

Water Treatment Technology Selection Guide Final Report

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Abstract

This is the final research report of the Water Treatment Technology Selection Guide Team for Spring 2014. Our goal this semester was to design a selection guide that provides a clear rubric for evaluating and comparing water treatment technologies. A major part of this involved developing the framework and decision-making methodology for such a decision-support system. Current technology selection guides tend to focus on providing information on treatment technologies based on contaminant removal requirements, while ignoring the realities of resource-constraints and skill-constraints of communities, and without considering sustainable engineering practices. An expert guidance tool is needed to empower water supply professionals to make better decisions and to learn the constraints determine which technologies are appropriate.

Introduction

The purpose of this guide is to bridge the information barrier that currently exists for the selection of a water treatment technology, especially for resource-poor communities. With rapidly evolving technologies that often are not well-known compared to more established technology options, it is difficult even for water supply professionals to select the best technology given a context and a water source. The result is that a high fraction of the capital invested in water treatment infrastructure is wasted on inferior technologies or the wrong unit processes for the water quality problem. This guide will aim to help clarify and prompt better, informed choices.

The research work involved figuring out which technology would be best suitable to design the guide. We considered technology platforms like LabVIEW, LabVIEW Web UI Builder, and web platforms like HTML, PHP. The chosen technology should provide:

1. Easy maintenance - Future developers should be able to add new features, and update the guide without re-writing a lot of code and logical reasoning
2. User-friendly interaction - The guide should be interactive, and easy to use for the end user

Another major challenge was to design the decision-making methodology and incorporate a wide range of technologies for varied water sources.

Objectives

This semester our objectives were the following:

- Decide a suitable technological platform to develop the guide. This platform should be easy to use and maintain, so that future users can easily build on our work.
- Create a web-based user-interface of the guide
- Compare AguaClara with other centralized treatment options (Package Plants, FIME Plants, Civil Work Plants)
- Research non-centralized distribution and treatment systems suitable for various scenarios
- Design a decision making methodology to give the best result back to the user
- Outline the information we need from the user, soliciting as few inputs as possible
- Construct a working prototype for the technology specific to surface water

Design Considerations

Technology Platforms

We considered two technology platforms for building the selection guide:

- LabVIEW - The LabVIEW Internet Toolkit when used with the Common Gateway Interface allows us to generate dynamic content on web-pages. The Common Gateway Interface is a standard method used to generate dynamic content on web pages and web applications[1]. CGI, when implemented on a web server, provides an interface between the web server and programs that generate the web content. We found a very helpful resource on creating LabVIEW applications using CGI[2]. With the CGI VIs in LabVIEW we can:
 - Allow a user to load and run a VI dynamically from a Web browser
 - Fill out an HTML form that will feed the inputs to VI
 - Publish the results back to the Web browser Set up security schemes for access to VIs (user authorization and authentication)
 - Have LabVIEW create dynamic HTML pages on the fly (e.g., a Web counter)
- PHP, CSS, HTML, mySQL, AJAX - The second option we considered was using a combination of various web based technologies. We briefly describe each one below:
 - PHP is a server scripting language, and is a powerful tool for making dynamic and interactive Web pages quickly.
 - AJAX stands for Asynchronous JavaScript and XML. AJAX is the art of exchanging data with a server, and updating parts of a web page dynamically (without reloading the whole page).
 - HTML stands for hyper text mark-up language and is used for creating websites CSS provides a way to control the style and layout of multiple Web pages all at once
 - MySQL is a database system used on the web and runs on a server. It supports standard SQL queries, and is the most popular database system to be used with PHP.
- Please refer the figure below to understand the architecture of a web application managed using PHP and a MySQL database.

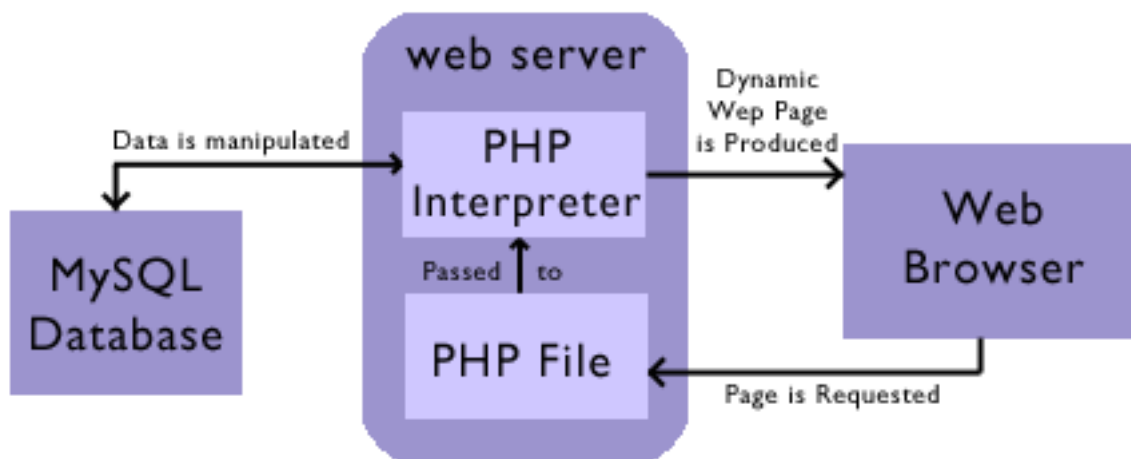


Figure 1: MySQL/PHP Architecture

Positives:

1. HTML/PHP/AJAX allows us make the front-end user experience very interactive, good looking and dynamic.
2. The majority of web-based applications are designed using the above technologies, so solutions to common problems can easily be found.

User Interface

1. HTML Form:

The form represents the part of the guide where the user provides relevant information which is later used to guide him towards a suitable water treatment technology. We have designed this page to make it look similar to the AguaClara homepage. We decided to add a navigation panel to incorporate the Technical Manual section of our guide. Figure 2 shows a snapshot of the first page shown to the user.

The form fields consist of :

- Name, Email, Organization : These fields serve for identification purposes
- Country: This is important because if needed we could use the region specific per capita water consumption to help us determine flow rate. This can potentially be used after linking the Plant Cost Calculator with the Guide
- Community Size: The community size/population helps us to determine the flow rate and what scales of technologies are appropriate
- Do you have a water distribution system in place: This question helps us decide whether to consider centralized or non-centralized treatment technologies
- Source of Water: The source of water is important since treatment technologies vary based on the source water quality. The present guide is limited to only surface water
- Turbidity : The level of turbidity helps us decide how much treatment is necessary (The images provided helps the users better quantify how turbid their water is)
- Heavy Metal Presence: This is a special case since many water treatment technologies including AguaClara cannot treat arsenic contamination effectively, as of today. In this case, we need to guide the user towards an appropriate technology which treats heavy metal contamination like arsenic.



Water Treatment Technology Selection Guide

AguaClara's Water Treatment Technology Selection Guide will suggest an appropriate water treatment method to suit your needs. Fill in the information below to get our recommendation for you.

Name:

Email:


Organization:

Country:

Community Size:

Do you have a distribution system in place? Yes No

Source of Water:



Turbidity: 10 NTU 25 NTU 50 NTU 100 NTU 250 NTU

Are there any heavy metals present? Yes No

Figure 2: Updated Form

2. Technical Manual:

After thoughtful consideration, we decided to incorporate a manual in our guide. The technical manual will allow the user to see all the technologies we used for comparison and how each distribution system functions. We also outline the advantages and disadvantages of each technology. Below are a few snapshots of the manual :

Centralized Treatment Technologies

AguaClara

► Roughing Treatment :

Roughing Filters are normally used as pretreatment to other filter systems that may not be able to tolerate very turbid water. Higher solids removal efficiencies are typically observed with a combination of roughing filters and other sand filters such as the rapid sand filter. Roughing filters are also sometimes used on its own, as simple screening treatment techniques when water of very low turbidity is not required. The advantage of using roughing filters is that it does not require the usage of chemicals or mechanical equipment, and are able to improve the microbiological water quality significantly. However, periodic backwashing is necessary to maintain the removal efficiency of the filters, without the need for frequent change of filter material. After an extended period of usage, roughing filters might get silted up, and require manual cleaning - scouring the top of the filter with a shovel or rake, and flushing the resuspended solids from the filter bed.

► Coagulation and Flocculation :

Coagulation and Flocculation are treatment techniques that are normally paired together to remove suspended solids from water of low turbidity. Coagulation involves the addition of coagulants such as poly aluminium chloride (PACl), aluminium sulphate (Alum) or ferric chloride to water. During this process, sufficient mixing of coagulant (acts like glue) and the water is needed to let solid particles come together and form micro-flocs. Flocculation is a mixing process that ensues coagulation. Here, the micro-flocs and coagulant come into more contact and continue to grow in size. These flocs will eventually be large enough to be settled out in a sedimentation tank or filtered out of the water. Coagulant aids are sometimes added during flocculation to increase the rate of bonding.

Flocculator

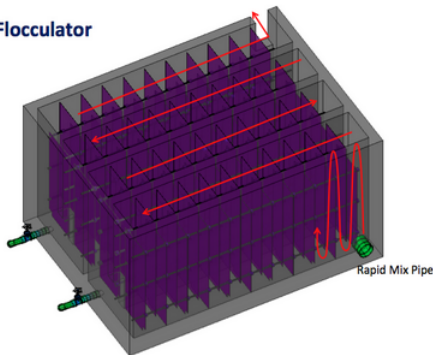


Figure 3: AguaClara: Roughing, Coagulation, Flocculation

► Sedimentation :

Sedimentation is a treatment process used to remove turbidity and pathogens from water. Here, suspended solids or flocs are allowed to settle out of the water via gravity. Hence, sedimentation is normally recommended for treating water with high turbidity. The color, taste and smell of the water can also be improved as organics are settled out from the water. This process is sometimes applied at the initial stages of the water treatment process to remove coarse suspended solids from water with high silt content. It is also applied right after coagulation and flocculation primarily to remove flocs. These suspended solids, if not removed, could clog up downstream filters and/or reduce disinfection efficiency. Tanks used for sedimentation are usually large open circular or rectangular tanks, where scrapers remove settled solids at the bottom of the tank, and the clean water overflows over to the next treatment unit.

Sedimentation Tank

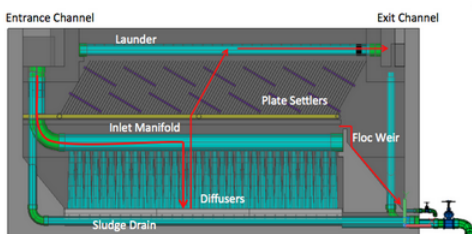
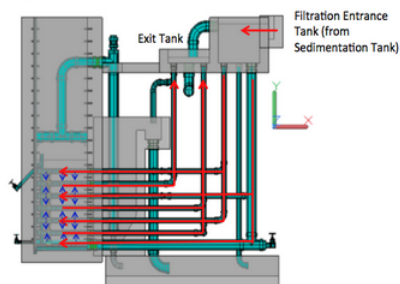


Figure 4: AguaClara: Sedimentation

► Stacked Rapid Sand Filters :

Stacked Rapid Sand Filters are filtration treatment units used to screen suspended solids from low turbidity water. Due to the low residence time, not much biological treatment takes place within these filters. These filters, which are made up of multiple layers of fine sand vertically stacked within a tank, help trap suspended solids and flocs. This treatment process is normally used after coagulation, flocculation and/or sedimentation. The water, usually with coagulants added, is distributed uniformly throughout the sand layers. Filtrate pipes between each layer collect the filtrate into a storage tank. Over time, trapped particles accumulate and start clogging up the filter. Such, periodic backwashing (reversing the flow of water through the sand bed) is necessary to clean the sand beds.

Stacked Rapid Sand Filtration



► Chlorination

Chlorination is a water treatment process that destroys disease-causing bacteria, parasites, and other organisms. This process also removes dissolved iron and manganese from water. The chlorine used is usually found in the form of sodium hypochlorite (bleach), hypo-chlorous acid or calcium hypochlorite. Chlorine reacts with organics in the water to form disinfection by-products, which makes water taste and smell bad. Hence, chlorine is almost always applied at the end of primary treatment processes to ensure disinfection of the cleanest water possible. This also allows greater success in maintaining residual chlorine throughout storage and the water distribution network (prior to supplying to the population). Depending on the accuracy of dosage required, the application of chlorine to water could be done via sophisticated chemical metering pumps or via a simple bucket-and-nozzle system.

Figure 5: AguaClara: SRSF, Chlorination

Non-Centralized Treatment Technologies

Membrane Filter Kiosks:

- The kiosks take in water from a water storage tank located above the equipment location area
- Typical kiosks can range from smaller ones with only one membrane filter designed to serve 250 gallons per day, to larger ones with 4 membrane filters that can output 3,500 gallons per day
- As the water feeds into the kiosk system, the water is transported through the various filters consisting of around 10,000 hair-thin membrane fibers with tiny pores that remove 99.99% of all bacteria, viruses, and parasites



Remote Kiosks:

- Remote kiosks bring the purified water from a community's main purification site to a location closer to the community. They are useful for remote areas which are not close to any water source.
- These kiosks serve as additional points of access and are purely a distribution system.

Figure 6: Non Centralized Options

3. Technology Evaluation Result Format:

In this section, I will remark on the way in which we decided to convey the final results. Essentially, after the user enters all of the fields that were prompted on the initial HTML form, the results will be displayed in a table showing the different areas of comparisons between AguaClara, package plants, kiosks, and point of use systems. Categories such as turbidity, cost (both capital and operation costs), ease of installation, and frequency of maintenance will be ranked for each distribution option. In addition to providing the user with these rankings, the decision tool will recommend the best option in each category by way of color association. The column highlighted in green will mean the option that is best suited for the user.

We create tables using CSS and PHP. The snapshots of the result tables corresponding to the centralized and non-centralized case are in Figure 7.

Technology Comparisons

Options	Quality of Treated Water (NTU)	Cost	Ease of Installation	Frequency of Component Failure	Energy Costs
AguaClara	0.3 - 1	Cheap	Hard	Low	Low
Package Plants	0.3 - 1	Insufficient Data	Easy	High	High
FIME	Insufficient Data	High	Easy	Medium	Low
Civil Works	0.3 - 1	High	Hard	Medium	Medium

Figure 7: Centralized Result

Decision Making Methodology

The main goal of the Water Treatment Technology Selection Guide is to suggest an appropriate water treatment distribution system to the user. We decided against suggesting one definitive result since we did not have very accurate data to work off of, and detailed quantitative data for different technology options is difficult to find or nonexistent. To display our recommendations, we have highlighted in green the best options of each category. This allows the user to make an informed decision as they can clearly see the technologies we considered and their inherent advantages and disadvantages. In addition to the table of technology rankings, we included the reasons behind our rankings, which are shown in Figures 8 and 9.

1. Centralized Treatment Systems:

The technologies we considered included AguaClara, Package Plants, FIME (Multiple Stage Filtration) Plants, and Civil Work Plants.

Reasoning

- **Quality of Treated Water :**
 - AguaClara has an average effluent water turbidity of 0.3 NTU.
 - Package Plants also have an effluent water turbidity of 0.3 NTU.
 - For FIME, if the influent water turbidity is above 10 NTU, the system requires excessive backwashing that renders the volume of treated water insufficient. In addition, there is insufficient data about the quality of treated water .
 - Civil Work plants also yield water with effluent turbidity around 0.3 NTU.
- **Costs :**
 - AguaClara has a lower average cost than Package Plants, Civil Works, and FIME (multiple stage filtration system).
 - There is insufficient data regarding the Package Plant costs so we are unable to rank it in accordance with the other two.
 - FIME requires a lot of land area; for 1 L/s, FIME plants need 33.4 meter-squared of land while an AguaClara plant only needs 1.67 meter-squared. In addition to requiring a lot of land, FIME plants also use expensive machinery and is a labor intensive process, thus increasing its overall costs.
 - Civil Works plants are expensive given that they require specialized employee training to operate the machinery.
- **Ease of Installation :**
 - AguaClara plants require a couple of months to fully install a plant.
 - Package Plants are readymade, making them easy to install.
 - FIME plants can also be installed easily.
 - Civil Works also require a couple of months to fully install a plant since most of the construction work happens on the site.
- **Frequency of Component Failure :**
 - AguaClara plants are very effective in that they do not require excessive repairs over their lifespan. If there needs to be a repair, the locally trained technician can diagnose the problem and get the replacement for the malfunctioning part, if needed, with relative ease since AguaClara uses resources native to the region. In addition, AguaClara plants can be understood be a single operator given that it has a low component count and relatively simple process.
 - Package Plants involve the use of multiple layers to run its system. Each layer makes use of complex processes. For example, in Package Plants, there is a combination of a software and hardware controlling solenoid valves that control air that control mechanized valves that finally control the flow of water. This sophisticated process requires maintenance by multiple workers of varying specialty.
 - FIME has more components prone to failure than in an AguaClara plant.
 - Civil Works also has more components prone to failure, however, not as many as in Package Plants.
- **Energy Costs :**
 - AguaClara does not run on electricity; it uses gravity powered technology to power the plant, thus decreasing its overall cost for installation and use.
 - Most Package Plants use electricity to run various parts of the plant. Package Plants have varying energy costs, but are usually on the order of 100 J/L.
 - FIME plants also run on gravity powered filtration systems so they do not need much energy and have energy costs similar to AguaClara.
 - Civil Works plants don't pump water between processes so their energy cost is not as high as package plants.

Figure 8: Centralized Reasoning

2. Non - Centralized Treatment Systems:

The technologies we considered included Membrane Filter Kiosks, Remote Kiosks, Biosand Filters, and Reverse Osmosis Filters.

Comparison Parameters

- **Quality of Treated Water :**
 - Membrane Filter Kiosks remove 99.99% of all bacteria, viruses, and pathogens.
 - Remote Kiosks are simply a distribution system; they serve as additional points of sale in order to bring purified water closer to communities.
 - Biosand Filters will function as long as the influent turbidity is below 50 NTU; if the water is more turbid then the filter will clog. In addition, Biosand Filters cannot remove dissolved compounds.
 - For Reverse Osmosis Filters, the influent water must be pretreated with chemicals to prevent the membrane from clogging.
- **Costs :**
 - Membrane Filter Kiosks range in price based on the amount of water being treated and distributed.
 - Remote Kiosks are cost effective as per-liter production costs were reduced by up to 56%.
 - Biosand Filters have negligible operation costs.
 - Reverse Osmosis Filters are very expensive. In addition, for individual treatment, Reverse Osmosis Filters produce very little reusable water; from the water that initially enters the system, only 5 to 15 percent can be reused, leaving 85 percent as wastewater
- **Ease of Installation :**
 - Membrane Filter Kiosks are made to be highly transportable and complete assembly takes a couple of hours.
 - Remote Kiosks are also easy to install.
 - Biosand Filters require a one time installation but oftentimes are heavy, thus making it difficult to move or transport
- **Frequency of Component Failure :**
 - Membrane Filter Kiosks do not require many different components for installation. Components are locally sourced and no replacement filters are needed.
 - Remote Kiosks are known for being sustainable enough that they do not fail frequently.
 - Biosand Filters require little maintenance and are easy to operate.
 - Reverse Osmosis Filters require frequent cleaning of the membrane and this membrane can trap bacteria.
- **Energy Costs :**
 - Membrane Filter Kiosks are gravity powered and thereby generate little to no energy costs.
 - Remote Kiosks offer little energy costs as well since they are simply a distribution system that usually is operated by a hand pump.
 - Biosand Filters also require no additional energy as water is simply passed through the layers by way of gravity.
 - Most Reverse Osmosis Filters do not consume any energy.

Please Note : Consider Setting Up a Centralized Distribution System

Since you do not have a distribution system in place, we suggest that you conduct an engineering study to find if it is viable to set up a centralized water distribution system in your community. In the case that your community qualifies for a centralized option, please refer to the results of our Water Treatment Technology Selection Guide that correspond to centralized treatment options.

Figure 9: Non-Centralized Reasoning

CSS & PHP Processing

The above HTML form has certain fields that the user fills out. When the user clicks the submit button, the form is submitted for processing. The PHP script which exists on the web server is responsible for doing the processing. To state it simply, the PHP script links to the HTML form. Therefore, the values entered in the HTML form fields can be accessed in the PHP script. Once we have access to the values of the fields submitted, we can perform logical operations, and return a new HTML page which consists of the relevant technology evaluations. CSS helps us design the layout of the HTML content in our guide. We have mostly used CSS to customize the way we show the results to the user (tabular form). For each parameter such as Quality of Effluent Water, and Cost we color the best technology option green.

Documentation

In this section we outline our code-base, and structure of the application to make it easier for future members to build on our work :

Setting up a local PHP server using MAMP :

Since the AguaClara WebServer is not PHP enabled, one has to run a PHP enabled server locally. This can be done in the following way:

1. Download and install MAMP from <http://www.mamp.info/en/downloads/>. The free version of MAMP is sufficient for our purpose.
2. Once MAMP is installed, double click on the MAMP icon to open it. Once it opens, there will be an option to start servers.
3. Click on start servers - this will start the PHP server and a webpage will automatically open displaying information about the server.
4. All the HTML/PHP files should be saved inside the htdocs folder inside MAMP. For example on a Mac, this would be `~Applications/MAMP/htdocs`.

Running the existing code :

1. Our existing code can be found in the AguaClara server in a folder named WTTSG_Code.
2. Copy the WTTSG_Code folder (contains our code) from the AguaClara webserver into the MAMP/htdocs folder. The path to our code within the server is RESEARCH/Plant Cost Calculator and WTTSG/Spring 2014/WTTSG_Code.
3. Follow the above steps to run MAMP and start a local server.
4. Open a web browser, and set the address to be : http://localhost:8888/WTTSG_Code/form.html. This will open the first page(form) of our guide.

Code Components:

1. HTML Files : Our code contains the following HTML files:
 - (a) form.html : The file represents the first page that is displayed to the user. It consists of the navigation panel on top with links to the Technical Manual. The rest of the page is occupied by the form which is to be filled out by the user of the guide. Please refer to the comments in the file for detailed explanation of each component of the form.
 - (b) techmanual.html : This file contains the technical manual accompanying the guide. In this page, we describe all the technologies that the guide has taken into account for decision-making.
2. PHP file : The only php file our folder contains is getresult.php. The php file is responsible for doing the processing work, after the user fills out the guide, and clicks the submit button. Once, the user clicks submit, the php file has access to the fields filled out by the user. It uses the values of these fields to decide what result to display to the user. The result is in the form of HTML code which is placed inside the PHP file. For more detailed logic, please refer to the comments in the php file.
3. CSS file : The only CSS file that our folder contains is nbstyle.css. The CSS file is used to style the components(paragraphs, navigation bar, font, containers, images, form) in the html and php files. Please refer to the resources section to learn more about CSS,

Online Resources to Learn HTML/PHP/CSS :

1. HTML form generation :
 - (a) http://www.w3schools.com/html/html_forms.asp
 - (b) http://www.w3schools.com/html/html5_form_elements.asp
 - (c) http://www.w3schools.com/html/html5_form_attributes.asp
2. PHP form processing :
 - (a) http://www.w3schools.com/php/php_forms.asp
 - (b) http://www.w3schools.com/php/php_form_validation.asp (Use this for future work [4])
3. CSS : http://www.w3schools.com/css/css_intro.asp
4. Inserting HTML in PHP :
 - (a) We have used the command “echo” to insert html code inside our PHP file (http://php.about.com/od/learnphp/qt/php_
5. General Helpful Resources:
 - (a) PHP tutorial : http://www.w3schools.com/php/php_intro.asp
 - (b) HTML tutorial : http://www.w3schools.com/html/html_intro.asp
 - (c) <http://www.codecademy.com/tracks/php>

In case any other help is needed feel free to reach out to nb287@cornell.edu.

Challenges Faced

1. Technology Platform: One of initial hurdles that we ran into was deciding on the main technical platform of the guide. Previously, we were advised to utilize LabVIEW UI Builder. However, after further research (as documented in our previous reports), we found that this platform will not be the most effective tool for the given purpose. After careful consideration, we decided to use web based technologies like HTML, and PHP to develop the guide.
2. Setting up a PHP Server: The AguaClara WebServer which hosts the current AguaClara web pages is not PHP enabled. This was an issue since we needed PHP to process the HTML form. We got around this by installing a software called MAMP which let us create local PHP-enabled web servers on our computer. In the future, when the guide is officially used we will need the AguaClara web server to be PHP enabled.
3. Learning HTML/PHP/CSS: Once the technology platform was finalized, we started looking for online resources to help us create HTML forms, and learn more about PHP. This was challenging since both of us have no prior web experience, and had to go through a steep learning curve. In order to make the web design more appealing, we have integrated CSS code into our page. As this is also new to us, it has been difficult to understand how to create custom styles for various parts of our page. We plan to attach a reference/tutorial document to help future users.
4. Technology Evaluation Results: The main issue with conveying the results is that there is no means of obtaining information about package plants, and other technologies regarding parameters like turbidity, quality of effluent water, as well as the costs of installing the plant. In addition, we realized that rankings are a very informal way of illustrating the best option as there is no concrete data to offer back to the user.

Accomplishments

1. Conducted a detailed analysis of the pros and cons of using LabView vs. HTML/PHP.
2. Researched centralized and non-centralized treatment options in the case of surface water.
3. Designed the user-interface of the web based guide which includes the home page with the form, and a navigation panel to take the user to the Technical Manual which accompanies the guide. We also outlined how we want to return the result back to the user in the the Technical Evaluations page.

Future Work

Here are a few things which future members can work on:

1. Research and obtain data for parameters like quality of water, and cost pertaining to centralized and non centralized technology options like Package Plants, FIME Plants, Membrane Filter kiosks.
2. Expand the model to include ground water and other sources.
3. Add the ability to record the name, organization, and country to keep track of who is using our guide.
4. Handle for errors - When the user misses fields, prompt him to re-fill it required fields, and click Submit.
5. Integrate the guide with the Plant Cost Calculator. This can be done by figuring out what inputs the plant cost calculator takes. One of the inputs required in the Plant Cost Calculator is flow rate, which can be easily calculated since we solicited the community size and region/country. Once we have specific data regarding the plant, we can feed it to the calculator to get the cost.
6. Incorporate the guide in the AguaClara Web Design Engine.

Bibliography

References

- [1] 2014.
- [2] Jeffrey Travis. *Using CGI with LabVIEW*, page 265. Â Internet Applications in LabVIEW. Prentice Hall PTR, Upper Saddle River, NJ, 2000.