Water Treatment Technology Selection Guide

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1. Abstract

The Water Treatment Technology Selection Guide Team seeks to build an attractive and functional web application that will allow parties interested in the construction of an AguaClara plant to compare various available treatment technologies and receive an estimate of plant costs. This semester's team was tasked with integrating plant cost calculator (PCC) and water treatment technology selection guide (WTTSG) tools, improving the regression equations which provide cost estimates to the PCC, and synthesizing and incorporating information about various treatment plants into the application. The team worked to completely overhaul previous semesters' web development work in order to pursue a design that embodies UI/UX (User Interface/User Experience) principles. The new tool is highly interactive with a sleek, modern design, and is in the process of being deployed live as part of AguaClara's web presence. The team has developed several regression equations useful for cost estimation, engaged in research related to plant cost and available treatment technologies, and made significant progress in the implementation of the WTTSG tool over the course of the semester.

2. Introduction

In this information age, web and mobile applications are a hugely important channel for the dissemination of information. These tools allow users in geographically disparate locations to engage with data that previously may have been inaccessible to them. More importantly, these tools can be highly interactive, allowing for responses highly tailored to user input. This can allow for localized recommendations which can thoughtfully take into account multiple constraints. Understanding the incredible affordances allowed by these web technologies, the project team AguaClara has decided to undertake the implementation of a web application that will give communities interested in its treatment plants the information they need to make an informed decision about whether such a plant would be right for them.

This tool takes into account such factors as source turbidity, heavy metal presence, operator wages, and the availability of a centralized distribution system in order to make a recommendation as to which treatment technology is most appropriate. In addition to this recommendation, the tool provides an estimate of how much it might cost to construct a plant that satisfies the specifications input by the user. This Water Treatment Technology Selection Guide (WTTSG) tool will ideally allow municipalities and other organizations interested in efficient, sustainable water treatment to gain a greater understanding of AguaClara technologies and engage in the comparison of multiple treatment options. It provides individualized feedback based on input parameters describing community resources, and will be invaluable in helping organizations seeking water treatment options to make informed decisions in their search.

3. Literature Review

3.1 Multi-Stage Filtration Technology

The process of multistage filtration (FIME) provides filtered water with low turbidity, free of impurities and of pathogenic organisms. The system first treats heavier materials, and then gradually separates out smaller impurities, such as colloidal particles and microorganisms (Veras et al., 2008). The process is comprised of two smaller subprocesses of coarse gravel filtration (CGF) and slow sand filtration (SSF). The two processes working in concert allow FIME to be an effective treatment option for severely contaminated water (Alberto et al., 1998). The first stage, called pre-treatment, involves the separation of suspended solids by sand filters. The next stage consists of removing fine particles and microorganisms. Slow filtration and chlorination are common processes for the second stage (Veras et al., 2008).

Just like its constituent subprocess of SSF, FIME is robust, reliable, and simple in maintenance of operation (ibid). FIME involves low-cost infrastructure and is especially appropriate for rural areas and smaller cities (ibid). It may also be combined with pre-processing via simple sedimentation, sand taps, or screens. FIME is more appropriate than chemical water treatment technologies in small-community contexts (Alberto et al., 1998). Terminal disinfection is an important component that should be included after FIME.

In general, FIME should be used when influent water contains impure substances of different sizes, and treatment should be comprised of at least two stages (Veras et al., 2008). In such scenarios, it can be concluded that the FIME process yields effluent water with low turbidity and coliform levels (ibid).

3.2 Package Plants

Package water treatment plants incorporate coagulation, flocculation, sedimentation and filtration. They represent an economic alternative with which small communities can treat surface water, and they conform with high water quality standards (Hansen, 1979). The cost of a package plant is considerably reduced because it is designed for unattended operation. This system can solve some important problems, such as tankage corrosion, and an adequate package plant will provide 20-year service (ibid). From the perspectives of construction, operation, and maintenance, package plants represent an affordable, effective, and appropriate option (ibid). However, it can be challenging to ascertain the capital and operating costs of a package plant, and it can be difficult for systems to undertake expansion, improvements and grant or loan requests in timely manner (Lykins et al., 1995). Still, package plants generally successfully meet the requirements of both the communities they serve and system regulations.

3.3 Direct Filtration

Direct filtration is a candidate process for treatment of raw water low in turbidity, color, and organisms, and free of paper fiber (Culp, 1977). The principal advantages of direct filtration technology are its lower costs of operations, managements, which are 30 percent lower than comparable systems' (ibid). Taking conditions of raw water and proper engineering designs into consideration, direct filtration can produce water reliability for a number of years (ibid).

3.4 Small Systems Treatment Options

When evaluating drinking water treatment options and alternatives for small systems, decision-makers must take into consideration potential costs for installation, repair, rehabilitation, and more; for long-term treatment projects, costs of maintenance and monitoring must also be considered (Goodrich et al., 1992). Of course, treatment technologies must also satisfy federal regulations, but small water systems have been, and will continue to be the least capable of meeting current and future drinking water regulations (ibid). Competitive options and alternatives are available in terms of package plants and Point-of-Entry (POE) drinking water treatment technology (ibid). Central treatment can no longer be thought of as the only solution, nor POE be thought of as temporary or for aesthetics only.

4. Previous Work

4.1 Spring 2014 WTTSG Team Report

This report provides an overview of the previous work of the WTTSG subteam, focusing on the development of a PHP-based tool with limited CSS design. The team synthesized information about various treatment technologies into a single webtool. Unfortunately, this tool was limited in that it was not deployed--the AguaClara website is not currently PHP-enabled--and that it did not engage significantly with human-centered design principles. The final product is capable of making some recommendations based on user input, but is largely unresponsive and somewhat difficult to read and understand as a layperson. Furthermore, the site does not engage in form checking, and breaks easily when subjected to different kinds of inappropriate input. Most valuable to the current subteam is Spring 2014's enumeration of a proposed conditional program flow, which will allow the website to provide better, more individually tailored feedback.

4.2 Water Treatment Supply Options

This fact sheet compiled by the Spring 2014 WTTSG team describes the advantages and disadvantages of various water treatment technologies, including roughing filters, coagulation and flocculation, sedimentation, Stacked Rapid Sand Filters (SRSFs), chlorination, and gravity-driven membrane technology. It also touches upon various community water supply systems, including membrane filter kiosks and remote kiosks. The discussion of the relative advantages and disadvantages of these techniques and processes will be instrumental in the current WTTSG team's formulation of a technology comparison tool, shaping the conditional logic used to display recommendations. The work of this team will also be incorporated into the recommendations themselves, providing support for any value statements made about various treatment options.

4.3 Spring 2014 PCC Team Report

This report explains the statistical analysis performed by the Spring 2014 PCC subteam in its implementation of a PHP-based webtool. The final implementation of this tool is problematic in that it can give wildly inaccurate estimates; especially worrying is the tool's provision of a negative cost estimate when it is forced to extrapolate too far out of its dataset (i.e., it is provided with a large flowrate). Much like the WTTSG tool, the PCC tool lacks any kind of form-checking, breaks easily, and has limited CSS design. It functions primarily as a single-page PHP form, which, by semester's end, was only hosted locally. The report also raises the key challenge of integrating the WTTSG and PCC tools in order to maximize the efficiency with which information is imparted to the user.

5. Web Development Work

5.1 Brainstorming

The proposed design for the WTTSG web application was loosely inspired by the design of Cornell University's homepage: the website features colorblocking, clean, simple fonts, and minimalist architecture. It is very responsive, and utilizes JavaScript to dynamically present different content and menus to the user. Various small cues, like the use of underlines for hovered-over hyperlinks, were taken from the Cornell site for incorporation into the tool.

To begin the design process, team members first sketched out a storyboard (Figure 1) visualizing different features the website should have and the order in which they should appear. The team decided upon a layout featuring a colorful, logo-bearing header, which will contain hyperlinks important to navigation (see Figure 2 for detail), and a neutral footer, which will feature supplementary information about AguaClara, AguaClara, LLC, and its implementation partners. An initial color scheme of grays and light blues was decided upon, since these colors evoke the idea of water and are soothing to the user. Further, in a manner consistent with the design of cornell.edu, it was decided that page content would primarily appear in a large horizontal "div" (HTML division) occupying the full width of the page, and transitions between pages would be implemented with the help of JavaScript.

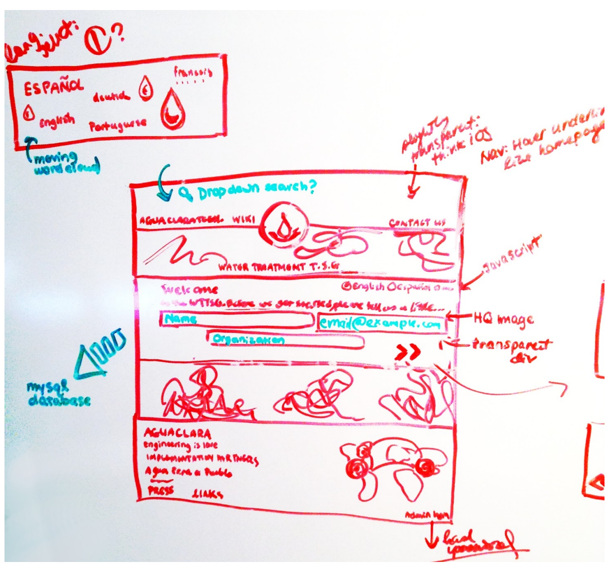


Figure 1: Web Design Storyboard Detail

This particular pane of the storyboard visualizes a layout for the launch page of the application, which prompts users to indicate their language preference and provide demographic information before continuing to engage with the tool.

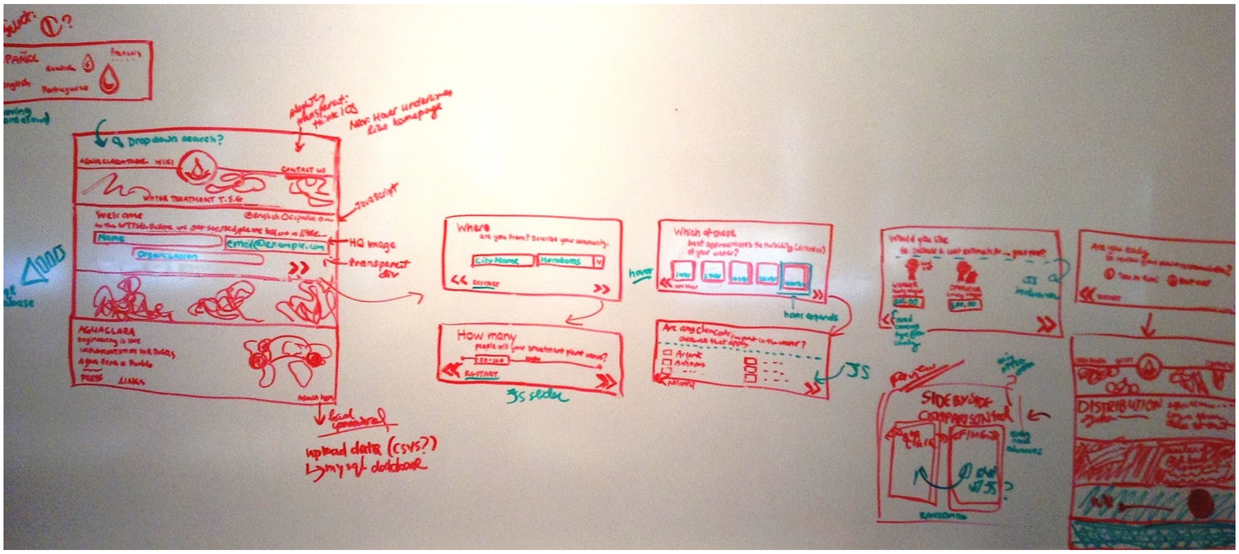


Figure 2: Web Design Storyboard
Before any CSS code was written, a design scheme for the website was brainstormed and laid out on a whiteboard. This view shows the interactions between various page components, with ideas for potential transitions and form options highlighted.

5.2 Skeleton Implementation

Once these important design considerations were established, the team could begin the implementation of the site as described. Various components, including a header (bearing the AguaClara logo), navigation bar, and sticky footer were incorporated into the site (Figure 3).

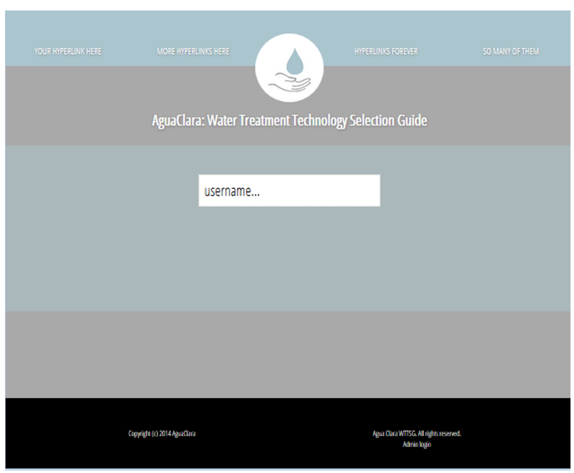


Figure 3: Skeleton Website CSS
A very preliminary stage of site implementation. The website can largely be broken up into three parts: a central pane for content, a header (that contains the navigation structure), and a footer.

- **Navigation Structure:** In order to lend the page a clearer navigational structure, both the title text and header image were converted into hyperlinks, so that when they are clicked, the user can return to the starting screen. In order to make this affordance clear, the cursor turns into a pointer when hovering over these elements; the page title additionally gains a drop shadow.

- **Multiple Pages:** In order to avoid overwhelming users with too many fields to fill out at once (i.e. to minimize user memory load), the WTTSG design broke forms up over multiple pages, featuring at most 3-4 fields per page. This functionality was implemented with hyperlinks and responsiveness to PHP GET variables.
- **Pagination:** In order to navigate between pages, users press chevron buttons (“<<<” and “>>>”) located at the bottom on the central content div (see bottom right corner, Figure 4). These icons glow when the user hovers over them, and they direct the user either back or forward in the page sequence. The website knows which page the user is on with the help of a PHP GET variable, and then conditionally displays the appropriate content based on how they interact with the chevron buttons.
- **Initial Functionality:** Appropriate fields for the first page of the site, namely, spaces to enter name and email address, were added to the first page of the site. Later, this would be changed to name and organization, to reflect user privacy concerns.

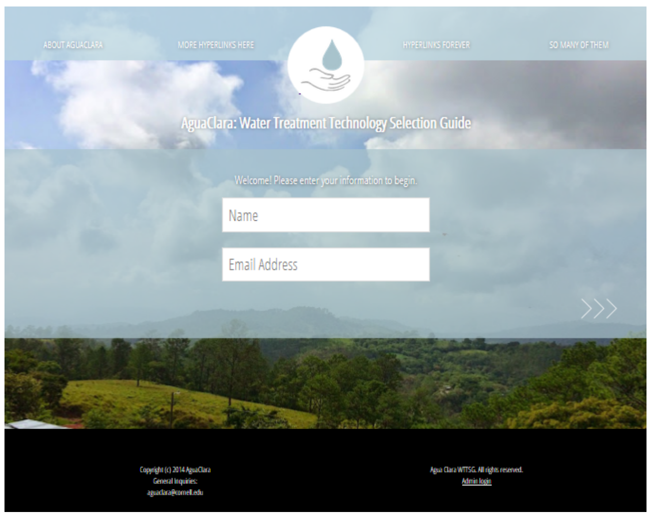


Figure 4: Early implementation

At this stage of website development, some input forms were made available, as well as a basic navigation structure. Chevrons were put in place to allow transitions between pages.

- **Icon:** Consideration was also given to making the WTTSG website easily distinguishable from a browser’s tab menu, and to underlining the connection between AguaClara and this online tool. Thus, the team chose to include a FavIcon (website icon) of the AguaClara logo, which was created with a FavIcon generator (See Figure 5).

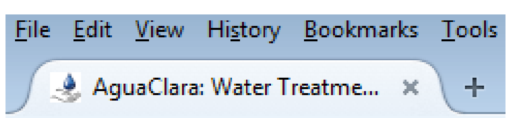


Figure 5: Website Icon (FavIcon)

AguaClara’s logo was added as an icon for the website so its tab may be identifiable at a glance.

- **Parallax:** Finally, the aesthetic quality of the site was improved by the introduction of a page background image, featuring a photograph taken at San Nicolas, Honduras (see Figure 4). This image was later animated via the inclusion of a parallax scrolling effect, in which the background and foreground of a page move at slightly different rates to produce a multi-dimensional effect.

5.3 Admin Login

Ideally, the team would like the PCC component of the website to afford the automatic generation of cost-governing regression equations. (For more discussion of regression efforts, see Section 6.) In order to allow the website to update its recommendations with the introduction of new data, the team decided to create an administrator panel. This will allow individuals associated with AguaClara to input plant final budget data as it becomes available. Only AguaClara administrators should have access to modify this information, so it is important that the admin page be password-protected. Through a special administrator login page, this functionality is implemented using PHP sessions and a MySQL database. Administrator usernames and hashed passwords are stored in a MySQL database and compared to submitted values to see if a user has correctly logged in. Then the page remembers that the user is logged in, until they end their browser session, with the use of PHP session variables.

A preliminary administrator login screen has been implemented, which can be accessed from a small hyperlink in the site's footer, using HTML forms and password input boxes (see Figure 6). Some basic measures have been taken to hash and store passwords through MySQL for when this functionality of the server is pushed live.

Figure 6: Administrator Login
Some very preliminary groundwork has been laid for a secure administrator login, which interacts with a MySQL database for a secure login.

5.4 Responsive CSS and JavaScript

One of the most important principles governing the design of a site is that it be interactive. Frequently, this takes the form of real-time feedback that is provided to the user, such as form-checking:

- **Form Checking**: Through the process of form-checking, a website confirms that certain content (for example, an email) satisfies certain constraints (should contain an "@" sign). If not, a warning message is displayed to the user before they attempt to submit the form, and often, they are prevented from being able to submit the form at all. The team is working to implement such form checking features on the site, including checking for a valid email format when the user enters their personal data on the first page (though this is not yet operational).

- **Prompt to Continue:** The team has also used the same principles of real-time updates to prompt the user to click the chevron once they have filled out both boxes. Using JavaScript, once the user has entered text into the boxes, the prompt "Click to Continue" appears above the corresponding arrow (see Figure 7). Some further fine-tuning is merited to make these interactions as smooth as possible.

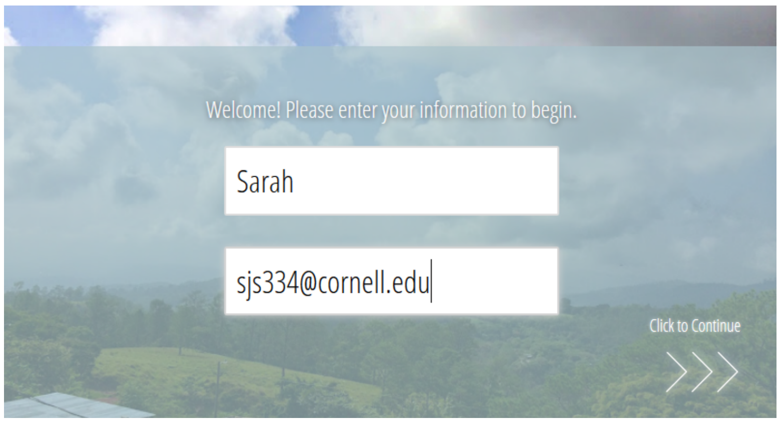
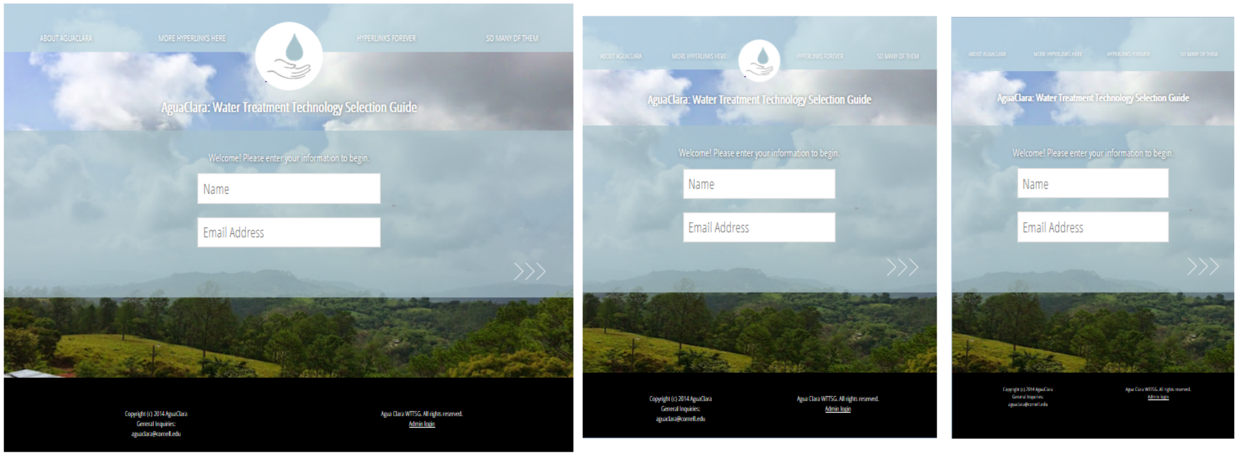


Figure 7: Detail Shot with User Prompt

When users fill in their name and organization (formerly email address, as seen in this progress screenshot), they are prompted to continue using JavaScript, which dynamically displays instructional text.

- **Browser Size:** Another important consideration in the design of a site is that its layout not "break" when the constraints of the screen size are changed. Layouts should be fluid, not based on hard-coded numbers of pixels, so that they are responsive to these changes. Here, the team also elected to make special consideration for ranges of window sizes, so that smaller screens have an optimized viewing experience. Using CSS's "media" property, three stylesheets were created for browsers under 700px, browsers between 700px and 1000px, and browsers greater than 1000px in width.
- **Scalability:** A primary concern for the design of these stylesheets was that the header and its accompanying hyperlinks would scale well. For the second-smallest version, the links downscale slightly. For the smallest, the AguaClara logo is removed from the header, and the navigation bar items expand to fill the full width of the space (see Figure 8). This ensures that the site renders well across a variety of browser sizes. Perhaps, in the future, attention might be paid to optimize the site for mobile as well.



Figures (from left) 8a, 8b, 8c: Website Appearance at Various Screen Resolutions
When the browser window is resized past various criteria, the CSS of the site is dynamically updated to maintain legibility and a clear layout. For screens smaller than 700 pixels, for example (8c), the AguaClara logo is removed from the header, allowing the hyperlinks to fill more space. The text of the links is similarly resized as the website is scaled down from normal size (8a) to below 1000 pixels (8b). The input boxes change dynamically any time the page is scaled.

- **Maintained Scroll Position:** Generally, when a new page is loaded, its scroll position reverts back up to the top of the page. However, this is annoying for a user who is hoping to essentially feel like they are paging through a slideshow; they have to keep scrolling back down until the main content div is visible again so they can click to continue, when they really expected the rest of the page to be stable, and just their content to be moving. Thus, the team was able to resolve this conflict between user expectation and reality by implementing a JavaScript add-in called Scroll Sneak which tracks a user's scroll position between pages. Now, the content will change places, while the rest of the site will appear to remain static, drastically improving user experience.

5.5 Fine-Tuning Functionality

With much of the CSS design blocked out, full-scale implementation of more functional aspects of the site was begun. In this stage, various inputs necessary to the operation of the site were identified and translated into code.

- **City and Country:** A free text field and a drop-down menu were used to implement a form in which the user can input their city and country (see Figure 9a). This feature will be logged in the MySQL database for demographics purposes, and will also give the team the ability to choose a currency with which to present monetary values by default.
- **Population Slider:** An HTML5 range slider was implemented to allow users to select a broad range of populations that their treatment plant might serve, since most individuals using the site will not be able to immediately nor exactly quantifiable. The range slider instead lets the individual indicate their perception of how many people will be served in

ranges of 100 people at a time. The range slider displays the population levels selected at all times using JavaScript (see Figure 9b).

- **Turbidity:** In order to allow laypersons to speak with confidence about the average turbidity of their water, it was decided that this metric be communicated visually rather than quantitatively. Instead of choosing a numerical value quantifying the NTU level of their water, individuals simply must click on a picture of a jar of that turbidity (see Figure 9d). For the experts who are using the tool, the value in NTUs is actually displayed on the picture as a hidden attribute that appears when the user hovers over the photo with their mouse. The photo also grows slightly, encouraging the user to click on it. Once clicked, a dark background is added to the selected image, and all other images are unselected. All in all, these accessible features enable a variety of users with different experience levels to use the same functionalities of the site with ease.
- **Maximum Turbidity:** The same layout is recycled for the next page of the site, which asks for the maximum turbidity generally seen by the plant, as opposed to the previous page, which asked for the average (see Figure 9c). This information will also contribute to a better-customized recommendation for the customer.

Figures (clockwise from top left) 9a, 9b, 9c, 9d: Various website components

Users can input their location (9a), the range of populations they expect the plant to serve (9b), and maximum (9c) and average (9d) turbidities for their drinking water. This will allow AguaClara to make an informed recommendation about effective treatment options.

- **Hyperlinks:** Hyperlinks in the header of the site, which had long been placeholders, were given real links, to the AguaClara homepage and wiki. This will allow the website to point users interested in AguaClara towards these resources for more information.

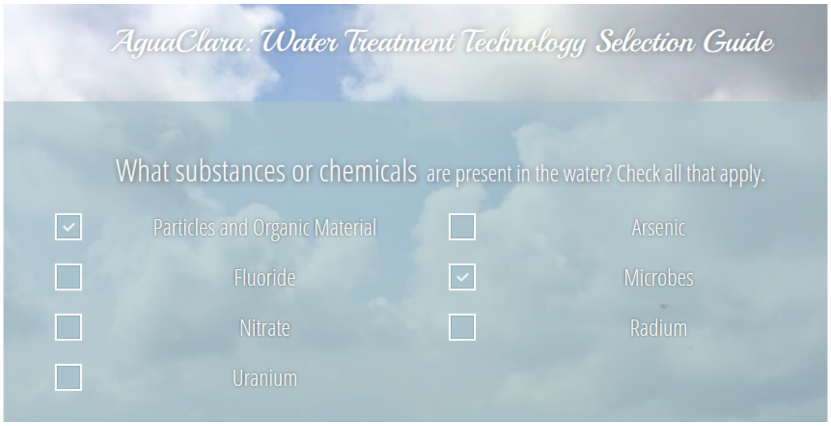


Figure 10: Checkboxes for Chemicals and Substances

Multiple-select checkboxes allow users to indicate which chemicals and substances are present in their source water. CSS masking was used to replace default checkboxes with larger ones matching the tool's color scheme.

- **Chemicals and Substances:** Checkboxes were used to allow users to (multiply) select the substances and chemicals present in their water (Figure 10). The seven available options are particles and organic materials, fluoride, nitrate, uranium, arsenic, microbes, and radium. These options were selected from lists of common water pollutants and represent a variety of water contaminants that can be very challenging to treat. Special consideration was lent to the checkbox CSS so that it would be consistent with the color scheme of the site.

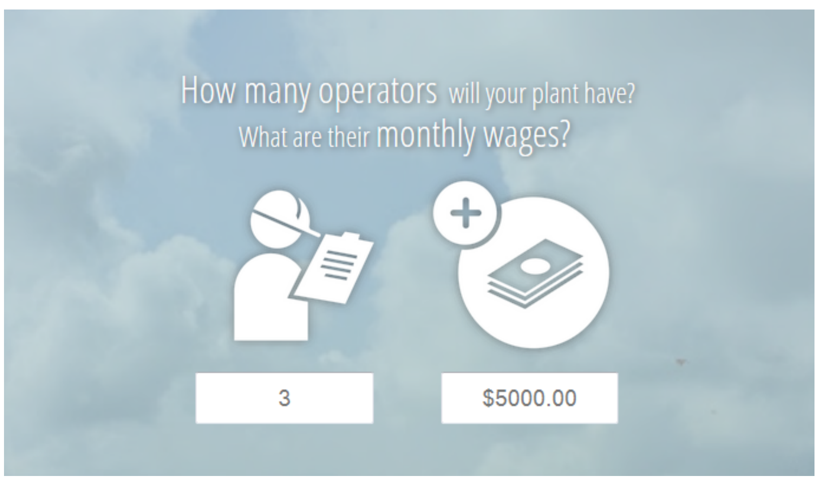


Figure 11: Operators and Wages

The plant cost calculation functions of the tool require information about operators and their wages to make an accurate recommendation. Users can input this information in text fields as shown above to receive a personalized cost estimation.

- **Operator and Wage Costs**: In order to provide a cost estimate for a plant, the tool must know how many operators will be employed, as well as their expected wages. Operator costs must be paid on a regular and continuing basis, and so are an important part of a plant cost estimate. The team implemented this feature using engaging graphics representing operators and their wages, with text fields collecting input (Figure 11).

5.6 Code Organization

Significant efforts were made to format and document the code, so that it may be more easily used by future team members. Certain types of data processing, like displaying appropriately hyperlinked arrows on the bottoms of each page, were encapsulated into functions. Better comments were introduced into code, and logically named variables were created to prevent statements from getting over-complicated. Now, for example, instead of seeing the result of a GET query that, when processed reveals the page number of the page, a variable called $page provides a concise version of this code. Other problematic features of the code were corrected: for example, it is bad practice for multiple elements to share the same selector id, so new, unique selectors were assigned to all objects on the page.

5.7 Data Exchange and Functionality

The exchange of data between the pages of the tool's multiple pages posed a formidable challenge in the implementation of the WTTSG. By turning the chevrons on the bottom of each page into submission buttons (and masking standard button appearance with an image), the team was able to post data between successive pages of the tool. Using PHP session variables, which remain set until a user closes their browser, the team could then save the data submitted in each form. After they have been sanitized and escaped, the user inputs can then directly be inserted into a MySQL database.

Utilizing session variables also allows the site to retrieve previously input data and use it to pre-populate forms whenever a user revisits a page. Since users are able to move back and forth between pages of the tool, it important that the WTTSG remember user inputs from one page to the next. If a user revisits pages with previously entered content, the content should be retrieved and displayed to the user. That way, they do not get the false impression that their content has not been saved when they encounter a blank field, and they can edit previous responses easily as well. Thus, the team used session variables, conditional statements, and various HTML input elements' default attributes in order to prepopulate text in text fields, select menu options from dropdowns, and more whenever a user returns to a previously completed page.

Though great strides have been made in remembering user input, not all pages currently possess this functionality; it must continue to be expanded. For instance, backwards navigation should be updated to include form submission as well. Currently, someone who travels backward will lose any data input on the page from which they started.

5.8 MySQL Databases

With session variables holding all data that is to be logged, preliminary implementation of MySQL functionality was undertaken, including the creation of a database configuration file and the introduction of msqli objects to website code.

In order to log user responses, store data needed to perform cost regressions, and store the credentials necessary to provide an administrative login, three tables were developed as a part of a MySQL database. First, the *users* table contains usernames and passwords hashed with the sha256 hash. Users attempting to login must match credentials with entries in the table.

Second, the *regression* table contains flow rates and costs per L/s for the various AguaClara plants whose data is being used in the derivation of the regression equation. Cost regressions will be provided only for AguaClara plants as part of the Plant Cost Calculator portion of the tool. Future teams may consider the possibility of providing regression data for other types of plants, but Ideally, administrators will have the ability to add new rows to this table, allowing the equation to update automatically as new data is provided. The primary key of the Regression table is the "PlantName" (e.g. "Moroceli") of the plants in question.

The final and most involved of the database tables, *userData,* provides a place for any information input by the user to be saved for later analysis, or potentially for future review if a user revisits the site. This table has several dozen fields, logging all form inputs and several intermediary stages in plant cost calculation for ease of review. The primary key for this table is an auto-incremented visitorID.

5.9 AguaClara Server

With the help of Cameron Willkens, the AguaClara server was PHP- and MySQL-enabled. In order to upload files to the server, team members will first need to log onto the Cornell VPN, initiate a remote desktop connection, and then transfer files into the appropriate directory (D:\inetpub\wwwroot). Currently, the team is working to configure the MySQL database, which has credentials unknown to Mr. Willkens. Considerable effort has been devoted to initializing the database and creating a new user login, but these attempts have not yet been successful. In the meantime, the team has installed phpMyAdmin, a GUI helpful for working with MySQL databases, onto the server where files will eventually be hosted. Once these challenges are resolved, the site may be deployed live for the first time.

6. Plant Cost Calculator

6.1 Governing Equations

The total cost of an AguaClara plant depends on the costs of its design, the wages that must be paid to its employees, and the cost of plant operation. The Spring 2014 team summed these three parameters and obtained the following equation for the total cost:

$$Total\ cost\ =\ Design\ cost\ +\ Wages\ cost\ +\ Operating\ cost \quad \textbf{(1)}$$

The team consulted information regarding design cost, wages, operating cost, and synthesised it into a series of equations, given in their semester report. The equations, which were instrumental in the implementation of the PCC tool, are highlighted and specified below.

6.1.1 Design Cost. The design cost equation provides the total cost for the design of an AguaClara plant. Its parameters are cost per flow rate, per capita water demand, and final population, each of which is identified below.

$$D = C * q * P(n) / 8640 \text{ } \mathbf{(2)}$$

- C = cost per flow rate (USD/L/S);
  Very Rough Estimate at C = 10000 (USD/L/S);
- q = per capita water demand (L/day/person)
  Default to: 150 L/day/person but allow user to change;
- P(n) = final population (person)
- $P(n) = Po * (1 + n)^t / 100$; **(3)**
  n = population growth rate, percent increase/year UI 1.79 % (2013 est.)
- Po = initial population (person); t = plant adequacy (years)

Here, the flow rate in L/s is given by $f = q * P(n) / 86400$ **(4)**

6.1.2 Wages Cost. In order to calculate the wages cost of a plant, one must consider the hourly wage of workers, number of employees, and the plant adequacy in years. Note that a plant must be staffed by at least one person around the clock, for a total of 8765.81 hours over the course of a year. The following equation describes how to calculate Wages Cost, and its parameters are identified below.

$$W = h * t * E * 8765.81 \text{ } \mathbf{(5)}$$

- 1 person in each plant at all times, 8765.81 hours in a year;
- h = hourly wage (USD/hr)
  Default to 2.6USD/hr (minimum hourly wage), but allow user to change.
- t = plant adequacy (years);
- E = employees (persons)
  Default to: 1, but allow user to change

6.1.3 Operating Cost. The total cost of operation depends basically on the amount of coagulant and chlorine used during the plant's operation. Coagulant makes particles in the water collect into flocks so they later can settle out, and chlorine is used to disinfect the water.

$$Op = (C\ coagulant) + (C\ chlorine) \text{ } \mathbf{(6)}$$

- C coagulant = cost chlorine/person/month (USD/person/month)
- C coagulant = $D\ coagulant * L\ coagulant * q * .70 * 30.4$ **(7)**
- D coagulant = dose coagulant (kg/L);
  Default: .000020kg/L (given by Dr. Weber-Shirk);
- L coagulant = cost of coagulant/kg;
- 1) Alum (aluminum sulfate) USD/kg Default: 1.1 USD/kg
- 2) PACI (poly aluminum chloride) USD/kg Default: .908 USD/kg (given by Dr. Monroe Weber-Shirk.

- q = per capita water demand (L/day/person).
- C chlorine = cost chlorine/person/month (USD/person/month)
- C chlorine= $D\ chlorine * L\ chlorine * q * .70 * 30.4$ **(8)**
- C chlorine= dose chlorine (kg/L)
  Default: 0.001kg/L
- L chlorine = cost of chlorine/kg

6.1.4 Team Challenges. At the end of the Spring 2014 semester, the previous WTTSG team stated that the precision of the calculator should be improved: "Using population of the vicinity of a given AguaClara plant and using default values for the remaining fields, our calculator estimate is within about 20,000 USD of the actual design cost for most plants." Some of the challenges they encountered were finding a reliable source of chlorine and coagulant costs and accurate information on each plant to devise a method that improves the Capital Cost estimate of 10,000 USD/(L/s). The Fall 2014 worked to improve on this estimate over the course of the semester.

6.2. Capital Cost

The capital cost of a plant includes the costs of building the plant, training operations, and operating the plant. The Spring 2014 team and performed a simple linear regression in order to improve the 10,000 USD/(L/s) estimate of the previous team. The capital cost for each plant has a fair correlation with its flow rate. A graph below is included to show this correlation along with a table of the various plants. Each of the points represents one plant that had sufficient data.

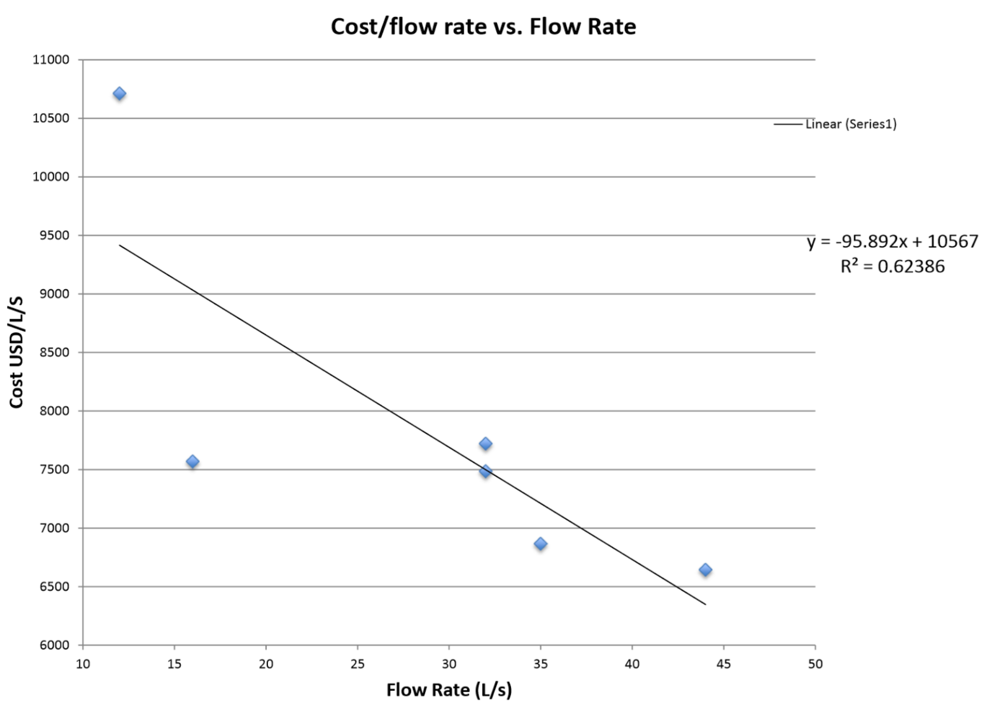


Figure 12: Simple Linear Regression Graph.
This Graph, generated by the Spring 2014 team, provides a simple linear regression of the capital cost of plants built in Honduras

Table 1: Honduran Plants, Their Flow Rates, and Their Associated Costs/Flow Rate
This table provides information about the costs associated with plants built by AguaClara in Honduras, and corresponds to the data in the above graph.

Name	Flow Rate (L/s)	Cost/Flow Rate (USD/(L/s))
Atima	16	7570
San Nicolas	32	7486
Alauca	12	10713
La Libertad Los Laurales	35	6867
La Libertad El Faldon	32	7722
Las Vegas Piedras Amarillas	44	6645

The regression equation generated is shown below:

$$C = -95.893 * f + 10567 \quad \textbf{(9)}$$

where C = cost per flow rate and f = flow rate.

This equation has a negative coefficient on flow rate, which indicates that a simple linear regression is not appropriate for our data set.

6.2.1 Curve Fitting with Linear Regression. When analyzing the data points in the Cost/Flow Rate vs. Flow Rate Graph (Figure 6), it is clear that they do not obey a linear equation because some fall far from the regression line. Also, not all of the plants used to create the graph were built with Stacked Rapid Sand Filter. This can make it harder to establish an accurate relation between capital cost and flow rate.

Since the inclusion of data from plants without filters could significantly skew a formula used to provide cost estimates for plants with filters, the WTTSG team resolved to only consider data from the plants which were designed and constructed with filters. These include San Nicolas, La Liberdad Los Laurales, La Liberdad El Faldon, Las Vegas Piedras Amarillas, Moroceli, and Jesus de Otoro. Aminta Nuñez, an AguaClara LLC engineer from Honduras, provided the budget for the last plant, as it has been constructed most recently, and these numbers are not otherwise readily available. A table below shows the flow rate and the cost per flow rate of each of these plants.

Table 2: Honduran Plants, Their Flow Rates, and Their Associated Costs/Flow Rate
This table provides information about the costs associated with plants built with filters.

Name	Flow Rate (L/s)	Cost/Flow Rate (USD/(L/s))
Moroceli	16	11777
San Nicolas	32	7486
La Libertad El Faldon	32	7722
La Libertad Los Laurales	35	6867
Las Vegas Piedras Amarillas	44	6645

A scatterplot of the data above was created, and performed a regression using the Excel Power curve of the scatterplot data. The curve equation obtained is

$$C = 61077f^{-.599} \quad \textbf{(10)}$$

This equation seems adequate because a negative cost would only result with a negative flow rate (see Figure 13).

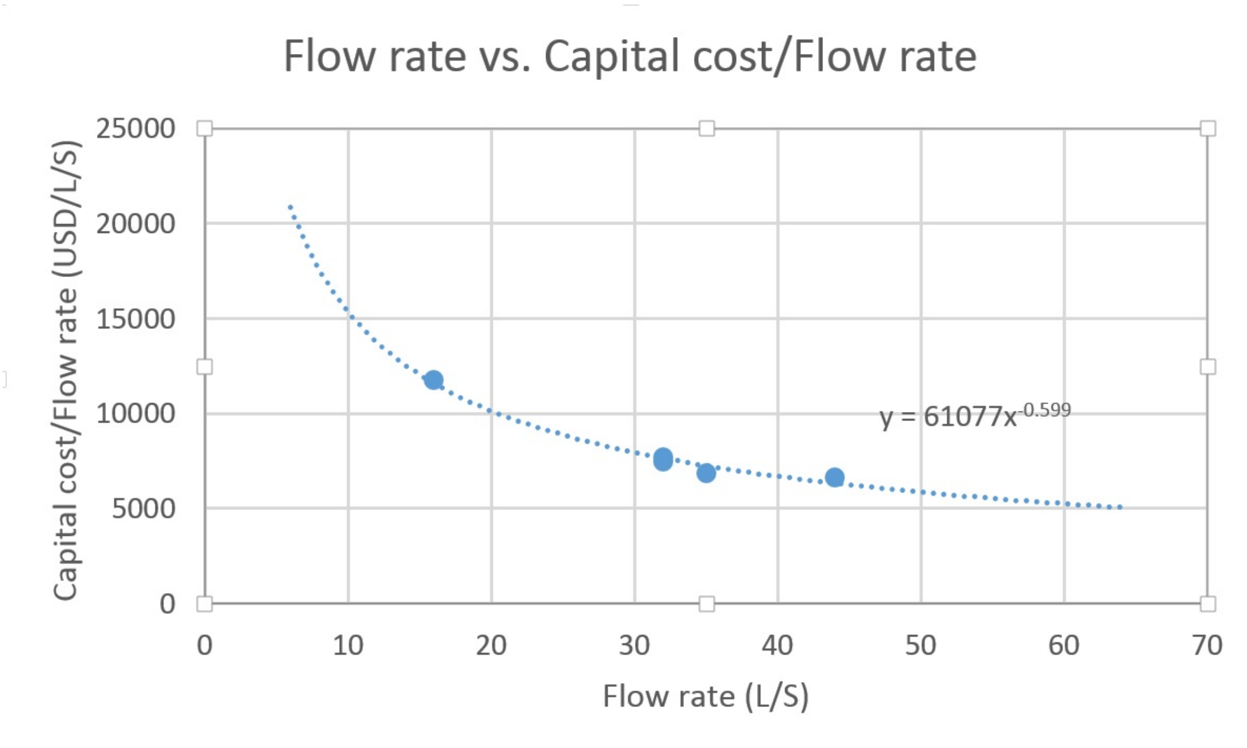


Figure 13: Curved Linear Regression Graph

A curved linear regression of the capital cost of plants with filters built in Honduras.

6.3 Estimating Water Treatment Cost

Using the information expressed in the construction cost regression equation, an estimation of total plant cost was developed as a combination of initial construction cost, monthly operating costs, and monthly maintenance costs. This estimation was translated into a series of parameters, for eventual input into the WTTSG website.

6.3.1 Cost Curves. The team investigated the possibility of using cost curves in this calculation. The Environmental Protection Agency suggests cost curves to estimate the general cost to be expected for a proposed project. The construction cost curves were developed aggregating cost data for the following eight components:

(1) Excavation and site work;
(2) manufactured equipment;
(3) concrete;
(4) steel;
(5) labor;
(6) pipes and valves;
(7) electrical equipment and instrumentation; and
(8) housing.

A 15-percent allowance should be added to the subtotal of these eight categories to cover miscellaneous items that were not included. The construction cost for each unit process is presented as a function of the most applicable design parameter for the process. (i.e: cost/L/s). It does not, however, include the costs for for special site work, general contractor overhead and profit, engineering, or land, legal, fiscal, and administrative work and interest during construction, which are added later.

The operation and maintenance cost curves are based on (1) energy requirements, (2) maintenance material requirement, (3) labor requirements, and (4) total operation and maintenance cost. Electrical energy requirements were developed for both process energy and building-related energy. Maintenance material costs include the cost of periodic replacement of component parts necessary to keep the process operable and functioning. Examples of maintenance material items included are valves, motors, instrumentation, and other process items of similar nature. The maintenance material requirements do not include the cost of chemicals required for process operation. Chemical costs must be added separately. The operating parameter or flow should be utilized for determining maintenance material requirements. The labor requirement curve includes both operation and maintenance labor and is presented in terms of hours per year. The operating parameter or flow should be used to determine the labor requirement.

These curves would have to be updated to time of construction. Most engineers and planners are accustomed to updating costs using one all-encompassing index, such as the Engineering News Record (ENR), the Construction Cost Indexes (CCI) and Building Cost Index (BCI). To update the construction cost using the CCI, which was 265.38 in October 1978, the following formula may be used:

$$Update\ Cost\ =\ Total\ Construction\ Cost\ from\ Curve\ (Current\ ENR\ CCI\ /\ 265.38)$$

6.3.2 Cost Curve Challenges. When reviewing the Cost Estimating Manual for Water Treatment Facilities by William McGivney and Susumu Kawamura, the team agreed that the cost curves may be risky to apply in an AguaClara project due to its alternative design and different construction locations. Historic costs have a way of remaining constant because they represent the actual price of goods and services at some time in the past. They can be adjusted to another time or place on the basis of a cost index published by either the government or a private entity that is generally accepted by the industry or constituency it represents. It is important that the estimator select the most reliable index and apply that index to the historic cost to compare it to other costs, either actual or estimated. Once adjusted, the resulting cost is no longer considered primary data. Adjusting actual costs from some time in the past to the current period presumes that the goods and services that made up historic cost have not changed and the costs for all components have changed in exactly the same way. Making this adjustment can introduce inaccuracies into the estimate. Adjusting the actual cost from place to place either across the country or from country to country is even riskier, and making both types of adjustments can eliminate any reasonable expectation of accuracy (Kawamura and McGivney, 2008).

Although the cost curve estimation method will not be used, the team will consider for the Plant Cost Calculator the parameters that were used to develop the construction curve, and the operations and maintenance curves.

6.4 Estimation of Costs

The WTTSG user, interested in estimating the cost of an AguaClara plant, will provide the following inputs, which are useful in estimating the plant's cost of construction, monthly maintenance costs, and monthly operating costs:

Table 3: User inputs for plant cost calculator

INPUTS	Default values
Per capita water demand (L/day/person)	Default: 150
Population growth rate (percent increase/year)	Default: .024
Initial population	Varies by location
Plant adequacy (years)	Default: 15
Dose Coagulant (mg/L)	Default: 12
Cost Coagulant (Lempira/Kg)	Default: 22.50
Dose Chlorine (mg/L)	Default: 1.2
Cost Chlorine (Lempira/Kg)	Default: 62.5
Purity of calcium hypochlorite	Default: .65
Monthly Wage	Default: 5000
Employees	Default: 3

Given the initial population, plant adequacy, and population growth rate, a measure of population can be obtained with equation 4. The plant flow rate is then calculated using that estimation of population and the per capita water demand (see equation 5). To obtain the total capital cost, which is the cost of construction, a regression equation is derived from the flow rate (see equation 7). The total monthly cost will consider building energy, cost of coagulant, cost of chlorine, wages expense, and maintenance material requirement.

Since an AguaClara plant is gravity-powered, the only energy consumed in the plants is electricity providing light to the operators. The cost of such energy is negligible but will be detailed in the monthly cost estimation so that the user can see how little he will have to spend with energy. The maintenance material expense is also inexpensive, totaling only about 0.15% of the monthly cost.

In addition to the costs of building energy, the monthly costs for coagulant, chlorine, and wages will be calculated from user input. The relevant formulas are listed below:

$$C\ coagulant\ =\ D\ coagulant\ *\ L\ coagulant\ *\ f\ *2592000 \quad \textbf{(11)}$$

$$C\ chlorine\ =\ D\ chlorine *\ L\ chlorine *\ f\ *2592000\ /\ 0.65 \quad \textbf{(12)}$$

where 2,592,000 is the seconds in a month.

$$W\ =\ employees\ *\ monthly\ wage \quad \textbf{(13)}$$

Building energy: 1 lamp of 100W working 24 hour a day for a period of a month:

$$(1*100\ W*24\ hours/day\ *30\ days)/1000\ =\ 72k\ Wh/month$$
$$1.4037\ Lempiras/kWh\ *\ 72\ kWh/month\ =\ 101.0664\ L./month$$

Maintenance material requirement: The total monthly cost for operation and maintenance is given by:

$$T\ =\ building\ energy\ +\ cost\ coagulant\ +\ cost\ chlorine$$
$$+\ wages\ expense\ +\ maintenance\ material\ requirement \quad \textbf{(14)}$$

7. Decision-Making Methodology

7.1 Decision Table

The Spring 2014 team decided to convey the final results of their web tool in a table showing the different areas of comparisons between AguaClara, package, FIME, and civil works plants. Categories such as quality of treated water, cost, ease of installation, frequency of component failure, and energy cost were ranked, and the decision tool recommended the best option in each category by highlighting it in green. In addition to the table of technology ranking, the team included reasoning for each category.

The Fall 2014 team decided to adopt a similar technology evaluation result format, presenting data via a table. The team is now researching some treatment information that was missing in the previous work. Some relevant changes were made: the treatment option civil works was eliminated, since it was poorly ranked in almost all categories; direct filtration was added to the roster since it is a more competitive option; the category ‘quality of treated water’ was replaced by the parameter ‘water turbidity’, since it is more relevant to know the turbidity of the water that needs to be treated; and a ‘contaminant removal’ category was added. The user will select which contaminants he is interested in treating among the following: arsenic, fluoride, microbes, nitrate, radium, uranium, and turbidity, particles, and organic material. The technology that treats the selected contaminants will be recommended in the contaminant removal category.

In the table below, the contaminants are represented by the following numbers:

1: turbidity, particles and organic materials.
2: arsenic
3: fluoride
4: microbes
5: nitrate
6: radium
7: uranium

Table 5. Technology comparisons
This table compares different parameters for centralized and non-centralized water treatment options

	Treatment Option	*Water Turbidity (NTU)*	*Cost*	*Ease of Installation*	*Frequency of Component Failure / Maintenance Requirement*	*Energy Cost*	*Contaminant Removal*
Centralized Options	AguaClara	Unknow	Low	Hard	Low	Low	1
	Package Plants	<100	Low	Easy	High	High	1, 2
	Direct Filtration	5 to 15	Low	Unknow	Low	Low	1, 2
	Multistage Filtration (FIME)	<150	High	Easy	Medium	Low	1, 2, 3
Non-Centralized Options	Membrane Filter Kiosks	< 200	Low	Easy	Medium	Low	1, 2, 4, 5
	Remote Kiosks	Unknow	Low	Easy	Low	Low	Unknow
	Biosand Filters	< 50	Low	Hard	Low	Low	1, 4

	Reverse Osmosis Filters	<1	High	Easy	High	High	1, 2, 3, 4, 6

Reasoning:

· **Water Turbidity:**

- *Package Plants:* Raw-water turbidity < 100 NTU.
- *Direct Filtration:* Primarily used for the treatment of good quality sources characterized by turbidity of less than 5 to 15 NTU.
- *FIME:* A moderate influent turbidity limit of around 20 NTU may be proposed for Slow Sand Filtration. In case of raw water turbidity level greater than 150 NTU, either pre-settling process in a plain sedimentation tank would be necessary, or water should be passed through an infiltration gallery for the removal of settleable suspended solids before putting into the two-stage pre-filtration processes (Dynamic Roughing Filter and Up-flow Roughing Filter) in Multistage Filtration system. If the raw water level remains within 60 NTU, the Dynamic Roughing Filter step may be omitted.
- *Membrane Filter Kiosks:* Several membrane filtration plants have been installed and successfully operated for more than nine years for the treatment of raw water supplies with occasional turbidity spikes up to 200 NTU.
- *Biosand Filters:* The turbidity of the source water should be less than 50 NTU. If it is more turbid, settle or strain the water before using the biosand filter.
- *Reverse Osmosis Filters:* Visible particles if not removed from reverse osmosis (RO) drinking water system will cause plug feed flow channels. To prevent such fouling, RO feed water needs to have turbidities of less than 1 NTU. We have found lots of documents about turbidity of raw water that RO can treat. Unfortunately, there are few references about how reverse osmosis filters treat raw water. The data stated below is about turbidity of drinking water that reverse osmosis filters can treat.

· **Cost:**

- *AguaClara:* AguaClara has a lower average cost than Package Plants, Direct Filtration, and FiME.
- *Package Plants:* Relatively low initial cost, as well as low operation and maintenance cost that results from automatic control features.
- *Direct Filtration:* Lower chemical costs due to lower coagulant dosages used in direct filtration, (2) lower capital costs as the sedimentation (and sometimes the flocculation) tank is not needed, and (3) lower operation and maintenance costs.
- *FIME:* Requires a lot of land area, uses expensive machinery, and is a labor intensive process.
- *Membrane Filter Kiosks:* Ranges in price based on the amount of water being treated and distributed. As advancements are made in membrane production and module design, capital and operating costs continue to decline.

- *Remote Kiosks:* Cost effective as per-liter production costs were reduced up to 56%.
- *Biosand Filters:* Negligible operating costs.
- *Reverse Osmosis Filters:* Very expensive. For individual treatment, produces 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:**

- *AguaClara:* Requires a few months to fully install a plant.
- *Package Plants:* Readymade, making them easy to install.
- *FIME:* Can also be installed easily.
- *Membrane Filter Kiosks:* Highly transportable and complete assembly takes a few hours.
- *Remote Kiosks*: Easy to install.
- *Biosand Filters:* Requires a one time installation but oftentimes are heavy, thus making it difficult to transport.
- *Reverse Osmosis Filters*: Fairly easy to install following the instructions manual.

· **Frequency of Component Failure:**

- *AguaClara:* Requires very few repairs over a plant lifespan. If there needs to be a repair, the locally trained technician can diagnose the problem and find the replacement for the malfunctioning part with relative ease since AguaClara uses resources native to the region. In addition, AguaClara plants can be understood by a single operator given that it has a low component count and relatively simple process.
- *Package Plants:* Involves the use of multiple layers to run its system. Each layer makes use of complex processes. For example, there is a combination of a software and hardware controlling solenoid valves which control mechanized valves that finally control the flow of water. This sophisticated process requires maintenance by multiple workers of varying specialization.
- *Direct Filtration:* The sedimentation (and sometimes the flocculation) tanks do not need to be powered or maintained.
- *FIME:* There are more components prone to failure, but not as many as in package plants.
- *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:* Requires little maintenance and are easy to operate.
- *Reverse Osmosis Filters:* Require frequent cleaning of the membrane, and this membrane can trap bacteria.

· **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.
- *Package Plants:* Most packages plants have varying energy costs, but are usually on the order of 100 J/L.

- *Direct Filtration:* The sedimentation (and sometimes the flocculation) tank need not to be powered.
- *FIME:* Plants also run on gravity-powered filtration systems so they do not need much energy and have energy costs similar to AguaClara plants.
- *Membrane Filter Kiosks:* Gravity-powered, and thereby generate little to no energy costs.
- *Remote Kiosks:* Offer little energy costs since they are simply a distribution system that usually is operated by a hand pump.
- *Biosand Filters:* Require no additional energy as water is simply passed through the layers by way of gravity.
- *Reverse Osmosis Filters:* The high pressure required for reverse osmosis means higher energy and capital costs for the membrane units. This can be significant compared to other technologies, making reverse osmosis one of the more expensive treatment options.

· **Contaminant Removal:**

- *AguaClara:* The AguaClara water treatment plants remove various particulates from the water through flocculation, sedimentation, and stacked rapid sand filters. AguaClara technology removes any suspended particles from the water. These particles can include clay, organic material, bacteria and parasites.
- *Package Plants:* Often used in water treatment for small communities. The unit is mounted on a frame for simple hook-up of pipes and services. It is most widely used for the removal of turbidity, color, and coliform organisms.The use of pre-engineered CMF package plants is a realistic possibility for new installations where water quality precludes the use of sorption treatment.
- *Direct Filtration:* Filtration is the removal of particulates. When the water flows through a porous medium, some contaminants are removed. A largely fraction of arsenic is removed through filtration using a 0.45 μm-pore-size filter.
- *FIME:* Filtration is the most practical treatment process. Arsenic is also removed by filtration through a 0.45μm-pore-size filter. It has been shown that combination of ultrafiltration with spectroscopic methods and fluoride ion-selective electrode greatly controls the precipitant.
- *Membrane Filter Kiosks:* A pressure-driven separation process. Any particulate matter larger than 1 micrometer in diameter is rejected by the membrane. Membrane treatment is a viable method to meet the reduced MCL. Ultrafiltration systems use a hollow fiber membrane to reduce bacteria. Nitrate selective membranes allow for treatment without significantly altering the balance of other ions in the water.
- *Biosand Filters:* The filter can also remove up to 95% of turbidity, and up to 95% of iron. It is best used as one step in a multi-barrier approach to safe drinking water. Although the water may look clear after filtration, there may still be some bacteria and viruses in the water. It is necessary to also disinfect the filtered water to ensure the safest drinking water possible.

- *Reverse Osmosis Filters:* Can effectively remove nearly all contaminants from the water. They are:

    arsenic (3),
    arsenic (5),
    barium,
    cadmium,
    chromium,
    radium (6),
    natural organic substances,
    pesticides
    microbiological contaminants.

8. Conclusions

Significant progress has been made in designing and implementing the WTTSG web tool, with design storyboards successfully translated into website layouts with CSS. Components such as a navigation structure, multi-page form structure, and administrator login were initialized, with careful attention paid to details like dynamic page resizing. JavaScript was leveraged to add extra functionality to the site, and a MySQL database was developed. Data can be passed from page to page, remembered and used to autocomplete forms, and prepared for storage in the database. While many components of the website still need to be implemented, what has been accomplished thus far provides a simple framework for the integration of further functionality.

Additionally, great progress has been made in developing cost regressions for the Plant Cost Calculator component of the tool. The team has collected the formulas necessary to make sensitive cost estimations, and cost and constraint information relevant to the comparison of a variety of treatment options has been synthesized for later incorporation into the WTTSG.

9. Future Work

First and foremost, future teams will need to build out the WTTSG tool to provide a final results page to users who have submitted data. Currently, the tool collects and begins to process the data, but there is not yet a final screen presenting an appropriate recommendation. Great progress has been made in researching various treatment technologies this semester, but this work should continue to be expanded until information about the treatment options is fully synthesized into the site.

Next, in order to make the website accessible to as many potential users as possible, it should be translated into various languages; since AguaClara has plants in both Honduras and India, having support for Spanish and Tamil/Hindi will be a necessity. The current website is English-only, but should support dynamic translation via the integration of a JavaScript language selection tool. Dr. Monroe Weber-Shirk has suggested interfacing with GoogleTranslate to provide full support for a variety of languages.

Once the website is operational, the WTTSG team must begin an extensive process of user testing in order to ensure that the site’s design is well-informed by human-centered principles. The conscientious integration of JavaScript in order to respond to user input, provide real-time feedback, and provide form checking will contribute significantly to this goal. Still, the team must ensure that whatever JavaScript is implemented degrades gracefully in non-JavaScript-enabled browsers. At this point, the team should engage with various website stakeholders to understand their experience of the site, collecting feedback used to refine the site's design and functionality. The team should monitor users who will actually use the tool as they engage with it in order to better understand who will use the tool and what they will look for in their experience.

As AguaClara continues to build more plants, any data related to construction, operation and maintenance should be transferred to the WTTSG team. Currently, detailed budgets are not available to the AguaClara research team. Though the team was able to find budgets for some of the most recently built plants, they are all in Spanish, which makes them harder to analyze. With more information available, the future team can continue to improve the Plant Cost Calculator tool.

Eventually, PHP and MySQL should be used in concert to provide automatic regression modeling when new plant cost data is uploaded to the webtool. In order to implement this functionality, the team should pursue the creation of an administrator panel, where users will be able to upload data as it is gathered. Such a portal could also be used to review submitted user data and demographics, and a visualization tool for this data should be carefully considered and designed.

Finally, the Spring 2014 team incorporated a technology manual in their guide, something that future teams might consider as well. Such a manual would inform users about the advantages and disadvantages of the water treatment options used for comparison. For reference, an incomplete version of this manual can be found in the Spring 2014 team's folder on the server.

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