North Creek Forest Lower Restoration Site Irrigation

In Partnership With:
Friends of North Creek Forest

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Introduction

Our team was partnered with the Friends of North Creek Forest organization. They are an organization that is dedicated to the preservation and restoration of "Bothell's Last Great Forest," the North Creek Forest. Our partner works to remove invasive species of plants, primarily blackberry bushes, from the forest and transplants plant species that were once native to the forest in "restoration sites" to replace the invasive ones. These restoration sites are monitored and watered over a span of two to three years, and a new restoration site is planted every year.

Our partner has restoration sites in the upper and lower parts of the forest. The lower part of the forest has two restoration sites that require irrigation for their plants. Previously, our partner watered the plants via a hose attached to a nearby house, which proved to be too expensive. In order to reduce cost, they have decided to switch to water from the fire hydrant; however, only paid staff from their organization are able to access the hydrant. This means that the volunteers are not able to access the hydrant water, which is not ideal for our partner's purposes, as they have few paid staff members available to water as often as is needed.

Problem Statement

Our partner has given us the task of designing a system to allow the volunteers to use the hydrant to water the restoration sites in the lower part of the forest. As new sites are planted each year, and old sites are graduated off of watering each year, the system would be ideally mobile. Our partner gave us several suggestions for watering methods. The first suggestion would be to use a tank to house water from the hydrant, so the volunteers can use the water from the tank after the water is piped in from the hydrant by a staff member. The next suggestion was that we could find some way to capture rainwater, and store that in the proposed tank as a way to lower the consumption of hydrant water. The last suggestion was that we find a way to incorporate a drip irrigation system into the design so that a volunteer would only need to turn on the system and monitor it as the watering was done automatically.

Design/Solution:

Our system will consist of using a fire hydrant, a 500 gallon tank, hoses, one inch diameter PVC pipe, PVC-to-hose adapters, PVC tee fittings, and ball valves. These components play an important role in making the system function smoothly and properly. First, the hydrant will be used by a staff member of our partner's organization to fill the tank at some point before each watering session. Approximately 450 feet of low friction (fire) hose will be used to transport the water from the hydrant to the tank. This transport system is best suited to do the job because the hose will easily disassemble and can easily be stored when not in use. The filling-time for this system will be low, at around two minutes as shown in Appendix II. Next, approximately 450 feet of PVC pipe will be used to transport the water from the tank down to each of the watering sites. PVC tee fittings will be used to redirect the flow of the water to branch out to each of the targeted sites. Subsequently, valves will be connected to each of these tee fittings to regulate and begin the watering at each site individually. Each valve will need a PVC-to-hose adaptor to attach a hose; allowing versatility of movement when watering the restoration sites.

In order to be able to design a gravity-fed watering system, the water source must be high enough in elevation to produce enough pressure to transport the water downhill to each targeted site. We chose a location for the tank behind a ruined building near the restoration sites, which is 450 feet from the hydrant and 24 feet above the lowest watering site, because the location is elevated and the ground is fairly leveled. After choosing a suitable location for the tank, the fluid dynamics of the system were studied by our team to show that the hydrant produced enough pressure to transport the water uphill to the tank, and that the tank locations allows gravity to transport the water back downhill through the PVC pipes and hoses to each of the targeted sites smoothly. The team's calculations in Appendix II and III show that stationing the tank approximately 450 feet away from the hydrant and approximately 24 feet above the lowest watering site should be sufficient for a gravity fed watering system. The calculations in the Appendices also show that there should be around 265 gallons of water flowing into the tank per minute, and that there should be at least 21 gallons per minute of water flowing through the taps at each watering site when each tap is operated one at a time.

Narrative

We looked into each of the suggestions given to us by our partner. We initially started with the idea of using a drip irrigation system being fed by a tank, and were looking into how such a system would work. We met with Emily Sprong, the executive director of our partner organization, to learn more about the problem and survey the restoration sites. We were shown several potential locations to place the tank and where each of the restoration locations were. We later came back to measure approximate distances between the available fire hydrant, potential tank locations, and restoration sites. We also returned to get approximate measurements on hydrant flow rate. Elevations for each site were provided for us by our partner.

Next, we met with an official city engineer, Eddie Low, to gain some insight on how to put together the chosen irrigation system. He also gave us insight on what required permits to get from the city to build the chosen system and other possible systems best suited for the given problem. He gave us some ideas about alternative ways we could go about irrigating the site. He gave us the idea of tapping directly into the water main with an automated controller to feed to the drip system at scheduled times, which would avoid the need for a tank altogether. He also informed us that there might be a way to use housewater in a cheaper manner by getting a meter to monitor the amount used for the irrigation at a discounted rate. During the meeting, he informed us that a permit was not necessary to acquire from the city to implement the team’s chosen irrigation system.

We then began to look for information on our own. With some help from another professional engineer, Don Hill, we were able to learn some information about how drip systems work. Using this information we determined it would be difficult to design a drip system for our site. We would not be able to place drip emitters closer than one foot away from one another, and some groupings of plants are much closer than that, and in groups. This would likely require different types of emitters for different groups of plants. We also found that we would lose water pressure in the pipes due to each emitter. This would mean we would have to calculate the loss in pressure from each branch and the pressure loss from each emitter. We would also have to ensure the pressure getting to each type of emitter is in the operating ranges of pressures, which would vary by the type of emitter used at each location. The lack of a topographical map of the restoration sites made this much harder to do as we would have to measure distances, and branch locations on our own in order to make an accurate design.

In terms of tapping into the city water main, we found little information, but what we did find was that it would likely cost several thousand dollars. In terms of using house water at a discounted price, we were unable to find any relevant information. We ran calculations as shown in Appendix II and III to find how well the water would be piped up to the potential tank location from the hydrant, and how well it would be piped down from the tank location to the watering locations without a pump. We ran calculations using the worst case scenarios of minor losses and took major loss equations from a few online sources. These showed what we believe to be acceptable flow rates for our system. We also ran a rudimentary cost analysis in Appendix I.

All of this led us to decide on the system we are proposing. This would involve piping water up to the tank from the hydrant, and piping it back down to a couple of spigots near the restoration sites to allow for watering from a hose. We believe this to be the best system because it is a simple design and should be relatively cheap, as shown in Appendix I.

Conclusion

Our design to supply water to accessible spigots through the hydrant and tank, has several aspects that should be noted. First of all, our design assumes that there is only one spigot active at a time for optimal performance of the system; to use both at the same time would require a more in depth analysis, but could be done. Because additional restoration sites are planted each year, additional analyses should be performed before each planting to ensure the system will still be functional. It was suggested that we ensure a mobile system design so that it could be moved as new restoration sites replace the current ones in completely new locations. The simplicity of the team's designed system allows for an easy disassembling procedure, easy reassembling procedure, and easy transporting of the system. This movement would require its own set of analyses to ensure the system will work.

APPENDIX I

Parts List:
1 in x 10 ft Sch 40 PVC pipe (Home Depot): $3.93 each x 45 segments = $176.85
1 in Sch 40 PVC Coupler (Home Depot): $0.47 each x 10 couplers = $4.70
1 in Sch 40 PVC Tee (Home Depot): $0.96 each x 1 = $0.96
1.25 in x 100 feet fire hose (Amazon): $159.13 x 5 segments = $795.65
500 gallon water tank (watertanks.com): $416.33 x 1 = $416.33
1 in PVC ball valve (Home Depot): $5.42 x 2 valves = $10.84
.5 in PVC Garden Hose Adapter (Home Depot): $2.59 x 2 adapters = $5.18
1 in x .5 in PVC reducer bushing (Home Depot): $0.88 x 2 bushings = $1.76

Total: $1412.27

Starting Volume: $V_i = 73\ ft^3$ Time elapsed $t = 11.27\ s$

Ending Volume $V_o = 72.5\ ft^3$

Flow Rate $Q = \dfrac{73 - 72.5\ ft^3}{11.27\ s} = \dfrac{.044\ ft^3}{s} = \dfrac{19.8\ gal}{min}$

Using 1.25" fire hose, of $L = 450$ feet, $Q_{in} = 19.8\ gal/min$; $P_i = 40$ psi

$(H_L)_{major}$ (in PSI) $= 14.1$ PSI (frictionlosscalculator.com) $\rightarrow$ h_L (in feet) $= \dfrac{2030\ lb/ft^2}{62.4\ lb/ft^3} = \boxed{32.5\ ft}$

$\Delta P = \gamma h_L$ $h_L = \dfrac{\Delta P}{\gamma}$

→ Because hose bends gradually, and no fittings prior to tank, we choose to disregard minor losses.

$$z_1 + \frac{P_1}{\rho g} + \frac{V_1^2}{2g} = z_2 + \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + h_L$$

$z_2 - z_1 = 450$ ft

$P_1 - P_2 = 0$

$h_L = .22$ ft

$z_2 - z_1 = 24$ ft

$g = 32.2\ ft/s^2$

$V_1 = \dfrac{Q}{A} = \dfrac{.044\ ft^3/s}{\pi\left(\frac{.75}{12}\ ft\right)^2} = 3.6\ ft/s$

$P_1 - P_2 = 40$ psi $= 5760\ lb/ft^2$

$\gamma = 62.4\ lb/ft^3$

$$\frac{V_2^2}{2g} = z_1 - z_2 - h_L + \frac{V_1^2}{2g} + \frac{(P_1 - P_2)}{\gamma}$$

$$= -(z_2 - z_1) - h_L + \frac{V_1^2}{2g} + \frac{(P_1 - P_2)}{\gamma}$$

$$V_2 = \sqrt{V_1^2 - 2g(z_2 - z_1) - 2g h_L + 2g\frac{(P_1 - P_2)}{\gamma}}$$

$$V_2 = \sqrt{3.6^2 - 2(32.2)(24) - 2(32.2)(32.5) + \frac{2(32.2)(5760)}{62.4}}$$

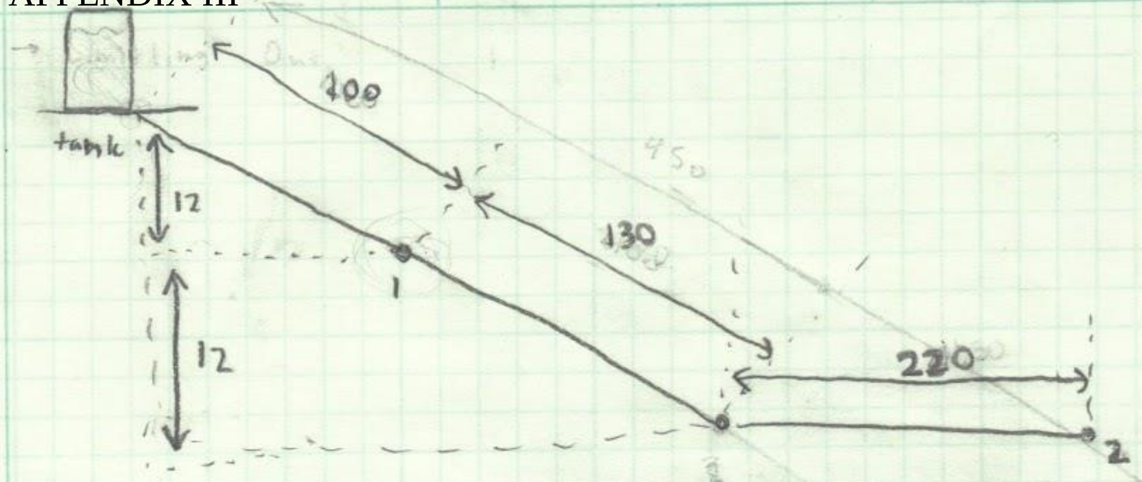
$$V_2 = \sqrt{12.96 - 1545.6 - 2093 + 5944.6} = 48\ ft/s$$

$$Q_2 = AV_2 = (48)\left(\pi\left(\tfrac{.75}{12}\right)^2\right) = .59\ ft^3/s$$

tank capacity = 500 gallons = 66.84 ft^3

Tank fill time $= \dfrac{66.84\ ft^3}{.59\ ft^3/s} = 113.3\ s \approx 2$ min

APPENDIX III



Assume:
- worst case scenario (tank almost empty)
- piping is all 1" Sch 40 PVC
- 1" Sch 40 PVC Tee Fitting at watering sites 1-2
- fully opened globe valve and threaded T-joint at watering sites
- only one site being watered at a time (only 1 valve open at a time at any site)

$\bar{V} = \frac{V_2}{2}$

engineer toolbox.com $f = 0.2083\left(\frac{100}{C}\right)^{1.852} \cdot q^{1.852} / d_H^{4.8655}$ (f: ft H₂O/100 ft; q: gpm; d_H: in)

$C = 150$ for PVC

$d_H = 1.049$ in

$q = \frac{V_2}{2}\pi\left(\frac{d_H}{24}\right)^2 \cdot 448.8$

$K_{L_1} = 10 + 2$

$K_{L_2} = 10 + 2 + 0.9$

$h_L = (f \cdot l + K_L)\left(\frac{V_2}{2}\right)^2 / 2g$ (hundred feet)

$z_1 = \frac{V_2^2}{2g} + h_L = \left(\frac{f \cdot l + K_L}{4} + 1\right)\frac{V_2^2}{2g}$

case 1 $12\text{ ft} = \left(\frac{0.2083\left(\frac{100}{150}\right)^{1.852}\left(\frac{V_2}{2}\pi\left(\frac{1.049}{24}\right)^2 448.8\right)^{1.852} / (1.049)^{4.8655} \cdot 1 + 12}{4} + 1\right)\frac{V_2^2}{2 \cdot 32.2}$

$V_2 \approx 8.9$ ft/s $q_2 \approx 23.9$ gpm

case 2 $24\text{ ft} = \left(\frac{0.2083\left(\frac{100}{150}\right)^{1.852}\left(\frac{V_2}{2}\pi\left(\frac{1.049}{24}\right)^2 448.8\right)^{1.852} / (1.049)^{4.8655} \cdot 4.5 + 12.9}{4} + 1\right)\frac{V_2^2}{2 \cdot 32.2}$

$V_2 \approx 7.9$ ft/s $q_2 \approx 21.2$ gpm