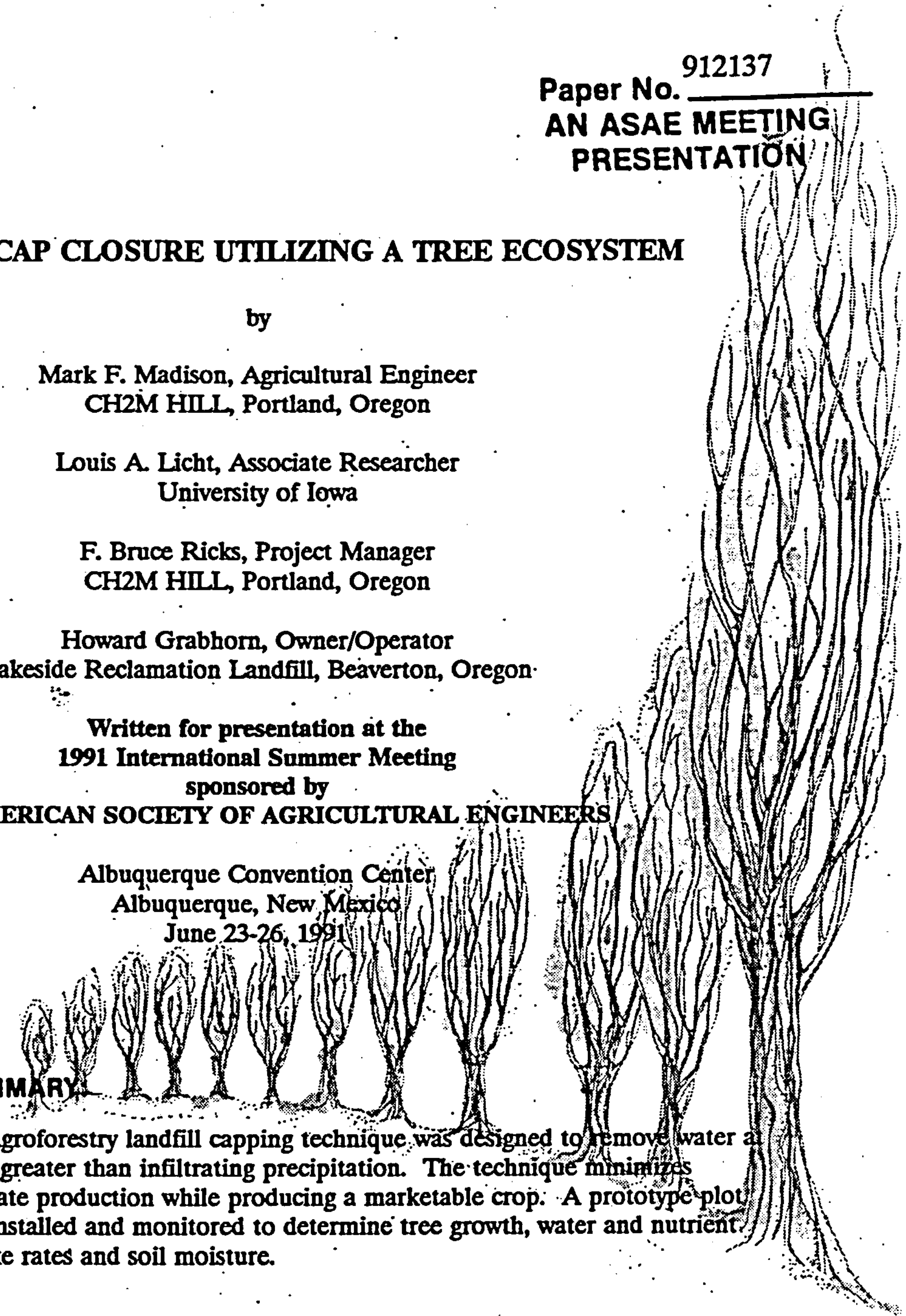
Paper No. 912137
AN ASAE MEETING PRESENTATION

American Society of Agricultural Engineers



LANDFILL CAP CLOSURE UTILIZING A TREE ECOSYSTEM

by

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Written for presentation at the
1991 International Summer Meeting
sponsored by
THE AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS

Albuquerque Convention Center
Albuquerque, New Mexico
June 23-26, 1991

SUMMARY:

An Agroforestry landfill capping technique was designed to remove water at rates greater than infiltrating precipitation. The technique minimizes leachate production while producing a marketable crop. A prototype plot was installed and monitored to determine tree growth, water and nutrient uptake rates and soil moisture.

KEYWORDS: Agroforestry, Biomass, Forest Engineering, Landfill, Lysimeters, Reforestation, Soil Moisture

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Prepared for
Lakeside Reclamation Landfill

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ABSTRACT

The Lakeside Reclamation Landfill (LRL), Beaverton, OR. planted 7,455 poplar trees in a 0.6 acre plot to cap and close a completed cell. This agroforestry capping technique was designed to remove water at rates greater than precipitation while growing a marketable crop. This prototype plot was designed to provide the data required to close the entire landfill using this revegetation technique. The Lakeside Reclamation Landfill is required to cover all landfilled waste according to its operating permit issued by Oregon Department of Environmental Quality (DEQ) under Condition 3 of Schedule C, Solid Waste Permit #214.

The prototype cap was planted April 18-19, 1990. The tree cutting survival exceeded 90% for 4 of 5 subplots. The average tree height for 60 sampled trees was 6 ft 8 in; the average tree base cross sectional area approximates 2.24 cm^2 (the size of a dime). The soil moisture data collected under the tree canopy indicated 'dry' soils at the 3 ft depth during the entire 1990 growing season.

These data collected at Lakeside Reclamation Landfill will be combined with results from an ongoing research program conducted at the University of Iowa, Iowa City, IA. to predict the future woody crop yield and future water uptake by tree roots for this capping system. The 1991 vegetative closure cap installation design will be based on the 1990 growing season experience. The management of LRL, with the technical support of CH2M Hill and Dr. Louis Licht, propose to expand the planted area by 2 acres requiring 14,000 to 16,000 trees.

INTRODUCTION

The conceptual idea for this agroforestry capping technique was based on a tree buffer design currently being used in Iowa to remove non-point source agricultural chemicals from drainage water leaving row-cropped land. Essentially, this buffer was designed to grow a marketable crop that also helps stabilize environments 'at risk'. In the farm situation, deep-rooted poplar trees were planted in riparian soils (between cropped fields and streams) to remove nitrates from water supplies, develop wildlife habitat, and reduce erosion while growing a renewable woody crop.

Populus spp. (poplar) are able to grow roots from preformed root initials (similar to buds) located beneath the bark of stems, offering a way to place perennial roots deeper in the soil profile. This physiological ability is uncommon for woody plants. These root initials enable root sprouting from the entire planted stem's buried length. Figure 1 shows the planting technique used to purposefully grow roots 150 cm (5 ft) deep in the soil profile.

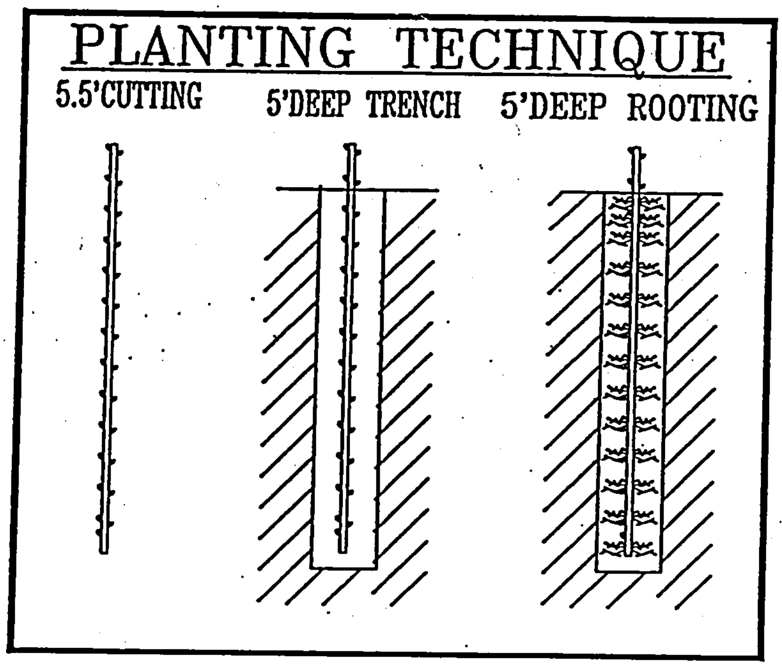


Figure 1: Technique for Growing Roots 150 cm (5 ft) Deep in the Soil Profile

The dense tree population, the deep root placement, and the large mass of water transpired per tree all contribute to a landfill cover designed to remove water at rates greater than precipitation.

The LRL landfill cap design uses the principle of planting deep-rooted poplar trees to produce a plant canopy that removes water from the cap soils with roots, then transpires the water through pores in the leaf (stomata). This water removal minimizes the mass of water seeping through the cap, thus preventing water from reaching the landfilled material. These deep-rooted poplar trees, along with an understory of cool-season grasses, will be able to remove a greater quantity of water to a greater depth in the cap than a sparse grass crop planted on a tighter clay cap.

1990 CLOSURE CAP INSTALLATION

From conception to completed installation, this project was executed very quickly. A brief review of the 1990 growing season is appropriate to gain a perspective on the effort expended.

The Lakeside Reclamation Landfill management staff attended a seminar on March 26, 1990 at the CH_2M Hill Portland office where the tree buffer research program at the University of Iowa was explained. Within a period of three weeks all arrangements were made for procuring instrumentation, selecting planting stock, building the planting equipment, and grading the site. The LRL cap was planted with 7,455 trees on April 18-19, less than a month following the research presentation. The instrument installation was complete by May 2, 1990. The summer effort included monitoring tree survival and controlling weeds. The tensiometer vacuum gauges were read from September 7 to December 12, 1990 to estimate soil moisture content in cap soils.

The Lakeside Reclamation Landfill is located adjacent to the Tualatin River in Beaverton, Oregon. The site map in Appendix 1, Figure 17, displays the general landfill design and the prototype cap site.

The vegetation located in the existing Tualatin river riparian border adjacent to the LRL is shown in Figure 2. The river corridor and adjacent land is capable of growing trees, both hardwoods and conifers.

The Lakeside Reclamation Landfill space is used for burying materials such as construction demolition debris, tree stumps, excavated soils, and yard wastes as shown in Figure 3. It is LRL management's plan to increase the processing of marketable products from reclaimed materials currently being buried.

Figure 2: Riparian Foliage Bordering Tualatin River
Downgrade from the Landfill Cap

Figure 3: Landfilled Material Mounded and Covered
on the Future Tree-planting Site

The final cap soil was installed on top of the landfilled materials to a depth prescribed by DEQ regulations. The landfill face was graded to a 3 to 1 slope. The top 2 ft of cover was rich soil delivered to LRL principally from Washington and Multnomah County construction sites. This soil was placed over a minimum 1 ft of compacted soils with higher clay content.

A planter to install tree cuttings to depths greater than 2 ft in the ground was constructed by modifying an existing soil ripper. This ripper was capable of fracturing the soils to 40 inch depths The finished planter pulled by a crawler tractor is shown in Figure 4.

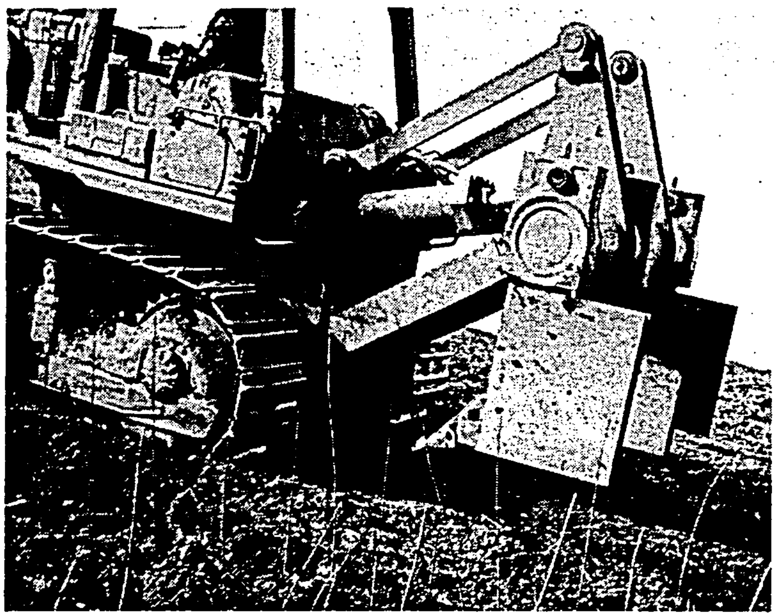


Figure 4:Planter Built from a Modified Soil Ripper
and Mounted on a Crawler Tractor

The 5 ft poplar cuttings were planted 40 inches deep by hand as the crawler tractor drove upslope as shown in Figures 5. The 2 ft poplar cuttings were planted 15 inches deep in shallower ripper cuts.

Figure 5: Planting 5 ft. Poplar Cuttings in the Landfill Cap, April 18, 1990

It was an objective of the 1990 growing season to test different tree varieties and cutting lengths, comparing survival, growth rates, and soil moisture movement between prototype plots. Three different *Populus spp.*

Nurseries, Canby, Oregon; Imperial Carolina variety from Ecolotree Inc., Iowa City, IA.; and NE-19 variety from Hramoor Nurseries, Manistee, MI. All tree varieties were available in 5 ft cutting lengths. The NE-19's were available as rooted stock. The D-01 and Imperial Carolina were only available in unrooted cuttings. D-01 and Imperial Carolina varieties were also available as 2 ft long cuttings.

The completed plot consisted of 7,455 trees planted on a 0.6 acre site; the planting density was estimated to be 3.4 ft^2 per tree. No other soil stabilizers, fertilizers, or pre-emergent weed herbicides were used. The final tree installation is shown in Figure 6.

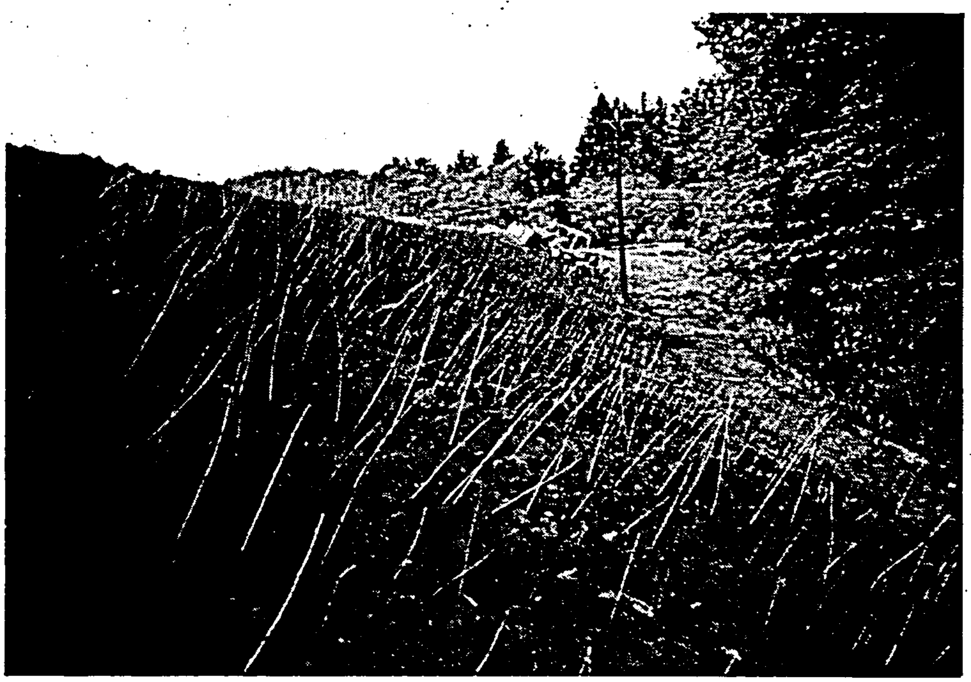


Figure 6: Tree-planted Cap at the Lakeside Reclamation Landfill Following Planting, April 20, 1990

1990 TREE SURVIVAL RESULTS

The 1990 growing season was spent monitoring the prototype plot, including tree survival, tree growth, animal damage, and general appearance. The 1990 prototype cap installation was used to collect data that will aid in designing the future LRL closure plan.

The numerical survival results are shown in Table 1. The survival rates for the Imperial Carolina variety (both 5 ft and 2 ft cuttings) and the DO-1 variety (2 ft cuttings) were over 90%.

The NE-19 variety had a 45.24% death loss; this death rate is unacceptable for future plantings. It is theorized that these cuttings were damaged by a December freeze. The NE-19 stock from the same lot exhibited a 50% death loss in Iowa when planted in excellent soils. The NE-19 is a desirable variety because it exhibits a longer growing season with later leaf drop in the fall. Thus, this tree could expand the season for evapotranspiring water. NE-19 will be replanted this year to see if a better survival rate is possible.

The DO-1 5 ft cutting suffered a 5% death loss from Roundup Herbicide drift applied on a warm July day.

POPLAR VARIETY	CUTTING LENGTH (FT)	# ROWS	TREES PLANTED	TREES SURVIVED	% SURVIVAL
IMPERIAL CAROLINA	5	11	723	665	91.98%
IMPERIAL CAROLINA	2	15	988	921	93.22%
DO-1	5	71	4176	3704	88.70%
DO-1	2	9	622	564	90.68%
NE-19	5	17	946	518	54.76%
TOTAL		**123**	**7455**	**6372**	**85.47%**

Table 1: 1990 Survival Results Listed by Variety and Cutting Length

The survival results are depicted in the bar graphs shown in Figure 8, with reasons for death. The trees planted on this extremely disturbed landfill cap soil had a better survival rate than the trees that were planted in buffers on Iowa farms.

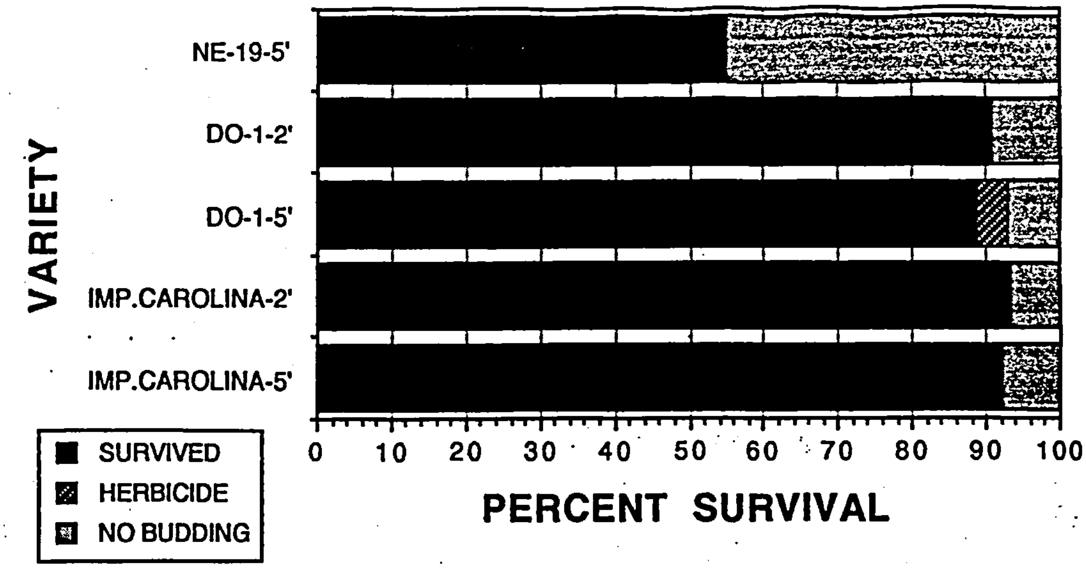


Figure 7: Tree Survival and Cause of Death by Variety for 1990

1990 TREE GROWTH RESULTS

In 1990 trees were not harvested to directly measure their weight. Rather, the base diameter of the tree stem and terminal bud height was measured to estimate the tree growth and vigor. The base diameter of a tree correlates to the total biomass in the tree and in the height. Of all the varieties and cutting lengths planted, the Imperial Carolina cutting had the greatest base diameter after the first growing season, averaging 17 millimeters (0.7 inches). The DO-1 5 ft cutting average base diameter for a row was 15.4 millimeters. Table 2 lists the average base diameter (measured at the end of the first growing season) for randomly selected rows of Imperial Carolina trees (2 ft and 5 ft. cuttings), NE-19 trees, and DO-1 (5 ft. cuttings).

VARIETY	CUTTING LENGTH (FT)	ROW #	# TREES IN ROW	AVG. BASE DIAMETER(MM)
IMPERIAL CAROLINA	2	88	63	12.59
IMPERIAL CAROLINA	5	74	59	16.69
NE-19	5	40	47	13.40
DULA D0-1	5	18	66	15.42

Table 2: Average Stem Base Diameter for Sampled Trees Measured by Whole-row Sampling

Figure 9 shows a scatter graph plotting the stem cross sectional area with its measured height for 60 randomly sampled trees.

The random sampling does not reflect that most of the Imperial Carolina were heavily grazed by local wild deer. Imperial Carolina trees grown from 2 ft cuttings were most heavily damaged due to the easily accessible tender terminal shoot. Loss of the terminal shoot does temporarily retard growth. The Imperial Carolina trees grown from 5 ft cuttings were most heavily grazed near the toe of the planted landfill face. Once the trees grew above the grazing reach of the browsing deer, the trees grew vigorously. The DO-1 were observed to have little damage from deer.

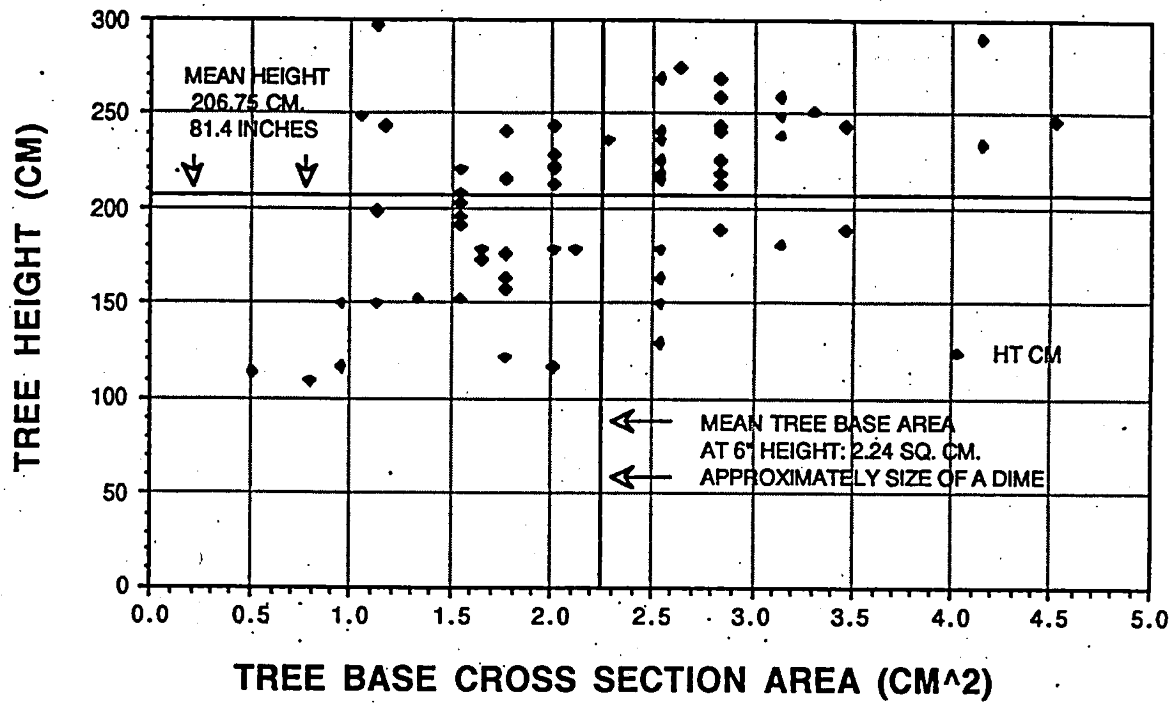


Figure 8: Tree Stem Base Cross Section Area vs.Tree Height for Randomly Selected Trees, November 1990

For the randomly selected samples across all plots, the average tree was 206.75 centimeters tall (81.4 inches or 6 ft, 9.4 inches) std.deviation of 18.42 inches. The average base diameter was 1.65 cm., std. deviation of 0.33 cm, at a height of 6 in above the soil. The average cross sectional area was 2.24 cm^2, standard deviation 0.85 cm^2. The trees appeared to have a generally good vitality as shown in Figure 9.

Figure 9: Tree Growth on the Lakeside Reclamation Landfill, November 1990

It can be concluded that the trees are growing with vitality and have survived the most critical phase of their establishment. Imperial Carolina and DO-1 varieties have demonstrated their ability to survive in disturbed soils, and to grow well. It is recommended that DO-1 and Imperial Carolina trees be planted again. Replanting NE-19 variety trees is recommended for one more growing season because of their longer growing season and late fall leaf retention. Several new varieties that have demonstrated vigorous rooting ability, fast growth, and disease resistance in the Pacific Northwest region will also be tested to diversify the cultivar base.

1990 SOIL WATER QUALITY RESULTS

Suction lysimeters were installed at 1 ft, 3 ft, and 5 ft depths to sample soil water from the unsaturated zone in the soil cap. One set of water samples was collected in May to screen for excessive nutrients.

In all the lysimeter samples from the cap soils, no nitrates were measured above the EPA's Maximum Contaminant Limits (MCL). This was expected because the soils are principally from building excavation.

1990 SOIL MOISTURE CONTENT RESULTS

To understand the impact of the trees on the fate and movement of precipitation infiltrating through the cap, instrument nests were installed on and off the cap. The instrument installation is shown in Figure 10. Each instrument nest contained three tensiometers and three suction lysimeters, installed at 1 ft, 3 ft, and 5 ft depths. Four nests were installed in the cap soils: two nests under 5-ft Imperial Carolina (between rows 75-76), one nests under 2-ft Imperial Carolina (between rows 88-89), one nest under 5-ft.DO-1 (between rows 102-103). The background nest was situated approximately 200 feet west of LRL excavation at the base of a naturally steep slope with 100+ feet vertical height; these tensiometer readings are very low indicating wetter conditions in this soil location compared to the readings in the landfill cap. Beginning in early November, puddled water was observed at the background tensiometer site. One 5 ft tensiometer was installed on a finished cap area planted to grass. One 5 ft tensiometer was installed in the riparian area between the fill and river adjacent to the tree canopy.

The ceramic cup tensiometers were used to qualify the moisture content in the landfill cap soils. The soil moisture content was measured by the suction of the unsaturated soils pulling water through a porous ceramic cap positioned at a desired depth . The gauge reading, measured in kilobars (kbar), represents the equilibrium suction between the soil and the tensiometer's tube of water. If a soil is saturated, there is no suction; therefore, the tensiometer reads '0'.

From September to December, 1990 LRL staff collected weekly tensiometer data to determine the moisture content of soils at various locations both on and off the cap. The first killing frost occurred on November 6, 1990. The soil moisture measuring was concluded December 12, 1990 when cold weather froze the soils, and tensiometer pressure gauges were removed for protection.

Figure 10: Lysimeter and Tensiometer Installation

Figures 11 - 15 graphically show the tensiometer readings from each instrument nest, Sept. 27 - Dec. 12, 1990.

The moisture content is described in general terms of 'wet' or 'dry'. The tensiometer readings collected from the landfill cap are difficult to correlate with typical readings for regional soil profiles because this landfill cap material is a mixture of repacked soils,

During the growing season, the upper 1 ft of soil was exposed to precipitation, evaporation, and tree rooting. The moisture content of the 1 ft horizon fluctuated from saturated to very dry. Figures 12 thru 14 show the soil at

1 ft depth rewetting after a 0.5 inch rain event October 5. The pattern was similar for all tree varieties. There was no apparent impact on the tensiometer reading at the 3 ft and 5 ft depths; this implies no change in the moisture content deeper in the cap soils. The upper 1 ft of soil again dryed, then slowly rewetted as the fall seasonal rains started. In late November the upper soils appeared to be resaturated.

At the 3 ft depth, tree rooting was extensive and the soil moisture content was very low during the growing season. The 3 ft depth consistently had the lowest moisture content for all varieties and cutting length. Rewetting didn't begin until late November. The 3 ft deep soils reach 'wet' conditions of 10 kbar approximately 3 weeks after the 1 ft deep soils rewet. The tensiometer readings indicated that the upper 3 ft of soil were very dry during the late summer and fall.

The soils at the 5 ft depths were more moist than the shallower soils during the first-year growing season under the trees. During the growing season, the moisture content was very consistent and stable throughout the late summer and fall for all varieties and cutting lengths. When the trees lost their leaves, the 5 ft soil depth was resaturated by mid-December for all plots.

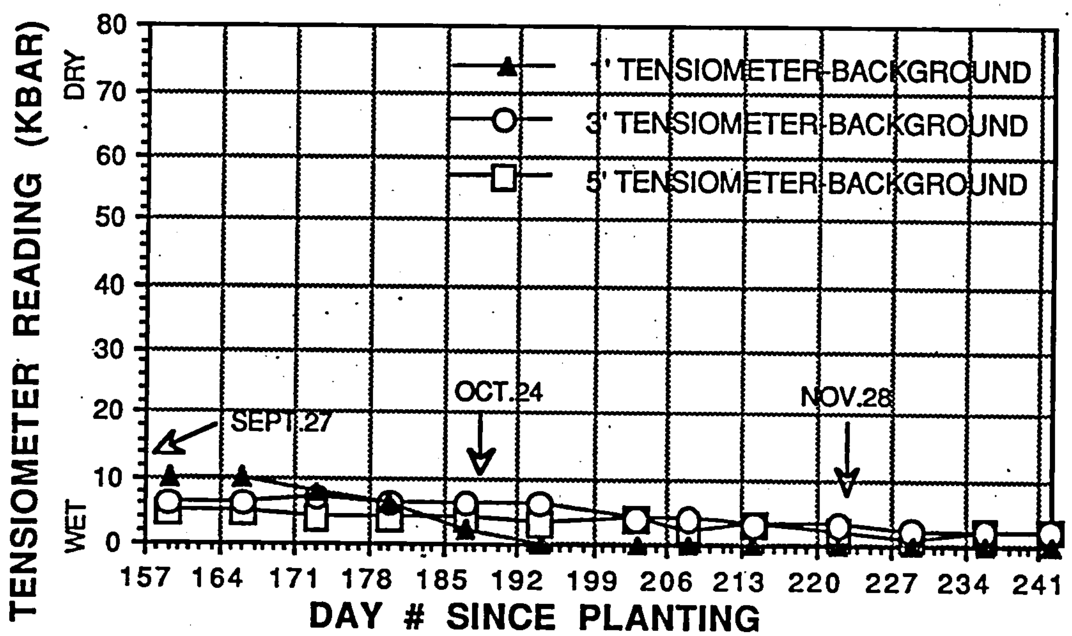


Figure 11: Background Well Tensiometer Readings

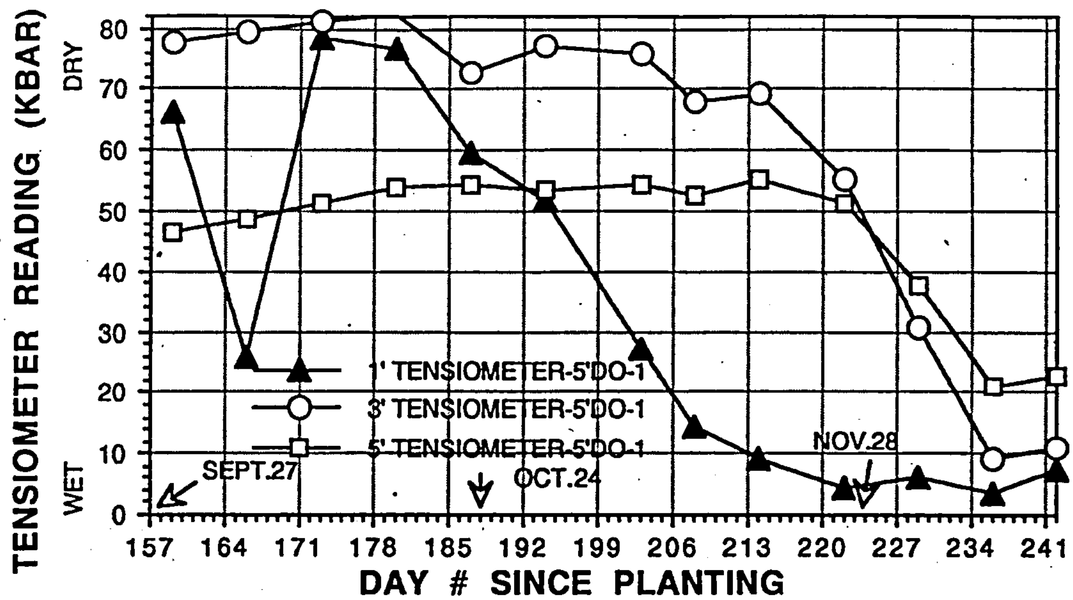


Figure 12: Dula DO-1 5 ft Cuttings Plot Tensiometer Readings

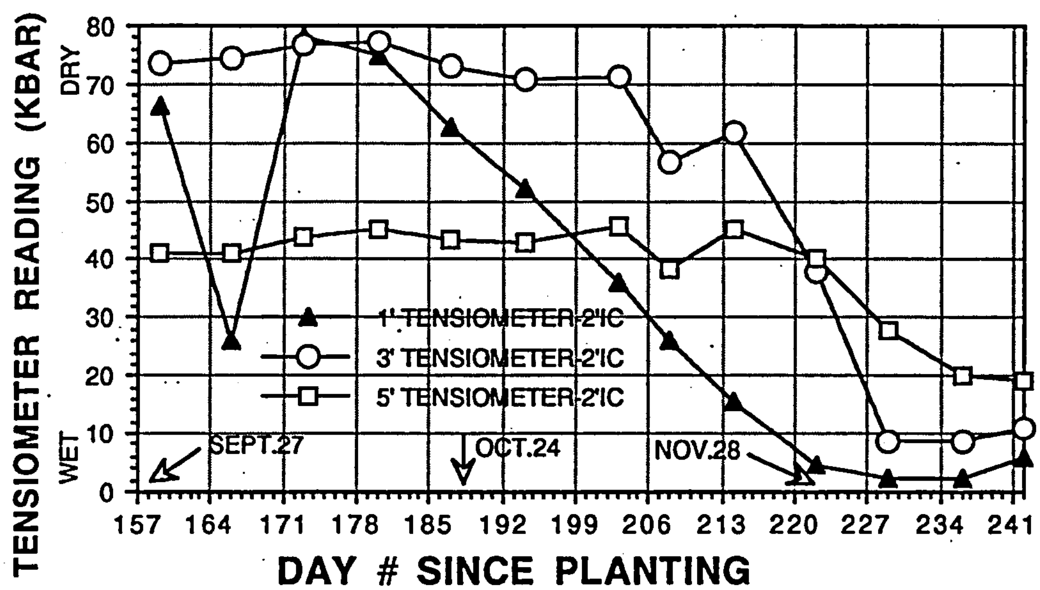


Figure 13: Imperial Carolina 2 ft Cuttings Plot Tensiometer Readings

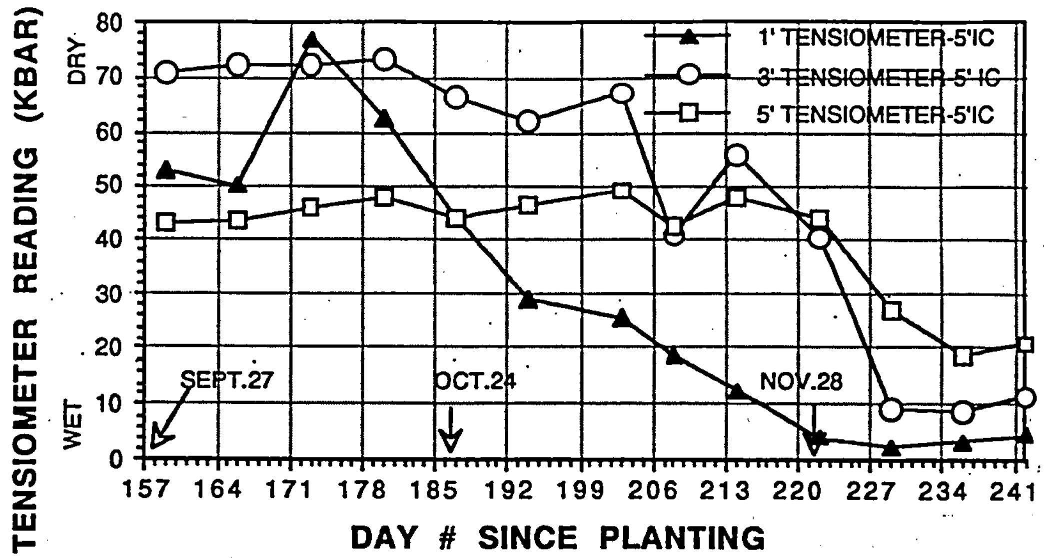


Figure 14: Imperial Carolina 5 ft Cuttings Plot Tensiometer Readings

As shown in Figure 15, an interesting comparison exists between the soil moisture content in soils planted with Imperial Carolina 2 ft cuttings and the moisture content in soils planted with 5 ft cuttings. At the 5 ft depth the soil contained more moisture during the growing season and resaturated faster in the fall under the trees from 2 ft cuttings. It was apparent that 5 ft long cuttings, planted 36 to 40 inches deep into the soil kept the 5 foot deep cap soil dewatered longer.

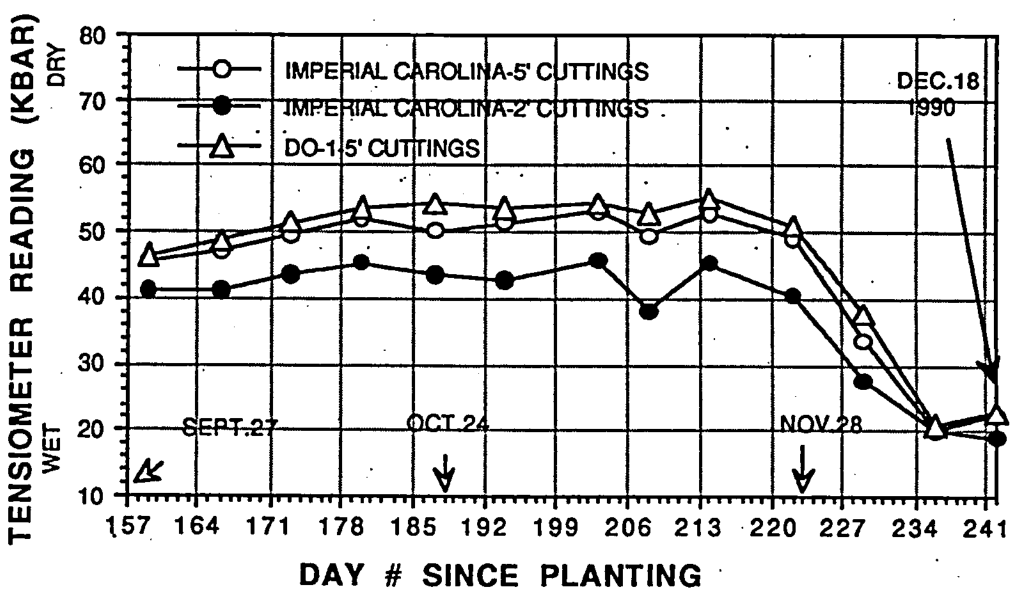


Figure 15: Tensiometer Readings Measured at 5 ft Depth
Comparing 2 ft Imperial Carolina Plot
with the 5 ft Imperial Carolina Plot and the Average of All 5 ft Trees.

As shown in Figure 16, an interesting comparison exists between the soil moisture content in riparian soils (between the river and the fill) and the moisture content in soils planted with 5 ft cuttings. The riparian soil is impregnated by mature grass and conifer tree roots and is dryer during the late summer but resaturates earlier than cap soils. At the 5 ft depth the moisture content in soil below a mature grass cover on completed fill was dryer than under the trees. This indicates more water uptake from this grass crop than by the new tree planting. Monitoring the soil moisture in the tree-planted cap, the riparian area, and the grass-planted cap will be continued in 1991.

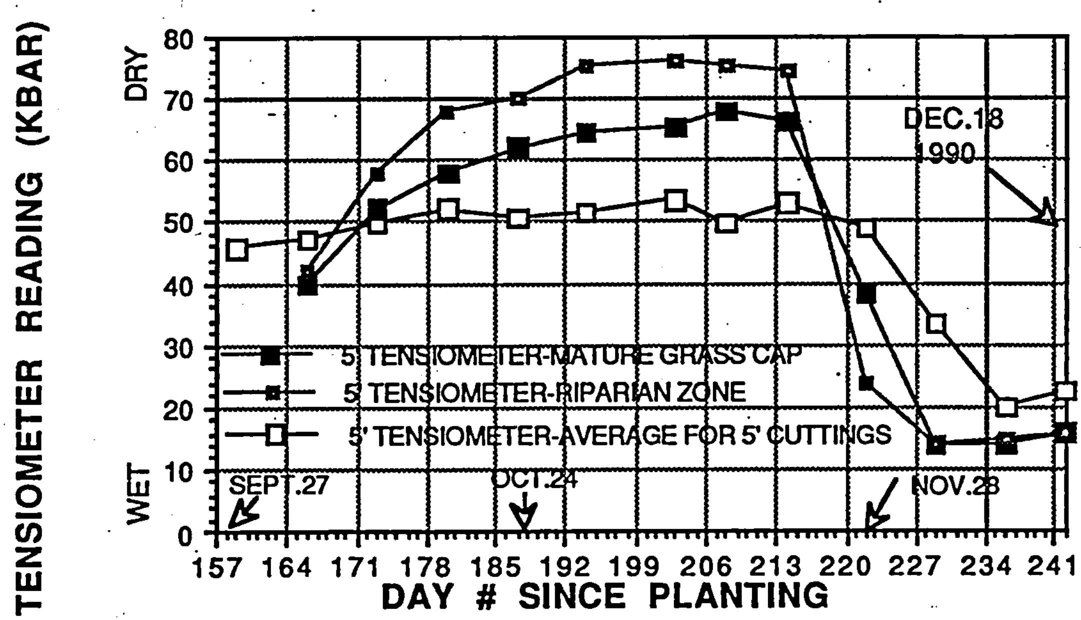


Figure 16: Tensiometer Readings at 5 ft Depth Comparing the Average Of All 5 ft Trees with a Mature Grass Cap and with the Riparian Zone

1990 CONCLUSIONS

1. Judging from survival, growth, and soil moisture data for the 1990 growing season, the deep-rooted vegetative cap densely planted with poplar trees can achieve landfill closure objectives while growing a luxuriant crop.
2. Five ft long poplar cuttings (both Imperial Carolina and DO-1) exceeded 90% survival rates when planted in 24 to 36-inch deep furrows.
3. Cutting death was principally attributed to 1989 in-field frost damage of cuttings and herbicide drift.

4. Both Imperial Carolina and DO-1 varieties demonstrated vigorous growth. The estimated average tree height for the plot is 6 ft 8 in, with many trees growing taller than 10 feet.
5. There was a measurable deer pressure on the Imperial Carolina variety; the deer ate the growing leader which stunted the 2 ft cutting growth. The DO-1 cuttings did not have this pressure.
6. The roots from the 5 ft cuttings had a measured impact on reducing the moisture in cap soils. The soils at 5 ft depths generally were dryer and are slower to resaturate after leaf drop than soils below 5 ft cuttings and below 2 ft cuttings.

1991 PLANTING PLAN

For the 1991 growing season, it is recommended that the vegetative cap be expanded by approximately 2 acres. The tree planting will include the total face of the completed first lift cover and be expanded to the second lift cover.

Seventy percent of the trees planted in 1991 will be of the same varieties (NE-19, DO-1, and Imperial Carolina) as planted in 1990. Two or more new varieties will be planted. For the 1991 growing season, 30 inch and 60 inch long cuttings will be planted using techniques similar to the 1990 prototype. The goal will be to place cuttings the full depth reached by the planter. The development of leaves and branches will be compared between the two cutting lengths.

For the 1991 growing season, the row spacing will also be modified to 5 ft between trees to permit use of small utility tractors for cultivation and weed control. This new planting density will approximate 5 ft^2/tree compared to 3.4 ft^2/tree for the 1990 installation. This will reduce the planting density by approximately 30%. In 1993, when the trees reach full canopy, little difference is expected in overall growth rates and evapotranspiration between planting densities.

During the 1991 growing season, the root development and their influence on soil moisture content.will be monitored for the 1990 cap installation. With Oregon's growing season normally being dry in late summer, this project will monitor the dehydration of the root zone and the time required for rehydration following leaf drop and the on-set of fall rains. Moisture contents of the cap soils in the winter and spring will be monitored with tensiometers to better understand soil resaturation and water uptake by plants.

Four additional instrument nests will be added: one in the new upper lift, one in an unplanted finished cap area, and two in the new lower lift. In fall of 1991 roots will be removed from the 1990 plot to examine structure and penetration depth.

In 1991, no irrigation will be used, minimum herbicides will be applied, and a small fertilizer nutrient will be applied where demanded by soil analyses.

For the 1991 growing season, a grass cover crop will be planted on a portion of the cap under the tree canopy. A cool season grass, such as a rye grass blend, will be planted to evapotranspire a portion of the water falling on the cap during the tree's dormant period. The introduction of a grass into the cap design will improve weed control and the overall soil stability. As an alternative to grass, an area of cap will be mulched with bark chips.

In 1991 a research grant will be actively pursued with federal, state, and/or private sources to fund the Oregon State University Bioresource Engineering Department to quantitatively define the water balance for the cap. This will take into account precipitation, runoff, evapotranspiration, plant uptake, and leakage below the root zone.

PROJECTED RESULTS

Using deep-rooted poplar cuttings to revegetate a landfill cap is a new concept. This capping technique is a applyingresluts from sustainable agriculture research to stabilize a landfill cap following closure. This vegetative cap was designed for precipitation to runoff the cap slope and for water removal from cover soils by plant roots. Using perennial plants with a large leaf surface area, such as poplar trees, it will be possible to establish a crop with a substantial root system capable of evapotranspiring a large water mass during a full growing season.

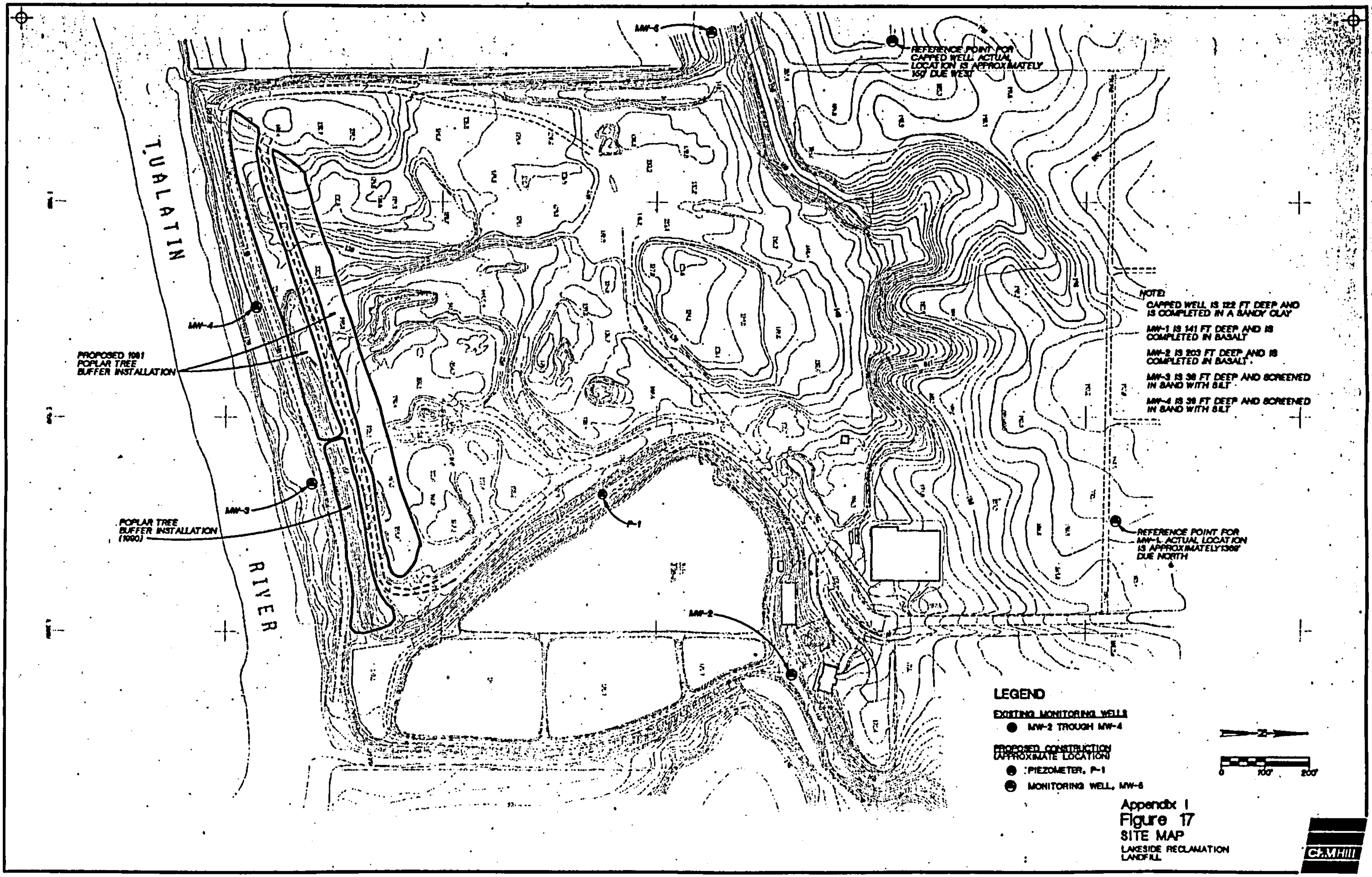
If the surface of the LRL can be revegetated using this technique, it will be possible to have an acreage able to produce a valuable commodity - wood chips. It is estimated that this technique will produce a sustainable yield between 8 to 13 tons of dry wood/acre/year after the second growing season. A yield of 20,000 pounds of poplar wood per acre per year is very feasible in the Oregon climate, and are achieved by plantations growing within 50 miles of LRL. This amount of stem dry matter would contain the heat value of 1,100 gallons of fuel oil if burned in pellet furnaces at documented efficiencies (assumes 20,000 lb dry matter, 8400 BTU/lb wood, 134,000 BTU/gal. fuel oil, 90% burning efficiency).

It is expected that the average tree stem will weigh between 900 and 1200 grams at the end of the second growing season. At planting densities of 3.4 ft^2/tree, the original 0.6 acre area is expected to grow approximately 14,000 lb of wood dry matter (assuming 1000 gr dry matter/tree, 6400 trees).

This closure technique uses perennial roots as a removal mechanism for precipitation infiltrating through the cap surface with the tree transpiring the water through plant leaves. By planting tree cuttings capable of rooting their entire buried depth, root growth is denser and deeper into the landfill cap soils than achieved by a sparse grass cover. Research underway at the University of Iowa, both in greenhouse and in field, demonstrates that fast growing plants are capable of removing a large amount of water from the rooted soils. Poplars have been documented to remove 600 to 1000 pounds of water for every pound of dry wood grown. This amount of plant growth has the capability to remove 1.0 to 1.7 million gallons of water for the capped area. This water uptake represents over 60 acre inches of water uptake potential for the planted area (assuming 14,000 lb dry wood growth, 600 lb water/lb wood grown, 0.6 acre site).

Rather than working against nature to prevent water from soaking into the landfill cap soils, tree and grass root systems are a more natural means to remove the water from the soil. In stark contrast to alternative membrane or clay cap covers, the revegetated LRL cap recreates an ecosystem. In addition to wood growth and water removal, the LRL cap is designed to reduce soil particle erosion by wind and rain, to flexibly adapt to differential settling, to diversify wildlife habitat, to offer a pleasing visual appearance, to sequester a large mass of carbon dioxide from the air, to releases a large mass of oxygen from plant photosynthesis, to grow a renewable crop that economically contributes to Oregon's economy, and to aid in the diversification of Lakeside Reclamation Landfill into new products from reclaimed material now buried.

Finally, the Lakeside Reclamation Landfill is an appropriate location to do this prototype landfill closure demonstration. The United States and other developed economies are looking for technologies that aid in restoring damaged ecosystems. This novel technique of using trees with their touted benefits for curbing future environmental problems demonstrates open minded approaches to development problems. By monitoring the results from the LRL cap, it will be possible to better predict the outcome of this closure technique on fills or spills containing more hazardous contents.



Appendix I
Figure 17
SITE MAP
LAKESIDE RECLAMATION LANDFILL

APPENDIX 2: Water Uptake vs. Poplar Stem Weight

Reference: Licht, L.A., Poplar Tree Buffer Strips Grown in Riparian Zones for Biomass Production and Non-point Source Pollution Control, Ph.D. Thesis, University of Iowa, Iowa City, IA., 1990.

Figure 18 shows the overall correlation between the weight of the poplar stem biomass growth in each growing chamber and the total volume of water fed. ... The evapotranspiration of water is related to the total leaf surface area and environmental factors such as air temperature, relative humidity, plant species, soil water content and plant maturity. These factors were not monitored. The mass of leaf and root was not measured and was not included in the total growing chamber biomass estimate.

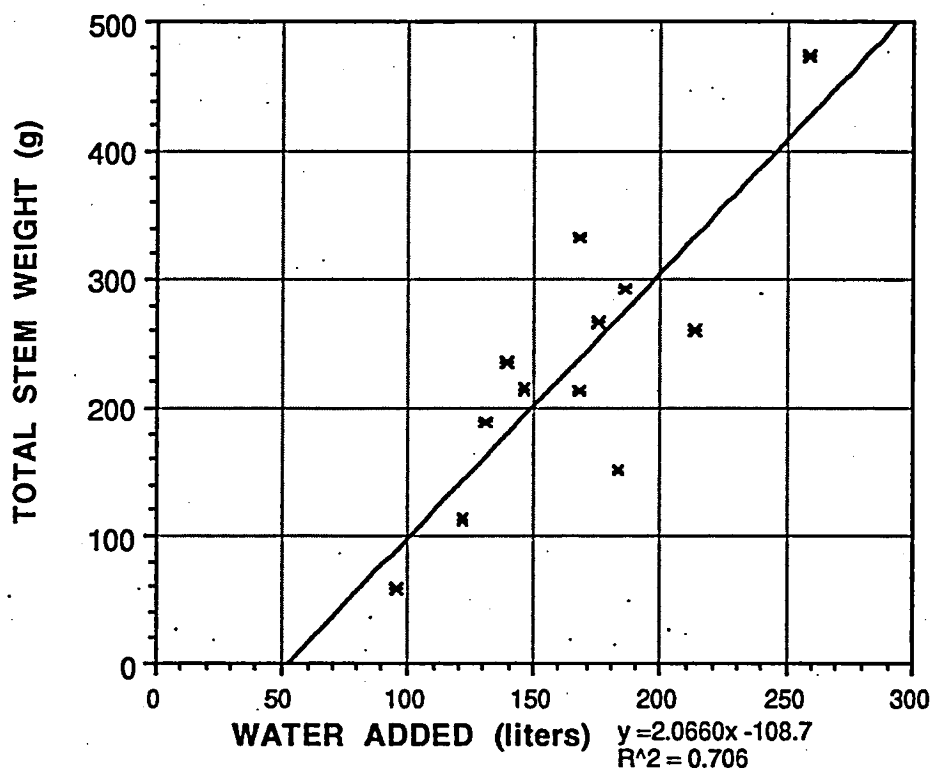


Figure 18: Water Added to Growing Chambers Correlated With the Total Stem Dry Matter Weight.

APPENDIX 3: Measured Second Growing Season Stem Growth

Reference: Licht, L.A., Poplar Tree Buffer Strips Grown in Riparian Zones for Biomass Production and Non-point Source Pollution Control, Ph.D. Thesis, University of Iowa, Iowa City, IA., 1990.

Following the 1988 growing season, the mean tree mass for 1 ft cutting plots was estimated at 39 g for the entire population based on ten trees sampled by measuring base diameter and height. The mean tree mass for the 6 ft cutting plot was estimated at 138.6 g using the same technique. Thus, the deep-planted cuttings grew at rates estimated at 3.6 times greater than the average short cutting during the 1988 growing season.

All long and short cuttings that survived the 1988 growing season lived through the winter dormant period and grew in 1989. When examined April 10, 1989, no new growth was observed though there was a noted change in bud coloration. The date April 10, 1989 was used as the beginning date for the 1989 growing season.

The 1989 biomass growth rate was estimated using whole trees harvested from interior rows of the Imperial Carolina variety plots on July 7, Sept 6 and Sept 28, 1989. Figures 19 and 20 show the 1989 growth curves for the average of the randomly sampled trees harvested respectively from 1 ft and 6 ft cutting plots.

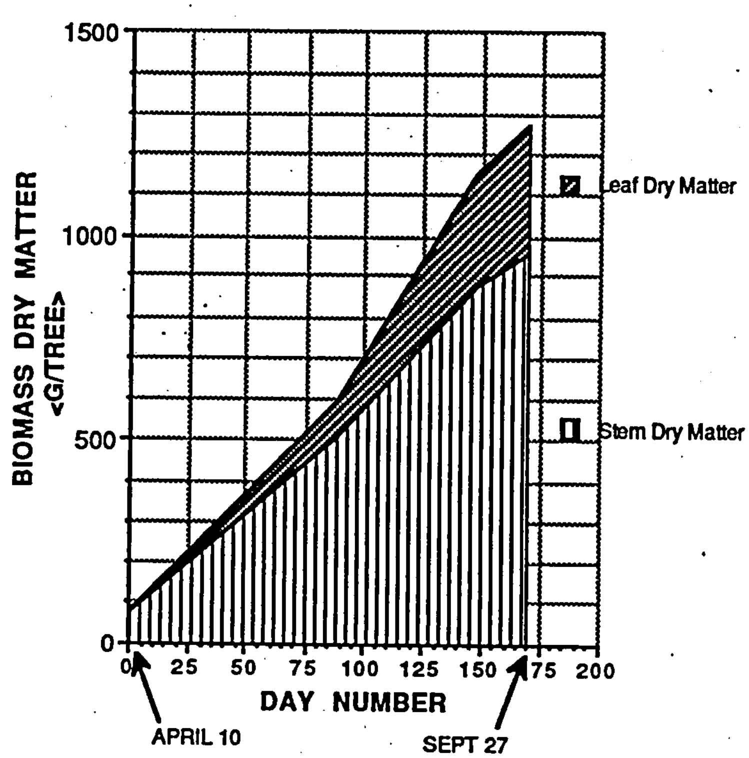


Figure 19: Leaf and Stem Biomass Growth Measured from Harvested Trees Grown from 1 ft Cuttings, 1989 Growing Season, Amana Plot

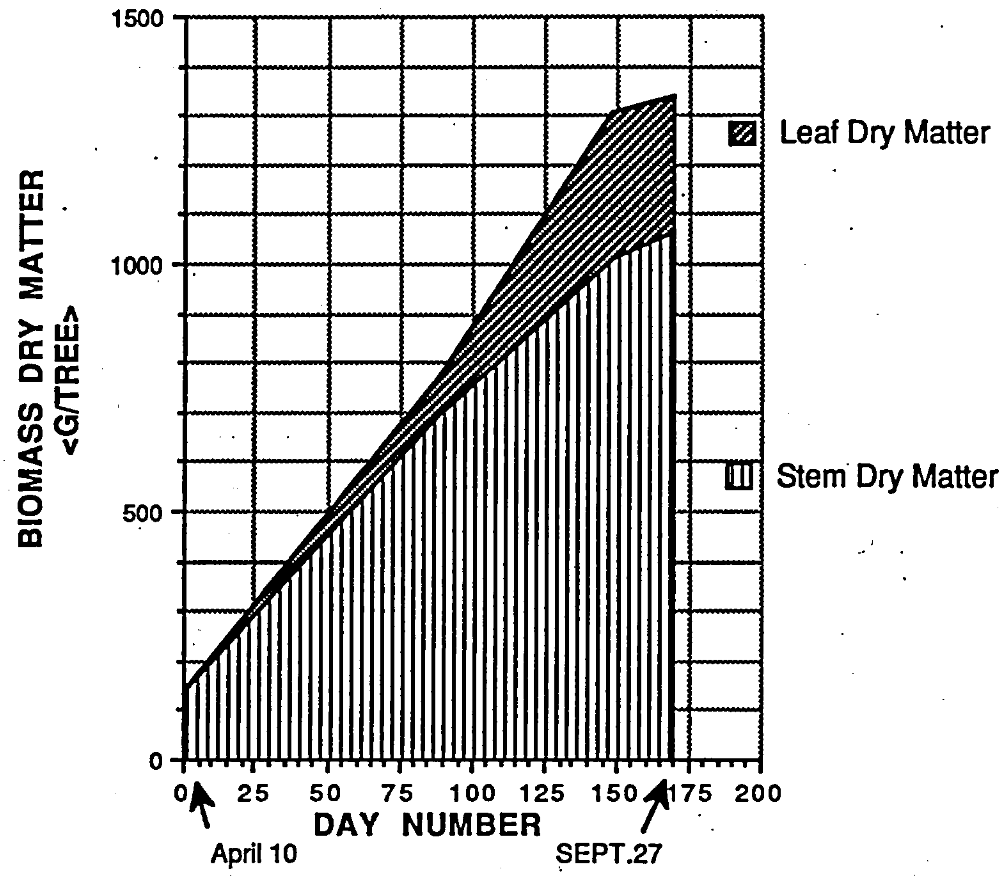


Figure 20: Leaf and Stem Biomass Growth Measured from Harvested Trees Grown from 6 ft Cuttings,1989 Growing Season, Amana Plot

The average growth rates for the poplar plots are shown in Figure 21, along with their linear least squares regression equation. There was no statistically significant difference ($p>0.1$) between the 1 ft and 6 ft cutting growth rate for the second growing season. There was a significant difference ($p<0.05$) between the growth rate intercepts, which indicate that the 1 ft cuttings started the second growing season significantly smaller than the 6 ft cuttings. Because there was no significant difference between the growth rates for 1 ft and 6 ft cuttings based on linear regression analyses, the rate used in subsequent equations will be the overall average of 5.4 grams stem dry matter growth per day.

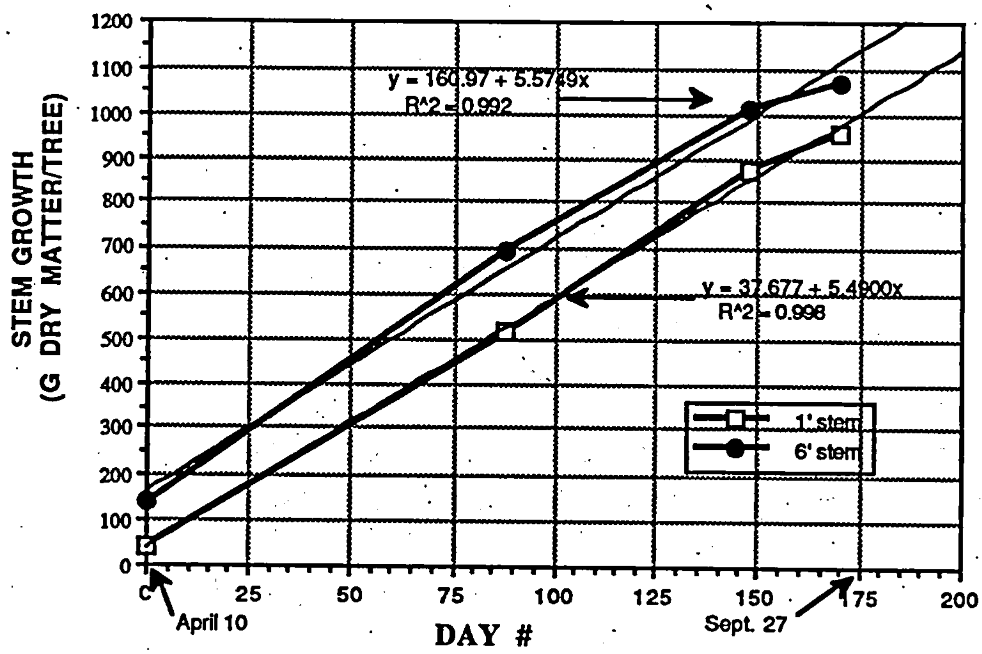


Figure 21: Stem Dry Matter Growth Curves for Populus spp. Trees Using 1 ft and 6 ft Cutting Stock, 1989 Growing Season.