Compost Use In Wetland Restoration Projects

RECYCLING TECHNOLOGY ASSISTANCE PARTNERSHIP
ReTAP

NIST MEP
Environmental Program

Compost Use In Wetland Restoration Projects

FINAL REPORT

Prepared for

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a division of the Department of Community, Trade & Economic Development
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EXECUTIVE SUMMARY

This project was undertaken with support from the Recycling Technology Assistance Partnership (ReTAP), a program of the Clean Washington Center of the Washington State Department of Community, Trade & Economic Development. The intent was to determine if the use of compost in wetlands had benefits which could add value to compost by decreasing the frequency of failure of restoration efforts. Commonly, restoration efforts fail for one of the following reasons:

- Hydraulic miscalculations
- Death of the target wetland plant species
- Invasive species propagation

The last two reasons stated above may very well be curtailed by the addition of compost. The addition of a rich strong organic matter with some essential plant nutrients (i.e. nitrogen, phosphorus, and potassium) can promote strong growth of target species and allow them to compete with the opportunistic invaders which adapt well to adverse soil conditions. This report presents the findings of a year long study at a wetland restoration site which showed excellent results in these areas. The results indicate that if a stable compost is applied at agronomic rates, the growth and survival rate of target wetland species can be aided. The plots which used compost showed approximately 20% more growth and 10 to 15% higher survival rate than the control plots, which used no compost. The surrounding surface water quality did not degrade as a result of the application.

This report outlines the steps necessary to design compost applications for restoration projects. A worksheet provides a template for the calculation of an agronomic rate of nitrogen application from a specific compost to a specific wetland condition.

The aim of this report is to serve as a tool for the wetland community to responsibly use compost in restoration projects and reduce the number of failures associated with the construction of

wetlands. The results of this study indicate that a compost with a high organic content and a low nitrogen content will serve this end use best by:

1. Providing strong organic substrate to mimic wetland soils
2. Preventing overloading of nitrogen and contamination of the surface water
3. Providing organic matter for absorption of ammonia N to prevent transport in surface water.

1.0 SITE AND PROJECT HISTORY

In early 1994, staff at the City of Everett's Department of Public Works , with the help of E&A Environmental Consultants, Inc. (E&A) and Adolfson Associates, Inc., submitted a technology validation project proposal to the Clean Washington Center's Recycling Technology Assistance Partnership (ReTAP). The proposed project was to determine if the use of compost in wetlands had benefits which could add value to compost by decreasing the frequency of failure of restoration efforts. The City knew that such a project was of keen interest to the Clean Washington Center (CWC) for its potential to open the wetland restoration market to compost products and funded the project. This report documents the findings of the study. Ultimately, the study will lead to guidelines outlining the best procedures for using compost to replicate wetland soils.

1.1 SITE HISTORY

Lower Bigelow Creek in the City of Everett, which flows from the Lowell neighborhood into the Snohomish River, consists of two large riparian wetlands connected by a 550 foot 18-inch culvert. This culvert diverts water around a two acre parcel which was filled in decades ago for the construction of a sawmill. At the outset of the project, the site was barren and all water was routed through the culvert. The fill material was very sandy, and the site was covered with Scot's Broom, an invasive brush. This plant is generally considered a nuisance and is not native to the area.

Railroad lines run through the property near the upper wetland. The wetlands are home to a variety of wildlife including a relatively large population of beavers. Beaver activity in and around the 550 foot culvert has caused constant flooding of the railroad tracks adjacent to the upper wetland. The railroad and the City of Everett proposed to alleviate the flooding problem by "removing" the beavers. However, a well organized group of neighbors opposed this plan, and as a result, a great deal of public attention has been focused on this project.

In response, the City proposed to expand the upper wetland at Bigelow Creek in order to control flooding, as mitigation for other impacted wetlands, and in order to allow the beavers to remain in the wetland area. The expansion of the upper wetland consisted of replacing the old culvert with a shorter, (80 foot) fish passable culvert. The shorter culvert would be easier to maintain and the expanded wetland would provide better flood attenuation and increased wildlife habitat. In addition, the City proposed to install perforated pipes in the series of existing beaver dams in the upper wetlands to further reduce the flooding. All would be accomplished using compost as the restoration's substrate.

1.2 GOALS

The goals of the project included the following:

1. Promotion of the use of compost in wetland projects,
2. Promotion of the beneficial re-use of locally-generated “waste” in local applications
3. Flood control for the area, and
4. Generate and evaluate data for determination of success.

One of the compost materials used was a biosolids and yard debris material from the Everett Wastewater Treatment Plant pilot composting project (which was also conducted by E&A). The use of this material constituted a full cycle recycling effort, since the compost feedstocks were all generated by the residents of the city of Everett and the product was returned for beneficial reuse within the City limits. Although the practice does promote responsibility for one's own waste, the concept of using biosolids compost to construct wetlands resulted in some concern in both the regulatory community and the local neighborhood. First, the neighbors were concerned about the potential contaminant levels of treated biosolids. However, the U.S. Environmental Protection Agency maintains strict guidelines to assure that biosolids compost from wastewater treatment plants are “high quality” and considered safe. Everett's material meets all guidelines and is considered a high quality material. Second, regulators were concerned about the potential for compost overloading resulting in nitrate transport to the surface water, and metals leaching. A surface water monitoring plan proposed as part of the experiment eased concerns about unmonitored application of the compost. In fact, the results of surface water testing during the project indicated no adverse effects from the compost application. After extensive collaboration with both groups, the project was able to proceed and demonstrate the concept of full cycle recycling.

Other goals included those associated with the marketing of compost. This use of compost could potentially add value to compost by opening new markets within the area of wetland restoration. If the use of compost increased the success rate of wetland restoration, it would be viewed as a means of preventing the costly replanting required when a site failed to promote the appropriate plant community. In addition, the wetland construction project served to stabilize the water levels in the area. The site handled the flow of 1996's heavy winter rains quite well, and the railroad tracks did not flood. This is an indication that the fen area served its purpose as a flood plain in heavy rain conditions.

In addition, there were research and demonstration goals which were addressed during the course of the project. The experimental plots examined the growth and survival of the target plants as well as the invasive species growth. The soil from each plot was analyzed for an array of parameters in an effort to replicate the soils in the surrounding existing wetland. These results are presented in Section 5 of this report.

1.3 COMMUNITY SUPPORT AND INVOLVEMENT

City staff conducted a series of one-on-one meetings with neighborhood leaders and other interested persons in the neighborhood to informally discuss the project objectives and to gather input for a conceptual design. The concept of using composted products as a wetland soil substitute was introduced during these informal meetings. Collaborating with the neighborhood leaders created a positive problem-solving atmosphere which lead to the creation of a plan addressing the concerns of the City, the railroad, and the neighborhood.

Early and comprehensive involvement of key members of the local neighborhood resulted in a project that was not just tolerated but demanded by the neighbors. Everett's community involvement program successfully formed an alliance with the local neighborhood that was instrumental in negotiating the regulatory hurdles that had to be cleared. After the consultant and Dan Thompson attended a community meeting and briefed the citizens, over 30 letters of endorsement requesting that the City restore the wetlands using biosolids compost were sent to the Mayor. The neighborhood civic association voted unanimously to endorse the use of biosolids to restore wetlands near their homes, and the majority of the project was planted by volunteer labor from the local neighborhood. The overwhelming support of the neighborhood overcame the initial skepticism of the regulators. All necessary permits were negotiated in less than four months.

1.4 STATE GUIDELINES FOR WETLAND RESTORATION

The Washington State Department of Ecology published a report entitled *Restoring Wetlands in Washington - A Guidebook for Wetland Restoration, Planning and Implementation*. The guidebook is a strong reference for such projects in the state, and offers suggestions on suitable substrates. The report states that restoration sites with suitable soil types are often limited. Organic amendments are recommended in order to boost organic content of wetland soils. Suggested materials are processed peat, straw, or hay which can be mixed with mineral soils to provide preliminary levels of organic matter. It is also suggested that importing hydric soils can be a benefit, since roots and microbes will aid in the success of a restoration project. The guidebook states that these measures are necessary to promote moisture retention, add organic materials, and add nutrients and micronutrients. The use of compost is not specifically outlined, although compost would add to all of the above stated criteria. This report will be forwarded to the state DOE and an amendment recommended.

2.0 SITE DESIGN

2.1 DESIGN GOALS

The site restoration plan was designed to allow for flow through the fen area, which served as a flood plain during heavy flow periods. The excavation plan also called for the gradual sloping of the experimental plots down to the water surface, which allowed for the planting of a wide variety of wetland species throughout the water regime. These excavation plans are shown in Appendix C.

In addition to the excavation plans, Appendix C contains the plot plans for the planting design. The fen area is shown, with the prescribed plant arrangements. The planting schemes for each of the experimental plots shows that the target species were placed in the same areas of each plot. An effort was made to ensure that each of the plots had similar slope, sun, and water conditions. This was accomplished for all but plot one, which was flooded after the original drainage culvert was plugged. The remainder of the plots all had similar conditions, and therefore represent identical plots aside from the compost application rate.

The application rates of the compost were designed to bracket the agronomic needs of the plant community chosen for each plot. Two plots were established for each of three application rates for two types of compost (greenwaste and biosolids/greenwaste) and a control (no compost) for a total of 14 plots. One of the three application rates was designed to closely match the agronomic rate, and the other two were designed to be higher and lower than the agronomic rate. Table 1 describes the application rates and compost type for each of the 14 plots.

Table 1: **Experimental Plot Design Loading**

Plot #	Compost Type	Target Pounds Available N/Acre
1	gw	200
2	gw/bio	200
3	control	0
4	gw	500
5	gw/bio	500
6	gw	350
7	gw/bio	350
8	gw	200
9	gw/bio	200
10	control	0
11	gw	500
12	gw/bio	500
13	gw	350
14	gw/bio	350

gw = greenwaste, bio = biosolids

3.0 EXPERIMENTAL DESIGN

3.1 TARGET PARAMETERS

Three application rates of two different composts were applied in an effort to simulate the existing wetland soil conditions. Analysis of the surrounding wetland soils defined the desired target ranges of the chosen soil parameters to be achieved in the restoration effort. These ranges were met through the introduction of a compost and sand mixture as a substrate in the newly constructed area. Parameters studied included organic content, C:N ratio, pH, conductivity, water holding capacity, soil oxygen levels, cation exchange capacity, and trace nutrients. In addition to the lab analyses, plant populations and dynamics (survival rate and plant height) were recorded to study the effect of compost use on promoting the growth and survival of target species as well as suppressing invasive species.

3.2 COMPOST INCLUSION RATE

Compost inclusion rates were based on creating optimum conditions for wetland plant growth while minimizing environmental impacts. A table was developed that summarizes literature information on nutrient uptake of wetland plants. Nitrogen (N) uptake will usually be the limiting factor for the application of the compost, since over-application of nitrogen can cause water quality degradation. The nutrient uptake shown in Table 3 follows the list of plants (Table 2) which were used in the experimental plots. The plants were grouped into similar categories (trees, shrubs, herbs, etc.). Each experimental plot contained a predetermined number of plants from each grouping. By assigning an average nitrogen uptake for each of the groups of plants, a weighted average of uptake can be estimated according to the number of each type of plant in each plot. This estimate can then be presented in pounds of nitrogen per acre.

Table 2: Plant Species and Quantities for Experimental Plots

Plant Species	Number of Plants to be Used		
	Per Plot	**# of Plots**	**Total**
SHRUBS			
Vine maple	2	20	40
Cascade oregongrape	3	20	60
Red-osier dogwood	3	20	60
Salal	3	20	60
Nootka rose	1	20	20
Red elderberry	1	20	20
Common snowberry	3	20	60
Total	16	20	320
HERBS			
Lady fern	6	20	120
Total	6	20	120
DECIDUOUS TREES			
Oregon ash	1	20	20
Willow wattle	3	20	60
Total	4	20	80
CONIFER TREES			
Sitka spruce	1	20	20
Total	1	20	20

Each plot contains:

- 16 shrubs
- 6 herbs
- 4 deciduous trees
- 1 conifer tree

Table 3: Similar Wetland Species Nutrient Uptake

Plant Species	Nutrient Uptake (pounds per acre)		
	Nitrogen (N)	Phosphorous (P)	Potassium (K)
GRASSES			
Reed canarygrass	169	30	282
Orchard grass	300	45	311
Brome grass	166	29	211
Bluegrass	200	29	149
Tall fescue	135	24	149
Common reed (Phragmites)	271	35	
Average	207	32	220
HERBS			
Cattail	185	38	
Moss	59		
Bulrush	185	47	
Average	143	42	
DECIDUOUS TREES			
Aspen	5.7	0.8	
Young deciduous	100		
Medium-mature deciduous	30-50		
Average	100	0.8	
CONIFER TREES			
Loblolly pine	9	1	4
Young conifer	60		
Medium-mature conifer	20-30		
Average	60	1	4

Next, the nitrogen content of the compost was examined. With data on moisture content, bulk density, and nitrogen content of the compost, an estimate was made of cubic yards of compost per acre. Assumptions were made concerning the availability of nitrogen in a wetland environment, and are presented later in this chapter. An assumption was made for the nitrogen uptake of shrubs which was based on the numbers for similar groundcover and trees. This estimate was used for the design of the experimental plots.

The evidence from the Monroe Cadman wetland restoration site was also examined to aid in determining compost inclusion rates. The Monroe Cadman project was a demonstration project sponsored by the Clean Washington Center completed prior to this project. The Clean Washington Center report was published in 1993. Its purpose was to complete a cursory demonstration of the use of compost in a wetland restoration project. This project is the follow up, and builds upon the previous work by examining soil parameters much more closely. There was strong evidence that varying levels of nitrogen loading gave varying degrees of success for plant survival and invasive species suppression. This evidence was noted and taken into consideration, but was eventually superseded by the nitrogen needs of the plants in each experimental plot.

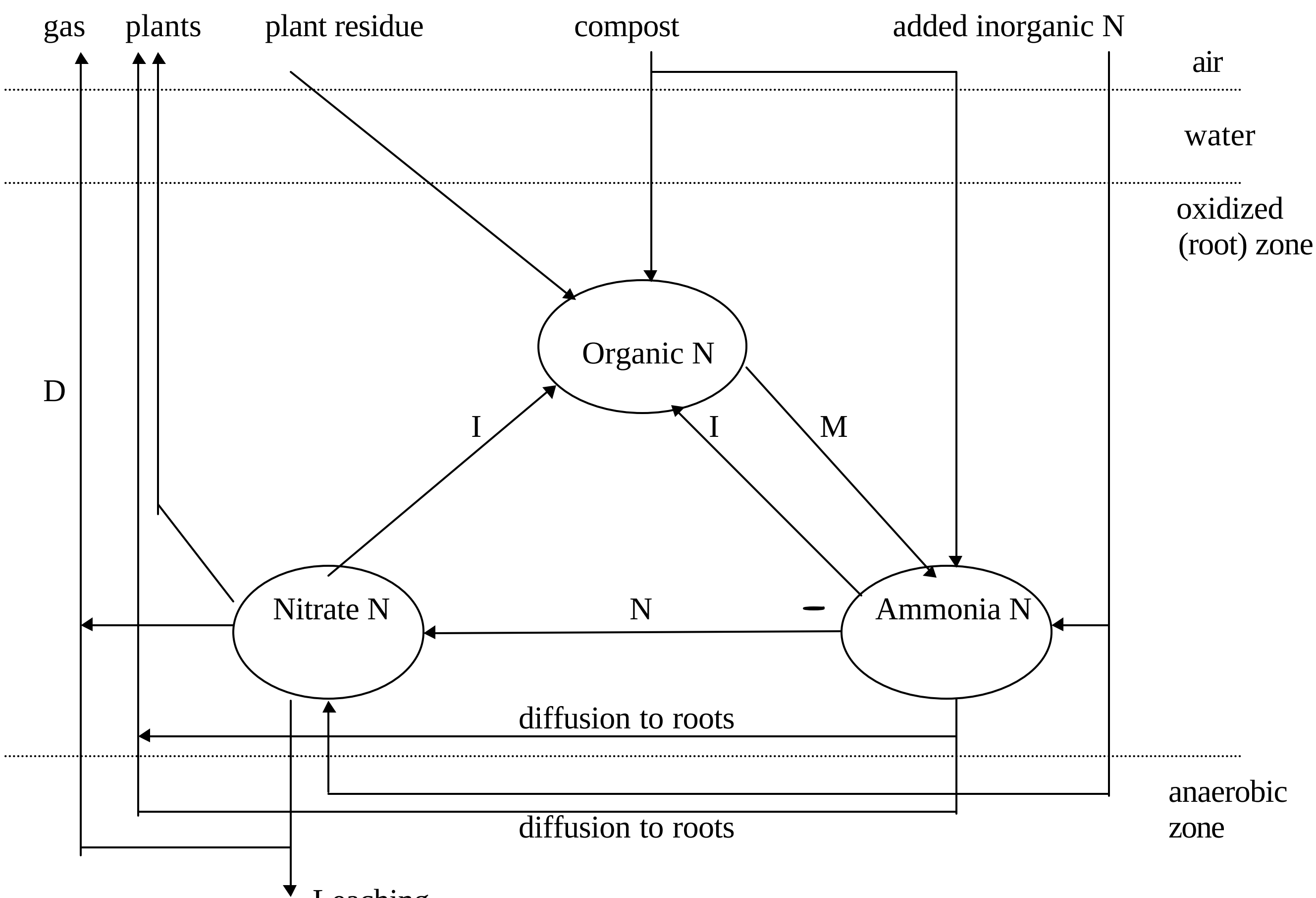
3.2.1 Similar Species Nutrient Uptake

In order to estimate the nutrient uptake of each plot, an investigation into the nutrient needs of wetland species was conducted. Nitrogen uptake is of special significance as it will usually be the limiting factor affecting application rate. Application rates that exceed the plants uptake rate will likely result in nitrate leaching and runoff. As a result, the experimental plots were designed to use no more nitrogen than was needed by the plants to be grown in each plot.

For agricultural soils, there is a tremendous amount of information regarding the transformation of organic N to inorganic N after an organic amendment is incorporated. Likewise, there is considerable information regarding plant nitrogen requirements. The research behind this data was prompted by the need to optimize fertilizer use for low cost and high crop yield. There is less information about this pertaining to wetland soils. However, some research has been done from the standpoint of using artificial wetlands for wastewater treatment. As a result, a small amount of data has been generated concerning the nutrient uptake of wetland species.

Nitrogen exists in three forms - inorganic, organic, and gaseous. Organic N consists of carbon based compounds such as protein and is not available to plants. Soil microbes convert organic N to inorganic N (mineralization). Plants use inorganic N for nutrition in the form of nitrate (NO_3-) and ammonia (NH_4+) ions, which are the plant available forms. Ammonia, which can be absorbed by clay and organic matter preventing transportation by water, is converted to nitrate by soil microbes (nitrification). Nitrate is very mobile in water. Microbes and plants convert inorganic N back to organic N (immobilization). N_2 gas comprises about 80% of the soil atmosphere, and can be used as a source of N for legumes but is not used by other plants. N_2 is the end product of denitrification, which occurs under anaerobic conditions when microorganisms convert nitrate to N_2 and N_2O gases which escape to the atmosphere. N_2 that does not escape to the atmosphere is rapidly converted to ammonia in the soil. Figure 1 describes the nitrogen cycle in a wetland setting.

Figure 1 Wetland Nitrogen Cycle



I=imobilization, M=mineralization, N=nitrification, D=denitrification

It is suspected that organic N nitrification rates in the wetland environment are considerably less than in the agricultural environment. Reducing conditions are seen under anaerobic conditions when inorganic compounds (such as nitrate) are used for electron exchange instead of oxygen. Reducing conditions not only inhibit nitrification, but also promote denitrification. For compost application in agricultural soils it is assumed 10 to 30 percent of the organic N becomes available in the first year, depending on soil type, temperature, moisture and other factors. It is also believed that the lack of oxygen in the wetland setting will inhibit the mineralization of nitrogen into plant available forms. Some oxygen will be introduced into the soil through the root zones of the plants, so mineralization will occur at some small level. Also, an unstable compost with high available carbon content will have a very low mineralization rate. The compost used in this project was very stable. This project used a conservative estimate of 10% mineralization for the compost. Levels of nitrogen were monitored throughout the project so as to form a better understanding of the dynamics of the soil.

The data for the trees and the data for the undergrowth (shrubs and herbs) assumed that the individual plant type was planted uniformly across the entire acreage. However, the trees and the undergrowth coexist on the same plot of land. Therefore, the weighted averages of the shrub and herb data were added to the weighted average of the tree data. This accounts for total potential nitrogen uptake.

Table 4: Estimated N Uptake and Weighted Averages

Plant Type	# Plants Per Plot	Estimated N Uptake (lbs/acre)
Shrubs	16	150
Herbs	6	143
Weighted average		148
Deciduous trees	4	100
Conifer trees	1	60
Weighted average		92
Total	27	240

Tables 5 and 6 show the data for the recently completed Monroe Cadman wetland restoration project in Monroe, as well as the target loading rates of nitrogen and corresponding volumes needed for the Everett restoration project. Consideration for the loading rates was based first on the success of the plots at the Cadman site and their corresponding loading rates. After looking at these numbers, the loading rates were adjusted according to the nutrient needs of the plants going into the experimental plots. Compost for the experimental plots was obtained from the Everett pilot compost project (biosolids/greenwaste) and from Phoenix Composting (greenwaste).

3.2.2 Application Rates For Fen And Experimental Plots

After determining allowable nitrogen loading has been made, it is necessary to calculate whether the organic content and the C:N ratio of the final mix is within the range of average wetland soils. Studies show that there is a wide range of data for certain parameters in what are considered wetland soils due to varying plant life, hydrology, and climate. Since wetland soils can vary greatly, there is a benefit in sampling the soil from an adjacent area with hydrology similar to the final design of the restoration area, if such an area exists. This will serve as a reference for determining the desired final mix ratios of compost and fill. The substrate from the down stream wetland was sampled along with the fill to be mixed with the compost. These samples were sent for analysis, and the results were used to calculate the target contents and final mix estimates contained in Table 7. The calculations assume that 55% of the organic matter consists of organic carbon.

Table 5: Cadman Wetland Restoration Compost Application Rates

plot #	compost type	surface area (ft^2)	cubic feet applied	bulk density lb/cf	percent solids	dry tons applied	dry tons per acre	TKN mg/kg	NO_3 mg/kg	NH_4 mg/kg	inorgani N mg/kg	organic N mg/kg	% avail organic N	available N total (mg/kg)	lbs/acre plant avail N
1	biosolids	1350	243	44	45%	2.41	78	10900	46	13	59	10887	10%	1148	178
2	yard debris	1350	243	51	45%	2.79	90	12200	71	8	79	12192	10%	1298	234
3	biosolids	1350	486	44	45%	4.81	155	10900	46	13	59	10887	10%	1148	356
4	yard debris	1350	486	51	45%	5.58	180	12200	71	8	79	12192	10%	1298	467
5	biosolids	1350	729	44	45%	7.22	233	10900	46	13	59	10887	10%	1148	535
6	yard debris	1350	729	51	45%	8.37	270	12200	71	8	79	12192	10%	1298	701

Table 6: Everett Wetland Target Compost Loading Rates

plot #	compost type	target available N/acre	TKN mg/kg	NO_3 mg/kg	NH_4 mg/kg	inorganic N mg/kg	organic N mg/kg	total available N (mg/kg)	organic matter %	C:N ratio	dry tons needed	bulk density lb/cf	percent solids	cubic feet needed	cubic yards needed
1	gw/bio	200	11400	280	725	1005	10675	2073	50%	24.4	0.66	49	42%	64.6	2.4
2	gw/bio	200	11400	280	725	1005	10675	2073	50%	24.4	0.66	49	42%	64.6	2.4
3	gw/bio	350	11400	280	725	1005	10675	2073	50%	24.4	1.16	49	42%	113.0	4.2
4	gw/bio	350	11400	280	725	1005	10675	2073	50%	24.4	1.16	49	42%	113.0	4.2
5	gw/bio	500	11400	280	725	1005	10675	2073	50%	24.4	1.66	49	42%	161.5	6.0
6	gw/bio	500	11400	280	725	1005	10675	2073	50%	24.4	1.66	49	42%	161.5	6.0
total															25.1
7	gw	200	15600	291	700	991	14900	2481	46%	16.4	0.56	49	42%	54.0	2.0
8	gw	200	15600	291	700	991	14900	2481	46%	16.4	0.56	49	42%	54.0	2.0
9	gw	350	15600	291	700	991	14900	2481	46%	16.4	0.97	49	42%	94.4	3.5
10	gw	350	15600	291	700	991	14900	2481	46%	16.4	0.97	49	42%	94.4	3.5
11	gw	500	15600	291	700	991	14900	2481	46%	16.4	1.39	49	42%	134.9	5.0
12	gw	500	15600	291	700	991	14900	2481	46%	16.4	1.39	49	42%	134.9	5.0
total															21.0

percent available N 10%

plot area 600 square feet

Table 7: C:N Ratio and Organic Content Estimates

plot #	compost type	fill organic percent	fill nitrogen percent	fill C:N ratio	fill bulk density	target organic content*	target range C:N ratio*	organic content final mix	C:N ratio final mix
1	gw/bio	0.40%	0.03%	7.4	110	> 5%	> 5%	4.74%	7.67
2	gw/bio	0.40%	0.03%	7.4	110	> 5%	> 5%	4.74%	7.67
3	gw/bio	0.40%	0.03%	7.4	110	> 5%	> 5%	7.53%	7.87
4	gw/bio	0.40%	0.03%	7.4	110	> 5%	> 5%	7.53%	7.87
5	gw/bio	0.40%	0.03%	7.4	110	> 5%	> 5%	9.99%	8.06
6	gw/bio	0.40%	0.03%	7.4	110	> 5%	> 5%	9.99%	8.06
total									
7	gw	0.40%	0.03%	7.4	110	> 5%	> 5%	3.78%	7.58
8	gw	0.40%	0.03%	7.4	110	> 5%	> 5%	3.78%	7.58
9	gw	0.40%	0.03%	7.4	110	> 5%	> 5%	6.01%	7.70
10	gw	0.40%	0.03%	7.4	110	> 5%	> 5%	6.01%	7.70
11	gw	0.40%	0.03%	7.4	110	> 5%	> 5%	8.01%	7.82
12	gw	0.40%	0.03%	7.4	110	> 5%	> 5%	8.01%	7.82

*existing wetland substrate   org % = 4 %

C:N = 5.5

The other parameters are probably not extremely critical and it is unlikely the addition of compost at reasonable rates would create a suboptimal growing environment for wetland species.

4.0 EXPERIMENTAL RESULTS

The experimental plots were designed to generate data in order to determine which application rate and compost type would best mimic the parameters of the surrounding wetlands. The results indicate that if a stable compost is applied at agronomic rates, the growth and survival rate of target wetland species can be aided. The plots which used compost showed approximately 20% more growth and 10 to 15% higher survival rate than the control plots, which used no compost. The surrounding surface water quality did not degrade as a result of the application. Details of experimental results are provided in the following sections.

4.1 PLANT GROWTH RESPONSE AND SURVIVAL RATES

In order to study the effects of the use of compost on wetland species growth and survival, this report presents and analyzes data on both of these items for each of the experimental and control plots. These items are of importance to the restoration of a wetland since they are indicators used to judge the success of a project. A regulatory agency can deem a project a success or failure based on plant survival and invasive species propagation. Other definitions of success include improvement of wetland functions such as hydrologic (flood peak reduction, shoreline stabilization, groundwater exchange), water quality improvement (sediment, nutrient), and food chain support (species diversity). If compost could be shown to promote better target species survival, it might prevent some regulatory failures, and therefore prevent costly replanting.

The average growth rate (height of plant) of the target plant species is an indication of their ability to take hold and out compete invasive species. Invasive species are highly adaptable and, therefore, can often out-compete a target plant when substandard substrate is used. The use of a good organic substrate offers the target species a good chance to survive against the opportunistic invaders. Figure 2 on the following page shows the average percent of grow rate for each of the application rates.

The first two bars indicate the first and second plots, and the third, the average of the two. As can be seen, nearly all of the application rates had considerably higher growth rates than the control plots. The one exception is the 200 lb/acre N greenwaste plots. This is likely due to high water in the first plot, which led to low growth and high mortality. The second plot did considerably better.

Figure 2 Experimental Plot Growth Comparison

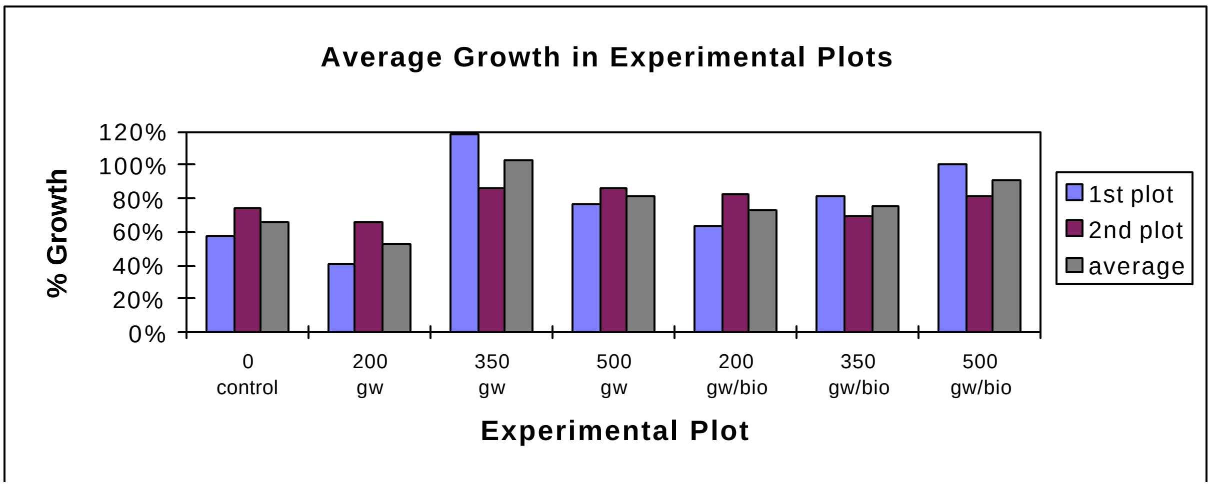
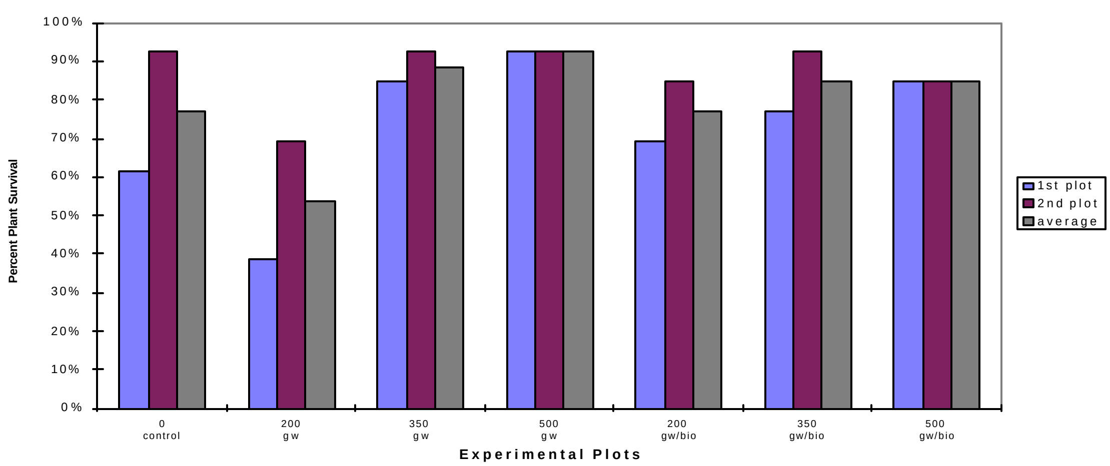


Figure 3 shows the survival rate of the target species in each application and in the control. Again, each plot is shown along with the average of the two. Similar to what was seen in the growth data, nearly all of the application rates had higher survival rates, on average, than the control plot. The one exception, again, is the 200 lb/acre N greenwaste plots. This is likely also due to the flooding in the first plot. The second plot did considerably better than the first.

Figure 3 Survival Rate Comparison for Experimental Plots



The data presented in the graphs above is available in a spreadsheet in Appendix A - Growth and Plant Survival Rate Spreadsheets.

4.2 SOIL ANALYSES

Several mesh bags of each soil/compost mixture were buried in each plot in order to track the nutrient dynamics and other parameters. At three points during the first year (0, 6, and 12 months) after construction, one bag was removed from each plot and sent for lab analysis. The purpose of these analyses was to determine how the different mixes would respond over time.

Two experimental plots were established for each compost application (type and loading rate) and control (no compost applied) for a total of 14 plots. In addition, soil samples were taken from the upstream wetland and analyzed for comparison. The graphics which follow for each of the target parameters show the results for the surrounding wetland as well as the averages for each of the experimental plots.

The following information describes the results of the analysis of the soils sampled from each of the experimental plots at 0, 6, and 12 months after the construction of the wetland. The target parameters studied included the following:

- Total solids content
- Volatile solids content
- Particle size
- pH
- Conductivity
- Nitrogen dynamics
- Phosphorus and potassium dynamics
- Copper

Each of these parameters is tracked and compared to the existing wetland substrate in the bar charts which follow. Along with the data is a description of each parameter and its importance within the soil ecosystem. Where appropriate, average wetland soil content of each parameter is described. In addition, the section includes information on additional parameters which were tracked, beyond those originally described in the proposal. These include:

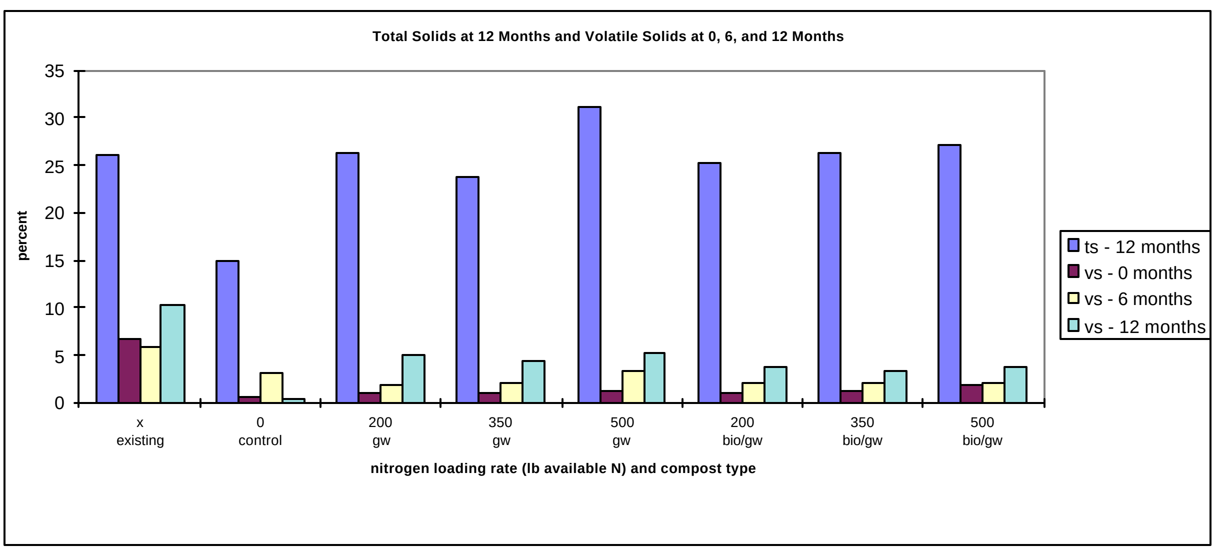
- Cation exchange capacity
- Magnesium
- Calcium
- Sodium
- Boron
- Sulfur
- Zinc
- Manganese

All data for each plot is included in a spread sheet in Appendix B in addition to the bar charts included in each of the following sections. At the end of the section is a matrix of all parameters and best matches to the existing substrate.

4.2.1 Total and Volatile Solids Content

Total solids are the total amount of suspended (or filterable) solids in the compost. Volatile solids are the organic fraction (anything that can be decomposed) of the total solids content. Their measure is important in determining biological stability. Total and volatile solids content at the end of the 12 month period for each application are shown in Figure 4. All of the plots, with the exception of the controls, had a solids content similar to that of the existing wetland. The volatile solids content (organic matter) for each of the applications was less than that of the existing substrate, but grew over the 12 month period. The control plot did not see this increase in organic content. The increase in the volatile solids might be explained by the favorable conditions for plant growth afforded by the addition of the compost. The growth of plants in these plots would result in increased root growth. The mesh bags may have allowed some root growth through the sides, which should account for the increased volatile solids.

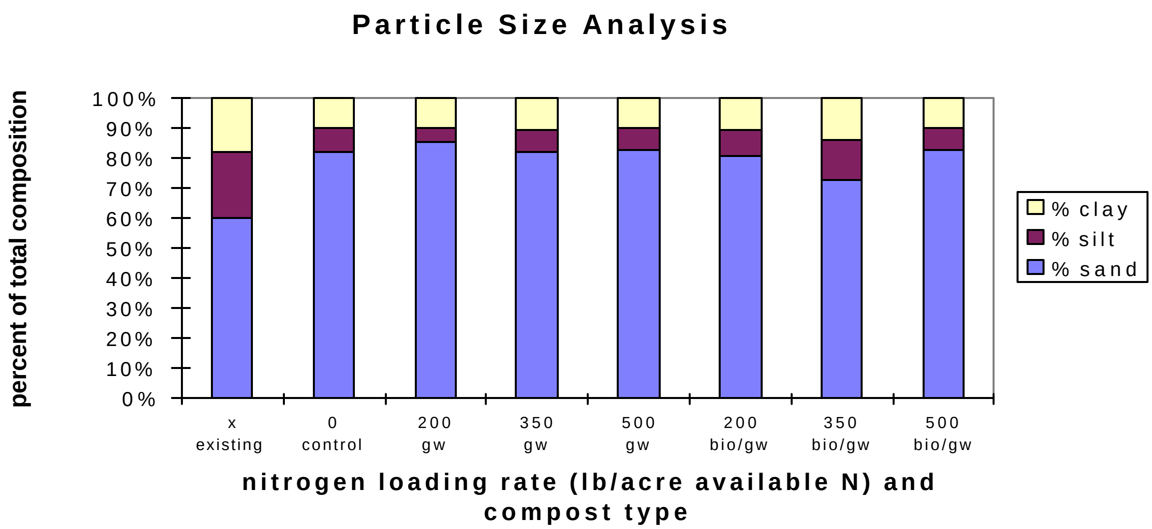
Figure 4 Total and Volatile Solids Content



4.2.2 Particle Size Analysis

Analyses of the particle size for each of the plots allowed for a comparison of soil composition. This comparison is shown in Figure 5. The mixes used for this project were designed so as not to over load the nitrogen. The composts chosen for use had average levels of nitrogen. As a result, large amounts of sand substrate had to be mixed with the compost in order not to overload the nitrogen on the wetland plots. The results are soils with 10 to 20% more sand content than the surrounding wetland soils. In hind sight, a compost with a high organic content and a lower nitrogen content should have been used to provide for a higher organic content and lower nitrogen content in the final application mix.

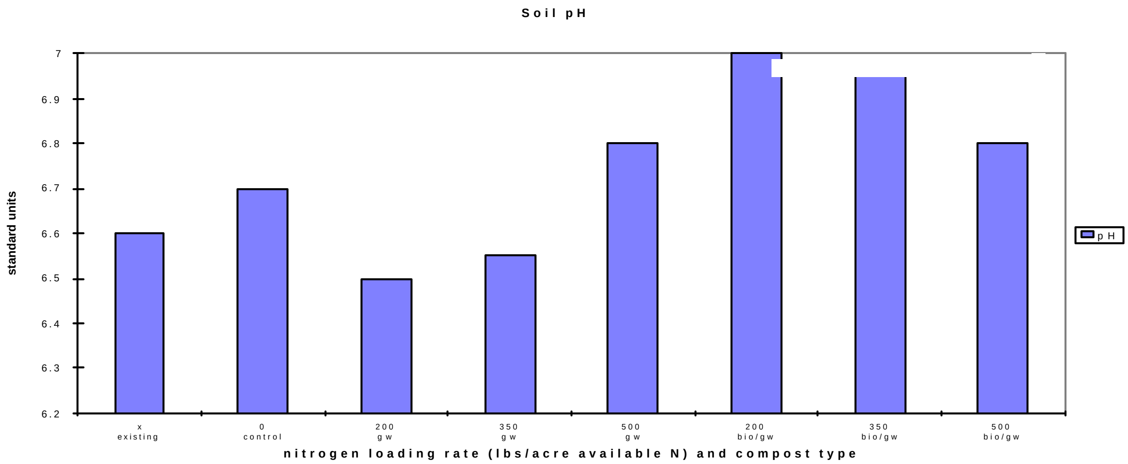
Figure 5 Particle Size Analysis



4.2.3 pH

The pH scale is defined as a measure of acidity or alkalinity. The range is from 0 to 14, with seven representing neutrality. Numbers lower than 7 represent acidity, and numbers greater than 7 represent alkalinity. Wetland soils are normally organic and slightly acidic. All of the pH measurements from the experimental plots were within one-half a point of the soils in the surrounding wetland. All were slightly acidic, and no dramatic patterns were seen from the data collected for each plot. The data can be seen in Figure 6.

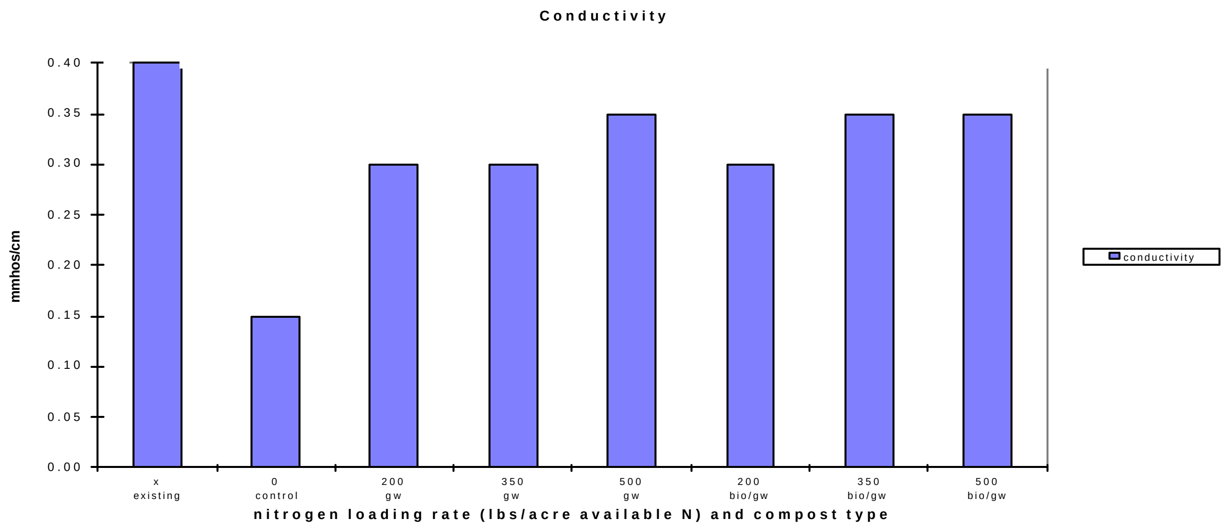
Figure 6 Analysis of pH at 12 Months



4.2.4 Conductivity

Conductivity is a measurement of the level of soluble salts in the soil. In agriculture the conductivity of a soil is generally not allowed to rise above 2 mmhos/cm for most crops. There is generally quite a bit less information on soil parameters in wetlands than in agriculture, where optimization of fertilizer use is driven by the desire to cut costs. The conductivity results, which are found in Figure 7, indicate that the experimental plots are all slightly less than the surrounding wetland soils (0.4 mmhos/cm) and slightly more than the control (0.15 mmhos/cm). No significant trend was found.

Figure 7 Conductivity Analysis

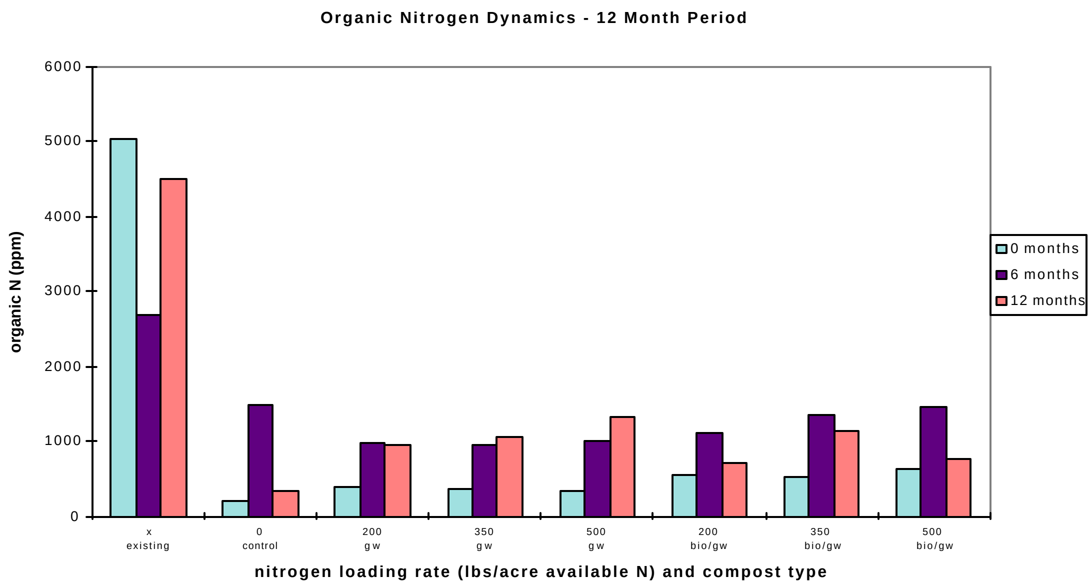


4.2.5 Nitrogen Dynamics

Nitrogen dynamics are of interest whenever applying a nitrogen source to the soil. The nitrogen cycle consists of converting organic nitrogen to plant available inorganic nitrogen and back. The addition of compost into a wetland is of benefit for both the organic matter and for the nitrogen added. Nitrogen will set the limit for application, since too much N can contaminate ground and surface water. Please refer to Section 3.3 for a full description of the nitrogen cycle.

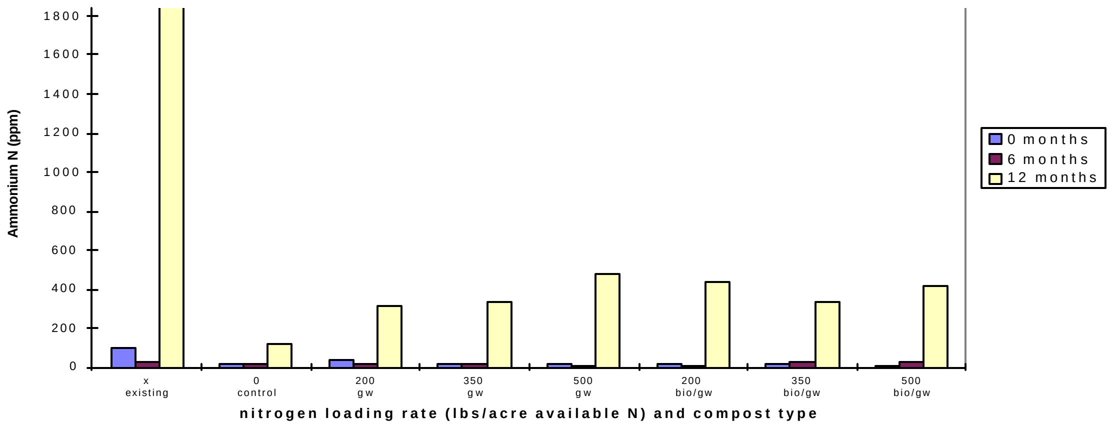
Organic N is Total Kjeldahl Nitrogen (TKN) minus ammonia N and nitrate N. Figure 8 shows the average levels of organic N for each treatment at 0, 6, and 12 months. As can be seen, some immobilization is taking place, as the organic N levels increase over time. The yard debris compost continues to rise for the 12 months, while the biosolids compost rises for the first six months, and then drops off again. This indicates that less immobilization occurs with the biosolids compost plots, allowing more of the N to remain plant available. None of the plots have levels approaching that of the surrounding soils, but all exceed the control plots.

Figure 8 Organic Nitrogen Analysis



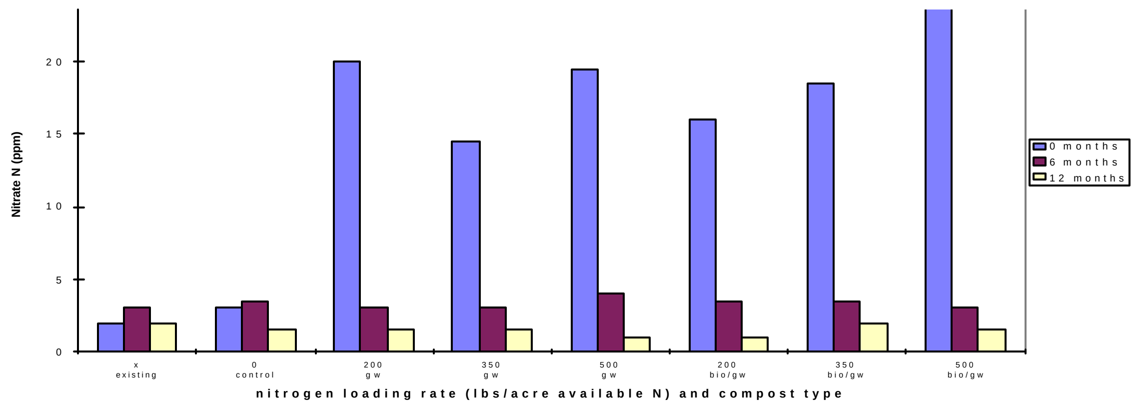
Ammonia N levels are shown in Figure 9. All of the plots show that mineralization is occurring in the soil, as the ammonia levels are increasing over the 12 month period. There are no significant patterns that can be drawn from the plots, except that all had higher levels than the controls and lower levels than the surrounding wetland soils. Both the yard debris and the biosolids composts reacted similarly with respect to ammonia levels.

Figure 9 Ammonia Nitrogen Dynamics



Nitrate levels in the plots over the 12 month period are shown in Figure 10. As is evidenced by the plots, a good deal of the nitrate is used or lost over the course of the experiment. The new plants likely used a good deal of this N over the course of the summer, when the plants were establishing themselves. The plots were planted in late March. The levels of nitrate N loss/use correspond to less than 10 lbs/acre on average. The estimate for plant uptake of N for each experimental plot was approximately 240 lb/acre. This assumed a 10% mineralization rate for the first year. The losses of nitrate N could be from denitrification caused by the anaerobic conditions of the soil during wet periods, plant uptake, or leaching. No degradation of the surface water was seen over the 12 month period.

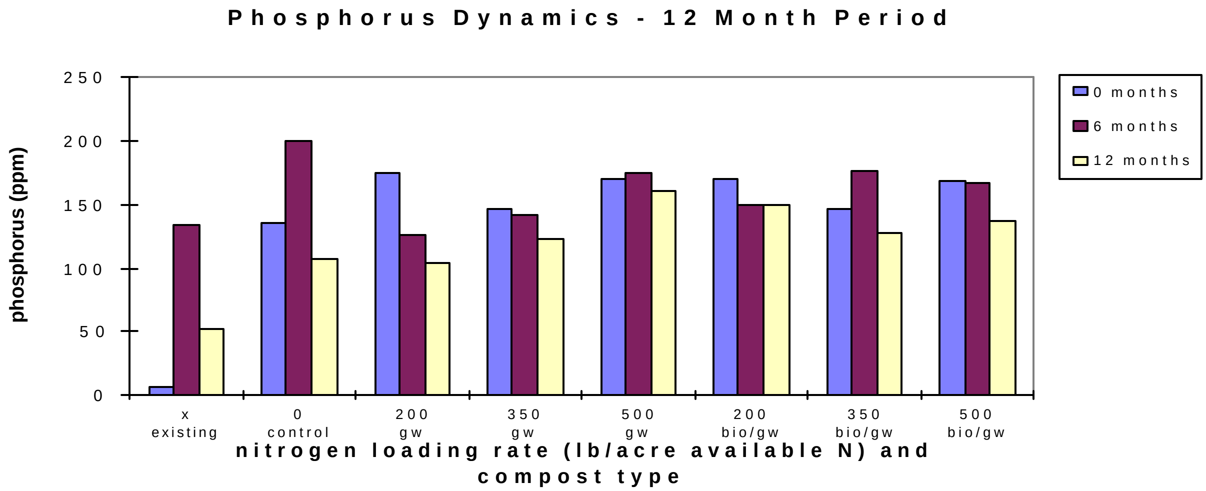
Figure 10 Nitrate Nitrogen Dynamics



4.2.6 Phosphorus and Potassium Levels

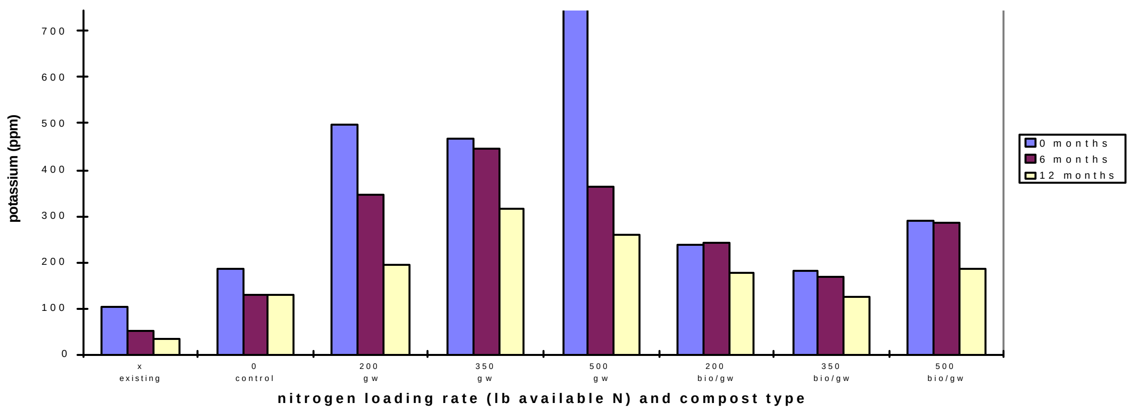
Both phosphorus (P) and potassium (K) were tracked in order to compare with the existing surrounding wetland soils and observe how the levels changed over time. Phosphorus levels over the 12 month period, shown in Figure 11, indicate similar trends for all plots. The existing soil shows slightly lower levels than the experimental plots. In each case, the experimental plots show a drop in phosphorus levels, indicating plant use or loss.

Figure 11 Phosphorus Levels



Potassium levels over the 12 month period are shown in Figure 12. This Figure shows that again, levels are greater in the experimental plots than in the surrounding soils and control. All of the data for the existing soil, control plots, and compost applications show a similar trend, indicating some possible seasonal effects. The plots all start out high and drop off rapidly during the first six months. This might indicate that the phosphorus in the compost is being used by the new plants in each of the plots. It also might indicate some loss or as stated above, a seasonal effect.

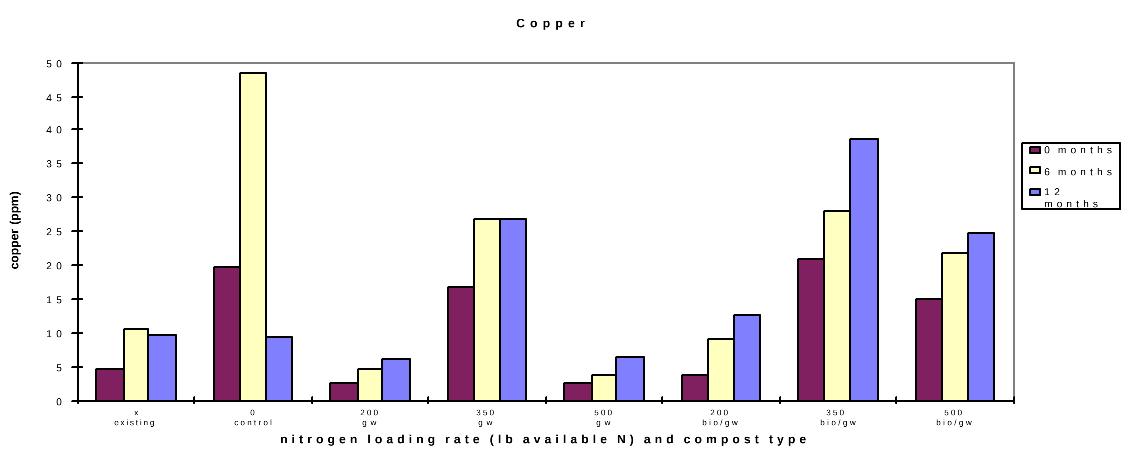
Figure 12 Potassium Levels



4.2.7 Copper

When present in water, copper can be highly toxic to fish. In order to determine if the copper present in the composts had any effect on the downstream wetland surface water, the levels of copper in the soils were tracked for the 12 month period of the project. In addition, the levels of copper in the surface water were tracked to see if the levels changed from upstream to downstream over the course of the year. No difference was seen during any of the three sampling periods between the upstream and downstream levels of copper in the surface water. The results of all surface water monitoring can be seen in Section 4.3. Figure 13 shows the copper levels in the soil during the course of the project. Soil contaminants are regulated under the Model Toxics Control Act (MTCA), which has no limit for copper. There are surface water limits for copper. These are discussed in Section 4.3.

Figure 13 Copper Levels in Experimental Plots

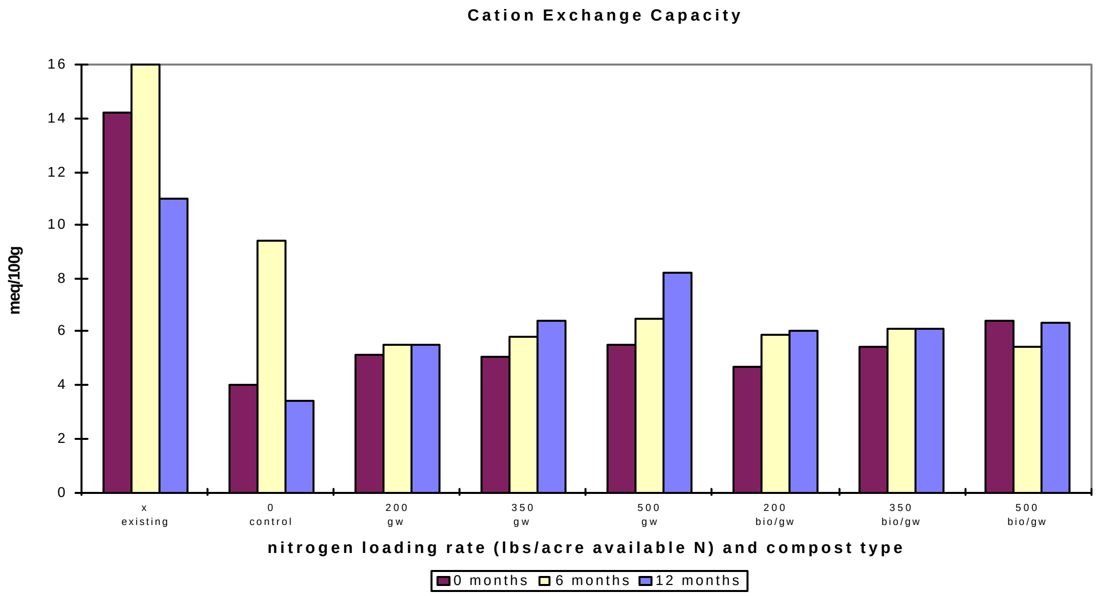


4.2.8 Other Analyses Performed

In addition to the analyses performed as indicated in the original proposal, several other parameters were examined. These parameters included cation exchange capacity (CEC), magnesium, calcium, sodium, boron, sulfur, zinc, and manganese. CEC is a measurement of the soil's ability to hold exchangeable cations, which indicates the soil's ability to resist leaching.

Figure 14 shows CEC throughout the duration of the project. All experimental plots are slightly less than the existing wetland soils, but all are also greater than the control plots except at 6 months. CEC is largely dependent upon the amount and type of clay present and the organic matter content.

Figure 14 Cation Exchange Capacity



The other parameters mentioned are all plant micronutrients. The results of the analyses for these constituents can be seen in Table 8 below.

Table 8: Micronutrient Analyses

Plot	N	Magnesium			Calcium			Sodium			Boron		
	lb/ac	0	6	12	0	6	12	0	6	12	0	6	12
exist	x	166	135	421	2460	2910	1350	69	47	21	2	3	2
control	0	83	150	49	300	1535	500	46	30	12	3	3.5	1.5
gw	200	90	138	83	425	655	775	22	28	20	20	3	1.5
gw	350	93	119	101	375	725	855	15	23	15	14.5	3	1.5
gw	500	82	94	70	395	930	1335	26	21	12	19.5	4	1
bio/gw	200	82	125	81	460	825	960	21	25	13	16	3.5	1
bio/gw	350	90	146	74	380	820	1020	15	60	15	18.5	3.5	2
bio/gw	500	118	123	96	555	715	950	21	30	18	24	3	1.5

Table 8 continued

Plot	N	Sulfur			Zinc			Manganese		
	lb/ac	0	6	12	0	6	12	0	6	12
exist	x	176	6	17	21.7	56.5	27.4	33	20	30
control	0	6	110	11	5.9	148	423	3	27.5	4.5
gw	200	7	12	14	5.7	12.6	18.4	4	54.5	68.5
gw	350	9.5	9.5	12.5	13.4	17.9	27.8	3	24.5	27
gw	500	15	17.5	14	14.1	17.3	50.4	2.5	51.5	59
bio/gw	200	17	10	14	20.1	24.5	35	3	51	41.5
bio/gw	350	96	9	10.5	16	20.5	27.7	1.5	51	29
bio/gw	500	88.5	10.5	12.5	30.6	46.3	43.7	3	40	34

4.3 SURFACE WATER QUALITY

This project also examined the surface water quality both upstream and downstream of the construction area to gain insight as to how the application of the compost may have changed water quality. While compost was applied to most plots at agronomic rates, some plots were overloaded to evaluate plant response at higher application rates. For the surface water quality evaluation, the overloading allowed experimenters to look at potential trade-offs between plant response from compost overloading and surface water quality.

The constituents examined were biochemical oxygen demand (BOD), conductivity, ammonia N, nitrate/nitrite N, total phosphorus, pH, dissolved oxygen, and copper. Of particular interest were the numbers for nitrate/nitrite and copper. Nitrate/nitrite is important because of the mobility of nitrate in water, and copper because of its toxicity to fish.

Neither nitrate/nitrite or copper showed higher levels downstream than were seen upstream for the duration of the project. In fact, the nitrate levels are slightly lower downstream and ammonia levels are higher. This makes intuitive sense, since as stated in Section 3.3, natural anaerobic wetland conditions will likely inhibit nitrification (conversion of ammonia N to nitrate N). Since ammonia can be absorbed by organic matter, a higher level of organic matter in the compost would likely help prevent transport of organic N. Again, a high organic content, low nitrogen compost will serve this use well. Analysis results are seen in Table 9.

Table 9: Surface Water Quality Analyses Results

Test	Unit	Upstream			Downstream			% difference		
		0	6	12	0	6	12	0	6	12
BOD	mg/l	<4	<4	<4	<4	<4	5	0%	0%	20%
Conductivity	mg/l	229	230	239	235	238	249	3%	3%	4%
Ammonia	mg/l	0.01	0.04	0.018	0.024	0.048	0.049	140%	14%	150%
Nitrate/nitrite	mg/l	1.74	1.35	2.45	1.35	1.26	1.86	-22%	-7%	-24%
Phosphorus	mg/l	0.02	0.03	0.042	0.035	0.037	0.032	67%	28%	-25%
pH		6.3	6.9	7.45	7.7	7.0	7.24	22%	1%	-3%
Dissolved Oxygen	mg/l	10.9	2.6	8.51	6.2	4.6	8.16	-43%	77%	-4%
Copper	mg/l	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	0%	0%	0%

Copper Limit: Federal Acute, 18 *m*g/l, Federal Chronic, 12 *m*g/l

4.4 WILDLIFE OBSERVATIONS

The area is home to many species of animals. The casual observations of the consultant on several trips to the site include the following birds. This list is not a comprehensive biological inventory.

- Belted kingfisher
- Red tailed hawk
- Great blue heron
- American goldfinch
- Virgina rail
- Sand piper
- Osprey
- Northern flicker

In addition, small fish fry were observed in the upstream, downstream, and restored wetlands. Identification of the species was not accomplished. Evidence of deer has been sighted and beaver activity in the area is also heavy.

5.0 GUIDELINE FOR USE OF COMPOST IN WETLAND RESTORATION

5.1 TYPE OF COMPOST

These guidelines are based on the experimental design and results. As mentioned, and shown in the design, some plots were overloaded with compost (greater than agronomic need). The results for survival rate and growth did not indicate that these plots were more successful. This information should discourage overloading and therefore help prevent higher levels of nitrate/nitrite in the surface water.

The compost selected should feature the following characteristics:

- A high organic content
- Low nitrogen content
- Highly stable and mature

It is important to try to match the organic content of the compost to the wetland's organic content. Wetland soils are traditionally high in organic content, and any restoration or construction effort will require a substrate mixture which is highly organic. In addition, the compost should be low in nitrogen content, since the nitrogen will be the limiting factor of the application. A lower nitrogen-content compost will allow for a higher application rate, thereby increasing the organic content of the mix. This is, of course, dependent upon the analysis of the surrounding wetland soils. Typically, though, this will be the case. Nitrogen content should be less than 20,000 ppm (2% N on dry weight basis) and organic content should be at or above 15 to 20%.

It is also important to investigate the stability of a product. An unstable product is a compost which has not degraded all of its carbon content. This condition can lead to an incorporated material actually robbing nitrogen from the surrounding soils for the available carbon. The use of this material would be detrimental to the target species, as the invaders are better suited to adapt to the nitrogen-poor soil. Therefore, the likelihood of failure is greater with the use of an unstable compost. Compost stability is determined by sight, smell, and lab analysis. The Clean

Washington Center published a report on field determination of compost stability, which may be of use in choosing a material. This report can be obtained through the Clean Washington Center. Please see the title page of this report for ordering information. Lab analysis of the material can quantify the stability of the compost by measuring the CO_2 respiration rate. The rate of CO_2 production calculated on the organic fraction determines the stability of the compost and measures the predicted change during use due to continued decomposition. Lab analysis includes an analysis of the compost with data interpretation, and an estimate of the stability of the product.

5.2 REQUIRED ANALYSES

The materials to be used in the project and the surrounding wetland substrate should be tested for the following parameters:

- Organic matter
- Solids content
- Total kjeldahl nitrogen
- Soluble salts (conductivity)
- pH

These analyses will be used to best mix the compost with a native organic soil in order to match the analyses of the existing substrate. The following is an example of how this can be accomplished. The data for the existing soils is for example purposes only, and any calculations will be site-specific. The plant nutrient uptake data is also based upon actual data, but the example is not site-specific.

1. Test existing substrate, compost, and mix soil for important parameters

Table 10: Example of Analyses of Existing Soils and Compost

Parameter	Existing Wetland Substrate	Compost	Restoration Area Site Soil (Sand)
Organic matter (%)	12.0	35	1.0
Bulk density (lb/cy)		1400	2400
Solids content (%)	35	45	60
Organic N (ppm)	5000	15,000	150
Conductivity (mmhos/cm)	1.5	3.5	0.2
pH (standard units)	7.0	7.0	6.8

2. Choose the plant population to be used

Chosen plants should be categorized as shrubs, herbs, and deciduous and conifer trees. This is done for the purpose of designing application rates to meet the agronomic demands of the wetland plant species.

Table 11: Sample Plant List

Plant Species	Plants Per Acre	Plant Species	Plants Per Acre
SHRUBS		**HERBS**	
Vine maple	64	Lady fern	24
Cascade oregongrape	36	Skunk cabbage	52
Red-osier dogwood	144	Slough sedge	375
Salal	24	Broadleaf arrowhead	375
Nootka rose	36	Bulrush	375
Red elderberry	16		
Common snowberry	12	Total	1200
Total	332		
CONIFER TREES		**DECIDUOUS TREES**	
Sitka spruce	20	Oregon ash	12
Total	20	Willow	64
		Total	76

Table12: Agronomic Rates of Plant Groups

Plant Type	# Plants Acre	Estimated % of Grouping Coverage	Plant N Uptake (lb/ac)	Estimated N Uptake
Shrubs	332	40%	150	60
Herbs	1200	60%	143	86
Group weighted average				146
Deciduous trees	76	80%	100	80
Conifer trees	20	20%	60	12
Weighted average				92
Additional understory	grass cover	75%	200	150
Total				388

Assuming the nitrogen needs of the plants used is 388 lb/acre, a nitrogen loading rate can be established. This nitrogen loading rate will be determined by the agronomic uptake of the plants as well as the mineralization rate for the compost. For the experimental plots, a rate of 10% was used. This may be a bit conservative, considering the saturation rate of the soil (see Section 3) but it caused no problems in the demonstration project. The organic nitrogen level of the compost is 2%. The plant available nitrogen per cubic yard of compost and mix soil needs to be calculated next. This is accomplished by multiplying the dry pounds of organic N (TKN - (ammonia N + nitrate N) per cubic yard by the mineralization rate of 10%. For the compost in the example, this calculation is as follows:

Plant available N per cubic yard (cy) of compost =
1 cy compost * 1400 lb/cy * 45% solids * 1.5% org N * 10% mineralization = 0.95 lb/cy avail N
Plant available N per cubic yard of site in-situ soil =
1 cy soil * 2400 lb/cy * 60% solids * 0.015% org N * 10% mineralization = 0.02 lb/cy avail N

The compost will be tilled in to a minimum of 8 inches into the soil, so the nitrogen in this portion of the soil strata will be available for plant use and should be subtracted from the agronomic needs of the plants in order to determine the loading rate of the compost. This calculation is as follows:

Plant available N in site soil =
0.02 lb/cy * 8/12 ft * 43560 ft^2 /27 = 20 lb/acre available N
Compost nitrogen loading rate = 388 lb/acre - 20 lb/acre = 368 lb/acre available N from compost

368 lb/acre
------------- = 387 cy/acre of compost
0.95 lb/cy

387 cy/acre * 27 ft^3/cy / 43560 ft^2/acre * 12 in/ft = 3” of compost

Assuming that the compost will be mixed to a depth of 8 inches, the compost to soil mix ratio is 3 inches to 8 inches, or 1:2.7. This ratio can then be used to calculate the mix soil parameters and compare them to those of the existing wetland. Table 13 shows this comparison.

Table 13: Soil Parameter Comparison

Parameter	Existing Substrate	Compost	Site In-Situ Soil	Typical Range	Compost Soil Mix
Organic matter (%)	12.0	38.0	1.0	12-20	11.0
Bulk density (lb/cy)		1,400	2,400	950*	2,100
Solids content (%)	35	45	60	25-60**	55
Organic N (ppm)	5000	15,000	150	low	4,200
Conductivity (mmhos/cm)	1.5	3.5	0.2	<2	1.1
pH (standard units)	7.0	7.0	6.8	6-7	6.9

As can be seen, for this example the mix ratio matches most of these important parameters fairly closely to the existing wetland substrate.

5.3 SUMMARY WORKSHEET FOR COMPOST APPLICATION

The preceding method for the determination of agronomic loading rate of compost to the wetland project is summarized in the following worksheet format. A sample spreadsheet is available in Appendix E.

Table 14: Worksheet for Agronomic Loading Rate of Compost to Wetland

Step	Action
Step 1	Test existing wetland substrate, compost, mix soil for: • % organic matter • % solids content • TKN • nitrate N • ammonia N
Step 2	Calculate organic N org N = TKN - (nitrate N - ammonia N)
Step 3	Choose plant population and categorize as: plant group — nitrogen uptake • shrubs (150 lb/acre) • herbs (143 lb/acre) • deciduous trees (100 lb/acre) • conifer trees (60 lb/acre) • additional understory (200 lb/acre)
Step 4	Calculate weighted averages of nitrogen uptake, add all weighted averages for total plant nitrogen needs
Step 5	Calculate plant available N in compost and in mix soil: • 1 cy compost * bulk density * % solids * % org N * % mineralization rate • 1 cy soil * bulk density * % solids * % org N * % mineralization rate Subtract available N in soil from available N in compost to obtain the agronomic loading rate
Step 6	Divide lb N/acre needed by lb N/cy in compost to obtain cy/acre of compost needed
Step 7	Calculate inches of compost needed and volumetric ratio of compost to soil, assuming tilled to 8” depth: • cy/acre * 27 ft^3/cy / 43560 ft^2/acre * 12 in/ft = inches of compost • inches of compost/8” = compost:soil ratio
Step 8	Test soil mix for: • organic matter (%) • bulk density (lb/cy) • solids content (%) • organic N (ppm) • conductivity (mmhos/cm) • pH (standard units)

In order to simplify this procedure, calculations for inches of compost needed have been made for a range of nitrogen contents and a plant community similar to the one outlined above. This information is provided in Table 15 below. The calculation is performed for composts with assumed N content of 0.5, 1, 2, and 3%, and assumes negligible N content in the substrate into which the compost is mixed. The compost is to be tilled in to a depth of 8 inches. Again, this is a general calculation and is not site specific. Individual sites may have different circumstances which would change the compost depths stated below.

Table 15 Inches of Compost to be Applied

Compost Nitrogen Content (% dry weight)*	**Inches of Compost Applied**
0.5%	7”
1%	3.5”
2%	2”
3%	1”

*1% dry weight is equal to 10,000 ppm or mg/kg on a dry weight basis

6.0 INFORMATION DISSEMINATION EFFORTS

E&A presented project design information and results at several conferences during 1995. In addition, an article was written for Biocycle magazine on the design concepts for the experimental plots. The magazine has expressed interest in having a follow-up article written when this report is completed. The original article appeared in the January 1996 issue. The conferences during which results were presented are outlined in Table 16.

Table 16: Conference Attendance and Information Dissemination

Conferences, Site Tours, Publications	Location	Date
Washington State Recycling Association Annual Conference	Spokane, WA	4/95
Northwest Biosolids Management Association Conference	Silverdale, WA	9/95
Water Environment Federation Annual Conference	Miami, FL	10/95
Biocycle West Coast Conference	Seattle, WA	3/96
Site tours for:		
Cowlitz County	Site	7/95
Seattle Metro	Site	7/95
GroCo Compost	Site	7/95
University of Washington	Site	11/95

7.0 ACKNOWLEDGMENTS

The author would like to acknowledge the commitment of the ReTAP program to expanding the market for recycled goods. ReTAP is a program of the Clean Washington Center, Washington State's lead agency of the market development of recycled materials. ReTAP is an affiliate of the national Manufacturing Extension Partnership (MEP), a program of the U.S. Commerce Department's National Institute of Standards and Technology. The MEP is a growing nationwide network of extension services to help smaller U.S. Manufacturers improve their performance and become more competitive. ReTAP is also sponsored by the U.S. Environmental Protection Agency and the American Plastics Council.

In addition, the author would like to acknowledge the assistance of:

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- The citizens of the Lowell Neighborhood Civic Group, for attending evening meetings, strongly supporting the project to the City of Everett officials, and for helping with the planting of the area.
- Melanie Jordan-Hecla of Phoenix Composting for supplying compost for the majority of the restoration area.

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APPENDIX A

GROWTH AND PLANT SUVIVAL RATE SPREADSHEETS

(Not included in this electronic file but available upon request)

APPENDIX B

LABORATORY RESULTS

(Not included in this electronic file but available upon request)

APPENDIX C

SITE DRAWINGS

(Not included in this electronic file but available upon request)

APPENDIX D

WETLAND SPECIES SUITABLE TO WESTERN WASHINGTON

(Not included in this electronic file but available upon request)

APPENDIX E

WORKSHEET FOR AGRONOMIC LOADING RATE OF COMPOST TO WETLANDS

(Not included in this electronic file but available upon request)