supply should incorporate these criteria into their decision making process.

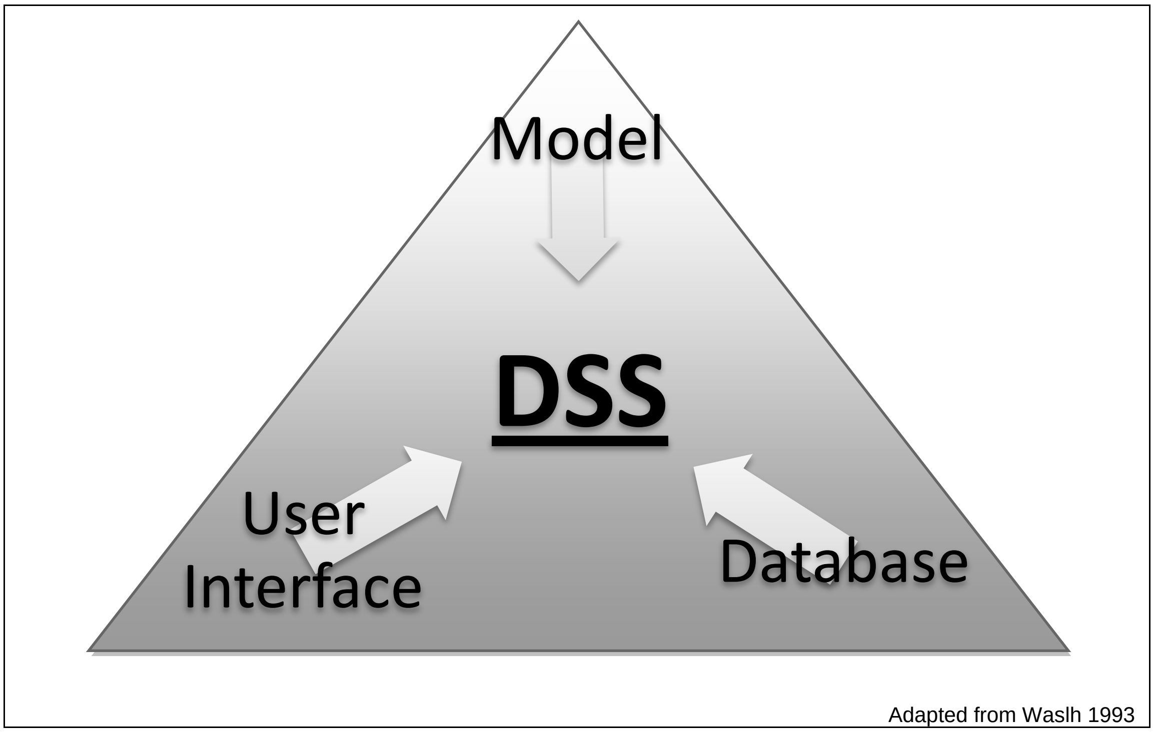

Figure 2.4 Typical Decision Support System Components

2.4.3 Computer Based Tools

Water supply systems are complex engineered structures. Software has been developed by commercial, governmental, and non-profit groups to assist in management and design of water networks. These software programs vary in their abilities and focus. Six different software packages are described in Table 2.4. Their applicability to rural water systems is characterized below.

Table 2.4 Reviewed Software for Water Supply Systems

Title	Developer	Focus
AirInPipes	Agua Para La Vida	Conduction Line Design and Air Block Resolution for Small Systems
EPANET 2	US Environmental Protection Agency	Hydraulic Flow and Water Quality Modeling in Medium Sized Networks
DSS-RWS	Water Research Commission	Feasibility and Planning for small water systems
InfoWater	MWHsoft	Large Network Design and Modeling
NeatWork	Agua Para La Vida	Distribution Network Design and Modeling for Small Systems
NWRS	Daniel Olsen, McMaster University	Source Selection and Project Feasibility
Peace_Corps_ Design_Template	Nathan Reents, Michigan Technological University	Design and Budgeting for Small Systems
WaterCAD	Haestad Methods	Large Network Design and Modeling
WaterCADE	Socio Economic Foundation Unit	Pumping Schemes and Distribution Network Design

There are many different types of software available for water system managers. Each program focuses on different areas of water supply.

The programs in Table 2.4 are intended to represent the wide variety of software that engineers have to choose from. This software was chosen to demonstrate capabilities of current software and is not intended to be a complete list of all resources available for water distribution systems. The list ranges from high-powered commercial software to academic specialty software created specifically for gravity flow water systems in rural areas. All programs in the list are readily available, and many can be downloaded directly from the World Wide Web. Other software that was not at the least searchable online was not included in the review because these are not available to designers of water systems working in remote areas. The range of costs for the reviewed software varies from thousands of dollars for a single license to free downloading and unlimited use. The reviewed software varies in its complexity and user friendliness.

AirInPipes

AirInPipes is a software program developed by Agua Para La Vida. APLV is a non-profit organization dedicated to assisting rural communities in improving their water supplies. The group has offices in the US and in France, and focuses its work in Central America, particularly in Nicaragua. AirInPipes is a 510KB Microsoft Excel® File utilizing VBA macros, and can be downloaded at: http://www.aplv.org/New/en/techresources.shtm. The spreadsheet software is designed to assist GFWS designers in selection of pipe diameters and section lengths between a water source and a reservoir tank. The spreadsheet attempts to minimize air blockages in the conduction line (Corcos 2003; Agua Para La Vida 2007).

EPANET 2

EPANET 2 was developed by the United States Environmental Protection Agencies Water Supply and Water Resources Division. The 1.34MB Windows 95/98/NT/XP program was created to model hydraulic and water quality variables in pressurized pipe networks. The program is available free to download at: http://www.epa.gov/nrmrl/wswrd/dw/epanet.html. EPANET 2 can be used for systems of any size and includes capabilities to model changing conditions over periods of time (Rossman 2000; U.S. Environmental Protection Agency 2007).

DSS-RWS

The DSS-RWS (Decision Support System – Rural Water Supply) program was developed by the Water Research Commission of South Africa. The software can be used in assessing the feasibility of rural water systems and in preparing of budgets and business plans. The software currently consists of a Delphi Shell and does not contain a graphical user interface (Carmichael, Forsyth, and Hughes 2001).

InfoWater

InfoWater is a product of MWH Soft Incorporated. InfoWater is a robust water modeling and management software package. Software licenses are sold depending on the size of network to be created or modeled. Prices range from US$ 1,000 for 100 links, up to US$ 14,000 for an unlimited number of linkages. The software is integrated fully with ESRI's ArcGIS and is designed for large urban applications. InfoWater has many capabilities, including design, calibration, water quality modeling, system skeletonizer, and network scheduling and maintenance tools (MWH Soft 2007).

NeatWork

NeatWork was also designed by APLV. This stand alone Java program is freely available to download from http://www.aplv.org/New/en/techresources.shtm. NeatWork is intended to assists in design of distribution network for rural water systems. The program suggests tube diameters in order to minimize costs for a given service level. The program also includes a simple modeling tool to improve water delivery to individual taps (Agua Para La Vida and Logilab 2007; Corcos and Vial 2004).

NRWS

NWRS (Nilgiris Rural Water Supply) is a Microsoft Excel® spreadsheet tool for use in selection of a water source for rural communities in the Nilgiris district of India. The software was created by Daniel Olsen of McMaster University in 2005. The software is available from the McMaster University website: http://www.eng.mcmaster.ca/civil/sustain/downloads.html. NRWS includes very specific precipitation and soil data pertaining to the Nilgiris area and is not designed to be universally implemented (Olsen 2005; McMaster University 2007).

Peace_Corps_Design_Template

The Peace_Corps_Design_Template is a Microsoft Excel® spreadsheet tool designed by Nathan Reents, who worked on several water systems as a Peace Corps Volunteer in Honduras. He created the Peace_Corps _Design_Template to assist him in his work. The template can be downloaded from Michigan Technological University's D80 Center website at http://www.d80.mtu.edu/Resources.html. The software provides a tool to assist in selection of tube diameters, flow rates, tank volumes, as well as some simple budgeting tools (Michigan Technological University 2007; Reents 2003).

WaterCAD

WaterCAD is a full-featured commercial hydraulic and water quality software package developed by Bently Systems, Incorporated. Bently Systems sells WaterCAD by the number of tubes required in the system, from US$ 176 for 10 pipes to US$ 4,496 for 1000 pipes. WaterCAD is offered with design, calibration, and skelotinzer tools as optionas (US$ 4,000 – 20,000 additional). WaterCAD is designed to interface with Autodesk's AutoCAD software (Bentley Systems, Inc. 2007).

WaterCADE

WaterCADE (Water Computer Aided Design and Estimation) is a tool for use in developing pumping schemes and distribution networks for water systems. The 64MB program uses a VBA interface tied to a Microsoft Access database. Information about the program is available at the website http://www.seuf.org/html/watercade.html; however no information is given about obtaining the program. Designed for the Kerala State in

India, specific data unique to the area are incorporated into the software (Zachariah and Sebastian 2005; Socio Economic Unit Foundation 2007).

2.5 COMPARISON OF CURRENT TOOLS

In order to assess the appropriateness of currently available technology for design of small-scale rural gravity flow water systems, a review of this software was completed. Evaluation criteria used for the review are detailed in Appendix B. Table 2.5 presents a comparison of different attributes for each program.

In evaluating the software in Table 2.5 the same criteria were applied to each piece of software. The evaluation began with a review of the general attributes of each piece of software. The availably of the software, whether it is free to download and use, user friendliness, and included documentation were examined. Inclusion of tools to assist in the different lifecycle stages of a project was also assessed. The stages of feasibility assessment, design, planning, implementation, and operation, maintenance, and evaluation were categorized. Specific design capabilities especially important to rural GFWSs are then discussed and tools to assist in design of conduction and distribution lines are noted. The presence of hydraulic calculations with and without cost minimizing functions was also assessed. Other design features such as tank sizing and air block diagnosis were marked if present. Finally, the post-design functionality of each program was evaluated. Inclusion of tools to simulate a systems service level; whether budgets, graphs, plots, and reports are produced; and sustainability assessment were also noted.

Table 2.5 Comparison of Software for Water System Systems

✓ = Meets Criteria	AirInPipes	EPANET 2	DSS-RWS	INFOWATER	NeatWork	NRWS	Peace_Corps_ Desing_Template	WaterCAD	WaterCADE	***GOODwater***
General Attributes										
Information Available Online	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Free to Obtain	✓	✓			✓	✓	✓			✓
Stand Alone Program		✓			✓			✓		
Help manuals included	✓	✓		✓	✓	✓	✓	✓		✓
Low System Requirements	✓	✓	✓		✓	✓	✓		✓	✓
Life Cycle Components										
Feasibility			✓			✓			✓	✓
Design	✓			✓	✓		✓	✓	✓	✓
Planning	✓		✓				✓		✓	✓
Implementation									✓	✓
Evaluation		✓		✓				✓		✓
Supported Design Capabilities										
Conduction Line Design	✓	✓		✓			✓	✓	✓	✓
Distribution Network Design		✓		✓	✓		✓	✓	✓	✓
Hydraulic Calculations	✓	✓		✓	✓		✓	✓	✓	✓
Capital Costs Optimizer	✓			✓	✓			✓	✓	✓
Tank size Calculator							✓			✓
Airblock Diagnosis	✓									✓
Post Processing Functionality										
Simulation capabilities	✓	✓		✓	✓			✓		
Budgeting tools	✓		✓	✓	✓	✓	✓	✓	✓	✓
Plotting/Graphing tools	✓	✓		✓			✓	✓	✓	✓
Report Generator		✓	✓	✓	✓	✓	✓	✓	✓	✓
Sustainability Assessment										✓

2.6 ***GOODwater*** AS A RURAL WATER SOLUTION

Though many software programs have been developed previously, none cater to all the needs of rural water system designers. Large commercial program such as INFOwater and WaterCAD provide excellent design functionality, but are beyond the price range of the average GFWS engineer working in a remote location. Software such as EPANET 2 and the Peace_Corps_Design_Template allow users to model a given system but do not assist in creating the optimal design to minimize capital costs, or in the other stages of a project's lifecycle. Programs such as AirInPipes and Neatwork help with this aspect of design at a smaller scale, but do not integrate sustainability considerations into their decision making processes, and also leave out many stages of a project's lifecycle. Other software such as the DSS-RWS, NRWS, and WaterCADE incorporate some of these criteria yet do not assist with creation of a quality design. ***GOODwater*** incorporates the lifecycle stages into one platform and allows the user to create optimized designs, reports, budgets, and business plans. By combining these necessary aspects under a sustainability framework ***GOODwater*** proposes to improve the quality of water supply projects implemented throughout the world.

3 DEVELOPMENT OF *GOODwater*

This section outlines the methodology proposed for sustainable implementation of rural water systems. ***GOODwater*** was developed to provide a framework through which this methodology can be made available to project managers. The software was created to assist managers of rural water projects throughout a project's lifespan, and includes modules for each stage of a projects lifecycle. This chapter begins with an overview of the program. Basic use of the software is outlined as well as how project filess can be saved and retrieved. Navigation through the program is explained, as well as the initial setup process for a given project. Project site assessment is treated next. This module, like the four subsequent modules, first presents the user with a series of actions to be undertaken. These actions are important to ensure the sustainability of a project and to collect data for the next phase of the module. After the user finishes with the action section, they are then asked to enter information necessary to complete the required calculations. Upon entering the required information, the program performs a series of calculations, and produces a report. For each of the five stages of a project, this chapter presents suggested actions to be undertaken and the inputs and options requested of the user. Then the calculation procedures used by the software and the resulting output are described. After the modules treating the five stages of a project's lifespan are presented, program options are discussed. Finally, the Help module is discussed. Treated within the help module section is an in-depth explanation of each suggested action, an explanation of each user input, a list of references cited within the program, and short text about the software.

3.1 PROGRAM OVERVIEW

The ***GOODwater*** file is a Microsoft Excel® template. A template is a pre-formatted workbook which includes standard styles, formulas, macros and other settings. Each time the ***GOODwater*** template is opened, a blank project is presented, with the workbook ready to use. The template presents users with empty forms, checkboxes, navigation menus, and other objects to be filled in as a project progresses. Throughout the software, action buttons are available and, when clicked, perform calculations on the data entered into the workbook. The user begins a new project by entering data and settings into the blank template. When ready to save, the project is saved under a new name using the "Save As" command in Microsoft Excel®. In this manner different projects are stored in their own unique file. Multiple versions of a project can be saved under different file names, and new projects can be started by opening the original ***GOODwater*** template and starting a blank workbook.

In order to calculate and automate the complex routines included within ***GOODwater***, the software makes use of Macro routines and the Solver add-in. Macros are small programs written in the Visual Basic for Applications programming language that can be run within Microsoft Excel®. As such they can store commonly-used complex functions and actions in a simple, easily to perform format. ***GOODwater*** uses macros to accomplish many of the more complex calculations needed to design water systems. In order to take advantage of the macros in ***GOODwater*** they need to be enabled. To enable macros, the "Macro Security Level" in Microsoft Excel® needs to be adjusted. The "Macro Security Level" can be changed in the Macro Setting tab of the "Trust Center" menu in Excel 2007. The "Trust Center" is found by selecting "Excel Options" in the main Excel menu. The Solver Add-In is a component of Excel developed by Frontline Systems, Inc. and comes standard with excel, though is not loaded with the typical installation. ***GOODwater*** uses the Solver Add-In to determine diameters during the site assessment module. The solver tool uses a generalized reduced gradient nonlinear optimization algorithm to assist users with complex problems. To load the Solver Add-In, users must check the Solver box in the Manage Excel Add-In sub menu, found in the Add-Ins tab of the Excel Options menu. Once macros are enabled and the Solver add-in has been loaded, the ***GOODwater*** software is ready for use (Microsoft Corporation 2008a, 2008b, 2008c, 2008d).

3.1.1 Home Page and Program Navigation

GOODwater is a robust program dealing with many aspects of gravity-fed water system projects. As such, there are many menus and submenus included within the workbook. Upon initialization of the program, the user encounters the *HOME* page in the MAIN menu. The *HOME* page contains a list of all the important pages to be found within the program. This page, like most pages in the software, is divided into three sections. Figure 3.1 shows a screen shot of the main menu.

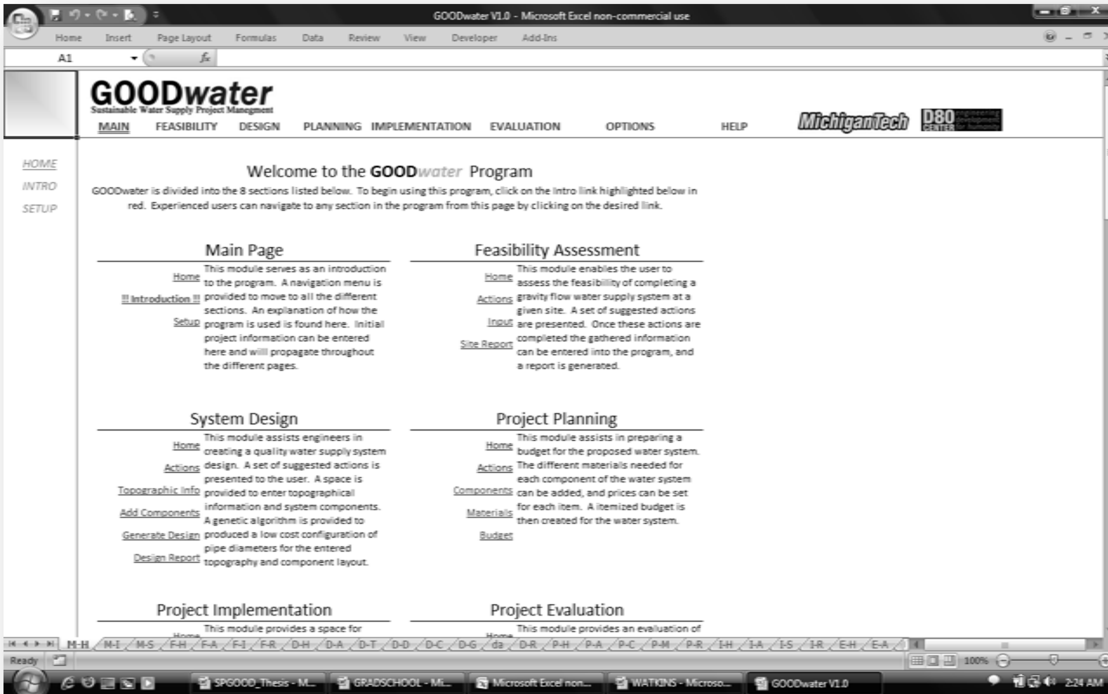

Figure 3.1 Screen Shot of the Main Menu of *GOODwater*

The top-most section includes the title of the program, information about the project if entered, and a bar of different menus. This bar is important for navigating throughout the workbook. Contained within the bar are eight options: MAIN, FEASIBILITY, DESIGN, PLANNING, IMPLEMENTATION, EVALUATION, OPTIONS, and HELP. Users can move to any of these sections in the program by clicking on the appropriate location in the navigation bar. When one of these sections is clicked, the user is directed to that module, and a sub-menu appears. The sub-menu is located on the left side of the sheet below the navigation bar, and is unique to each module's features. Again, by clicking on the desired sub-menu option on the left, the user navigates to specific sheets addressing confined topics. In the center right of the sheet, below the navigation bar and to the right of the sub-menu area, the substance of ***GOODwater*** is displayed. In this area the forms, options, checkboxes, descriptions, graphs, and reports of the program are displayed. This area also includes action buttons which, when clicked, manipulate the data entered into the program.

Throughout this document, the eight modules will be referenced in all caps with a double underline (i.e. MAIN) and all module sub-menus are referenced in all caps italics (i.e. *HOME*). This follows the fashion in which menus are labeled within the software.

3.1.2 Program Introduction

When ***GOODwater*** is opened, the MAIN - *HOME* page is displayed first. This page suggests that first time users navigate to the *INTRODUCTION* page. The *INTRODUCTION* page provides a summary of what the ***GOODwater*** software is designed to accomplish. An explanation of the menus and how to navigate between pages is included. A summary of how to enable macros and load the Solver add-in is also provided. This page contains the first of many action buttons of the software. These buttons are used to prompt the software to accomplish specific tasks. When clicked, the actions buttons call macros and evaluate or manipulate data entered into the workbook. Clicking an action button initiates a series of actions, and it is important to note that these cannot be undone using the back or undo buttons in excel. After the *INTRODUCTION* page has been reviewed, first time users are directed to the *SETUP* page.

3.1.3 User Setup

Each project managed with ***GOODwater*** should be initialized with a new *SETUP* page. In the *SETUP* page, users are prompted to enter general information about the project. Information about the community to be entered includes: community name, community municipality/county, community state/province, and country. Information about the organization overseeing the project can be entered as well. This includes: project title, engineer name, organization name, and organization address (two lines). The information entered into this form propagates throughout the workbook and will appear on reports generated by ***GOODwater***. Appendix D provides a full list of the inputs requested by the program, and a full description of their meanings and parameters. When this section has been completed, an assessment of a specific site can begin.

3.2 SITE ASSESSMENT

The goal of ***GOODwater*** is to provide a clear methodology for managers to implement sustainable gravity flow water system projects. Projects should begin with an assessment of possible project sites. Site assessment is an investigative process which typically begins with a request for assistance from a community or organization present in the region. A representative of the solicited organization should then visit the community to collect information (McConville and Mihelcic 2007). The desire for progress in the project, as well as participation of the community with the organizations to be involved, needs to be evaluated at this time. Provincial development priorities, local skills and resources available, regional issues, environmental and monetary concerns should be assessed during this period (Deverill et al. 2002). These various considerations are addressed by the ***GOODwater*** software. Through use of the ***GOODwater*** program, managers can quickly generate standardized reports for different locations which can then be reviewed by decision makers. It is hoped that in this manner only projects meeting minimum criteria will be initiated.

3.2.1 Site Assessment Actions

The ***GOODwater*** DSS begins the site assessment by presenting users with a list of twenty suggested actions. The purpose of these suggestions is to develop water supply projects within a sustainable framework. By running through the presented tasks, various stakeholders and political and cultural issues, as well as economic and environmental impacts, are considered before a project begins. This is designed to enhance the sustainability of the project, increasing the water system's longevity and usefulness while decreasing its detrimental impacts on the reigion. These actions were adopted from the work of Jennifer McConville (2006) and are summarized in Table 3.1. The table is divided into five areas: 1) Socio-Cultural Respect, 2) Community Participation, 3) Political Cohesion, 4) Economic Sustainability, and 5) Environmental Sustainability (McConville and Mihelcic 2007). Users are directed to read and understand each item on the list. For further clarification each item is linked to a more complete description which can be accessed by clicking on the interested action. Appendix C presents the complete descriptions which are available in the software. After reading and understanding the suggested actions, project managers should travel to the proposed community where the water system is to be installed and complete those actions which the manager deems appropriate. Not all actions are expected to be completed in all projects, as some may be impossible or unreasonable for specific sites. However, in general the more actions from the list completed, the higher the degree of sustainability that will achieved. Throughout the process of performing these actions, information about the community is generated; this information must be recorded and saved. Upon completing the actions, users return to the program and select the check boxes for those actions which were completed.

Table 3.1 Suggested Actions For Site Assessment

Suggested Action	Description
Socio- Cultural Respect	• Generate a yearly calendar of work and social life in the community • Identify social preferences and traditional beliefs associated with water supply and sanitation practices • Determine the level of health education in the community • Recognize differences in gender roles in water and sanitation
Community Participation	• Conduct a participatory needs assessment at the local level to determine local development priorities. • Identify stakeholders and community leaders. • Determine the type of political organization and cohesion at the community level. • Reach a consensus with community members that project intervention is appropriate
Political Cohesion	• Conduct a situational analysis of regional and national issues, such as political structure and stability, government policies, and foreign aid. • Ensure that proposed project is consistent with regionally-identified development priorities and plans. • Research the history of NGO and government projects in the area. • Establish communication lines with existing NGO and/or government institutions in the area.
Economic Sustainability	• Understand the local and national economic situation (poverty level, employment, cost of living, flow of resources). • Understand how the community economic situation is affected by water and sanitation issues. • Identify sources of monetary and non-monetary resources (materials, labor, and tools) within the community. • Assess the community willingness-to-pay in both monetary and non-monetary terms for current water and sanitation services
Environmental Sustainability	• Identify local resources for water and sanitation. • Collect data on climate and environmental constraints that will factor into project design. • Identify potential environmental concerns at the local and regional level. • Determine community understanding of environmental problems and the willingness to correct them.

3.2.2 Assessment Input

Information about proposed site is entered into the program through the FEASIBILITY - *INPUT* page. The information requested by this page should have been gathered while completing the actions suggested in the previous sub-section. Information about the community and the surrounding area is needed. Distances and elevations to proposed sources should be determined or estimated and entered into the programs. The type (spring, stream) and flow rate of the source(s) during the driest season of the year must also be provided. Data on regional climate, local holidays, and seasonal harvests that can affect the months laborers are available to work on the water project are entered to provide an estimate of the time frame required for the GFWS project. The contribution that each family can provide for the project's maintenance, as well as an estimate of the available initial funding for the project, are input so as to provide an estimate of the proposed sites finical feasibility. Appendix D lists all the requested inputs for this section, as well as descriptions of the purpose of each input.

3.2.3 Assessment Calculations

The ***GOODwater*** software calculates various parameters for use in assessing the feasibility of a water project for a given site. Estimates of the proposed system's water usage and construction timeframe, as well as initial capital costs and long term operating costs are calculated using the data entered in the previous section. Adjustable constants and coefficients from the OPTIONS module are also used in these calculations. These constants will be discussed later in Section 3.7. The action button in the upper right side of the site assessment *INPUTS* page with the label "Generate Report" initiates the computation of the site assessment parameters.

Estimates of the water demands for the community are calculated first. ***GOODwater*** assesses the appropriateness of the proposed site for both public and private tapstand configurations. For both of these types of systems ***GOODwater*** calculates the daily volume of water required V_r; the source flow rate required for a system without a storage tank Q_{peak}; and the source flow rate required for a system with a storage tank Q_{tank}. These calculations make use of the three constants: V_{lpcd}, the number of liters of water allotted per person per day; $\mathrm{N}_{\mathrm{tap}}$, the number of people to share a tapstand and; Q_{tap}, the minimum flow rate (liters/sec) to a tapstand. The values of V_{lpcd}, $\mathrm{N}_{\mathrm{tap}}$, Q_{tap} are different for public and private systems, and standard values from literature are presented in the OPTIONS module. Calculation of the required volume and flow rates are accomplished using the following equations from the Jordan text:

$$V_r = V_{\mathrm{lpcd}} P \qquad (1)$$

$$Q_{tank} = V_r / 86400 \qquad (2a)$$

$$Q_{peak} = \frac{\mathrm{P}}{\mathrm{N}_{\mathrm{tap}}} Q_{\mathrm{tap}} \qquad (2b)$$

where P is the population of the proposed community. As seen above in Equation 1, the required volume of water is estimated by multiplying the population by average daily water needs per individual. The flow rate needed by a community depends on whether the water system will have a storage tank between the community and the water source. If a storage tank is included (Equation 2a), the tank can accumulate water over the course of 24 hours (86400 seconds). This results in a lower required flow rate and often times a more economical system. If no tank is to be included (Equation 2b), the water source must be able to provide the peak demand flow of the system, i.e. the sum of the minimum flow demands of all the tapstands and extraction points (Jordan 1984).

GOODwater next performs an estimate of the construction time needed for the proposed project. This analysis begins by calculating the average daily length of pipe trench dug by a laborer L_{day}, and the total number of days of labor that the project will require T_{Total}, by using the following equations:

$$L_{day} = \frac{1}{E_{rt} W_t D_t} \tag{3}$$

$$T_{Total} = \frac{L_s + L_d}{L_{day}} \tag{4}$$

In Equation 4, L_s and L_d are the length from the source to the community, and the length of the distribution network within the community respectively. W_t and D_t are constants and refer to the width and depth of the pipe trench and are adjustable in the OPTIONS module. The amount of trench that a laborer can dig in an average day (Equation 3) is mostly dependent upon the type of soil in the area, as represented by E_{rt}. E_{rt} is the excavation rate in days per cubic meter and varies from 0.55 person-days/m^3 for ordinary soil to 2.50 person-days/m^3 for hard rock cutting (Jordan 1984).

The total amount of days of labor (Equation 4) is calculated by dividing the total estimated distance by the distance a single laborer can accomplish in a single day. The time that a given laborer has available to work on the project in days, TA_{days} (Equation 5a), and weeks, TA_{weeks} (Equation 5b), are a function of days of the week that workers have available D_a and the months of the year that construction takes place M_a. The time required by each house in days, TR_{days}, (Equation 6a) and weeks, TR_{weeks} (Equation 6b), are dependent upon the total days of labor needed and number of laborers. These equations are presented as follows:

$$TA_{days} = 52 D_a \frac{M_a}{12} \tag{5a}$$

$$TA_{weeks} = 52 \frac{M_a}{12} \tag{5b}$$

$$TR_{days} = \frac{T_{Total}}{N_{wrks}} \quad (6a)$$

$$TR_{weeks} = \frac{T_{Total}}{D_a N_{wrks}} \quad (6b)$$

Throughout this analysis, labor is assumed to come from the community in which the project is to be completed. The total number of laborers N_{wrks} is calculated by dividing the population by the number of individuals per private tapstand, or roughly one worker per family. These laborers often have other work and family commitments and are only available to work on the water project a few days a week or less. Also depending on location and culture there may be months of the year when weather, religious holidays, government obligations, and other external events prohibit construction of the water system. It is hoped that this information will be discovered during the community diagnosis suggested in the actions section.

Estimates of the financial constraints of the proposed project are next assessed. Initial capital outlays and long term operating costs for both public and private systems are calculated. Roy et al. (1992) used a set of analytical equations to estimate the cost of different parts of water systems. They provide several equations (7a-11b) which are appropriate for cost approximations in many countries with different economies. In ***GOODwater*** the following equations are used to asses initial IC_i and operational OC_i costs, where α_i and β_i are cost coefficients for component *i* :

For sources:

$$IC_s = \alpha_1 {Q_s}^{\beta_1} \quad (7a)$$

$$OC_s = \alpha_2 {Q_s}^{\beta_2} \quad (7b)$$

where Q_s is the source flow rate.

For the main line to the source:

$$IC_m = (\alpha_3 + \alpha_4 {\phi_m}^{\beta_3})L_m \quad (8a)$$

$$OC_m = (\alpha_5 + \alpha_6 {\phi_m}^{\beta_4})L_m \quad (8b)$$

where ϕ_m is an average diameter, and L_m is the length to the source

For the storage tank:

$$IC_{tnk} = \alpha_7 V_r^{\beta_5} \quad (9a)$$

$$OC_{tnk} = \alpha_8 IC_{tnk} \quad (9b)$$

where V_r is the volume of the storage tank.

For the distribution network:

$$IC_n = (\alpha_9 + \alpha_{10} {\phi_n}^{\beta_6})L_n \quad (10a)$$

$$OC_n = (\alpha_{11} + \alpha_{12} {\phi_n}^{\beta_7})L_n \quad (10b)$$

where ϕ_n is an average diameter, and L_n is the length of the distribution network.

The average diameters in Equation 8a and 8b and Equation 10a and 10b are approximated with the Hazen-Williams equation, assuming PVC tubing, and using the changes in elevation and flow rates provided to find an equivalent diameter for the cost estimation (Moghazi 1998). The volume used in Equation 9a is the volume required from Equation 1.

These values for diameters and volumes are not meant to be the actual values of the proposed system, but equivalent diameters only used to estimate system costs. The α_i and β_i coefficients are set to local currency and economic conditions. They must be calibrated in the OPTIONS module using costs from at least three different ‘benchmark’ systems recently constructed in the surrounding area. The greater the number of 'benchmark' systems entered, the more accurate the cost estimate should be. However, it is possible that occasionally the Solver Add-In may not converge and then no cost estimates can be produced. ***GOODwater*** also calculates the total initial investment needed and the probable operating costs of the water system by summing the separate component costs as follows:

$$IC = IC_s + IC_m + IC_r + IC_n \quad (11a)$$

$$OC = OC_s + OC_m + OC_r + OC_n \quad (11b)$$

where *IC* and *OC* represent the total system initial and operating costs, respectively.

3.2.4 Site Assessment Report

Once the ***GOODwater*** site assessment module has been run, a report of the proposed site's feasibility as a location for a gravity flow water system is created. Appendix E contains an example of a site assessment report generated by ***GOODwater***. The site assessment report is divided into a header and six sections. The header contains information about the organization or institution planning the water project, as well as the title of the project. The first section of the report presents community information: the name of the community, where it's located, and what its population is. The second section presents a list of the environmental parameters that the site encompasses: what kind of source is present, what is its flow rate, how far away are the source(s), how long will the distribution network be, etc. The third section presents estimates of the proposed systems water requirements. The amount of water and flow rates needed to install private and public tapstands is offered. The fourth section provides an estimate of the timeframe required to construct the system with the village population. The number of days and weeks that each household would contribute to the construction effort, as well as the overall time length of the construction phase, is estimated and presented. The fifth section outlines estimated financial costs of the project. For both public and private tapstand configurations, the initial capital costs and operating costs for the intake structures, the main conduction line, a storage tank, and the distribution network are presented. The sixth section of the site assessment report presents a summary of the findings for this module. This summary presents what type of system configuration (public or private tapstands) is physically possible with the given topography and sources, and whether a storage tank will be required. Finally, the type of configuration that is financially possible and economically sustainable with the given available financiall resources and community contributions is presented to the user.

3.3 SYSTEM DESIGN

In order to provide the appropriate level of service to water recipients, water systems must be designed using standard engineering principles. Due to the economic constraints often imposed while working in developing countries, it is important to be able to supply the desired service capacity at the least capital cost. Availability and costs of materials can differ greatly worldwide and it is important that the proposed system be designed with the most appropriate materials and technology for a given region. Gravity flow systems are many times located in mountainous regions, thus adding additional constraints of uneven topography which the designer must consider. By balancing demands for service, financial limits, and topographical constraints, the design module of ***GOODwater*** produces appropriate, technically sound designs for small-scale rural water systems.

One of the stated goals of the ***GOODwater*** software is to assist project managers in designing GFWS in the most economical manner. This requires selection of the optimum configuration of pipe diameters, while maintaining minimum and maximum pressure limits. Pipe diameters are discrete values because materials only come in specific sizes, and as such, optimization solutions for water supply networks are made up of non-continuous variables. Many different approaches have been proposed by engineers to deal with this difficult problem, with solutions falling into two categories. The first category refers to problems that split each link into sub-links with lengths and diameters that vary in accordance with the desired head loss in that section. Alperovits and Shamir (1977), as well as many others, have proposed methods for determining the best configuration for water supply networks using split pipe algorithms The second category refers to optimization routines which assume that the pipes between two points will all be the same diameter. The solution to this problem is preferable as it does not lead to impractical configurations.

For ***GOODwater*** only solutions of the second category are sought. Yates et al. (1984) proved that water system optimization problems of this category are **NP**-Hard, meaning that they belong to a class of mathematical problems for which no practical algorithm can be developed. In response to this situation, and the development of faster computer processing, many heuristic methods have been developed to address these problems. Heuristic methods, such as evolutionary optimization, genetic algorithms, simulated annealing, harmony search, and others, use iterative computational processes to develop an approximate solution. These methods offer advantages such as enabling pipe diameters to assume discrete values and including multiple objectives in the optimization process, and have been applied many times to the problem of water system optimization since their inception (Mays 1997).

GOODwater uses a simple genetic algorithm (**GA**) to generate designs for water system designers. A genetic algorithm is a heuristic search method that mimics the evolutionary process found in nature. Figure 3.1 shows how a GA operates. In a typical GA an initial population of solutions is chosen from the solution space. This population of solutions is then evaluated for its fitness. Solutions are then selected proportionally according to their fitness, with better solutions having a higher probability of selection. Once selections are made the crossover process combines selected solutions to create new solutions. These new solutions are slightly mutated at random locations. If the stopping criterion has been achieved, the best solution is then offered to the user; if not, the process continues again at the evaluation step (Pham and Karaboga 2000).

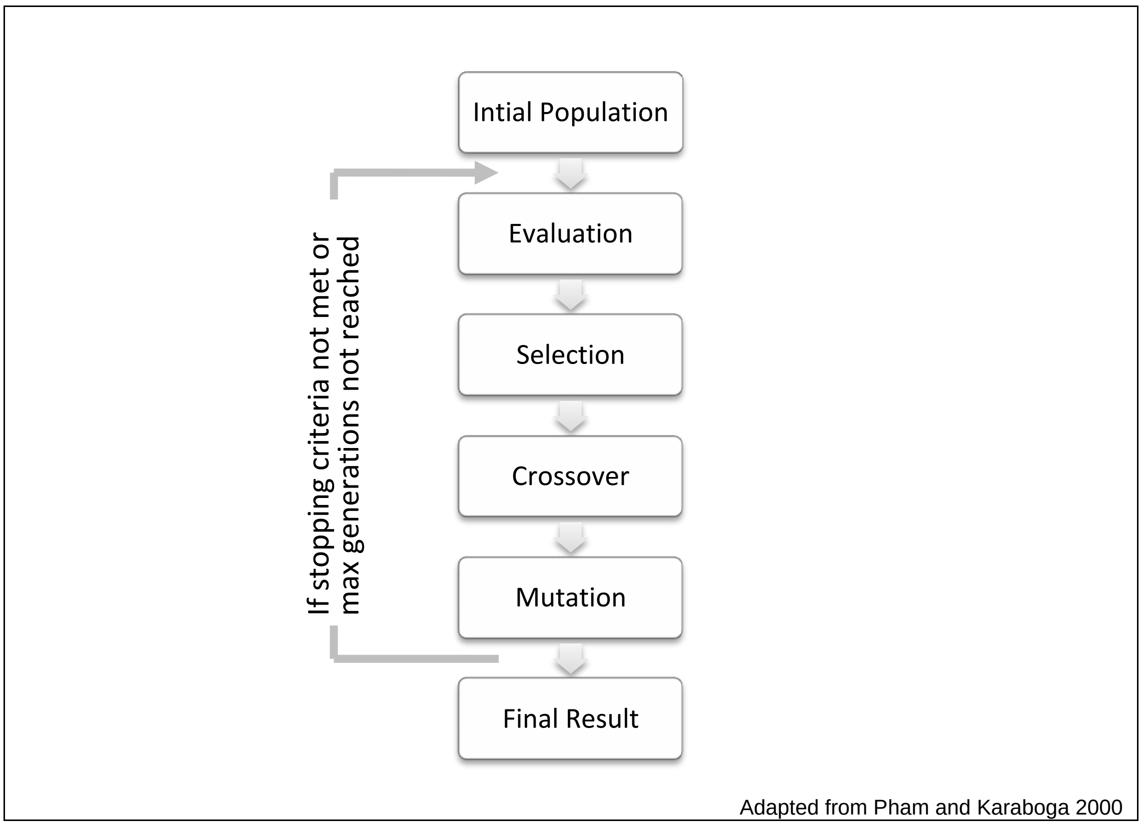

Figure 3.2 Flowchart for Genetic Algorithm Process

3.3.1 Design Actions

The design module, as with the site assessment module, begins with a set of twenty suggested actions. The purpose of these suggestions is to develop water supply projects within a sustainable framework. These actions, again adopted from the work of Jenny McConville (2006), are divided into five groups: 1) Socio-Cultural Respect, 2) Community Participation, 3) Political Cohesion, 4) Economic Sustainability, and 5) Environmental Sustainability. Table 3.2 summarizes the actions presented in this module. As discussed previously, actions are checked by the user after they are completed.

It is also important at this stage that a detailed survey be conducted of the area topography. The particular lines where the water pipes are to be installed must be decided upon. Topographic information along these lines must be collected, specifically the lengths (along the water lines from the source) and the elevations of all points. Abney levels, measuring tapes, altimeters, GPS units, and other basic surveying tools are commonly used.

All high and low points should be included in the survey, as well as points where system components are to be installed. The location of tapstands, public and or private, must also be integrated with the collected survey data. Good references on how to conduct the necessary survey are F. Longland's *Field Engineering* (1998) and Thomas Jordans *A Handbook of Gravity-Flow Water Systems* (1984). Once proper survey data are available, managers can move to the topographical data entry page.

Table 3.2 Suggested Actions For System Design

Suggested Action	Description
Socio- Cultural Respect	• Assess how the proposed interventions will affect daily activities and socio-cultural roles within the community. • Evaluate the willingness and capacity of the community to perform • Design recognizes and respects traditional gender roles. • Recognize why biases exist towards certain technologies by donors
Community Participation	• The project goals are clearly defined and understood by the community and development workers. • Identify a representative committee that can act as the community liaison throughout the project. • Present several technically feasible alternatives for community evaluation and feedback. • Community members formally select a design based on an understanding of the constraints involved in the selection process.
Political Cohesion	• Develop a working relationship with partner organization(s), including at least one that is based in the host country. • Consult the plans and designs of other organizations on similar projects. • Explore options to integrate existing technologies or programs into conceptual designs. • Contact potential partner institutions for project financing
Economic Sustainability	• Estimate the implementation costs of each conceptual design. • Estimate operation, maintenance, and disposal costs for each • Assess the community willingness-to-pay in both monetary and non-monetary terms for each improved system. • Conduct an economic feasibility assessment to evaluate long-term project viability based on cost estimates, projected operation and maintenance costs, community willingness to pay, the need for outside resources, and the availability of outside funding.
Environmental Sustainability	• Assess the capacity for sustainable water use in the geographic area. • Consider seasonal variation in water supply and demand • Consider land needs and availability of suitable land for each alternative. • Conduct a site impact analysis for each alternative.

3.3.2 Topography Input

GOODwater creates a water system design for the proposed project by analyzing the topography of the area and deciding upon a set of pipes that will provide the desired water service level to the community. Topography is entered into ***GOODwater*** through the *TOPO INFO* page in the DESIGN module. Users specify a number of reaches, with a limit of 40 reaches total.

Reaches refer to specific sections or branches of the pipe network, and can have up to 25 individual points per reach, giving a total of 1000 possible points. The first reach must begin at the highest point in the system, normally the main water source. For all subsequent points, the total distance along that reach and all its previous reaches (i.e. from the current point to the initial point) must be specified. Also, for each point the elevation must be specified, either in meters relative to the first point, or in absolute meters above sea level.

All reaches after the first reach must also be connected to previous reaches. These reaches can connect at any point along a previous reach apart from its initial point. Reaches can be connected in series to form longer reaches. Multiple reaches may also be connected to the same previous reach to form branching, tree-like, networks. However, no two reaches can connect at the same point on the same reach.

GOODwater also includes a simple data entry tool. This feature allows users to copy long strings of survey data points (i.e. when a survey has hundreds of points on one reach) into the spreadsheet quickly. The survey data entry tool then reduces these long sets of data to 25 points or less, as specified by the user, and copies this new set of data to a specified reach in the *TOPO INFO* page. Notes for each point can also be stored within the program.

When entering survey data into the software, it is important that all critical locations be listed as points in the topography page. Critical locations are spots where a system component is to be installed. Locations where tanks and tapstands are to be situated are obvious examples of critical locations. If these spots are not listed as specific and unique data points, no component can be placed there. High points in a reach, such as the crest of a ridge or hill are also critical locations where the diameter of pipe may need to change. If these points are omitted, no change of diameter will be possible in this reach. The end points of gully or stream crossings, where a specific pipe material is required are critical and need to be added to the topography information page. Also, no two components may be placed at the same point on the same reach, or at point where a reach branches off. If this is desired by the user, successive points should be added, with their distance between them very small so as to be computationally insignificant.

3.3.3 Component Input

Water supply systems are made up of both pipe networks and other infrastructure components. Once the topography of the water system has been added to the software, the location of all system components needs to be specified. Users can add water sources, a single storage tank, multiple non storage tanks, public tapstands, private tapstands, and clusters of tapstands, as well as other extraction points to a design. For each component, the reach upon which the object is to be located and the precise point on that reach needs to be stated. The program does not permit two objects to occupy the same point on the same reach.

Addition of components in ***GOODwater*** is achieved through the *COMPONENTS* sub-menu in the DESIGN section. Sources should be added first. For each source to be added a flow rate in liters per minute needs to be specified, in addition to the reach and point it is located on. Non-storage tanks can be added next. Non-storage tanks refer to objects which to do not alter the flow rate through them, yet reset the static head in the tube lines to atmospheric pressure. These include items such as sedimentation tanks, break pressure tanks, and other common components of rural water systems. Extraction points are also to be included at this time. Four different types of extraction points are included with ***GOODwater***. These are: 1) public tapstands, 2) private tapstands, 3) clusters of tapstands, and 4) other extractions. Public tapstands are communal water points where multiple families will acquire water. Module 2 includes an assessment of how many public tapstands should be installed in the community if desired, though the project manager may install more or less than the suggested value.

Public taps are assumed to require a specific flow rate of $Q_{tap-public}$, a constant adjustable in the OPTIONS module. Private tapstands are water points installed at each home in the community. This can be a tapstand located outside a home, or a domestic connection, as decided upon by the project manager. Private taps are also assumed to require a specific flow rate of $Q_{tap-private}$, a constant adjustable in the OPTIONS module. Project managers can also specify locations of clusters of tapstands. This feature allows for larger, more complex systems to be modeled in a simpler fashion. Groups of homes which are located together, and where multiple tapstands are to be installed, can be reduced to one component. For clusters, users must specify the number of taps to be included in the set. The flow rate set for clusters is determined by multiplying the number of taps per cluster by $Q_{tap-private}$. A fourth extraction type is available for nontraditional components. Items such as public wash stations or community bathing areas can be included here. For each of these components, a specific flow rate in liters per second must be specified, in addition to the point and reach of the object.

Finally, after entering all sources and extraction points, the program allows users to include a storage tank. ***GOODwater*** requires that the storage tank be located on the first reach. If a storage tank is included, all sources should be above the tank, and all extraction points below the tank. ***GOODwater*** advises that a storage tank be included if the sum of the required flow rates for all extraction points exceeds the sum of all source inputs. If this condition is satisfied, ***GOODwater*** displays a message of "STORAGE TANK REQUIRED" in the storage tank area on the *COMPONENTS* page; if the source exceed demands, and no storage of water is required, a message of "NO STORAGE REQUIRED" is displayed. Once all sources, tanks, and extraction points have been entered correctly, ***GOODwater*** is ready to size the pipe that make up the conduction lines.

3.3.4 Design Generation

GOODwater creates an appropriate system design in two phases. Both phases are run from the *GENERATE DESIGN* page in the DESIGN module. During the first phase, the topography and component information previously entered is copied to a workspace in the program. Flow rates and static pressure heads are then calculated for the network, and a pipe material is assigned to each link in each reach. During the second phase, the genetic algorithm is run, and pipe diameters are assigned for each link in each reach.

To start the first phase the "Generate Base Network" button must be clicked. Users can then adjust the materials and diameters of any of the specific sections of the systems by adding values to the two orange columns. The "Generate Base Network" macro should then be run again as the network has changed. Also, anytime users add, subtract, or change components or topography, this macro should be re-run. With the network created and any special link materials or sizes specified, the "Generate Design Button" is clicked to start phase two. Once a suitable design has been created, the third action button is clicked to create a report of the proposed design.

The first phase of the design stage is initiated with the "Generate Base Network" action button. When clicked, ***GOODwater*** begins by copying the topographical information from the *TOPO INFO* sheet to a workspace on a separate sheet. All components are then overlaid on top of the topographical information in their correct locations. For locations where tanks are installed, a mirror point is created 0.01m after the tank. This mirror point allows the software to calculate different values for the pressures before and after the tank. Flow rates are next assigned for each link. Starting at the bottom of the system, flow rates are set by extraction points. Moving from the ends of reaches towards the initial point on the main reach, the flow rate for any specified location is set as the sum of all extraction points below, minus contributions of any sources.

Non-storage tanks do not affect the flow rates. If no storage tank was specified by the user, and the sum of extractions is less than the sum of the sources, the flow rate at the initial source will be less than the water produced there, with overflow resulting at the first source. If a storage tank is specified, flow rates are summed from the end of reaches below the storage tank until the tank is reached. Then moving from the primary source downwards towards the tank flow rates are set at the value of the primary source plus that of any additional sources passed, minus any extractions.

Static heads are next established. Moving from the primary source (also the highest point) downwards, static head is set as the change in elevation from the current point to the previous point, minus the static head at the previous point, neglecting all frictional losses. The software notes the locations of tanks (storage and non-storage) and resets the static head to zero at the mirror point of each tank. Pipe materials are determined for each link at this time. ***GOODwater*** selects the most affordable pipe material for each section. The average cost per millimeter of pipe inner diameter for each material is calculated from the information entered into the *PIPE INFO* page in the OPTIONS module. The pipe material that can be installed in a given link is selected that has the lowest average cost and also ensures that the static head does not exceed the limit of the pipe material. Finally, any links where users have specified materials or sizes are copied over to the workspace. Users may wish to override the suggested materal type or tube size in instances such as gully or road crossings, where more durable materials may be desired.

The second phase of the design stage is initiated with the "Generate System Design" action button. The genetic algorithm used by ***GOODwater*** is a simple application. The ***GOODwater*** GA is governed by five user inputs: N_{pop}, the GA population number; N_{gen}, the number of generations; τ, the tolerance or stopping criteria; ε the crossover coefficient, μ the mutation coefficient. N_{pop} is the number of individual configurations present during each iteration of the GA and can be a value from 1 to 1000. N_{gen} is the total number of generations (iterations) to complete if the stopping criteria is not met, and may not exceed 10,000 iterations.

The tolerance τ is used if τ generations have passed without a change in the best system configuration; at this point the GA is stopped. The crossover coefficient ε refers to the probability of any specific point in a selected configuration being bred into the next generation and ranges from 0 to 1. The mutation coefficient μ dictates the probability of any point in a newly bread configuration mutating and also ranges from 0 to 1.

The first step of the GA is creation of the initial population N_{pop}. ***GOODwater*** creates a group of N_{pop} different configurations with each different point in each configuration randomly assigned from the available diameters for that section's specified material. The second step in the GA is evaluation of each configuration's fitness. In order to evaluate the fitness the hydraulic condition of each link must be calculated. Since flow rates and pipe materials are set in the previous phase and each iteration produces diameters for each link, the head loss, ΔH_i, for link *i* can be calculated quickly with the Hazen-Williams formula. With this value the elevation of the hydraulic grade line (HGL) can be calculated for each point, and the residual head H_i is calculated as the difference between the HGL and ground surface profile (**GSP**). The fitness $\mathcal{F}$ for each configuration with *i* links is then defined by the following formulas adapted from Savic and Walters. (1997) and Gupta (1999):

$$\frac{1}{\mathcal{F}} = L_i \sum_{i=1}^{N_{pop}} f_c(M_i, D_i) + \sum_{i=1}^{N_{pop}} f_p(H_i) \qquad (12)$$

In Equation 12, $f_c(D_i, L_i)$ is the cost per meter of link *i* with a material M_i, a diameter of D_i and a length of L_i and $f_p(H_i)$ is the penalty cost for link *i* with a residual head of H_i meters. The value of f_c is set in the *PIPE INFO* page in the options module. The penalty cost function is defined by the following formulas adapted Liong and Atiquzzaman (2004):

$$f_p(H_i) = 2\, C_{max}\,(H_{min} - H_i) \qquad \text{if } H_i < 0 \qquad (13a)$$

$$f_p(H_i) = C_{max}\,(H_{min} - H_i) \qquad \text{if } 0 < H_i < H_{min} \qquad (13b)$$

$$f_p(H_i) = C_{max}\,(H_i - H_{max}) \qquad \text{if } H_{max} < H_i \qquad (13c)$$

where C_{max} is the cost of the most expensive system possible, H_{min} is the minimum head allowed, and H_{max} is the maximum head allowed. C_{max} is calculated as if all links in the system were made up of the most expensive material and diameter available. H_{min} and H_{max} are specified in the *GLOBALS* page in the OPTIONS menu. H_{max} is only applied to locations where pipes discharge into tanks or where water extraction points are located. Once all of the N_{pop} populations have been evaluated and a fitness parameter assigned for each configuration, the selection process begins. Selection is determined using the standard "roulette wheel" approach (Pham and Karaboga 2000).

The probability of selection $\mathbb{P}$, for configuration j of N_{pop} is assigned according to Equation 14, as outlinded by Pham and Karaboga (2000).

$$\mathbb{p} = \frac{\mathcal{F}_j}{\sum_{i=1}^{N_{pop}} \mathcal{F}_i} \tag{14}$$

Once probabilities have been assigned to each configuration, N_{pop} configurations are selected from the current population using $\mathbb{p}$ to weight the probability of choosing any specific configuration. These new configurations are then subject to the crossover stage. Savic and Walters (1997) found that a simple 1:1 crossover functioned well in their water system optimization research, and a simiarl procedure is used in ***GOODwater***. In this crossover, two configurations are randomly chosen from the newly selected population. A new configuration is produced by randomly copying an element from one of the two chosen configurations. The probability of picking from the first or second configuration is governed by ε the crossover coefficient. The crossover process continues until N_{pop} new configurations are produced.

The final stage of the GA is the mutation process. During the mutation process, each point in each of the N_{pop} configurations can be randomly changed to a different pipe diameter one size larger or smaller, with the probability of mutation for any point defined by the mutation coefficient μ. This constitutes one generation of the GA, and the configuration with the best fitness is saved. The process is then repeated from the evaluation stage forward with the newly selected, bred and mutated configurations, until the number of generations is reached. If the configuration with the best fitness has not changed in τ generations, the GA is stopped and the best configuration is presented to the user. A report of the best configuration can now be prepared.

3.3.5 Program Output

Once the ***GOODwater*** DESIGN module has been run, a report of the proposed design can be created. Appendix E contains an example of the DESIGN report. The DESIGN report includes a header which contains information about the organization or institution planning the water project, as well as the title for the project itself. Below the header all the reaches and the points within them are listed. For each point on the reach seven values are printed, along with any notes the user has made for that point. The first two values listed are the distance and elevation for the point. The design flow rate is printed in the third column. The fourth and fifth columns show the suggested material type and diameter number. The last two values printed are the HGL elevation and the residual head at the point. All these values are printed for all points in the network. To the right of each reach printout is a graph of the GSP and HGL.

3.4 PROJECT PLANNING

With the creation of a suitable design, the Planning stage can begin. The PLANNING module provides assistance in creation of a project's budgets and materials lists. Creation of budgets and materials lists is important for ensuring that the project can move forward. Budgets can be presented to donor agencies or supervisors to provide transparency. In order to solicit funds for different projects, an itemized budget and design are often required. The PLANNING module includes a few different tools to help in creation of these documents. Space is provided to note all the different components involved in the system. Tools are also provided to diagnose locations where air blocks may arise and where washouts should be considered. A list of all materials needed for the project is generated, and this can be taken to vendors to receive price quotes. Finally, a fully itemized budget can be created at the end of this module.

3.4.1 Planning Actions

The PLANNING module, as with the previous modules, begins with a set of twenty suggested actions. The purpose of these suggestions is to develop water supply projects within a sustainability framework. As in previous stages, these actions are McConville are divided into five areas: 1) Socio-Cultural Respect, 2) Community Participation, 3) Political Cohesion, 4) Economic Sustainability, and 5) Environmental Sustainability (McConville 2006). Table 3.3 summarizes the actions presented in this module. As discussed previously, actions that have been completed are checked by the user.

Table 3.3 Suggested Actions For Budgeting and Planning

Suggested Action	Description
Socio- Cultural Respect	• Understand the traditional structure of community projects. • Consider the seasonality of labor in setting the timeline. • Explore options for increasing gender equity in project roles and capacity building. • Confirm that labor and resource contributions are equitably divided.
Community Participation	• Community input is solicited in refining the selected technical design. • Final technical design is approved through a process of community consensus. • Community members are involved in identifying and sequencing tasks that will be incorporated into an action plan. • The community members and development workers approve of the timeline and responsibilities laid out in the action plan.
Political Cohesion	• The roles and responsibilities of partner institutions are defined in a detailed action plan. • Agree on financial commitments. • A timeline is drafted that meets the requirements of all institutions involved. • Final project design and action plan are presented to partner institutions and local, regional, and/or national level authorities.
Economic Sustainability	• Verify the costs and availability of resources. • Confirm the community contribution for money, materials, equipment, tools, and labor. • Finalize budget based on local costs, available resources, and community contribution. • Develop an action plan for resource procurement.
Environmental Sustainability	• The final project design minimizes ecological disturbance, energy use and waste emissions. • The project design uses renewable and/or recyclable local resources. • The action plan considers the seasonality of resources. • Develop an environmental action plan to mitigate impacts during construction.

3.4.2 Component Items

Formation of accurate project budgets begins with identification of all materials required to implement the proposed system. The *COMPONENTS* page provides a space to enter all items needed for the project. The "Copy Design Pipe Configuration" action button located on this page can be clicked if the DESIGN module was used to generate a system design. The macro started when this button is clicked copies and tallies the quantities of pipes of different material types and sizes from the previous module to a list of pipes for this module. The specific numbers of pipes are calculated by dividing the total meters of each type and diameter of pipe by the length of pipe that is available locally. The quantities of pipes can also be adjusted manually by users if they wish to modify the number of pipes of each diameter to be purchased. This sheet also offers space to include the materials needed for each component in the system.

A total of 50 possible components can be included. For each component all materials required are entered in the form below the component name. If many instances of the same component are to be included in the system (i.e. tapstands), the number to be installed can also be entered. The materials needed for each component, item name, and code/size should to be entered. Finally, the quantity of the item required for one instance of the component needs to be specified.

The *COMPONENTS* page includes two other tools to assist in planning a water system. Links to these tools are provided near the top of the page. The first tool is available to assist in determining the size of the tank to be installed in the system. This tool requires that managers enter a schedule for water use throughout the day. The schedule allows users to customize the system to the particular demands of water users. The day is broken up into 8 three-hour periods. For each period managers must specific the percent of water that users will extract during the period. The total volume of water demanded by the community daily, V_{total} , is calculated as follows:

$$V_{total} = \left[\mathrm{N_{tap}}\,\mathrm{V_{lpcd}}\,\mathrm{Tc}\right]_{\mathrm{public}} + \left[\mathrm{N_{tap}}\,\mathrm{V_{lpcd}}\,\mathrm{Tc}\right]_{\mathrm{private}} \qquad (15)$$

where $\mathrm{N_{tap}}$ is the number of users per tapstand, $\mathrm{V_{lpcd}}$ is the number of liters per day per person per, and Tc is the number of tapstands of this type. $\mathrm{N_{tap}}$, $\mathrm{V_{lpcd}}$, Tc all may have different values for public and private taps. The water demanded during any period of the day is calculated simply using the percentage schedule specified and the value of V_{total}. Tank inflows are calculated assuming a constant flow rate entering the tank. Tank outflows are subtracted from inflows to determine if there is a deficit during the day. The largest deficit is suggested as the volume of the storage tank (Jordan 1984).

The second tool included in this page can be used to assess where air blocks or sedimentation may occur, and where air valves and washouts should be located. Air blocks occur when a pocket of air becomes trapped inside a pipe as it is filling. When this happens, flow through the pipe can be reduced and possibly blocked completely. In order to remove air blockages, simple valves can be installed at points where air blocks have developed. This tool identifies possible locations where airlocks can develop. Any point where the previous and next point is of lower elevation is designated as possible air block location to be considered. If a system is built and air blocks are determined to be an issue, managers should start at the first listed point and work downstream installing air release valves (automatic and manual are commonly available). Washouts are low points in the system where sediment and other debris may collect. Washouts can also be used to drain the pipeline to provide service to sections of pipe. Any point where the previous and next point is of higher elevation is listed as a location where a washout should be considered. Once all materials have been added to their appropriate components, and air blocks and washouts considered, the materials prices should be gathered.

3.4.3 Materials Listings

The *MATERIALS* page in the PLANNING module provides a list of all the items needed for the water system. When users click the "Set Materials" action button on this page the materials listed in the *COMPONENTS* page are totaled. Any item appearing in multiple component lists is totaled, providing a system-wide list of items needed. This page also provides a place to insert prices for each item. Quotes for each item should be gathered, preferably from multiple vendors. These prices can be entered into the spreadsheet. Once all the items in the list have been assigned a cost, then the project budget can be generated by clicking the "Create Budget" action button.

3.4.4 Project Budgets

Once the ***GOODwater*** PLANNING module has been run, a report of the proposed system's budget can be created. Appendix E contains an example of the PLANNING report. The PLANNING report includes the same header as earlier reports, which contains information about the organization or institution planning the water project, as well as the project title. The report generated is a budget for the designed system. The first part of the budget is a summation of all the components in the system, including the pipelines. For each component, the quantity to be installed is provided, along with the unit cost of the component.

The total cost of installing all components of a particular type is then presented. The total cost of installing all components is listed as the total capital investment needed for the project. Below this summary each component is listed with the individual materials needed for its construction. All components are listed, and for each component a sub-total is presented to provide its individual construction cost.

3.5 PROJECT IMPLEMENTATION

Implementation of water supply projects is the time when physical construction of the proposed system takes place. As noted by Mihelcic et al. (2008), proper planning of how a construction project is to be accomplished is very important in developing nations. Both monetary and time savings can be accrued by appropriate organization of materials and labor for the project. Transportation of materials to the work site can constitute significant challenges for the project supervisor. Lack of materials can slow down construction, and put the project off schedule. Issues with supply of materials can often result in excess costs incurred when managers are forced to purchase materials from vendors who have higher costs than the vendor providing the initial cost estimate. Labor can be difficult to organize and move to the construction site. The importance of trained laborers cannot be understated. Every effort must be made to insure that laborers will be knowledgeable of what their responsibilities are and when and where they must be each day. Creation of a project schedule can help with planning how the construction phase will progress (Mihelcic et al. 2008).

3.5.1 Implementation Actions

The IMPLEMENTATION module, as with the previous modules, begins with a set of twenty suggested actions. The purpose of these suggestions is to develop water supply projects within a sustainable framework. These actions are divided into five areas: 1) Socio-Cultural Respect, 2) Community Participation, 3) Political Cohesion, 4) Economic Sustainability, and 5) Environmental Sustainability (McConville 2006). Table 3.4 summarizes the actions presented in this module. As before, completed actions are checked by the user after they are completed.

Table 3.4 Suggested Actions For Project Implementation

Suggested Action	Description
Socio- Cultural Respect	• Set a realistic work schedule, based on available resources and preferred work styles. • Scheduling includes float time to allow for the unexpected. • Encourage the involvement of women throughout the construction process. • Use public gatherings to review benefits of the project, promote education, and discuss operation and maintenance
Community Participation	• Involve the community in revisions of the action plan, program changes, and problem solving. • Work with a local foreman or work supervisor in organizing labor. • Train local laborers in any new techniques and tools that are introduced. • Finalize the management plan with respect to the “built” system.
Political Cohesion	• Contact institutions in the area for assistance in training and labor requirements. • Inform partner institutions of the start of construction, project milestones and major changes. • Invite local government and NGO officials to view the construction site. • Discuss partner roles in operation and maintenance.
Economic Sustainability	• Community members contribute to project implementation. • Recheck the quality of materials and equipment during resource procurement. • Monitor spending and budget restrictions throughout the project implementation phase. • Draft final report on the budget and share with community members and partner organizations.
Environmental Sustainability	• Recheck physical and environmental constraints used in the project design and make design corrections if necessary. • Take precautions to avoid contaminating existing water resources and minimize environmental impacts during implementation. • Involve the community in waste management and environmental education. • Restore any areas disturbed during construction.

3.5.2 Project Scheduling

GOODwater assists in project implementation by assisting in creation of a construction schedule. In the *SCHEDULE* menu in the IMPLEMENTATION module users can enter the dates that specific components are to be constructed. When the "Copy Components" action button is clicked, all components to be installed which are listed in the PLANNING module are brought to the current module. If no components are set in the PLANNING module, a user can manually enter those components which they plan to include in the system. Components can also be removed if there is no desire to include these objects. If there are other aspects of the construction which are not yet included, these tasks can be added below the current components. Tasks such as laborer training or materials delivery, not considered construction, yet still important stages of the project can also be included in the list. The order of the items on the list is not important; the list will be sorted later. Once all components are included starting dates and ending dates need to be set for each item. For each item in the list a bar will be created on the schedule for the period during which the task is schedule. Events that span multiple years will be divided into different calendars for each year. The calendar can be created by clicking the action button "Create Calendar".

3.5.3 Implementation Calendar

GOODwater creates a project specific calendar for use in implementation of the water supply system. Appendix E contains an example of the calendar created by ***GOODwater.*** The calendar includes the same heading that is included in the reports from the previous modules. The created calendar displays how construction of the proposed water system will evolve. Items are displayed on the calendar with their starting dates and durations expressed as bars. If the project is to last multiple years, separate calendars are created for subsequent years and displayed below the first years calendar.

3.6 EVALUATION

The final module of ***GOODwater*** provides project supervisors with an evaluation of how sustainably the water supply project was managed. Evaluation is an important stage during which mistakes can be corrected for future projects. This section includes a set of actions and the final report. This report is a summary of all the previous modules' sustainability scores.

3.6.1 User Actions

The final module EVALUATION, as with the previous modules, begins with a set of twenty suggested actions. The purpose of these suggestions is to develop water supply projects within a sustainability framework. These actions, again adopted from the work of Jenny McConville are divided into five areas: 1) Socio-Cultural Respect, 2) Community Participation, 3) Political Cohesion, 4) Economic Sustainability, and 5) Environmental Sustainability (McConville 2006). Table 3.5 summarizes the actions presented in this module. As earlier, completed actions are checked by the user after they are completed. This page also includes the action button "Generate Final Project Evaluation" which when clicked generates the final report for the system.

Table 3.5 Suggested Actions For Project Evaluation

Suggested Action	Description
Socio- Cultural Respect	• Discuss unanticipated constraints to system use. • Discuss unexpected limitations to maintenance schemes. • Reassess how gender roles affect the proper use and perceived benefits of the system. • Ensure that costs and benefits are equitably distributed within the community
Community Participation	• Community members are actively involved in performing the necessary operation and maintenance. • Conduct a participatory evaluation to get community feedback and suggestions for improvements. • A community organization exists with the capacity to make decisions regarding the operation and maintenance of the system. • The system is controlled by culturally-appropriate and traditionally-respected people.
Political Cohesion	• Invite officials to the opening ceremony. • Coordinating institutions sign a formal agreement that defines their roles and expectations in operation and maintenance of the system. • A locally-based institution is involved in project monitoring. • Share monitoring reports and project evaluations with partner institutions.
Economic Sustainability	• Estimate realistic, long-term operation and maintenance costs based on the “built” system. • Financing exists to cover projected operation and maintenance costs. • A financial management organization exists to manage operational/maintenance costs and the distribution of benefits. • Regularly review and adjust the financing system.
Environmental Sustainability	• Minimize, treat, and dispose of waste properly. • Explore alternative plans for reducing the use of consumables. • Monitor and evaluate environmental impacts. • Continue environmental and hygiene education efforts.

3.6.2 Final Project Evaluation

The final report prepared by ***GOODwater*** provides scores of the sustainability of the water project. Appendix E provides an example of a report for this section. The report begins with a table of the scores received by each module for each sustainability category. These scores are calculated based on the number of actions completed and checked for each section. Each module receives a score out of 20 possible points. Also, each sustainability category receives a score out of 20 points. The overall project score is presented on a scale of 0 – 100, with 100 being the best possible score. Radar plots are presented for both the scores divided by category and by module. These plots show the sustainability coverage for each division (McConville and Mihelcic 2007).

3.7 OPTIONS

GOODwater includes three different options pages. These pages can be configured by an institution to unique local conditions and standards. Once these are set many different projects can be worked through without changing these pages. Included here are a set of global variables used throughout the program, *GLOBALS*; a macro to establish the constants used to estimate the financial estimates in the site assessment modules, *FA CONST.*; and information about types and costs of pipes available in the area.

3.7.1 Global Variables

The *GLOBALS* page in the OPTIONS module is a set of constants used throughout the software. Different modules use the values set in this page in calculations throughout the software. Table 3.6 shows the different parameters used in ***GOODwater***, and their standard values. A standard value and reference is listed for each parameter. If the user clicks the "Restore Defaults" button all values are reset to the standard values found in literature. Users can also alter the global variables to different institution specific values.

Table 3.6 Global Variables in *GOODwater*

Parameter	Suggested Value	Units
Public Tapstand Water Allotment	30	Lpcd *
Private Tapstand Water Allotment	100	Lpcd *
Number of Users Per Public Tapstand	250	Persons ‡
Number of Users Per Private Tapstand	5	Persons
Minimum Flow Rate Per Public Tapstand	0.125	Liters/second ‡
Minimum Flow Rate Per Private Tapstand	0.125	Liters/second ‡
Ordinary Soil Excavation Rate	0.55	Laborer-days/m^3 ɣ
Gravely Soil Excavation Rate	0.77	Laborer-days/m^3 ɣ
Boulder Mix Excavation Rate	1.1	Laborer-days/m^3 ɣ
Medium Rock Cutting	1.6	Laborer-days/m^3 ɣ
Hard Rock Cutting	2.5	Laborer-days/m^3 ɣ
Pipe Trench Depth	100	Centimeters ɣ
Pipe Trench Width	40	Centimeters ɣ
Minimum Head Throughout Network	7	Meters ɣ
Maximum Head at Tapstands and Tanks	56	Meters ɣ

Parameters and values used throughout ***GOODwater***
(Howard and Bartram 2003)* (Reed 2005)‡ (Jordan 1984)ɣ

3.7.2 Feasibility Coefficient Generator

In order to estimate the probable cost for a proposed water system during the FEASIBILITY module, eight equations are employed which make use 19 coefficients (α_i and β_i). These coefficients must be calibrated before accurate results can be obtained. By entering information about previously-constructed water supply systems, ***GOODwater*** scales cost estimates to local conditions.

The *FA CONST.* page includes space to enter information about water systems previously constructed in the region and will be referred to as the 'benchmark' systems for this module. These may be projects which the user's organization was involved with or similar projects implemented near the proposed site. A minimum of three different systems should be input into the sub-module. Basic information about the 'benchmark' systems including the population, approximate distances and elevations needs to be entered first. Estimates of construction costs and operational costs must also be entered for each system. When the appropriate information has been entered, the coefficients are calculated by clicking on the "RUN" action button**.**

GOODwater employs the solver tool and a least-squares regression in the computation process to estimate the project cost functions. With the available information all values for Equations 7 – 10 are known, with the exception of the α_i and β_i coefficients. Flow rates and tank volumes for the gauging systems are estimated as a function of the population using Equation 1 and 2a. The diameters of the 'benchmark' systems are calculated in the same manner as in Section 3.2.3, by using Hazen-Williams and the input distances and slopes. A least-squares regression is applied to Equations 7 – 10 using initial α_i and β_i coefficients with values of 0. ***GOODwater*** then employs the Solver Add-In to look for and find values of the coefficients that minimize the sum of the squared error for cost estimates for all ‘benchmark’ systems. This sets all the α_i and β_i coefficients for accurate estimation of water system costs.

3.7.3 Pipe Information

The third sub-module of the OPTIONS module is the *PIPE INFO* page. This page enables users to specify the pipe materials and sizes available locally. A total of six different types of pipe materials can be entered into the form. For each material ten different diameters can be specified. These diameters must be input in millimeters. For each material type entered, the maximum pressure in meters of head must be specified, as well as the Hazen-Williams *C* value. A table is located below the input form which lists common material types, maximum head values, and Hazen-Williams C values. Table 3.7 also shows this information. For each pipe material and diameter, a price per meter of tubing should be inputted. The check boxes next to each price are to be used to select those pipes available locally. Only pipes with boxes checked will be included in the system design.

Table 3.7 Hazen-Williams *C* & Pressure Limits for GFWS materials

Material	Hazen-Williams *C*	Pressure Limit (Bars)	Pressure Limit (m Head)
PCV (Class B)	150 ‡	6 *	61
PCV (Class C)	150 ‡	9 *	91
PCV (Class D)	150 ‡	12 *	122
PCV (Class E)	150 ‡	15 *	125
PE (medium density)	150 ‡	12.5 *	127
PE (high density)	150 ‡	16 *	163
Iron Tubing	120 ‡	40 *	407
Prestressed Concrete	120 ‡	20 *	204

Standard values for typical pipe materials ‡(Menon 2005), * (Purcell 2003)

3.8 HELP

The final module included with ***GOODwater*** is the HELP module. The HELP module includes four different sub-modules: *HOME*, *ACTIONS*, *INPUTS*, and *REFRENCES*. These four pages are designed to assists project managers working through the ***GOODwater*** software. The first page in the HELP module includes information about the development of ***GOODwater***, the current version of software, and the date that the software was developed is presented. Copyright information and a liability statement are presented to ***GOODwater*** users on this page. A description of the Michigan Technological University's Masters International Program is also available to interested users.

3.8.1 Action Descriptions

The *ACTIONS* page includes a full list of all the suggested tasks and actions presented throughout the software. Appendix C presents a copy of the information available on this page. For each of the suggested actions, a full description of what the action will entail is offered. This information comes from the work of J. McConville (2006) and provides a valuable guide for working through water and sanitation projects in a sustainable manner.

3.8.2 User Input Descriptions

The *INPUTS* page includes a full list of the parameters to be entered into ***GOODwater.*** Appendix D presents a copy of the information available on this page. For each parameter a full description of what the parameter refers to and the units that it requires is offered.

3.8.3 References Used

The final page in ***GOODwater*** contains a list important reference for water system managers. All references cited throughout the software are present in this list. This list is incorporated into the references offered in chapter 6.

4 APPLICATION OF ***GOODwater*** DSS

Information for a gravity-fed water system serving two rural communities in the Dominican Republic is included with the ***GOODwater*** software. This case study serves to demonstrate to the reader the capabilities of the software. All modules of the program were run with data collected from the authors experience working with the two communities, from 2005 to 2007. The results of the case study are presented and analyzed below. The author lived in these two communities while working as a water and sanitation engineer with Peace Corps Dominican Republic. During this time a gravity flow water system was constructed by community residents collaborating with the Peace Corps and local government, as well as Dominican and international NGO's. In total, over $40,000 US dollars were raised for the project throughout a two year period.

Guaranal and Quita Sueño are two small agricultural communities located in the northern mountain range of the Dominican Republic. Each community contains roughly 80 homes, though both communities are growing rapidly. There are three churches, two primary schools, a community center, and a number of small businesses located throughout the two communities. Situated atop a long ridge, community members used rainwater harvesting for the majority of their water needs. Three springs are also located near the communities, though these are significantly distant from many members of the community, requiring trips of up to 1 km to reach water during the drier months of the year.

In the fall of 2005 the author arrived in Guaranal and Quita Sueño with the goal of working towards a solution to the water scarcity issue faced by the two communities. A water board was organized to provide leadership from the community during the project. The mountain stream known as "Arroyo Blanco" was decided upon as the water source for a gravity flow water system. From 2005 onward, the author progressed through all the stages outlined in this manuscript, completing most of the calculations by hand, or with rudimentary spreadsheets. Information from actual topographical surveys, local prices, and other regional parameters are used as data for this case study. Table 4.1 shows the parameters used to set up the case study. The reports from each module are presented in Appendix E. All prices in this case study are in Dominican pesos ($RD).

Table 4.1 Values Input into *GOODwater* for Guaranal and Quita Sueño Application

Parameter	Value
Community Name	Guaranal y Quita Sueño
Community Municipality	Altamira
Community State / Province	Puerto Plata
Country	La República Dominicana
Project Title	Community Water System
Engineer Name	Stephen Good
Organization Name	Peace Corps Dominican Republic
Organization Address	Cuerpo De Paz, Embajada De Los Estados Unidos, Santo Domingo, Dominican Republic

4.1 SITE ASSESSMENT

An assessment of the communities of Guaranal and Quita Sueño was made before the author's arrival by Peace Corps Dominican Republic. The site was deemed a good location for a GFWS. The type, size, water source, and many other aspects of the system were not known at this time, however. The author conducted a census of the population, investigating the communities' water and sanitation concerns and issues. This census also attempted to gauge the amount that community members could contribute, both monetarily and in labor, to the project. Various water sources located near the community were visited during this stage. A GPS receiver was used to estimate the distances and elevations of each possible source. Flow rates for these sources were also measured over a series of months. From discussions with Peace Corps staff and local government officials, an estimate of funds to be made available for the project was assessed. Table 4.2 shows the values used in the Guaranal and Quita Sueño case study site assessment.

Table 4.2 Site Assessment Values for Guaranal and Quita Sueño Application

Parameter	Value
Community Population	626
Water Source Type	Mountain Stream
Number of Sources Used	1
Total Flow Rate From Source	6.3 L/s
Source Elevation	470 m
Distance To Source	5200 m
Network Length in Community	8100 m
Highest Pt. Served In Community	340 m
Lowest Pt. Served In Community	150 m
Area Soil Type	Ordinary Soil
Number of Days per Week Laborer Can Work	0.5 Days per week
Number of Months per Year available for Work	9 Months
Monthly Community Contribution Per Family	30 $RD
Total Funding Available For Project	1,500,000 $RD

The ***GOODwater*** Site Assessment module was run with the above inputs. A complete copy of this modules report is available in Appendix E. The report notes that the proposed system would entail a total of over 13 kilometers of pipeline, encompassing a change in elevation of 320 meters. If three public tapstands were to be installed, a source producing 31,380 liters daily, or a flow rate of 0.36 liters per second would be required. For 125 private tapstands, 62,600 liters of water is required, with a flow rate of 0.54 liters per second (1.25 liters per second without a storage tank). The proposed water source "Arroyo Blanco" produces 544,320 liters daily, with an average flow rate estimated at 6.3 liters per second. The site assessment report estimates that 125 workers would be available for the 1.2 years that the project is expected to last. At 4.5 meters of trench dug per day, ***GOODwater*** estimates that laborers would need to work 23 days each, working 1 day every other week for 46 weeks, to install all the pipes. A public water system is estimated to cost 808,185 $RD, and a private system 931,559 $RD. The report states that both public and private systems are possible. For a public or private system, no storage tank would is required; however this necisitates the use of larger tubing to bring more water into the communitie (since there is no storage compacity) and thus a larger capital investment. Enough funding is available for either option. The community is also willing to contribute enough funds to maintain either type of system.

During the initial site assessment of Guaranal and Quita Sueño by Peace Corps Dominican Republic staff, the site was deemed feasible by their standards. Through the author's work in the communities he concluded that both public and private tapstand configurations were possible. He also concluded that a storage tank would be necessary for the project. These findings coincide with those drawn by the ***GOODwater*** software.

4.2 SYSTEM DESIGN

GOODwater was used to generate a design for the water system in Guaranal and Quita Sueño. A comparison of the results of the ***GOODwater*** solution to that of the author's original can be found in Section 4.6. Before the original design was created in 2006, a detailed survey was conducted of the area with an Abney level and a 50-meter tape. Around 500 individual data points were generated in this process. This original survey data was condensed to the points found in the design report in Appendix E. Including all participating members homes, as well as additional tapstands at the schools, churches, and community centers 160 tapstands were installed in Guaranal and Quita Sueño in 2007. Figure 4.1 is a topographical map of the area surrounding the two communities and also includes the source location. Figure 4.2 is a detailed schematic of the layout of the water supply system.

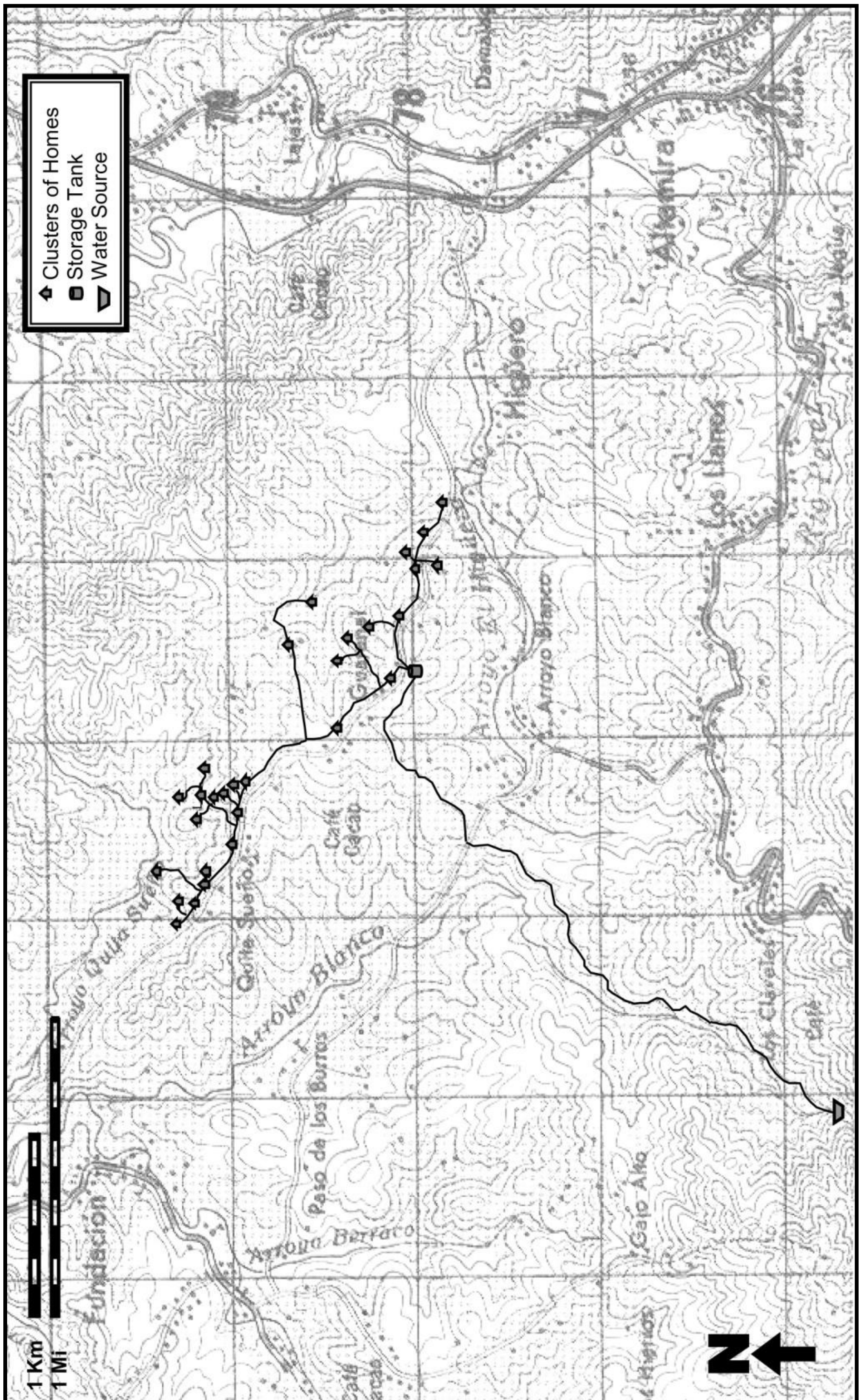

Figure 4.1 Map of the Guaranal and Quita Sueño Water System

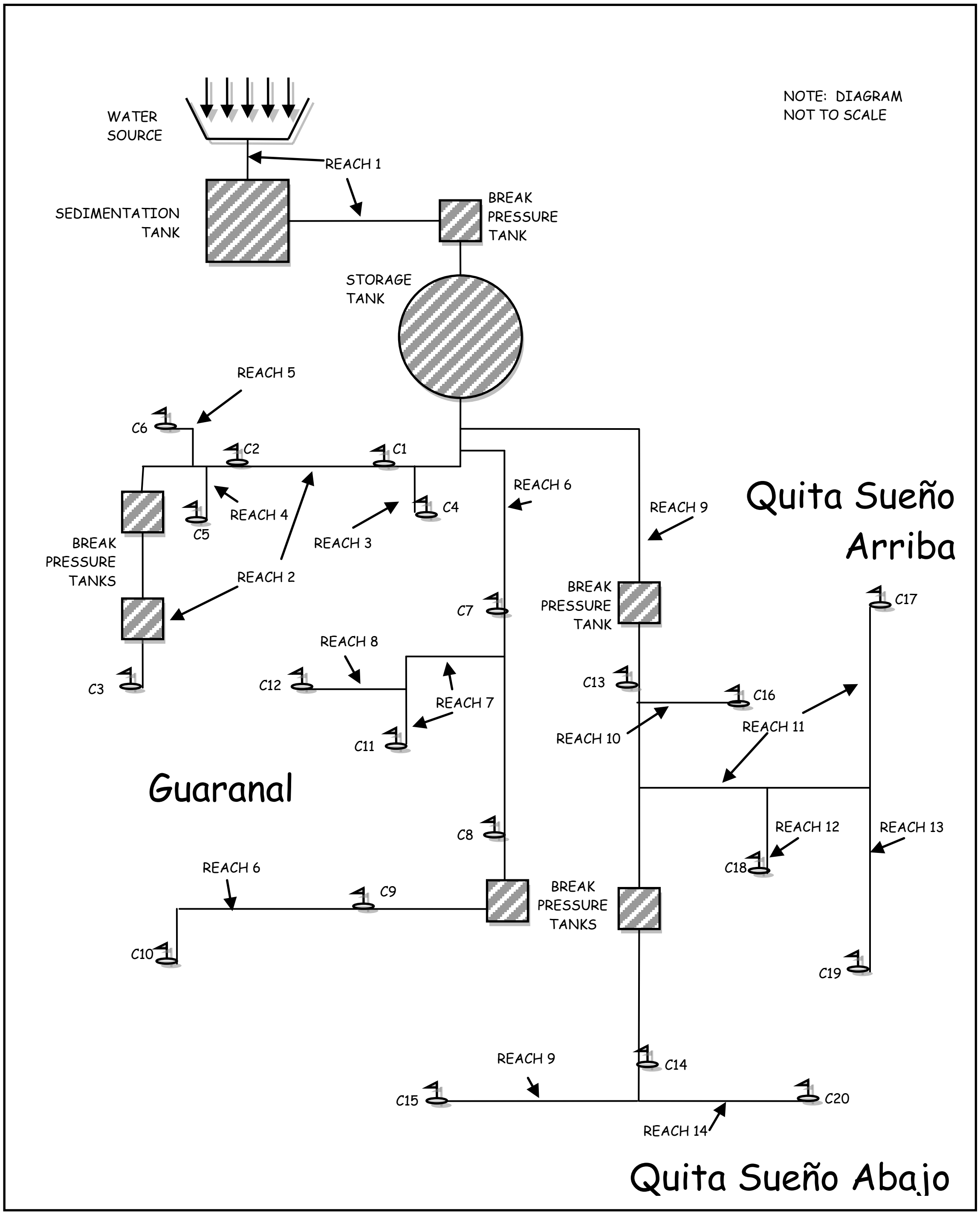

Figure 4.2 Schematic of the Guaranal and Quita Sueño Water System

Between the source and the communities a sedimentation tank was inserted. There are three small rivers which were crossed using galvanized iron piping, and these were specified in the design. The community of Guaranal has two main lines (Reach 2 and Reach 6) which serve the majority of the homes. Quita Sueño is served by one main line, though the community is divided into two parts (Quita Sueño Arriba and Quita Sueño Abajo). A flow rate of 0.54 liters per second was models as the extraction rate from the water source. The Peace Corps Dominican Republic specified a water allotment of 75 liters per capita daily, and a minimum pirvate tap flow rate of 0.01 liters per second. All other global constants in the options menu were set to standard values. Within the communities five break pressure tanks were modeled.

A design was generated with an estimated cost of 792,629 $RD. The limits for minimum head and maximum head are not violated by the new design. Lists of the selected tube number and types are offered in the report found in Appendix E. Also included in the report are graphical plots generated by ***GOODwater*** which show the ground surface profile (**GSP**) and hydraulic grade line (**HGL**) for each reach. Figure 4.3 shows the convergence of the genetic algorithm to the least cost solution proposed. A solution was obtained after 176 runs using a population size of 250, a crossover coefficient of 0.5, a mutation coefficient of 0.05, and stopping criteria of 100 generations. The GA took 1 minute 21 seconds to terminate on an Intel Pentium 4 Microprocessor.

This figure show how ***GOODwater*** converged to the current solution. The number of generations is present on the X axis, and $1/\mathcal{F}$ on the Y axis.

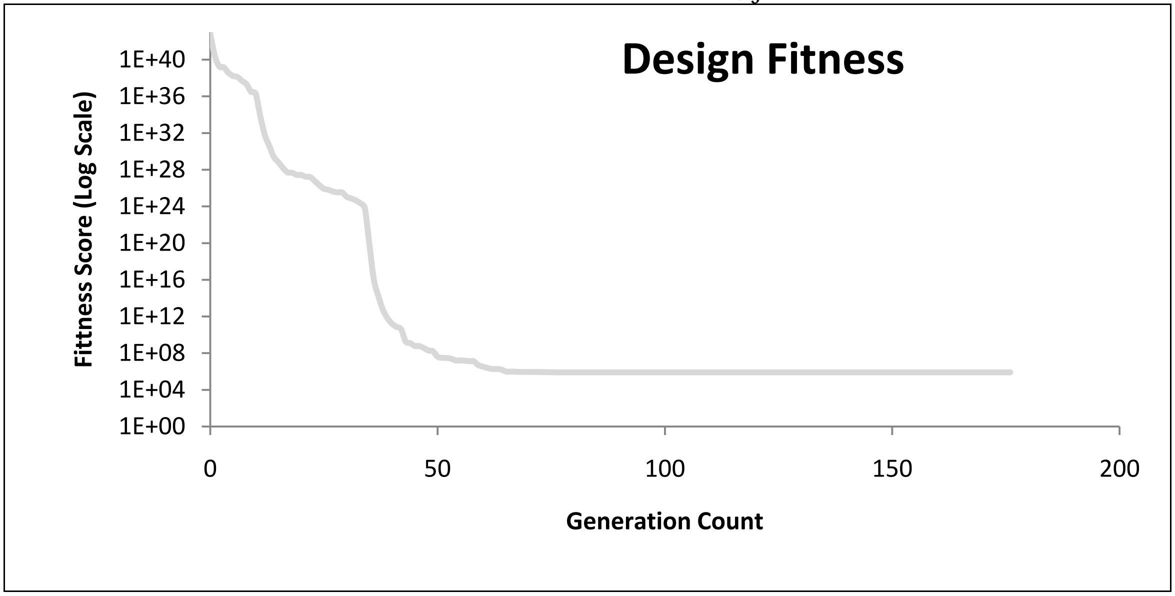

Figure 4.3 Convergence of Genetic Algorithm to Least Cost Solution

The original design for the water system in Guaranal and Quita Sueño was estimated at 1,418,149 $RD, with 845,582 $RD in tubing materials. The ***GOODwater*** solution resulted in a system costing 792,629 $RD for the tubing materials. The original design incorporated 11 break pressure tanks, while the ***GOODwater*** solution consists of 6 tanks. It should be noted that in the actual system, no break pressure tank was installed between the storage tank and the water source, and many problems arose due to broken pipes in this area. In the case study, ***GOODwater*** provided a quick analasys of where pressure limits were exceeded, allowing the user to specifiy break pressure tanks at these locations. The ***GOODwater*** solution includes a break pressure tank in this region and has lower pressures in this section of the pipe line.

4.3 PROJECT PLANNING

GOODwater was used to recreate a budget for the water system in Guaranal and Quita Sueño. For the componets listed in the design stage all the required items were listed in the *COMPONENTS* menu of the PLANNING module. These materials were then copied to the *MATERIALS* page. Prices from the authors original budget were used for the all the items required by the budget. The full project budget as created by ***GOODwater*** is available in Appendix E.

The PLANNING module also includes the Tank Sizing Tool and Air Block & Washout Tool. The demand schedule used in this case study is presented in Table 4.3. The software suggests a tank volume of 45,505 L if a safety factor of 1.5 is input (Peace Corps DR uses this safety factor on their tanks). The tank constructed in Guaranal and Quita Sueño has a volume of 45,000 L, which is very close to the value calculated by the software. The software also suggested 17 locations where air blocks may be an issue, and 13 locations where washouts should be installed. In the actual system constructed, there were three air blocks, all within 500m of the source. The other points suggested by ***GOODwater*** did not form air blocks.

Table 4.3 Community Water Use Schedule Input for Case Study

Period	Percent of Use	Tank Inflows	Tank Outflows	Tank Level
12:00pm-3:00am	0 %	10260 L	0 L	53220 L
3:00am-6:00am	40%	10260 L	32000 L	31480 L
6:00am-9:00am	30 %	10260 L	24000 L	17740 L
9:00am-12:00am	0 %	10260 L	0 L	28000 L
12:00am-3:00pm	0 %	10260 L	0 L	38260 L
3:00pm-6:00pm	0 %	10260 L	0 L	48520 L
6:00pm-9:00pm	30 %	10260 L	24000 L	34780 L
9:00pm-12:00pm	0 %	10260 L	0 L	45040 L

4.4 IMPLEMENTATION PHASE: Guaranal Y Quita Sueño

The IMPLEMENTATION module was used to create a calendar for construction of the current system. Times were estimated for each component. The normal Dominican rainy season was also included. Appendix E contains the full report.

4.5 PROJECT EVALUATION

The final module in the ***GOODwater*** software evaluates the project's sustainability. For each module, tasks that were accomplished during the author's time in the Dominican Republic were checked. The project received a score of 76 out of 100. Each individual stage was also scored, as well as the specific suitability categories. Radar plots of these results are available in Appendix E.

5 CONCLUSIONS AND RECOMMENDATIONS

GOODwater has been developed to assist in improving the lives of those facing water scarcities. It is hoped that by using this software managers and engineers of water will be better able to provide their needed services. This chapter presents concluding remarks about the software discussed in this manuscript. Recommendations for future development are also presented.

5.1 FINAL CONCLUSIONS

This manuscript presented software to be used by organizations, individuals, and institutions involved in managing rural water projects. The motivation for this research stemmed from time spent in working with rural water systems as a Peace Corps Engineer in the Dominican Republic. Five main modules were presented which help the manager of a water supply project. The target audience for this work are those individuals worldwide involved in water systems projects who do not have the knowledge, time, or tools accomplish their task efficiently.

Water scarcity and quality are serious problems affecting many individuals throughout the world. Gravity flow water systems provide a cost effective means of providing those in need of improved water with a sustainable service. The current tools and methods utilized by engineers addressing rural water systems are discussed above. It is clear that a need existed for a tool specifically tailored to address the unique challenges of development of rural water systems. It is hoped that the software package ***GOODwater*** can fill this void.

GOODwater was developed in Microsoft Excel®, using the Visual Basic for Applications programming language. The program consists of different modules which assist the project manager during the various life stages of a project. Menus and navigation are intuitive to use and simple to learn. Once an organization sets up a ***GOODwater*** template, users can quickly enter in information about the proposed system and generate standardized reports. A module is provided to help in assessing the suitability of different sites for a gravity flow water system. Once a site is chosen, detailed topographical information needs can be entered into the design module. This module creates a system design optimized for least capital cost using a genetic algorithm. Budgets and schedules can also be prepared in subsequent modules of the software. Finally ***GOODwater*** evaluates the sustainability of the project throughout its lifespan. A case study was presented in which ***GOODwater*** was applied to the communities of Guaranal and Quita Sueño in the Dominican Republic, where the author lived for two years.

5.2 RECOMMENDATIONS FOR FUTURE WORK

GOODwater provides new tools for the water system project manager. However, there are many more steps which can be taken. First, translation of ***GOODwater*** into different languages would greatly benefit those in other countries working on similar water supply projects. Water scarcity affects many non-English-speaking nations throughout the world, and ***GOODwater*** was designed with these people in mind.

The case study presented demonstrates the software's ability to assist in a water supply project in the Dominican Republic. Due to the author's familiarity with this country and their water needs, a bias may exist within the software towards practices and methodologies of this region. Further case studies with projects from different regions of the world, and different types of water projects, should be carried out. By rigorously testing the software with different case studies, bugs, and errors can also be identified and corrected.

The genetic algorithm optimization routine used in ***GOODwater*** provides a simple solution to the problem of pipe configuration. Many different genetic algorithms have been developed during the last decades, and many of these have been applied to water system optimization. Improving the quality and complexity of the optimization engine in ***GOODwater*** may provide users with more accurate and quicker results.

In addition to the optimization engine, ***GOODwater*** also includes many other automated tools to assist in water project design and implementation tasks which provide for opportunities for future work. The air block tool is an example of one tool that could be improved to diagnose more precisely the size and location of pockets of air which may become entrapped in a water supply system. Other tools not present are items such as a calculator for the tension and anchor weights necessary when suspending pipe materials from suspended cables. This situation often arises when rivers or other obstacles must be crossed. A tool which helps in planning the quantity of materials needed to construct a tank of a given volume could also be included in the software. Standard blueprints of different components could also be integrated into the ***GOODwater*** program.

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APPENDIX A: GFWS DESIGN SURVEY RESPONSES

- Gravity Fed Water System Design Survey –

Your Name: Respondent 1 **Date: April 15, 2007**

- ***General Project Information***

How many projects were you involved in? (And where) 4 Projects – Dominican Republic
1. Peace Corps - Design and Construction of gravity fed water system in El Copey de Altamira
2. CORAAPLATA – Design and proposal of the rehabilitation of 42 km of streams in Puerto Plata
3. CORAAPLATA – Supervision of the construction of a sewer system in a small neighborhood, Padre Granero, in Puerto Plata

What was your role in these projects?
1: Surveyor, Designer, Manager, Supervisor. 2: Surveyor, Designer. 3: Supervisor

- ***Specific Design Criteria***

What kind of topographical survey was performed? (GPS, Abbney level, a mix, other, etc.)
1. Abney level.
2. Measuring tape to measure the lengths of the rives and average depth.
3. None

What kind of source was used?
1. Spring Source
2. N/A – design never implemented– never made it into the CORAAPLATA budget
3. N/A

How many gallons did you design you system to carry per person per day? (or per house)
100 gal/household ~25gpcd
What formulas did you use to calculate the flow rates within the system? (List whatever you can here) The flow from the source to the tank was taken as the actual flow going into the designed pipe size, as it traveled along the flow changed according to headlosses (iterative process). The flow in the distribution system was taken as the flow from the tank minus headlosses minus flow from every five houses in the system to the end (iterative process).
What kind of storage tank was built? (And with what materials)
Block tank – blocks, rebar, cement, sand, gravel, HG pipes for exits, entrances, valves, wood
What type of connection did the users receive?
Each user has a llave outside of their home.
What was the source for all these design criteria that you used? (i.e. Local government regulations, Peace Corps suggestions, what it says in Jordan and so on, …) Source of design was from Basic Hydraulics class in school and head losses were from Peace Corps suggestions.

- ***Specific Design Methodology***

How did you go about designing your system? (Paper and Pencil, using an excel spreadsheet, a program such as EPANET, and so on)
Excel spreadsheet
How did you decide on the tube sizes that you needed? (i.e. graphically, with a program, solved simultaneous differential equations, and so on) The pipe sizes within the system were based on several factors, the static and dynamic head, the frictional losses, the flow and the ground profile. The basic energy equation was used to calculate the pipe diameter and the head losses were calculated using the "Rigid PVC Frictional Head Loss Factors" table from Faiia, 1982, as was used by several other Peace Corps Volunteers.
Did you use a computer in any part of the design process, and if so for what and with what programs? I used excel during the whole process. I put the survey data points in to look at the ground profile, calculated the headlosses, calculated the flows, calculated the pipe diameters
What were the limitations to the design method you used? (Could there be any improvements you can think of?) I would have probably calculated the headlosses differently if I were to do it over again maybe using the Darcy Weisbach equation, but I think that it wouldn't have really made that much of a difference.. I think the way we did it was pretty basic and there's not much variability to basic hydraulics.

Please email this survey to Stephen Good at [redacted]. Thank you very much!

Figure A.1 GFWS Survey Response 1

- Gravity Fed Water System Design Survey –

Your Name: Respondent 2 **Date: 20 March 2007**

- ***General Project Information***

How many projects were you involved in? (And where)
Many, in Honduras
What was your role in these projects?
Surveyer, designer, sometimes organizer.

- ***Specific Design Criteria***

What kind of topographical survey was performed? (GPS, Abbney level, a mix, other, etc.)
Used GPS and altimeters for preliminary work, locating potential sources and house locations to rough in a general feasibility; Abney for actual surveying, with some use of altimeter to confirm critical points.
What kind of source was used?
Small streams or stream/spring combinations.
How many gallons did you design you system to carry per person per day? (or per house)
Ideally 25 – 35 g/p/d. Going toward the higher end for more suburban areas. If no alternatives available, would design for as little as 17 g/p/d, after growth calculation.
What formulas did you use to calculate the flow rates within the system? (List whatever you can here)
Hazen-Williams
What kind of storage tank was built? (And with what materials)
None during my time, but usually reinforced brick sealed with grout.
What type of connection did the users receive?
Usually a hose bib in rural areas, service connection to interior plumbing in suburban areas.
What was the source for all these design criteria that you used? (i.e. Local government regulations, Peace Corps suggestions, what it says in Jordan and so on, …)
From Peace Corps, with referenced to sources.

- ***Specific Design Methodology***

How did you go about designing your system? (Paper and Pencil, using an excel spreadsheet, a program such as EPANET, and so on)
Usually a spreadsheet, with final drawing pencil-on-paper
How did you decide on the tube sizes that you needed? (i.e. graphically, with a program, solved simultaneous differential equations, and so on)
Graphically, for the most part. No loops, so generally simple.
Did you use a computer in any part of the design process, and if so for what and with what programs?
Excel for design, Word for communications, and Minesweeper for diversion.
What were the limitations to the design method you used? (Could there be any improvements you can think of?)
Never real clear on instantaneous flow rates at system periphery. i.e. when 3 neighbors at the end of a line all open the tap, what happens? Do I get negative pressure at any point?

Please email this survey to Stephen Good at [redacted]. Thank you very much!

Figure A.2 GFWS Survey Response 2

- Gravity Fed Water System Design Survey –

Your Name: Respondent 3 **Date: 3/27/07**

- ***General Project Information***

How many projects were you involved in? (And where)
6 projects (houndours)
What was your role in these projects?
Both design engineer and project manager

- ***Specific Design Criteria***

What kind of topographical survey was performed? (GPS, Abbney level, a mix, other, etc.)
GPS and Abney Level
What kind of source was used?
Springs and small streams
How many gallons did you design you system to carry per person per day? (or per house)
20-25 gallons per person per day
What formulas did you use to calculate the flow rates within the system? (List whatever you can here)
Real Flow formulas embedded within spreadsheets, which accounted for frictional losses, changes in elevation, etc…
What kind of storage tank was built? (And with what materials)
Reinforced concrete and brick, circular, 2,000 – 10,000 gallons
What type of connection did the users receive?
Each house received an outdoor standpipe, bronze
What was the source for all these design criteria that you used? (i.e. Local government regulations, Peace Corps suggestions, what it says in Jordan and so on, …)
Both national government guidelines and peace corps recommendations

- ***Specific Design Methodology***

How did you go about designing your system? (Paper and Pencil, using an excel spreadsheet, a program such as EPANET, and so on)
Excel Spreadsheet
How did you decide on the tube sizes that you needed? (i.e. graphically, with a program, solved simultaneous differential equations, and so on)
program
Did you use a computer in any part of the design process, and if so for what and with what programs?
The whole process. Data entry, design (both excel) and drawings (Auto-CAD)
What were the limitations to the design method you used? (Could there be any improvements you can think of?)
Not able to teach nationals to use it and leave it behind. Too often equations had errors and needed to be worked out making it tough for a non engineer to use.

Please email this survey to Stephen Good at [redacted]. Thank you very much!

Figure A.3 GFWS Survey Response 3

- Gravity Fed Water System Design Survey –

Your Name: Respondent 4 **Date: 2003-2006**

- ***General Project Information***

How many projects were you involved in? (And where)
6 projects while I was a PCV in Fianarantsoa, Madagascar.
I remain involved in the design and implementation of GFWSS with local NGO's in Madagascar in my position as water and sanitation advisor for the USAID Santenet and ERI projects.
What was your role in these projects?
Survey, design, buy materials, and oversee implementation. Establishing and supporting community management structures

- ***Specific Design Criteria***

What kind of topographical survey was performed? (GPS, Abbney level, a mix, other, etc.)
Abbney level
What kind of source was used?
Spring
How many gallons per day per person was allotted? (or per house)
60 liters per household per day (drinking, cooking, body washing) other water needs (i.e. washing clothes, animal husbandry, gardening) were not designed to be provided by the water supply system.
What formulas did you use to calculate the flow rates within the system? (List whatever you can here)
Bernoulli's pipe flow equation for the distribution network when the pipe was flowing full, continuity equation
What kind of storage tank was built? (And with what materials)
A square or slightly rectangular tank; made of reinforced concrete
What type of connection did the users receive?
Public Tap Stands
What was the source for all these design criteria that you used? (i.e. Local government regulations, Peace Corps suggestions, what it says in Jordan and so on, …)
Jordan, previous PCV's in MTU program, background in hydraulics. At that time there were no standard regulations in Madagascar, there are now.

- ***Specific Design Methodology***

How did you go about designing your system? (Paper and Pencil, using an excel spreadsheet, a program such as EPANET, and so on)
Excel Spreadsheet
How did you decide on the tube sizes that you needed? (i.e. graphically, with a program, solved simultaneous differential equations, and so on)
Trial and error with an excel spreadsheet. Iterative solution of choosing the pipe sizes and viewing the corresponding HGL
Did you use a computer in any part of the design process, and if so for what and with what programs?
Yes, to run the excel software
What were the limitations to the design method you used? (Could there be any improvements you can think of?)
-The Abbney level, of course, has it's limitations with accuracy that must be considered. I feel that some of the recommendations in Jordan's guide are idealized. For instance, it is often not possible to have 10m of head between the ground level and HGL or 7m of residual head at every tap. In these cases proper judgment needs to be used so that needy villages are not denied water because of blind adherence to ideal, textbook conditions.
-The lack of a proper field textbook for the design of a square, circular or rectangular reinforced concrete reservoir. My reservoirs were almost certainly over designed. Valuable resources were wasted buying unnecessary materials. A field manual should be written about how to build a reinforced concrete reservoir using minimal materials for different size storage tanks.

Please email this survey to Stephen Good at [redacted]. Thank you very much!

Figure A.4 GFWS Survey Response 4

- Gravity Fed Water System Design Survey –

Your Name: Respondent 5 **Date: March 13, 2007**

- ***General Project Information***

How many projects were you involved in? (And where)
2 Separate Aqueducts in the Southwest Dominican Republic (2001-2002).
What was your role in these projects?
Water/Sanitation Volunteer – Engineered, Designed and Managed construction of the sytem.

- ***Specific Design Criteria***

What kind of topographical survey was performed? (GPS, Abbney level, a mix, other, etc.)
We used an Abney Level. Upon completion my PC Volunteer Coordinator came out to check my start and end elevations. I think I was off by approximately 5 meters, over a 3-4 KM length. (We were very happy)
What kind of source was used?
1 was a mountain spring and the second tapped the 4" overflow pipe of an existing system which was using a mountain spring. (The overflow was constant as their was an abundance of water.
How many gallons did you design you system to carry per person per day? (or per house)
50 liters/person/day
What formulas did you use to calculate the flow rates within the system? (List whatever you can here)
Plotted Head Loss Tables Using Head Loss Tables Provided in PC Dominican Republic Handbook.
What kind of storage tank was built? (And with what materials)
Square 6" Block Tank –Reinforced with #3 Rebar. Poured Foundation, midwall bond beams and top bond beam poured monolithically with reinforced roof. Corners were also poured reinforced columns. Tanks were 10,000 gallon tanks, way oversized to keep the community positive toward the project. (Who wants a dinky tank?) Luckily the budget could handle the additional cost. Tanks were built with skilled masons living in the community with my direction.
What type of connection did the users receive?
Each family who worked on the brigades their share got a tapstand at their house.
What was the source for all these design criteria that you used? (i.e. Local government regulations, Peace Corps suggestions, what it says in Jordan and so on, …)
A little bit of Jordan, a lot of PC advice from experienced trainer and also the Peace Corps Water/Sanitation manual.

- ***Specific Design Methodology***

How did you go about designing your system? (Paper and Pencil, using an excel spreadsheet, a program such as EPANET, and so on)
Paper and Pencil and then plotting Head Loss graphs on Excel.
How did you decide on the tube sizes that you needed? (i.e. graphically, with a program, solved simultaneous differential equations, and so on)
Graphically with Head Loss Tables.
Did you use a computer in any part of the design process, and if so for what and with what programs?
Was not available in 2001-2002. (in my area)
What were the limitations to the design method you used? (Could there be any improvements you can think of?)
Personally, I think since I did it by hand, basically on my own their was some apprehension and factors of safety were increased to make myself feel confident and avoid any costly mistakes. If a computer was available, I may have been more confident, the design may have been done quicker, but computer programs don't always take everything into account, so it may not have rendered a better design. This is a great discussion topic. While designing a system, I think your biggest fear is failing to come through for all these people that have become your family.

Good Luck with your research Stephen.

Please email this survey to Stephen Good at [redacted]. Thank you very much!

Figure A.5 GFWS Survey Response 5

- Gravity Fed Water System Design Survey –

Your Name: Respondent 6 **Date: 23/4/2007**

- ***General Project Information***

How many projects were you involved in? (And where)
1. **Laleia, East Timor, 2006**
2. **Samalai, East Timor, 2006**
3. **Cairui, East Timor, 2006**

What was your role in these projects?
Project Manager and WatSan Engineer during final 4 months (project length was 12 months)

- ***Specific Design Criteria***

What kind of topographical survey was performed? (GPS, Abbney level, a mix, other, etc.)
GPS
What kind of source was used?
Laleia - 4" Bore well (existing)
Samalai - 4" Bore well (new)
Cairui – 2 x 4" Bore well (new)
All 12-30meters deep
How many gallons per day per person was allotted? (or per house)
30L/person (Timor standard)
What formulas did you use to calculate the flow rates within the system? (List whatever you can here)
EPANet computer software for flow rates and head loss
What kind of storage tank was built? (And with what materials)
Laleia – addition of 20kL concrete reinforced
Samalai - 30kL concrete reinforced
Cairui – 60kL concrete reinforced
What type of connection did the users receive?
Laleia – rehab only of existing house hold connection
Samalai - public tapstand 1:80persons
Cairui – public tapstand 1:80persons
What was the source for all these design criteria that you used? (i.e. Local government regulations, Peace Corps suggestions, what it says in Jordan and so on, …)
Sphere Standards and East Timor Department of Water and Sanitation Guidelines (DNAS – Departmentu National Aguas ho Sanamentu)

- ***Specific Design Methodology***

How did you go about designing your system? (Paper and Pencil, using an excel spreadsheet, a program such as EPANET, and so on)
EPANET and Excel
How did you decide on the tube sizes that you needed? (i.e. graphically, with a program, solved simultaneous differential equations, and so on)
EPANET to meet general flow minimums and maximums
Did you use a computer in any part of the design process, and if so for what and with what programs?
1 Laptop with: Drawings: CorelDraw, Excel: Calculations, Budgeting, and Design, Word: Reporting, documentation, planning, implementation, celebration, EPANET: Design

Please email this survey to Stephen Good at [redacted]. Thank you very much!

Figure A.6 GFWS Survey Response 6

- Gravity Fed Water System Design Survey –

Your Name: Respondent 7 **Date: 03/27/07**

- ***General Project Information***

How many projects were you involved in? (And where)
Two – Villages 2-hour walk from each other
What was your role in these projects?
Designer – Project manager, pretty much everything. I hired a mason to build the spring box, and storage tank.

- ***Specific Design Criteria***

What kind of topographical survey was performed? (GPS, Abbney level, a mix, other, etc.)
Abbney level
What kind of source was used?
Spring
How many gallons did you design you system to carry per person per day? (or per house)
We just took whatever the spring could give us. Very dependent on season. During rainey season storage tank was always full, and everybody had water – during dry season, the spring couldn't produce enough to keep tank full.
What formulas did you use to calculate the flow rates within the system? (List whatever you can here)
Flow rates from spring – a bucket and stop watch.
Headloss – Hazen williams
What kind of storage tank was built? (And with what materials)
Concrete – Concrete slab floor with re-inforced concrete block walls – and top slab placed concrete.
What type of connection did the users receive?
PVC line going directly up to the kitchen of each house with simple faucet.
What was the source for all these design criteria that you used? (i.e. Local government regulations, Peace Corps suggestions, what it says in Jordan and so on, …)
A little of all of the above.

- ***Specific Design Methodology***

How did you go about designing your system? (Paper and Pencil, using an excel spreadsheet, a program such as EPANET, and so on)
Paper and Pencil
How did you decide on the tube sizes that you needed? (i.e. graphically, with a program, solved simultaneous differential equations, and so on)
Headloss Calcs
Did you use a computer in any part of the design process, and if so for what and with what programs?
Briefly, to put together list of materials for cost estimate
What were the limitations to the design method you used? (Could there be any improvements you can think of?)
Hire a more experienced Mason. We used local sand and gravel (ocean stones), which had some organics and probably made a weaker concrete.

People became lazy at points, and didn't want to work if food (or money) wasn't being provided. If I had to do it again, I probably provide food every day, so we could do a better job. When only two or three people show up, you can only get a certain quality work.

Also, I think I would rather pour the concrete tank walls, rather than use block. Unless you have a very good mason, I didn't like the method of making a watertight structure out of block.

Please email this survey to Stephen Good at [redacted]. Thank you very much!

Figure A.7 GFWS Survey Response 7

- Gravity Fed Water System Design Survey –

Your Name: Respondent 8 **Date: 03/12/07**

- ***General Project Information***

How many projects were you involved in? (And where)
I designed 18 systems while I was in Honduras. I directed the construction of 3 of the 18 designs.
What was your role in these projects?
For each project I did a topographic study and a design. For 3 of the projects I was able to get funding, buy materials and organize the construction of the projects.

- ***Specific Design Criteria***

What kind of topographical survey was performed? (GPS, Abbney level, a mix, other, etc.)
Abbney level
What kind of source was used?
Springs and small streams
How many gallons did you design you system to carry per person per day? (or per house)
30 gallons per person per day
What formulas did you use to calculate the flow rates within the system? (List whatever you can here)
Frictional losses Hazen-Williams
What kind of storage tank was built? (And with what materials)
We built cylindrical tanks, constructed with reinforced brick walls, reinforced concrete ceiling.
What type of connection did the users receive?
One tap at each house, with concrete basin.
What was the source for all these design criteria that you used? (i.e. Local government regulations, Peace Corps suggestions, what it says in Jordan and so on, …)
Peace Corps suggestions

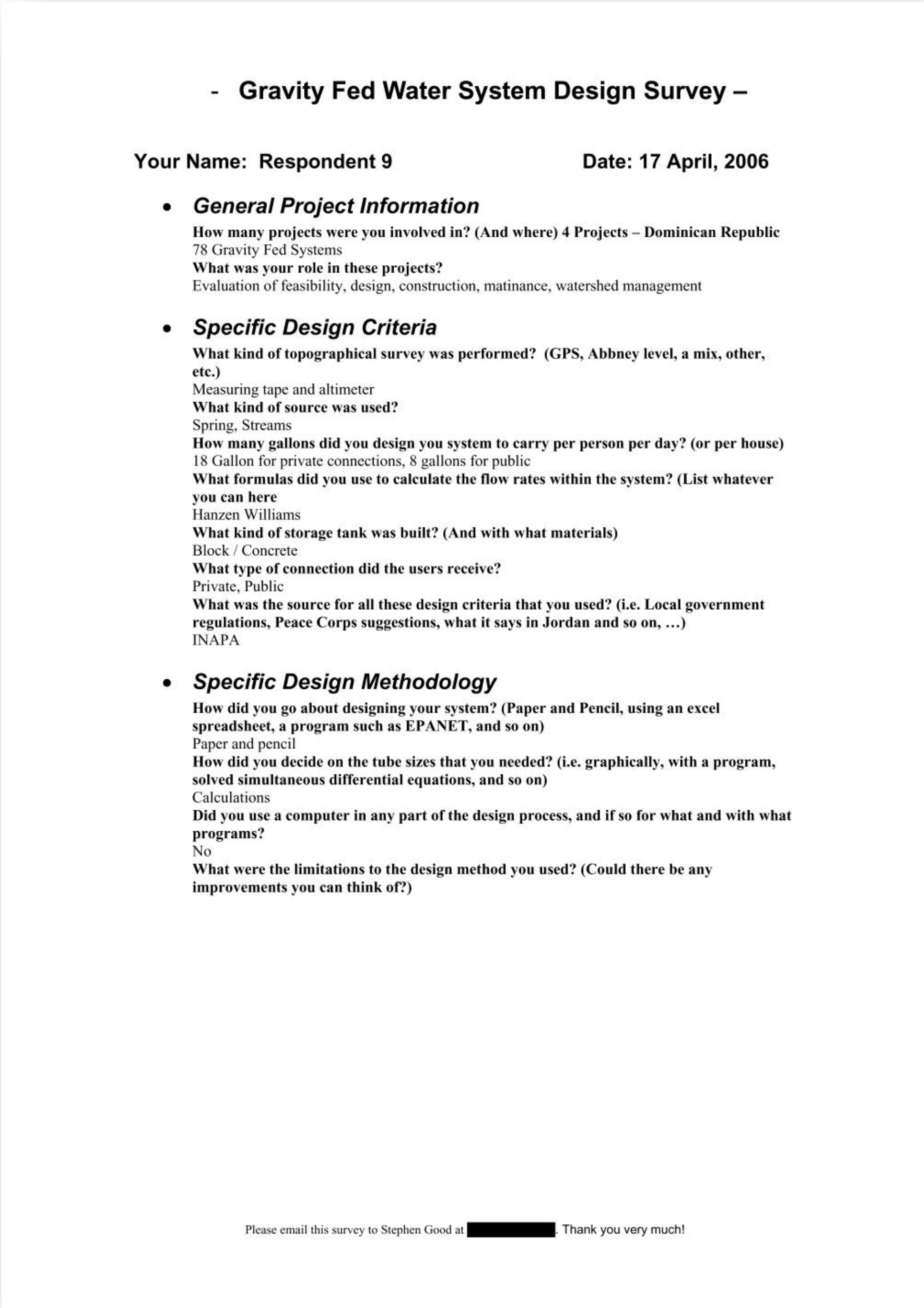
- ***Specific Design Methodology***

How did you go about designing your system? (Paper and Pencil, using an excel spreadsheet, a program such as EPANET, and so on)
Design plans with AutoCAD. Calculations with Excel.
How did you decide on the tube sizes that you needed? (i.e. graphically, with a program, solved simultaneous differential equations, and so on)
Graphically with excel
Did you use a computer in any part of the design process, and if so for what and with what programs?
Yes, design plans with AutoCAD, calculations with Excel.
What were the limitations to the design method you used? (Could there be any improvements you can think of?)
It took a long time. I´m pretty sure there are programs that do a lot of the work for you like WaterCAD. I think it is important to learn calculations with Excel first.

Note: I have also included the Excel program I used with email.

Please email this survey to Stephen Good at [redacted]. Thank you very much!

Figure A.8 GFWS Survey Response 8



- Gravity Fed Water System Design Survey –

Your Name: Respondent 9 **Date: 17 April, 2006**

- ***General Project Information***

How many projects were you involved in? (And where) 4 Projects – Dominican Republic
78 Gravity Fed Systems
What was your role in these projects?
Evaluation of feasibility, design, construction, matinance, watershed management

- ***Specific Design Criteria***

What kind of topographical survey was performed? (GPS, Abbney level, a mix, other, etc.)
Measuring tape and altimeter
What kind of source was used?
Spring, Streams
How many gallons did you design you system to carry per person per day? (or per house)
18 Gallon for private connections, 8 gallons for public
What formulas did you use to calculate the flow rates within the system? (List whatever you can here
Hanzen Williams
What kind of storage tank was built? (And with what materials)
Block / Concrete
What type of connection did the users receive?
Private, Public
What was the source for all these design criteria that you used? (i.e. Local government regulations, Peace Corps suggestions, what it says in Jordan and so on, …)
INAPA

- ***Specific Design Methodology***

How did you go about designing your system? (Paper and Pencil, using an excel spreadsheet, a program such as EPANET, and so on)
Paper and pencil
How did you decide on the tube sizes that you needed? (i.e. graphically, with a program, solved simultaneous differential equations, and so on)
Calculations
Did you use a computer in any part of the design process, and if so for what and with what programs?
No
What were the limitations to the design method you used? (Could there be any improvements you can think of?)

Please email this survey to Stephen Good at [redacted]. Thank you very much!

Figure A.9 GFWS Survey Response 9

- Gravity Fed Water System Design Survey –

Your Name: Respondent 10 **Date: 11 March, 2007**

- ***General Project Information***

How many projects were you involved in? (And where) 4 Projects – Dominican Republic
Two primary, 5-6 secondary...
What was your role in these projects?
Lead engineer for the two, advisor and trouble shooter for the others

- ***Specific Design Criteria***

What kind of topographical survey was performed? (GPS, Abbney level, a mix, other, etc.)
GPS w/altimeter once, primarily Abbney level, a faw with the good old eyeball
What kind of source was used?
Springs**.**
How many gallons did you design you system to carry per person per day? (or per house)
I forget, what ever the PCDR manual suggests.
What formulas did you use to calculate the flow rates within the system? (List whatever you can here
Within the system just head loss equations... As far as flow rates go between houses most systems in very rural areas branch out like a trees with a lot of space between the houses. It was always by feel, never a set method.
I design for 3gpm per house, then cut it to 1/2 to 1/4.
I look at how many houses are fed from that pipe and cut the number of houses by 1/2 to 1/4. Example: Starting at the last house on the line... 1 house design for 3gpm line conects with neighbors, 2 houses; 6gpm. This conects to a cluster of 8 houses; 12 gpm. This conects to the mainline feeding 100 houses; 75 gpm.
The idea is one tap turning on should never throw off your flow. If it's your close nieghbor the line needs to be designed for two on at the same time. If its from some one up the way design it for a bit bigger. If it's across town you won't feel it at all.
This assumes a fairly flat area. If you got a huge drop of at the end of the line you need to under size these pipes so the folks down low don't drain the line when more than a few people got the taps open.
Or if the end of the line goes up you need to over size the trunk line and under size the radials so they don't take all the water from the people above. Sometimes you even have to put in flow reducers to keep the flow down. Then when you put in reducers people get pissed because they think your giving them less water and that you don't like them then they won't talk to you for a month and you don't know why but don't care because your so busy with the aqueduct that you don't notice then they go to a water committee meeting and talk bad about you the whole time and storm out because you won't say your sorry for some insult that you didn't even know you gave then they decide that they'll just be clever and cut out the reducer and not tell you then when you turn the water on it comes shooting out of their tap so hard they can't even fill up a bucket and then they try and fix it them selves but don't turn off the water first so when they cut the pipe it shoots water all over the road and washes out all the fresh dug trench backfill. AND THEN THEY HAVE THE NERVE TO ASK YOU TO FIX IT! Isn't that right, Ogenio!? You listen to the engineer now don't you*!*

What kind of storage tank was built? (And with what materials)
I had one ferro-cement and one cinder block.
What type of connection did the users receive?
Llave de chorro, one per house. It was a ball valve that was made in italy. The insides were indestructable but the locking mechanism on the top broke with in two seconds of installation. Fortunatly they only took 20 seconds to rebuild and improve.
What was the source for all these design criteria that you used? (i.e. Local government regulations, Peace Corps suggestions, what it says in Jordan and so on, …)
PC suggestions and Jordan. I also saw how a lot of system worked and didn't work. The biggest problem I saw was poorly sized pipes. When people don't get the flow they need they turn it on

Please email this survey to Stephen Good at [redacted]. Thank you very much!

Figure A.10 GFWS Survey Response 10a

- Gravity Fed Water System Design Survey –

and put a bucket under and walk away. Next thing you know it's over-flowing and wasting water

- ***Specific Design Methodology***

How did you go about designing your system? (Paper and Pencil, using an excel spreadsheet, a program such as EPANET, and so on)
Paper-pencil, HP 30 solar, sitting on the patio while my dona brings me fresh cafecito. Man, that was engineering. Sure beats my office now.
How did you decide on the tube sizes that you needed? (i.e. graphically, with a program, solved simultaneous differential equations, and so on)
Estimate flow as previously described and use head loss equationS
Did you use a computer in any part of the design process, and if so for what and with what programs?
Nope. I couldn't count on having access to a computer and I couldn't count on having a printer or power when I could.
What were the limitations to the design method you used? (Could there be any improvements you can think of?)
Everything worked. The biggest break through was to stop thinking of the flow through the distribution system as continuous and even. It's not. You got to look at every realistic scenario looking for the worst case. What if every other house has thier tap on, all the houses in this section. All the houses here and this one there. Etc... Some you just can't economicly handle, some will be obvious and you have to cover them. People need to count on that water. That keeps people from hording and keeping the tap on at all times to catch it when it does come and really throwing off the flow.
But what do I know, I'm just a Geotech.

Please email this survey to Stephen Good at [redacted]. Thank you very much!

Figure A.11 GFWS Survey Response 10b

APPENDIX B: SOFTWARE REVIEW CRITERIA

Information Available Online
Water projects, and the agencies involved in them, are often located in remote locations. Software with no information available online can be difficult for GFWS project managers to know about. If information about the software is present on the World Wide Web, a positive was marked for this category.

Free to Obtain
Designers of gravity flow water systems in remote areas of the world are often faced with limited or no resources to purchase software for their work. Completely free products are therefore of the most useful to rural water system designers in the developing world. If any costs were necessary to obtain the software a negative was marked for this category.

Stand Alone Program
Many of the reviewed software programs available are not stand alone software programs, but instead require another program from within which they must be run. Examples of operating platforms are Autodesk's AutoCAD, ESRI's ArcGIS, or Microsoft's Excel. If the reviewed software is not "stand alone" but requires another operating platform, the costs and technical requirements of these platforms must be considered. Designers in remote areas working independently or for budget constrained organizations may not be able to purchase the platform needed to run a given software program. If additional software is necessary to run the software a negative was marked for this category.

Help Manuals Included
Documentation about how to use software is important. When no help files are included the software may not be used correctly, or to its fullest potential. If Help Manuals are included a positive was marked.

Low System Requirements (<100MB)
Each piece of software requires specific computer resources in order to be run. Memory requirements and processor speeds are an important issue. Users in remote or rural areas may not have access to the newest computers. Software which does require large quantities of memory or fast processors is preferred. Installation of a given program is also an important consideration. If the software requires more then 100 MB of memory space a negative was marked for this category.

Feasibility
Assessment of feasibility for projects is important. If a feasibility study is not completed, work may begin and be forced to stop once conditions become apparent. Software can guide managers through feasibility assessment, and if a tool is included to assist project managers in this regard, a positive score is noted.

Design
Proper design of a pipe networks and structural components is necessary for systems to operate at their intended level of service. Software created to assist in this task can be very useful to the engineer of a GFWS. If design tools are included with the software, a positive is marked for this category.

Planning
In order to move a water project from a design into reality planning is necessary. These plans are often created by the same individual who designs a given water system. Many system designers use the same standard components and procedures throughout their designs. Plans for spring boxes, small dams, various tank types, and various connection types, can be included with a software package. Locations of materials and schedules of workers must be assessed during this phase. The inclusion of a planning module can ensure that the project moves smoothly, and if one is present a positive score is earned.

Implementation
Implementation of water projects can be a complicated endeavor. Many tasks must me kept properly organized and timed correctly. Movement of materials, labor, and funds must be properly supervised. If tools are included to assist in implementation of a project, a positive is marked.

Evaluation
When a construction of a project is completed a final stage is entered. Community members must be trained in operation and maintenance of the system. An evaluation of the entire project is important to ensure that problems are resolved and do not reoccur. If Operation, Maintenance, and Evaluation are treated by the software, a positive score is noted.

Conduction Line Design
Supply of water to the site of a community's reservoir is often dependent upon the amount of water found in a given water source and the overall daily water demand of a community. Water carried in this, the conduction line, often travels long distances over uneven terrain. A tool to assist in design of the conduction line included with the software merits a positive mark.

Distribution Network Design
Distribution lines are frequently dependent upon the instantaneous demand of a users spread throughout the community. The distribution network can be a complicated system and require much calculations. If a tool is included in the program to help at this stage, a positive score is marked.

Hydraulic Calculations
Water supply systems are complex engineered systems. The water carried by pipes is pressurized. Information about the hydraulic conditions present in a system is important for safety, service, and sustainability of a system. If hydraulic calculations are preformed by the software and presented to the user a positive score is marked.

Capital Costs Optimizer
The largest capital cost of small water systems is often the purchase of tubing to connect water sources to tanks and connect tanks to community members. Designers of small systems need to minimize these costs as there are often large budgetary constraints on the resources of a given community. A tool providing the design with the least capital costs that that satisfies specified constraints is very important in producing effective designs. The complexity of the optimization tools found within the reviewed software varies greatly. The most important feature is that the optimized system can be found quickly and easily. If a tool is included for a user to generate an optimum design the program was marked positive in this category.

Tank Volume Calculator

Choosing the correct volume of the reservoir tank or tanks in a given systems is very important in the design of small scale water systems. The size of a reservoir tank must be calculated to match the consumption pattern of a community. That consumption pattern must be balanced against the output of the sources to be used. If there is little demand, but much water, the tank can be small. For a community with large water demand, but small flow rates from their sources, tanks must appropriately be sized larger. Oversized tanks can be a problem due to excessive costs. If a tool that calculates the optimum tank size for a given community/source configuration is present, a positive was recorded for this category.

Air Block Diagnosis

As water moves through tubing air can become trapped, blocking further flow. Special steps and equipment can be utilized to mitigate air block problems if their probable locations are know. If a tool is included that presents a diagnosis of likely air block locations a positive score is noted.

Simulation capabilities

After a water system is designed it is important to model the flows and pressures to make sure there are will be no problems. This modeling is accomplished with the use of simulation tools. Simulators let the user's model specific instances of a system. The inclusion of a simple simulation tool to diagnose water system designs is necessary for a positive mark in this category.

Budgeting tools

With a small scale water system properly designed and modeled, a budget must be often be compiled for the construction of the system. For each water line, a specific number of tubes must be included in the budget. For elements such as tanks and tap stands, pipe fittings, construction materials, and other supplies must be summed. Throughout the project transportation and labor costs may need to be calculated. When a budget is linked with the design in one program, any changes to the design propagate throughout the budget as well. Work orders of material lists can be generated for item quotes and material purchases. Summaries of the finances for a project often need to be presented to financiers or project overseers. The benefits of a budgeting tool integrated into the water system designer are significant, and if included a positive score is marked.

Plotting/Graphing tools

The different profiles and layouts of a small water system are often hard to visualize without the plots. Hydraulic grade lines and ground surface elevation plots are common engineering tools generated for water projects. Plan views of the layout of a water system allow for the visualization of the complete system at one time. The tools necessary to create these plots are not complicated. However, not all water systems designers may know how to generate professional looking plots. Inclusion of a plotting tool is important, and if present, a positive score is noted.

Report Generator

With all of the information generated in the process of designing water systems, high quality reports are important. These reports often include many sections. General information about the communities involved can be presented. The topographical information from the survey, and the designed tubes sizes and flow rates for each water line can also be incorporated into a report. Parameters of water system elements such as the tanks and tap stands can provide useful information. Construction plans of any elements may also accompany a report. Any plots of ground surface profiles and hydraulic grade lines can also be included in a report. A prepared budget with a work order may also be presented. Overall, any information stored within a given program should be able to be extracted through the compilation of a detailed report. The ability of a program to generate quality reports is necessary to score in this category.

Sustainability Assessment

Sustainable project implementation is important. By considering social, economic, and environmental concerns of stakeholders the long term viability of a project can be increased. Any tool included that helps in assessing the sustainability of a project earns a positive mark.

APPENDIX C: ACTION AND ASSESSMENT STEPS

Information in this appendix adapted from the work of J. McConville (McConville 2006)

Site Assessment Stage

□ Generate a yearly calendar of work and social life in the community.
- How is a year defined?
- How are the seasons identified?
- What are the characteristics of each season?
- What is the primary employment in the area?
- Is this work constant throughout the year or seasonal?
- What time of year is the busiest? Are other seasons very slow?
- Are there patterns of seasonal migration?
- What is the primary religion in the area?
- When are the major holidays?
- When do weddings, baptisms, and other social ceremonies take place?

□ Identify social preferences and traditional beliefs associated with water supply and sanitation practices.
- Are certain water sources preferred over others?
- Is there folklore or old stories associated with water sources or water use?
- Are there traditional methods for protection a water source?
- Do people add things to their water? At the source or at home?
- Do people consider sanitation issues around the water sources?
- Are there social caste issues about the use of water from certain sources?
- Is there a history of filtering or screening water sources?
- Are there seasonal changes in the quality of the water supply? How are they explained?
- What is the preferred sanitation method in the community?
- What are preferred methods of anal cleansing?
- How do people feel about handling excreta (even when decomposed)?
- Are the religious constraints to be considered?
- Do people believe that excreta are harmful? .
- Are people afraid to use latrines? Why?
- Are there taboos associated with washing hands with soap? (In Mali, this practice was believed to wash away a person's wealth)
- For further examples refer to (Pickford 1995).

□ Determine the level of health education in the community.
- Have community members been involved in answering questions on community health? In formal and informal settings?
- What is their education background?
- What health education issues are covered in schools?
- Who receives education? Men or women? (Note: that there may be discrepancies between who receives education and who performs water/sanitation related tasks)
- How often do people get sick in the community?
- Why do people get sick? (According to them)
- Do people connect water and sanitation issues with disease?
- What is the community motivation for improved water and sanitation services?

- Are there health care facilities available?
- How is the quality of the water? How is quality perceived in the community?
- How do you perceive the cleanliness of the community? How do community members perceive it?
- Do they wash their hands with soap?
- Do they have a latrine?
- Do they use a latrine? Do the children?

□ Recognize differences in gender roles in water and sanitation.

- How do men use water? How much?
- How do women use water? How much?
- Who provides water for the household? Agriculture? Business?
- How much time do men/women spend per day on water collection?
- Do men and women follow separate sanitation practices?
- Are there separate latrines for men and women?
- Who is in charge of the children's hygiene?

□ Conduct a participatory needs assessment at the local level to determine local development priorities.

- Did you use a participatory approach to needs assessment? There are a range of methodologies based on a participatory approach to evaluate development needs, for example: Rapid Rural Appraisal (RRA), Participatory Rural Appraisal (PRA), and Participatory Analysis for Community Action (PACA). In general, they all aim to identify community problems and to plan solutions with the active participation of the community members (Selener and Carvajal 1999). Each method uses a set of "tools" to assist the locals in analyzing the characteristics of their community (community map, social calendars), identifying problems (problem lists, priority analysis), and developing possible solutions (solution brainstorming, feasibility matrix). Participatory tools are most useful when a representative group of community members are involved (men, women, youth, elders, ethnic groups, community leaders and organizations). The participatory needs assessment must take place in the community itself. In depth literature can be found on all of these methods. It is not necessary that all techniques be used during the needs assessment. In fact, development workers should select the tools that are the most applicable to the community. Whatever tools are used the result should still be the identification of the top community needs.
- Is the group involved in the needs assessment representative? Are they influenced by local power groups?
- Can the following types of questions be answered by community members?
  - □□ What are the general characteristics of this community? (employment, services available, ethnic groups, community history)
  - □□ What are the strengths of the community?
  - □□ What are the problems in the community?
  - □□ What is thepresent level of satisfaction with the existing water/sanitation system?
  - □□ What are the causes and effects of these problems?
  - □□ Which problems have priority for the community?
  - □□ What can be done to address the problems?
  - □□ Does the community have knowledge of options for improved water/sanitation systems?
  - □□ What are the preferred options?
  - □□ What technical, financial, and capacity building assistance does the community need

to reach these solutions?

□ Identify stakeholders and community leaders.
- Who will be directly affected by project intervention?
- Who will be indirectly affected?
- Who will pay?
- Are both genders considered?
- Are all age groups considered?
- Are there ethnic groups with varying needs? Can they be equally or proportional represented in the project process?
- Who are the community leaders?
- Who are the local influential people (LIPs)?
- Are there people with veto power? (mayor, village chef)
- Are there influential people without official titles who will affect how others accept the project? (leading scorer on the soccer team, favorite old man, people of wealth or connections)
- Are all these people behind the project? What will make them agree?
- Are there any existing water/sanitation committees?

□ Determine the type of political organization and cohesion at the community level.
- How is the community governed?
- Who are the decision makers in the community? Official? Unofficially?
- How representative is the community government?
- What is the level of participation in community decision making?
- Who implements the decisions?
- What are the rules and procedures governing community action?
- What is the level of participation in community activities?

□ Reach a consensus with community members that project intervention is appropriate.
- Is there a perceived need for water and/or sanitation intervention within the community?
- Do community members understand the project possibilities?
- Is the community aware of the capabilities/limitations of the development workers?
- Are community priorities in line with development workers' area of expertise?
- Is there agreement within the community to participate in project intervention?

□ Conduct a situational analysis of regional and national issues such as political structure and stability, government policies, and foreign aid.
- Are there any overwhelming local/regional issues that may affect the project?
  - War
  - Drought
  - Disease (AIDS and other epidemics)
- How stable is the national government?
- What is the financial situation of the country?
  - Debt levels
  - Inflation rates
- What is the structure of the national government?
- What do community members think about the government?
- How active are government officials in the community?
- Does the government address water and sanitation issues?
- Are there government programs/initiatives in water/sanitation?

- How transparent are government finances and policies?
- How prominent are foreign aid projects?
- Are there NGO programs/initiatives in water/sanitation in the area?
- Have you looked at potential information sources such as: UNDP Human Development Report, local interviews, government and NGO reports?

□ Ensure that proposed project is consistent with regionally identified development priorities and plans.
- What are the priorities outlined in the National Poverty Reduction Strategy Papers (PSRPs), National Strategic Plans, and/or Sector-Wide Approaches (SWaps)? These are national initiatives that outline the development priorities for the country. There will be more government funding and institutional support for projects that address these priorities.
- Are there local development schedules within the community or region? (check with mayor, village counsel, community leaders)
- What is the availability of grants or aid money for water and/or sanitation intervention?

□ Research the history of NGO and government projects in the area.
- What NGOs have worked in the community before?
- What type of project were they involved in?
- Were they successful?
- What work has the government done in the area?
- How was the community involved in the project implementation?
- Are past project reports available?
- Are the projects on-going?

□ Establish communication lines with existing NGO and/or government institutions in the area.
- Have government officials in the area been contacted?
- Have NGOs with a history in the area been contacted?
- Are they familiar with your organization?
- What initiatives/projects are they currently working on in the area?
- What advice do they have for working in the area?

□ Understand the local and national economic situation (poverty level, employment, cost of living, flow of resources).
- What is the primary source of employment?
  - National?
  - Locally?
- How stable is the employment level?
- What is the average income?
- How is wealth distributed? (ratios of high/low income, inequality in wealth)
- What is the average cost of living in the community?
- What do people spend money on? When?
- Do people rent or own their property?
- What are indicators of wealth? (livestock, vehicle, improved home, multiple wives)

□ Understand how the community economic situation is affected by water and sanitation issues.
- Is income lost due to disease?
- How do people compensate for the loss of children?
- How much time is spent gathering water or dealing with sanitation?
- What percentage of income is spent on water and/or sanitation services?

- Do community members understand the economic consequences of water and sanitation systems?
- Would improved services provide economic gains?

□ Identify sources of monetary and non-monetary resources (materials, labor, and tools) within the community.

- How do people make money?
  - Paid salary
  - Agriculture
  - Trade
  - Small enterprises (hand crafts, food sales at market, odd jobs)
- How constant is the income?
  - Does it vary by season?
  - Can people save money?
- Does this vary by gender?
- Are there construction tools (wheelbarrows, shovels, picks, masonry tools) available?
- Is aggregate (sand, gravel, or rock) or lumber available?
- Can a community labor force be organized?
- Does the community have the means to transport supplies?

□ Assess the community willingness-to-pay in both monetary and non-monetary terms for current water and sanitation services.

- What do people pay for water and sanitation services?
  - In cash
  - In organized community labor
  - In materials
- If there are fees (monetary or otherwise) for current services do community members pay them?
- Are current services considered adequate?
- Would people be willing to pay for an improved water supply or sanitation services?
- Do people rent or own their property?
  - It can affect how much they are willing to pay for improvements to the property
  - Will landlords charge higher rent if water/sanitation services are improved?
  - Are tenants wlling to pay higher rent for improved services?

□ Identify local resources for water and sanitation.

- What is the present system for water supply?
- What are potential water sources in the area?
  - How reliable are they?
  - What quantity and qualityof water can they produce?
  - Where are they located?
- What systems are present for sanitation (excreta, grey water, and refuse disposal)?
  - How many people are served?
  - Are the systems well used?
- Where is water used? And reused?
- How do water or sanitation needs compare to the supply?

□ Collect data on climate and environmental constraints that will factor into project design.

- Did you consider the following set of data?
  - Soil conditions

- Groundwater levels
- Topography
- Physical size of village
- Population trends
- Seasonal climate variations (Rainfall, Temperature ranges)
- Stream and river flow rates
- Evaporation and run-off data

• Can community members assist in the collection of this data?

□ Identify potential environmental concerns at the local and regional level.

• Are any of the following current environmental concerns? Is there potential that they will become issues?
- Desertification
- Deforestation
- Erosion
- Overgrazing
- Soil salination
- Aquifer depletion
- Ecosystem/watershed deterioration
- Loss of biodiversity

• How severe are the impacts?

□ Determine community understanding of environmental problems and the willingness to correct them.

• How does the community perceive the threats to the environment?
• Can they identify potential environmental concerns?
• Are they concerned about ecosystem loss or climate change?
• What they received education concerning environmental problems?
• Would they be willing to change their behavior patterns for environmental benefits?

<u>Design Stage</u>

□ Assess how the proposed interventions will affect daily activities and socio-cultural roles within the community.

• Can you brainstorm potential social advantages and disadvantages of potential systems?
• Will the new system elevate or lower the social status of any group or individual? (By giving them new responsibilities or eliminating their roles?)
• Does the new system have the potential to shift social values? Is this positive or negative?
• How can designs address these concerns so that the system will be culturally acceptable?
- Will the system result in increased or decreased free time? For whom?
  - Water supply systems can reduce the amount of time spent transporting water to households.
  - Yet, hand pumps installed on borehole wells in Mali often yielded less water per hour than the women could pull by hand from hand-dug wells.
  - Improved sanitation systems may be more convenient, but will they require increase time for cleaning and structure maintenance.

• How will these changes in free time affect the lives of community members?
  - Will increased free time allow for gainful economic employment?
  - Will it affect social time? (Women often socialize together at the water source)

 Will it affect how children are employed in household chores? (If children no longer fetch water, what will they do? Is it reasonable to expect that they will be able to go to school?)

• Will the new system affect political or power roles in the community?

□ Evaluate the willingness and capacity of the community to perform operation, maintenance, and disposal requirements for each design.

• How much technical knowledge is required to operate the system?
 Does this knowledge exist within the community?
 Can people be trained to operate this system?
 Do people want to be trained?
 Will trained people remain in the community? (Labor forces can be migratory. Educated people tend to be drawn to urban centers where there are better job opportunities.)

• Are cultural and traditional preferences and taboos considered and respected?
 Consider how favorite aspects of the current system can be incorporated into the design (location, taste of water, ease of operation, privacy). People are most willing to accept something with which they are familiar.
 Refer to information gathered during needs assessment
 Ex: Certain sanitation systems may require handling of excreta that may be unacceptable in some cultures.

• When will the system require maintenance? (Daily, monthly, seasonally)
 Will people have the time to perform maintenance?
 Will this vary depending on the season? (seasonality of labor)
 Ex: During the harvest people are very busy and will be unwilling to take on any additional tasks.
 Can maintenance schedules be timed to coordinate with labor availability?

□ Design recognizes and respects traditional gender roles.

• Women are often in charge of household water supply, while men are involved in construction and technology. Will a new system interfere with the traditional gender power balance?
• What will be the role of men and women in the new system?
• How can the project encourage ownership by both gender groups?
• Are separate facilities provided for men and women if necessary?

□ Recognize why biases exist towards certain technologies by donors and/or locals.

• Are certain improved systems associated with prestige and wealth?
• Are there political pressures/incentives to adopt certain technologies?
• Are some systems more acceptable because of their familiarity to either residents or donor agencies?
• What significance is placed on system convenience, privacy, comfort, or aesthetics?
• Are there differences in cultural standards of quality or cleanliness that need to be reconciled?
• Remember that not all biases are negative. Some may be helpful in promoting the use and general acceptance of the system.

□ The project goals are clearly defined and understood by the community and development workers.

• What need had the highest priority?

- How do community members visualize the expected benefits? How do the development workers?
  - Increased health?
  - Increased incomes?
  - Reduction in seasonal migrations?
  - Time and labor savings?
- Who will benefit from the project?
  - Will all members benefit equally?
  - Are all the beneficiaries represented in community discussions?
- Are community members and development workers in agreement?

□ Identify a representative committee that can act as the community liaison throughout the project.
- Can this committee present the community opinions and views to the project planners?
- Will they be responsible for reporting project plans back to the community, including explanations of alternatives?
- Is the committee capable of performing (or assigning the responsibility for) the following roles?
  - Assisting in feasibility studies
  - Gathering of field data
  - Organizing community education
  - Generating support for the project.
- Can an existing committee fill this role?
- Is it necessary to create a new committee? (Note: there is a danger of too many committees within a community. It can lead to a confusion of roles.)
- Does this group represent all beneficiaries? (men, women, ethnic diversity)
- Are members of this committee respected within the community?
- Does this committee operate according to local customs?

□ Present several technically feasible alternatives for community evaluation and feedback.
- Does the presentation of each design include a technical description, estimated costs, installation time, and operation and maintenance needs?
- Is the potential for long-term management of each system emphasized?
- Are presentations of alternatives done in a fair and balanced way?
- Does the community understand the proposed technology?
- Are advantages and disadvantages of each design understood and discussed?
- Does the community think that they can manage and maintain the system on their own?
- What education, training or support services would be necessary for the proposed designs?
- Are there any community concerns not addressed in the conceptual designs?
- Are there legal issues surrounding use of the water source or necessary land?
- Is there sufficient knowledge within the community to manage the systems being considered?

□ Community members formally select a design based on an understanding of the constraints involved in the selection process.
- Are community members allowed to judge the advantages and disadvantages of differing systems?
- Are decision-makers given time to reflect before selecting a design?
- How is the decision reached? Democratic process? Leader decides?
- Is this process consistent with traditional methods of community decision making?

- Is the decision influenced by outside forces?
- Is it possible to judge if the design was chosen on technical merit or political motivation?
- Do community members seem happy with the selected design?

□ Develop a working relationship with partner organization(s), including at least one that is based in the host country.
- Have local government officials, NGOs, or private enterprises been contacted?
- Do partner organizations have compatible programs and agendas?
- What is the expected level of support and interaction from all parties?
- Do partners have suggestions or feedback on the designs?
- Are government officials kept informed?
- Can the basic goals of the working relationship be written in a Memorandum of Understanding (MOU) (EWB-USA 2005)

□ Consult the plans and designs of other organizations on similar projects.
- Have similar projects been implemented in the area?
- Will the project be redundant or in conflict with another project?
- What technical designs are working in nearby communities?
- What constraints did they use?
- Were there problems? How were they resolved?
- How long did the projects take?

□ Explore options to integrate existing technologies or programs into conceptual designs.
- What water supply and sanitation technologies are being promoted by government or NGO programs in the area?
- What is the potential to use these technologies in the design?
- Could other programs offer education or training support?
- Are there institutions pushing health initiatives that could provide educational services and support?

□ Contact potential partner institutions for project financing.
- Are there grants or low-interest loans available?
  - For agencies?
  - For individuals?
- What are the conditions for receiving funding?
- Are funds available for operation and maintenance?
- Are programs and funding available for supportive health/sanitation education?

□ Estimate the implementation costs of each conceptual design.
- Are training costs included?
- How much will materials and equipment cost?
- What local materials can be used? What will it cost?
- How can non-local materials be obtained?
- What will transportation of materials, equipment, and laborers cost?
- What will labor cost? Skilled and unskilled?
- Will food be provided for labor crews? What will it cost?
- Can community members provide local cost information?
- Will there be political fees that should be included in the budget?
- How should development workers' time be included?
- What about costs for promoting use of the system or health education?

□ Estimate operation, maintenance, and disposal costs for each conceptual design.
- Include costs for materials, replacement parts, and skilled laborers.
- Can these parts and materials be found locally?
  - If not, include cost estimates for transportation of supplies or displacement of people to get supplies
- How often will materials and parts need replacement?
- What are the minimum costs to keep the system running?
  - Daily
  - Weekly
  - Monthly
  - Annually
- How will recurrent costs be recovered?
  - Fees
  - Outside aid

□ Assess the community willingness-to-pay in both monetary and non-monetary terms for each improved system. There are a number of methods in use for determining willingness-to-pay: contingent valuation surveys, estimations based on a percentage of income or current expenditures. (Goldblatt 1999; Raje, Dhobe, and Deshpande 2002; Dale Whittington et al. 1990; D. Whittington, Lauria, and X. Mu 1991). The community willingness to pay should be determined on more than a "rule of thumb" based on a percentage of household income. It should be voiced by community members themselves, either directly in interviews or indirectly by costs that they currently pay for services.
- What do people pay for water and sanitation services?
- What is considered an adequate level of service?
- How much money are people willing to pay to obtain this service?
  - Construction/Implementation fee?
  - Monthly?
  - Yearly?
  - Per use?
- What are people willing to contribute to construction and start-up capital costs?
  - Monetary
  - Non-monetary items
  - Are people willing to work to obtain this service? (labor, supplies, construction material, tools)
- What are people willing to pay to maintain an improved system?
  - Indirectly: service fees
  - Directly: labor for maintenance or repairs, replacement parts or materials

□ Conduct an economic feasibility assessment to evaluate long-term project viability based on cost estimates, projected operation and maintenance costs, community willingness to pay, the need for outside resources, and the availability of outside funding.

An economic feasibility assessment is suggested in place of a traditional cost-benefit analysis. In international water and sanitation projects, benefits are often hard to quantify. There are data limitations that make it difficult to estimate the health and economic benefits that would traditionally be used to justify costs. The larger question in developing countries is the sustainability of the project. The measurable benefits will be negligible if the project is not maintained. In fact, sanitation systems such as latrines can have negative health impacts if they are not properly cleaned and used (Pickford 1995). An economically sustainable project is one that offers long-term benefits (i.e. remains in operation) at an affordable price. The definition of an affordable price will be determined by what beneficiaries and government officials are willing to pay. There are many methods for determining the community willingness to pay (see above). Willingness to pay on the part of the government (or other aid organizations) can be determined based on the amount of grants, subsidies, or other funding currently directed at water and sanitation systems (see element 2,3).

In an economical feasibility assessment, the project viability is determined by weighing cost estimates for construction, operation and maintenance, versus the willingness of the government and community to pay for it. For example, an unsustainable project may have sufficient funding and community support to construct the system, but operational costs exceed what the community and aid institutions are willing to pay. Decision makers will have to evaluate the long-term viability of the project based on the gap between anticipated support and expected costs.

- What is the total cost to implement the project?
- What can the community contribute to these costs?
- What funding is available to implement the project?
- What is the estimated start-up cost?
- What are realistic estimations of operation and maintenance costs? Note the danger of investing more money up front (high technology) to avoid operation and maintenance costs. The high cost of fixing these systems when they do require maintenance (and they will) may be quite inhibitory(Howe and Dixon 1993).
- What is the total annual cost per household (including capital and recurrent costs)? (for more details refer to (Pickford 1995))
- What percentage of this is the community willing to pay?
- Will outside resources be needed for operation and maintenance?
- Will these resources be available?

□ Assess the capacity for sustainable water use in the geographic area.
- Can the water source provide an adequate supply throughout the year?
- How will use of the water source affect the aquatic ecosystem?
- How will the watershed be protected?
- Will sanitation practices endanger existing water sources?

□ Consider how seasonal variation in water supply, demand, and environmental conditions will affect each conceptual design.
- Does water availability vary by season?
- How does demand for water vary throughout the year?
- Will evaporation rates affect the project design?
- How much does the water table fluctuate during the year?
    - How will this affect designs for sanitation systems? (latrine depth, septic systems, infiltration rates for soak pits)
    - How will this affect water sources? (necessary well depth, recharge of surface water)
- Is the area subject to flooding?
- How will these variations affect the feasibility and cost of conceptual designs?

□ Consider land needs and availability of suitable land for each alternative.
- Is the necessary land available?
- Is the available land suitable as a project site?
- Is the available land in a convenient location? How far from users?
- What are the potential repercussions of displacing other land uses?

□ Conduct a site impact analysis for each alternative.
- How will resource gathering (lumber, aggregate, water) affect the site environment?
- How invasive are proposed construction techniques?
- How will the operation of the system affect the environment? At the site? In surrounding areas?
    - Water contaminant
    - Waste discharges
    - Disposal of used parts and fuel containers (Where? How?)
    - Ecosystem disturbance
    - Resource consumption (fuel, batteries, water, chemicals)
- How susceptible is the site to environmental damage?
- What is the potential for remediation/mitigation of damage?

<u>Planning Stage</u>

□ Understand the traditional structure of community projects.
- Is there a history of community projects? (people working together for the common good)
- How are community projects traditionally organized?
- Who determines what projects will require community effort? (Local action planners, leaders)
- Who directs the work? (foreman, village chief, committee)
- Who performs the work?
- Are there culturally determined roles that must be respected?
- Do all households contribute? How?

□ Consider the seasonality of labor in setting the timeline.
- When will laborers be available?
- Consider employment schedules, migratory patterns, planting, harvest, holidays, weather

□ Explore options for increasing gender equity in project roles and capacity building.
- What role do women traditionally play in community projects?
    - Construction projects
    - Communal agricultural efforts (harvest, planting, irrigation)
    - Operation of water and sanitation services
- What roles do women feel comfortable playing?
- Are there ways to increase the involvement of women in the current project?
    - Ex: Bringing water to the site for mixing concrete or cleaning the work site.
    - Ex: Train them in operation and maintenance

□ Confirm that labor and resource contributions are equitably divided.
- Among households?
- Among ethnic groups?

□ Community input is solicited in refining the selected technical design.

□ Final technical design is approved through a process of community consensus.

□ Community members are involved in identifying and sequencing tasks that will be incorporated into an action plan.

- What concrete tasks need to be accomplished?
    - Gathering supplies and finances
    - Arranging legal requirements for project work (land/water rights)
    - Storing materials and equipment
    - Recruiting skilled and unskilled laborers
    - Construction work
    - Construction supervision

- Who will be in charge of completing these tasks?
    - Community members or someone from outside the community?
    - Managerial roles (oversight, consulting, informing other of the work, managing resources)
    - Labor roles
- Is there a management system in place?
    - Is there an existing water board or committee?
    - Will it be necessary to establish a governing board for the system?
- When do these tasks need to be completed?
    - Develop a timeline
    - Set a schedule for task completion
- How will the project be promoted in the community?
- Who will receive technical/ operational training?
- Who will receive health education (hygiene, hand-washing, proper use of system)?
- Are assumptions in roles and contributions explicitly stated? (Ex: If community members will provide labor, meals for workers, or tools)

□ The community members and development workers approve of the timeline and responsibilities laid out in the action plan.
- Are the roles and responsibilities of individuals and organizations explicitly stated?
    - Performing the work
    - Overseeing progress
    - Consulting
    - Informing others of the work
    - Managing resources
- Are all parties aware of their own roles and responsibilities, as well as, those of everyone else?
- Are the skills, knowledge and attitude of individuals factored into role assignments?
- Does the timeline include tasks to be completed by both community members and development workers?
- Does the timeline include dates for the community monetary contribution paid, resource gathering, start of work, expected progress, completion?

□ The roles and responsibilities of partner institutions are defined in a detailed action plan.
- What level of involvement is each organization willing to commit to?
    - Financial support
    - Consulting
    - Sub-contracting
    - Training and Education
    - Direct community involvement
- What specific reporting or procedural requirements does each organization need?
    - Progress and monitoring reports

- Contracts
- Site visits
- Education or capacity building activities
- Other paperwork

• Who needs to be informed of project activities?
• Who will supervise the project?
• Who will monitor progress?
• Who will work directly with the community?
• Who will recruit skilled laborers?

□ Agree on financial commitments.
• Who will contribute to project financing?
- How much?
- When will funds be available?

• Who will control the project budget?
• What strings are attached to institutional funds?
- Earmarks
- Reporting requirements

□ A timeline is drafted that meets the requirements of all institutions involved.
• What are the funding and reporting schedules of the institutions?
• When will work start?
• When are progress and final reports due?
• When will work be completed?
• Are institutional deadlines respected?

□ Final project design and action plan are presented to partner institutions and local, regional, and/or national level authorities.
• Are all parties aware of their role and the timeline agreed upon?
• Have all parties seen the finalized design? (Even if they are not directly involved, they appreciate being informed.)

□ Verify the costs and availability of resources.
• Present an itemized budget for review by community members (they understand the local market)
• What are the local prices?
• Do they fluctuate? By how much? (It is best to verify prices as close to the purchasing time as possible)
• What is the currency conversion rate in the country? (Check the rate on the open market as it can differ from the official rate)
• Can anything be improvised or constructed on site?
• What about transportation costs?
• What do laborers cost? Unskilled? Skilled?
• Does the cost of labor vary depending on the time of year? (issue of availability)
• Are costs for training included in the budget?

□ Confirm the community contribution for money, materials, equipment, tools, and labor.
• Who will provide the monetary contribution? How much?
• Who will provide tools and equipment?
• Is there a storage area for large tool and construction supplies?

- How many laborers can the community contribute?
- Will meals be provided for laborers? By whom?
- Who will provide for food and housing for trainers from outside the community?
- Are individual contributions consistent with their ability to pay?
- The community makes a formal commitment to the agreed contribution.

□ Finalize budget based on local costs, available resources, and community contribution.
- Include a contingency plan for unexpected costs.
- Can the budget adjust for alternative plans if required materials become unavailable?

□ Develop an action plan for resource procurement.
- When will materials be required throughout the construction process?
- Where will materials be purchased? By whom? When?
- How will they be transported to the site?
- Is manufacture of materials required?
  - Ex: breaking rocks into gravel or blacksmithing of parts
  - How long will it take?
  - How far in advance can it be performed?
- Are skilled laborers required?
  - When are they available?
  - Is a signed contract required?
- Who will arrange for unskilled laborers?

□ The final project design minimizes ecological disturbance, energy use and waste emissions.
- How different is the final design from the conceptual design? Does the site impact assessment still hold true?
- Have all environmental impacts been considered during the design process?
- Have efforts been made to reduce these impacts?
- Is energy saving technologies used?
- Are secondary treatment options implemented where appropriate?
- Are there methods for monitoring environmental impacts during the project life?

□ The project design uses renewable and/or recyclable local resources.
- Are local alternatives to imported materials considered during the design development?
- Are these resources abundantly available?

□ The action plan considers the seasonality of resources.
- When is the site or resource accessible?
  - Will flooding affect site accessibility; by boat, by road?
  - Ex: Sand may only be available when the rivers are low.
- Will the size, availability, and productivity of the labor pool vary with the season?
- What time of year is best for construction?
  - Rain
  - Temperature

□ Develop an environmental action plan to mitigate impacts during construction.
- Use of erosion control techniques
- Consideration of temporary water sources
- Non-invasive construction methods
- Waste disposal

- Site restoration needs after construction

Implementation Stage

□ Set a realistic work schedule, based on available resources and preferred work styles.
- What is a typical work day?
- What time do communal work projects normally start? And finish?
- What are expectations for breaks and meal times?
- Are there certain days of the week that work can not be performed?
  - Religious observances
  - Markets
- Are there conflicting labor demands (harvest, planting, regular jobs) that affect the availability of personnel?
- How will the availability of equipment limit work?
  - Ex: How many shovels are there? (It will limit the number of workers at one time.)

□ Scheduling includes float time to allow for unexpected.
- Is time allowed for unplanned social functions such as, funerals, soccer games, or religious observances?
- What are the consequences of not planning for unexpected events?
  - Incomplete project requirements
  - Going over budget
  - Angering people by working through social events
  - Conflicts between development workers and community members

□ Encourage the involvement of women throughout the construction process.
- Can they collect sand and gravel? Or sift the sand and gravel?
- Can they bring water to the construction site?
- Can they fill management roles?
- Are they included in capacity building exercises? (Including technical and managerial skills.)

□ Use public gatherings to review benefits of the project, promote education, and discuss operation and maintenance.
- Are all project beneficiaries included?
- Can the project functions and benefits be demonstrated?
- Are project updates given?
- Can hygiene education or other health topics be presented?
- Can people be trained in health education?
- Can this time be used to plant the seeds of operation and maintenance requirements and organizational needs?

□ Involve the community in revisions of the action plan, program changes, and problem solving.
- Is everyone aware of their responsibilities?
- Do development workers meet regularly with community leaders to review the action plan and program changes?
- Are mid-way evaluations and progress monitoring conducted?

□ Work with a local foreman or work supervisor in organizing labor.
- Can a local representative help with the following activities?
  - Organize procurement and storage of materials and equipment.

- Manage work crews and daily construction activities.
- Daily briefing on the task to be accomplished.
- Monitor and correct public safety concerns.

□ Train local laborers in any new techniques and tools that are introduced.
- Can health and hygiene education be included in the training?
- Does the training include construction techniques and procedures for operation and maintenance?
- Can operation personnel be selected from laborers who show the most aptitude for the system?

□ Finalize the management plan with respect to the "built" system.
- Is the community given complete specifications for the equipment and operating system, including manuals and specific training for operation and maintenance?
- Are community members involved in planning for operation and maintenance?
- Is responsibility for the system officially transferred to community?

□ Contact institutions in the area for assistance in training and labor requirements.
- Do they have training instructors who speak the local-language?
- Can they provide technical training or supportive education programs?
- Do they have skilled laborers for hire?
- Can they benefit from involvement in the project? (shared trainings)
- Are partner institutions invited to be involved in training exercises?

□ Inform partner institutions of the start of construction, project milestones and major changes.
- Are progress reports and evaluations shared?
- Is consideration given to how major changes in the design or implementation schedules may affect partner interventions or the government regulatory processes?

□ Invite local government and NGO officials to view the construction site.
- Are the "right" officials invited?
- Are efforts made to include everyone that could be interested or have a stake in the project?

□ Discuss partner roles in operation and maintenance.
- Is agency involvement necessary?
- What role can government and donor agencies play in operation and maintenance of the system?
    - Monitoring and evaluations
    - Promotional activities
    - Financial support
    - Providing training and/or payment for maintenance personnel
    - Equipment or support services
    - Ex: Can the municipality (or private company) provide vacuum tanker trucks for emptying latrines?
    - Ex: Can they train technicians to fix the hand pumps next to the community wash area?
- Do partner agencies have the capacity to address these roles?
- Do other agencies need to be recruited to help with operation and maintenance issues?
- Can a tentative agreement be made on an action plan for system operations?

□ Community members contribute to project implementation.
- Are resources (monetary or non-monetary) collected prior to the start of construction?
- Is labor for construction provided?
- Is someone keeping track of all contributions? (cash, labor, food shelter, land, materials, and water rights)

□ Recheck the quality of materials and equipment during resource procurement.
- How sturdy are the tools? Can the hold up under strong use?
- What is the quality of the aggregate? Is it acceptable? Does it require cleaning/sifting?
- Are better quality options available? What will they cost?
- If not, will the design need to be modified?

□ Monitor spending and budget restrictions throughout the project implementation phase.
- Is someone keeping track of when material and equipment purchases are over budget?
- Is a reliable person or committee is in charge of gathering and keeping track of resources?
- Can a respected community member with accounting experience (i.e. village treasurer) be used?
- Are they able to keep records of resources, collect receipts, and arrange for the storage of materials?
- Is a culturally appropriate system of accountability discussed?
- Is a responsible party in charge of labeling and storing spare parts after construction?
- Are procurement and construction schedules processing on-time?
- Are extra fees required to keep the project on schedule?
- Can the budget be adjusted to accommodate for changes?
- How much can the contingency plan cover?
- Are options to improvise tools and equipment explored when necessary?

□ Draft final report on the budget and share with community members and partner organizations.
- Are final costs calculated?
- Is an itemized list of community contributions and their cash equivalents included? Is it shared with community?
- Are financial repayment schedules reviewed? (if individual or community loans were used to finance the project)

□ Recheck physical and environmental constraints used in the project design and make design corrections if necessary.
- Groundwater levels
- Soil infiltration rates
- Soil conditions
- Temperature
- Stream and river flow rates
- Evaporation rates

□ Take precautions to avoid contaminating existing water resources and minimize environmental impacts during implementation.
- Are erosion control methods used during resource extraction (sand, gravel, rock, timber) and construction?
- How can energy or fuel use be reduced? (transportation, extraction needs)
- Can the transport of materials (esp. of heavy equipment) be minimized?
- Can packaging be recycled?

- Are wells covered near the construction sites?
- Are temporary water sources and/or sewage disposal methods used?

□ Involve the community in waste management and environmental education.
- Are there plans to properly dispose of any waste that is produced?
- Are efforts made to minimize solid waste and energy use?
- Can community members implement the waste management plan?
- Are community members educated on waste management practices?
- Can other environmental issues be discussed?
- Can down time during construction be used for informal education sessions?

□ Restore any areas disturbed during construction.
- Is the site cleaned-up after construction?
- Are disturbed ecosystems restored?
- Is maintenance of these areas needed and planned for?

<u>Operation, Maintenance, and Evaluation Stage</u>

□ Discuss unanticipated constraints to system use.
- Why do people not use the system?
  - Distance from home
  - Latrines are full
  - Insufficient water
  - Inconvenient operating schedule
  - Unwillingness to pay
  - Smell or insects

- Is the system being used properly?
  - Is it cleaned?
  - Is it used for the intended purpose?
  - Ex: latrines: Are they being overloaded with water or additional waste? Is the use of twin pits alternated?
- Did people receive instruction on proper use of the system?

□ Discuss unexpected limitations to maintenance schemes.
- Did people trained in system maintenance leave the community?
- Is performing maintenance seen as shameful or dirty work?
- Are there traditions, taboos, or fears that were overlooked in project planning?
  - Ex: Cultural unwillingness to handle excreta (even when decomposed)

□ Reassess how gender roles affect the proper use and perceived benefits of the system.
- Are both men and women aware of proper operating rules?
- Have both men and women adopted appropriate behavior changes?
  - Ex: A study in Ghana found that men had changed their latrine habits due to a hygiene education program, but women, who were not involved, kept up bad practices (Pickford 1995)
- Who cleans the system?
  - Ex: Study of latrine cleanliness in Dar es Salaam found that conditions were better when the male head of the household cleaned rather than a wife or child (Pickford 1995).

- How can differences be addressed?

□ Ensure that costs and benefits are equitably distributed within the community.
- Are equitable user fees and operating rules agreed on within the community?
- Do community members have equal access or opportunity to receive services?
  - Ethnic groups
  - Gender
  - Income groups/Casts

□ Community members are actively involved in performing the necessary operation and maintenance.
- Are the operation/maintenance tasks handles locally?
- Has staff been trained?
- Are operation/maintenance requirements documented and available to the community?
- Is a transition plan in place to train replacement staff?
- Are continuing training plans in place?
- Are operation/maintenance responsibilities clear?

□ Conduct a participatory evaluation to get community feedback and suggestions for improvements.
- Are a variety of community members involved in the evaluation?
- Was the project perceived as a success? Why? Why not?
- How can system functioning be improved?
- How can utilization of the facilities be improved?
- Were their suggestions for improvements taken into account on the existing system?
- Does the feedback provide suggestions for improving future projects?

□ A community organization exists with the capacity to make decisions regarding the operations and maintenance of the system.
- How will the community contribute to system maintenance?
- Who will take care of preventive maintenance, and repairs?
- Can the community control who is hired to operate and maintain the system?
- Is an attendant necessary to oversee the system (i.e. public water taps or latrines)?
- How will the attendant be paid?
- Who collects fees?
- Who will keep records and accounting reports?
- Can the community implement suggestions for improvement?
- Can the organization contact other agencies for help if needed?

□ The system is controlled by culturally appropriate and traditionally respected people.
- Do community leaders determine roles and responsibilities of an oversight committee?
- How are operation and maintenance managers selected?
- Are they selected for their dedication and dependency? Or political reasons?
- Is the oversight committee susceptible to elite capture?

□ Invite officials to the opening ceremony.
- Are all participants from planning and implementing stages included?
- Are appropriate local and regional officials included?
- Is credit and thanks given to all who helped?

□ Coordinating institutions sign a formal agreement that defines their roles and expectations in operation and maintenance of the system.
- What roles will government and donor agencies play in operation and maintenance of the system?
  - Monitoring and evaluation reports
  - Promotional activities
  - Financial support
  - Providing training and/or payment for maintenance personnel
  - Equipment or support services
- Who will fill these roles?
- How often are services or support expected?

□ A locally based institution is involved in project monitoring.
- Do they double-check/monitor technical aspects?
- Can they help in refining management structures?
- Do they keep in touch with any changes in local practice?
- Are partners contacted for follow-up and adjustments if problems arise?
- Do they reach out to regional peers to share knowledge and resources?

□ Share monitoring reports and project evaluations with partner institutions.
- Are periodic reports on operations and maintenance shared?
- Are financial report shared, if appropriate?

□ Estimate realistic, long-term operation and maintenance costs based on the "built" system.
- Are costs for materials, replacement parts, and skilled personnel included?
- What labor efforts are needed to keep the system running?
  - Cleaning
  - Emptying for latrines
  - Oiling of mechanical parts
  - Repair of supply lines, tanks, and other physical structures
- How often will materials and parts need replacement?
  - Chemicals for water treatment
  - Spare parts
- Where will replacement materials and parts be purchased?
- What about transport costs?
- What are the minimum costs to keep the system running?
  - Daily
  - Weekly
  - Monthly
  - Annually

□ Financing exists to cover projected operation and maintenance costs.
- Are there monetary needs to keep the system running? Labor needs?
- How will these needs be met?
  - User fees
  - Community taxes
  - Labor contributions
  - Institutional aid
- What is an appropriate fee for use? What are people willing to pay?
- Who collects the fees?

- Who will provide labor for upkeep and repairs?
- Is outside aid provided?
- Are there mechanisms for getting outside aid if needed?
- Are there options for cost recovery?
    - Ex: Sale of latrine waste for fertilizer
    - Ex: Raising fish in irrigation ponds

□ A financial management organization exists to manage operational/maintenance costs and the distribution of benefits.

- Does this organization have the capacity to collect and account for monetary contributions? Labor contributions?
- Can it keep track of the beneficiaries?
- Is there a correlation between payments and benefits received?
- Is this organization controlled by the community?
- Is the role of this organization recognized and respected at all levels of governance?
- Is the organization appropriate to the project size and community?

□ Regularly review and adjust the financing system.

- Is the financing system reviewed on a regular basis?
- Can it be adjusted for inflation and changes in resource availability?
- Can it adjust for changing demands and perceptions of the project benefits?
- Can it adjust for social constraints (non-payment of fees, under/over utilization)?
- Can fees/labor needs be changed?
- Can support from partners be adjusted?

□ Minimize, treat, and dispose of waste properly.

- Is there waste resulting from the use of the project?
- Is waste properly treated?
- Is the creation and disposal of project related waste monitored and reported?
    - Wastewater
    - Runoff water/Grey water
    - Used parts and equipment
- Are monitoring reports and treatment procedures checked by a managing organization?

□ Explore alternative plans for reducing the use of consumables.

- What consumables are used during operation/maintenance of the project?
    - Chemicals in water/sanitation treatment
    - Spare parts
    - Fuel/Batteries
    - Plastics (PVC, liners, bottles)
    - Filters
    - Packaging
- Are there ways to reduce the amount of material consumed?
- Are alternative sources of parts, materials, or energy periodically explored?
- How does usage of consumable parts and energy compare with similar projects?
- Are potential alternatives tested?

□ Monitor and evaluate environmental impacts.

- Is the site periodically surveyed to check for impacts?
- Is a methodology in place for impact assessments?

- Are secondary impacts considered?
  - Does an improved water supply change disposal habits for grey water? Where? How much?
  - If water sources are closer to home, does it bring sanitation problems closer to home?
  - Are there runoff problems around the tap stands?
  - Are people using more water now than before?

- Are the systems functioning properly?
  - What are the environmental impacts if the system malfunctions?
  - Sanitation systems in particular can have negative impacts if not properly maintained.
- Were restoration areas restored properly? And maintained?
  - If trees were replanted, are they watered?
  - If water was diverted from a source, is there enough overflow water to maintain the stream habit?

□ Continue environmental and hygiene education efforts.

- Are community member aware of improvements since the system became operational? Or deterioration?
- Are supporting behavioral changes reinforced? (hand washing, proper trash and grey water disposal)
- Do people understand the benefits of improved systems?
- Are people motivated to continue to work for environmental improvements?
- Are people aware of their own role in maintaining a healthy environment?

APPENDIX D: USER INPUT DESCRIPTIONS

Main: Setup
Community Name: The name of the community where the water system is to be built.
Community Municipality / County: The municipality or county where the community is located.
Community State / Province: The state or province where the community is located.
Country: The country where the community is located.
Project Title: Enter the name of the project.
Engineer Name: Enter the name of the lead engineer on the project.
Organization Name: The name of the organization overseeing the project.
Organization Address: Address of the overseeing organization.

Feasibility: Inputs
Community Population: The number of inhabitants within the community to be served by the water system.
Water Source Type: The type of water source that will be used (spring, stream, mix etc.).
Number of Individual Sources to Be Utilized: How many different water sources will be connected to the water system.
Total Flow Rate from Sources: The total flow rate in Liters per second from all the sources to be used.
Source Elevation: The elevation of the water source, if multiple sources are to be used, state the lowest. If absolute elevations are not known, the elevation difference between the source and the community can be entered.
Distance to Source: Distance to the water source in meters.
Network Length in Community: Estimated length of distribution network throughout the community in meters.
Highest Pt. Served In Community: Elevation of the highest point in the community that will be served by the water system.
Lowest Pt. Served In Community: Elevation of the lowest point in the community that will be served by the water system.
Area Soil Type: The type of soil found in the area. This is used to estimate work rates.
Number of Days per Week Labors Can Work: How many days per week will labors be able to work on the water system.
Number of Months per Year Available for Work: How many months of the year are available to work on the water system.
Monthly Community Contribution per Family: How much can each family pay per month to the water system.
Total Funding Available For Project: An estimate of the funding available for this project.

APPENDIX E: MODULE REPORTS

Stephen Good — Cuerpo De Paz, Embajada De Los Estados Unidos
Peace Corps Dominican Republic — Santo Domingo, Dminican Republic

Community Water System - Site Assessment Report
Guaranal and Quita Sueno, Alatamira, Puerto Plata

Community Information

Community Name	Guaranal and Quita Sueno
Community Municipality / County	Alatamira
Community State / Province	Puerto Plata
Community Country	La Republica Dominicana
Community Population	626

Environmental Parameters

Source Types	Mountain Stream	
Source Count	1	
Total Daily Source Production	544320	(L)
Average Source Flow Rate	6.3	(L/sec)
Distance To Source	5200	(m)
Change In Elevation To Source	130	(m)
Distance In Distribution Network	8100	(m)
Change In Elevation In Distribution Network	190	(m)
Distance Total	13300	(m)
Change In Elevation Total	320	(m)

Proposed Water System Estimates	(If Public Tapstands Are Installed)	
Number of Individuals Per Tapstand	250	persons/Tap
Number of Public TapStands Required	3	Tapstands
Water Allotment Per Person Daily	50	(L/person/day)
Volume of water needed for public Tapstands	31300	(L)
Flow Rate needed (Without Storage Tank)	0.313	(L/sec)
Flow Rate needed (With Storage Tank)	0.36	(L/sec)
	(IF Private Tapstands Are Installed)	
Number of Individuals Per Tapstand	5	persons/Tap
Number of Private TapStands Required	125	Tapstands
Water Allotment Per Person Daily	75	(L/person/day)
Volume of water needed for private Tapstands	46950	(L)
Flow Rate needed (Without Storage Tank)	1.252	(L/sec)
Flow Rate needed (With Storage Tank)	0.54	(L/sec)

Construction Assessment

Estimate of laborers available	125.2	Laborers
Meters of Trench Dug Daily Per Worker	4.5	(m)
Days available to work	19.5	days/wkr/yr
Weeks available to work	39	wks/wkr/yr
Days Requied per worker	23.4	Days
Weeks Required Per Worker	46.7	Weeks
Estimated Laborer-Days of Construction	2926	Days of Labor

Figure E.1 Feasibility Report Page 1

Estimated Years of Construction 1.2 Years

Financial Estimate	(Public)	(Private)
Initial Capital Investment Required:		
Intake Structures	$51,496.39	$61,275.78
Main Line	$347,047.51	$347,047.51
Storage Tank	$91,714.63	$91,782.45
Distribution Network	$317,926.53	$431,453.65
Total Initial Costs:	$808,185.07	$931,559.39
Operational Costs		
Intake Structures	$76.14	$82.71
Main Line	$209.62	$348.60
Storage Tank	$86.44	$86.51
Distribution Network	$312.74	$312.74
Total Operational Costs:	$684.93	$830.56

Report Summary

Public Tapstands are possible with current water source(s).
No Storage Tank is required with public Tapstands.
Enough Funding available for construction of public Tapstand water system.
Enough community contributions to maintain public sysetem.
Private Tapstands are possible with water current source(s).
No Storage Tank is required with private Tapstands.
Enough Funding available for construction of private water system.
Enough community contributions to maintain private sysetem.

Figure E.2 Feasibility Report Page 2

Community Water System — Cuerpo De Paz, Embajada De Los Estados Unidos
Stephen Good — Santo Domingo, Dminican Republic

Community Water System - Sytem Design

Guaranal and Quita Sueno, Alatamira, Puerto Plata

Reach 1

X (m)	GSP (m)	Q (L/sec)	Material	D (mm)	HGL (m)	Head (m)	Notes
0	467				467	0	Arroyo Blanco (Source)
182	450	0.54	PVC PIPE	25.4	457	17	Sedimentation Tank
182.01	450	0.54	PVC PIPE	19.1	450	0	Sedimentation Tank
833	405	0.54	PVC PIPE	38.1	445	45	
853	405	0.54	GI PIPE	38.1	445	45	River 1, GI Pipe
990	426	0.54	PVC PIPE	50.8	445	24	
1130	438	0.54	PVC PIPE	50.8	445	12	
1588	421	0.54	PVC PIPE	38.1	441	29	
1996	376	0.54	PVC PIPE	25.4	420	74	BP Tank 1
1996.01	376	0.54	PVC PIPE	38.1	376	0	BP Tank 1
2268	316	0.54	PVC PIPE	38.1	374	60	
2281	317	0.54	GI PIPE	50.8	374	59	River 2, GI Pipe
2337	334	0.54	PVC PIPE	25.4	371	42	
2488	303	0.54	PVC PIPE	38.1	370	73	
2507	303	0.54	GI PIPE	38.1	370	73	River 3, GI Pipe
2604	311	0.54	PVC PIPE	25.4	365	65	
3211	290	0.54	PVC PIPE	38.1	360	86	
3813	257	0.54	PVC PIPE	38.1	356	119	
4096	243	0.54	GI PIPE	38.1	353	133	Bottom Of Valley
4225	254	0.54	PVC PIPE	50.8	353	122	
4537	281	0.54	PVC PIPE	50.8	352	95	
4974	291	0.54	PVC PIPE	50.8	351	85	
5132	330	0.54	PVC PIPE	38.1	350	46	
5201	340	0.54	PVC PIPE	38.1	350	36	STORAGE TANK
5201.01	340	1.53	PVC PIPE	25.4	340	0	STORAGE TANK
5220	330	1.53	PVC PIPE	38.1	339	10	
5254	329	1.53	PVC PIPE	50.8	339	11	

Reach 2

X (m)	GSP (m)	Q (L/sec)	Material	D (mm)	HGL (m)	Head (m)	Notes
5254	329				339	0	REACH 2
5256	328	1.53	PVC PIPE	38.1	339	12	
5258	327	1.53	PVC PIPE	50.8	339	13	
5354	316.116	0.96	PVC PIPE	50.8	338	24	
5474	311.3595	0.5	PVC PIPE	50.8	338	29	
5543	308.5722	0.34	PVC PIPE	38.1	338	31	CLUSTER 1 (8 taps)
5588	305.4991	0.26	PVC PIPE	25.4	337	35	
5621	307.004	0.26	PVC PIPE	38.1	337	33	
5673	311.216	0.26	PVC PIPE	25.4	336	29	
5818	315.7111	0.26	PVC PIPE	50.8	336	24	CLUSTER 2 (12 taps)
5820	318.6195	0.14	PVC PIPE	25.4	336	21	
5822	316.0407	0.1	PVC PIPE	50.8	336	24	

Figure E.3 Design Report Page 1

5943	310.5	0.07	PVC PIPE	12.7	332	30	
6042	301.0336	0.07	PVC PIPE	19.1	331	39	
6142	302	0.07	PVC PIPE	38.1	331	38	
6242	283.2413	0.07	PVC PIPE	19.1	331	57	
6279	279.5344	0.07	PVC PIPE	25.4	331	60	BP Tank 5
6279.01	279.5344	0.07	PVC PIPE	50.8	280	0	BP Tank 5
6357	269	0.07	PVC PIPE	25.4	279	11	
6406	264.5678	0.07	PVC PIPE	19.1	279	15	
6445	256.8	0.07	PVC PIPE	38.1	279	23	
6527	241.832	0.07	PVC PIPE	25.4	279	38	
6582	234	0.07	PVC PIPE	19.1	279	46	BP Tank 2
6582.01	234	0.07	PVC PIPE	50.8	234	0	BP Tank 2
6650	212	0.07	PVC PIPE	19.1	234	22	
6695	198	0.07	PVC PIPE	12.7	232	36	
7142	180.2022	0.07	PVC PIPE	12.7	217	54	CLUSTER 3 (7 taps)
Reach 3							
X (m)	GSP (m)	Q (L/sec)	Material	D (mm)	HGL (m)	Head (m)	Notes
5474	311.3595				338	0	REACH 3
5489	315.5086	0.16	PVC PIPE	25.4	338	24	
5553	311.1688	0.16	PVC PIPE	12.7	327	29	CLUSTER 4 (16 taps)
Reach 4							
X (m)	GSP (m)	Q (L/sec)	Material	D (mm)	HGL (m)	Head (m)	Notes
5820	318.6195				336	0	REACH 4
5870	318.6195	0.04	PVC PIPE	12.7	336	21	
5912	324.9483	0.04	PVC PIPE	38.1	336	15	CLUSTER 5 (4 taps)
Reach 5							
X (m)	GSP (m)	Q (L/sec)	Material	D (mm)	HGL (m)	Head (m)	Notes
5822	316.0407				336	0	REACH 5
5841	317.6427	0.03	PVC PIPE	25.4	336	22	
5891	308.0308	0.03	PVC PIPE	19.1	336	32	
5941	297.7064	0.03	PVC PIPE	19.1	336	42	
5972	291.7028	0.03	PVC PIPE	25.4	336	48	CLUSTER 6 (3 taps)
Reach 6							
X (m)	GSP (m)	Q (L/sec)	Material	D (mm)	HGL (m)	Head (m)	Notes
5354	316.116				338	0	REACH 6
5360	329.5012	0.46	PVC PIPE	25.4	338	10	
5432	325.1878	0.46	PVC PIPE	25.4	335	15	
5500	323.5134	0.46	PVC PIPE	38.1	335	16	CLUSTER 7 (21 taps)
5576	318.325	0.25	PVC PIPE	25.4	334	22	
5633	308.6	0.22	PVC PIPE	38.1	334	31	
5738	296.3518	0.22	PVC PIPE	50.8	334	44	CLUSTER 8 (11 taps)
5865	288.9509	0.2	PVC PIPE	25.4	333	51	
6001	281.1753	0.2	PVC PIPE	38.1	332	59	
6053	285.9	0.2	PVC PIPE	12.7	320	54	BT Tank 6
6053.01	285.9	0.2	PVC PIPE	25.4	286	0	BT Tank 6
6185	246	0.2	PVC PIPE	50.8	286	40	
6299	274	0.2	PVC PIPE	38.1	286	12	

Figure E.4 Design Report Page 2

6414	269.1337	0.2	PVC PIPE	50.8	286	17	
6539	272.6453	0.2	PVC PIPE	19.1	282	13	CLUSTER 9 (7 taps)
6655	263.6115	0.13	PVC PIPE	25.4	281	22	
6725	252.23	0.13	PVC PIPE	38.1	281	34	
6804	239.4453	0.13	PVC PIPE	38.1	281	46	
6897	255.8913	0.13	PVC PIPE	19.1	280	30	
6988	270.5692	0.13	PVC PIPE	25.4	279	15	CLUSTER 10 (13 taps)
Reach 7							
X (m)	GSP (m)	Q (L/sec)	Material	D (mm)	HGL (m)	Head (m)	Notes
5576	318.325				334	0	REACH 7
5583	316.8542	0.03	PVC PIPE	50.8	334	23	
5613	314.9794	0.03	PVC PIPE	38.1	334	25	
5640	315.6469	0.03	PVC PIPE	38.1	334	24	
5671	315.8273	0.03	PVC PIPE	12.7	333	24	
5717	304.5042	0.03	PVC PIPE	50.8	333	35	
5749	302.5974	0.03	PVC PIPE	25.4	333	37	
5766	298.2453	0.03	PVC PIPE	12.7	333	42	CLUSTER 11 (3 taps)
Reach 8							
X (m)	GSP (m)	Q (L/sec)	Material	D (mm)	HGL (m)	Head (m)	Notes
5738	296.3518				334	0	REACH 8
5760	299.9829	0.02	PVC PIPE	12.7	333	40	
5779	291.1607	0.02	PVC PIPE	19.1	333	49	
5798	284.7923	0.02	PVC PIPE	50.8	333	55	
5822	288.3052	0.02	PVC PIPE	25.4	333	52	
5838	289.8387	0.02	PVC PIPE	38.1	333	50	
5866	289.5537	0.02	PVC PIPE	38.1	333	50	CLUSTER 12 (2 taps)
Reach 9							
X (m)	GSP (m)	Q (L/sec)	Material	D (mm)	HGL (m)	Head (m)	Notes
5258	327				339	0	REACH 9
5360	326	0.57	PVC PIPE	38.1	338	14	
5432	325.1878	0.57	PVC PIPE	50.8	338	15	
5500	323.5134	0.57	PVC PIPE	25.4	334	16	
5576	318.325	0.57	PVC PIPE	38.1	333	22	
5633	308.6	0.57	PVC PIPE	19.1	320	31	
5738	296.3518	0.57	PVC PIPE	25.4	314	44	
5861	298.2625	0.57	PVC PIPE	25.4	307	42	
5961	275.565	0.57	PVC PIPE	19.1	284	64	BP Tank 3
5961.01	275.565	0.57	PVC PIPE	19.1	276	0	BP Tank 3
6060	260.7283	0.57	PVC PIPE	50.8	275	15	
6166	261.2772	0.57	PVC PIPE	38.1	275	14	
6258	262.1556	0.57	PVC PIPE	25.4	269	13	
6344	251	0.57	PVC PIPE	50.8	269	25	CLUSTER 13 (16 taps)
6435	249.3801	0.41	PVC PIPE	25.4	266	26	
6585	248	0.36	PVC PIPE	25.4	262	28	
6685	212.0069	0.18	PVC PIPE	12.7	243	64	
6756	199.6	0.18	PVC PIPE	12.7	228	76	BP Tank 4
6756.01	199.6	0.18	PVC PIPE	25.4	200	0	BP Tank 4

Figure E.5 Design Report Page 3

6835	188.7047	0.18	PVC PIPE	19.1	197	11	
6975	179.4703	0.18	PVC PIPE	19.1	194	20	CLUSTER 14 (12 taps)
7095	180.4011	0.06	PVC PIPE	19.1	193	19	
7219	168.9697	0.06	PVC PIPE	19.1	193	31	
7330	166.8558	0.02	PVC PIPE	19.1	193	33	
7479	153.7035	0.02	PVC PIPE	38.1	193	46	CLUSTER 15 (2 taps)
Reach 10							
X (m)	GSP (m)	Q (L/sec)	Material	D (mm)	HGL (m)	Head (m)	Notes
6435	249.3801				266	0	REACH 10
6480	247	0.05	PVC PIPE	12.7	265	29	CLUSTER 16 (5 taps)
Reach 11							
X (m)	GSP (m)	Q (L/sec)	Material	D (mm)	HGL (m)	Head (m)	Notes
6585	248				262	0	REACH 11
6635	226.2129	0.18	PVC PIPE	19.1	261	49	
6662	224.0945	0.18	PVC PIPE	19.1	260	51	
6706	222.6869	0.18	PVC PIPE	19.1	259	53	
6751	220.5932	0.18	PVC PIPE	19.1	258	55	
6801	222.4109	0.13	PVC PIPE	25.4	258	53	
6851	218.9952	0.13	PVC PIPE	19.1	257	57	
6891	211.2486	0.13	PVC PIPE	25.4	257	64	
6938	206.5398	0.13	PVC PIPE	25.4	257	69	
6978	200.5124	0.08	PVC PIPE	12.7	255	75	CLUSTER 17 (8 taps)
Reach 12							
X (m)	GSP (m)	Q (L/sec)	Material	D (mm)	HGL (m)	Head (m)	Notes
6751	220.5932				258	0	REACH 12
6784	205.3173	0.05	PVC PIPE	19.1	258	70	CLUSTER 18 (5 taps)
Reach 13							
X (m)	GSP (m)	Q (L/sec)	Material	D (mm)	HGL (m)	Head (m)	Notes
6938	206.5398				257	0	REACH 13
6974	218	0.05	PVC PIPE	12.7	256	58	
7010	210	0.05	PVC PIPE	25.4	256	66	CLUSTER 19 (5 taps)
Reach 14							
X (m)	GSP (m)	Q (L/sec)	Material	D (mm)	HGL (m)	Head (m)	Notes
7219	168.9697				193	0	REACH 14
7279	163.5207	0.04	PVC PIPE	38.1	193	36	
7329	158.5837	0.04	PVC PIPE	25.4	193	41	
7379	154.6607	0.04	PVC PIPE	25.4	193	45	
7429	151.9714	0.04	PVC PIPE	19.1	193	48	CLUSTER 20 (4 taps)

Figure E.6 Design Report Page 4

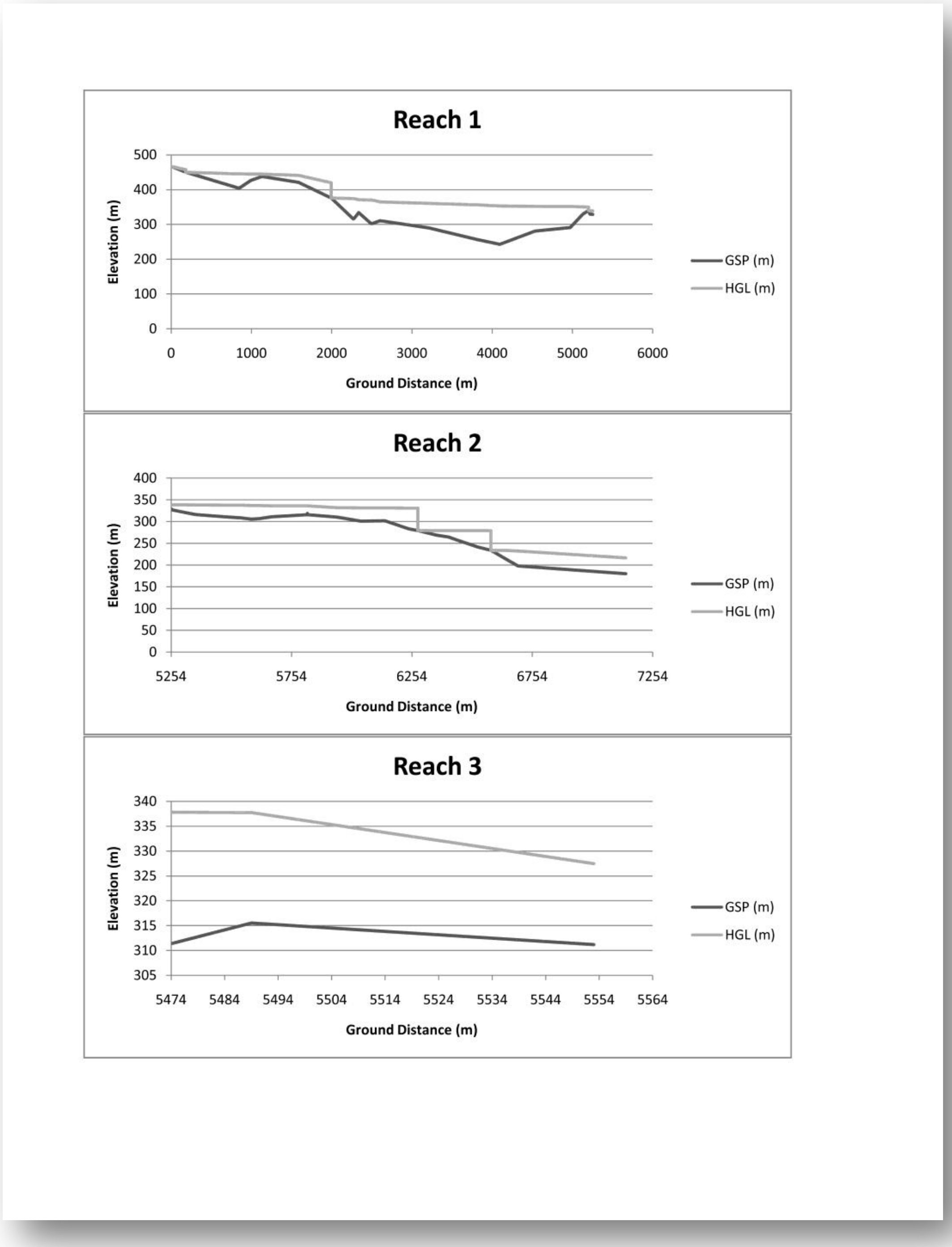


Figure E.7 Design Report Page 5

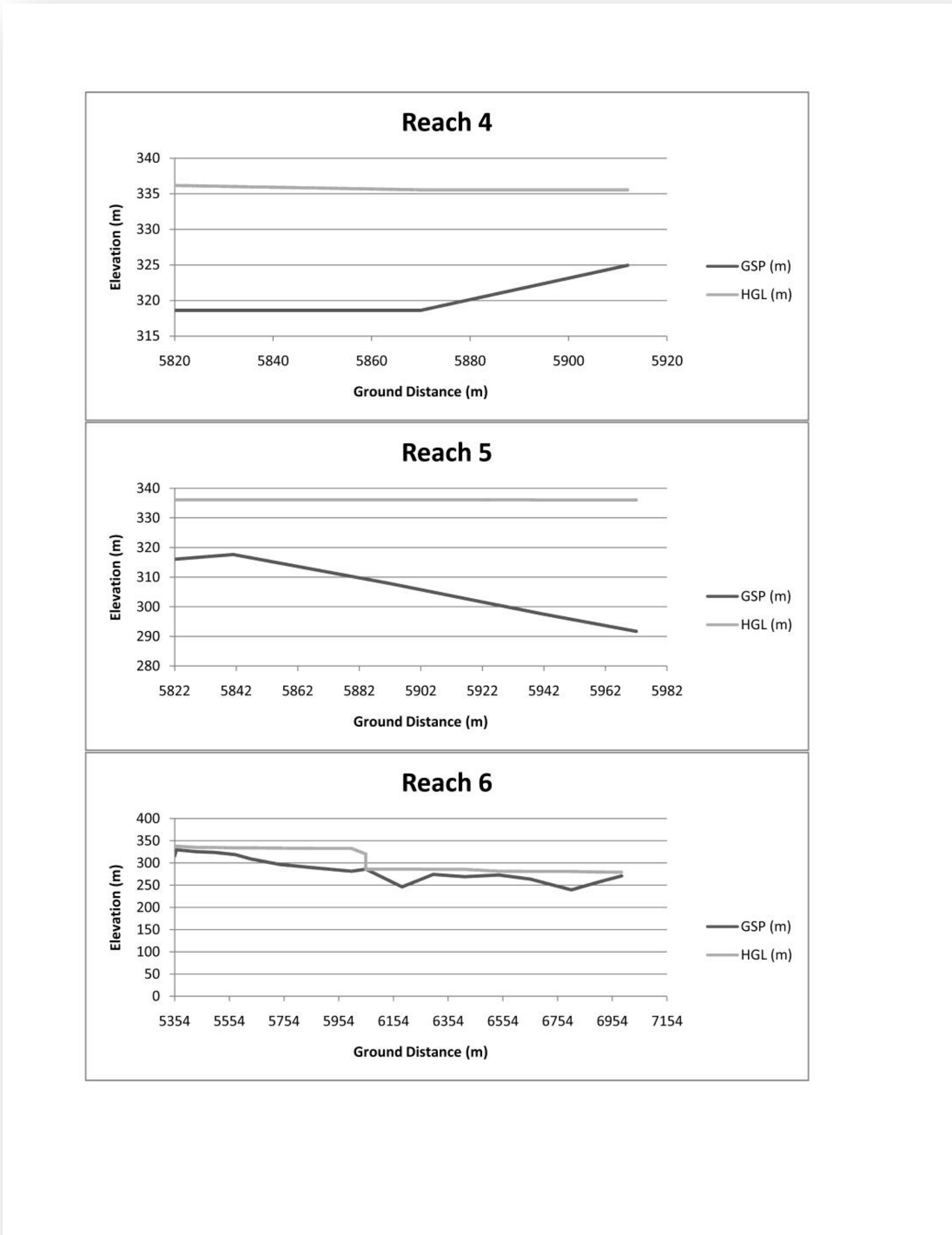


Figure E.8 Design Report Page 6

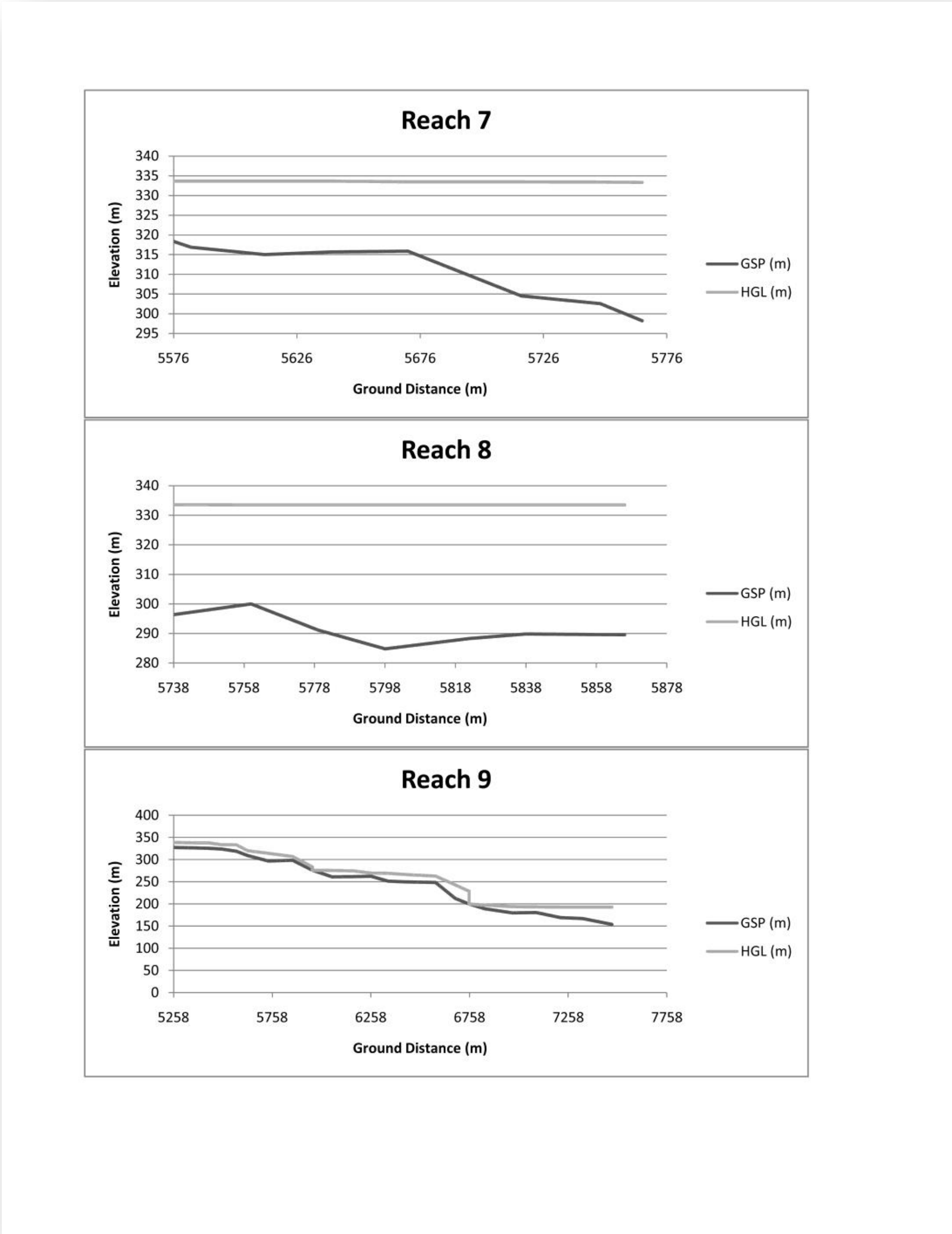


Figure E.9 Design Report Page 7

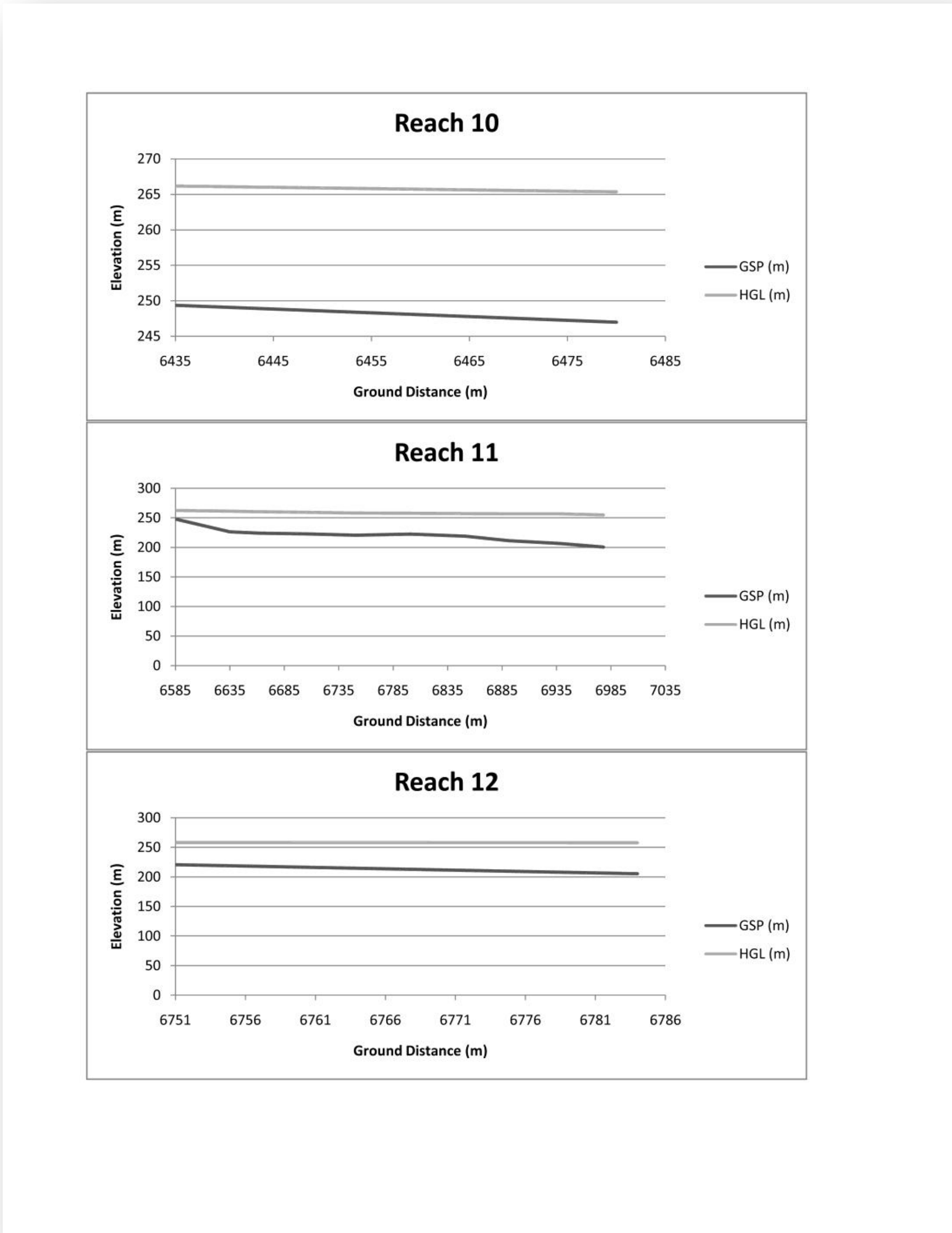


Figure E.10 Design Report Page 8

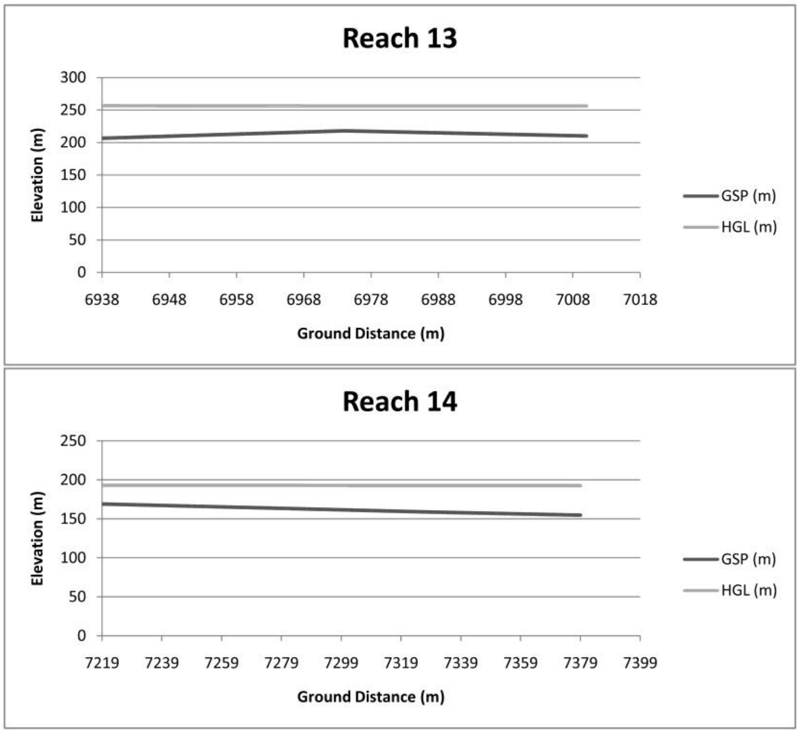


Figure E.11 Design Report Page 9

Stephen Good
Peace Corps Dominican Republic

Cuerpo De Paz, Embajada De Los Estados Unidos
Santo Domingo, Dminican Republic

Community Water System - Project Budget
Guaranal and Quita Sueno, Alatamira, Puerto Plata

Componets In System

Componet	Count	Cost Per Componet	Cost
Pipe Totals	1	$792,629.09	$792,629.09
Intake	1	$7,895.19	$7,895.19
Sedementaion Tanl	1	$15,009.56	$15,009.56
Storage Tank	1	$62,271.15	$62,271.15
BP Tanks	6	$14,748.41	$88,490.46
Tapstands	160	$503.18	$80,508.99
		Total Project Cost:	$1,046,804.43

Pipe Totals

Item Name	Size/Code	Count	Cost per Unit	Item Total
PVC PIPE	12.7	197	$128.20	$25,255.48
PVC PIPE	19.1	301	$194.61	$58,578.39
PVC PIPE	25.4	441	$240.85	$106,216.00
PVC PIPE	38.1	760	$429.34	$326,297.18
PVC PIPE	50.8	387	$560.66	$216,975.42
GI PIPE	38.1	56	$967.34	$54,171.08
GI PIPE	50.8	2	$2,567.77	$5,135.53
			Total for pipelines:	$792,629.09

Intake

Item Name	Size/Code	Count	Cost per Unit	Item Total
PVC PIPE	50.8	1	$560.66	$560.66
PVC - GI adapter	50.8	1	$22.00	$22.00
PVC Elbow 90	50.8	1	$21.00	$21.00
GI PIPE	50.8	2	$2,567.77	$5,135.53
GI Cap	50.8	2	$24.53	$49.06
GI Union	50.8	2	$24.00	$48.00
Cement	Bag	3	$110.00	$330.00
Sand	m^3	1	$665.00	$665.00
Teflon Tape	Roll	1	$11.94	$11.94
Purple Primer	250ML can	1	$351.00	$351.00
PVC Cement	250ML can	1	$701.00	$701.00
			Total:	$7,895.19

Sedementaion Tank

Item Name	Size/Code	Count	Cost per Unit	Item Total
GI PIPE	50.8	1	$2,567.77	$2,567.77
GI Elbow 90	50.8	1	$53.00	$53.00

Figure E.12 Planning Report Page 1

GI Tee		50.8	1	$66.23	$66.23
PVC PIPE		114.3	1	$363.00	$363.00
PVC Elbow 90		114.3	1	$51.00	$51.00
PVC Reducer	38.1-12.7		1	$20.64	$20.64
GI PIPE		12.7	1	$313.41	$313.41
GI Elbow 90		12.7	4	$8.84	$35.36
GI Ball Valve		38.1	1	$137.00	$137.00
GI Tee		38.1	1	$43.89	$43.89
GI Universal Union		38.1	2	$146.00	$292.00
PVC - GI adapter		38.1	1	$11.00	$11.00
GI PIPE		38.1	1	$967.34	$967.34
GI Elbow 90		38.1	2	$33.00	$66.00
Chicken Wire Mesh	m^3		9	$21.91	$197.19
Rebar	"3/8"		5	$110.00	$550.00
Rebar	"1/4"		6	$25.68	$154.08
Tie Wire	Roll		1	$4.00	$4.00
Cistern Lid	Large		1	$5,752.00	$5,752.00
Pad Lock	Small		1	$21.71	$21.71
Cement	Bag		15	$110.00	$1,650.00
Teflon Tape	Roll		1	$11.94	$11.94
Purple Primer	250ML can		1	$351.00	$351.00
Sand	m^3		1	$665.00	$665.00
Gravel	m^3		1	$665.00	$665.00
				Total:	$15,009.56

Storage Tank

Item Name	Size/Code		Count	Cost per Unit	Item Total
GI Elbow 90		50.8	8	$53.00	$424.00
GI Union		50.8	1	$24.00	$24.00
GI PIPE		50.8	5	$2,567.77	$12,838.83
PVC PIPE		114.3	2	$363.00	$726.00
PVC Elbow 90		114.3	1	$51.00	$51.00
GI Ball Valve		50.8	3	$510.00	$1,530.00
GI Tee		50.8	6	$66.23	$397.38
GI Reducer	50.8-12.7		12	$30.00	$360.00
GI Union		12.7	3	$36.00	$108.00
GI Universal Union		50.8	6	$176.00	$1,056.00
GI Union		50.8	3	$24.00	$72.00
PVC - GI adapter		50.8	4	$22.00	$88.00
Cement Block	8"		400	$18.35	$7,340.00
Gravel	m^3		9	$665.00	$5,985.00
Sand	m^3		7	$665.00	$4,655.00
Cistern Lid	Large		1	$5,752.00	$5,752.00
Teflon Tape	Roll		1	$11.94	$11.94
Purple Primer	250ML can		1	$351.00	$351.00
PVC Cement	250ML can		1	$701.00	$701.00
Cement	Bag		70	$110.00	$7,700.00

Figure E.13 Planning Report Page 2

Rebar	"3/8"		110	$110.00	$12,100.00
				Total:	$62,271.15

BP Tanks

Item Name	Size/Code	Count		Cost per Unit	Item Total
GI PIPE		50.8	2	$2,567.77	$5,135.53
GI Elbow 90		50.8	3	$53.00	$159.00
GI Tee		50.8	1	$66.23	$66.23
PVC PIPE		114.3	1	$363.00	$363.00
PVC Elbow 90		114.3	1	$51.00	$51.00
Float Vavle		50.8	2	$775.00	$1,550.00
Cement Block	8"		40	$18.35	$734.00
Tie Wire	Roll		1	$4.00	$4.00
Cistern Lid	Small		1	$3,500.00	$3,500.00
Pad Lock	Small		1	$21.71	$21.71
Rebar	"3/8"		3	$110.00	$330.00
Gravel	m^3		1	$665.00	$665.00
Sand	m^3		1	$665.00	$665.00
Cement	Bag		4	$110.00	$440.00
Teflon Tape	Roll		1	$11.94	$11.94
Purple Primer	250ML can		1	$351.00	$351.00
PVC Cement	250ML can		1	$701.00	$701.00
				Subtotal:	$14,748.41
				Total for 6 units:	$88,490.46

Tapstands

Item Name	Size/Code	Count		Cost per Unit	Item Total
GI Union		12.7	1	$36.00	$36.00
GI Elbow 90		12.7	2	$8.84	$17.68
GI Faucet		12.7	1	$59.00	$59.00
PVC - GI adapter		12.7	1	$2.20	$2.20
PVC Elbow 90		12.7	1	$3.70	$3.70
PVC PIPE		12.7	3	$128.20	$384.60
				Subtotal:	$503.18
				Total for 160 units:	$80,508.99

Figure E.14 Planning Report Page 3

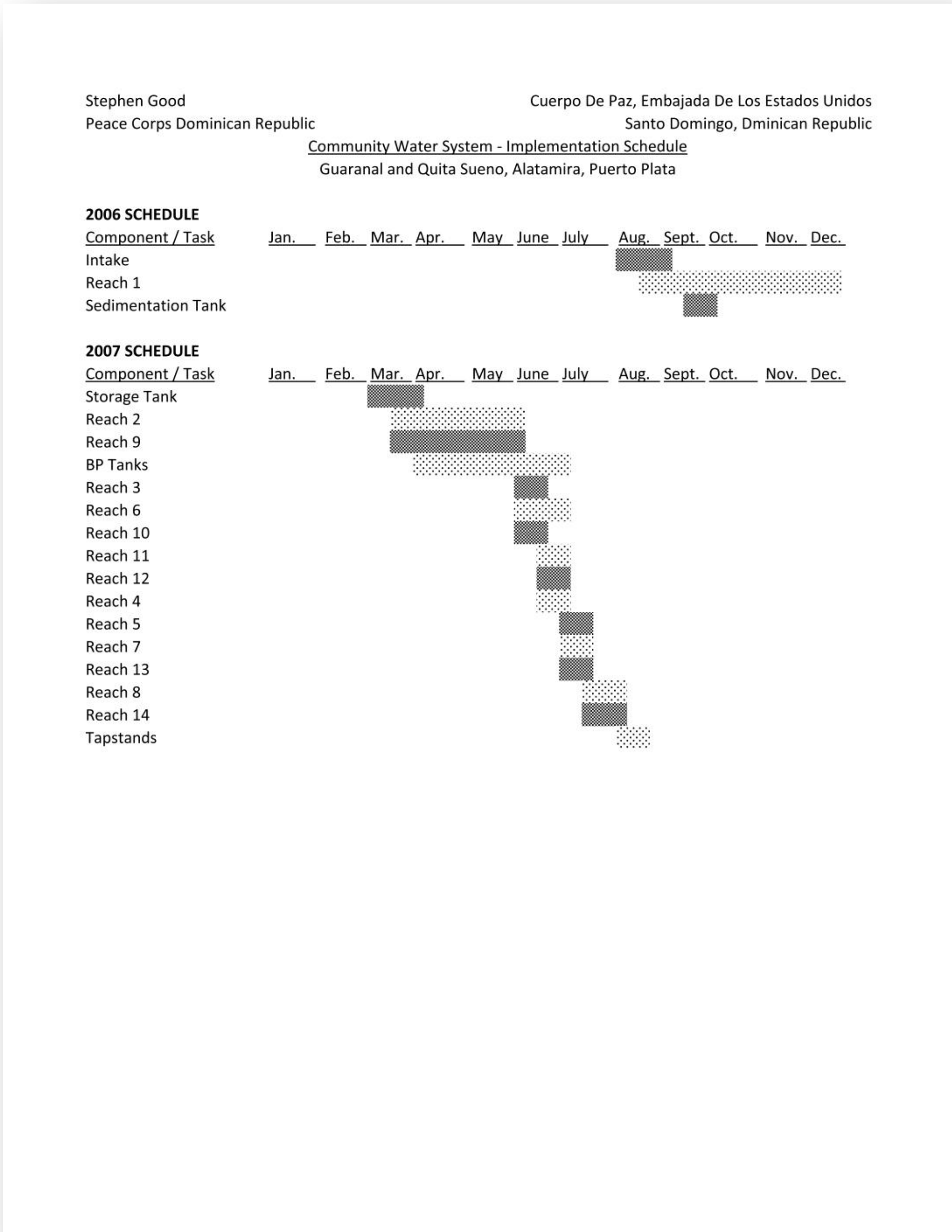


Figure E.15 Implementation Report Page 1

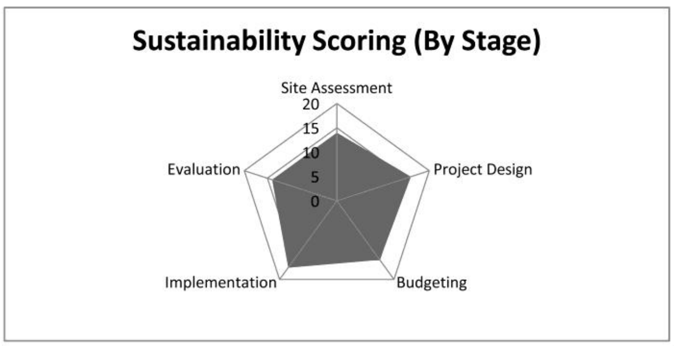
Stephen Good
Peace Corps Dominican Republic

Cuerpo De Paz, Embajada De Los Estados Unidos
Santo Domingo, Dminican Republic

Community Water System - Final Evaluaiton
Guaranal and Quita Sueno, Alatamira, Puerto Plata

Total Project Sustainability Score: 76

Stage Sustainability Report	Site Assessment	Project Design	Budgeting	Implementation	Evaluation	Total
Socio - Cultural Respect	2	3	4	4	2	15
Community Participation	3	2	3	4	3	15
Political Cohesion	1	3	2	3	3	12
Economic Sustainability	4	4	4	4	4	20
Environmental Sustainability	4	4	2	2	2	14
Total:	14	16	15	17	14	**76**



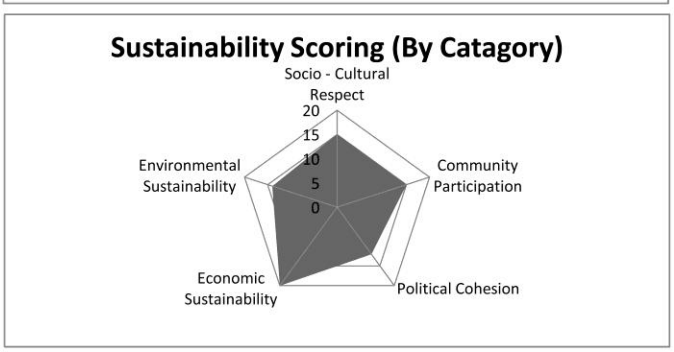


Figure E.16 Evaluation Report Page 1

APPENDIX F: *GOODwater* VBA CODE

```
'==========================================================================================
'
'          SET-UP MACROS
'
'==========================================================================================
Sub ResetALL()
'Resets All Forms in GOODwater
'
'

   ResetSetup
   ResetFeasibility
   'Reset design
   'Reset planning
   'reset imp
   'reset eval

End Sub
'
Sub ResetSetup()
'Clears the boxes on the set up page
'
'
   Sheets("M-S").Range("$AF$19:$AF$35").Value = ""
End Sub
'
'
'
Private Sub Workbook_Open()
   Sheets("M-H").Select
   Application.DisplayFullScreen = True
End Sub

'==========================================================================================
'
'          FEASIBILITY ASSESSMENT MACROS
'
'==========================================================================================
'
Sub Feasibility()
   Set a = AddIns("Solver Add-In")
   If a.Installed = True Then
      'Reset Values
      Sheets("fa").Range("$D$30:$D$33").Value = 0
      'FindDiameter for Different Types of System
      Dim b As Integer
      Dim rowStart As Integer
      Dim colStart As Integer
      b = 0
      rowStart = 30
      colStart = 4
      Sheets("fa").Select
      Do While b < 4
         SolverReset
         SolverOk SetCell:=Sheets("fa").Cells(rowStart + b, colStart + 4), MaxMinVal:=3, ValueOf:="0",
ByChange:=Sheets("fa").Cells(rowStart + b, colStart)
         SolverOptions AssumeNonNeg:=True
         SolverSolve UserFinish:=True
         b = b + 1
      Loop
```

```
        Sheets("F-I").Select
        Call SiteReport
    Else
        Sheets("M-I").Select
        MsgBox "The Solver add-in is not installed"
    End If
End Sub
'Resets The Check Boxes on the Action Page
'
'
Sub ResetFA()
    Sheets("fa").Range("$B$2:$B$21").Value = False
End Sub
'Resets The Inputs Page
'
'
Sub ResetFI()
    Sheets("F-I").Range("$AF$19:$AF$45").Value = ""
End Sub
'
'Resets the Feasibility Module
'
Sub ResetFeasibility()
    ResetFA
    ResetFI
    Sheets("F-R").Cells.Delete
    Sheets("F-R").Hyperlinks.Add Anchor:=Sheets("F-R").Cells(1, 6), Address:="", SubAddress:="'F-I'!A1",
TextToDisplay:="BACK"
End Sub
'
'   Create The Site Assessment Report
'
Sub SiteReport()
    Dim myrange
    Sheets("F-R").Cells.Delete
    Sheets("F-R").Hyperlinks.Add Anchor:=Sheets("F-R").Cells(1, 6), Address:="", SubAddress:="'F-I'!A1",
TextToDisplay:="BACK"
    'Header
    Sheets("F-R").Columns("A:G").ColumnWidth = 15
    Sheets("F-R").Columns("E:E").HorizontalAlignment = xlLeft
    Sheets("F-R").Columns("D:D").HorizontalAlignment = xlRight
    Sheets("F-R").Cells(1, 1) = Sheets("M-S").Cells(29, 32)
    Sheets("F-R").Cells(2, 1) = Sheets("M-S").Cells(31, 32)
    Sheets("F-R").Cells(1, 5) = Sheets("M-S").Cells(33, 32)
    Sheets("F-R").Cells(2, 5) = Sheets("M-S").Cells(35, 32)
    Sheets("F-R").Cells(1, 5).HorizontalAlignment = xlRight
    Sheets("F-R").Cells(2, 5).HorizontalAlignment = xlRight
    Sheets("F-R").Cells(3, 3) = Sheets("M-S").Cells(27, 32) & " - Site Assessment Report"
    Sheets("F-R").Cells(3, 3).Font.Underline = xlUnderlineStyleSingle
    Sheets("F-R").Cells(3, 3).HorizontalAlignment = xlCenter
    Sheets("F-R").Cells(4, 3) = Sheets("M-S").Cells(19, 32) & ", " & Sheets("M-S").Cells(21, 32) & ", " & Sheets("M-
S").Cells(23, 32)
    Sheets("F-R").Cells(4, 3).HorizontalAlignment = xlCenter
    'community info
    Sheets("F-R").Cells(6, 1) = "Community Information"
    Sheets("F-R").Cells(6, 1).Font.Bold = True
    Sheets("F-R").Cells(7, 1) = "Community Name"
    Sheets("F-R").Cells(8, 1) = "Community Municipality / County"
    Sheets("F-R").Cells(9, 1) = "Community State / Province"
    Sheets("F-R").Cells(10, 1) = "Community Country"
    Sheets("F-R").Cells(11, 1) = "Community Population"

    Sheets("F-R").Range("E7:E10").HorizontalAlignment = xlRight
```

```
    Sheets("F-R").Cells(7, 5) = Sheets("M-S").Cells(19, 32)
    Sheets("F-R").Cells(8, 5) = Sheets("M-S").Cells(21, 32)
    Sheets("F-R").Cells(9, 5) = Sheets("M-S").Cells(23, 32)
    Sheets("F-R").Cells(10, 5) = Sheets("M-S").Cells(25, 32)
    Sheets("F-R").Cells(11, 5) = Sheets("fa").Cells(2, 8)
    'Natural Parameters
    Sheets("F-R").Cells(13, 1) = "Environmental Parameters"
    Sheets("F-R").Cells(13, 1).Font.Bold = True
    Sheets("F-R").Cells(14, 1) = "Source Types"
    Sheets("F-R").Cells(15, 1) = "Source Count"
    Sheets("F-R").Cells(16, 1) = "Total Daily Source Production"
    Sheets("F-R").Cells(17, 1) = "Average Source Flow Rate"
    Sheets("F-R").Cells(18, 1) = "Distance To Source"
    Sheets("F-R").Cells(19, 1) = "Change In Elevation To Source"
    Sheets("F-R").Cells(20, 1) = "Distance In Distribution Network"
    Sheets("F-R").Cells(21, 1) = "Change In Elevation In Distribution Network"
    Sheets("F-R").Cells(22, 1) = "Distance Total"
    Sheets("F-R").Cells(23, 1) = "Change In Elevation Total"
    Sheets("F-R").Cells(14, 4) = Sheets("F-I").Cells(21, 32)
    Sheets("F-R").Cells(15, 4) = Sheets("F-I").Cells(23, 32)
    Sheets("F-R").Cells(16, 4) = Sheets("fa").Cells(2, 13)
    Sheets("F-R").Cells(17, 4) = Sheets("fa").Cells(6, 13)
    Sheets("F-R").Cells(18, 4) = Sheets("fa").Cells(5, 8)
    Sheets("F-R").Cells(19, 4) = Sheets("fa").Cells(4, 8) - Sheets("fa").Cells(7, 8)
    Sheets("F-R").Cells(20, 4) = Sheets("fa").Cells(6, 8)
    Sheets("F-R").Cells(21, 4) = Sheets("fa").Cells(7, 8) - Sheets("fa").Cells(8, 8)
    Sheets("F-R").Cells(22, 4) = Sheets("fa").Cells(6, 8) + Sheets("fa").Cells(5, 8)
    Sheets("F-R").Cells(23, 4) = (Sheets("fa").Cells(4, 8) - Sheets("fa").Cells(7, 8)) + (Sheets("fa").Cells(7, 8) -
Sheets("fa").Cells(8, 8))
    Sheets("F-R").Cells(16, 5) = "(L)"
    Sheets("F-R").Cells(17, 5) = "(L/sec)"
    Sheets("F-R").Cells(18, 5) = "(m)"
    Sheets("F-R").Cells(19, 5) = "(m)"
    Sheets("F-R").Cells(20, 5) = "(m)"
    Sheets("F-R").Cells(21, 5) = "(m)"
    Sheets("F-R").Cells(22, 5) = "(m)"
    Sheets("F-R").Cells(23, 5) = "(m)"
    'System Info
    Sheets("F-R").Cells(25, 1) = "Proposed Water System Estimates "
    Sheets("F-R").Cells(25, 5) = "(If Public Tapstands Are Installed)"
    Sheets("F-R").Cells(25, 5).HorizontalAlignment = xlRight
    Sheets("F-R").Cells(25, 1).Font.Bold = True
    Sheets("F-R").Cells(26, 1) = "Number of Individuals Per Tapstand"
    Sheets("F-R").Cells(27, 1) = "Number of Public TapStands Required"
    Sheets("F-R").Cells(28, 1) = "Water Allotment Per Person Daily"
    Sheets("F-R").Cells(29, 1) = "Volume of water needed for public Tapstands"
    Sheets("F-R").Cells(30, 1) = "Flow Rate needed (Without Storage Tank)"
    Sheets("F-R").Cells(31, 1) = "Flow Rate needed (With Storage Tank)"
    Sheets("F-R").Cells(26, 4) = Sheets("O-GV").Cells(23, 31)
    Sheets("F-R").Cells(27, 4) = Round(Sheets("fa").Cells(3, 16))
    Sheets("F-R").Cells(28, 4) = Sheets("O-GV").Cells(19, 31)
    Sheets("F-R").Cells(29, 4) = Sheets("fa").Cells(3, 13)
    Sheets("F-R").Cells(30, 4) = Sheets("fa").Cells(3, 17)
    Sheets("F-R").Cells(31, 4) = Round(Sheets("fa").Cells(7, 13), 1)
    Sheets("F-R").Cells(26, 5) = "persons/Tap"
    Sheets("F-R").Cells(27, 5) = "Tapstands"
    Sheets("F-R").Cells(28, 5) = "(L/person/day)"
    Sheets("F-R").Cells(29, 5) = "(L)"
    Sheets("F-R").Cells(30, 5) = "(L/sec)"
    Sheets("F-R").Cells(31, 5) = "(L/sec)"
    Sheets("F-R").Cells(32, 5) = "(IF Private Tapstands Are Installed )"
    Sheets("F-R").Cells(32, 5).HorizontalAlignment = xlRight
    Sheets("F-R").Cells(33, 1) = "Number of Individuals Per Tapstand"
```

```
Sheets("F-R").Cells(34, 1) = "Number of Private TapStands Required"
Sheets("F-R").Cells(35, 1) = "Water Allotment Per Person Daily"
Sheets("F-R").Cells(36, 1) = "Volume of water needed for private Tapstands"
Sheets("F-R").Cells(37, 1) = "Flow Rate needed (Without Storage Tank)"
Sheets("F-R").Cells(38, 1) = "Flow Rate needed (With Storage Tank)"
Sheets("F-R").Cells(33, 4) = Sheets("O-GV").Cells(25, 31)
Sheets("F-R").Cells(34, 4) = Round(Sheets("fa").Cells(4, 16))
Sheets("F-R").Cells(35, 4) = Sheets("O-GV").Cells(21, 31)
Sheets("F-R").Cells(36, 4) = Sheets("fa").Cells(4, 13)
Sheets("F-R").Cells(37, 4) = Sheets("fa").Cells(4, 17)
Sheets("F-R").Cells(38, 4) = Round(Sheets("fa").Cells(8, 13), 1)
Sheets("F-R").Cells(33, 5) = "persons/Tap"
Sheets("F-R").Cells(34, 5) = "Tapstands"
Sheets("F-R").Cells(35, 5) = "(L/person/day)"
Sheets("F-R").Cells(36, 5) = "(L)"
Sheets("F-R").Cells(37, 5) = "(L/sec)"
Sheets("F-R").Cells(38, 5) = "(L/sec)"
'Construcit Info
Sheets("F-R").Cells(40, 1) = "Construction Assessment"
Sheets("F-R").Cells(40, 1).Font.Bold = True
Sheets("F-R").Cells(41, 1) = "Estimate of laborers available"
Sheets("F-R").Cells(42, 1) = "Meters of Trench Dug Daily Per Worker"
Sheets("F-R").Cells(43, 1) = "Days available to work"
Sheets("F-R").Cells(44, 1) = "Weeks available to work"
Sheets("F-R").Cells(45, 1) = "Days Requied per worker"
Sheets("F-R").Cells(46, 1) = "Weeks Required Per Worker"
Sheets("F-R").Cells(47, 1) = "Estimated Laborer-Days of Construction"
Sheets("F-R").Cells(48, 1) = "Estimated Years of Construction"
Sheets("F-R").Cells(41, 4) = Sheets("fa").Cells(10, 13)
Sheets("F-R").Cells(42, 4) = Round(Sheets("fa").Cells(12, 15), 1)
Sheets("F-R").Cells(43, 4) = Round(Sheets("fa").Cells(14, 13), 1)
Sheets("F-R").Cells(44, 4) = Round(Sheets("fa").Cells(16, 13), 1)
Sheets("F-R").Cells(45, 4) = Round(Sheets("fa").Cells(13, 13), 1)
Sheets("F-R").Cells(46, 4) = Round(Sheets("fa").Cells(15, 13), 1)
Sheets("F-R").Cells(47, 4) = Round(Sheets("fa").Cells(12, 13), 0)
Sheets("F-R").Cells(48, 4) = Round(Sheets("fa").Cells(17, 13), 1)
Sheets("F-R").Cells(41, 5) = "Laborers"
Sheets("F-R").Cells(42, 5) = "(m)"
Sheets("F-R").Cells(43, 5) = "days/wkr/yr"
Sheets("F-R").Cells(44, 5) = "wks/wkr/yr"
Sheets("F-R").Cells(45, 5) = "Days"
Sheets("F-R").Cells(46, 5) = "Weeks"
Sheets("F-R").Cells(47, 5) = "Days of Labor"
Sheets("F-R").Cells(48, 5) = "Years"
'  Capital Cost Estimate
Sheets("F-R").Cells(50, 1) = "Financial Estimate"
Sheets("F-R").Cells(50, 1).Font.Bold = True
Sheets("F-R").Cells(50, 4) = "(Public)"
Sheets("F-R").Cells(50, 5) = "(Private)"
Sheets("F-R").Range("D50:D62").HorizontalAlignment = xlLeft
Sheets("F-R").Cells(51, 1) = "Initial Capital Investment Required:"
Sheets("F-R").Cells(52, 1) = "  Intake  Structures"
Sheets("F-R").Cells(53, 1) = "  Main Line"
Sheets("F-R").Cells(54, 1) = "  Storage Tank"
Sheets("F-R").Cells(55, 1) = "  Distribution Network"
Sheets("F-R").Cells(56, 1) = "          Total Initial Costs:"
Sheets("F-R").Cells(57, 1) = "Operational Costs"
Sheets("F-R").Cells(58, 1) = "  Intake Structures"
Sheets("F-R").Cells(59, 1) = "  Main Line"
Sheets("F-R").Cells(60, 1) = "  Storage Tank"
Sheets("F-R").Cells(61, 1) = "  Distribution Network"
Sheets("F-R").Cells(62, 1) = "          Total Operational Costs: "
Sheets("F-R").Cells(52, 4) = FormatCurrency(Sheets("fa").Cells(19, 13))
```

```
    Sheets("F-R").Cells(53, 4) = FormatCurrency(Sheets("fa").Cells(22, 13))
    Sheets("F-R").Cells(54, 4) = FormatCurrency(Sheets("fa").Cells(25, 13))
    Sheets("F-R").Cells(55, 4) = FormatCurrency(Sheets("fa").Cells(28, 13))
    Sheets("F-R").Cells(56, 4) = FormatCurrency(Sheets("fa").Cells(31, 13))
    Sheets("F-R").Cells(58, 4) = FormatCurrency(Sheets("fa").Cells(20, 13))
    Sheets("F-R").Cells(59, 4) = FormatCurrency(Sheets("fa").Cells(23, 13))
    Sheets("F-R").Cells(60, 4) = FormatCurrency(Sheets("fa").Cells(26, 13))
    Sheets("F-R").Cells(61, 4) = FormatCurrency(Sheets("fa").Cells(29, 13))
    Sheets("F-R").Cells(62, 4) = FormatCurrency(Sheets("fa").Cells(32, 13))
    Sheets("F-R").Cells(52, 5) = FormatCurrency(Sheets("fa").Cells(19, 14))
    Sheets("F-R").Cells(53, 5) = FormatCurrency(Sheets("fa").Cells(22, 14))
    Sheets("F-R").Cells(54, 5) = FormatCurrency(Sheets("fa").Cells(25, 14))
    Sheets("F-R").Cells(55, 5) = FormatCurrency(Sheets("fa").Cells(28, 14))
    Sheets("F-R").Cells(56, 5) = FormatCurrency(Sheets("fa").Cells(31, 14))
    Sheets("F-R").Cells(58, 5) = FormatCurrency(Sheets("fa").Cells(20, 14))
    Sheets("F-R").Cells(59, 5) = FormatCurrency(Sheets("fa").Cells(23, 14))
    Sheets("F-R").Cells(60, 5) = FormatCurrency(Sheets("fa").Cells(26, 14))
    Sheets("F-R").Cells(61, 5) = FormatCurrency(Sheets("fa").Cells(29, 14))
    Sheets("F-R").Cells(62, 5) = FormatCurrency(Sheets("fa").Cells(32, 14))
    '  Report Summary
    Sheets("F-R").Cells(64, 1) = "Report Summary"
    Sheets("F-R").Cells(64, 1).Font.Bold = True
    If Sheets("fa").Cells(7, 15) = True Then
        Sheets("F-R").Cells(65, 1) = "   Public Tapstands are possible with current water source(s)."
    Else
        Sheets("F-R").Cells(65, 1) = " ! Public Tapstands are not possible with water current source(s), more water must be
located."
    End If
    If Sheets("fa").Cells(3, 15) = False Then
        Sheets("F-R").Cells(66, 1) = "   No Storage Tank is required with public Tapstands."
    Else
        Sheets("F-R").Cells(66, 1) = " ! Storage Tank required for public Tapstands"
    End If
    If Sheets("fa").Cells(3, 19) = True Then
        Sheets("F-R").Cells(67, 1) = "   Enough Funding available for construction of public Tapstand water system."
    Else
        Sheets("F-R").Cells(67, 1) = " ! Not Enough Funding available for construction of public Tapstand water system."
    End If
    If Sheets("fa").Cells(3, 20) = True Then
        Sheets("F-R").Cells(68, 1) = "   Enough community contributions to maintain public sysetem."
    Else
        Sheets("F-R").Cells(68, 1) = " ! Not Enough community contributions to maintain public sysetem."
    End If
    If Sheets("fa").Cells(8, 15) = True Then
        Sheets("F-R").Cells(69, 1) = "   Private Tapstands are possible with water current source(s)."
    Else
        Sheets("F-R").Cells(69, 1) = " ! Private Tapstands are not possible with current water source(s), more water must be
located."
    End If
    If Sheets("fa").Cells(4, 15) = False Then
        Sheets("F-R").Cells(70, 1) = "   No Storage Tank is required with private Tapstands."
    Else
        Sheets("F-R").Cells(70, 1) = " ! Storage Tank required for private Tapstands"
    End If
        If Sheets("fa").Cells(4, 19) = True Then
        Sheets("F-R").Cells(71, 1) = "   Enough Funding available for construction of private water system."
    Else
        Sheets("F-R").Cells(71, 1) = " ! Not Enough Funding available for construction of private water system."
    End If
    If Sheets("fa").Cells(4, 20) = True Then
        Sheets("F-R").Cells(72, 1) = "   Enough community contributions to maintain private sysetem."
    Else
        Sheets("F-R").Cells(72, 1) = " ! Not Enough community contributions to maintain private sysetem."
```

```
    End If
    Sheets("F-R").Select
End Sub

'==========================================================================================
'
'           SYSTEM DESIGN MACROS
'
'==========================================================================================
'
Dim Counter
Dim publicQ As Double
Dim privateQ As Double
Dim Continue As Boolean
'
' Reset Design
'
Sub ResetDesign()
    Call ResetDA
    Call ResetTopo
    Call ResetComponets
    Call ResetBase
    Sheets("D-R").Cells.Delete
    Sheets("D-R").Hyperlinks.Add Anchor:=Sheets("D-R").Cells(1, 9), Address:="", SubAddress:="'D-G'!A1",
TextToDisplay:="BACK"
End Sub
'
'Resets The Check Boxes on the Action Page
'
'
Sub ResetDA()
    Sheets("da").Range("$B$2:$B$21").Value = False
End Sub
'
'Resets The Topo Info
'
Sub ResetTopo()
    Sheets("D-T").Cells(18, 10) = "place name of reach here"
    Sheets("D-T").Cells(22, 19) = "- Datum -"
    For i = 0 To 39 Step 1
        Sheets("D-T").Cells(18, 10 + i * 33) = "place name of reach here"
        Sheets("D-T").Cells(18, 72 + i * 33) = ""
        Sheets("D-T").Cells(19, 72 + i * 33) = ""
    Next i
    Sheets("D-T").Range("$M$24:$Y$70").Value = ""
    Sheets("D-T").Range("$AT$24:$bf$70").Value = ""
    Sheets("D-T").Range("$CA$24:$CM$70").Value = ""
    Sheets("D-T").Range("$DH$24:$DT$70").Value = ""
    Sheets("D-T").Range("$EO$24:$FA$70").Value = ""
    Sheets("D-T").Range("$FV$24:$GH$70").Value = ""
    Sheets("D-T").Range("$HC$24:$HO$70").Value = ""
    Sheets("D-T").Range("$IJ$24:$IV$70").Value = ""
    Sheets("D-T").Range("$JQ$24:$KC$70").Value = ""
    Sheets("D-T").Range("$KX$24:$LJ$70").Value = ""
    Sheets("D-T").Range("$ME$24:$MQ$70").Value = ""
    Sheets("D-T").Range("$NL$24:$NX$70").Value = ""
    Sheets("D-T").Range("$OS$24:$PE$70").Value = ""
    Sheets("D-T").Range("$PZ$24:$QL$70").Value = ""
    Sheets("D-T").Range("$RG$24:$RS$70").Value = ""
    Sheets("D-T").Range("$SN$24:$SZ$70").Value = ""
    Sheets("D-T").Range("$TU$24:$UG$70").Value = ""
    Sheets("D-T").Range("$VB$24:$VN$70").Value = ""
    Sheets("D-T").Range("$WI$24:$WU$70").Value = ""
```

```
    Sheets("D-T").Range("$XP$24:$YB$70").Value = ""
    Sheets("D-T").Range("$YW$24:$ZL$70").Value = ""
    Sheets("D-T").Range("$AAD$24:$AAP$70").Value = ""
    Sheets("D-T").Range("$ABK$24:$ABW$70").Value = ""
    Sheets("D-T").Range("$ACR$24:$ADD$70").Value = ""
    Sheets("D-T").Range("$ADY$24:$AEK$70").Value = ""
    Sheets("D-T").Range("$AFF$24:$AFR$70").Value = ""
    Sheets("D-T").Range("$AGM$24:$AGY$70").Value = ""
    Sheets("D-T").Range("$AHT$24:$AIF$70").Value = ""
    Sheets("D-T").Range("$AJA$24:$AJM$70").Value = ""
    Sheets("D-T").Range("$AKH$24:$AKT$70").Value = ""
    Sheets("D-T").Range("$ALO$24:$AMA$70").Value = ""
    Sheets("D-T").Range("$AMV$24:$ANH$70").Value = ""
    Sheets("D-T").Range("$AOC$24:$AOO$70").Value = ""
    Sheets("D-T").Range("$APJ$24:$APV$70").Value = ""
    Sheets("D-T").Range("$AQQ$24:$ARC$70").Value = ""
    Sheets("D-T").Range("$ARX$24:$ASJ$70").Value = ""
    Sheets("D-T").Range("$ATE$24:$ATQ$70").Value = ""
    Sheets("D-T").Range("$AUL$24:$AUX$70").Value = ""
    Sheets("D-T").Range("$AVS$24:$AWE$70").Value = ""
    Sheets("D-T").Range("$AWZ$24:$AXL$70").Value = ""
End Sub
'
'Resets The Componet Info
'
Sub ResetComponets()
        Sheets("D-C").Range("$r$20:$Aa$20").Value = ""
        Sheets("D-C").Range("$L$22:$AQ$69").Value = ""
        Sheets("D-C").Range("$AV$20:$CA$69").Value = ""
        Sheets("D-C").Range("$cf$20:$cl$69").Value = ""
        Sheets("D-C").Range("$Dp$20:$dv$69").Value = ""
        Sheets("D-C").Range("$ez$20:$Fi$69").Value = ""
        Sheets("D-C").Range("$gj$20:$Gv$69").Value = ""
        Sheets("D-C").Range("$CU$12:$CU$12").Value = ""
End Sub
'
'
'
Sub ResetBase()
    Sheets("da").Range("$B$29:$x$2027").Value = ""
    Sheets("da").Range("$AL$29:$AL$2027").Value = ""
    Sheets("da").Range("$AZ$29:$CT$2027").Value = ""
    Sheets("D-G").Range("$AL$39:$AL$2037").Value = ""
    Sheets("D-G").Range("$AZ$39:$AZ$2037").Value = ""
End Sub
'
' Generate base system
'
Sub Gen()
    Sheets("da").Range("$B$29:$x$2027").Value = ""
    Sheets("da").Range("$AL$29:$AL$2027").Value = ""
    Sheets("da").Range("$AZ$29:$CT$2027").Value = ""
    publicQ = Sheets("da").Cells(18, 102)
    privateQ = Sheets("da").Cells(19, 102)
    Continue = True
    Sheets("da").Cells(25, 107) = "Copying Topographic Information . . ."
    If Continue Then Call CopyTopo
        Sheets("da").Cells(25, 107) = "Copying Source Information . . ."
    If Continue Then Call CopySources
        Sheets("da").Cells(25, 107) = "Copying Tank Information . . ."
    If Continue Then Call CopyTanks
        Sheets("da").Cells(25, 107) = "Copying Public Tapstand Information . . ."
    If Continue Then Call CopyPublic
```

```
        Sheets("da").Cells(25, 107) = "Copying Private Tapstand Information . . ."
    If Continue Then Call CopyPrivate
        Sheets("da").Cells(25, 107) = "Copying Tapstand Clusters . . ."
    If Continue Then Call CopyClusters
        Sheets("da").Cells(25, 107) = "Copying Other Points . . ."
    If Continue Then Call CopyOthers
        Sheets("da").Cells(25, 107) = "Setting Flow Rates . . ."
    If Continue Then Call SetQ
        Sheets("da").Cells(25, 107) = "Calculating Static Head . . ."
    If Continue Then Call SetStatic
        Sheets("da").Cells(25, 107) = "Ajusting Tanks . . ."
    If Continue Then Call MoveTanks
        Sheets("da").Cells(25, 107) = "Base Network Created"
End Sub
'
'Copies Topo Info To DG...
'
Sub CopyTopo()
    Dim branchCounter
    Dim BranchRoot
    Dim BranchSpot
    Dim GoSpot
    Dim BranchName
    Counter = 0
    branchCounter = 1
    For i = 0 To 39 Step 1
        BranchRoot = 1
        BranchSpot = 1
        If i > 0 Then BranchRoot = Sheets("D-T").Cells(18, 39 + i * 33)
        If i > 0 Then BranchSpot = Sheets("D-T").Cells(19, 39 + i * 33)
        BranchName = Sheets("D-T").Cells(18, 39 + i * 33)
        For j = 0 To 24 Step 1
            If Sheets("D-T").Cells(j * 2 + 22, 10 + i * 33) <> "" Then
                Sheets("da").Cells(Counter * 2 + 29, 2) = Counter + 1
                Sheets("da").Cells(Counter * 2 + 29, 5) = Sheets("D-T").Cells(j * 2 + 22, 13 + i * 33)
                Sheets("da").Cells(Counter * 2 + 29, 11) = Sheets("D-T").Cells(j * 2 + 22, 19 + i * 33)
                Sheets("da").Cells(Counter * 2 + 29, 80) = Sheets("D-T").Cells(j * 2 + 22, 25 + i * 33)
                branchCounter = 1
                If j = 0 Then
                    Sheets("da").Cells(Counter * 2 + 29, 5) = Sheets("da").Cells(Counter * 2 + 29, 5) * -1
                    For k = 0 To Counter Step 1
                        If Sheets("da").Cells((k + 1) * 2 + 29, 5) < 0 Then branchCounter = branchCounter + 1
                        If branchCounter = BranchRoot Then
                            Sheets("da").Cells(Counter * 2 + 29, 5) = (k + BranchSpot) * -1
                            If BranchRoot > 1 Then Sheets("da").Cells(Counter * 2 + 29, 5) = (k + BranchSpot + 1) * -1
                            If Sheets("D-T").Cells(18, 10 + i * 33) = "" Or Sheets("D-T").Cells(18, 10 + i * 33) = "place name of reach
here" Then
                                Sheets("da").Cells(Counter * 2 + 29, 80) = "REACH " & (i + 1)
                            Else
                                Sheets("da").Cells(Counter * 2 + 29, 80) = Sheets("D-T").Cells(18, 10 + i * 33)
                            End If
                            If i <> 0 Then
                                If Sheets("da").Cells(Counter * 2 + 29, 98) = "" Then
                                    Sheets("da").Cells(Counter * 2 + 29, 98) = "R"
                                Else
                                    MsgBox "Too Many Objects At One Point " & i & " , Check Topography"
                                    Continue = False
                                End If
                            End If
                            k = Counter + 1
                        End If
                    Next k
                End If
```

```
            Counter = Counter + 1
         End If
      Next j
   Next i
End Sub
'
'Copies Source Info To DG...
'
Sub CopySources()
   Dim Sourcebranch
   Dim SourceSpot
   Dim SourceQ
   Dim currBranch
   For i = 0 To 24 Step 1
      If Sheets("D-C").Cells(i * 2 + 20, 9) <> "" Then
         Sourcebranch = Sheets("D-C").Cells(i * 2 + 20, 12)
         SourceSpot = Sheets("D-C").Cells(i * 2 + 20, 15)
         SourceQ = Sheets("D-C").Cells(i * 2 + 20, 18)
         CurBranch = 0
         For j = 0 To Counter
            If Sheets("da").Cells((j) * 2 + 29, 5) < 0 Then CurBranch = CurBranch + 1
            If CurBranch = Sourcebranch Then
               Sheets("da").Cells(((j + SourceSpot - 1) * 2) + 29, 17) = SourceQ * -1
               Sheets("da").Cells(((j + SourceSpot - 1) * 2) + 29, 73) = 0
               If Sheets("D-C").Cells(i * 2 + 20, 27) = "" Then
                  Sheets("da").Cells(((j + SourceSpot - 1) * 2) + 29, 80) = "SOURCE " & (i + 1)
               Else
                  Sheets("da").Cells(((j + SourceSpot - 1) * 2) + 29, 80) = Sheets("D-C").Cells(i * 2 + 20, 27)
               End If
               If Sheets("da").Cells(((j + SourceSpot - 1) * 2) + 29, 98) = "" Then
                   Sheets("da").Cells(((j + SourceSpot - 1) * 2) + 29, 98) = "S"
               Else
                    MsgBox "Too Many Objects At One Point, Check Sources"
                    Continue = False
               End If
               j = Counter
            End If
         Next j
      End If
   Next i
   If Sheets("D-C").Cells(20, 18) <> "" Then Sheets("da").Cells(29, 17) = Sheets("D-C").Cells(20, 18)
End Sub

'
'Copies Tanks Info To DG...
'
Sub CopyTanks()
   Dim tankArray
   Dim tankbranch
   Dim TankSpot
   Dim ArraySpot
   Dim currBranch
   Dim StorageTankSpot
   If Sheets("D-C").Cells(12, 99) <> 0 Then
      StorageTankSpot = Sheets("D-C").Cells(12, 99)
      Sheets("da").Cells((StorageTankSpot - 1) * 2 + 29, 80) = "STORAGE TANK"
      Sheets("da").Cells((StorageTankSpot - 1) * 2 + 29, 73) = 0
      If Sheets("da").Cells((StorageTankSpot - 1) * 2 + 29, 98) = "" Then
         Sheets("da").Cells((StorageTankSpot - 1) * 2 + 29, 98) = "T"
      Else
         MsgBox "Too Many Objects At One Point, Check Tanks"
         Continue = False
      End If
```

```
    End If
    For i = 0 To 24 Step 1
        If Sheets("D-C").Cells(i * 2 + 20, 45) <> "" Then
            tankbranch = Sheets("D-C").Cells(i * 2 + 20, 48)
            TankSpot = Sheets("D-C").Cells(i * 2 + 20, 51)
            CurBranch = 0
            For j = 0 To Counter
                If Sheets("da").Cells((j) * 2 + 29, 5) < 0 Then CurBranch = CurBranch + 1
                If CurBranch = tankbranch Then
                    Sheets("da").Cells(((j + TankSpot - 1) * 2) + 29, 73) = 0

                    If Sheets("D-C").Cells(i * 2 + 20, 54) = "" Then
                        Sheets("da").Cells(((j + TankSpot - 1) * 2) + 29, 80) = "TANK " & (i + 1)
                    Else
                        Sheets("da").Cells(((j + TankSpot - 1) * 2) + 29, 80) = Sheets("D-C").Cells(i * 2 + 20, 54)
                    End If
                    If Sheets("da").Cells(((j + TankSpot - 1) * 2) + 29, 98) = "" Then
                         Sheets("da").Cells(((j + TankSpot - 1) * 2) + 29, 98) = "T"
                    Else
                          MsgBox "Too Many Objects At One Point, Check Tanks"
                          Continue = False
                    End If
                    j = Counter
                End If
            Next j
        End If
    Next i
End Sub
'
'Copies Public Info To DG...
'
Sub CopyPublic()
    Dim publicbranch
    Dim publicSpot
    Dim currBranch
    For i = 0 To 24 Step 1
        If Sheets("D-C").Cells(i * 2 + 20, 81) <> "" Then
            publicbranch = Sheets("D-C").Cells(i * 2 + 20, 84)
            publicSpot = Sheets("D-C").Cells(i * 2 + 20, 87)
            CurBranch = 0
            For j = 0 To Counter
                If Sheets("da").Cells((j) * 2 + 29, 5) < 0 Then CurBranch = CurBranch + 1
                If CurBranch = publicbranch Then
                    Sheets("da").Cells(((j + publicSpot - 1) * 2) + 29, 17) = publicQ
                    If Sheets("D-C").Cells(i * 2 + 20, 90) = "" Then
                        Sheets("da").Cells(((j + publicSpot - 1) * 2) + 29, 80) = "PUBLIC TAP " & (i + 1)
                    Else
                        Sheets("da").Cells(((j + publicSpot - 1) * 2) + 29, 80) = Sheets("D-C").Cells(i * 2 + 20, 90)
                    End If
                    If Sheets("da").Cells(((j + publicSpot - 1) * 2) + 29, 98) = "" Then
                        Sheets("da").Cells(((j + publicSpot - 1) * 2) + 29, 98) = "E"
                    Else
                        MsgBox "Too Many Objects At One Point, Check Tapstands"
                        Continue = False
                    End If
                    j = Counter
                End If
            Next j
        End If
    Next i
End Sub
'
'Copies Public Info To DG...
```

```
'
Sub CopyPrivate()
    Dim Privatebranch
    Dim PrivateSpot
    Dim currBranch
    For i = 0 To 24 Step 1
        If Sheets("D-C").Cells(i * 2 + 20, 117) <> "" Then
            Privatebranch = Sheets("D-C").Cells(i * 2 + 20, 120)
            PrivateSpot = Sheets("D-C").Cells(i * 2 + 20, 123)
            CurBranch = 0
            For j = 0 To Counter
                If Sheets("da").Cells((j) * 2 + 29, 5) < 0 Then CurBranch = CurBranch + 1
                If CurBranch = Privatebranch Then
                    Sheets("da").Cells(((j + PrivateSpot - 1) * 2) + 29, 17) = privateQ
                    If Sheets("D-C").Cells(i * 2 + 20, 126) = "" Then
                        Sheets("da").Cells(((j + PrivateSpot - 1) * 2) + 29, 80) = "PRIVATE TAP " & (i + 1)
                    Else
                        Sheets("da").Cells(((j + PrivateSpot - 1) * 2) + 29, 80) = Sheets("D-C").Cells(i * 2 + 20, 126)
                    End If
                    If Sheets("da").Cells(((j + PrivateSpot - 1) * 2) + 29, 98) = "" Then
                        Sheets("da").Cells(((j + PrivateSpot - 1) * 2) + 29, 98) = "E"
                    Else
                        MsgBox "Too Many Objects At One Point, Check Tapstands"
                        Continue = False
                    End If
                    j = Counter
                End If
            Next j
        End If
    Next i
End Sub
'
'Copies Clusters Info To DG...
'
Sub CopyClusters()
    Dim Clustersbranch
    Dim ClustersSpot
    Dim ClustersQ
    Dim currBranch
    For i = 0 To 24 Step 1
        If Sheets("D-C").Cells(i * 2 + 20, 153) <> "" Then
            Clustersbranch = Sheets("D-C").Cells(i * 2 + 20, 156)
            ClustersSpot = Sheets("D-C").Cells(i * 2 + 20, 159)
            ClustersQ = Sheets("D-C").Cells(i * 2 + 20, 162) * privateQ
            CurBranch = 0
            For j = 0 To Counter
                If Sheets("da").Cells((j) * 2 + 29, 5) < 0 Then CurBranch = CurBranch + 1
                If CurBranch = Clustersbranch Then
                    Sheets("da").Cells(((j + ClustersSpot - 1) * 2) + 29, 17) = ClustersQ
                    If Sheets("D-C").Cells(i * 2 + 20, 165) = "" Then
                        Sheets("da").Cells(((j + ClustersSpot - 1) * 2) + 29, 80) = "CLUSTER " & (i + 1) & "  (" & Sheets("D-
C").Cells(i * 2 + 20, 162) & " taps)"
                    Else
                        Sheets("da").Cells(((j + ClustersSpot - 1) * 2) + 29, 80) = Sheets("D-C").Cells(i * 2 + 20, 165)
                    End If
                    If Sheets("da").Cells(((j + ClustersSpot - 1) * 2) + 29, 98) = "" Then
                        Sheets("da").Cells(((j + ClustersSpot - 1) * 2) + 29, 98) = "E"
                    Else
                        MsgBox "Too Many Objects At One Point, Check Tapstands"
                        Continue = False
                    End If
                    j = Counter
                End If
```

```
            Next j
        End If
    Next i
End Sub
'
'Copies Others Info To DG...
'
Sub CopyOthers()
    Dim Othersbranch
    Dim OthersSpot
    Dim OthersQ
    Dim currBranch
    For i = 0 To 24 Step 1
        If Sheets("D-C").Cells(i * 2 + 20, 189) <> "" Then
            Othersbranch = Sheets("D-C").Cells(i * 2 + 20, 192)
            OthersSpot = Sheets("D-C").Cells(i * 2 + 20, 195)
            OthersQ = Sheets("D-C").Cells(i * 2 + 20, 198)
            CurBranch = 0
            For j = 0 To Counter
                If Sheets("da").Cells((j) * 2 + 29, 5) < 0 Then CurBranch = CurBranch + 1
                If CurBranch = Othersbranch Then
                    Sheets("da").Cells(((j + OthersSpot - 1) * 2) + 29, 17) = OthersQ
                    If Sheets("D-C").Cells(i * 2 + 20, 201) = "" Then
                        Sheets("da").Cells(((j + OthersSpot - 1) * 2) + 29, 80) = "EXTRACTION " & (i + 1) & "  (" & Sheets("D-
C").Cells(i * 2 + 20, 198) & " l/s)"
                    Else
                        Sheets("da").Cells(((j + OthersSpot - 1) * 2) + 29, 80) = Sheets("D-C").Cells(i * 2 + 20, 201)
                    End If

                    If Sheets("da").Cells(((j + OthersSpot - 1) * 2) + 29, 98) = "" Then
                        Sheets("da").Cells(((j + OthersSpot - 1) * 2) + 29, 98) = "E"
                    Else
                        MsgBox "Too Many Objects At One Point, Check Others"
                        Continue = False
                    End If
                    j = Counter
                End If
            Next j
        End If
    Next i
End Sub
'
'  Sets The Flow Rates
'
Sub SetQ()
    Dim CurQ
    Dim Qbranch
    Dim Qspot
    Dim TankSpot
    TankSpot = Sheets("D-C").Cells(12, 99)
    If TankSpot = "" Then
        For i = Counter To 2 Step -1
            If Sheets("da").Cells(((i - 1) * 2) + 29, 5) > 0 Then
                Sheets("da").Cells(((i - 1) * 2) + 29, 17) = Sheets("da").Cells((i * 2) + 29, 17) + Sheets("da").Cells(((i - 1) * 2) +
29, 17)
            Else
                Sheets("da").Cells((Sheets("da").Cells(((i - 1) * 2) + 29, 5) * -1) * 2 + 27, 17) = Sheets("da").Cells((i * 2) + 29, 17)
+ Sheets("da").Cells(((i - 1) * 2) + 29, 17)
            End If
        Next i
    Else
        For i = Counter To TankSpot + 1 Step -1
            If Sheets("da").Cells(((i - 1) * 2) + 29, 5) > 0 Then
```

```
                Sheets("da").Cells(((i - 1) * 2) + 29, 17) = Sheets("da").Cells((i * 2) + 29, 17) + Sheets("da").Cells(((i - 1) * 2) +
29, 17)
            Else
                Sheets("da").Cells((Sheets("da").Cells(((i - 1) * 2) + 29, 5) * -1) * 2 + 27, 17) = Sheets("da").Cells((i * 2) + 29, 17)
+ Sheets("da").Cells(((i - 1) * 2) + 29, 17)
            End If
        Next i
        For i = 1 To TankSpot - 1 Step 1
                Sheets("da").Cells((i * 2) + 29, 17) = Sheets("da").Cells(((i - 1) * 2) + 29, 17) - Sheets("da").Cells((i * 2) + 29, 17)
        Next i

    End If
'    For i = 0 To Counter - 1
'        If Sheets("da").Cells(i + 29, 17) = "" And Sheets("da").Cells(i + 29, 2) > 0 Then
'            MsgBox "Too Many Objects At One Point, Check " & Sheets("da").Cells(i + 29, 2) & " - " & i + 29
'            Continue = False
'        End If
'    Next i
End Sub
'
'   Sets The Static Head
'
Sub SetStatic()
    For i = 0 To Counter - 1 Step 1
        If Sheets("da").Cells((i * 2) + 29, 73) = "" Then
            If Sheets("da").Cells((i * 2) + 29, 5) > 0 Then
                Sheets("da").Cells((i * 2) + 29, 73) = Sheets("da").Cells(((i - 1) * 2) + 29, 11) - Sheets("da").Cells((i * 2) + 29, 11)
+ Sheets("da").Cells(((i - 1) * 2) + 29, 73)
            Else
                Sheets("da").Cells((i * 2) + 29, 73) = Sheets("da").Cells((((Sheets("da").Cells((i * 2) + 29, 5)) + 1) * -2) + 29, 11)
- Sheets("da").Cells((i * 2) + 29, 11) + Sheets("da").Cells((((Sheets("da").Cells((i * 2) + 29, 5)) + 1) * -2) + 29, 73)

            End If
        End If
    Next i
    For i = Counter - 1 To 0 Step -1
        If Sheets("da").Cells((i * 2) + 29, 73) < 0 And Sheets("da").Cells((i * 2) + 29, 17) < 0 Then
          If Sheets("da").Cells((i * 2) + 29, 17) <> 0 Then Sheets("da").Cells((i * 2) + 29, 73) = Sheets("da").Cells(((i + 1) * 2)
+ 29, 11) - Sheets("da").Cells((i * 2) + 29, 11) + Sheets("da").Cells(((i + 1) * 2) + 29, 73)
        End If
    Next i
    For i = 0 To Counter
        If Sheets("da").Cells((i * 2) + 29, 17) = "" Then Sheets("da").Cells((i * 2) + 29, 73) = ""
    Next i
End Sub
'
'  Moves The Tanks Down one Place
'
Sub MoveTanks()
    Dim TankCt
    TankCt = 0
    For i = 0 To Counter Step 1
        If Sheets("da").Cells((i * 2) + 29, 98) = "T" Then
            TankCt = TankCt + 1
            For j = Counter To i + 1 Step -1
                Sheets("da").Cells((j * 2) + 29, 98) = Sheets("da").Cells((j - 1) * 2 + 29, 98)
                Sheets("da").Cells((j * 2) + 29, 73) = Sheets("da").Cells((j - 1) * 2 + 29, 73)
                Sheets("da").Cells((j * 2) + 29, 17) = Sheets("da").Cells((j - 1) * 2 + 29, 17)
                Sheets("da").Cells((j * 2) + 29, 11) = Sheets("da").Cells((j - 1) * 2 + 29, 11)
                Sheets("da").Cells((j * 2) + 29, 5) = Sheets("da").Cells((j - 1) * 2 + 29, 5)
                Sheets("da").Cells((j * 2) + 29, 80) = Sheets("da").Cells((j - 1) * 2 + 29, 80)
                If Sheets("da").Cells((j * 2) + 29, 5) < 0 And i < Sheets("da").Cells((j * 2) + 29, 5) * -1 Then
                    Sheets("da").Cells((j * 2) + 29, 5) = Sheets("da").Cells((j * 2) + 29, 5) - 1
```

```
            End If
        Next j

        If Sheets("da").Cells(((i + 2) * 2) + 29, 17) <> "" Then
            Sheets("da").Cells(((i + 1) * 2) + 29, 17) = Sheets("da").Cells(((i + 2) * 2) + 29, 17)
        Else
            Sheets("da").Cells(((i + 1) * 2) + 29, 17) = Sheets("da").Cells(((i) * 2) + 29, 17)
        End If
        Sheets("da").Cells(((i) * 2) + 29, 98) = "E"
        Sheets("da").Cells(((i + 1) * 2) + 29, 5) = Sheets("da").Cells(((i + 1) * 2) + 29, 5) + 0.01
        Sheets("da").Cells(((i) * 2) + 29, 73) = Sheets("da").Cells(((i - 1) * 2) + 29, 73) + Sheets("da").Cells(((i - 1) * 2) +
29, 11) - Sheets("da").Cells(((i) * 2) + 29, 11)
        Sheets("da").Cells(((Counter) * 2) + 29, 2) = Counter + 1
        Counter = Counter + 1
        i = i + 2
      End If
'       If Sheets("da").Cells((i * 2) + 29, 5) < 0 And i <> 0 Then
''              Sheets("da").Cells((i * 2) + 29, 5) = Sheets("da").Cells((i * 2) + 29, 5) - TankCt
'              Sheets("da").Cells((i * 2) + 29, 1) = TankCt & " Z " & i
'       End If
    Next i
End Sub
'
'   Converts The Raw Data
'
Sub ResolveData()
    Dim Resolution
    Dim reach
    Dim TotalDistance
    Dim Segments
    Dim NumDataPts
    For i = 0 To 10000 Step 1
        NumDataPts = i
        If Sheets("D-D").Cells(5 + i, 1) = "" Then i = 10000
    Next i
    Range("C1:E1005").Value = ""
    Resolution = Sheets("D-D").Cells(1, 1)
    reach = Sheets("D-D").Cells(2, 1)
    If Resolution <> "" And reach <> "" Then
        If Resolution > 24 Or Resolution > NumDataPts Then
            MsgBox "Error with number of data points"
        Else
            For i = 1 To Resolution - 1 Step 1
                Sheets("D-D").Cells(i + 4, 4) = Sheets("D-D").Cells(i * Round(NumDataPts / (Resolution)) + 5, 1)
                Sheets("D-D").Cells(i + 4, 5) = Sheets("D-D").Cells(i * Round(NumDataPts / (Resolution)) + 5, 2)
            Next i
            Sheets("D-D").Cells(Resolution + 4, 4) = Sheets("D-D").Cells(NumDataPts + 4, 1)
            Sheets("D-D").Cells(Resolution + 4, 5) = Sheets("D-D").Cells(NumDataPts + 4, 2)
            For i = 0 To Resolution - 1
                Sheets("D-T").Cells(24 + i * 2, 13 + 33 * (reach - 1)) = Sheets("D-D").Cells(i + 5, 4)
                Sheets("D-T").Cells(24 + i * 2, 19 + 33 * (reach - 1)) = Sheets("D-D").Cells(i + 5, 5)
            Next i
        End If
    Else
        MsgBox "Enter Resolution and Reach information"
    End If
End Sub

'==========================================================================================
'
'      DESIGN OPTIMIZATION MACROS
'
'==========================================================================================
```

```
'
'  Set Global Variables
'
'
Dim NumDiams As Integer
Dim TubeType As Double
Dim Tube As Double
Dim NumPipeDiams As Integer
Dim NumPipeTypes As Integer
Dim Kval As Double
Dim Tolerance As Integer
Dim Pop As Integer
Dim Gens As Integer
Dim CossoverCoef As Double
Dim MutationCoef As Double
Dim TimesChange As Integer
Dim CurGen As Integer
Dim Continue As Boolean
Dim MinHeadAllow As Double
Dim EHeadAllow As Double
Dim NumDataPts
Dim maxC
Dim maxD
Dim pipeInfo(7, 16)
Dim Confgs(1000, 1000)
Dim TopoX(1000) As Double
Dim TopoY(1000) As Double
Dim TopoQ(1000) As Double
Dim TopoT(1000) As Integer
Dim TopoD(1000) As Integer
Dim TopoS(1000) As Double
Dim TopoI(1000) As String
Dim TopoN(1000) As String
Dim BestSetUp(1000) As Double
Dim BestTubeDiams(1000) As Double
Dim BestLoss(1000) As Double
Dim BestHGL(1000) As Double
Dim BestResidual(1000) As Double
'
'   Run the Optimization Routine
'
Sub RundOpti()
    Sheets("da").Range("DK29:DL710029").Value = ""
    Sheets("da").Cells(23, 107) = " "
    Sheets("da").Cells(24, 107) = " "
    Sheets("da").Cells(25, 107) = "Starting . . ."
    Continue = True
    Sheets("da").Cells(25, 107) = "Counting Data Points . . ."
    If Continue Then Call CountPts
    Sheets("da").Cells(25, 107) = "Collecting Pipe Information . . ."
    If Continue Then Call GetPipeInfo
    Sheets("da").Cells(25, 107) = "Setting Pipe Types . . ."
    If Continue Then Call SetTubeTypes
    Sheets("da").Cells(25, 107) = "Setting Pipe Sizes . . ."
    If Continue Then Call SetTubeSizes
    Sheets("da").Cells(25, 107) = "Setting Pipe Information . . ."
    If Continue Then Call CopySystem
    Sheets("da").Cells(25, 107) = "Generating Initial Values . . ."
    If Continue Then Call SetInitialValues
    Sheets("da").Cells(25, 107) = "Generating Initial Configurations . . ."
    If Continue Then Call GetInitalConfigs
    Sheets("da").Cells(25, 107) = "Running Optimization . . ."
    Sheets("da").Cells(21, 107) = Time
```

```
    If Continue Then
        For CurGen = 0 To Gens Step 1
            Call Evaluation
            Call Check
            Call Selection
            Call CrossOver
            Call Mutation
            Sheets("da").Cells(24, 107) = BestSetUp(0)
            Sheets("da").Cells(29 + CurGen, 115) = CurGen
            Sheets("da").Cells(29 + CurGen, 116) = BestSetUp(0)
            Sheets("da").Cells(25, 107) = "Running Optimization . . . " & CurGen
            If TimesChange >= Tolerance + 1 And BestSetUp(0) <> 1 * 10 ^ 50 Then
                Sheets("da").Cells(23, 107) = "After " & CurGen & " generations"
                CurGen = Gens
            End If
        Next CurGen
    End If
    Sheets("da").Cells(22, 107) = Time
    If BestSetUp(0) <> 1 * 10 ^ 50 Then
            Sheets("da").Cells(25, 107) = "Calculating Final Values . . ."
        Call CalcResults
            Sheets("da").Cells(25, 107) = "Writing Final Configuration . . ."
        Call PrintBest
        Call CopySystemBack
    End If

End Sub
'
'   Count the number of data points in system
'
Sub CountPts()
    NumDataPts = 0
    For i = 0 To 1000
        If Sheets("da").Cells(29 + i * 2, 2) <> "" Then NumDataPts = NumDataPts + 1
    Next i
End Sub
'
'   Get the Pipe Information
'
Sub GetPipeInfo()
    For i = 0 To 6
        For j = 0 To 16
            pipeInfo(i, j) = Sheets("da").Cells(4 + j, 110 + i)
        Next j
    Next i
End Sub
'
'   Set the pipe materials
'
Sub SetTubeTypes()
    Sheets("da").Range("$X$29:$X$2027").Value = ""
    For i = 0 To NumDataPts - 1
        If Sheets("da").Cells((i * 2) + 29, 5) >= 0 Then
            For j = 1 To 6
                If Sheets("da").Cells((i * 2) + 29, 73) < pipeInfo(j, 2) And pipeInfo(j, 13) <> 0 And pipeInfo(j, 14) <
pipeInfo(Sheets("da").Cells((i * 2) + 29, 24), 14) Then Sheets("da").Cells((i * 2) + 29, 24) = j
            Next j
            If Sheets("da").Cells((i * 2) + 29, 31) > 0 Then
                If Sheets("da").Cells((i * 2) + 29, 73) < pipeInfo(Sheets("da").Cells((i * 2) + 29, 31), 2) Then
                    Sheets("da").Cells((i * 2) + 29, 24) = Sheets("da").Cells((i * 2) + 29, 31)
                Else
                    MsgBox "User definded pipe diameter not suitable!!  Consider changing or removing specified pipe type at
point " & i + 1 & "."
```

```
                i = NumDataPts - 1
                Continue = False
            End If
        End If
        If (Sheets("da").Cells((i * 2) + 29, 24) = 0 Or Sheets("da").Cells((i * 2) + 29, 24) = "") And Continue Then
            MsgBox "Static head limit exceeded!!  No suitable pipes available for POINT " & i + 1 & ".  Consider adding
break pressure tanks or including stronger pipes on pipe information page."
            i = NumDataPts - 1
            Continue = False
        End If
    End If
  Next i
End Sub
'
'   Set The Pipe Sizes
'
Sub SetTubeSizes()
  Sheets("da").Range("$AL$29:$Al$2027").Value = ""
  For i = 0 To NumDataPts - 1
    If Sheets("da").Cells((i * 2) + 29, 5) >= 0 And Sheets("da").Cells((i * 2) + 29, 45) > 0 Then
        If pipeInfo(Sheets("da").Cells((i * 2) + 29, 24), Sheets("da").Cells((i * 2) + 29, 45) + 2) <> 0 Then
            Sheets("da").Cells((i * 2) + 29, 38) = Sheets("da").Cells((i * 2) + 29, 45)
        Else
            MsgBox "No pipes of type " & Sheets("da").Cells((i * 2) + 29, 24) & " are set with diameter " &
Sheets("da").Cells((i * 2) + 29, 45) & "."
            i = NumDataPts - 1
            Continue = False
        End If
    End If
  Next i
End Sub
'
'   Copy the System Informatin to the Work Space
'
Sub CopySystem()
  Sheets("da").Range("$CV$29:$DH$2027").Value = ""
  For i = 0 To NumDataPts - 1
    Sheets("da").Cells(29 + i, 100) = Sheets("da").Cells(29 + i * 2, 2)
    Sheets("da").Cells(29 + i, 101) = Sheets("da").Cells(29 + i * 2, 5)
    Sheets("da").Cells(29 + i, 102) = Sheets("da").Cells(29 + i * 2, 11)
    Sheets("da").Cells(29 + i, 103) = Sheets("da").Cells(29 + i * 2, 17)
    Sheets("da").Cells(29 + i, 104) = Sheets("da").Cells(29 + i * 2, 24)
    Sheets("da").Cells(29 + i, 105) = Sheets("da").Cells(29 + i * 2, 38)
    Sheets("da").Cells(29 + i, 109) = Sheets("da").Cells(29 + i * 2, 73)
    Sheets("da").Cells(29 + i, 110) = Sheets("da").Cells(29 + i * 2, 98)
    Sheets("da").Cells(29 + i, 111) = Sheets("da").Cells(29 + i * 2, 80)
  Next i
  Sheets("da").Cells(29, 101) = 0
End Sub
'
'    Estiblish Initial Variables
'
Sub SetInitialValues()
  For i = 0 To NumDataPts Step 1
    TopoX(i) = CDbl(Sheets("da").Cells(29 + i, 101))
    TopoY(i) = CDbl(Sheets("da").Cells(29 + i, 102))
    TopoQ(i) = CDbl(Sheets("da").Cells(29 + i, 103))
    TopoT(i) = CInt(Sheets("da").Cells(29 + i, 104))
    TopoD(i) = CInt(Sheets("da").Cells(29 + i, 105))
    TopoS(i) = CDbl(Sheets("da").Cells(29 + i, 109))
    TopoI(i) = CStr(Sheets("da").Cells(29 + i, 110))
    TopoN(i) = CStr(Sheets("da").Cells(29 + i, 111))
    BestSetUp(i) = 0
```

```
    Next i
    Pop = Sheets("D-G").Cells(13, 62)
    Gens = Sheets("D-G").Cells(15, 62)
    If Sheets("D-G").Cells(17, 62) <> "" Then
        Tolerance = Sheets("D-G").Cells(17, 62)
    Else
        Tolerance = Gens
    End If
    CrossOverCoef = Sheets("D-G").Cells(19, 62)
    MutationCoef = Sheets("D-G").Cells(21, 62)
    MinHeadAllow = Sheets("da").Cells(20, 102)
    EHeadAllow = Sheets("da").Cells(21, 102)
    BestSetUp(0) = 1 * 10 ^ 50
    maxD = 0
    For i = 1 To NumDataPts Step 1
        If TopoX(i) < 0 Or i = NumDataPts Then
            For j = i - 1 To 0 Step -1
                If TopoX(j) = 0 Then
                    maxD = maxD + TopoX(i - 1)
                    j = 0
                End If
                If TopoX(j) < 0 Then
                    maxD = maxD + TopoX(i - 1) - TopoX((TopoX(j) * -1) - 1)
                    j = 0
                End If
            Next j
        End If
    Next i
    For i = 1 To 6
        If pipeInfo(i, 15) = 6 Then maxC = pipeInfo(i, 14) * maxD
    Next i
End Sub
'
'  Set Initial Configurations
'
Sub GetInitalConfigs()
    For i = 0 To Pop - 1
        Confgs(i, 0) = 0
        For j = 1 To NumDataPts - 1 Step 1
            If TopoX(j) < 0 Then
               Confgs(i, j) = 0
            Else
                If TopoD(j) = 0 Then
                    Confgs(i, j) = RandD(Int(j), 0, 0)
                Else
                    Confgs(i, j) = TopoD(j)
                End If
            End If
        Next j
    Next i
End Sub
'
'   Generate Random Values for Optimization
'
Function RandD(L As Integer, D As Integer, P As Double)
    Dim Temp(10)
    Dim pos
    Dim cur
    Dim lower
    Dim upper
    pos = 0
    cur = 0
    For i = 0 To 9
```

```
        If pipeInfo(TopoT(L), i + 3) > 0 Then
            Temp(pos) = i + 1
            If i + 1 = D Then cur = pos
            pos = pos + 1
        End If
    Next i
    pos = pos - 1
    upper = Round(cur + (P * pos))
    lower = Round(cur - (P * pos))
    If lower < 0 Then lower = 0
    If upper > pos Then upper = pos
    RandD = Temp(Int((upper - lower + 1) * Rnd + lower))
End Function
'
'   Evalute the present configuration
'
Sub Evaluation()
    Dim TempArray(1000) As Double
    For i = 0 To Pop - 1 Step 1
        For j = 0 To NumDataPts - 1 Step 1
            If TopoX(j) < 0 Then
                Confgs(i, j) = 0
            Else
                TempArray(j) = Confgs(i, j)
            End If
        Next j
        Call GetTrueCost(TempArray)
        Confgs(i, 0) = TempArray(0)
        Call GetPenaltyCost(TempArray)
        Confgs(i, 0) = Confgs(i, 0) + TempArray(0)
        Confgs(i, NumDataPts + 1) = TempArray(NumDataPts + 1)
        Confgs(i, NumDataPts + 2) = TempArray(NumDataPts + 2)
        Confgs(i, NumDataPts + 3) = TempArray(NumDataPts + 3)
        Confgs(i, NumDataPts + 4) = TempArray(NumDataPts + 4)
        Confgs(i, NumDataPts + 5) = 0
        Confgs(i, NumDataPts + 6) = TempArray(NumDataPts + 6)
    Next i
End Sub
'
'   Find Actual Cost of Current Configuration
'
Sub GetTrueCost(TempArray() As Double)
    Dim TempCost As Double
    Dim branchTemp

    TempArray(0) = 0
    For i = 1 To NumDataPts - 1 Step 1
        If TopoX(i) > 0 Then
            If TopoX(i - 1) < 0 Then
                branchTemp = TopoX((TopoX(i - 1) * -1) - 1)
            Else
                branchTemp = TopoX(i - 1)
            End If
            TempCost = pipeInfo(TopoT(i), 2 + TempArray(i)) * (TopoX(i) - branchTemp)
            TempArray(0) = TempArray(0) + TempCost
        End If
    Next i
    TempArray(NumDataPts + 6) = TempArray(0)
End Sub
'
'   Find Penalty Cost of Current Configuration
'
Sub GetPenaltyCost(TempArray() As Double)
```

```
Dim PenaltyCost As Double
Dim LossArray(1000) As Double
Dim HGLArray(1000) As Double
Dim Residual(1000) As Double
Dim Cval As Double
Dim TubeD  As Double
Dim HeadPenalty
Dim ChangePenalty
Dim branchTemp
Kval = 1.22
TempArray(0) = 0
HGLArray(0) = TopoY(0)
Residual(0) = 0
TempArray(NumDataPts + 1) = 0
TempArray(NumDataPts + 2) = 0
TempArray(NumDataPts + 3) = 0
TempArray(NumDataPts + 4) = 0

'Calculate Head Using Hazen Williams
For i = 1 To NumDataPts - 1 Step 1
    If TopoX(i) > 0 Then
        If TopoX(i - 1) < 0 Then
            branchTemp = TopoX((TopoX(i - 1) * -1) - 1)
        Else
            branchTemp = TopoX(i - 1)
        End If
        If i = 1 Then branchTemp = 0
        Cval = pipeInfo(TopoT(i), 1)
        TubeD = pipeInfo(0, TempArray(i) + 2)
        LossArray(i) = (Kval * (10 ^ 10)) * (TopoX(i) - branchTemp) * ((Abs(TopoQ(i)) / Cval) ^ 1.852) / (TubeD ^ 4.871)
        If LossArray(i) <= 0 Then LossArray(i) = 0.001
        LossArray(i) = LossArray(i) * TopoQ(i) / Abs(TopoQ(i))
        If TopoS(i) = 0 Then
            HGLArray(i) = TopoY(i)
        Else
            HGLArray(i) = HGLArray(i - 1) - LossArray(i)
        End If
        Residual(i) = HGLArray(i) - TopoY(i)
    Else
        HGLArray(i) = HGLArray((TopoX(i) * -1) - 1)
        If TopoY(i) < 0 Then LossArray(i) = -1
    End If
Next i

'check min head req
PenaltyCost = 0
For i = 1 To NumDataPts - 1
    If TopoI(i) = "S" And Residual(i) <> 0 Then
        PenaltyCost = PenaltyCost + Abs(Residual(i)) * 2
    Else
        If TempArray(i) > 0 And TopoI(i) <> "R" And TopoI(i) <> "T" Then
            If Residual(i) < MinHeadAllow Then PenaltyCost = PenaltyCost + (MinHeadAllow - Residual(i))
            If Residual(i) < 0 Then PenaltyCost = PenaltyCost * 2
        End If
    End If
Next i
PenaltyCost = PenaltyCost * maxC
TempArray(NumDataPts + 1) = PenaltyCost
TempArray(0) = TempArray(0) + PenaltyCost

'check max head req
PenaltyCost = 0
For i = 1 To NumDataPts - 1
```

```
        If TopoI(i) = "E" Then
            If Residual(i) > EHeadAllow Then PenaltyCost = PenaltyCost + (Residual(i) - EHeadAllow)
        End If
    Next i
    PenaltyCost = PenaltyCost * maxC
    TempArray(NumDataPts + 2) = PenaltyCost
    TempArray(0) = TempArray(0) + PenaltyCost
End Sub
'
'   Find Best Current Configuration
'
Sub Check()
    For i = 0 To Pop - 1 Step 1
        If Confgs(i, 0) < BestSetUp(0) Then
            TimesChange = 0
            For j = 0 To NumDataPts + 6 Step 1
                BestSetUp(j) = Confgs(i, j)
            Next j
        End If
    Next i
    TimesChange = TimesChange + 1
End Sub
'
'   Select Configurations to breed
'
Sub Selection()
    Dim TotalProb
    TotalProb = 0
    Dim ProbArray(1000)
    Dim NewConfgs(1000, 1000)
    Dim Temp As Double
    For i = 0 To Pop - 1 Step 1
        TotalProb = TotalProb + (1 / Confgs(i, 0))
    Next i
    For i = 0 To Pop - 1 Step 1
        ProbArray(i) = (1 / Confgs(i, 0)) / TotalProb
    Next i
    For i = 0 To Pop - 1 Step 1
        If i <> 0 Then ProbArray(i) = ProbArray(i) + ProbArray(i - 1)
    Next i
    For i = 0 To Pop - 1 Step 1
        Temp = Rnd
        For j = 0 To Pop Step 1
            If Temp < ProbArray(j) Then
                NewConfgs(i, 0) = Confgs(j, 0)
                For k = 1 To NumDataPts
                    NewConfgs(i, k) = Confgs(j, k)
                Next k
                j = Pop
            End If
        Next j
    Next i
    For i = 0 To Pop Step 1
        For j = 0 To NumDataPts Step 1
            Confgs(i, j) = NewConfgs(i, j)
        Next j
    Next i
End Sub
'
'     Breed new Configurations
'
Sub CrossOver()
    Dim NewConfgs(1000, 1000)
```

```
    Dim temp1
    Dim temp2
    Dim RndChoice
    For i = 0 To Pop - 1 Step 1
        temp1 = Int(Rnd * (Pop - 1)) + 1
        temp2 = Int(Rnd * (Pop - 1)) + 1
        For j = 1 To NumDataPts - 1 Step 1
            If Confgs(i, j) > 0 Then
                RndChoice = Rnd
                If TopoD(j) = 0 Then
                    If RndChoice > CrossOverCoef Then
                        NewConfgs(i, j) = Confgs(temp1, j)
                    Else
                        NewConfgs(i, j) = Confgs(temp2, j)
                    End If
                Else
                    NewConfgs(i, j) = TopoD(j)
                End If
            End If
        Next j
    Next i
    For i = 0 To Pop - 1 Step 1
        For j = 0 To NumDataPts - 1 Step 1
            Confgs(i, j) = NewConfgs(i, j)
        Next j
    Next i
End Sub
'
'   Mutate Configurations
'
Sub Mutation()
    Dim Types
    For i = 0 To Pop - 1 Step 1
        For j = 1 To NumDataPts - 1 Step 1
            If Rnd < MutationCoef And TopoD(j) = 0 Then
                Types = 0
                For k = 0 To 9
                    If pipeInfo(TopoT(j), 3 + k) <> 0 And pipeInfo(TopoT(j), 13) <> 0 Then Types = Types + 1
                Next k
                Confgs(i, j) = RandD(Int(j), Int(Confgs(i, j)), 2 / Types)
            End If
        Next j
    Next i
End Sub
'
'   Calcuate Results for best configuration
'
Sub CalcResults()
    Dim Cval As Double
    Dim TubeD  As Double
    Dim HeadPenalty
    Dim branchTemp
    Kval = 1.22
    BestLoss(0) = 0
    BestHGL(0) = TopoY(0)
    BestResidual(0) = 0
    'Calculate Head Using Hazen Williams
    For i = 1 To NumDataPts - 1 Step 1
        If TopoX(i) > 0 Then
            If TopoX(i - 1) < 0 Then
                branchTemp = TopoX((TopoX(i - 1) * -1) - 1)
            Else
                branchTemp = TopoX(i - 1)
```

```
            End If
            If i = 1 Then branchTemp = 0
            Cval = pipeInfo(TopoT(i), 1)
            TubeD = pipeInfo(0, BestSetUp(i) + 2)
            BestLoss(i) = (Kval * (10 ^ 10)) * (TopoX(i) - branchTemp) * ((Abs(TopoQ(i)) / Cval) ^ 1.852) / (TubeD ^ 4.871)
            If BestLoss(i) <= 0 Then BestLoss(i) = 0.001
            BestLoss(i) = BestLoss(i) * TopoQ(i) / Abs(TopoQ(i))
            If TopoS(i) = 0 Then
                BestHGL(i) = TopoY(i)
            Else
                BestHGL(i) = BestHGL(i - 1) - BestLoss(i)
            End If
            BestResidual(i) = BestHGL(i) - TopoY(i)
        Else
            BestHGL(i) = BestHGL((TopoX(i) * -1) - 1)
            If TopoY(i) < 0 Then BestLoss(i) = -1
        End If
    Next i
End Sub
'
'    Write the best result
'
Sub PrintBest()
    For i = 0 To NumDataPts - 1
        Sheets("da").Cells(29 + i, 105) = BestSetUp(i)
        Sheets("da").Cells(29 + i, 106) = BestLoss(i)
        Sheets("da").Cells(29 + i, 107) = BestHGL(i)
        Sheets("da").Cells(29 + i, 108) = BestResidual(i)
        Sheets("da").Cells(29 + i, 108) = BestResidual(i)
    Next i
End Sub
'
'    Copy the best result to the work space
'
Sub CopySystemBack()
    For i = 0 To NumDataPts - 1
        Sheets("da").Cells(29 + i * 2, 38) = Sheets("da").Cells(29 + i, 105)
        Sheets("da").Cells(29 + i * 2, 52) = Sheets("da").Cells(29 + i, 106)
        Sheets("da").Cells(29 + i * 2, 59) = Sheets("da").Cells(29 + i, 107)
        Sheets("da").Cells(29 + i * 2, 66) = Sheets("da").Cells(29 + i, 108)
    Next i
        Sheets("da").Cells(24, 107) = BestSetUp(NumDataPts + 6)
        If BestSetUp(NumDataPts + 6) = BestSetUp(0) Then
            Sheets("da").Cells(25, 107) = "Run Successful:  All Conditions Met"
        Else
            If BestSetUp(NumDataPts + 1) > 0 Then Sheets("da").Cells(25, 107) = "Problem with minimum head"
            If BestSetUp(NumDataPts + 2) > 0 Then Sheets("da").Cells(25, 107) = "Problem with maximum head"
'           Sheets("da").Cells(25, 107) = BestSetUp(NumDataPts + 6) & "-" & BestSetUp(0) & " - " & BestSetUp(NumDataPts
+ 1) & " - " & BestSetUp(NumDataPts + 2) '"Run Failure:  Conditions Not Met"
        End If
    Sheets("da").Cells(29, 38) = ""
End Sub
'
'   Create Report
'
Sub DesignReport()
    Dim r1, r2, myrange As Range
    Dim C, Num, Xaxis
    Dim start
    Dim Finish
    Dim TitleString
    Sheets("D-R").Cells.Delete
```

```
    Sheets("D-R").Hyperlinks.Add Anchor:=Sheets("D-R").Cells(1, 9), Address:="", SubAddress:="'D-G'!A1",
TextToDisplay:="BACK"
    Sheets("D-R").Columns("H:H").HorizontalAlignment = xlRight
    Sheets("D-R").Columns("A:G").HorizontalAlignment = xlLeft
    Sheets("D-R").Columns("A:G").ColumnWidth = 15
    Sheets("D-R").Cells(1, 1) = Sheets("M-S").Cells(29, 32)
    Sheets("D-R").Cells(2, 1) = Sheets("M-S").Cells(31, 32)
    Sheets("D-R").Cells(1, 8) = Sheets("M-S").Cells(33, 32)
    Sheets("D-R").Cells(2, 8) = Sheets("M-S").Cells(35, 32)
    Sheets("D-R").Cells(3, 5) = Sheets("M-S").Cells(27, 32) & " - Sytem Design"
    Sheets("D-R").Cells(3, 5).Font.Underline = xlUnderlineStyleSingle
    Sheets("D-R").Cells(3, 5).HorizontalAlignment = xlCenter
    Sheets("D-R").Columns("A:G").ColumnWidth = 8
    Sheets("D-R").Columns("H:H").ColumnWidth = 20
    Sheets("D-R").Cells(4, 5) = Sheets("M-S").Cells(19, 32) & ", " & Sheets("M-S").Cells(21, 32) & ", " & Sheets("M-
S").Cells(23, 32)
    Sheets("D-R").Cells(4, 5).HorizontalAlignment = xlCenter

    C = 7
    Num = 1
    start = C - 1
    Finish = 0
    Sheets("D-R").Cells(1, 1) = Sheets("M-S").Cells(27, 32)
    Sheets("D-R").Cells(2, 1) = Sheets("M-S").Cells(29, 32)
    Sheets("D-R").Cells(start, 1) = "Reach " & Num
    PrintTitles (start + 1)
    For i = 0 To NumDataPts - 1
        Sheets("da").Cells(25, 107) = "Writing Reach " & Num & " . . ."
        If TopoX(i) < 0 Or i = NumDataPts - 1 Then
            Sheets("D-R").Cells(start - 1, 1).Font.Bold = True
            Sheets("D-R").Cells(start - 1, 1) = "Reach " & Num
            PrintTitles (start)
            Finish = C - 1
            Set r1 = Sheets("D-R").Range(Sheets("D-R").Cells(start, 1), Sheets("D-R").Cells(Finish, 2))
            Set r2 = Sheets("D-R").Range(Sheets("D-R").Cells(start, 6), Sheets("D-R").Cells(Finish, 6))
            Set myrange = Union(r1, r2)
            Sheets("D-R").Select
            TitleString = "Reach " & Num
            Sheets("da").Cells(25, 107) = "Ploting Reach " & Num & " . . ."
            Sheets("D-R").Shapes.AddChart.Select
            ActiveChart.SetSourceData Source:=myrange
            ActiveChart.ChartType = xlXYScatterLinesNoMarkers
            ActiveChart.ChartWizard PlotBy:=xlRows
            ActiveChart.ChartWizard PlotBy:=xlColumns
            ActiveChart.HasTitle = False
            ActiveChart.HasTitle = True
            ActiveChart.ChartTitle.Text = TitleString
            ActiveChart.ChartWizard ValueTitle:="Elevation (m)"
            ActiveChart.ChartWizard CategoryTitle:="Ground Distance (m)"
            ActiveChart.Parent.Top = (start - 1) * 15
            ActiveChart.Parent.Left = 450
            If i - (Finish - start) <> 0 Then
                Xaxis = TopoX(TopoX(i - (Finish - start)) * -1 - 1)
            Else
                Xaxis = 0
            End If
            ActiveChart.Axes(xlCategory).MinimumScale = Xaxis
                Sheets("D-G").Select
            start = C + 1
            C = C + 2
            Num = Num + 1
        End If
        Sheets("D-R").Cells(C, 4) = pipeInfo(TopoT(i), 0)
```

```
        Sheets("D-R").Cells(C, 5) = BestSetUp(i)
        Sheets("D-R").Cells(C, 3) = TopoQ(i)
        Sheets("D-R").Cells(C, 1) = TopoX(i)
        Sheets("D-R").Cells(C, 2) = TopoY(i)
        Sheets("D-R").Cells(C, 6) = BestHGL(i)
        Sheets("D-R").Cells(C, 7) = TopoS(i)
        Sheets("D-R").Cells(C, 8) = TopoN(i)
        If TopoX(i) <= 0 Then
            If TopoX(i) <> 0 Then Sheets("D-R").Cells(C, 1) = TopoX(TopoX(i) * -1 - 1)
            Sheets("D-R").Cells(C, 5) = ""
            Sheets("D-R").Cells(C, 4) = ""
            Sheets("D-R").Cells(C, 3) = ""
        End If
        C = C + 1
    Next i
    Sheets("da").Cells(25, 107) = "Report Created"
    Sheets("D-R").Select
End Sub
'
'   Print Title For Report
'
Function PrintTitles(a)
    Sheets("D-R").Cells(a, 1) = "X (m)"
    Sheets("D-R").Cells(a, 2) = "GSP (m)"
    Sheets("D-R").Cells(a, 3) = "Q (L/sec)"
    Sheets("D-R").Cells(a, 4) = "Type #"
    Sheets("D-R").Cells(a, 5) = "Diam. #"
    Sheets("D-R").Cells(a, 6) = "HGL (m)"
    Sheets("D-R").Cells(a, 7) = "Head (m)"
    Sheets("D-R").Cells(a, 8) = "Notes"
End Function
'
'   Move Back To the Project
'
Sub GoBack()
    Sheets("D-H").Select
End Sub

'==========================================================================================
'
'           PROJECT PLANNING MACROS
'
'==========================================================================================
'
'
'
Dim pipeInfo(7, 16)
Dim List(1310, 3)
Dim TempList(1310, 3)
'
'
'
Sub ResetPlan()
    Call ResetPA
    Call ResetPC
    Call ResetMaterials
    Sheets("P-R").Cells.Delete
    Sheets("P-R").Hyperlinks.Add Anchor:=Sheets("P-R").Cells(1, 6), Address:="", SubAddress:="'P-M'!A1",
TextToDisplay:="BACK"
End Sub
'
'Resets The Check Boxes on the Action Page
'
```

```
'
Sub ResetPA()
   Sheets("pa").Range("$B$2:$B$21").Value = False
End Sub
'
' Resets the Compont list
'
Sub ResetPC()
   Sheets("P-C").Range("$J$24:$AE$142").Value = ""
   Sheets("P-C").Range("$AT$24:$BAL$72").Value = ""
   For i = 0 To 49
      Sheets("P-C").Cells(20, 49 + i * 27) = "Enter Component Name Here"
      Sheets("P-C").Cells(20, 67 + i * 27) = "Quantity"
   Next i
   Sheets("P-C").Range("$AT$100:$BB$322").Value = ""
End Sub
'
' Resets Materials
'
Sub ResetMaterials()
   Sheets("P-M").Range("$I$22:$CL$3000").Value = ""
End Sub
'
'  Set Pipe Totals
'
Sub CountPipes()
   Dim lineEnd As Boolean
   Dim Counter
   Dim pipeCount(60)
   Dim TempX
   Dim TempT
   Dim TempD
   Dim pipeLength
   lineEnd = False
   Counter = 0
   pipeLength = Sheets("P-C").Cells(21, 31)
   Call GetPipeInfo
   Sheets("P-C").Range("$J$24:$AE$142").Value = ""
   Do While lineEnd = False
      If Sheets("da").Cells(30 + Counter, 101) > 0 Then

         TempT = Sheets("da").Cells(30 + Counter, 104)
         TempD = Sheets("da").Cells(30 + Counter, 105)
         If Sheets("da").Cells(29 + Counter, 101) >= 0 Then
            TempX = Sheets("da").Cells(30 + Counter, 101) - Sheets("da").Cells(29 + Counter, 101)
         Else
            TempX = Sheets("da").Cells(30 + Counter, 101) - Sheets("da").Cells((Sheets("da").Cells(29 + Counter, 101) * -
1) + 28, 101)
         End If
         pipeCount(((TempT - 1) * 10) + TempD - 1) = pipeCount(((TempT - 1) * 10) + TempD - 1) + TempX
      End If
      If Sheets("da").Cells(30 + Counter, 101) = 0 Then lineEnd = True
      Counter = Counter + 1
   Loop
   Counter = 0
   For i = 0 To 60
      If pipeCount(i) <> 0 Then
         Sheets("P-C").Cells(24 + Counter * 2, 13) = pipeInfo(Int(i / 10) + 1, 0)
         Sheets("P-C").Cells(24 + Counter * 2, 10) = pipeInfo(0, i - Int(i / 10) * 10 + 3)
         Sheets("P-C").Cells(24 + Counter * 2, 19) = pipeCount(i)
         Sheets("P-C").Cells(24 + Counter * 2, 25) = pipeInfo(Int(i / 10) + 1, i - Int(i / 10) * 10 + 3)
         Sheets("P-C").Cells(24 + Counter * 2, 31) = pipeCount(i) / pipeLength
         Counter = Counter + 1
```

```
        End If
    Next i
'    Call setComponents
    Call AirBlocks
End Sub
'
'   Get the Pipe Information
'
Sub GetPipeInfo()
    For i = 0 To 6
        For j = 0 To 16
            pipeInfo(i, j) = Sheets("da").Cells(4 + j, 110 + i)
        Next j
    Next i
End Sub
'
'  Set Materials
'
Sub materials()
    Dim TempItem, TempCode, TempNum, TempCount, TempCost
    For i = 0 To 100
        List(i, 0) = ""
        List(i, 1) = ""
        List(i, 2) = ""
        List(i, 3) = ""
        If Sheets("P-M").Cells(22 + i * 2, 9) <> "" And Sheets("P-M").Cells(22 + i * 2, 68) <> "" Then
            TempList(i, 0) = Sheets("P-M").Cells(22 + i * 2, 9)
            TempList(i, 1) = Sheets("P-M").Cells(22 + i * 2, 68)
            TempList(i, 3) = Sheets("P-M").Cells(22 + i * 2, 90)
        End If
    Next i
    Sheets("P-M").Range("$I$22:$CL$3000").Value = ""
    For i = 0 To 59
        TempItem = Sheets("P-C").Cells(24 + i * 2, 13)
        TempCode = Sheets("P-C").Cells(24 + i * 2, 10)
        TempNum = Sheets("P-C").Cells(24 + i * 2, 31)
        TempCost = Sheets("P-C").Cells(24 + i * 2, 25) * Sheets("P-C").Cells(21, 31)
        For k = 0 To 1309
            If List(k, 0) = TempItem And List(k, 1) = TempCode Then
                List(k, 2) = List(k, 2) + TempNum
                k = 1309
            End If
            If List(k, 0) = "" Then
                List(k, 0) = TempItem
                List(k, 1) = TempCode
                List(k, 2) = TempNum
                List(k, 3) = TempCost
                k = 1309
            End If
        Next k
    Next i
    For i = 0 To 49
        For j = 0 To 24
           If IsNumeric(Sheets("P-C").Cells(24 + j * 2, 67 + i * 27)) = True Then
                If IsNumeric(Sheets("P-C").Cells(20, 67 + i * 27)) = True Then
                    TempCount = Int(Sheets("P-C").Cells(20, 67 + i * 27))
                Else
                    TempCount = 1
                End If

                TempItem = Sheets("P-C").Cells(24 + j * 2, 46 + i * 27)
                TempCode = Sheets("P-C").Cells(24 + j * 2, 61 + i * 27)
                TempNum = Int(Sheets("P-C").Cells(24 + j * 2, 67 + i * 27)) * TempCount
```

```
            For k = 0 To 1309
                If List(k, 0) = TempItem And List(k, 1) = TempCode And TempNum <> 0 Then
                    List(k, 2) = List(k, 2) + TempNum
                    k = 1309
                End If
                If List(k, 0) = "" Then
                    List(k, 0) = TempItem
                    List(k, 1) = TempCode
                    List(k, 2) = TempNum
                    k = 1309
                End If
             Next k
        End If
    Next j
Next i
For i = 0 To 1309
    If List(i, 0) = "" Then
        i = 1309
    Else
        Sheets("P-M").Cells(22 + i * 2, 9) = List(i, 0)
        Sheets("P-M").Cells(22 + i * 2, 68) = List(i, 1)
        Sheets("P-M").Cells(22 + i * 2, 78) = Int(List(i, 2))
        If List(i, 3) = "" Then
            Sheets("P-M").Cells(22 + i * 2, 90) = getTempItemCost(List(i, 0), List(i, 1))
        Else
            Sheets("P-M").Cells(22 + i * 2, 90) = List(i, 3)
        End If
    End If
Next i
End Sub
'
'  Generate Budget
'
Sub Budget()
    Dim myrange
    Dim C
    Dim ComponetList(51, 60, 2)
    Sheets("P-R").Cells.Delete
    Sheets("P-R").Hyperlinks.Add Anchor:=Sheets("P-R").Cells(1, 6), Address:="", SubAddress:="'P-M'!A1",
TextToDisplay:="BACK"
    'Header
    Sheets("P-R").Columns("A:G").ColumnWidth = 15
    Sheets("P-R").Columns("E:E").HorizontalAlignment = xlLeft
    Sheets("P-R").Columns("D:D").HorizontalAlignment = xlRight
    Sheets("P-R").Cells(1, 1) = Sheets("M-S").Cells(29, 32)
    Sheets("P-R").Cells(2, 1) = Sheets("M-S").Cells(31, 32)
    Sheets("P-R").Cells(1, 5) = Sheets("M-S").Cells(33, 32)
    Sheets("P-R").Cells(2, 5) = Sheets("M-S").Cells(35, 32)
    Sheets("P-R").Cells(1, 5).HorizontalAlignment = xlRight
    Sheets("P-R").Cells(2, 5).HorizontalAlignment = xlRight
    Sheets("P-R").Cells(3, 3) = Sheets("M-S").Cells(27, 32) & " - Project Budget"
    Sheets("P-R").Cells(3, 3).Font.Underline = xlUnderlineStyleSingle
    Sheets("P-R").Cells(3, 3).HorizontalAlignment = xlCenter
    Sheets("P-R").Cells(4, 3) = Sheets("M-S").Cells(19, 32) & ", " & Sheets("M-S").Cells(21, 32) & ", " & Sheets("M-
S").Cells(23, 32)
    Sheets("P-R").Cells(4, 3).HorizontalAlignment = xlCenter
    'Build List
    For i = 0 To 1309
        If Sheets("P-M").Cells(22 + i * 2, 90) = "" Or IsNumeric(Sheets("P-M").Cells(22 + i * 2, 90)) = False Or Sheets("P-
M").Cells(22 + i * 2, 9) = "" Or Sheets("P-M").Cells(22 + i * 2, 68) = "" Then
            i = 1309
        Else
```

```
            List(i, 0) = Sheets("P-M").Cells(22 + i * 2, 9)
            List(i, 1) = Sheets("P-M").Cells(22 + i * 2, 68)
            List(i, 3) = Sheets("P-M").Cells(22 + i * 2, 90)
        End If
    Next i
    'Build Componets
    For i = 0 To 59
        If Sheets("P-C").Cells(24 + i * 2, 13) <> "" And Sheets("P-C").Cells(24 + i * 2, 10) <> "" And IsNumeric(Sheets("P-
C").Cells(24 + i * 2, 31)) = True Then
            ComponetList(0, i + 1, 0) = getItemNumber(Sheets("P-C").Cells(24 + i * 2, 13), Sheets("P-C").Cells(24 + i * 2, 10))
            ComponetList(0, i + 1, 1) = Int(Sheets("P-C").Cells(24 + i * 2, 31))
            ComponetList(0, 0, 0) = ComponetList(0, 0, 0) + List(ComponetList(0, i + 1, 0), 3) * ComponetList(0, i + 1, 1)
        End If
        ComponetList(0, 0, 1) = "Pipe Totals"
        ComponetList(0, 0, 2) = 1
    Next i
    For i = 0 To 49
        For j = 0 To 24
          If IsNumeric(Sheets("P-C").Cells(24 + j * 2, 67 + i * 27)) = True Then
              If IsNumeric(Sheets("P-C").Cells(20, 67 + i * 27)) = True Then
                  TempCount = Int(Sheets("P-C").Cells(20, 67 + i * 27))
              Else
                  TempCount = 1
              End If
              TempItem = Sheets("P-C").Cells(24 + j * 2, 46 + i * 27)
              TempCode = Sheets("P-C").Cells(24 + j * 2, 61 + i * 27)
              TempNum = Int(Sheets("P-C").Cells(24 + j * 2, 67 + i * 27)) ' * TempCount
              ComponetList(i + 1, j + 1, 0) = getItemNumber(TempItem, TempNum)
              ComponetList(i + 1, j + 1, 1) = TempNum
              ComponetList(i + 1, 0, 0) = ComponetList(i, 0, 0) + List(ComponetList(i + 1, j + 1, 0), 3) * ComponetList(i + 1, j +
1, 1)

            End If
        Next j
        ComponetList(i + 1, 0, 1) = Sheets("P-C").Cells(20, 49 + i * 27)
        ComponetList(i + 1, 0, 2) = Sheets("P-C").Cells(20, 67 + i * 27)
    Next i

   'Print Totals
    Dim TotalCost
    TotalCost = 0
    C = 8
    Sheets("P-R").Cells(C - 2, 1) = "Componets In System"
    Sheets("P-R").Cells(C - 2, 1).Font.Bold = True
    Sheets("P-R").Cells(C - 1, 1) = "Componet"
    Sheets("P-R").Cells(C - 1, 1).Font.Underline = xlUnderlineStyleSingle
    Sheets("P-R").Cells(C - 1, 2) = "Count"
    Sheets("P-R").Cells(C - 1, 2).Font.Underline = xlUnderlineStyleSingle
    Sheets("P-R").Cells(C - 1, 3) = "Cost Per Componet"
    Sheets("P-R").Cells(C - 1, 3).Font.Underline = xlUnderlineStyleSingle
    Sheets("P-R").Cells(C - 1, 5) = "Cost"
    Sheets("P-R").Cells(C - 1, 5).Font.Underline = xlUnderlineStyleSingle
    For i = 0 To 50
        If ComponetList(i, 0, 0) <> "" Then
            Sheets("P-R").Cells(C, 1) = ComponetList(i, 0, 1)
            Sheets("P-R").Cells(C, 2) = ComponetList(i, 0, 2)
            Sheets("P-R").Cells(C, 3) = FormatCurrency(ComponetList(i, 0, 0))
            Sheets("P-R").Cells(C, 5) = FormatCurrency(ComponetList(i, 0, 0) * ComponetList(i, 0, 2))
            TotalCost = TotalCost + (ComponetList(i, 0, 0) * ComponetList(i, 0, 2))
            C = C + 1
            Else
                i = 50
            End If
```

```
        Next i
    Sheets("P-R").Cells(C, 5) = FormatCurrency(TotalCost)
    Sheets("P-R").Cells(C, 5).Font.Underline = xlUnderlineStyleSingle
    Sheets("P-R").Cells(C, 4) = "Total Project Cost: "
    Sheets("P-R").Cells(C, 4).Font.Underline = xlUnderlineStyleSingle

    'Print Componets
    C = C + 6
    For i = 0 To 50
        If ComponetList(i, 0, 0) <> "" Then
            Sheets("P-R").Cells(C - 2, 1) = ComponetList(i, 0, 1)
            Sheets("P-R").Cells(C - 2, 1).Font.Bold = True
            Sheets("P-R").Cells(C - 2, 5) = "(" & ComponetList(i, 0, 2) & " included)"
            Sheets("P-R").Cells(C - 1, 1) = "Item Name"
            Sheets("P-R").Cells(C - 1, 1).Font.Underline = xlUnderlineStyleSingle
            Sheets("P-R").Cells(C - 1, 2) = "Size/Code"
            Sheets("P-R").Cells(C - 1, 2).Font.Underline = xlUnderlineStyleSingle
            Sheets("P-R").Cells(C - 1, 3) = "Count"
            Sheets("P-R").Cells(C - 1, 3).Font.Underline = xlUnderlineStyleSingle
            Sheets("P-R").Cells(C - 1, 4) = "Cost per Unit"
            Sheets("P-R").Cells(C - 1, 4).Font.Underline = xlUnderlineStyleSingle
            Sheets("P-R").Cells(C - 1, 5) = "Item Total"
            Sheets("P-R").Cells(C - 1, 5).Font.Underline = xlUnderlineStyleSingle
            For j = 1 To 60
                If ComponetList(i, j, 1) > 0 Then
                    Sheets("P-R").Cells(C, 1) = List(ComponetList(i, j, 0), 0)
                    Sheets("P-R").Cells(C, 2) = List(ComponetList(i, j, 0), 1)
                    Sheets("P-R").Cells(C, 3) = ComponetList(i, j, 1)
                    Sheets("P-R").Cells(C, 4) = FormatCurrency(List(ComponetList(i, j, 0), 3))
                    Sheets("P-R").Cells(C, 5) = FormatCurrency(List(ComponetList(i, j, 0), 3) * ComponetList(i, j, 1))
                    C = C + 1
                End If
            Next j
            Sheets("P-R").Cells(C, 5) = FormatCurrency(ComponetList(i, 0, 0))
            Sheets("P-R").Cells(C, 5).Font.Underline = xlUnderlineStyleSingle
            Sheets("P-R").Cells(C, 4) = "SubTotal: "
            Sheets("P-R").Cells(C, 4).Font.Underline = xlUnderlineStyleSingle
            C = C + 4
        Else
            i = 50
        End If
    Next i
    Sheets("P-R").Select
End Sub
'
'
'
Function getItemCost(T1, T2)
    For i = 0 To 1309
        If List(i, 0) = T1 And List(i, 1) = T2 Then getItemCost = List(i, 3)
    Next i
End Function
'
'
'
Function getTempItemCost(T1, T2)
    For i = 0 To 1309
        If TempList(i, 0) = T1 And TempList(i, 1) = T2 Then getTempItemCost = TempList(i, 3)
    Next i
End Function
'
'
'
```

```
Function getItemNumber(T1, T2)
    For i = 0 To 1310
        If List(i, 0) = T1 And List(i, 1) = T2 Then getItemNumber = i
    Next i
End Function
'
'
'
Sub setComponents()



End Sub
'
'
'
Sub AirBlocks()
    Sheets("P-C").Range("$AT$100:$BB$322").Value = ""
    Dim Counter, reach, point, desc, pspot
    Dim xval(2), yval(2)
    Counter = 0
    pspot = 0
    reach = 1
    point = 1
    Do While lineEnd = False

        xval(0) = Sheets("da").Cells(30 + Counter - 1, 101)
        yval(0) = Sheets("da").Cells(30 + Counter - 1, 102)
        xval(1) = Sheets("da").Cells(30 + Counter, 101)
        yval(1) = Sheets("da").Cells(30 + Counter, 102)
        xval(2) = Sheets("da").Cells(30 + Counter + 1, 101)
        yval(2) = Sheets("da").Cells(30 + Counter + 1, 102)
        desc = Sheets("da").Cells(30 + Counter, 110)
        If xval(0) < 0 Then
            yval(0) = Sheets("da").Cells(28 + xval(0) * -1, 102)
            xval(0) = Sheets("da").Cells(28 + xval(0) * -1, 101)
        End If

        If xval(1) <= 0 Then
            reach = reach + 1
            point = 1
        Else
            If xval(2) > 0 And desc <> "T" And desc <> "E" Then
                If yval(0) > yval(1) And yval(2) > yval(1) Then
                    Sheets("P-C").Cells(100 + pspot * 2, 46) = reach
                    Sheets("P-C").Cells(100 + pspot * 2, 50) = point
                    Sheets("P-C").Cells(100 + pspot * 2, 54) = "Possible Washout Point"
                    pspot = pspot + 1
                End If
                If yval(0) < yval(1) And yval(2) < yval(1) Then
                    Sheets("P-C").Cells(100 + pspot * 2, 46) = reach
                    Sheets("P-C").Cells(100 + pspot * 2, 50) = point
                    Sheets("P-C").Cells(100 + pspot * 2, 54) = "Possible AirBlock"
                    pspot = pspot + 1
                End If
            End If
        End If
        If Sheets("da").Cells(30 + Counter, 101) = 0 Then lineEnd = True
        Counter = Counter + 1
        point = point + 1
    Loop
End Sub
```

```
'==========================================================================================
'
'          PROJECT IMPLEMENTATION MACROS
'
'==========================================================================================
'
'Resets The Check Boxes on the Action Page
'
'
Sub ResetIA()
    Sheets("ia").Range("$B$2:$B$21").Value = False
End Sub
'
'
'
Sub CopyScheduleComponents()


End Sub
'
'
'
Sub CreateSchedule()
    Dim startDate As Date
    Dim C, pr, curyear
    Dim Cname As String
    Dim Crank, Cstart, Cend
    Dim schedule(1000, 2)
    Dim TempStart, TempEnd
    pr = 0
    C = 0
    Cname = Sheets("I-S").Cells(20 + C * 2, 9)
    Do While Cname <> ""
        Cname = Sheets("I-S").Cells(20 + C * 2, 9)
        Cstart = Sheets("I-S").Cells(20 + C * 2, 29)
        Cend = Sheets("I-S").Cells(20 + C * 2, 44)
        If year(Cstart) <> year(Cend) Then
            schedule(pr, 0) = Cname
            schedule(pr, 1) = Cstart
            schedule(pr, 2) = DateValue("12/31/" & year(Cstart))
            schedule(pr + 1, 0) = Cname
            schedule(pr + 1, 1) = DateValue("1/1/" & year(Cend))
            schedule(pr + 1, 2) = Cend
            pr = pr + 2
        Else
            schedule(pr, 0) = Cname
            schedule(pr, 1) = Cstart
            schedule(pr, 2) = Cend
            pr = pr + 1
        End If
        C = C + 1
    Loop

    'sort list


    'Header
    Sheets("I-R").Cells.Delete
    Sheets("I-R").Hyperlinks.Add Anchor:=Sheets("I-R").Cells(1, 56), Address:="", SubAddress:="'I-S'!A1",
TextToDisplay:="BACK"
    Sheets("I-R").Columns("A:A").ColumnWidth = 20
    Sheets("I-R").Columns("B:BC").ColumnWidth = 0.72
    Sheets("I-R").Columns("B:BB").HorizontalAlignment = xlLeft
```

```
    Sheets("I-R").Columns("BC:BC").HorizontalAlignment = xlRight
    Sheets("I-R").Cells(1, 1) = Sheets("M-S").Cells(29, 32)
    Sheets("I-R").Cells(2, 1) = Sheets("M-S").Cells(31, 32)
    Sheets("I-R").Cells(1, 55) = Sheets("M-S").Cells(33, 32)
    Sheets("I-R").Cells(2, 55) = Sheets("M-S").Cells(35, 32)
    Sheets("I-R").Cells(3, 22) = Sheets("M-S").Cells(27, 32) & " - Implementation Schedule"
    Sheets("I-R").Cells(3, 22).Font.Underline = xlUnderlineStyleSingle
    Sheets("I-R").Cells(3, 22).HorizontalAlignment = xlCenter
    Sheets("I-R").Cells(4, 22) = Sheets("M-S").Cells(19, 32) & ", " & Sheets("M-S").Cells(21, 32) & ", " & Sheets("M-
S").Cells(23, 32)
    Sheets("I-R").Cells(4, 22).HorizontalAlignment = xlCenter

    'print calender
    C = 0
    pr = 5
    curyear = 0
    Do While schedule(C, 0) <> ""
        If year(schedule(C, 1)) <> curyear Then
            pr = pr + 1
            Sheets("I-R").Cells(pr, 1) = year(schedule(C, 1)) & " SCHEDULE"
            Sheets("I-R").Cells(pr, 1).Font.Bold = True
            Sheets("I-R").Cells(pr + 1, 1) = "Component / Task"

            Sheets("I-R").Cells(pr + 1, 1).Font.Underline = xlUnderlineStyleSingle
                Sheets("I-R").Cells(pr + 1, Fix(((DateValue("1,1," & year(schedule(C, 1))) - DateValue("1,1," & year(schedule(C,
1)))) + 6) / 7) + 2).Font.Underline = xlUnderlineStyleSingle
                Sheets("I-R").Cells(pr + 1, Fix(((DateValue("1,1," & year(schedule(C, 1))) - DateValue("1,1," & year(schedule(C,
1)))) + 6) / 7) + 2) = "Jan.     "
                Sheets("I-R").Cells(pr + 1, Fix(((DateValue("2,1," & year(schedule(C, 1))) - DateValue("1,1," & year(schedule(C,
1)))) + 6) / 7) + 2).Font.Underline = xlUnderlineStyleSingle
                Sheets("I-R").Cells(pr + 1, Fix(((DateValue("2,1," & year(schedule(C, 1))) - DateValue("1,1," & year(schedule(C,
1)))) + 6) / 7) + 2) = "Feb.     "
                Sheets("I-R").Cells(pr + 1, Fix(((DateValue("3,1," & year(schedule(C, 1))) - DateValue("1,1," & year(schedule(C,
1)))) + 6) / 7) + 2).Font.Underline = xlUnderlineStyleSingle
                Sheets("I-R").Cells(pr + 1, Fix(((DateValue("3,1," & year(schedule(C, 1))) - DateValue("1,1," & year(schedule(C,
1)))) + 6) / 7) + 2) = "Mar.     "
                Sheets("I-R").Cells(pr + 1, Fix(((DateValue("4,1," & year(schedule(C, 1))) - DateValue("1,1," & year(schedule(C,
1)))) + 6) / 7) + 2).Font.Underline = xlUnderlineStyleSingle
                Sheets("I-R").Cells(pr + 1, Fix(((DateValue("4,1," & year(schedule(C, 1))) - DateValue("1,1," & year(schedule(C,
1)))) + 6) / 7) + 2) = "Apr.     "
                Sheets("I-R").Cells(pr + 1, Fix(((DateValue("5,1," & year(schedule(C, 1))) - DateValue("1,1," & year(schedule(C,
1)))) + 6) / 7) + 2).Font.Underline = xlUnderlineStyleSingle
                Sheets("I-R").Cells(pr + 1, Fix(((DateValue("5,1," & year(schedule(C, 1))) - DateValue("1,1," & year(schedule(C,
1)))) + 6) / 7) + 2) = "May      "
                Sheets("I-R").Cells(pr + 1, Fix(((DateValue("6,1," & year(schedule(C, 1))) - DateValue("1,1," & year(schedule(C,
1)))) + 6) / 7) + 2).Font.Underline = xlUnderlineStyleSingle
                Sheets("I-R").Cells(pr + 1, Fix(((DateValue("6,1," & year(schedule(C, 1))) - DateValue("1,1," & year(schedule(C,
1)))) + 6) / 7) + 2) = "June     "
                Sheets("I-R").Cells(pr + 1, Fix(((DateValue("7,1," & year(schedule(C, 1))) - DateValue("1,1," & year(schedule(C,
1)))) + 6) / 7) + 2).Font.Underline = xlUnderlineStyleSingle
                Sheets("I-R").Cells(pr + 1, Fix(((DateValue("7,1," & year(schedule(C, 1))) - DateValue("1,1," & year(schedule(C,
1)))) + 6) / 7) + 2) = "July     "
                Sheets("I-R").Cells(pr + 1, Fix(((DateValue("8,1," & year(schedule(C, 1))) - DateValue("1,1," & year(schedule(C,
1)))) + 6) / 7) + 2).Font.Underline = xlUnderlineStyleSingle
                Sheets("I-R").Cells(pr + 1, Fix(((DateValue("8,1," & year(schedule(C, 1))) - DateValue("1,1," & year(schedule(C,
1)))) + 6) / 7) + 2) = "Aug.     "
                Sheets("I-R").Cells(pr + 1, Fix(((DateValue("9,1," & year(schedule(C, 1))) - DateValue("1,1," & year(schedule(C,
1)))) + 6) / 7) + 2).Font.Underline = xlUnderlineStyleSingle
                Sheets("I-R").Cells(pr + 1, Fix(((DateValue("9,1," & year(schedule(C, 1))) - DateValue("1,1," & year(schedule(C,
1)))) + 6) / 7) + 2) = "Sept.    "
                Sheets("I-R").Cells(pr + 1, Fix(((DateValue("10,1," & year(schedule(C, 1))) - DateValue("1,1," &
year(schedule(C, 1)))) + 6) / 7) + 2).Font.Underline = xlUnderlineStyleSingle
```

```
                Sheets("I-R").Cells(pr + 1, Fix(((DateValue("10,1," & year(schedule(C, 1))) - DateValue("1,1," &
year(schedule(C, 1)))) + 6) / 7) + 2) = "Oct.     "
                Sheets("I-R").Cells(pr + 1, Fix(((DateValue("11,1," & year(schedule(C, 1))) - DateValue("1,1," &
year(schedule(C, 1)))) + 6) / 7) + 2).Font.Underline = xlUnderlineStyleSingle
                Sheets("I-R").Cells(pr + 1, Fix(((DateValue("11,1," & year(schedule(C, 1))) - DateValue("1,1," &
year(schedule(C, 1)))) + 6) / 7) + 2) = "Nov.     "
                Sheets("I-R").Cells(pr + 1, Fix(((DateValue("12,1," & year(schedule(C, 1))) - DateValue("1,1," &
year(schedule(C, 1)))) + 6) / 7) + 2).Font.Underline = xlUnderlineStyleSingle
                Sheets("I-R").Cells(pr + 1, Fix(((DateValue("12,1," & year(schedule(C, 1))) - DateValue("1,1," &
year(schedule(C, 1)))) + 6) / 7) + 2) = "Dec. "
                Sheets("I-R").Cells(pr + 1, 49).Font.Underline = xlUnderlineStyleSingle
            curyear = year(schedule(C, 1))
            pr = pr + 2
        Else
            Sheets("I-R").Cells(pr, 1) = schedule(C, 0)
            TempStart = Fix(((schedule(C, 1) - DateValue("1,1," & year(schedule(C, 1)))) + 6) / 7) + 2
            TempEnd = Fix(((schedule(C, 2) - DateValue("1,1," & year(schedule(C, 1)))) + 6) / 7) + 2
            For i = TempStart To TempEnd
                If pr Mod 2 = 0 Then
                    Sheets("I-R").Cells(pr, i).Interior.Pattern = xlGray75
                Else
                    Sheets("I-R").Cells(pr, i).Interior.Pattern = xlGray25
                End If
            Next i
            C = C + 1
            pr = pr + 1
        End If
    Loop

    Sheets("I-R").Select
End Sub

'==========================================================================================
'
'           PROJECT EVALUATION MACROS
'
'==========================================================================================
'
'Resets The Check Boxes on the Action Page
'
'
Sub ResetEA()
    Sheets("ea").Range("$B$2:$B$21").Value = False
End Sub
'
'
'
Sub Ereport()
    Dim C, z
    Dim r1, r2, myrange
    C = 0
    z = 0
    Sheets("E-R").Cells.Delete
    Sheets("E-R").Hyperlinks.Add Anchor:=Sheets("E-R").Cells(1, 9), Address:="", SubAddress:="'E-A'!A1",
TextToDisplay:="BACK"
    'Header
    Sheets("E-R").Columns("A:G").ColumnWidth = 15
    Sheets("E-R").Columns("E:E").HorizontalAlignment = xlLeft
    Sheets("E-R").Columns("h:h").HorizontalAlignment = xlRight
    Sheets("E-R").Cells(1, 1) = Sheets("M-S").Cells(29, 32)
    Sheets("E-R").Cells(2, 1) = Sheets("M-S").Cells(31, 32)
    Sheets("E-R").Cells(1, 8) = Sheets("M-S").Cells(33, 32)
    Sheets("E-R").Cells(2, 8) = Sheets("M-S").Cells(35, 32)
```

```
    Sheets("E-R").Cells(1, 8).HorizontalAlignment = xlRight
    Sheets("E-R").Cells(2, 8).HorizontalAlignment = xlRight
    Sheets("E-R").Cells(3, 4) = Sheets("M-S").Cells(27, 32) & " - Final Evaluaiton"
    Sheets("E-R").Cells(3, 4).Font.Underline = xlUnderlineStyleSingle
    Sheets("E-R").Cells(3, 4).HorizontalAlignment = xlCenter
    Sheets("E-R").Cells(4, 4) = Sheets("M-S").Cells(19, 32) & ", " & Sheets("M-S").Cells(21, 32) & ", " & Sheets("M-
S").Cells(23, 32)
    Sheets("E-R").Cells(4, 4).HorizontalAlignment = xlCenter
    Sheets("E-R").Columns("C:G").ColumnWidth = 5
    Sheets("E-R").Columns("H:H").ColumnWidth = 25
    Sheets("E-R").Columns("B:B").HorizontalAlignment = xlRight

    C = 7
    z = 2
    'Sustainabiligy Info
    Sheets("E-R").Cells(C, 1) = "Stage Sustainability Report"
    Sheets("E-R").Cells(C, 1).Font.Bold = True

    Sheets("E-R").Cells(C, z + 1).Orientation = 90
    Sheets("E-R").Cells(C, z + 1) = "Site Assessment"
    Sheets("E-R").Cells(C, z + 1).Orientation = 90
    Sheets("E-R").Cells(C, z + 2) = "Project Design"
    Sheets("E-R").Cells(C, z + 2).Orientation = 90
    Sheets("E-R").Cells(C, z + 3) = "Budgeting"
    Sheets("E-R").Cells(C, z + 3).Orientation = 90
    Sheets("E-R").Cells(C, z + 4) = "Implementation"
    Sheets("E-R").Cells(C, z + 4).Orientation = 90
    Sheets("E-R").Cells(C, z + 5) = "Evaluation"
    Sheets("E-R").Cells(C, z + 5).Orientation = 90
    Sheets("E-R").Cells(C, z + 6) = "Total"
    Sheets("E-R").Cells(C, z + 6).Font.Underline = xlUnderlineStyleSingle
    Sheets("E-R").Cells(C, z + 6).Orientation = 90
    Sheets("E-R").Cells(C + 1, 2) = Sheets("fa").Cells(2, 1)
    Sheets("E-R").Cells(C + 2, 2) = Sheets("fa").Cells(6, 1)
    Sheets("E-R").Cells(C + 3, 2) = Sheets("fa").Cells(10, 1)
    Sheets("E-R").Cells(C + 4, 2) = Sheets("fa").Cells(14, 1)
    Sheets("E-R").Cells(C + 5, 2) = Sheets("fa").Cells(18, 1)
    Sheets("E-R").Cells(C + 6, 2).Font.Underline = xlUnderlineStyleSingle
    Sheets("E-R").Cells(C + 6, 2) = "Total:"

    Sheets("E-R").Cells(C + 1, z + 1) = Sheets("fa").Cells(3, 1)
    Sheets("E-R").Cells(C + 2, z + 1) = Sheets("fa").Cells(7, 1)
    Sheets("E-R").Cells(C + 3, z + 1) = Sheets("fa").Cells(11, 1)
    Sheets("E-R").Cells(C + 4, z + 1) = Sheets("fa").Cells(15, 1)
    Sheets("E-R").Cells(C + 5, z + 1) = Sheets("fa").Cells(19, 1)
    Sheets("E-R").Cells(C + 6, z + 1) = Sheets("fa").Cells(22, 1)

    Sheets("E-R").Cells(C + 1, z + 2) = Sheets("da").Cells(3, 1)
    Sheets("E-R").Cells(C + 2, z + 2) = Sheets("da").Cells(7, 1)
    Sheets("E-R").Cells(C + 3, z + 2) = Sheets("da").Cells(11, 1)
    Sheets("E-R").Cells(C + 4, z + 2) = Sheets("da").Cells(15, 1)
    Sheets("E-R").Cells(C + 5, z + 2) = Sheets("da").Cells(19, 1)
    Sheets("E-R").Cells(C + 6, z + 2) = Sheets("da").Cells(22, 1)

    Sheets("E-R").Cells(C + 1, z + 3) = Sheets("pa").Cells(3, 1)
    Sheets("E-R").Cells(C + 2, z + 3) = Sheets("pa").Cells(7, 1)
    Sheets("E-R").Cells(C + 3, z + 3) = Sheets("pa").Cells(11, 1)
    Sheets("E-R").Cells(C + 4, z + 3) = Sheets("pa").Cells(15, 1)
    Sheets("E-R").Cells(C + 5, z + 3) = Sheets("pa").Cells(19, 1)
    Sheets("E-R").Cells(C + 6, z + 3) = Sheets("pa").Cells(22, 1)

    Sheets("E-R").Cells(C + 1, z + 4) = Sheets("ia").Cells(3, 1)
    Sheets("E-R").Cells(C + 2, z + 4) = Sheets("ia").Cells(7, 1)
```

```
    Sheets("E-R").Cells(C + 3, z + 4) = Sheets("ia").Cells(11, 1)
    Sheets("E-R").Cells(C + 4, z + 4) = Sheets("ia").Cells(15, 1)
    Sheets("E-R").Cells(C + 5, z + 4) = Sheets("ia").Cells(19, 1)
    Sheets("E-R").Cells(C + 6, z + 4) = Sheets("ia").Cells(22, 1)

    Sheets("E-R").Cells(C + 1, z + 5) = Sheets("ea").Cells(3, 1)
    Sheets("E-R").Cells(C + 2, z + 5) = Sheets("ea").Cells(7, 1)
    Sheets("E-R").Cells(C + 3, z + 5) = Sheets("ea").Cells(11, 1)
    Sheets("E-R").Cells(C + 4, z + 5) = Sheets("ea").Cells(15, 1)
    Sheets("E-R").Cells(C + 5, z + 5) = Sheets("ea").Cells(19, 1)
    Sheets("E-R").Cells(C + 6, z + 5) = Sheets("ea").Cells(22, 1)

    Sheets("E-R").Cells(C + 1, z + 6).FormulaR1C1 = "=SUM(RC[-5]:RC[-1])"
    Sheets("E-R").Cells(C + 2, z + 6).FormulaR1C1 = "=SUM(RC[-5]:RC[-1])"
    Sheets("E-R").Cells(C + 3, z + 6).FormulaR1C1 = "=SUM(RC[-5]:RC[-1])"
    Sheets("E-R").Cells(C + 4, z + 6).FormulaR1C1 = "=SUM(RC[-5]:RC[-1])"
    Sheets("E-R").Cells(C + 5, z + 6).FormulaR1C1 = "=SUM(RC[-5]:RC[-1])"
    Sheets("E-R").Cells(C + 6, z + 6).FormulaR1C1 = "=SUM(RC[-5]:RC[-1])"
    Sheets("E-R").Cells(C + 6, z + 6).Font.Bold = True
    Sheets("E-R").Select

    Sheets("E-R").Cells(6, 2) = "Total Project Sustainability Score:"
    Sheets("E-R").Cells(6, 3) = Sheets("E-R").Cells(C + 6, z + 6)

    'make Chart 1
    Set r1 = Sheets("E-R").Range("C7:G7")
    Set r2 = Sheets("E-R").Range("C13:G13")
    Set myrange = Union(r1, r2)
    Sheets("E-R").Shapes.AddChart.Select
    ActiveChart.SetSourceData Source:=myrange
    ActiveChart.ChartType = xlRadarFilled
    ActiveChart.ChartWizard PlotBy:=xlRows
    ActiveChart.HasTitle = False
    ActiveChart.HasTitle = True
    ActiveChart.ChartTitle.Text = "Sustainability Scoring (By Stage)"
    ActiveChart.HasLegend = False
    ActiveChart.Axes(xlValue).MaximumScale = 20
    ActiveChart.Parent.Top = 300
    ActiveChart.Parent.Left = 25
    ActiveChart.Parent.Height = 200

    'make Chart 1
    Set r1 = Sheets("E-R").Range("B8:B12")
    Set r2 = Sheets("E-R").Range("H8:H12")
    Set myrange = Union(r1, r2)
    Sheets("E-R").Shapes.AddChart.Select
    ActiveChart.SetSourceData Source:=myrange
    ActiveChart.ChartType = xlRadarFilled
    ActiveChart.ChartWizard PlotBy:=xlColumns
    ActiveChart.HasTitle = False
    ActiveChart.HasTitle = True
    ActiveChart.ChartTitle.Text = "Sustainability Scoring (By Catagory)"
    ActiveChart.HasLegend = False
    ActiveChart.Axes(xlValue).MaximumScale = 20
    ActiveChart.Parent.Top = 510
    ActiveChart.Parent.Left = 25
    ActiveChart.Parent.Height = 200
    Sheets("E-R").Select
End Sub

'==========================================================================================
'
'        OPTIONS MACROS
```

```
'
'==========================================================================================
'
'Resets the Options
'
Sub ResetOptions()
    ResetGlobals
    ResetCoefficients
End Sub
'
'Resets the Globals Variables to suggested Values
'
Sub ResetGlobals()
    Dim z As Integer
    For z = 0 To 35
        Sheets("O-GV").Cells(19 + z, 31) = Sheets("O-GV").Cells(19 + z, 51)
    Next z
End Sub
'
'Resets the Coefficients Form
'
Sub ResetCoefficients()
    Dim z As Integer
        Sheets("O-GC").Range("$I$19:$CC$37").Value = ""
        Sheets("gc").Range("$O$6:$O$15").Value = 2
        Sheets("O-GC").Range("$U$43:$AY$61").Value = ""
        Sheets("O-GC").Range("$U$67:$AY$85").Value = ""
End Sub
Sub genCoefficients()
'
' makeConstants Macro
' This Macro creates the Alpaha and Beta Constants for estimation of project costs
'
'
    Set a = AddIns("Solver Add-In")
    If a.Installed = True Then
        Sheets("gc").Select
        Sheets("gc").Range("$B$18:$B$36").Value = 0
        Sheets("gc").Range("$G$32:$G$41").Value = 0
        Sheets("gc").Range("$G$45:$G$53").Value = 0
        Dim b As Integer
        Dim rowStart As Integer
        Dim colStart As Integer
        b = 0
        rowStart = 32
        colStart = 7
        Do While b < 10
            SolverReset
            SolverOk SetCell:=Sheets("gc").Cells(rowStart + b, colStart + 3), MaxMinVal:=3, ValueOf:="0",
ByChange:=Sheets("gc").Cells(rowStart + b, colStart)
            SolverOptions AssumeNonNeg:=True
            SolverSolve UserFinish:=True
            b = b + 1
        Loop
        b = 0
        rowStart = 45
        Do While b < 10
            SolverReset
            SolverOk SetCell:=Sheets("gc").Cells(rowStart + b, colStart + 3), MaxMinVal:=3, ValueOf:="0",
ByChange:=Sheets("gc").Cells(rowStart + b, colStart)
            SolverOptions AssumeNonNeg:=True
            SolverSolve UserFinish:=True
            b = b + 1
```

```
        Loop
        SolverReset
        SolverOk SetCell:="$E$18", MaxMinVal:=2, ValueOf:="0", ByChange:="$B$18,$B$30"
        SolverOptions AssumeNonNeg:=True, Scaling:=True, estimates:=2, derivatives:=2
        SolverSolve UserFinish:=True
        SolverReset
        SolverOk SetCell:="$E$19", MaxMinVal:=2, ValueOf:="0", ByChange:="$B$19,$B$31"
        SolverOptions AssumeNonNeg:=True, Scaling:=True, estimates:=2, derivatives:=2
        SolverSolve UserFinish:=True
        SolverReset
        SolverOk SetCell:="$E$20", MaxMinVal:=2, ValueOf:="0", ByChange:="$B$20,$B$21,$B$32"
        SolverOptions AssumeNonNeg:=True, iterations:=1000, Scaling:=True, estimates:=2, derivatives:=2
        SolverSolve UserFinish:=True
        SolverReset
        SolverOk SetCell:="$E$21", MaxMinVal:=2, ValueOf:="0", ByChange:="$B$22,$B$23,$B$33"
        SolverOptions AssumeNonNeg:=True, iterations:=1000, Scaling:=True, estimates:=2, derivatives:=2
        SolverSolve UserFinish:=True
        SolverReset
        SolverOk SetCell:="$E$22", MaxMinVal:=2, ValueOf:="0", ByChange:="$B$24,$B$34"
        SolverOptions AssumeNonNeg:=True, iterations:=1000, Scaling:=True, estimates:=2, derivatives:=2
        SolverSolve UserFinish:=True
        SolverReset
        SolverOk SetCell:="$E$23", MaxMinVal:=2, ValueOf:="0", ByChange:="$B$25"
        SolverOptions AssumeNonNeg:=True, Scaling:=True, estimates:=2, derivatives:=2
        SolverSolve UserFinish:=True
        SolverReset
        SolverOk SetCell:="$E$24", MaxMinVal:=2, ValueOf:="0", ByChange:="$B$26,$B$27,$B$35"
        SolverOptions AssumeNonNeg:=True, iterations:=1000, Scaling:=True, estimates:=2, derivatives:=2
        SolverSolve UserFinish:=True
        SolverReset
        SolverOk SetCell:="$E$25", MaxMinVal:=2, ValueOf:="0", ByChange:="$B$28,$B$29,$B$36"
        SolverOptions AssumeNonNeg:=True, iterations:=1000, Scaling:=True, estimates:=2, derivatives:=2
        SolverSolve UserFinish:=True
        Sheets("O-GC").Select
    Else
        Sheets("M-I").Select
        MsgBox "The Solver add-in is not installed"
        End If
End Sub
'
'  Resets The Pipe Information
'
Sub resetPipeInfo()
    Sheets("da").Range("$cx$7:$dc$16").Value = False
    Sheets("O-P").Range("$z$25:$z$43").Value = "enter tube diameter "
    Sheets("O-P").Range("$aj$19:$cc$19").Value = "enter pipe type"
    Sheets("O-P").Range("$aj$21:$cc$21").Value = "friction coefficient"
    Sheets("O-P").Range("$aj$23:$cc$23").Value = "enter maximum head"
    Sheets("O-P").Range("$aj$25:$cc$43").Value = 0
End Sub
```