Design Report:
Filtration Pond for Decontamination of Irrigation Water and Farm Production Efficiency & Sustainability in the Treasure Valley

[redacted]

March 3rd 2014

EXECUTIVE SUMMARY

Proposed water quality regulations by the Food and Drug Administration (FDA) have created a need for farmers in Oregon's Treasure Valley to decontaminate their irrigation water prior to field application. The regulations would establish minimum standards for the concentration of *Escherichia coli* (*E. coli*) in irrigation water that is applied to crops that can be consumed raw. Proposed standards for irrigation water limit the maximum concentration of *E. coli* to under 235 colony-forming units (CFU) in any single 100 milliliter sample, or a rolling geometric mean (n=5 samples) of no more than 126 CFU per 100 milliliter sample [*Food and Drug Administration*, 2013]. Currently, water in irrigation canals is not compliant with these standards, as found by the Warmsprings Irrigation District 2011 Water Quality Sampling Results [*Hammond and Finnerty*, 2013]. The contamination is due primarily to surface runoff from pasture fields, creating a non-point source pollution system that forces farmers to develop compatible on-site treatment mechanisms.

To decide on the most suitable treatment technology, the team approached the problem by emphasizing the potential for a treatment technology to improve the production and sustainability of the farm as a system, specifically in furrow-irrigated farms. Approximately 50% of onion production in the Treasure Valley is irrigated with furrow systems. The team drafted a representative farm with five 30-acre fields in annual crop rotation with one growing onions per year. As a means of analyzing treatment systems, a set of minimum criteria were developed that focused on the technical ability, economic viability, compatibility with farm practices, and ability for the technology to improve the efficiency of production and sustainability of the farm. Multiple technologies were assessed; including chlorination, ozonation, ultraviolet radiation, zero-valent iron, and a filtration pond. The team pursued the filtration pond design using native soil as the filter, because it best incorporated the ideals of the design approach and met all design criteria.

Soils have a natural ability to retain and eliminate pathogens by physical, chemical, and biological processes. The team used these intrinsic properties as the basis of our design. Studies have shown between 1 to 6 log reductions in fecal coliform by filtration through soil media. A small-scale simulation conducted at the Malheur Experiment Station in Ontario, Oregon, was studied to gain a better understanding of the relationship between surface area, hydraulic conductivity, and flow rate through the soil column. From the findings of this study, and the teams technical calculations, it was estimated that a 1.5-acre pond filter area would be sufficient to provide the treatment capacity and satisfy a 900 gallons/minute flow requirement for furrow irrigation on a 30-acre field of onions. The filtration pond will be placed at or near the lowest point on the farm to allow for recovery of tailwater runoff from the five fields in addition to water filtration for the onion field. This placement allows the pond to connect the field outputs of water, sediment and nutrients from runoff back to the crops. Overall, this improves the efficiency and sustainability of the farm as a system by reusing inputs to crop production and retaining non-renewable resources on the farm.

In regards to the filter design, the pond consisted of a 12-in. layer of native Owyhee silt-loam soil for primary treatment, a 6-in. layer of sand to act as a foundation layer for the soil, landscape fabric to prevent the movement of sand, and a 6-in. layer of gravel for drainage. Drain tile was be placed under the gravel layer to direct water to an exit point. An estimated excavation depth of 10 ft. is proposed for the

pond to allow for sufficient head to meet the flow requirements.

By collecting tailwater from all 5 fields, the pond was estimated to collect 0.44 acre-ft (1500 tons) of sediment per year based on an erosion rate of 10 tons/acre-yr. It was estimate that the pond would collect 6800 lbs of Phosphorus fertilizer, based on the eroded sediment carrying 0.1% phosphorus. At $0.57/lb this totals a value of $3900 per year.

Total cost is estimated between $34,000 and $130,000, corresponding to a $0 to $400/acre annualized cost over a 30 yr design life. Estimates showed that initial excavation of the pond comprised a substantial amount of the overall cost, ranging from $10,000- $85,000. Using the excavated material to create berms was considered as a way of decreasing the required excavated volume while keeping the effective volume the same, but came at the expense of more than doubling the land use required, and the construction costs to build the berms was not likely to provide significant savings over excavating the full 10 ft. Pipe costs are expected to be about $14,000 due to the length of pipe required to reach the furthest field but is variable dependent on field configuration and farm layout. A large cost-savings is made from the collection and reuse of phosphorous entrained in eroded sediment, which showed an annual savings of $3900. If the capital and annual costs are at or near expected values, the total cost to the farm to install the pond will be around $130 per acre-year over a 30-year design life. A reduction in the excavation cost and/or length of pipe would reduce the cost associated with the filtration pond and possibly increase the attractiveness of the system as a viable water treatment method for onion growers in Treasure Valley.

Given that the additional benefits to water savings, fertilizer savings, erosion control, water quality, and sustainability are important issues, this filtration pond system design is worth pursuing further to asses the suitability of the design to a particular farm.

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1.0 INTRODUCTION

1.1 Background

The Food & Drug Administration has proposed standards for the bacterial concentration of irrigation water that is applied to raw-edible food crops [*Food and Drug Administration*, 2013]. These regulations limit the concentration of generic *Escherichia coli (E. coli)* to not exceed 235 colony forming units (CFU) per 100 ml of water for any sample or a rolling geometric mean (n=5 samples) of more than 126 CFU per 100ml [*Food and Drug Administration*, 2013]. If this regulation is passed as written, it would have a far-reaching impact on the onion growers of Oregon and Idaho's Treasure Valley. Water in the valley's irrigation canals has been found to be noncompliant with the proposed standards. Data from the Warmsprings Irrigation District 2011 Water Quality Sampling Results showed 30% of the samples exceeding 2000 CFU/100 mL with a maximum value of 13,200 CFU/100 mL[*Hammond and Finnerty*, 2013]. Contamination is primarily introduced to irrigation water via runoff of manure that is applied to cropland throughout the region. The irrigation canals and districts are interconnected with runoff from one user becoming irrigation water for the next user downstream. This non-point source contamination and complex canal network prevents a centralized treatment solution from being feasible.

The Treasure Valley is comprised of 4.7 million acres of farmland of which one quarter is in cropland [*United States Department of Agriculture*, 2009]. The valley lies within several counties on the border of Oregon and Idaho (Figure 2), including Malheur County, the southeastern most in Oregon. Malheur County is the number one producer of onions in the United States, which are primarily grown in the Treasure Valley [*Mansour*, 1999; *United States Department of Agriculture*, 2009].

Figure 1. The location of the Treasure Valley between Oregon and Idaho with its extent circled in red.

Figure 2. This photo shows the green irrigated fields of the valley, as well as Malheur County to the west of the dashed border, July 2012 [Google Earth, 2012].

1.2 Problem Statement

Considering that contamination originates diffusely in the basin and is conveyed throughout the canals, growers cannot be certain of the quality of water entering their farm. Therefore, each grower must be able to treat their irrigation water to the proposed standards in a way that is compatible with existing irrigation practices, infrastructure and crop rotation. Based on the Warmsprings Irrigation District report, a 2.0 log reduction is required to treat the maximum value reported of 13,200 to 126 CFU/100mL[*Hammond and Finnerty*, 2013].

Growers in the region commonly rotate onions every five years to avoid crop disease, so a treatment system must be compatible with this pattern. In addition, the seasonal market price of onions can prohibit onion production from being profitable in a given year. This stresses the need for solutions with relatively low start-up and operation costs.

Historically, water quality of irrigation runoff has been a concern in the region due to the impact of high concentrations of suspended solids, nitrate and potassium on drinking water quality and wildlife[*Foley et al.*, 2012; *Hammond and Finnerty*, 2013]**.** Priority was given to solutions that will allow growers to meet the FDA standards, are compatible with farm practices & economics, and that can improve runoff water quality.

1.3 Report Focus

This report details the design of a filtration pond with tailwater collection to meet the requirements of a representative farm, as well as the benefits this system provides to production efficiency and sustainability of the farm. This design addresses the sizing, cost, and materials required for the major components, as well as the associated economics, environmental impacts, and social impacts. As such, it addresses the main design considerations, but does not address all of the detail that would be needed for implementation. Aspects that need to be further addressed are described in the Discussion. Design calculations are provided in the Appendices.

As a foundation for the design, the report describes the representative farm, the team's approach to the problem, and the criteria used for designing the pond & alternative treatment technologies. This report also summarizes the evaluation of other treatment technologies that were considered and the reasons they were not ultimately chosen.

1.4 Representative Farm & Practices

The information used for modeling the representative farm was gathered from conversations with Dr. Clint Shock, Director of and Professor at the Malheur Experiment Station, the Web Soil Survey, and The Bureau of Reclamation[*USDA*, 2009; *US Bureau of Reclamation*, 2013]. The specifications, team decisions and assumptions that had the most influence on the model are stated below, with further detail provided in Appendix A.

Based on conversations with Dr. Shock, onion fields averaged from 10-40 acres in size and utilize a 5 crop rotation, commonly of onions, alfalfa, sugar beets, potatoes and field corn. About half of the onions in the region are irrigated using furrow systems, while the other half use drip irrigation. The representative farm consisted of five 30-acre fields that were annually growing these crops using furrow irrigation. 30-acre fields were chosen by the team to represent a rotation of average to large field sizes.

The field layout pictured in Figure 3 was assumed as a worst case scenario in term of the distance water would need to be conveyed to the furthest field and to simplify the movement of headwater and tailwater to the pond. This model also assumes that the grower is carrying out a five year crop rotation within these contiguous fields.

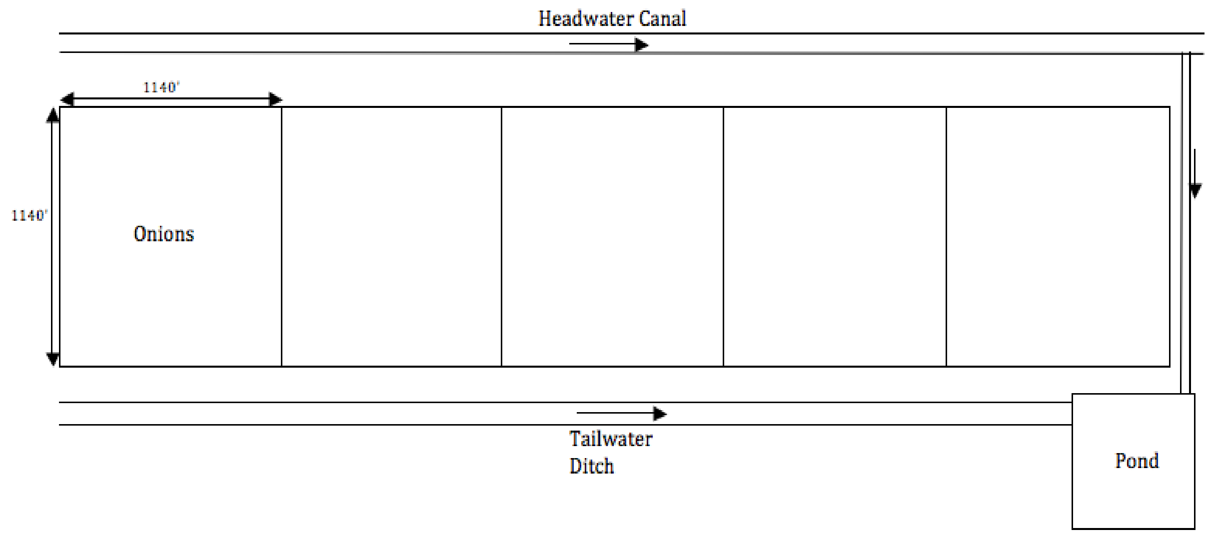


Figure 3. Schematic of field layout with filtration pond and tailwater collection (not to scale)

An important feature of the design is the collection of tailwater to be filtered for onion irrigation. For simplifying the design at this stage, it was assumed that all crops had the same irrigation season. Therefore all crops could provide tailwater flow during onion irrigation. To check the validity of this assumption, the seasonality of tailwater flow from each crop was inferred from 2013 crop evapotranspiration (ETc) dates from the Agrimet station in Ontario, OR (see Table 1). The team considered this a reasonable assumption, because 34 out of 142 days of onion ET have 4 crops being irrigated.

	Onion 2	Alfalfa Mean	Beet	Potato 2	Field Corn
ETc season (month.day)	4.1 - 8.20	3.15 - 10.10	4.10- 9.30	5.5 - 9.10	5.1 - 8.20
Time crop is not providing tailwater [days]	0	0	9	34	30
Seasonal ET during onion ET [in.]	35	38	32	30	28

Table 1: 2013 Seasonal timing of crop ETc based on published values from Agrimet [*US Bureau of Reclamation*, 2013]

In regards to the irrigation demand from each crop, it was assumed that all fields would have the same seasonal water needs. Table 1 shows the seasonal ET by crop, which are all about 30 inches.

In regards to the runoff from each crop, it was assumed that all fields would have the same runoff as a proportion of water applied. In their article, Bjorneberg et al. estimated that 20% of water applied in furrow irrigation is runoff [*Bjorneberg et al.*, 2002]. The design team used this value to determine that the pond could collect 5 tailwaters (see appendix D-c).

Based on Web Soil Survey soil maps, Owyhee silt loam was chosen as a representative topsoil for the central Treasure Valley between Vale, OR and Ontario, OR.

1.5 Design Approach

Compared to the costs of farm equipment and operations, this project represents a substantial infrastructure addition and investment for growers. In addition, this is an upgrade to the water system where each gallon of water must be collected, processed, and then conveyed to the field. Many growers consider water to be the most important input to a farm, because it translates the initial costs put into the fields to crop growth and eventual harvest. Considering that water conducts necessary functions on the farm and that the project is a significant investment in water processing, the team asked- can we design a system that decontaminates water while also improving the efficiency and sustainability of the farm? This question informed the approach the team took evaluating potential technologies and designing the pond with tailwater collection. The resulting design did require additional complexity and initial investment compared to simply filtering the irrigation water, but overall this system has the potential to be a net economic gain, especially when all externalities are considered, and enables the farm to retain non-renewable soil and nutrients.

1.6 Criteria

The criteria that were prioritized were the system's technical ability at meeting the water quality standards and providing sufficient water quantity, economic viability for growers, compatibility with existing farm practices & infrastructure, and ability for the technology to improve the efficiency of production and sustainability of the farm. The criteria are listed below in the order that they were prioritized for selecting a technology.

- Technical treatment ability
    - Treats 900 gpm (see Appendix C) to water quality standards while operating under maximum sediment accumulation from one year of tailwater collection (see Appendix E)
    - Can supply water to furthest field from the pond
- Economic viability (see Economics section)
    - Costs less than $150/acre-yr over design life
- Compatible with existing canal infrastructure
- Minimizes land use
- Improves the resource use efficiency and sustainability of the farm by conserving water, soil, and phosphorus fertilizer

2.0 TREATMENT ALTERNATIVES

Five treatment options were investigated: chlorination, ozonation, ultraviolet radiation, zero-valent iron particles, and filtration ponds. To accurately compare these alternatives, the team looked at the technical aspects of each system, how compatible each alternative was with current farming practices, economic cost and profitability, as well as any farm system benefits each method could provide.

2.1 Chlorination

The process of chlorinating contaminated irrigation water prior to application is practiced in the Treasure Valley. Chlorine reacts with water and forms hypochlorous acid, which serves as the disinfecting agent

[*Lazarova et al.*, 1999]. The main concern with a chlorination treatment is the potential for disinfection by-products (DBPs) to form, and the maintenance involved in monitoring and removing them [*Lazarova et al.*, 1999]. Residual chlorine is often a major source of acute toxicity in chlorinated effluents [*Lazarova et al.*, 1999]. Additional measures are sometimes needed to assure that residual chlorine levels are at an acceptable level to minimize the formation of DBPs. Aside from being a familiar treatment method to many farmers, chlorination provides minimal benefits to the farm as a whole, and with the risk of forming DBPs in the environment, it was determined to be insufficient in meeting our selection standards.

2.2 Ultraviolet Radiation

An ultraviolet (UV) system functions by passing contaminated water over ultraviolet light bulbs. The radiation generated by the bulbs penetrates the cell wall of microbes and damages the genetic material, rendering the cell unable to reproduce [*Clarke and Bettin*, 2006]. UV treatment benefits from the absence of chemical inputs and has a minimal ecological footprint aside from the power requirements. However, the reliability and maintenance demands of a UV system were a concern. Bulbs burn out and periodically need to be replaced and are also subject to sediment buildup on the surface of the bulb, requiring frequent monitoring and cleaning to maintain system efficacy [*Clarke and Bettin*, 2006]. Given the maintenance and energy demands of a UV system, it was dismissed from further consideration.

2.3 Ozonation

Ozone is produced when an oxygen molecule is dissociated into individual oxygen atoms. These oxygen atoms then react with an oxygen molecule to produce ozone. Ozonation is the process of ozone molecules oxidizing bacterial membranes[*Office of Water*, 1999]. Ozone molecules are highly unstable and must be generated on site [*Langlais et al.*, 1991]. A feed gas source is also needed to supply the oxygen. This leads to a complex system of processes that demand large amounts of energy for effective decontamination. In addition, an ozonation system has little potential to improve the efficiency and sustainability of the farm. The ozonation treatment system does not meet our criteria because of the complexity of the equipment, high energy demand, and lack of potential farm benefits.

2.4 Zero-valent Iron

Zero Valent Iron (ZVI) is the elemental form of iron with zero electric charge. This allows it to reliably and effectively inactivate water-soluble minerals and waterborne contaminants by the process of oxidation-reduction [*US EPA*, 2012]. ZVI has been used extensively in groundwater [*Cundy et al.*, 2008].

Preliminary lab studies have shown that it is effective at removing bacteria, including *E. coli* [*Cundy et al.*, 2008]. However, studies on the effects on bacteria are limited and it remains unclear if a ZVI system could be applied to an irrigation water treatment system. A lack of supporting evidence results in a lack of confidence in this treatment method for irrigation water.

2.5 Filtration Pond

A filtration pond best supported all selection criteria and incorporated the ideals of the group's design approach. This system is an "appropriate technology" for solving the problem in a farm setting. Appropriate technologies stress small-scale, decentralized, energy-efficient, and environmentally sound solutions that utilize local resources while still meeting design requirements. Filtration ponds can also provide additional benefits to the whole farm. Ponds can be located as to capture and recycle excess irrigation runoff and can reduce nutrient loading and soil erosion. A filtration pond can be utilized to not only filter irrigation water but can improve the efficiency and sustainability of the farm by better using resources.

3.0 FILTRATION POND SYSTEM

3.1 Treatment Mechanisms

Filtration ponds are based on the natural ability of soils to physically retain and chemically & biologically breakdown fecal pathogens. These systems have shown a significant ability to remove fecal coliform with efficiencies ranging from 1 to 6-log [*Guessab et al.*, 1993; *Castillo et al.*, 2001; *Ross and Shock*, 2013]. The primary microbial removal and retention mechanisms in these systems are straining and adsorption [*Kristian Stevik et al.*, 2004]. Some of the factors in elimination are moisture content, pH, temperature, organic matter content and the microbial community present in the filtration media [*Kristian Stevik et al.*, 2004]. Straining of *E.coli* refers to the capture of microbes in pores smaller than 1 μm, while adsorption is the binding of *E.coli* to the surface of particles [*Kristian Stevik et al.*, 2004]. Sand and soil were evaluated as possible filtration media. Sand filters have been shown to be somewhat effective for filtering *E. coli* and The World Health Organization recommends designs for sand filters for treating water for human consumption[*Huisman and Wood,* 1974]. A study by Mankin et al. found that silt-loam soils have a higher sorption rate than sand however, and were effective at removing up to 99.7% of *E. coli* in filtered water [*Mankin et al.,* 2007]. They also stated that soils with a higher clay content could be even more effective at filtering out *E. coli*.

According to basic concepts in filtration and supported by a study done by Mankin et al., increasing the thickness and volume of the silt-loam component of the filtration pond system will increase the efficacy of filtration [*Brissaud et al.*, 2001; *Mankin et al.*, 2007]. The silt-loam layer of the system limits the flow rate by having the lowest hydraulic conductivity of the layers and any increase in the thickness of this layer will decrease flow. Fine sediments captured and entrained from the tailwater runoff will increase the efficacy of the filtration mechanism of the pond however these fines will lower the hydraulic conductivity of the soil and greater hydraulic head will be required to maintain flow rate.

3.2 Pond Design

The designed filtration pond will be excavated to a depth of 10 ft. with the sides cut on a 1.5:1 slope [*Coche and Muir*, 1995]. 6 in. drain tiles will be placed on the bottom of the pond for conveyance to the outlet. A 6 in. layer of gravel or crushed rock will be installed over the drain tiles to provide a solid foundation for the filtration media. Next, a layer of landscape fabric will be placed over the gravel to prevent sediment from infiltrating down into the rock layer. A 6 in. layer of sand will be placed above the landscape fabric as a foundation for the filtration media. The filtration media is a 12 in. layer of the native Owyhee silt-loam that was excavated from the original ground surface. Figure 4 shows a simple schematic of the pond cross-section.

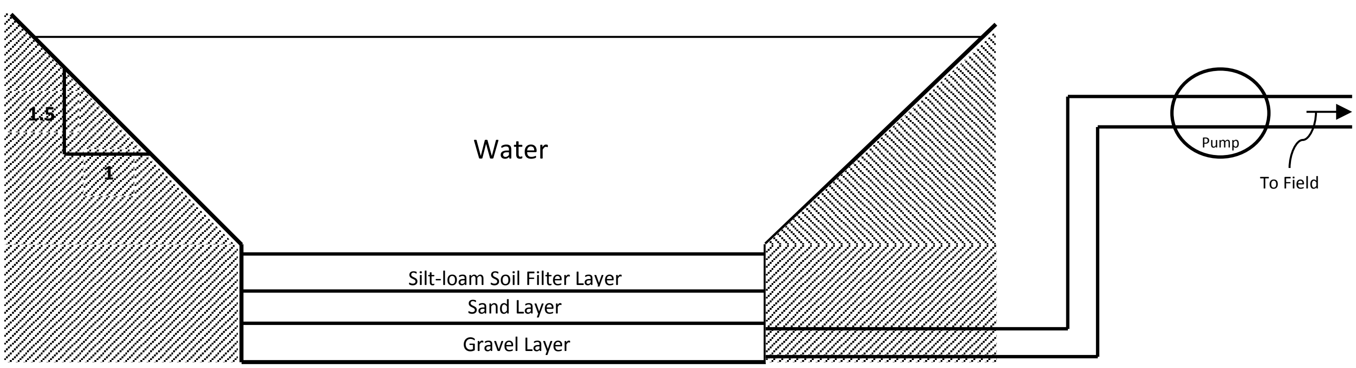


Figure 4 Filtration pond cross-section with gravel, sand, and soil media layers (not to scale).

Figure 5 shows one possible field and pond configuration which we consider a worst-case-scenario in terms of pumping. Other field configurations may result in shorter pumping distances and therefore less cost associated with pipe and power requirements.

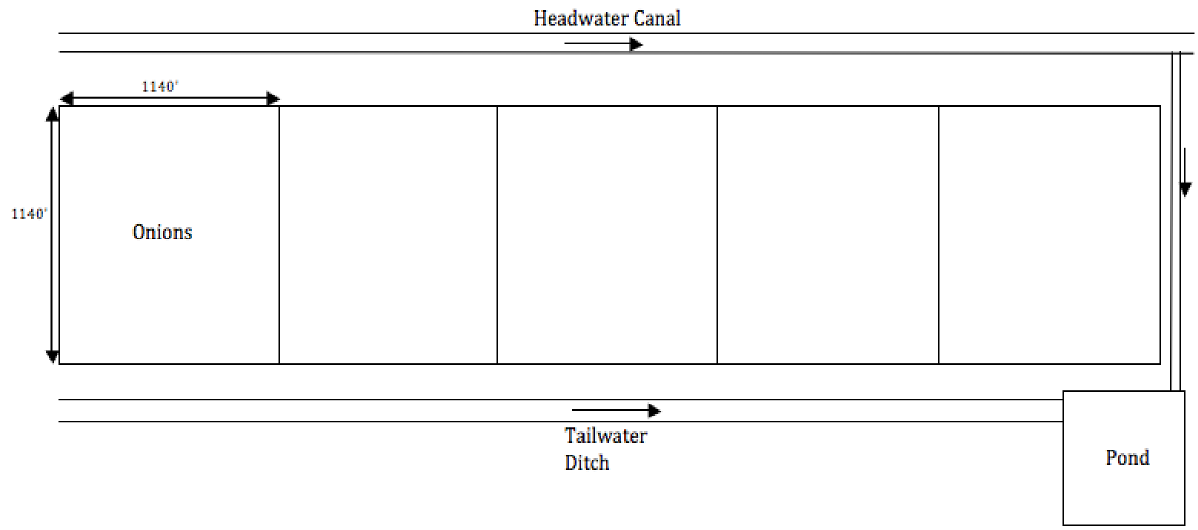


Figure 5: Possible field configuration with 5 adjacent fields and the filtration pond at the lowest point to facilitate tailwater recovery.

Placement of the pond at the bottom of the fields will allow the filtration pond to double as a tailwater recovery pond by capturing tailwater and recycling it for irrigation. Water from the head canal can be gravity fed to the filtration pond through a ditch or pipe to augment tailwater. Filtered water exiting the filtration pond will be pumped to the top of the onion field and discharged through a gated pipe to the furrows to prevent mixing with the untreated canal water.

3.3 Benefits to Crop Production

By connecting the outflow of tailwater back to irrigation, the farm reuses water and utilizes the resources within it. This results in improved efficiency and sustainability of crop production by closing resource loops and retaining water and sediment. This improvement is noticeable when comparing system diagrams of a farm with and without this system. The collection of headwater and tailwater has proven to be most beneficial to the farm by allowing for the collection of nutrient-rich sediments that are transported in the water. As seen in Figure 7, the pond collects headwater and tailwater (W), separates the sediment (S), and then routes the uncontaminated water back to the crop. Nutrients (N) build up on top of the filter and are returned to the field when cleaning and maintenance occur. Without this system, it can be seen in Figure 6 that water, soil, and nutrients are lost as runoff after irrigating and exit the system.

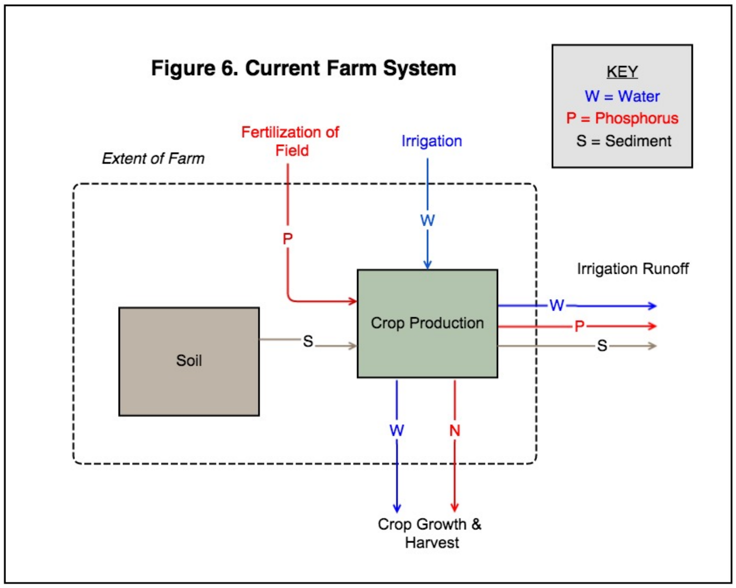


Figure 6. Systems diagram of a farm without a pond or tailwater collection

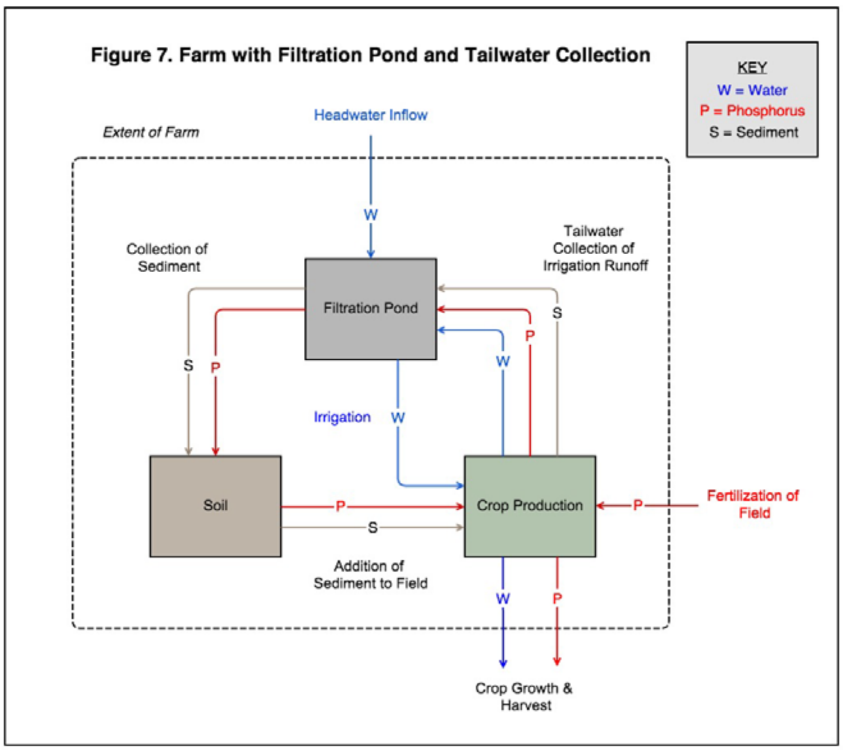


Figure 7. Systems diagram of a farm with a pond and tailwater collection

3.3.1 Water Collection

The pond contributes to the sustainability of the farm and agriculture in Treasure Valley by conserving water that would normally exit the farm as tailwater. Water shortage is increasingly a concern in the

American West due to shortages of freshwater and agriculture's reliance on irrigation. Several farmers in the Treasure Valley have reported receiving one-third less water from the irrigation district to successfully irrigate their crops [*Shock et al.*, 2013]. As previously stated, about 20% of the water that is applied to a furrow irrigated field will runoff [*Bjorneberg et al.,* 2002]. Tailwater recovery can help assure they have enough water to fulfill crop requirements. The design accounts for the uncertainty of water availability by collecting tailwater runoff.

3.3.2 Sediment Collection

Another significant cycle that is closed by a filtration pond is the movement of sediment from the field. Calculating the annual amount of collected sediment from tailwater was based on several sources (see Appendix D-a) and showed a wide range of values between 1.4 and 67.0 tons/acre. Dr. Shock stated that this variability has also been his experience and that even the average of these values is atypical on steep slopes. He suggested 9 to 10 tons/acre-year to be more accurate. Using this value, it was determined that for the 30 acre field the total amount of sediment collected from runoff was 30 tons/year.

Additionally, sediment is carried into the farm in headwater as a result of erosion from upstream farms. There were two options when considering the placement of the pond within the farm: placing the pond at the top of the farm to collect sediment in headwater and thus not require infrastructure for tailwater, or locate the pond at the bottom of the farm and collect sediments from five fields. To compare the value of headwater and tailwater, the team calculated the sediment load of each stream based on data from the Warmsprings Irrigation District 2011 Water Quality Sampling Results (see Appendix D-b). It was found that tailwater erosion was 9 times more concentrated than headwater, so placement of the pond at the bottom of the farm was determined to be more valuable.

The filtration pond allows for the efficient accumulation of sediment from headwater and tailwater, which prevents soil from clogging head ditches and makes the farm a net accumulator of soil. This function of the filtration pond reverses the loss of this non-renewable resource, helping to ensure the sustainability of growing crops on the land. The team estimated the pond would accumulate 1500 tons of sediment per year (0.44 acre-ft.) which can be reapplied to the fields.

3.3.3 Phosphorus Collection

To maintain soil fertility, farmers must apply fertilizers containing phosphorus to their fields each year. Much of this applied phosphorus fertilizer is eroded with sediment. Westermann et al. and Lentz and

Lehrsch found that of the sediment collected as runoff that 0.1% is total phosphorus [*Westermann et al.*, 2001; *Lentz and Lehrsch*, 2010]. It can be seen in Figure 7 that the pond collects phosphorus via the sediment transported in the water. Of the 1500 tons of sediment collected per year, 6800 pounds is phosphorus, which can be reapplied to the field. This saves an estimated $3900 per year (see Appendix D-d).

3.4 Pond sizing

The determination of pond area was an iterative process whereby an initial area was calculated using Darcy's Equation based on a flow rate requirement of 900 gpm.

$$A = \frac{Q \cdot L(A)}{ksat \cdot h}$$

The volume of sediments accumulated from tailwater collection was then determined and area was then re-calculated to assure that the desired flow rate was maintained after one season's worth of sediment was deposited into the pond. The final filtration area was determined to be 1.3 acres. Calculations related to pond area and sediment accumulation can be found in Appendix E and D respectively.

The use of built up berms on the perimeter of the pond was considered in an effort to minimize the excavation depth. Calculations were performed to determine the volume of berms and volume of material removed from excavation to optimize the sizing of the berms. If all of the excess excavated material were to be used to build up the berms, the berms would be 7 ft. 9 in. high. A slope of 3:1 would be required to assure stability of the berms [*Williams*, 2000], and the resulting width of each berm would be 54 ft. at the base. The footprint of the pond with berms would be approximately 2.5 acres. Full berm calculations can be found in Appendix F. Care would have to be exercised in the construction of the berms to assure they do not fail. They would likely need to be compacted in 6 in. lifts and some material from the excavation may not be suitable for constructing berms. The use of berms also poses a challenge in the conveyance of headwater and tailwater up and over the berms to the pond and could require additional pumping.

A pond excavated entirely below the ground surface could have steeper sides of 1.5:1 [*Coche and Muir*, 1995]and would result in a smaller footprint of approximately 1.5 acres. It was decided that little to no cost savings would be realized by the use of berms especially when the potential lost production of an additional acre of land was considered.

3.5 Component Sizing

As previously discussed above, a flow rate of 900 gpm was established to meet crop requirements. To size the pump, calculations for head losses and pump power requirements were performed. The Darcy-Weisbach equation shown below was used to calculate the friction losses in 6,000 ft. of 10 in. aluminum pipe.

$$h_f = f\left(\frac{L}{D}\right) * \left(\frac{v^2}{2g}\right) = 0.015\left(\frac{6000\,ft}{\left(\frac{10}{12}ft\right)}\right)\left(\frac{\left(3.6\,\frac{ft}{s}\right)^2}{64.2\,\frac{ft}{s^2}}\right) = \boldsymbol{22\,ft. friction\ loss}$$

The energy equation shown here was then used to determine the pump head requirements for the system.

$$\frac{P_1}{\gamma} + \alpha_1\frac{{v_1}^2}{2g} + z_1 + h_p = \frac{P_2}{\gamma} + \alpha_2\frac{{v_2}^2}{2g} + z_2 + h_f$$

$$\boldsymbol{h_p = 35ft.}$$

The power requirement for the pump was calculated with the following equation:

$$\boldsymbol{P} = \gamma Q h_p = \boldsymbol{6020\,Watts}$$

Berkeley pump B6ZPL was selected and the pump curve showed a 66% efficiency for 900 gpm at 35 ft. of head. Dividing the power output obtained with the power equation by 66% yielded a final pump power requirement of 9 kW. For detailed pump power calculations and Berkeley pump curve, see Appendix G.

Based on advice from pipe suppliers, an initial pipe diameter of 10 in. was used in the calculations for power requirements and pump size. If 8 in pipe is used, pump size would need to be increased (at a cost of an additional $2000) and power requirement would increase to 20 kW. Additional work will need to be done to determine if the cost savings for purchasing 8 in pipe would offset the increased energy use and pump upgrade.

4.0 ECONOMICS

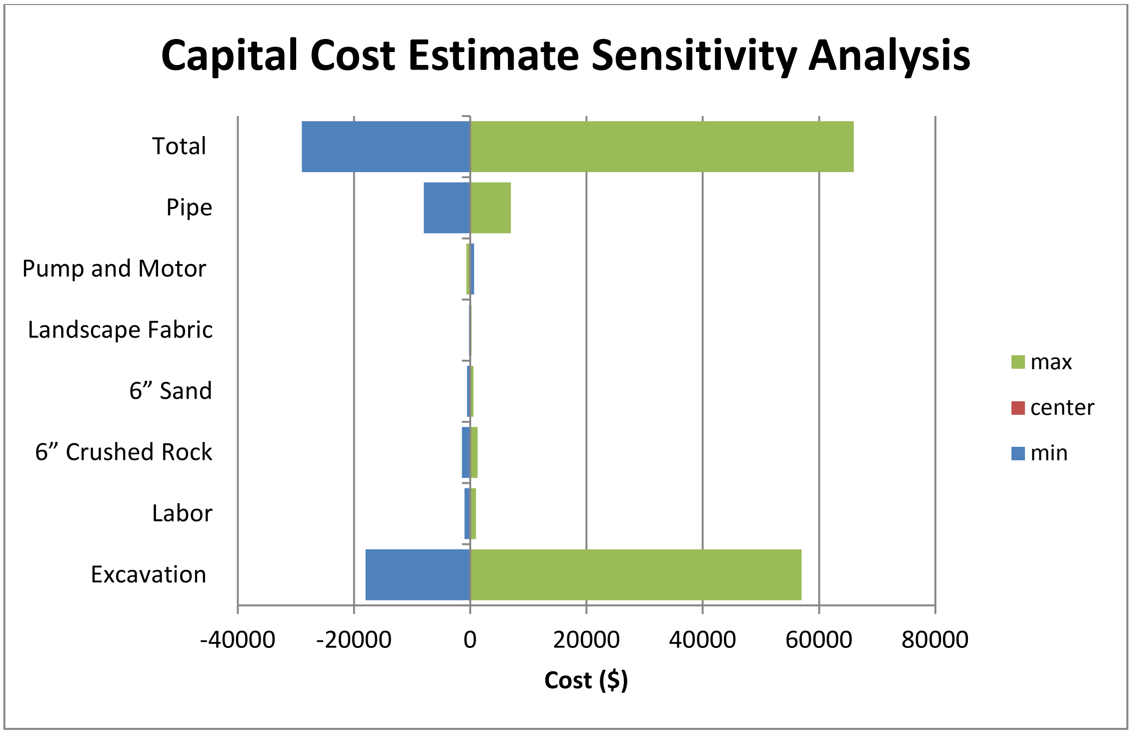
The following table shows a breakdown of estimated capital and annual costs for the proposed system along with a sensitivity analysis.

	Cost Estimate with Sensitivity Analysis			
Capital Costs	Expected	Min	Max	Comments
Excavation	28,000	10,000	85,000	1
Labor	1,500	500	2,500	2
6" Crushed Rock	9,750	8,300	11,000	3
6" Sand	3,750	3,200	4,300	3
Landscape Fabric	1,500	1,275	1,725	4
Pump and Motor	4,400	3,750	5,060	4
Pipe	14,000	6,000	21,000	5
Total	63000	33000	131000	
Capital costs amortized over 30 yrs				
2%	2800	1500	5800	6
3%	3200	1700	6700	
4%	3600	1900	7600	
5%	4100	2100	8500	
6%	4600	2400	9500	
Annual Operating Costs				
Profit Loss	750	0	1,500	7
Electricity	1,000	875	1,200	8
Pond Maintenance	2,000	800	4,800	9
P2O5 savings	(3,900)	(4,400)	(3,300)	10
Total	(150)	(2,725)	4,200	
Total annualized costs				
2%	2,650	(1,225)	10,000	

3%	3,050	(1,025)	10,900	
4%	3,450	(825)	11,800	
5%	3,950	(625)	12,700	
6%	4,450	(325)	13,700	
Cost per acre over 30 acres				
2%	90	(40)	330	
3%	100	(30)	360	
4%	120	(30)	390	
5%	130	(20)	420	
6%	150	(10)	460	

1	Minimum price based on estimate provided by E.D. Hughes, Philomath, OR. Maximum cost based on removal rate per cubic yard provided by Knife River, Roseburg, OR.
2	Estimated miscellaneous labor costs
3	Expected price quoted from Knife River, Philomath OR. Minimum/Maximum prices determined by a 15% decrease/increase in expected cost
4	Price from online vendor. Minimum/Maximum prices determined by a 15% decrease/increase in expected cost
5	Price from Ernst Irrigation, Portland, OR. Min based on used pipe and shortest distance determined by field configurations. Max bases on new pipe and furthest distance determined by field configurations
6	$A=P \{ i(1+i)^n/[(1+i)^n - 1] \}$
7	This category considers potential loss of income due to pond placement on productive land.
8	Minimum/Maximum prices determined by a 15% decrease/increase in expected cost based on 1400 hour irrigation time for the season.
9	Minimum cost assume the use of polyacrylamide(PAM) to reduce field erosion and sediment accumulation in pond with an excavation cost of $\$2/yd^3$. Maximum cost assumes no PAM and an excavation cost of $\$6/yd^3$.
10	Estimates of phosphorous savings see Appendix D-d

Table 2: This table shows the estimated costs associated with the construction and operation of the filtration pond system. Expected values are listed along with best (min) and worst (max) case scenarios.



Plot 1: Shows the large variability and influence of excavation on project costs.

The large footprint of this design could make it likely that the filtration pond will be taking up land previously occupied by productive farmland. If we assume an annual net revenue for onions to be $1000 per acre [*Mike Thornton et al.*, 2011], then taking up 1.5 acres with a filtration pond could cost the farmer $1500 per year in lost production. We anticipate that the costs related to taking farmland out of production can be reduced by using less productive land for the filtration pond. The location of the filtration pond will need to be determined on a farm by farm basis due to varying site conditions, however, we anticipate the placement of the pond will be at a low elevation point on the farm to enable the pond to collect tailwater runoff via gravity feed ditches.

4.1 Excavation

Excavating the pond will be the largest financial component of the design. As shown in Table 2, excavation accounts for anywhere from one-third to two-thirds of the total capital costs. A visual representation of this impact can be seen in the chart in Appendix H. The maximum cost does take into account the hauling of the excavated material off site, but it is likely that many farms will not need to remove this material. In response to this significant cost, the team analyzed the benefits and costs of installing berms around the perimeter of the pond. Berms may be used to reduce the volume of excavated material while keeping the effective volume of the pond constant. As discussed in section 3.4, after sizing calculations were performed (shown in Appendix F), the total land use needed for the pond increased to 2.5 acres. Additionally, there was no significant trade-off in costs when construction of the berms, including filling and compacting, was analyzed. Berms did not prove to be a feasible alternative at this time.

4.2 Filtration Material

An important aspect of this design was to minimize the use of off site materials. Because soils have a natural ability to retain and eliminate pathogens by physical, chemical, and biological processes the team used these intrinsic properties as the basis of our design.. The use of the native Owyhee silt loam also means that the topsoil excavated from the site can be reused at no extra cost to the farmer. Once the initial excavation of the site is completed drain tile is laid down to rout water to a pump. Next a layer of crushed gravel is added followed by a fabric barrier then sand with the final silt loam layer. A visual model of the pond and the layers of the filter can be seen in Figure 4. The sand, gravel and landscape fabric together account for 24% of the total capital costs.

4.3 Pump & Pipe

If all fields are adjacent to one another, approximately 6000 ft of pipe would be required to convey water from the pond to the top of the furthest field. This length of pipe represents a significant component of the cost. A 10 in. diameter pipe was selected based on consultations with Dr. Shock and agricultural supply vendors. However further work could be done to determine if 8 in. pipe might be used to reduce capital costs. Berkeley centrifugal pump B6ZPL was specified for use with 10 in. aluminum pipe. The use of 8 in. pipe would represent a lower capital cost, but would increase the power required to pump the water, at an additional cost of about $800 per year, and a bigger pump would cost an additional $2000.

4.4 Maintenance

The filtration pond system will require annual maintenance to maintain system efficiency. It is recommended that the pump and motor be visually inspected and cleaned if needed twice per season as well as at the beginning, and end of the season [*Morris et al.*, 2006]. The pipes will require new gaskets every 3 to 5 years and occasional patching if punctured. The pump and pipe maintenance can most likely be done with existing farm resources at minimal cost. The main annual maintenance cost of the system is associated with the removal of accumulated sediments from the tailwater runoff and their re-application to the field. The annual cost to excavate the sediment buildup was estimated at $2000 per year.

4.5 Phosphorus Recovery

By capturing sediment and reapplying it to the fields, the farm could realize a savings of approximately $4000 per year in applied phosphorus(see appendix D-d).

4.6 Grant Funding

The Natural Resources Conservation Service (NRCS) offers several financial assistance programs which may be applicable to the construction and implementation of a filtration/tailwater recovery pond system. Grants are available for systems or practices that improve water quality, conserve water and soil, and improve environmental quality. Under the NRCS Agricultural Water Enhancement Program (AWEP), the Vale Oregon Irrigation District received $1.5 million for reducing water use on 12,000 acres of furrow irrigated lands. Averaged over the entire area, the grant funded projects at a rate of $125 per acre. The Owyhee, and other irrigations districts in the same area may also be able to benefit from the AWEP program.

The NRCS also has other programs with the potential to fund water and soil enhancement projects like the system we propose such as the National Water Quality Initiative, the Conservation Activity Plan, and the Conservation Innovation Grant program. The U.S. Bureau of Reclamation also has their Water Smart Grant program that funds irrigation district projects for water conservation.

5.0 ENVIRONMENTAL & SOCIAL IMPACTS

In addition to meeting the technical requirements of water treatment, the project enables a farm to reuse water, better retain nutrients and to prevent net loss of soil. This reduces the impact of farming on the water quality of the Treasure Valley and better retains soil and phosphorus, which are non-renewable resources. In contrast, the implementation and operation of the project will require the addition of materials and use of energy.

A simple life cycle analysis was performed to evaluate the energy and material expenditures of the project. Material use was estimated to determine the embodied energy involved with the system. A table showing major system components and embodied energy is shown in Appendix I. Embodied energy was estimated in terms of total kW-hr used in the production of materials. The construction of the pond, pump, motor, and pipe had an estimated embodied energy of 210,000 kW-hr at an annual expenditure of 27,000 kW-hr.

As a benefit to people of the Treasure Valley, this project can be used to show a water treatment system that also benefits crop production. This project exemplifies a system perspective of crop production where the previously lost resources of water, soil and nutrients are retained and routed back to the crop. This could provide educational opportunities to farmers and the public, which may encourage the adoption of sustainable farming in the Treasure Valley. While filtration ponds and tailwater collection are not new ideas in the Treasure Valley, this design could be used to show the practical and quantified benefits of a tailwater recovery to crop production. The farming community has been open to innovation for centuries, but frequently needs to see a few proven adopters before a new technology is adopted in a region.

6.0 DISCUSSION

With the possibility of new regulations being adopted to set minimum standards for irrigation water, onion growers are in need of a viable, sustainable, and effective solution. A review of filtration pond technologies for use in removing *E. coli* from the canal water showed promising results. Based on several studies, soils high in silt and clay can be highly effective at filtering *E. coli* from water, which is more than satisfactory at meeting the regulations [*Castillo et al.*, 2001; *Kristian Stevik et al.*, 2004; *Mankin et al.*, 2007; *Jarboui et al.*, 2008; *Ross and Shock*, 2013]. Calculations using Darcy's equation for flow through a porous media, and results from a filtration pond simulation performed at the Malheur Experiment Station, found that flows of 600-1000 gpm could be achieved from a 1 to 1.5 acre size pond. Treatment efficacy in the system will be improved further with the addition of accumulated fine sediments from the tailwater runoff.

The largest drawback from this design is the initial cost. The total estimated costs for construction of the system ranged from $34,000 to $129,000. As seen from the sensitivity analysis included in the economic section of this report, the greatest variability in the cost of the system is the excavation of the pond. Estimates obtained from contractors ranged from $10,000 to $85,000. Given that the excavation costs and pipe requirements for the system are highly dependent on actual site conditions, cost estimates will have to be completed for every individual site to obtain more precise figures.

One major benefit that this system confers to the farm is the recapture of irrigation water, soil, and nutrients in the runoff. Farmers in the area are already beginning to see the value of tailwater recovery ponds and are implementing them into their farming practices. Several farmers have reported receiving one-third less water from the irrigation district to successfully irrigate their crops [Shock and Welch 2011]. Tailwater recovery can help assure they have enough water to fulfill crop requirements. The entrainment of eroded soil in the pond also confers a significant benefit to the farm. Through the reapplication of the eroded soil to the top of the fields, farmers can be more confident that they will not see diminishing yields due to erosion of topsoil. According to studies done by Westermann et al. and Lentz & Lehrsch, the sediments that runoff furrow irrigated fields are comprised of approximately 0.1% total phosphorus[*Westermann et al.*, 2001; *Lentz and Lehrsch*, 2010]. Phosphorus is a nonrenewable nutrient that can increase eutrophication when runoff reaches surface waters. By collecting tailwater, farms can not only significantly reduce fertilizer use, but potentially improve the quality of surface waters in the area.

7.0 CONCLUSION

Major factors in the design selection was system efficacy and compatibility with current farming practices. The proposed filtration pond design integrates ecological engineering philosophies with current farming practices to create a sustainable and effective treatment system that can ensure pathogen removal throughout the design life. A system footprint of 1.5 acres allows the required 900 gpm flow rate to the onion field while allowing for the capture and re-application of tailwater runoff. Initial capital costs for the representative farm are expected to be approximately $63,000 resulting in an annual per-acre cost of $130. The filtration pond design is highly site specific however and costs could range from $34,000 to $130,000 with annualized net costs in the range of $0 (due to the phosphorus savings) to $400. Financial assistance may be available to irrigation districts from NRCS to reduce the effective cost of the system. Excavating the pond is clearly the largest and most variable cost associated with installation, but annual savings from collected phosphorous runoff can help mitigate these costs. Given the variability in onion prices from year to year, and the variability in farm size and operation costs, this treatment system may prove to be too expensive, or otherwise too risky, for some farms. This filtration pond does have a high capital cost and will not be appropriate for every farm. If cost were simply the only measure that was important, then this system will likely not be a very attractive solution, however, if the additional benefits to water savings, fertilizer savings, erosion control, water quality, and sustainability are important issues to farms then this filtration pond system design may be worth pursuing further to asses the suitability of the design to a particular farm.

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Appendix A

Representative farm and crops in the treasure valley

- 5 fields, each 30 acres (see schematic in Appendix B)
- Five crops grown annually: onions, alfalfa, sugar beet, potato, and field corn
- Dimensions of each field: 1140 ft x 1140 ft
- Soil type – Owyhee silt loam
- Slope of all fields = 1 ft/ft
- Existing canals as indicated in the schematic in Appendix B

Irrigation Management & Costs

- 4" application/set using furrow irrigation
- 1 set every 4 days on any given area of a field during the peak of the growing season
- Bjorneberg et al. estimated that 20% of the total amount of water entering a furrow irrigated field will leave as runoff [*Bjorneberg et al.*, 2002].

Table 1: Agrimet published values for 2013 ETc season of the 5 crops in Ontario, OR [*US Bureau of Reclamation*, 2013]

	Onion 2	Alfalfa Mean	Beet	Potato 2	Field Corn
ETc season (month.day)	4.1 - 8.20	3.15 - 10.10	4.10- 9.30	5.5 - 9.10	5.1 - 8.20
Time crop is not providing tailwater [days]	0	0	9	34	30
Seaonal ET during onion ET [in.]	35	38	32	30	28

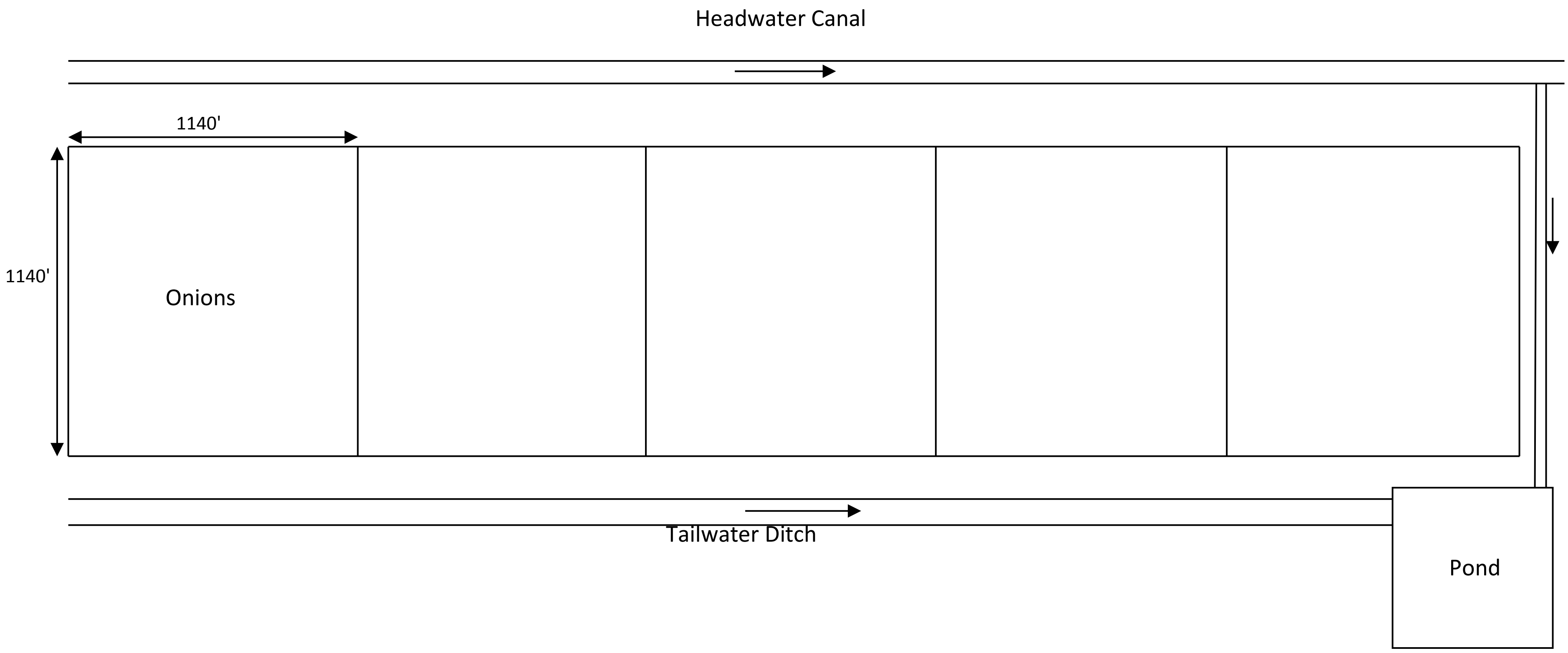
Commentary

Table 1 is used to approximate the irrigation season of each crop. These represent the potential times of the season that runoff from furrow irrigating these crops could provide water to the pond. All of the crop ET seasons overlap during the onion irrigation season. This shows all fields can provide water in the form of tailwater during the water demand of the onion field. Furthermore it is assumed that each field follows the same irrigation schedule as onions and will have a similar proportion of runoff, 1/5. Therefore each field is assumed to have similar seasonal erosion rates if they are on the same soil type and slope.

Appendix B

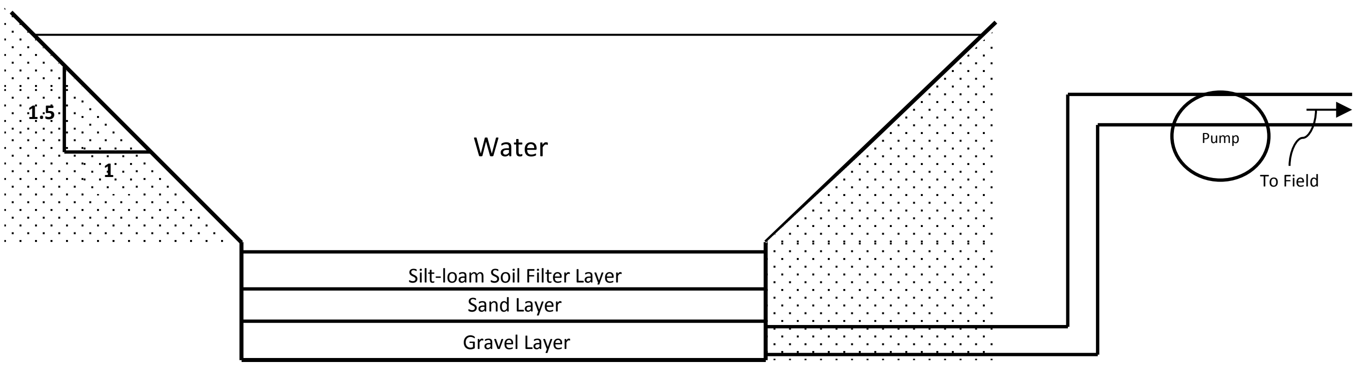
Schematics of system with farm fields, filtration pond and tailwater collection

- Conceptual field layout and pond location. (Not shown to scale)
- Shown below is a field layout considered a worst case scenario in terms of pumping requirements. In this scenario, water from the pond will have to be pumped 6850 feet. (Irrigation pipes not shown)
- Slope is 0.01 ft/ft from the top left to the bottom right toward the pond
-



Schematic of conceptual cross-section of the pond (Pond not to scale)

Citation: Slope of 1.5:1 as suggested in Coche et. Al [*Coche and Muir*, 1995].



Appendix C

Design Flow Rate

GIVEN

- 4-inch application
- 30 acre field
- ¼ of a field per set, i.e. 7.5 acres
- 12 to 24 hour sets

Source: Estimate of average practices by Clint Shock in conversation, November 2013.

FIND Q, range and maximum design flow rate, gpm

SOLUTION

$$Q = 4\ in. * \frac{1\ ft}{12\ in} * 7.5\ acres * \frac{43560\ ft^2}{acre} * \frac{1}{12\ to\ 24\ hours} * \frac{1\ hr}{60\ mins} * \frac{7.48\ gallons}{ft^3}$$

$$Q = 600\ to\ 1200\ gpm$$

The design flow rate was based on a description given by Dr. Shock for irrigating a 40 acre field. This consisted of one 4” application per day occurring over 12 to 24 hours that is applied to one of four equal areas of the field. This results in the whole field being irrigated every 4 days. The calculated design flow rate was based on an 18 hour set to allow the grower to apply peak irrigation in less than 24 hours per day, but also to reduce the cost and size of the pond associated with the highest flow rate in a 12 hour set.

$$\boldsymbol{Design\ Q = 900\ gpm}$$

Appendix D Tailwater and Sediment erosion

Appendix D-a

Summary of research and calculations for annual sediment erosion (tons/acre)

- *Lentz et al.* reports that runoff from a field with 175 meter long furrows, a slope of 1.6% with 5 irrigation sets per season of 8 to 24 hours resulted in an average 3.14 Mg/ha[*Lentz et al.*, 1998].

$$3.14\frac{Mg}{ha} * \frac{ha}{2.47\ acres}\frac{1.1\ ton}{Mg} = 1.4\frac{ton}{acre}$$

- *Bjorneberg et al*. report in recently tilled, furrow irrigated fields 1000 to 10,000 Mg/L of sediment runoff, and in well managed fields 100 Mg/L of sediment runoff. Annual losses in Southern Idaho were estimated to be 0.5 to 141 Mg/ha, whereas losses in Washington State estimated to 0.2 to 50 Mg/ha [*Bjorneberg et al.*, 2002].

  Average runoff for S. Idaho and conversion to Mg/acre

$$\frac{\frac{0.5\ Mg}{ha} * + \frac{141\ Mg}{ha}}{2}\frac{ha}{2.47\ acres}\frac{1.1\ ton}{Mg} = 31.5\frac{ton}{acre}$$

  Average runoff for Washington State and conversion to Mg/acre:

$$\frac{\frac{0.2\ Mg}{ha} + \frac{50\ Mg}{ha}}{2}\frac{ha}{2.47\ acres}\frac{1.1\ ton}{Mg} = 11.2\frac{ton}{acre}$$

- *Shock et al.* reports that in furrow irrigated fields of Nyssa silt loam with a 3% slope average seasonal sediment losses were 60.1 tons/acre [*Shock et al.*, 1996].

- Based on field observations at a headwater canal in Ontario, OR at the Malheur experimental station there has been an estimated 300 mm of erosion over 50 years of production

$$\frac{300\ mm}{50\ years} = 6\frac{mm}{year}$$

Assuming the bulk density of the silt loam is 2.5 g/cm^3 [*Brady and Weil*, 2010]

$$\frac{2.5\ g}{cm^3} * \frac{4.05 * 10^7 cm^2}{acre} * 0.6\ cm * \frac{1.1\ tons}{10^6 g} = 67\ \frac{tons}{acre}$$

Summary of seasonal erosion rates:

a) 1.4 ton/acre
b) 31.5 ton/acre & 11.2 ton/acre
c) 60.1 ton/acre
d) 67 tons/acre

Average: 34 tons/acre

Commentary

Based on the literature review in solutions a) to c) and our own observation in solution d), it was obvious that there is a wide range of erosion rates. We consulted with Clint Shock about this variability, including his own study in solution c), and whether he recommended an average erosion rate for furrow irrigated onions in the Treasure Valley. Clint stated that this variability has also been his experience and that 20-30 tons/acre-year is atypical on steep slopes. He suggested 9 to 10 tons/acre-year would be more accurate. For this reason, we believe that it is best to follow his judgment considering that he has worked with onion production in the region for many years.

The annual erosion rate from furrow irrigatation that is used throughout the rest of this work is **10 tons/acre-yr**.

Appendix D-b

Comparison of annual sediment load in headwater to tailwater

BACKGROUND

In the Treasure Valley irrigation canals, a grower's tailwater becomes the downstream grower's headwater. Therefore, is there a difference in value to collect tailwater within a farm at the bottom of fields when the pond can be placed at the top of the farm and collect headwater? If its placed at the top, the design can utilize gravity for conveyance. If placed at the bottom, the pond would require a larger pump to bring water to the top of the onion field and can collect tailwater runoff from fields within the farm. Which source of water is more valuable in terms of sediment collection?

GIVEN

- Warmsprings Irrigation District 2011 Water Quality Sampling Results prepared by Ellen Hammond[*Hammond and Finnerty*, 2013]

- Assumed maximum applied water = 4 ft/yr, which is the maximum allotted to each grower

- Area of field = 30 acres

FIND

The amount of sediment in irrigation headwater in the central Treasure Valley and compare that to the amount of sediment in tailwater coming off a furrow irrigated field

SOLUTION

The water quality report summarizes sampling results in the mid Treasure valley between Vale and Ontario, OR. To better represent water quality in irrigation canals, data points were chosen from agricultural canals within the Blanton drainage system, which is the largest drainage in the Warmsprings Irrigation District. The Blanton drainage system is above three major inflows from the Owhyee Irrigation District. Data was taken as an annual average of samples from Table 5 ,column 3(pg 12), which are waters contributed by the Shoestring canal to the middle of the Blanton drain. The average was taken from the points May early through August late, during the irrigation season.

Table 5. Concentration of total suspended solids associated with the Blanton Drain

SAMPLING EVENT	TOTAL SUSPENDED SOLIDS (mg/l)					
	Head of Nevada Ditch (a)	Contributed by Shoestring Canal	End of Nevada Ditch	Wood Drain	Entering Malheur River from Blanton Drain (b)	Increase within Blanton drainshed (b-a)
April early	Canal dry	Dry	Dry	12	74	
April late	152	10	55	525	280	128
May early	74	139	272	227	416	342
May late	Weir just cleaned	196	129	340	Not sampled	--
June early	68	79	176	339	393	325
June late	53	172	125	303	374	321
July early	62	15	916	405	649*	587*
July late	91	276	527	432	481*	390*
August early	109	285	400	369	36	-73
August late	72	123	155	115	161	89
September early	69	464	98	190	152	83
September late	44	482	106	149	120	76
October early	34	280	92	110	76	42
October late	20	139	41	69	82	62
November early	Canal dry	Dry	60	16	16	16
AVERAGE TSS (late June-late Oct)	***62***	***248***	***252***	***216***	***215***	***153***

* Blanton Ditch was cleaned in July below the Wood Drain, resulting in large sediment loads to the Malheur River.

p

Table 5 from WID 2011 Water Quality Sampling Results [*Hammond and Finnerty*, 2013]

$$Average\ Annual\ TSS = \frac{\left(139 + 196 + 79 + 172 + 15 + 276 + 285 + 123\,\frac{mg}{L}\right)}{8}$$

$$= 161\ mg/L$$

$$4\,\frac{ft}{yr} \cdot 30\ acres \cdot \frac{1.23 * 10^6\ L}{1\ acre\ ft} \cdot 161\,\frac{mg}{L} \cdot \frac{Mg}{10^6 g} \cdot \frac{1.1\ ton}{Mg}$$

$= 26.1\ tons/yr$ from headwater delivered to one field

$10\,\frac{tons}{acre \cdot yr} \cdot 30\ acres = 300\ tons/yr$ from tailwater of one field

From this result, tailwater within the farm is a much more concentrated source of sediment than the headwater canal. Since our goal is to maximize the retention of sediment in the farm, tailwater should be used as influent for the pond as opposed to headwater.

Appendix D-c

Estimated sediment accumulated per year

FIND

a) Maximum number of tailwater inflows that can be collected, N, to provide for irrigation demands treated by pond
b) Total sediment accumulated by the pond if N tailwaters collected, tons/yr S & $acre \cdot ft$/yr S

GIVEN

- Assume all crops, C, require the same application as onions, O (see Appendix A)
- About 0.20 of applied water is runoff from furrow applications [*Bjorneberg et al.*, 2002]
- Erosion rate = 10 tons/acre-yr (see Appendix Da)
- Density of sediment = 2.5 g/cm^3 [*Brady and Weil*, 2010]

a) SOLN

If three tailwaters are collected as runoff that each equal 1/5 of water applied, then those will equal 5/5 parts of one application on a crop. Since all crops have the same irrigation demands, then 5 tailwater collections will supply one application on onions.

N = 5 tailwaters each from one field

This value represents a maximum number of tailwaters that would provide for the water needs of the pond if they are all running simultaneously. They will not likely be running simultaneously, so pond will need to be augmented with headwater.

b) SOLN

$$10\ \frac{tons}{acre \cdot yr} \cdot 30\ \frac{acres\ eroded}{tailwater} \cdot 5\ tailwaters = 1500\frac{tons}{yr}S$$

$$1500\frac{tons\ S}{yr} \cdot \frac{Mg}{1.1\ ton} \cdot \frac{10^6 g}{Mg} \cdot \frac{cm^3}{2.5\ g} \cdot \frac{acre \cdot ft}{1.23\ \cdot 10^9 cm^3} = 0.44\ acre \cdot ft/yr$$

Appendix D-d

Estimated phosphorus accumulated per year and economic value

FIND

a) Total phosphorus, P, accumulated per year, lbs/yr P
b) Value of phosphorus in $/yr on P205 basis

GIVEN

- 1500 tons Sediment eroded/yr into pond
- 0.001 Total Phosphorus, TP/ S, [*Bjorneberg et al.*, 2002; *Lentz and Lehrsch*, 2010]
- 2011 University of Idaho enterprise budget for onions produced in Southwestern Idaho and Eastern Oregon[*Mike Thornton et al.*, 2011]
    - Dry P2O5 applied per yr = 115.00 lb/acre
    - $0.57/lb

a) SOLN

$$1500\ \frac{tons\ S}{yr}\cdot\frac{0.001\ ton\ TP}{ton\ S}\cdot\frac{2000\ lbs}{ton}\cdot 1\ y = 3000\ lbs\ TP$$

$$3000\ lbs\ TP\cdot\frac{453.6\ g}{lb}\cdot\frac{1\ mol\ P}{30.97\ g}\cdot\frac{mol\ P_2O_5}{2\ mol\ P}\cdot\frac{141.94\ g}{1\ mol\ P_2O_5}\cdot\frac{lb}{453.6\ g} = 6800\ lbs\ P_2O_5$$

b) SOLN

$$6800\ lbs\ \ P_2O_5\cdot\frac{\$0.57}{lb} = \$3900$$

If all of the sediment collected in a year is applied to a field, then the cost of producing in that field will be decreased by $3900 over the period it becomes available. This equals $130/acre for a 30 acre field.

Appendix E Filter area, A, necessary to provide design flow rate with one year of sediment

COMMENTARY

A goal with this design is to minimize the area of the pond by maximizing the depth. Maximum depth of the pond is set at 10 ft, which was the observed depth of the sedimentation pond in Ontario, OR in October, 2013. Constants include the head, h, set at 8 ft to allow for 2 ft of buffer between the water surface and the top of the pond. It has been observed in studies on erosion that sediment will increase in silt and clay content relative to the silt loam[*Bjorneberg et al.*, 2002]. Its assumed that this sediment will resemble silty clay and ksat is a constant for this soil texture [*Brady and Weil*, 2010].

GIVEN

S = 1500 tons

$$Vs = 0.44\, acre \cdot ft \times 43560 \frac{ft^3}{acre \cdot ft} = 11590\, ft^3$$

Q = 900 gpm = 2.00 $\frac{ft^3}{s}$ (Appendix B)

Ksat = $1.6 \cdot 10^{-6} \frac{ft}{s}$ [*Brady and Weil*, 2010]

h = 8 ft.

FIND A, acres

SOLN - Darcy's Equation rearranged to solve for filter area, A. Solved using numerical iteration.

$$A = \frac{Q \cdot L(A)}{ksat \cdot h}$$

L(A) = Vs/A

$$A = \frac{\left(2.00\ \frac{ft^3}{s}\right) \cdot \left(\frac{Vs}{A}\ ft^2\right)}{\left(1.6\ \cdot 10^{-6}\ \frac{ft}{s}\right) \cdot (8.0\, ft.)}$$

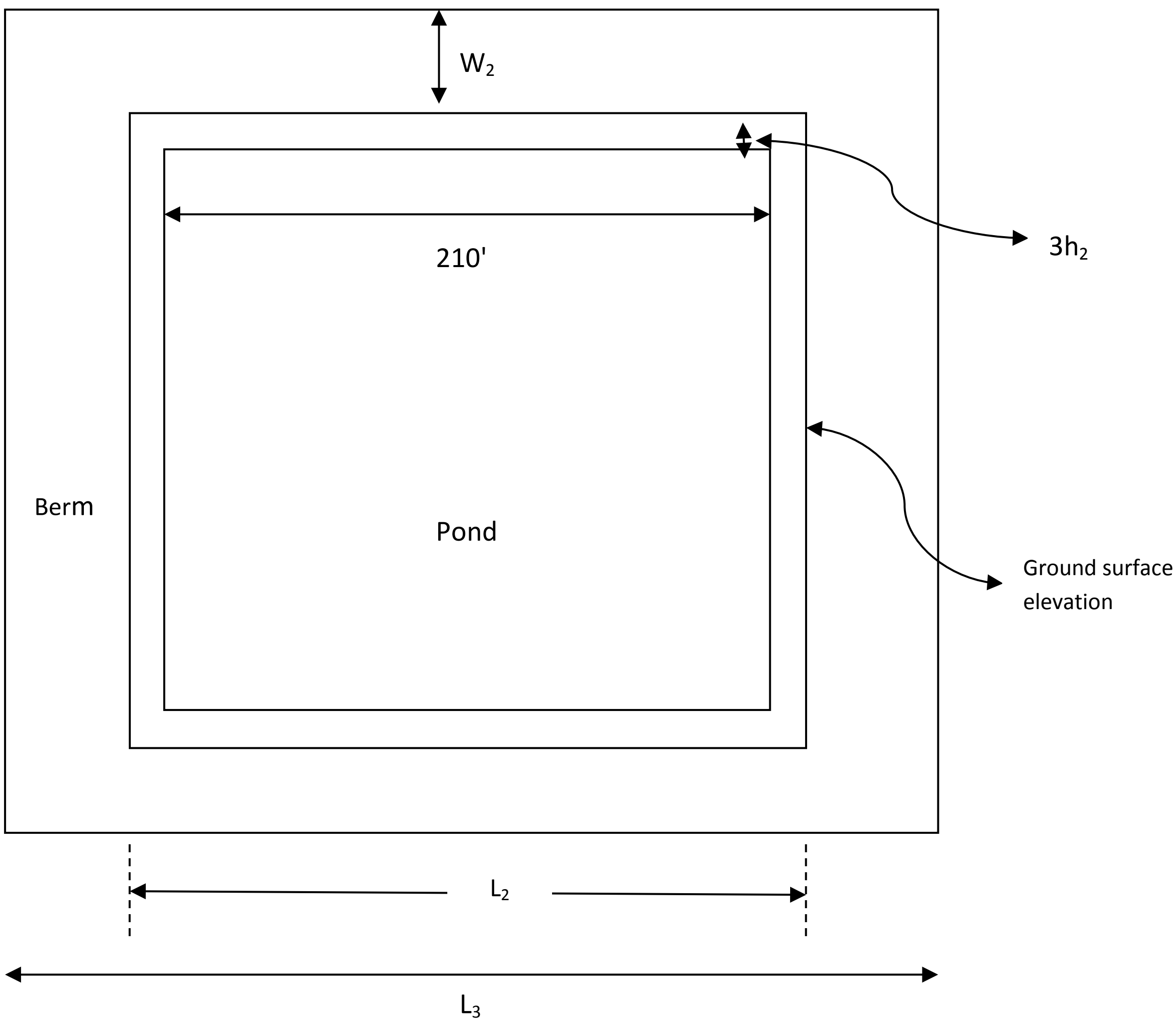
$$A = 54900\, ft^2 = 1.3\, acre$$

Appendix F

Calculations to minimize excavation by building berms

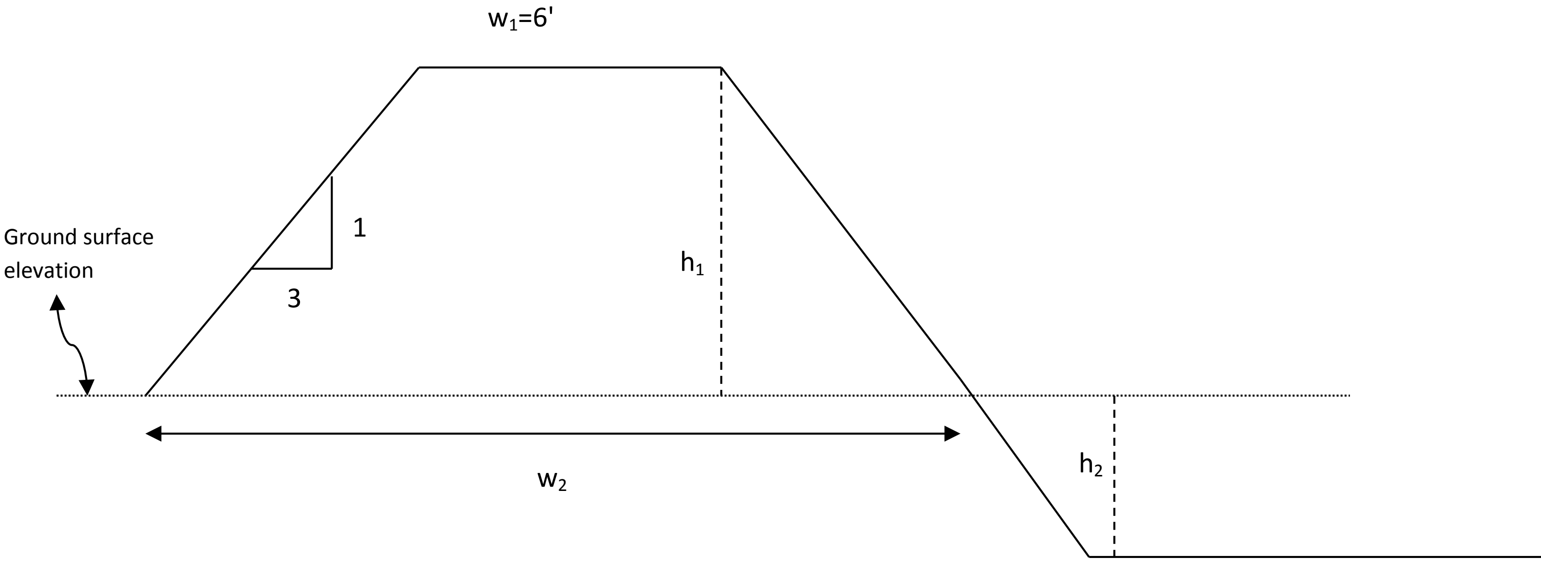
Problem: Excavation costs were the biggest contributing element in the price of the filtration pond design. In an effort to minimize the volume of material removed, an attempt was made to use the excavated material to build up berms on the outside of the pond to gain depth.

What volume must be excavated to minimize excavation?



A slope of 3:1 was chosen based upon Langston University pond construction guidelines[*Williams*, 2000]

Pond filtration area (determined in previous calculations) of 1 acre was used.



Cross-sectional area of berm:

$$A = 6h_1 + \frac{h_1(w_2 - 6)}{2}$$

$$A = \frac{h_1(w_2 + 6)}{2}$$

Width of berm (w_2): $w_2 = 6 + 6h_1$

$$L_3 = 210' + 6h_2 + 2w_2$$

$$L_2 = 210' + 6h_2$$

Volume of berm(V_b):

$$V_b = 4[w_2 * L_2 + 0.5(L_3 - L_2)w_2]$$

Rearrange and substitute for w_2...

$$V_b = (6 + 6h_1)(2L_2 + 2L_3)$$

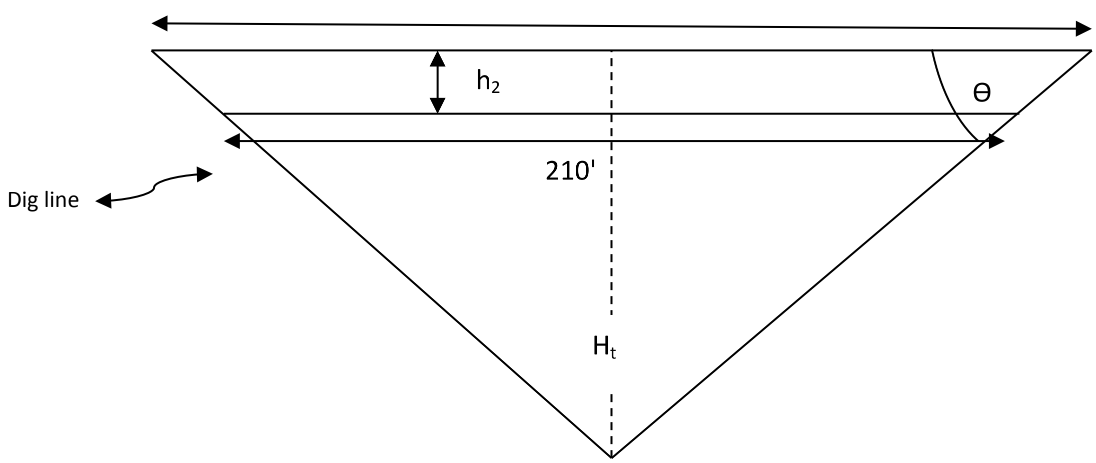
Substitute for L_2, and L_3...

$$V_b = (6 + 6h_1)\{2(210' + 6h_2) + 2\big(210' + 6h_2 + 2(6 + 6h_1)\big)\}$$

Simplify...

$$V_b = 144(h_1 + 1)(h_1 + h_2 + 36)$$

With volume of the berm calculated, volume of the dugout portion of the pond needed to be calculated. Goal was to use all the material dug out to use for the 12" filter layer and build the berms.



$H_t = 0.5(210' + 6h_2)\tan\Theta$ $\Theta = 18.435$

$h_l = 0.5(210')\tan\Theta$ $h_l = H_t - h_2$

Volume of the dugout portion equals the volume of the total pyramid - the smaller pyramid. (Only the upper section above the dig line is excavated, the lower portion is used conceptually for ease of calculation.)

Excel was then used to calculate various depths and determine optimum volume of excavation. The following table shows that by digging 2 feet down the material can be used to build the berms and supply the 12" filtration layer.

h_1	h_2	V_{berm} (ft^3)	Cu. yards	h_2	Ht	V_{big_pyrm}	hL	V_{dug} (ft^3)	Cu. yards
6	4	46000	1700	0	35	515000	35	500	19
6.25	3.75	48000	1800	0.25	35.3	526000		11500	430
6.5	3.5	50000	1900	0.5	35.5	537000		22500	800
6.75	3.25	51000	1900	0.75	35.8	548000		33500	1200
7	3	53000	2000	1	36	560000		45500	1700
7.25	2.75	55000	2000	1.25	36.3	572000		57500	2100
7.5	2.5	56000	2100	1.5	36.5	584000		69500	2600
7.75	2.25	58000	2100	1.75	36.8	596000		81500	3000
8	2	60000	2200	2	37	608000		93500	3500
8.25	1.75	61000	2300	2.25	37.3	620000		105500	3900
8.5	1.5	63000	2300	2.5	37.5	633000		118500	4400
8.75	1.25	65000	2400	2.75	37.8	646000		131500	4900
9	1	66000	2400	3	38	658000		143500	5300

The footprint for the entire installation was then calculated:

$$\text{Footprint} = (L_3)^2 = \left(210' + 6h_2 + 2(6 + 6h_1)\right)^2 = 36(2h_1 + h_2 + 37)^2$$

Using 2.25' excavated and 7.75' berms the footprint is almost 2.5 acres.

<u>Appendix G</u>

Calculations for pump power requirements

<u>ASSUMPTIONS</u>

- 10 inch Aluminum pipe; D = 10 inches; Length, L = 6000 feet (Length of pipe needed from the pond at the lowest point of the farm to the field at the highest point.)
- Roughness coefficient, $K_s = 6x10^{-5}$ inches.
- Flow rate, Q = 1000 gpm = 0.063 m^3/s
- Turbulent flow conditions; α = 1
- Δ Field elevation = 20 feet = 6.1 meters
- Temperature of water = 20 degrees Celsius

Kinematic Viscosity of water = $1.2x10^{-5} \frac{ft^2}{s}$

$$v = \frac{Q}{A} = \left(\frac{1000\ \frac{gal}{min}}{\left(\frac{5}{12}ft\right)^2 * \pi}\right) * \left(\frac{1\ ft^3}{7.48\ gal}\right) * \left(\frac{1\ min}{60\ sec}\right) = \mathbf{4.1\ \frac{ft}{s} = 1.25\ \frac{m}{s}}$$

<u>Moody diagram</u>

Relative roughness:

$$\frac{K_s}{D} = 6x10^{-6} ==> f = 0.015$$

<u>Darcy-Weisbach Equation</u>

$$h_f = f\left(\frac{L}{D}\right) * \left(\frac{v^2}{2g}\right) = 0.015\left(\frac{6000\ ft}{\left(\frac{10}{12}ft\right)}\right)\left(\frac{\left(4.1\ \frac{ft}{s}\right)^2}{64.2\ \frac{ft}{s^2}}\right) = \mathbf{28\ ft\ friction\ loss}$$

$$= \mathbf{8.5\ m\ friction\ los}$$

f = friction factor

g = acceleration due to gravity =32.2 ft/s^2

Energy Equation

h=head in the pond (m/m)

z = elevation difference between pond and top of field (m)

P = Total pressure in water column (kg/m^2)

v = velocity of water through pipe (m/s)

γ = Unit weight of water (kN/m^3)

h_p = head loss due to pump (m)

h_f – head loss due to friction (m)

$$\frac{P_1}{\gamma} + \alpha_1 \frac{{v_1}^2}{2g} + z_1 + h_p = \frac{P_2}{\gamma} + \alpha_2 \frac{{v_2}^2}{2g} + z_2 + h_f$$

$$\frac{P_1}{\gamma} + \cancel{\alpha_1 \frac{{v_1}^2}{2g}} + \cancel{z_1} + h_p = \cancel{\frac{P_2}{\gamma}} + \alpha_2 \frac{{v_2}^2}{2g} + z_2 + h_f$$

$$\frac{\rho g h}{\gamma} + h_p = \frac{{v_2}^2}{2g} + z_2 + h_f$$

$$h_p = \frac{{v_2}^2}{2g} + z_2 + h_f - \frac{\rho g h}{\gamma}$$

(Metric units used here)

$$h_p = \frac{(1.25\frac{m}{s})^2}{2(9.81\frac{m}{s^2})} + 6.1\,m + 8.5\,m - \frac{\left(1000\frac{Kg}{m^3}\right) * \left(9.81\frac{m}{s^2}\right) * (2m)}{9810\ \frac{N}{m^3}}$$

$$\boldsymbol{h_p = 12.7\ meters}$$

Power

$$P = \gamma Q h_p = \left(9810\ \frac{N}{m^3}\right) * \left(0.063\ \frac{m^3}{s}\right) * (12.7\ m)$$

$$\boldsymbol{P = 7850\, Watts}$$

1000 gpm at 42 feet head (12.7 meters) yields a pump efficiency of 70% (Berkeley B6ZPL) (see attached pump curve)

$$\text{P} = 7850 \text{ Watts @ } 70\% ==> 11000\, W = \mathbf{11\ kW}$$

CONCLUSION

11 kilowatts are required to pump 1000 gpm with 42 feet of head losses using the Berkeley pump model number B6ZPL.

Pump Curve [*Water Pump Supply*, 2012]

BERKELEY

CENTRIFUGAL PUMPS

B SERIES

Pump Size: 6 x 8 x 9 L

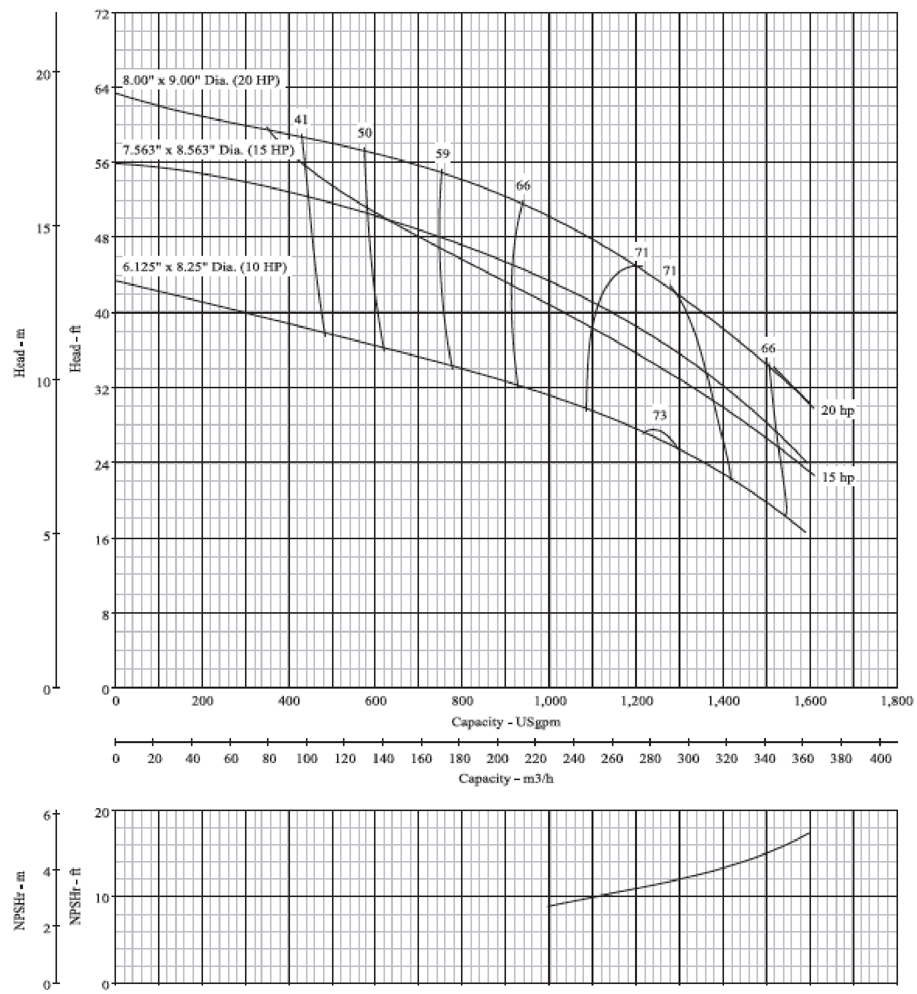
Model: B6Z_L

Curve No. 5838

Type	CCMD	FM CPLG	FM BELT	SAE	Hydraulic	AC Engine
Model	B6ZPL	B6ZRL	B6ZRL	B6ZQL		

King Pumps

Nominal RPM:	**1750**
Based on Fresh Water@	68 deg. F.
Maximum Working Pressure:	266 PSI



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Appendix H

Economics & Sensitivity Analysis

	Cost Estimate with Sensitivity Analysis			
Capital Costs	Expected	Min	Max	Comments
Excavation	28,000	10,000	85,000	1
Labor	1,500	500	2,500	2
6" Crushed Rock	9,750	8,300	11,000	3
6" Sand	3,750	3,200	4,300	3
Landscape Fabric	1,500	1,275	1,725	4
Pump and Motor	4,400	5,060	3,750	4
Pipe	14,000	6,000	21,000	5
Total	63000	34000	129000	
Capital costs amortized over 30 yrs				
2%	2800	1500	5800	6
3%	3200	1700	6600	
4%	3600	2000	7500	
5%	4100	2200	8400	
6%	4600	2500	9400	
Annual Operating Costs				
Profit Loss	750	0	1,500	7
Electricity	1,000	875	1,200	8
Pond Maintenance	2,000	800	4,800	9

P2O5 savings	(3,900)	(4,400)	(3,300)	10
Total	(150)	(2,725)	4,200	
Total annualized costs				
2%	2,650	(1,225)	10,000	
3%	3,050	(1,025)	10,800	
4%	3,450	(725)	11,700	
5%	3,950	(525)	12,600	
6%	4,450	(225)	13,600	
Cost per acre over 30 acres				
2%	90	(40)	330	
3%	100	(30)	360	
4%	120	(20)	390	
5%	130	(20)	420	
6%	150	(10)	450	

*Numbers in parenthesis indicate savings (negative costs).

1 Minimum price based on estimate provided by E.D. Hughes, Philomath, OR. Maximum cost based on removal rate per cubic yard provided by Knife River, Roseburg, OR.

2 Estimated miscellaneous labor costs

3 Expected price quoted from Knife River, Philomath OR. Minimum/Maximum prices determined by a 15% decrease/increase in expected cost

4 Price from online vendor. Minimum/Maximum prices determined by a 15% decrease/increase in expected cost

5 Price from Ernst Irrigation, Portland, OR. Min based on used pipe and shortest distance determined by field configurations. Max bases on new pipe and furthest distance determined by field configurations

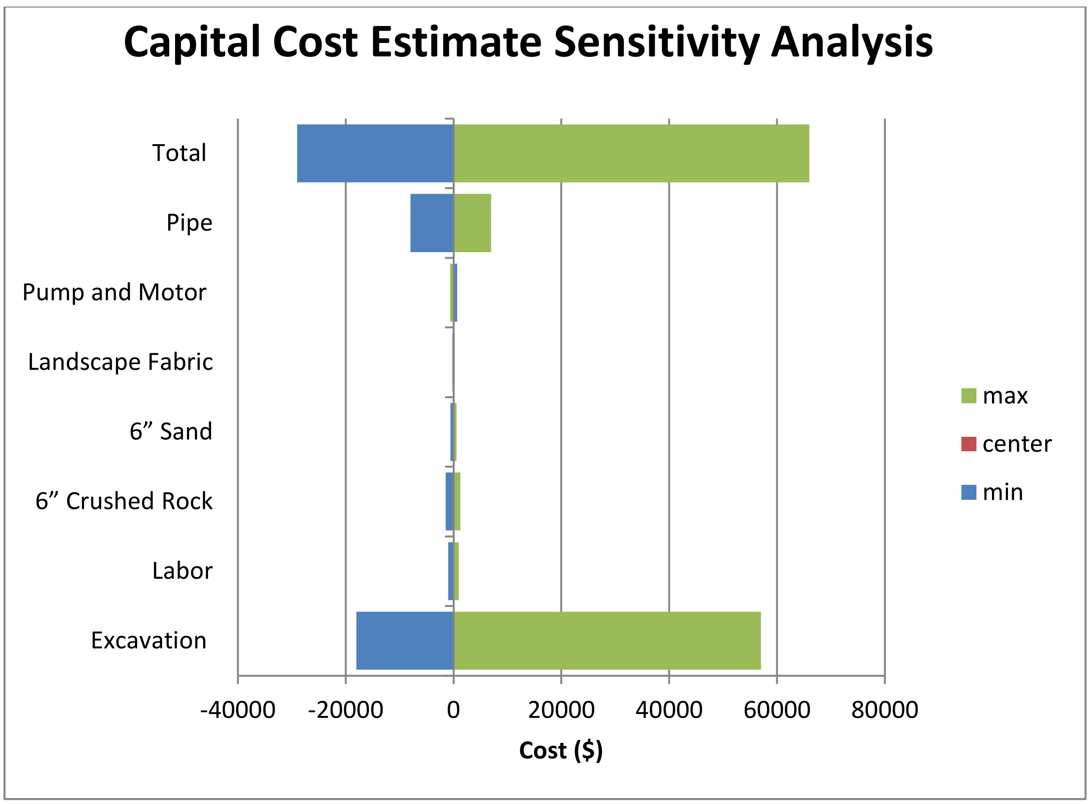
6 $A=P\ \{\ i(1 + i)^n/[(1 + i)^n - 1]\ \}$

7 This category considers potential loss of income due to pond placement on productive land.

8 Minimum/Maximum prices determined by a 15% decrease/increase in expected cost based on 1400 hour irrigation time for the season.

9 Minimum cost assume the use of polyacrylamide (PAM) to reduce field erosion and sediment accumulation in pond with an excavation cost of $\$2/yd^3$. Maximum cost assumes no PAM and an excavation cost of $\$6/yd^3$.

Sensitivity Analysis



COMMENTARY

Excavation costs are the driving factor in determining the economic feasibility of the pond. Decreasing these costs as much as possible is key.

Appendix I

Major System Components with embodied energy

Area of individual field = 30 acres

Component	Weight (lbs)	Major Material Type	**Embodied energy (kW-hr)**	kW-hr/$	MJ/$	References (see below)
Powermate PM0601250 - 12,500 Watt Electric Start Generator	360	Steel	**5520**	2.3	8.3	6, 7
Berkeley Pumps 8"X 6"X 9" Cast Iron 1800 RPM Flanged # B6ZPLS	465	Steel	**10120**	2.3	8.3	6,8
8 in Aluminum Pipe (7000' Used)	7940	Aluminum	**86800**	6.2	22.4	1,5,6
600 Yd3 2"- Crushed Rock	1500000	Rock	**68900**	5.3	19.1	6
600 Yd3 sand	1300000	Sand	**26500**	5.3	19.1	6
Landscape fabric 40,000 ft2	800	Plastic	**10600**	5.3	19.2	6
4" Drainage tile at bottom of the pond to pump	170	Plastic	**2120**	5.3	19.2	3,4,6

Energy used	Energy Used/Year		**Embodied energy (kW-hr)**	kW-hr/$	MJ/$
Annual operation					
Electricity	12000	kW			
Pond Construction			**27000**	1.8	6.63

SIZING OF PIPE AND ESTIMATE OF MATERIAL WEIGHT

Area of individual field [acres]= 30

Dimension of square field [ft]= 1140

Item	8" mainline from pump to head of furthest onion field	Gated pipe for 1/4 length of field being irrigated	Solid mainline - 3/4 length of field for furthest irr. set	4" Drainage tile at bottom of the pond to pump
Length [ft]	6858.9			
Length of section [ft]	40	30	40	NA
# of Sections	171	10	21	NA
Material	Aluminum	Aluminum	Aluminum	Polyethylene
Density [lb/ft3]	167	167	167	59.3
D [in]	10	10	10	6
Width of wall [in]	0.064	0.064	0.064	0.06
Cross-sectional Area of wall [ft2]	0.007	0.007	0.007	0.004
Volume [ft3]	48	2	6	4
Mass [lb]	8022	334	1000	234
Final estimate with +5% error	8500	360	1060	250
References (see below)	1,5	2,5	5	3,4

TOTAL MATERIALS ESTIMATE [lb]	
Aluminum	**7940**
Plastic	**170**

Appendix J

Decision Matrix for Alternative Selection

Technical Alternative ?		Calculation cell	Filt Pond	UV	CL	O3	ZVI
	Weightage						
Technical	35%						
Mature Technology	8	10	6	8	9	9	5
Scalable	8	10	9	9	9	9	5
Compatibility	6	10	6	4	4	3	6
Design Life	6	10	9	5	7	5	8
Operation and maintenance	7	10	7	5	5	4	7
Overall Technical score		35	26	23	25	22	21
Environmental	25%						
Chemical Byproducts	6	10	10	10	3	5	10
Soil Erosion	3	10	6	5	5	5	6
Water Use	5	10	4	5	5	5	4
Nutrient Pollution	3	10	6	5	5	5	6
Energy Use	6	10	7	4	7	2	7
Overall Environmental Score		25	9	9	8	7	9
Social	5%						
Physical Hazard	7	10	9	9	6	4	9
Public Acceptance	4	10	8	5	6	5	7
Farming Community Acceptance	9	10	5	5	8	5	5
Educational Opportunity	5	10	8	5	1	1	7
Overall Social score		5	4	3	3	2	3
Economic	35%						
Annual cost	9	10	5	4	6	4	5
Capital cost	9	10	4	4	6	4	3
Overall Economic Score		35	16	14	21	14	14
Overall Score							
	0	100	54	48	56	45	48
Scores Normalized to 100							

Notes on scoring:

Criteria	Meaning
Scalable	10 = Can be scaled for any farm size.
Compatibility	10 = Integrates seamlessly into existing operations.
Design Life	10 = 20 year design life.
Operation/Maintenance	10 = Requires no maintenace.
Energy Use	10 = No energy use.
Physical Hazard	10 = No hazard exists
Public Acceptance	10 = Public will have no objections
Farming Community Acceptance	10 = Farmers will have no objections

Scale	Description
1	extremely Low
2	very low
3	low
4	moderately low
5	moderate
6	moderately high
7	high
8	very high
10	outstanding

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