Incorporation of Sustainability in the Senior Design Project: a Multimedia Water Filtration System

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Abstract
Sustainability is an important topic in engineering education. It requires conservation of the natural resources and energy, while minimization of the impacts of a product or a system to the natural environment to a level within the nature's self-sustaining capacity. In typical classroom teaching, students have rare chances to practice the concept of sustainability. However, the capstone projects for senior engineering students provide a valuable opportunity for them to utilize and to practice the concept in a system or in a technological design, build and evaluation. In this paper, a group of Civil Engineering students designed, built and tested a chemical-free multimedia filtration system to treat the St Joseph River water for clean water supply. Small-scaled water treatment systems are important supplements to centralized drinking water supply, because of their minimal or even no chemical usage, low start-up and operation costs, high mobility, and the ability to be built economically to meet different water quality requirements. All these characters fit the requirements of sustainable development. The system utilized natural gravel and sand as the filter media. There were four filtration columns with the first three filled with gross, medium, and fine gravels, respectively; while the last column was a slow sand filter (SSF) filled with fine sand with diameter of 0.2-0.3 mm. The multimedia filtration system was tested by feeding the raw St. Joseph River water to the system continuously at the filtration rate of 0.15-0.25 m/hr. The average turbidity removal rate of the system was 95.5%, which is comparable to coagulation, flocculation, and sedimentation together, the conventional drinking water treatment processes. After completion of the project, the students better understood the concept and the principles of sustainability in engineering design and system evaluation.

1. Introduction

Population growth and economic development have been exerting more and more pressure on the natural resources and the environment. Consequently, sustainability is an important content of modern engineering education to support the harmony and prosperity of the society. Sustainability requires the conservation of environmental resources such as clean air, water, forests and soils; maintaining genetic diversity; and using energy, water and raw materials efficiently. [1] The concept of sustainability needs to be incorporated from the phase of a product or a system design to its final disposal. Accordingly, the needs of sustainability education are addressed in ABET outcomes (h) and (j) in its Engineering Accreditation program (ABET Engineering Accreditation Commission, 2007). These outcomes are (h) "the broad education necessary to understand the impact of engineering solutions in a global and societal context" and (j) "a knowledge of contemporary issues".[2]

In typical classroom teaching, students have rare chances to practice the concept of sustainability. However, the capstone projects for senior engineering students provide a valuable opportunity for them to utilize and to practice the concept in a system or in a technological design, build and evaluation. In water and wastewater treatment area, sustainability requires less chemical usage, smaller footprint, less power consumption, less waste especially hazardous waste generation, preference of sustainable water resources over non-rechargeable groundwater, and tired-use of water based on different water quality requirements. Figure 1 shows the flow chart of the typical senior design processes in the Department of Engineering, Indiana University-Purdue University Fort Wayne.

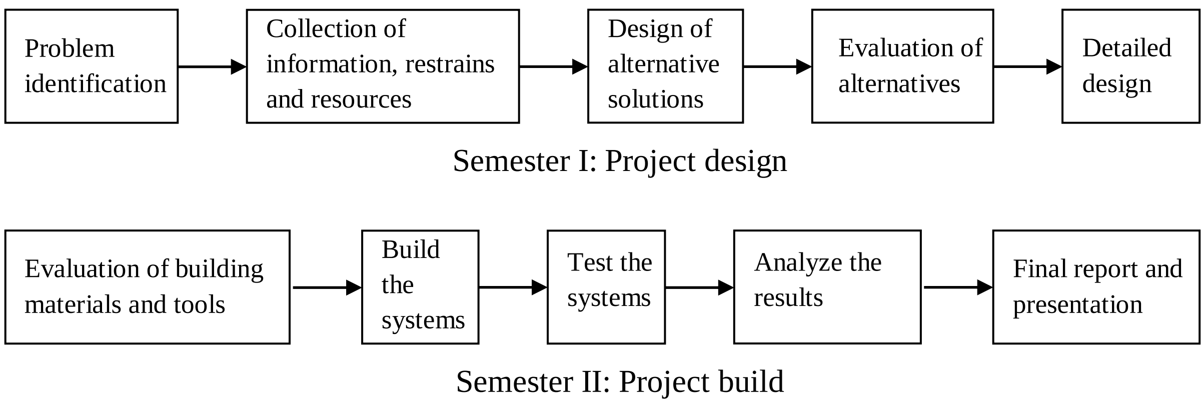

Figure 1. The flow chart of a typical senior design project.

2. Project of decentralized water treatment

The objective for this project was to provide a small-scaled decentralized water treatment system in a sustainable manner. Small-scaled water treatment systems are important supplements to centralized drinking water supply, because of their potentially minimal or even no chemical usage, low start-up and operation costs, high mobility, and the ability to be built economically to meet different water quality requirements. When centralized water treatment systems are affected by natural disasters like hurricanes or earthquakes, the decentralized systems can be deployed to the disaster suffering areas to provide clean water. All these characters fit the requirements of sustainable development. In this project, the St Joseph River water was selected as the raw water to be treated, because it is a renewable resource instead of a non-renewable one like a confined aquifer. However, river waters are directly affected by human activities and ground pollutions. The waters containing suspended and colloidal particles and dissolved contaminants normally require extensive treatment processes. In order to provide deep purification of the river water, multiple treatment stages are highly desirable. Through extensive studies, the following three technical alternatives were selected to treat the St. Joseph River water to provide clean water supply.

Alternative (i): riverbank filtration
Alternative (ii): gross-media filtration + slow sand filtration (i.e., multimedia filtration)
Alternative (iii): coagulation + flocculation + sedimentation

The alternative (i) riverbank filtration is a water treatment and collection system adjacent to a river. It utilizes the natural soil media in the riverbank to remove contaminants from the river water. The soil particles can reject the suspended and colloidal inorganic and organic particles in the river water through steric exclusion. The rejected organic particles serve as food sources for microbial growth and promote microbial decontamination of the water. Both filtration and microbiological degradation contribute to the purification mechanisms of water. However, the feasibility of river bank filtration highly depends on the porosity and the permeability of the soils. It would be ideal if shallow aquifers are available, which directly connect to the river through the river bank or the river bed.

The alternative (ii) gross-media filtration + slow sand filtration (SSF) (i.e., multimedia filtration) involves physical chemical and microbiological treatment mechanisms. Gross media filtration works as the pretreatment stages for the SSF to prevent clogging of the filtration system and to increase the removal capacity of particulate and dissolved contaminants. The size of the filter media decreased along the process of water treatment. The filtration operates by letting water slowly percolate through a series of porous filtration columns or beds filled with from gross gravels to fine sand by gravity flow. For the SSF, the water flows slowly from the top to the bottom, where most of the particulate matters were removed by the top layer of the SSF. The retained particulate matters further enhance the steric exclusion effect by providing smaller spaces among the particles for water to pass through. The rejected organic matters on the top layer stimulate microbial growth and thus enable microbiological degradation of the organic contaminants in the water. Similar to river bank filtration, SSF is an engineering system to treat water on- or offsite. SSF can serve as an alternative solution when river bank filtration is not feasible due to poor soil permeability.

The alternative (iii) coagulation + flocculation + sedimentation are conventional treatment processes, which are widely adopted by modern centralized drinking water treatment plants. The suspended and colloidal particles as well as dissolved organic matters have been in the river water for long time as a stable dispersion system. These contaminants bear negative charge typically. The charge repulsion keeps them suspended in water and prevents from attaching to each other. Coagulation is the addition of chemicals, also known as coagulants such as aluminum sulfate and ferric chloride, to the water that have opposite charges to that of the contaminants in the water. As a result, the coagulants and contaminants can grow together to form big flocs through the mechanisms of double-layer compression, surface charge neutralization, and adsorption and interparticle bridging.[3] The flocs continuously grow bigger and bigger in the flocculation process, which is facilitated by a slow mixing. Consequently the flocs are ready to settle to the bottom of the tank during the sedimentation process and thus being removed from the water.

The students had investigated the soil profiles through soil boring reports of more than 10 different sites along the St. Joseph River near the campus of Indiana University-Purdue University Fort Wayne. Unfortunately, the dominant soil type along the St Joseph River is clay, which has very low permeability. In addition, no apparent shallow aquifer in this region was found either. As a result, the option of river bank filtration was unlikely feasible for this project. Therefore, the alternative (ii) multimedia filtration vs. the alternative (iii) coagulation +

flocculation + sedimentation were compared with respected to sustainability and purification efficiency.

Table 1 shows the comparison of major aspects of sustainability between the alternatives (ii) and (iii). As can be seen, the alternative (ii) multimedia filtration better fits the characteristics of sustainability than the alternative (iii) coagulation + flocculation + sedimentation in 5 out of 6 aspects including chemical consumption, waste generation, power consumption, easy operation/maintenance, and small footprint. The alternative (iii) only has a higher treatment capacity than the alternative (ii). If the same weight is assigned to each of the 6 aspects, obviously multimedia filtration should be the choice of sustainability for the design and build of the project.

Table 1. Comparison of the sustainability between the alternative (ii) multimedia filtration and the alternative (iii) coagulation/ flocculation/sedimentation

Criteria of sustainability	**Chemical consumption**	**Waste generation**	**Power consumption**	**Easy operation/ maintenance**	**Small footprint**	**Treatment capacity**
Multimedia filtration	none	a little	a little	yes	yes	low
Coagulation/ flocculation/ sedimentation	yes	yes	moderate	moderate	no	high

3. Design of the decentralized multimedia filtration system

Table 2 lists the key design parameters of the alternative (ii) multimedia filtration system. All of the filtration media are natural gravels and fine sand. Choosing natural materials for the treatment units can reduce carbon footprint and energy consumption in the manufacturing processes than synthetic materials. The designed filtration rate was 0.15-0.25 m/hr, which produced about 15.9-26.6 gallons of clean water per day. In addition, Carmen-Kozeny equation was used to calculate the headloss of each filter column at the designed filtration rate.[4]

Table 2. Designed parameters of the multimedia filtration system

	Pretreatment Column 1	**Pretreatment Column 2**	**Pretreatment Column 3**	**SSF**	**Filtration rate (m/hr)**
Size of the filter media	9.5-15.9 mm gravel	6.4-12.7 mm gravel	3.2-6.4 mm gravel	0.2-0.3 mm sand	0.15-0.25
Dimension of the column	4.25 in diameter 2.5 ft height	4.25 in diameter 2.5 ft height	4.25 in diameter 2.5 ft height	5.75 in diameter 3.0 ft height	

4. Build and test the decentralized multimedia filtration system

Figure 2 shows the finally built multimedia filtration system, which is composed of three roughing filters (i.e., column 1-3) as the pre-treatment stages preceding the SSF. The columns for the SSF and the roughing filters were composed of acrylic. The three roughing filter cylinders had an overall height of three feet with 2.5 feet of the columns containing different sized gravels. The SSF cylinder was composed of two three-foot sections of extruded acrylic that were held in place by a rubber pipe coupling. Both the roughing filters and the SSF had an acrylic base attached to the bottom of the columns. The hose connecting the filters together was 3/8” I.D. clear plastic. The flow control valves were used to control the filtration rate through each filter column.

Figure 2. The built multimedia filtration system. The raw river water was stored in the plastic container at the top of the shelf to feed the system by gravity flow. The unit of the dimension is in foot.

After the system had been built, the raw St Joseph River water was fed to the system through the elevated tank by gravity flow. The performance of the system was evaluated by measuring the turbidity (which reflects the cloudiness of water) and UV-Vis absorbance at the wavelength at 254, 280, and 400 nm, respectively of the water before and after the treatment. Cleaner water has lower turbidity and lower UV-Vis absorbance values. In addition, the purification efficiency of the multimedia filtration system was compared to the alternative (iii) coagulation + flocculation + sedimentation process, which was investigated by doing jar tests with dosing the coagulant of aluminum sulfate or ferric chloride. As illustrated in Figure 3 and Table 3, the multimedia filtration (i.e., SSF) system had comparable finished water quality in both turbidity and UV-Vis absorbance with the processes of coagulation + flocculation + sedimentation, the conventional treatment method adopted in centralized modern drinking water treatment plants. In other words, the alternative (ii) multimedia filtration process produced similar quality of the product water as the conventional treatment method while having the significant advantages of sustainability as shown in Table 1, including chemical-free, low power consumption, composing of natural materials, a little waste generation, easy maintenance and small footprint. This system can be served as an important supplement to the centralized drinking water treatment facilities.

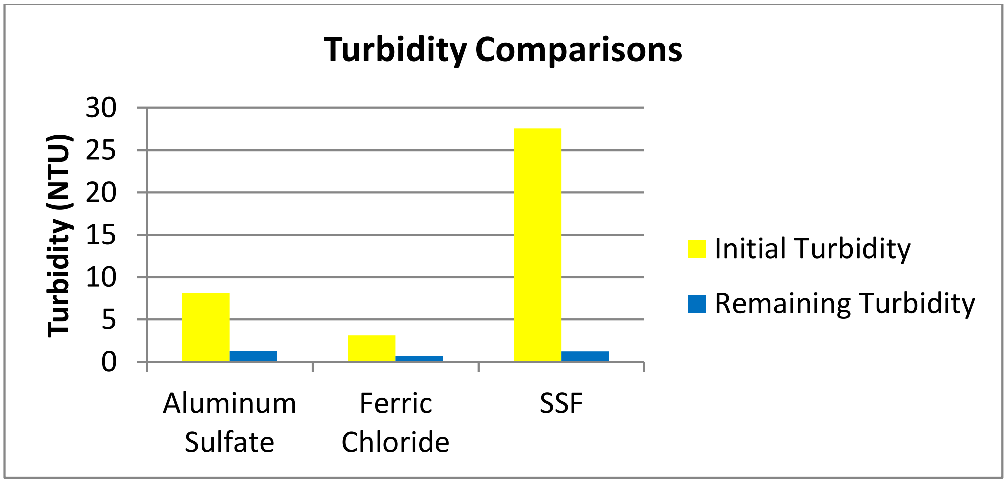

Figure 3: Comparison of turbidity removal among the alternative (ii) SSF and the alternative (iii) coagulation + flocculation + sedimentation with the best coagulant dosage of aluminum sulfate (50 mg/L) or ferric chloride (30 mg/L). The initial turbidity was of the raw river water before treatment. The remaining turbidity was of the treated water.

Table 3. Comparison of the purification efficiency in turbidity and UV-Vis absorbance between the alternatives (ii) and (iii)

Alternatives		**Remaining turbidity (NTU)**	**Turbidity removal rate (%)**	**Remaining UV-Vis absorbance**		
				254 nm	**280 nm**	**400 nm**
coagulation/ flocculation/ sedimentation	Aluminum sulfate	1.36	83.7	0.081	0.056	0.006
	Ferric chloride	0.68	78.3	0.119	0.092	0.015
Multimedia filtration		1.49	94.6	0.120	0.088	0.015

5. Conclusions

The capstone project for senior engineering students provided a valuable opportunity for them to utilize and to practice the concept of sustainability in a system or a technological design, build and evaluation. In this project, a group of Civil Engineering students designed, built and tested a chemical-free multimedia filtration system to treat the St Joseph River water for clean water supply. Small-scaled water treatment systems are important supplements to the centralized drinking water supply, because of their minimal or even no chemical usage, utilizing natural filter media, low energy consumption, small footprint, high mobility, little waste generation, and the ability to be built economically to meet different requirements of water quality. All these characters fit the requirements of sustainable development. The multimedia filtration system including SSF was tested by feeding the raw St. Joseph River water to the system continuously at the filtration rate of 0.15-0.25 m/hr. The average turbidity and UV-Vis absorbance removal rates were comparable to the conventional centralized drinking water treatment methods including coagulation, flocculation, and sedimentation processes together. Certainly the multimedia filtration system has more significant characteristics of sustainability than conventional water treatment processes. After completion of the project, the students better understood the concept and the principles of sustainability in engineering design and system evaluation.

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