County: Island

Grant No: SEANWS-2014-IsCoPH-00002

PROJECT TITLE: Effectiveness of Phytoremediation for Removing Contaminates from Water

TASK NUMBER: 2.2 Phytoremediation

DELIVERABLE: 2.5 Data from lab analysis as aggregated data and final report for the entire phytoremediation project.

PERIOD COVERED: 2010-2015

DATE SUBMITTED: 9/25/2015

PUGET SOUND PARTNERSHIP

This project has been funded wholly or in part by the United States Environmental Protection Agency. The contents of this document do not necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

Effectiveness of Phytoremediation for Removing Contaminates from Water

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September 2015

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Introduction

Waste water from homes, farms and towns around the Puget Sound causes problems in both the ecological health of the ecosystem and the economic health of fisheries and tourism. Some larger communities have sewer treatment plants that meet tertiary standards by using mechanical and chemical engineered systems. Smaller communities should have the opportunity to also use the treatment capacity of lagoon storage, wetlands, agricultural soil, and root zone treatment when crop land is close. Thus a direct discharge from the waste water treatment plant into salt water can be replaced by lagoon storage, irrigation, plant uptake and soil microbe disinfection. Water would be released by evaporation, transpiration, and percolation through roots to subsurface drainage pipes for subsequent discharge or percolation to groundwater.

Phytoremediation is the use of plants and soils to remove contaminates from water. There are no total phytoremediation waste water treatment systems in the Puget Sound area. A compelling reason for choosing Coupeville and Ebey's Prairie to test full-scale waste water phytoremediation treatment is that the area is in the rain shadow from the Olympic Mountains and only receives about 18 inches of rainfall per year. This results in a chronic water shortage for optimum agricultural production. Ebey's Landing National Historic Reserve is a National Park with farm land permanently protected as farm land for farmers.

Central Whidbey Island is also a sole-source aquafer meaning that only water falling on the land surface of the Island can percolate through the soil to replenish the aquafer for extraction by wells. Most of the fresh water consumed in Coupeville homes is treated in the Coupeville Treatment Plant and released into the salt water of Penn Cove. An average of over 150,000 gallons of water is released per day from the Treatment Plant. This system of releasing treated waste water into salt water only amplifies the pressure on the Island's aquafer. Stream outflow and storm drain outflows also release fresh water into Penn Cove. This removes this water as a source of replenishment for the Central Whidbey aquafer. Would there be a way to economically treat this water and somehow return it to the aquafer?

This report summarizes 5 studies on the effectiveness of phytoremediation at removing contaminates from storm water and effluent from a community sewer treatment plant.

Chapter 1: Phytoremediation treatment of storm water

A project was designed to test the effectiveness of filtering storm water through roots and soil in removing contaminates. This project was a joint effort of the Town of Coupeville, National Park Service, Ecolotree, Inc. and the Island County Marine Resources Committee. The storm water project was located to receive the storm water from the impervious surfaces and roofs of a 7-acre commercial development and a small parking lot. A ditch designed to remove the storm water from this development was converted to a phytoremediation swale. The land for the swale is immediately adjacent to an asphalt parking lot which is 40 feet wide and 250 feet long. All storm water from this parking lot also drains into the swale area. Land for the swale project was donated by the National Park Service.

Soil from the ditch and surrounding area were removed and the bottom was graded to maintain flow of the water for the length of the swale. A perforated drain pipe was installed in the bottom of the swale to catch the water that percolates through the roots and soil. This pipe was wrapped with cloth to prevent roots from entering the drain pipe. The flat surface of the swale was approximately 12 feet across. After the pipe was installed, the swale area was refilled to a depth of about 2 feet over the drain pipe. Compost and sand were added to the soil during the refilling process. Grass seed was planted on the surface of the refilled area and the berm opposite the parking lot. Equipment and labor to construct the swale were donated by the Town of Coupeville.

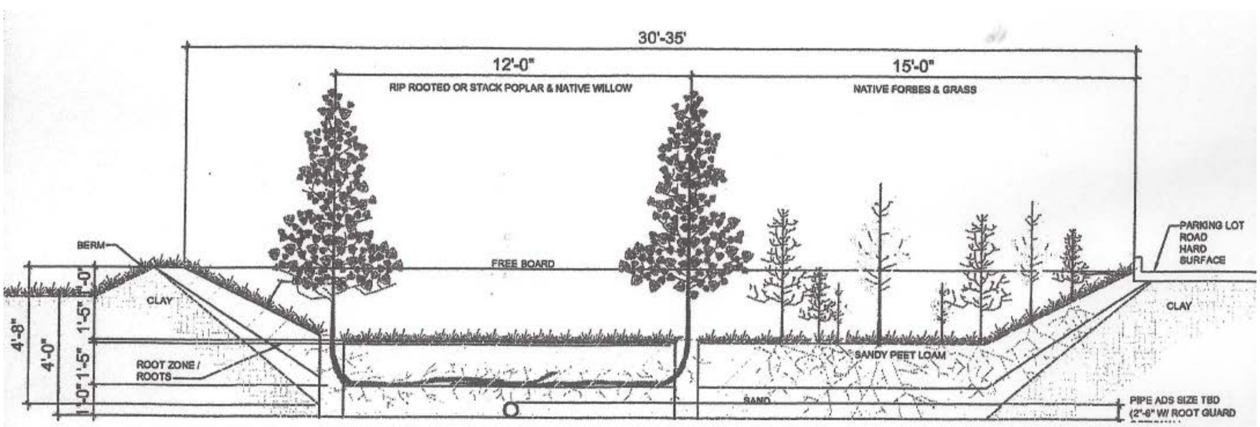

Figure 1-1. Diagram of Phytoswale Rain Garden in Coupeville, WA. Design by Lou Licht, Ecolotree

Native willow and hybrid poplar shoots, 6 feet and 10 feet in length respectively, were planted in trenches about 8 inches below the surface of the swale in November, 2010. The trenches were dug perpendicular to the flow of the swale and were about 10 feet in length. A willow shoot was planted on one end of each trench and a poplar shoot was planted from the other end of the trench, overlapping in the middle. In the next trench, the placement of the willow and poplar shoots was reversed. The shoots were planted to allow about 6 inches of shoot to be exposed out of the trench. Willow and poplar shoots that are planted underground will root the full length of the covered shoot. This dense design was used to develop a mass of tree roots under the grass cover that would reach into the deeper soil.

The summer of 2011 was a dry summer and some of the planted trees did not survive into the next winter.

Figure 1-2. Digging trenches for tree planting in the swale.

Figure 1-3. Swale including underlying drain pipe outlet.

The entry into the phyto swale and the outlet of the underlying drain pipe were constructed to allow the collection of swale input water and percolated output water. Input and output samples were taken every 2 weeks during the winter months following the start of the rainy winter season. At some of the collection dates there would be either no input water flowing or no output water flowing. So both input water and output water were not available at each of the collection dates. Most of the input and output water samples were collected during January, February, and March of each sampling year.

Filtration time from surface water to water leaving the outflow pipe was not measured, so the amount of time from water entering the swale until it flowed from the outlet pipe is unknown.

Water samples collected were sent to Edge Analytical, Burlington, WA for analysis. Measurements taken included pH, conductivity, dissolved oxygen, turbidity, fecal coliform, nitrate, ortho phosphorous, total copper, dissolved copper, zinc, lead, and hardness. Not all of these measurements were taken on all of the sampling years as can be seen in the data tables.

Results

Table 1-1. The effect of filtering storm water through soils and roots on nitrate, phosphate, copper, zinc and lead levels

Year	Nitrate mg/L	Phosphate mg/L	Total Copper mg/L	Dissolved Copper mg/L	Zinc mg/L	Lead mg/L
2010-2011						
Inflow (n=6)	.20	NM	.004	NM	.014	.0005
Outflow (n=5)	.08	NM	.003	NM	.000	.0001
2011-2012						
Inflow (n=6)	.19	.08	.004	NM	NM	NM
Outflow (n=6)	.10	.08	.004	NM	NM	NM
2012-2013						
Inflow (n=7)	.34	.13	.005	.003	NM	NM
Outflow (n=7)	.23	.08	.004	.004	NM	NM
Overall Averages						
Inflow	.24	.10	.004			
Outflow	.14	.08	.004			

NM – Not Measured

Filtering storm water through soil and roots removed about half of the nitrate and some of the phosphate from the storm water. These results are consistent with other studies.

Total copper levels were low in this storm water and filtering through soil and roots resulted in a slight reduction of readings. Dissolved copper levels were slightly higher in outflow water than in input water perhaps indicating some modification of copper containing molecules in the filtration process.

Zinc and lead were measured during the first year of this trial. Results indicated that nearly all of these 2 metals were removed in the filtration process. Therefore, we discontinued the measurement of these 2 metals.

Table 1-2. The effect of filtering storm water through soils and roots on pH, conductivity, dissolved oxygen, turbidity, fecal coliform, and hardness levels

Year	pH	Conductivity µS/cm	Dissolved Oxygen mg/L	Turbidity NTU	Fecal Coliform cfu/100ml	Hardness mg/L
2010-2011						
Inflow (n=6)	7.6	292	10	58.6	28.0	129
Outflow (n=5)	7.0	359	1	9.8	17.5	153
2011-2012						
Inflow (n=6)	7.5	257	10	13.5	54.1	104
Outflow (n=6)	7.0	288	4	3.3	4.5	130
2012-2013						
Inflow (n=7)	7.0	274	9	63.3	119.6	110
Outflow (n=7)	6.6	238	5	5.8	21.0	90
Overall Averages						
Inflow	7.4	274	9.7	45.1	67.2	114
Outflow	6.9	295	3.3	6.3	14.3	124

The pH of the outflow water was about 0.5 lower than the pH of the inflow water as has been shown in other phytoremediation studies.

The conductivity of the inflow water was higher than the conductivity of the outflow water in the first two years of this trial. The conductivity of the last input sample collected in 2013 had a higher reading than any other sample collected in this trial. Removing that one sample from the average, resulted in all of the outflow averages being higher than the inflow average for 2012-2013 like the other sampling years.

Filtering storm water through soil and roots results in lower dissolved oxygen levels, lower turbidity readings and lower fecal coliform counts.

Differences in hardness readings of inflow and outflow water were not consistent across the years. Hardness readings were higher in outflow water than in inflow water in 2 of the 3 years of data collection.

Conclusions

1. Contaminant levels were not as high as expected in this storm water.
2. Filtering the water removed about half of the nitrate and some of the phosphate.

3. Filtering the water removed most of the zinc and lead but not the copper in the storm water.
4. pH levels in the filtered water were lower than the levels in the storm water.
5. Filtering the storm water resulted in lower levels of dissolved oxygen, turbidity and fecal coliforms.
6. Results of filtering the storm water were inconsistent for conductivity and hardness.

Chapter 2: Phytoremediation treatment of Treatment Plant effluent

A project was designed to test the effectiveness of filtration through different growing mediums and tree roots to remove contaminates from effluent water from a sewer treatment plant. Water tested was from the Coupeville Treatment Plant in Coupeville, WA, a town of about 1800 people with no heavy industry. The treatment plant emits Class B water into Penn Cove following ultraviolet treatment to kill bacteria.

A group of 15 boxes were developed to test the filtration of the effluent water. The internal dimensions of the boxes were 12 inches by 12 inches by 34 inches. The external shell of the boxes was 3 inches of Styrofoam surrounding the sides and bottom of each box. A 0.75 inch hole was bored into the side of each box at the bottom of the internal opening in the boxes. A 30 inch piece of 0.75 OD plastic tubing was installed in the hole across the bottom of the box opening. Holes were drilled in this tubing to allow the water to drain from the boxes. The tubing inside the box was covered with cloth fabric to prevent the roots from entering the drain tubes.

Figure 2-1. Phytobox setup containing perlite-only with trees planted.

Twelve of these phytoboxes were planted with 4 shoots of hybrid poplar trees and 2 shoots of willow trees. Each of the tree shoots were approximately 40 inches in length. Poplar and willow shoots will root the whole length of the shoot that is underground. Each of the shoots was planted the entire depth of the phytoboxes, resulting in about 32 inches of shoot below the surface of the growing medium in the phytoboxes. The phytoboxes were planted with 6 shoots to accelerate the growth of a dense mass of tree roots to assist with the filtration.

Three of these phytoboxes were filled with perlite, an inorganic volcanic rock.

Figure 2-2. First sampling of phytoboxes at the Coupeville Treatment Plant on November 4, 2011.

Three of these phytoboxes were filled with a sandy soil common to the agricultural land in central Whidbey Island.

Three of the phytoboxes were filled with sandy soil with a small (2qt.) amount of compost added.

Three of these phytoboxes were filled with soil with higher clay content from central Whidbey Island mixed with perlite (50/50) to insure perk of the effluent water. The higher clay soil was taken from an agricultural area on central Whidbey where water tended to stand following a rain.

Three of the phytoboxes were filled with only perlite with no trees to give a measurement of perlite-only filtration on contaminant removal.

The phytoboxes were filled with the growing mediums and trees planted on June 20, 2011. The phytoboxes were watered with well water from June 20 until July 15. From July 15 until September 9, the phytoboxes were watered with a mixture of sewer effluent water and well water. The phytoboxes were installed at the Coupeville Treatment Plant on September 10, 2011 and watered only with effluent from that date.

Not all of the tree shoots that were planted in the boxes grew. In each of the 12 phytoboxes planted with trees, 4, 5, or 6 of the shoots grew. The growing medium in which the tree shoots were planted did not affect the number of tree shoots that grew. Therefore, the phytoboxes were considered equal, regardless of the number of growing shoots.

An automatic watering system was established to apply water to all of the phytoboxes at once. The automatic system allowed different number of waterings per day as well as watering for different lengths of time at each watering. Phytoboxes were watered from 1 to 4 times per day depending on season of year and ambient temperature. Phytoboxes were watered for 1 to 3 minutes per watering as well. The usual amount of water added to a phytobox per minute of application was about 600 ml.

The water applied to the phytoboxes was taken from the effluent chamber of the Coupeville Treatment Plant. The Coupeville plant is a secondary wastewater treatment plant with the following components:

1. Headworks providing grit settling and bar screening.
2. Racetrack shaped aeration basin.
3. Secondary clarifier to settle out solids.
4. Aerobic digester to produce a product suitable for disposal.
5. Ultra Violet treatment of the final product prior to release to the effluent pipe into Penn Cove.

Effectiveness of the phytoboxes at removing contaminates was measured at various times following the installation of the phytoboxes at the Coupeville Treatment Plant. The drain tube from each phytobox was directed into a clean, empty sample bottle, so there were output sample bottles evaluated for each phytobox at each sampling date. In addition, a sample of the input water to the phytoboxes (Treatment plant effluent) was evaluated.

Water samples were collected 5 times when the trees were not in an actively growing condition (senescent) on 11/04/2011, 11/18/2011, 03/26/2012, 03/12/2013, and 12/16/2014. Water samples were collected when the trees were in an active, leafy condition (leafy) on 08/31/2012, 10/26/2012, and 10/24/2014. Water quality measures of samples collected in 2011, 2012, and 2013 were done by 2 volunteers who had extensive previous experience using Chemetric kits for testing water quality from various sources. Testing of the water for nitrate (kits 6905, 6901), phosphate (kits 8500, 8510) and hardness (kit 1705) was done with kits from CHEMetrics, Inc. from Midland, Virginia. Acidity (pH) was measured using a Thermo Orion 420A+ and conductivity was measured by YSI Model 85. These 2 pieces of equipment were those used by the Treatment Plant for their routine water quality testing. The water quality samples collected in 2014 were evaluated by Edge Analytical, Burlington, WA with financial assistance from the National Park Service.

Results

Results will be presented by water quality measure.

Table 2-1. Nitrate levels (mg/L) of plant effluent (n=1) and averages of the measurements (n=3) of the phytoboxes with the different growing mediums

Trees Senescent

		GROWING MEDIUM				
Date	*Plant Effluent*	*Perlite Only*	*Perlite + Trees*	*Heavy Soil + Perlite*	*Sandy Soil*	*Sandy Soil + Compost*
11/04/11	*7.5*	*2.3*	*1.7*	*3.0*	*2.7*	*1.3*
11/18/11	*13.5*	*2.0*	*0.0*	*1.0*	*1.0*	*0.0*
03/26/12	*8.6*	*0.1*	*0.2*	*3.0*	*1.2*	*1.3*
03/12/13	*9.3*	*1.2*	*1.0*	*0.4*	*0.0*	*0.0*
12/16/14	*9.1*	*NM*	*ND*	*ND*	*ND*	*ND*

Trees Leafy

		GROWING MEDIUM				
Date	*Plant Effluent*	*Perlite Only*	*Perlite + Trees*	*Heavy Soil + Perlite*	*Sandy Soil*	*Sandy Soil + Compost*
08/31/12	*12.0*	*3.3*	*1.2*	*0.1*	*0.0*	*0.0*
10/26/12	*4.5*	*3.0*	*0.1*	*0.1*	*0.3*	*0.0*
10/24/14	*11.5*	*NM*	*ND*	*ND*	*ND*	*ND*

NM – Not Measured
ND – Not Detectable

Nearly all of the nitrate was removed by the growing mediums with trees. Most of the nitrate in the effluent water was removed by the phytoboxes containing only perlite without any trees. A possible explanation is that the microbial populations on the perlite particles utilized most of the nitrate in the effluent. Another possible explanation is the release of nitrogen into the atmosphere through denitrification. Differences among the growing mediums containing trees were very small. Time of year of the sampling had little effect on nitrate levels in the effluent and the output water from the phytoboxes. There is no indication that the continuous application of high nitrate water to the phytoboxes resulted in an increase in nitrate content of the output of the phytoboxes.

Table 2-2. Total Phosphate levels (mg/L) of plant effluent (n=1) and averages of the measurements (n=3) of the phytoboxes with the different growing mediums

Trees Senescent

		GROWING MEDIUM				
Date	*Plant Effluent*	*Perlite Only*	*Perlite + Trees*	*Heavy Soil + Perlite*	*Sandy Soil*	*Sandy Soil + Compost*
11/04/2011	*10.0*	*3.6*	*2.7*	*2.5*	*4.0*	*6.0*
11/18/2011	*6.3*	*2.3*	*1.3*	*0.2*	*0.9*	*4.1*
03/26/2012	*3.0*	*0.8*	*0.7*	*0.3*	*0.3*	*1.3*
03/12/2013	*6.5*	*3.3*	*0.3*	*0.5*	*0.2*	*1.2*

Trees Leafy

		GROWING MEDIUM				
Date	*Plant Effluent*	*Perlite Only*	*Perlite + Trees*	*Heavy Soil + Perlite*	*Sandy Soil*	*Sandy Soil + Compost*
08/31/12	*20.0*	*10.2*	*4.3*	*0.1*	*3.7*	*5.2*
10/26/12	*9.0*	*9.3*	*5.7*	*0.0*	*3.5*	*2.3*

Total phosphate varied more than nitrate in the plant effluent water and there was more variation in the proportion of the total phosphate in the plant effluent water removed by the filtration through the phytoboxes. But in general, filtering the water through the phytoboxes lowered the level of total phosphate in the phytobox output. In general, the perlite-only phytoboxes were less effective in removing total phosphate than the phytoboxes containing trees. Phytoboxes containing heavy soil + perlite removed more of the total phosphate in the plant effluent than the other growing mediums.

Table 2-3. Averages of other measures of water quality of plant effluent (n=1) and measurements (n=3) of the output of the phytoboxes with the different growing mediums

		GROWING MEDIUM				
Quality Measure *Leaf Status*	*Plant Effluent*	*Perlite Only*	*Perlite + Trees*	*Heavy Soil +Perlite*	*Sandy Soil*	*Sandy Soil +Compost*
pH						
Senescent (n=12)	*10.7*	*9.4*	*9.2*	*9.3*	*9.2*	*9.7*
Leafy (n=6)	*7.5*	*7.2*	*7.3*	*6.9*	*6.9*	*6.7*
Hardness (mg/L)						

Senescent (n=12)	*153*	*169*	*199*	*173*	*133*	*158*
Leafy (n=3)	*200*	*235*	*220*	*223*	*227*	*227*
Conductivity (µS/cm)						
Senescent (n=12)	*1106*	*1010*	*1070*	*1073*	*1055*	*1105*
Leafy (n=6)	*1293*	*1126*	*2718*	*3100*	*2498*	*2683*

pH levels in the water filtered through the phytoboxes were lower than the levels in the plant effluent regardless of the presence or absence of trees, regardless of the growing medium in the phytoboxes, or whether trees were leafy or not. The results for hardness and conductivity were mixed with no apparent effects of filtration, growing medium, or growing status of the trees.

Conclusions

1. Most of the nitrate in the plant effluent was removed by the filtration through the phytoboxes.
2. Level of total phosphate was lower in the phytobox outputs than in the plant effluent.
3. pH was lower in the phytobox output than in the plant effluent.
4. Filtration, growing medium and growing status did not appear to affect hardness or conductivity.

Chapter 3: Phytoremediation treatment of contaminated stream water

The Island County Department of Public Health has been evaluating the outflow water from the intermittent stream entering Admiralty Inlet at Ebey's Landing for the past few years. This outflow water is a combination of road, agricultural field, agricultural building, and underground field drain runoff. The water in this stream is sampled and analyzed for contaminates twice per month by Island County Public Health and has been found to be very contaminated with nitrates and fecal coliform.

Figure 3-1. Stream outflow at Ebey's Landing

Water samples were collected from this stream flowing into Admiralty Inlet at Ebey's Landing during the month of April 2013. This water was used to irrigate the phytoboxes located at the Coupeville Treatment Plant. Stream flow water was collected in plastic jugs on April 1, 4, 8, 11, 15, 18, 22 and 25. Twelve phytoboxes were watered with 1 gallon of stream water each day of this project, resulting in approximately 1.25 inches of stream water applied per day to each phytobox. These phytoboxes were not watered with sewer effluent during this project. Phytoboxes which were irrigated with Ebey's Landing water were the 9 phytoboxes containing heavy soil + perlite, sandy soil, and sandy soil + compost.

Outflow from the 9 phytoboxes was collected overnight on April 29 and 30. Samples of the stream flow water collected on April 22 and 25 were composited and refrigerated to analyze for the composition of the input water.

The input sample and the output samples were analyzed using the arrangement of Island County Public Health with Edge Analytical, Burlington, WA. The composite sample of April 22+25 was not analyzed for fecal coliform. However, water samples collected by Island County from this stream flowing into Admiralty Inlet at Ebey's Landing on April 11 and 25 contained 2800 and 32 cfu/100 ml. respectively, indicating fecal coliform contamination.

Results

Table 3-1. Effect of filtering water from the outflow (n=1) of the stream at Ebey's Landing through the phytoboxes (n=3) on nitrate, phosphate and fecal coliform levels

		SOIL MEDIUM		
	Stream Outflow	*Heavy Soil +Perlite*	*Sandy Soil*	*Sandy Soil + Compost*
Nitrate (mg/L)	*29.6*	*1.2*	*0.0*	*0.0*
Phosphate (mg/L)	*0.77*	*0.04*	*0.47*	*0.99*
Fecal coliform (cfu/100ml)	*NM*	*0.60*	*0.00*	*0.00*

NM – Not Measured

Nitrate – Nitrate levels in the Ebey's outflow water were about 3 times as high as the effluent from the Coupeville Treatment Plant. But, the results were the same as found from filtering the treatment plant effluent through the phytoboxes. Basically, filtering the Ebey's outflow water through these phytoboxes removed nearly all of the nitrate contamination.

Phosphate – Phosphate levels in the Ebey's outflow water were much lower than the levels found in the Treatment Plant effluent. Filtering the Ebey's outflow water through the phytoboxes did not appear to change the phosphate levels.

Fecal coliform – Fecal coliform levels were not evaluated on the composite input water sample. However, the readings done by Island County would indicate the water of the outflow stream at Ebey's Landing contained a sizeable population of fecal coliforms. Basically there were no fecal coliforms found in the water following filtration through the phytoboxes.

Table 3-2. Effect of filtering water from the outflow (n=1) of the stream at Ebey's Landing through the Phytoboxes (n=3) on pH, Conductivity, and Copper

		SOIL MEDIUM		
	Stream Outflow	*Heavy Soil +Perlite*	*Sandy Soil*	*Sandy Soil + Compost*
pH	*6.9*	*5.6*	*5.5*	*5.5*
Conductivity (µS/cm)	*1621*	*1547*	*1477*	*1501*
Copper (mg/L)	*0.003*	*0.004*	*0.000*	*0.003*

pH – pH in the water collected from the Ebey's Landing stream was lower than that measured in the Treatment Plant effluent. But, as found with the Treatment Plant effluent, filtering the water through the phytoboxes resulted in a lowering of the pH.

Conductivity – The levels of total dissolved salts in the water collected from the phytoboxes was less than the level in the water collected at the Ebey's Landing Stream.

Copper – Copper level in the water from Ebey's Landing stream were very low. Filtering the water through the phytoboxes did not change the copper levels.

<u>Conclusions</u>

1. Nearly all of the nitrate in the stream water was removed by the filtration through the phytoboxes.
2. Phosphate levels in the stream water were very low and filtration did not change the phosphate levels.
3. Fecal coliform levels were very low in the outflow from the phytoboxes. Previous tests of the stream water indicated much higher levels of fecal coliform than found in the filtered water.
4. pH levels in the filtered water were lower than the level found in the stream water.
5. Conductivity levels in the stream water were higher than in the phytobox outflow.
6. Copper levels were very low in the stream water and in the phytobox outflow.

Chapter 4: Effect of phytoremediation on metals content of Treatment Plant Effluent

Metals are another possible environmental contaminate that may be harmful to animals. As an example, copper in the water has been found to be harmful for the survival of salmon smolts. One possible source of contaminating metals is the effluent from Treatment Plants that is released into the environment. The effluent from the Coupeville Treatment plant is released into the waters of Penn Cove, which salmon smolts inhabit.

Treatment plant effluent was applied to the phytoboxes at the Coupeville Treatment Plant. The effluent applied was Class B effluent collected following ultraviolet treatment. Water was applied to the phytoboxes automatically 1-4 times each day. Outflow water was collected from each of the phytoboxes on August 22, 2014 (trees leafy) and December 17, 2014 (trees senescent). Water was collected from 3 phytoboxes for each of the 4 different growing mediums planted with willow and poplar trees. The 4 growing mediums were perlite only, heavy soil + perlite, sandy soil, and sandy soil + compost. Twelve output samples were evaluated at each collection date as well as samples of the Plant Effluent applied to the top of the phytoboxes.

Analysis of these samples was done by the King County Environmental Laboratory, Seattle, WA. Each sample was evaluated for Mercury, Aluminum, Antimony, Arsenic, Barium, Cadmium, Calcium, Chromium, Cobalt, Copper, Iron, Lead, Magnesium, Manganese, Nickel, Potassium, Selenium, Silver, Sodium, Thallium, Tin, Vanadium, and Zinc.

Results

The results of these 2 analyses are shown in Tables 4-1 and 4-2. At both sampling dates, the amount of Copper, Lead, Tin, and Zinc was lower in the outflow from the phytoboxes than the amount in the Plant Effluent applied to the top of the phytoboxes. It is not known whether these metals are absorbed by the plant roots or microbes in the growing medium or whether they are adsorbed by the particles in the growing medium.

The amount of Cobalt, Iron, Manganese and Nickel was higher in the outflow from the phytoboxes than in the Plant Effluent applied to the top of the phytoboxes at both sampling dates.

The amount of Sodium in the outflow water from the boxes was much higher than in the Plant Effluent when the trees were leafy but not when the trees were senescent. Further research is needed to clarify this difference.

The amount of Arsenic in the outflow water from the phytoboxes containing prairie soils was much higher than in Plant Effluent when the trees were leafy. Soils on the prairie are known to have elevated levels of Arsenic. The Arsenic levels in the outflow from the phytoboxes containing only perlite were not as high when the trees were leafy as the outflow from the phytoboxes containing prairie soils.

The amount of arsenic in the outflow from the phytoboxes was similar to the amount in the Plant Effluent at the sampling when the trees were senescent. The reason for this is unknown to the authors.

The results for the other metals were not consistent for the phytobox growing mediums or leaf growing conditions.

Conclusions

Filtering Treatment Plant effluent through roots and growing mediums was effective at removing Copper, Lead, Tin, and Zinc when the trees were leafy and when the trees were senescent.

Filtering Treatment Plant effluent through roots and growing mediums resulted in higher levels of Cobalt, Iron, Manganese and Nickel when the trees were leafy and when the trees were senescent.

Table 4-1: Metals content of treatment plant effluent and outflow water from phytoboxes, sampled 8/22/2014
(TREES LEAFY) **All units = µg/L**

		Output From Phytoboxes			
Metal	**Treatment Plant Effluent**	**Perlite + Trees**	**Heavy Soil + Perlite + Trees**	**Sandy Soil + Trees**	**Sandy Soil + Compost + Trees**
Mercury	0.007	0.001	0.008	0.015	0.011
Aluminum	60.3	19.4	25.6	37.4	55.5
Antimony	<0.3	<0.3	0.57	<0.3	0.35 (2)
Arsenic	4.15	6.02	16.12	14.44	10.28
Barium	38.20	26.90	55.40	69.87	65.40
Beryllium	<0.1	<0.1	<0.1	<0.1	<0.1
Cadmium	0.13	0.07 (1)	0.07 (1)	0.14 (1)	0.35 (2)
Calcium	56900	63700	65800	81500	71100
Chromium	0.55	0.24	0.59	0.72	0.82
Cobalt	0.18	0.17	8.77	28.55	31.27
Copper	46.6	11.1	4.8	3.1	8.8
Iron	93	168	1515	19893	17193
Lead	1.89	1.68	0.61	0.20	0.27
Magnesium	41200	56333	55900	59533	57333
Manganese	15	14	1220	1477	1592
Nickel	2.25	2.85	13.24	25.47	30.19
Potassium	24100	12430	20250	28133	30400
Selenium	0.63	0.51 (2)	0.59 (2)	0.65	0.77
Silver	0.041	<0.04	<0.04	<0.04	0.042
Sodium	200000	358667	403000	433333	366667
Thallium	<0.04	<0.04	<0.04	<0.04	0.062 (1)
Tin	0.68	<0.3	<0.3	<0.3	<0.3
Vanadium	2.50	0.38	3.76	3.16	5.67
Zinc	177.0	9.6	13.8	16.4	63.4

n=1 for all measures of Treatment Plant Effluent; n=3 for all measures of phytoboxes except those with (n).
For the phytoboxes with (n)<3, other readings were below Test Minimum Detection Level.
<0.## - All values were less than listed Minimum Detectable Level.
Red - Phytobox output < Plant Effluent: Blue - Phytobox output > Plant Effluent

Table 4-2: Metals content of treatment plant effluent and outflow water from phytoboxes, sampled 12/17/2014
(TREES SENESCENT) All units = µg/L

		Output from Phytoboxes			
Metal	**Treatment Plant Effluent**	**Perlite + Trees**	**Heavy Soil + Perlite + Trees**	**Sandy Soil + Trees**	**Sandy Soil + Compost + Trees**
Mercury	0.00271	0.00025	0.00110	0.00249	0.00230
Aluminum	24.3	19.2	18.83	34.8	23.0
Antimony	0.33	<0.3	0.34(1)	<0.3	<0.3
Arsenic	2.05	3.00	2.54	3.07	2.91
Barium	31.6	15.8	31.6	28.03	26.17
Beryllium	<0.1	<0.1	<0.1	<0.1	<0.1
Cadmium	0.074	<0.05	<0.05	0.094	<0.05
Calcium	48700	34333	37767	31200	32100
Chromium	0.45	0.25	0.40	0.90	0.58
Cobalt	0.19	0.11	3.48	3.31	5.91
Copper	33.7	7.1	3.48	2.70	1.25
Iron	97.9	26.5(2)	516	8775	7993
Lead	1.46	0.40	0.58	0.14	0.21(2)
Magnesium	33400	23367	27700	22267	22367
Manganese	10.5	2.33(2)	400.57	732	843
Nickel	2.68	1.29	5.45	4.39	6.40
Potassium	17000	12900	11467	9970	9420
Selenium	1.38	0.84(2)	0.81(2)	0.91	0.88
Silver	<0.04	<0.04	<0.04	<0.04	<0.04
Sodium	191000	133000	187333	144000	151333
Thallium	<0.04	<0.04	<0.04	<0.04	<0.04
Tin	0.46	<0.3	<0.3	<0.3	<0.3
Vanadium	5.17	2.54	6.48	8.16	6.44
Zinc	541	16	14	5	3

n=1 for all measures of Treatment Plant Effluent; n=3 for all measures of phytoboxes except those with (n).
For the phytoboxes with (n)<3, other readings were below Test Minimum Detection Level.
<0.## - All values were less than listed Test Minimum Detectable Level.
Red - Phytobox output < Plant Effluent: Blue - Phytobox output > Plant Effluent

Chapter 5: Phytoremediation effect on fecal coliform counts

On April 6, 2015, daily watering the phytoboxes at the treatment plant with pre-ultraviolet treatment water containing fecal coliforms was started. Water samples were collected on May 17, 2015 and on June 16, 2015 for fecal coliform counts of the outflow water from the phytoboxes. Samples were prepared and evaluated by Treatment Plant personnel who routinely evaluate samples for regulatory purposes. Because of limited incubation space, samples were only taken from 2 phytoboxes containing heavy soil + perlite and trees, and 2 phytoboxes containing sandy soil and trees at both sampling dates. At the June sampling, we also collected 2 samples from phytoboxes containing only perlite and no trees. Samples of the input water were collected and evaluated at both sampling dates.

Results

Table 5-1. Fecal coliform counts (cfu/100ml) of plant effluent (n=1) and averages of the outflow from the phytoboxes (n=2)

		Phytobox Growing Medium		
Sampling Date	*Plant Effluent*	*Heavy Soil +Perlite*	*Sandy Soil*	*Perlite Only*
05/17/2015	*9300*	*1375*	*145*	*NM*
06/16/2015	*3700*	*1580*	*1040*	*475*

NM – Not Measured

Conclusions

1. Filtering water that is high in fecal coliform count through soils and trees reduces the fecal coliform counts.
2. Sandy soil + trees is more effective at reducing fecal coliform counts than heavy soil + perlite + trees.
3. Perlite only appears to be more effective at reducing fecal coliform counts than Ebey's Prairie soils and trees.

Overall Summary

Five experiments were conducted in Central Whidbey Island to evaluate the effectiveness of phytoremediation at removing contaminates from water. Storm water and sewer plant effluent were the sources of the contaminated water. Experiments were conducted from 2010 through 2015.

A phyto swale was constructed to receive storm water from a 7 acre commercial development and a small parking lot.

A group of 15 experimental boxes were developed to allow the filtration of contaminated water from the effluent from the Coupeville Treatment plant and other sources. These boxes were filled with 5 combinations of growing medium and trees giving triplicate measurements of each combination.

Conclusions for selected contaminates:

Nitrate – phytoremediation removes most of the nitrates.

Phosphate – phytoremediation removes about half of the phosphates.

Turbidity – phytoremediation removes most of the turbidity.

pH – phytoremediation reduces the pH but levels remain in acceptable range

Fecal coliforms – phytoremediation removes most of fecal coliforms.

Copper – phytoremediation removes most of the copper.

Zinc – phytoremediation removes most of the zinc.

Iron – phytoremediation increased levels of iron.

In our experiments, phytoremediation is effective at lowering the level of many contaminates in water. Phytoremediation should be considered as a viable contaminates removal process.

Increasing population levels and global warming are increasing the pressure on fresh water supplies in many areas of the world including the U.S.A. We need to be utilizing ways of capturing or reusing rain water and waste water. Using phytoremediation treatment of both sources for either reuse or aquafer regeneration should be considered today and will probably be necessary in the near future.

Acknowledgements

The authors would like to thank the following individuals for their collaboration in these phytoremediation projects and their assistance to make this work successful:

Town of Coupeville Mayor Nancy Conard, Larry Smith, Willy LaRue, Kelli Rietma, Paul Vinsant, Jessie Lynn, Coupeville Town Council

National Park Service Craig Holmquist

Island County Department of Natural Resources Anna Toledo, Karen DuBose, Heather Roberts, others

Island County Marine Resources Committee Rex Porter, Ian Jefferds, Ed Adams, others

Other Collaborators Marshall English, Karen Bishop, Rob Hallbauer, others