Water Treatment Technology Selection Guide, Fall 2015

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Abstract

The engineering project team AguaClara is working on a Water Treatment Technology Selection Guide (WTTSG) that can provide water treatment technology recommendations to interested municipalities. This tool takes the form of a website hosted on the AguaClara servers which allows organizations to input descriptive parameters about their water sources and receive a tailored recommendation. In developing this tool, the WTTSG team subscribes to the following principles: use of the site must be intuitive and accessible, adhering to interaction design principles; the site must must use sound decision logic to provide a high-quality recommendation to its users; and the site must be scalable and responsive to changes in constraint and cost data. In past semesters, the WTTSG team has made strides in building out front- and back-ends of the site, culminating in a tool able to successfully interact with data, provide automatic language translation, and interact with a MySQL database. The site is further equipped to calculate cost regressions, log user input, and provide extensive administrator functionality. This semester, the WTTSG team performed extensive research and literature review while investing effort to ensure the website is shareable and scalable to new constraints and technologies.

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Introduction

In today's data-driven age, information is everywhere. When faced with this deluge, finding high-quality information can be challenging. Consequently, an emerging category of webtool offers assistance in finding insights, making decisions, and other aspects of problem solving. By anticipating potential user problems and promptly satisfying questions with clear answers, such webtools work to give users a positive experience. Many of these webtools can provide recommendations to users based on logged data and user inputs to yield a recommended song, product, or service that individual users may enjoy.

In this same category of recommendation services, Cornell's AguaClara project team works to implement a Water Treatment Technology Selection Guide (WTTSG), a tool that will provide recommendations municipalities can use to make an informed decision about which AguaClara treatment options best treat their unique water quality issues. By allowing the user to input information about the population, distribution system, and source water of a potential plant, the tool can provide recommendations for AguaClara technologies that will best serve the needs of the community in question. The focus on AguaClara is a necessary artifact of the difficulty obtaining data about competitors' treatment options; however, the infrastructure of the tool will remain scalable should these other technologies ever be introduced into the tool.

Literature Review

Graphs from Daniel Smith (2012) and C.L Hamann, J.B. McEwen, and A.G. Myers (1990) serve as good starting points for data collection regarding the performance of water treatment technologies, as separated by process. Performance is detailed in various areas such as turbidity treatment, specific contaminant treatment, and ease of installation. Data gathered from water treatment companies can be used to complement information from these two reports.

Maximum contaminant levels (MCLs) from the United States Environmental Protection Agency (EPA) are currently employed by the webtool as a baseline for allowable contaminant levels. Guideline values from the World Health Organization's Guidelines for Drinking-Water Quality (4th ed.) were also looked into to perhaps obtain allowable contaminant levels that were less stringent than the US EPA's standards.

Spring 2015 WTTSG Team Report

This report explains the methodology of the Spring 2015 WTTSG team, which added a rich variety of features to the tool, including MySQL support, automatic language translation, administrative actions, the layout of the results page, and functionality enabling the editing of saved inputs on the fly. The team worked to ensure that data would be saved as users traversed the site both backwards and forwards, and built a framework allowing user data to be saved for later reference. Under this team, the site was finally configured and deployed live to the server, where it can be accessed via remote desktop connection.

Fall 2014 WTTSG Team Report

The Fall 2014 team engaged in much of the preliminary implementation of the WTTSG tool, designing the site and its navigation structure while engaging in data-passing and the creation of MySQL tables. Efforts to provide a regression equation for plant cost are detailed in this report, with equations that will be used in estimating total plant cost. Some preliminary literature review is provided on the use cases for various water treatment options, but it largely lacks citations.

Spring 2014 WTTSG Team Report

Work on the WTTSG as a webtool was pioneered by the the Spring 2014 team, who developed a rudimentary tool capable of providing limited treatment option recommendations. These recommendations were ultimately displayed in a color-coded HTML table, in which good and bad options were highlighted in green and red, respectively. This version of the WTTSG was highly buggy, breaking on any invalid user inputs, and was furthermore unattractive and uncompelling to use. This version of the website was ultimately abandoned, but it does demonstrate a potential structure to the logic of providing recommendations.

Methods

Data Gathering

Challenges

The information necessary for providing a strong recommendation to a user is largely unknown. To close this information gap, the WTTSG subteam first sought to gather performance data from water technology companies, seeking to identify parameters like the maximum turbidity treatable and degree to which a given treatment technology can treat a contaminant (e.g. uranium is reduced by 10-20% using plate settlers). Contaminants investigated include uranium, radium, nitrates, microbes, particles and organic matter, fluoride, and arsenic (as of Sept 28).

However, the scope of information available posed a significant challenge. Publically available brochures and literature from water technology companies largely do not provide sufficient information to govern the decision logic of the webtool. This is because most brochures do not provide substantial amounts of information directly applicable to the concerns of practitioners; instead, these materials focus on information like plant dimensions. While such factors can influence the effectiveness of unit processes, they do not reveal much about various treatment options' ability to reduce pollutants or turbidity. Therefore, a plan for more direct questioning of the water treatment companies was developed to gather performance data in a time-efficient manner.

Survey

A survey using Google Forms was created to gather information from water companies on treatment technologies, their capabilities, and their constraints. The survey asks for: estimated plant life, the unit processes used in the treatment option, turbidity standard that is held to,

maximum turbidity of influent water treatable to the given turbidity standard, maximum flow rate that can be supported, what water source types (i.e. groundwater, surface water) the plant treats, if the treatment option requires a distribution system, the turbidity standard the technology treats to (e.g. 5 NTU in Honduras, 0.3 NTU in the US), and the estimated turnkey cost of the treatment option for the minimum and maximum flow rates.

The survey also asks for maximum concentration of contaminants in influent water that can be treated to the US standards as given by the [Environmental Protection Agency](). The list of contaminants on the survey include: nitrates, arsenic, fluoride, manganese, cyanide, iron, heavy metals, organic chemicals, radionuclides, viruses, bacteria, as well as Cryptosporidium and Giardia lamblia. For the specific element contaminants, the survey asks for the maximum concentration of each contaminant in influent water that can be treated the US standard. For heavy metals, organic chemicals, and radionuclides, it is asked as to whether the treatment option could be relied upon for contamination removal.

This structure was motivated by the fact that there are many different specific contaminants in each category, so asking for each could make the questionnaire quite lengthy. For viruses, bacteria, Cryptosporidium, and Giardia lamblia, the survey asks whether the treatment option can remove or inactivate 99.99% of the contaminant. Lastly, an open-ended question is posed asking if there are any noteworthy qualities of the treatment option that set it apart from other treatment options. Users may add additional data as they see fit.

The survey was designed to be distributed through email with or without using the Google Form, discussed over the phone, or used as a follow up after a phone conversation if answers are not immediately available or known at the time of phone conversation. The finished form can be viewed [here]().

Querying about Contaminants

The structure of the information gathered appeared to be more complex than could be sufficiently captured through yes/no questions. For example, asking water treatment technology companies whether or not their treatment option can treat a particular contaminant has risky implications: it might seem like the treatment option can only completely treat the contaminant or not treat it at all. Therefore, instead of asking yes/no questions, the team turned to quantifiable data, capturing the degree to which a given contaminant is treatable by a given process/technology. This was operationalized on a 1 to 5 scale where: 1: 0-20% removal, 2: 20-60% removal, 3: 60-80% removal, 4: 80-90% removal, and 5: 90-100% removal.

With percentage removal data known from different technologies, a better recommendation can be provided to users of WTTSG given user input of concentration of contaminant in the source water. For example, there is little use in having a treatment process to treat radium if it only exists in concentrations that meet drinking water standards. Any contaminant can be present in negligible, trace amounts, so asking users whether or not a contaminant is present in the source water is not entirely valuable for the final recommendation. This motivated a change in phrasing from "What contaminants are present in the water?" to "What contaminants violate drinking

water standards?" and "What are the concentrations of these contaminants?". This change requires more input information, including the standards for a given region or reference to a standard such as that of the World Health Organization.

Feedback from NYSAWWA

Marty Aman from the New York Section American Water Works Association (NYSAWWA) and his colleagues provided further input on the survey. Aman prompted the team to consider hardness and cost of electricity for different processes (for example, membrane filtration is very energy-demanding) as critical facets of a water treatment plant. Aman and his colleagues from NYSAWWA were also generous in helping to generate lists of contacts at various water treatment companies, and expressed interest in being included in further research endeavors.

Still, they also posed concerns about the willingness of water treatment companies to answer questionnaires about their treatment options. For obvious reasons, it can be quite a roadblock if companies refuse to provide information. However, Aman believed that not all companies would be unwilling to answer the survey, and the companies that are might still provide engineering literature on their processes potentially relevant to the WTTSG.

These concerns proved to be apt, and the WTTSG team struggled in getting accurate data from its industry contacts. For the majority of contacts, information was either not available or unable to be publicly disclosed. This required the reevaluation of the WTTSG team's approach to data collection.

A Change in Mission

In the face of difficulty in obtaining reliable data from industry contacts, as of November 2, 2015, the goals of the WTTSG team changed. Instead of comparing all currently available water technologies, the webtool will instead provide a user with the user inputs as described in this report, regardless of whether AguaClara technologies can support their water contaminant issues. This will be determined using information that is currently available for AguaClara technologies, as well as some extrapolation for the sedimentation, coagulation, and filtration unit processes in order to close the information gaps that currently exist. With time, as AguaClara develops new technology such as fluoride filters, upflow anaerobic sludge blankets, and aerobic granular sequencing batch reactors, additional information can be updated on the webtool as well.

Data from the field regarding AguaClara technology can currently provide insight into particle, microbe, and natural dissolved organics removal. This data is openly accessible and expansive enough to make strong recommendations. Baseline standards, such as the United States Environmental Protection Agency's Maximum Contaminant List (MCL) or World Health Organization guidelines, can be used in conjunction with the dataset in judging whether AguaClara technologies sufficiently handle the water quality issues of each set of user inputs.

Treatment Recommendation

Goals and Challenges

The WTTSG team seeks to provide a treatment option recommendation capable of treating all contaminants exceeding certain drinking water standards in a user's source water. In providing recommendations, the team must decide whether the recommendation will consist of unit processes combined to meet the needs of the practitioner (e.g. putting together a plant that has aeration, lime softening, and chemical oxidation in order to reduce contaminants to satisfy drinking water standards), or whether integrated options should be exclusively recommended instead. For the former option, it must be discussed and investigated how many technologies would be part of the recommendation. Essentially, is there a hard limit on the amount of technologies that can be combined to provide water treatment? Is this dependent on what technologies are being used?

Target Flow Rate

The generated recommendation must also include a target flow rate for the plant. The target flow rate can be modeled by the following equation:

$$Plant\ Flow\ Rate = P_o \left(1 + \frac{k}{100}\right)^T \left(\frac{U\ liters}{day * person} * \frac{day}{24\ hours} * \frac{hour}{3600\ seconds}\right)$$

where Plant Flow Rate is in liters/second; P_o is the initial population input by the user; U is per capita use of water in liters/ day*person; k/100 is the population growth constant as a percentage for the given area or a user input; and t is the lifespan of the water treatment plant in years. All of these variables, except perhaps the lifespan of the water treatment plant (which is currently static at 15 years) are user-inputted. To convert the output of the right-hand side of the equation to liters/second, unit conversions from day to hours, then from hour to seconds, are made by dividing by 24 and 3600, respectively.

The flow rate must be able to accommodate the population of the community as it grows throughout the plant's lifespan, rather than some static value. Otherwise, the flow rate will not be able to support the growth in population over the duration of the plant's lifespan. Thus, it is important to model the growth of the community over time, to ensure the community can be served by the plant throughout its entire life cycle.

Recommendation Logistics

It is currently unclear where the estimated cost of the plant ought to fall within the recommendation. Future attention should be paid to this aspect of the tool as the plant cost calculator is developed to accommodate options like Foam Filtration and EStaRS.

It is also critically important that users be able to trust their received recommendation; otherwise, the webtool cannot carry out its purpose. Sources and explanations accompanying recommendations to gain credibility must be included. For information specific to certain water technologies, it may be necessary to ask for documentation that will back any claims on performance from water treatment technology companies.

Contaminants and Recommendations

The scope of the WTTSG's recommendation has significantly changed, from the comparison of all water treatment technologies to the comparison of various AguaClara technologies. A critical differentiating factor between AguaClara options is whether they can satisfactorily treat contaminant levels from the user inputs to an established standard (likely either EPA or WHO). Even if AguaClara technologies cannot meet the standards, information regarding the extent of AguaClara's current capabilities can be displayed, empowering the user to make a sound decision.

The webtool will check whether AguaClara technologies can accommodate the following inputs:

- Population size, given the initial population and either a defaulted or user-inputted population growth rate and per capita use of water, to ensure AguaClara can use the calculated flow rate.
- Given contaminants and their concentrations/values, using a percentage removal equation where the percentage removal for AguaClara technologies can be backed by performance data, and where performance data is not available, information on the unit process of sedimentation, flocculation, and filtration can be used to provide a rough estimate of AguaClara capabilities.
- Availability of an existing distribution system or willingness to have one for centralised solutions. For low population sizes / flow rates, foam filtration can be recommended as long as it meets the contaminant standards.

For each contaminant with a user-inputted concentration (Cyanide, Fluoride, Arsenic, Iron, Manganese, Nitrates), a value ranging from 0 to 100 should be obtained. This will express the contaminant removal percentage for an AguaClara technology for each contaminant.

R values, representing percentage removal, for Arsenic, Cyanide, Fluoride, Nitrates, Iron, and Manganese were obtained from "Guide to Selection of Water Treatment Processes" and "Guidelines for Drinking-water Quality: First Addendum to Third Addition: Recommendations" by the World Health Organization. They are as follows:

Iron: 70 ; Arsenic: 40; Cyanide: 90; Nitrates: 0; Fluoride: 20; Manganese: 70

Effluent contaminant concentration is modeled by the following equation:

$$Effluent\ Contaminant\ Concentration = C_o\,(1-R)$$

where C_o represents the user-inputted concentration of the respective contaminant, and R represents the percentage removal of the contaminant that AguaClara can provide.

The webtool can check whether or not the effluent contaminant concentration is less than or equal to the standard that is being used according to the following equation:

$$Effluent\ Contaminant\ Concentration \leq Allowable\ Contaminant\ Standard$$

If the above statement is true, then AguaClara technology sufficiently handles the issue; otherwise, it does not, and the estimated effluent contaminant concentration could be presented in the results page. However, the degree of transparency in this presentation should be discussed in further detail. For the purpose of providing a recommendation, the webtool will use the US EPA maximum contaminant level standards in evaluating effluent contaminant concentrations, since the international guideline levels laid out by the World Health Organization are more stringent than the EPA's standards.

Explanation of Constraints

This is the current list of constraints that influence plant recommendation logic, and which must be presented to users of the tool:

- **Turbidity:** AguaClara's gravity-powered treatment plants are able to handle even the highest levels of turbidity, boasting consistent removal of particles of 99%, or often greater. While higher levels such as 500 NTU are more difficult to treat, it is reasonable to treat for short periods of time with higher levels of coagulant dosages.
- **Heavy Metals:** AguaClara uses a combination of unit processes to treat source water to an allowable drinking water standard. The combination of unit processes of coagulation, sedimentation, and filtration should be able to reasonably handle the large majority of heavy metal contaminants. However, the unit process used in AguaClara plants cannot be reasonably recommended for Barium, Selenium, and Chromium contamination. In particular for Selenium and Chromium, only the +3 ion for Chromium and +4 ion for Selenium can be reasonably treated using AguaClara plants. Since it may be difficult to determine which ions are present in the source water, it should be assumed that AguaClara cannot adequately handle Selenium and Chromium.
- **Organics:** Although the initial treatment of water through coagulation, sedimentation, and filtration is ineffective at removing organic chemicals in the source water, the disinfection (chemical oxidation) that occurs after initial treatment is quite effective at breaking up many organic chemicals.
- **Calcium and Magnesium (hardness):** When calcium and magnesium are present in source water, either of the two chemicals do not pose a health risk. However, their presence in the water will lead to buildup in the pipes, reducing water flow.
- **Radionuclides:** AguaClara's initial treatment can remove uranium, however, if there is radon or radium present in the source water, AguaClara will not likely be a reasonable solution for these water quality issues.

Cost Estimation

Cost for AguaClara plants can be modeled in accordance with the Plant Cost Calculator team's work:

$$Cost\ per\ Flow\ Rate\ \frac{USD}{L/s} = a * Plant\ Flow\ Rate^{-b}$$

Where the above equation is a power regression formula provided by Microsoft Excel using Table 1 (a and b were determined using these plot points):

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

Table 1: The relationship between flow rate and cost per flow rate for a selection of completed AguaClara plants.

The current values for a and b are: 61076 and .599 respectively. The values are updated automatically with the input of new plant data into the administrator Historical Cost/Flow Rate page, further details on this subject will be covered in the regression parameters and visibility portion of the website implementation.

Future Concerns for Contaminants

For the broader contaminant categories (heavy metals, radionuclides, organics, hardness) the recommendation is slightly more nuanced. It can be overwhelming to a user to be asked to input dozens of concentration levels for various contaminants that may or may not be present in their water. The WTTSG strives to minimize the burden on the user in providing such information, instead asking only for what is necessary. At a higher level, then, the tool will seek to understand whether AguaClara options can be reasonably recommended to treat the contaminants. Thus, the decision logic will be encoded as binary: either yes or no for the broad contaminant categories.

In general, for the broad categories that are currently asked of the user (heavy metals, organics, calcium/magnesium, radionuclides) we can provide a recommendation for the general trend of AguaClara performance on these contaminant types, and provide the user with information on plant constraints; for example, the unit process of coagulation, sedimentation, and filtration

appears to do well with the majority of heavy metals (Hamann, et. al). However, barium as well as particular ions of selenium and chromium seem to be treated to a lesser degree with the same unit process.

Since performance data is not available for AguaClara plants on any contaminant aside from coliforms and turbidity, it will need to be mentioned in the results page that the percentage removal is uncertain. AguaClara has not been used to treat water specifically for contaminants other than natural organics, turbidity, and microbes, so any such statistics would be necessarily qualified.

In any case, whether or not AguaClara handles the given contamination issues as well as the necessary flow rate, the webtool on the results page can refer to other technologies and provide a short description of each, along with the positive and negative aspects to each, where the user can then look into each technology to determine if that technology is a better fit for them. Along the same lines as before with the previous goal of providing a recommendation among the many water treatment technologies, some references should be provided in order to improve credibility to any users that may express doubt in the webtool, this should presumably be easier to obtain for AguaClara technologies than information from the water technology industry.

With the work of the Plant Cost Calculator subteam, it may be possible to disclose plant cost information, using the regression equation that they had provided, however, again transparency is something to be discussed. Plant cost information for other treatment technologies will likely not be covered in the results page alongside the information for other treatment options, due to the difficulty in obtaining the information, although, relative cost can be a consideration (i.e. reverse osmosis, membrane filtration costs significantly more than other treatment options due to their energy demands.)

Other Treatment Options

In order to gather some credibility of users for the webtool, other treatment options should be described to provide the user with the sense that the webtool is not simply a proxy to push AguaClara technology onto them for their water quality issues.

- ***Package Plants:*** The conventional package plant, like AguaClara plants, use sedimentation, coagulation, and filtration to treat water. They can treat low to moderate levels of turbidity, handle microbes. Package plants are relatively easy to operate, compact in size, and for the most part are already constructed. Package plants though, have been shown to be prone to mechanical failures, reducing the effectiveness of their water treatment.
- ***Slow Sand Filtration:*** Slow sand filters are relatively cheap, simple, and effective with removing turbidity and microbes when paired with disinfection from high quality water. Slow Sand filters can handle a turbidity of up to 20 NTU, although turbidities of 10 NTUs

or less are ideal. With chlorination, slow sand filters are excellent at removing microbes, 99.99% removal.

References for Results Page

The results page should provide sources to users which allow them to assess and verify the accuracy of information. It is important to establish the WTTSG as a reliable webtool (albeit a somewhat incomplete one, due to necessary assumptions about contaminant removal based on unit processes.) Sources include live performance data from AguaClara plants, as hosted on the AguaClara website. This is currently relevant only for turbidity removal data, as no other data is currently available. If more data becomes available, it should be integrated into the tool as well.

For the assumptions and general information regarding contaminant removal for AguaClara's unit processes, consult Hamman et al., 1990 and World Health Organization, 2006. For information on the other water treatment technologies, see United States Environmental Protection Agency, 1990. Complete citations of these works are found in the References section.

Website Implementation

Navigability of the Admin Panel

After the work of Spring 2015, the WTTSG boasted a fully functional administrative pane, yet its navigation structure was somewhat confusing (Figure 1). Tables were named by their MySQL identifiers rather than in human-readable text, there were no cues showing which page was selected at a given time, and there was no explanatory text to expound upon the purpose of any page. A brand new administrator would not be able to intuit how to use the tool.
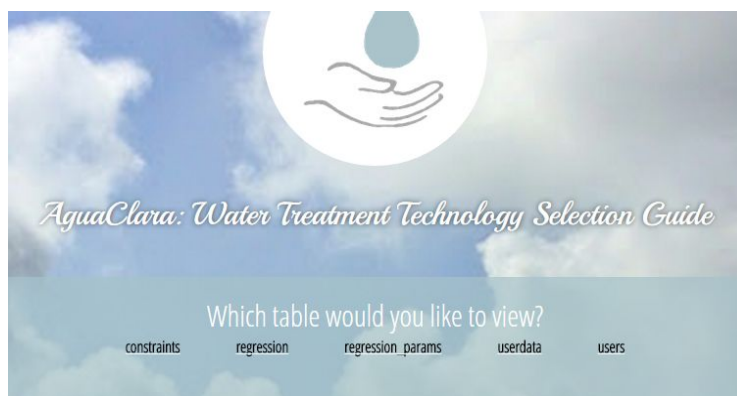

Figure 1: The admin landing page from Spring 2015. Note that tables are named by their MySQL identifiers, and there is no explanatory text showing the functionality of the admin page.

Thus, the guide was updated to feature friendlier text on the landing page. Some words of explanation were added to let the user know their place in the context of the larger tool (Figure 2). Similar explanations were added to each individual page of the admin panel, explaining how

each specific table can be interacted with and what its values mean.The hyperlinks to the table were also given human-readable names that self-document their functionality. These links can be found consistently at the top of every page of the admin panel. Moreover, each page's table hyperlink turns blue when it is selected, further notifying the user where they are in the context of the page.
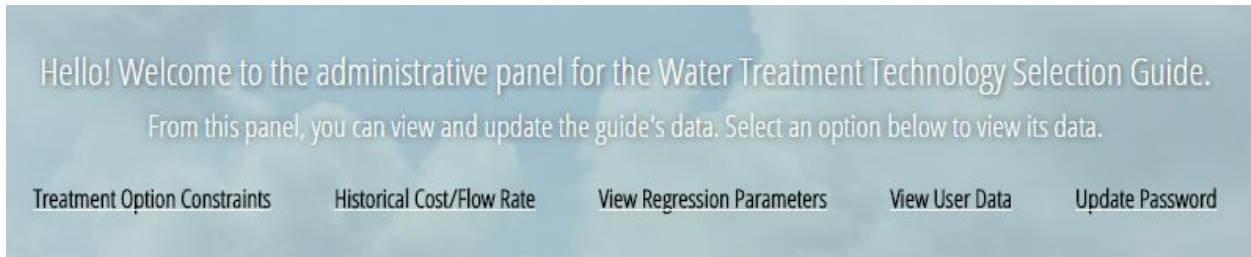

Figure 2: The updated admin landing page. Users know exactly where they are in the context of the tool, and what is possible when they click on the links below.

Work was also done to resize the constraints table so that it would fit on one page without horizontal scrolling. The text boxes for Boolean input (0, 1) values were resized to be proportionally smaller than those for larger text inputs (Figure 3). In this stage, a bug was discovered (and fixed) that had previously maintained the wrong correspondence between table columns and input into the database.
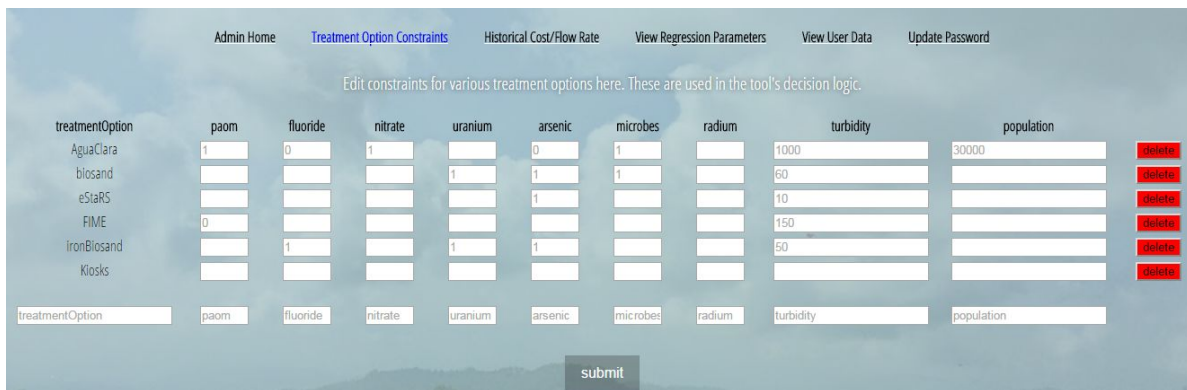
Figure 3: The constraints page. Textboxes were resized to better fit on the page, explanatory text was added, the selected hyperlink was highlighted blue, and bugs were fixed in its interaction with the MySQL database.

Finally, some small changes were made to give better and more prominent error messages when users failed to update their passwords successfully. Consideration should be paid in the future to make sure that all such use cases are abundantly clear in their error reporting, so that users know exactly what has gone wrong in their interaction and how they can resolve it. Constructive and intuitive error reporting is one of Nielsen's ten usability heuristics for interaction design, and the tool should strive to meet this standard.

Logging User Data in the Database

So that administrators of the WTTSG may maintain a record of who has visited the tool and what data they have input, the team worked to save the data in browser session variables to a specially devoted MySQL table. The query performing this functionality is sent whenever the user hits the results page, and data is passed anew as inputs are dynamically edited on the results page. This will allow the WTTSG team to perform analysis later on of how users adjust their input values once they have received feedback from the results page of the tool. New additions to the table include the current time stamp, so that visit dates may be logged, as well as a unique id for the visit (which will be further discussed in the next section).

Finally, work was done to ensure administrators can download the database contents as a csv (Figure 4); some issues with permissions on the server had previously been blocking this functionality.

Figure 4: Downloading user data. Parameters from the tool, as well as descriptive information like the timestamp, are saved in a file for easy download now that the interaction between the site and the userData table has been established. This data may be used later for analysis.

Permalinking the Results Page

Two very important characteristics of the WTTSG are that a) it should be able to save users' data so that they can return to the tool at any time and b) it should be able to be shared between users, so that all involved parties in the construction of a water treatment plant can review its recommendations. The team envisions a use case where an individual representing their municipality may fill out the tool, and then move to share its results with other leaders in the town.

In order to accomplish this, the team designed a "permalinking" functionality, by which each distinct version of user inputs is associated with a unique id. This is generated with PHP's uniquid() function, which creates a unique id based on the current system time in microseconds. This id is then attached to the most current entry in the MySQL table "userdata", where it can be used to fetch a distinct row from the table. The team next implemented code that adds a special string to the end of every results page url, which functions as a get request prompting the site to

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read in data from the table. Each time the page is updated, a new request is sent through, allowing the user to revisit the page as it was whenever the url was generated. As a positive side effect, this functionality allows site administrators to track how people tweak their inputs to the tool over time, and may provide great insight about people's expectations for a treatment option, as well as how effective the WTTSG is at meeting their needs.

Recommendation Text

Treatment option recommendations are more than the decision logic that determines which technologies should be presented to the user; indeed, this recommendation must be expressed to the user in plain text, so that they can learn more about the technology and understand why it has been chosen. The generation of this explanatory text must further comply with the two main goals of the WTTSG webtool: it must provide a high-quality user experience, and it must be scalable in the face of the addition of multiple treatment options and constraining factors. In order to meet these goals, the team decided to create a database storing human-generated descriptive text that could be fetched and integrated into the results page of the tool.

A new MySQL database, option_text, was created featuring various input fields representing different aspects of the recommendation that need explication. For example, the database will store general introductory information about the treatment option, an explanation of the contaminants and turbidity it can reliably treat, and more. Each of these fields is represented by a column in the database (belonging to a row whose primary key is the treatmentOption identifier). Further attention may be paid to ensure that addition of treatmentOption fields are symmetric between the option_text and constraints database tables--it is an invariant that if a row exists in one table, it should exist in the other. This will be further investigated as the semester progresses.

Next, a user interface was created so that administrators can update the descriptive text for each treatment option within the administrative pane, rather than needing to interface with the database directly. This page shares several notable similarities with other administrative pages in the tool, in that options are presented to add, delete, and modify rows. A notable difference between this and other pages, however, is that text is fetched as a paragraph-length text input, which allows the user to edit a larger chunk of text more quickly and easily, displaying multiple lines simultaneously.

Figure 5: Editing descriptive recommendation text.. Paragraph-length text can be generated, managed, and saved for eventual population on the results page.

Some preliminary work has been done to populate these descriptive text fields into the results page itself, and the team has successfully demonstrated that such a method is feasible. However, this should be more fully built out in future weeks, as more complete descriptive text is added to the tool for all considered options.

Uploading Option Photos

The design for the results page incorporates a photo depicting the top-recommended treatment option. Current skeletal implementations of the results page hard-coded the URL source of this image, but any hardcoding violates the tenet of scalability in the face of new prospective treatment options. It would also be very difficult for an administrator without technical knowledge to change or update the photos representing various treatment options in the eventuality that better photos became available; this would involve complicated edits at the code level and the use of Remote Desktop Connection to upload new image files to the server. To circumvent this difficult process, the WTTSG team endeavored to create a photo upload feature that would easily allow admins to add photos through the webtool's existing admin interface.

First, a new database table was created to house file paths, alternative descriptive text, and treatment option names describing all entered photos. This table was added to the administrative pane as a new tab called "Upload Recommendation Photos" (Figure 6). Existing code used to generate tables for review on the admin pane was tweaked to display the file path as an image, rather than as the text of a url ("Current Picture" in the figure below). This allows users to preview the photos that have been previously uploaded. The add/delete row mechanism seen in other pages of the admin pane was replaced by a photo upload button, which allows users to select a file from their computer for upload onto the AguaClara server. The user can additionally edit the "alt text" of the photo, which is what displays when the photo fails to load in the browser.
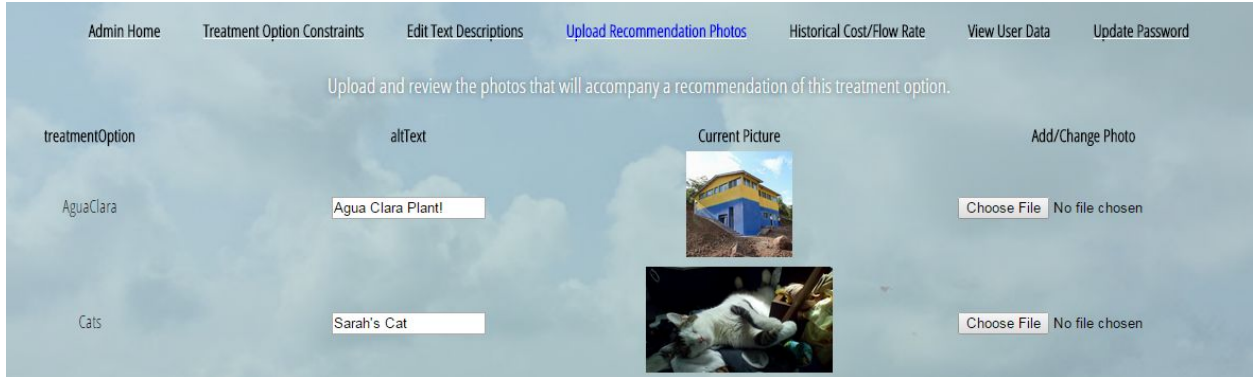
Figure 6: Uploading option photos. Testing the photo uploading feature using pictures of Sarah's cat. Alternative descriptive text may be tweaked, and photos uploaded using a file browser button.

When a user submits a version of the page to which they have added pictures using the "Choose File" tool, the uploaded pictures are transferred to the AguaClara server into a folder called Uploads, where they are renamed according to a set convention. Before transferring, photos are checked for valid file extensions and size, and the operation only proceeds if these checks are met. The newly generated file path for the photo (i.e. its location in Uploads + specific file name) is then saved in the database along with its accompanying alt text. These fields can be used to generate an image using HTML elsewhere in the tool.

Regression Parameters and Visualization

Previous incarnations of the administrative page included separate tables for displaying the regression parameters and editing the data that generates said parameters, a somewhat confusing decoupling. Thus, the tool was updated to merge the two relevant pages. This reduced the number of tabs present on the administrative pane, and further reinforced that the parameters are generated from the data.

However, these alpha and beta values in isolation are not meaningful to the average user, and are divorced from any intuition of the parameters' impact on the cost/flow rate regression equation. Viewers found it difficult to translate the parameters to the shape of the exponential distribution they determine. Thus, the team endeavored to pair the presentation of the alpha and beta parameters with a visualization of the regression equation they define.

Using d3, a JavaScript library for creating data visualizations, the team worked to generate a dynamic visualization of the graph of the plant cost/flow rate regression equation (Figure 7). This graphic interpretation of the regression makes parameter review functionality more intuitive for administrators, and reinforces the connection between updating historical data and generating a revised regression equation. This feature was added to the "Historical Cost/Flow Rate" tab of the administrative panel, which also presents the regression parameters and an editable table of historic regression data.
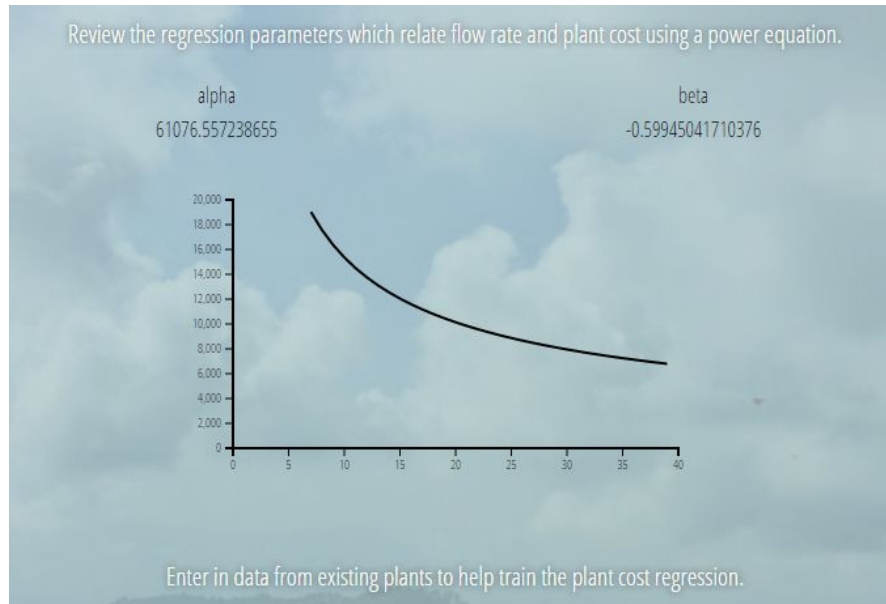
Figure 7: Regression parameter visualization. This graphical representation of the cost/flow rate regression equation is updated dynamically with the alpha and beta parameters of the database (shown above.) This figure makes it far easier to understand the relationship between cost and flowrate.

Contaminants

As mentioned in the Data Gathering section of the report, the WTTSG has been investigating new ways to operationalize the effect of contaminants on the efficacy of various treatment options. Changes include quantifying the degree of contamination for certain chemicals, as well as greatly expanding the umbrella of which contaminants are included in the tool. Previously, this list was limited to microbes, radium, uranium, fluoride, particles and organic materials, nitrates, and arsenic. The team wanted to expand this list to be more comprehensive, now including:

- Organics
- Heavy Metals
- Iron
- Arsenic
- Manganese
- Radioactive nuclides
- Calcium/Magnesium (hardness)
- Nitrates
- Fluoride
- Cyanide
- Microbes (including bacteria, viruses, Cryptosporidium, and Giardia, notably)

Redefining the list in this way had serious implications for the infrastructure of the tool. Since the previous list of contaminants had been in effect since the WTTSG's conception, it was

hardcoded into the tool in many places. With this reminder that the list of contaminants to include was likely still in flux, it was important to take time to decouple the contaminant list from the webtool's functionality. This involved several notable changes.

The first step was to get rid of every hardcoded reference to the contaminant list. This meant rewriting existing code to be scalable using PHP loops rather than defined HTML. It also meant that any references to contaminants had to be fetched from the database, so that in the future, any changes to the database would automatically populate throughout the tool, without any additional changes needed (see the updated constraints table, Figure 8).

The team accomplished this by saving the list of contaminants in the database into session variables, which are accessible to PHP on every page. For functions using JavaScript, these same session variables were passed using AJAX into an accessible array. Thus, every single static reference to the name of a constraint was removed from the code. Again, this means the contaminant list can be completely redefined and the code to display and store its values will still work. This required considerable effort to ensure data passing between the index, results, and admin pages, as well as the user data database, was still functioning correctly.

Figure 8: Contaminants. The new list of contaminants is significantly expanded, and is loaded in dynamically from the database for scalability reasons.

Next, because the team wanted to track additional information about microbe content in source water, an additional page was added to the tool. Under the paradigm of scalability, this meant creating a new database table, "microbes", in order to hold the names of the microbe options being queried. Just like the other contaminants, the list of microbes was read in from the database and saved in a session variable, as well as passed through to the JavaScript side of the website using AJAX. A new page was created to allow users to select which microbes are a problem in their source water using checkboxes (Figure 9a). The results page's editing dropdown menu also had to be updated to allow users to revise their choices as they review them (Figure 9b). This meant accommodating an additional line for microbe data in the menu, as well as rewriting the JavaScript generating editable checkboxes to include microbes as well. Finally, microbes were also added as editable fields to the constraints page in the admin pane.
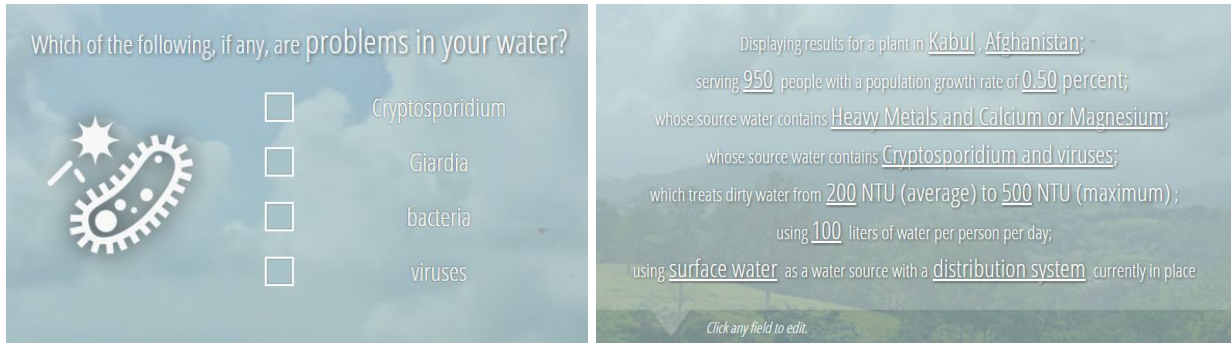
Figures 9a (left) and 9b (right): Microbes. Users are probed about whether their source water contains Cryptosporidium, Giardia, bacteria, or viruses. This was also added as a new line on the dynamic editing menu on the results page, which allows users to see how editing their inputs will change their treatment recommendation without backtracking through the entire tool.

Another paradigm change regarding the contaminants was that some fields should depend upon numerical values (i.e. concentration levels) instead of Boolean ones. This required a way to distinguish these contaminants from one another in the database while maintaining scalability in assigning constraints to the different value conditions.

Thus, the team created another table in the database to hold the names of those treatment options which would require numerical information. This can be used to display the options differently across separate pages in future weeks. Changes to which contaminants are included are made easily through a checkbox input form in the constraints admin page (Figure 10). This adds and subtracts inputs to the table as necessary.
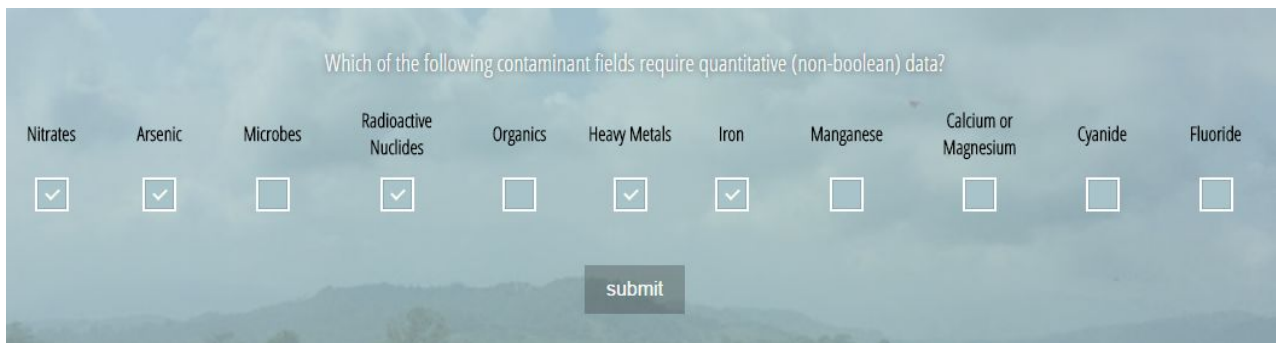

Figure 10: Non-boolean values. This tool on the admin pane allows contaminants to be easily associated with whether they should include boolean or non-boolean (i.e. numerical constraint) values.

With the requirement for boolean/non-boolean data now easily toggleable, an input form needed to be created on the user's side so that they could enter float concentration values in places they were required. In order to avoid overwhelming the user, the team decided to hide the input boxes for any options the user had not selected. This would allow users to spend less time filling out the page, allowing them to focus on only what they needed to (Figure 11).

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This functionality was implemented by first partitioning the contaminants into boolean and nonboolean portions for display on separate pages. For the nonboolean options, Javascript was added to hide the input boxes on load, and selectively make them reappear/disappear upon the checking/unchecking of the corresponding checkbox. This functionality also had to be integrated with session variable code remembering previous user input--anything saved in the user's session would have to be checked, the checkbox made visible, and the saved concentration value populated in the checkbox. Data passing between pages of the tool was implemented with PHP session variables, as well as AJAX to transmit inputs to the Javascript of the results page. Several edits were made to the infrastructure of the tool to support this change, including changes to the results page which ultimately logs user data for review.

Figure 11: Non-boolean values input concentration. When a contaminant is selected, an input box appears for the user to input their concentration in mg/L. The corresponding is-checked/input value pair is saved in a session variable to be input into the database.

Documentation

Finally, since it is important that the codebase of the WTTSG be understandable to future developers, great effort was paid to improve the documentation of the tool. This involved breaking some sections of code into separate files, such as a new JavaScript file for the edit menu feature on the results page, and breaking other pieces of code into smaller, more legible functions. Where code had previously been left loose, it was compartmentalized into functions, complete with detailed specifications. Extensive comments were added, including in-line descriptions of functionality, explanations of where to find relevant other sources of code, and function/page specifications. Ideally, the improvements in the documentation of the tool will allow incoming developers to have a much shorter onboarding time familiarizing themselves with the codebase.

Conclusions

This semester, the team made strides in implementing new functionalities for the results and administrative pages of the WTTSG, working to facilitate data passing to the MySQL database so that user-inputs can be easily retrieved for sharing and review. Infrastructure continues to be put into place so every aspect of the recommendation logic is scalable, from the treatment option constraints to the descriptive recommendation text to the inclusion of accompanying photos. Progress has also been made in making the website more usable and making the functionality of the administrative pane more apparent.

The team has also made progress in the realm of data collection, doing the groundwork required to obtain data from corporations, researchers, and other knowledgeable parties in the water treatment field. By conceptualizing a structure for the data and logic of the site, future teams have been better positioned to fill in the gaps in decision logic.

This semester, the team made the notable decision to explore only AguaClara technologies in providing treatment option recommendations. The implications of this should continue to be explored to ensure that high-quality, accurate, and substantiated recommendations may be provided. In the meantime, this decision has positioned the team to provide a better-focused recommendation, tailoring the tool to data that is actually available.

Future Work

Information regarding the AguaClara technologies and their limitations should be continued to be gathered to allow for the website to be able to provide better decisions on whether AguaClara is a sensible solution for each user's water quality needs. This will involve discussion with people familiar with AguaClara's Foam Filtration and Enclosed Stacked Rapid Sand Filters (EStaRs), as well as confirmation information and any new data available for the traditional AguaClara technologies. Furthermore, attention must be paid to ensure all information is properly cited, so users will trust the tool.

Once this information has been obtained, both decision logic parameters and explanatory text features must be stored in an accessible place; thought should be paid to conceptualizing a structure to hold all of this accompanying information. Furthermore, attention must be paid to ensure all information is properly cited, so users will trust the tool.

The team will continue to work to add a variety of functionality-enhancing features to the site, including options that make the contaminants included in the tool easily editable. Further work should also be done to integrate the photo upload feature into the content-production pipeline of the results page, along with the explanatory text of the option_text database. This will function in coordination with the recommendation logic, which also must be implemented.

A variety of outstanding bugs have been identified but still need to be addressed. These are referenced at various points in the code as comments for future developers. For example, the delete/add functionality on constraints page currently affects both constraints and microbes

tables, due to the name collision between the submission buttons for the two forms. Work must be done to separate these tables. Additionally, the results page edit menu does not yet accommodate the boolean/non boolean distinction made by the constraints pages of the tool. Thus it is currently impossible to edit user input about these values. Finally, for the index page, clicking on a turbidity picture twice unselects it in code but not in graphic design, and the population slider has some small inconsistencies as the user repeatedly travels back and forth across its page; there are errors in its value calculation. These bugs must all be addressed so that the page can function reliably.

Future teams must engage in user testing, showing the site to engineers from organizations like APP and other AguaClara partners to get authentic feedback. Once the tool is capable of providing convincing recommendations, it will be useful to share so that we can accumulate/distribute feedback.

The WTTSG could also consider providing recommendations based on the unit process(es) of water treatment. This prospect has been previously discussed with Monroe Weber-Shirk and Tom Grubb of Muerer Research. For example, AguaClara plants and conventional package plants could both be categorized by their constituent unit process of sedimentation, flocculation, and filtration. However, there are notable differences in performance across technologies, which makes generalizing by process challenging. Accordingly, unit processes could be treated as subcategories of various treatment technologies, so long as information could be provided for them under the unit process with their respective constraints. The feasibility of this categorization should be explored.

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