Executive Summary

Mitigation of Climate Change through Land Reclamation with Biosolids:

Carbon storage in reclaimed mine soils, life cycle analysis of biosolids reclamation, and ecosystem services with reforestation

Masters Thesis presented

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Introduction

- Humans are changing the climate by altering the composition of the atmosphere. The main process responsible for anthropogenic climate change is carbon dioxide (CO_2) emitted as a result of burning fossil fuels (IPCC, 2007). Large amounts of carbon are also stored in biomass and in partially decomposed organic carbon in soils. Historic and ongoing atmospheric release of carbon from these biogenic sources, primarily through forest clearance and soil degradation, have contributed to significant additions of CO_2 to the atmosphere (Canadell et al., 2007). Reversing biomass and soil carbon losses through changed land management, such as improved soil tillage practices, reduced deforestation, and the reclamation of degraded soil could increase the amount of biological carbon stored in soils and biomass and help to mitigate further increases in atmospheric CO_2 levels (Lal, 2004; Pacala and Socolow, 2004).

- Land reclamation with municipal wastewater solids (biosolids) can play a role in reducing climate change (Brown and Subler, 2007). Reclaimed soils accrue carbon over their natural recovery (Akala and Lal, 2001), and numerous studies have shown that biosolids application in agriculture (Spargo et al., 2008) and during land reclamation after surface mining disturbance (Daniels and Haering, 1994) can increase soil carbon storage. However, fewer studies have been able to directly compare the differences in carbon storage between conventionally reclaimed soils and soils reclaimed with biosolids. Research on the long-term persistence of soil carbon enhancement with biosolids is only just beginning (Tian et al., 2009).

- **Study Goals:** 1) To better quantify the long-term increases in soil carbon with biosolids in mine reclamation compared to conventional reclamation; 2) to use this information in a wider life cycle assessment study to estimate the greenhouse gas emissions consequences of using biosolids in reclamation versus conventional reclamation with alternative biosolids use, and a non-reclamation land-use endpoint; and 3) to evaluate the potential impacts of biosolids in reclamation on enhancing other ecosystem services for generating human well-being.

Methods and Study Locations

- **<u>Site selection:</u>** Soils from five different reclaimed former surface mine areas were sampled (Table 1). In each mine area sites were selected within zones reclaimed with biosolids and zones reclaimed conventionally (i.e. synthetic fertilizer and/or topsoil placement only). Additional information on site history was collected from knowledgeable sources and from available documentation, including time since reclamation, biosolids application rate, mean annual temperature and precipitation, and dominant vegetation cover type.

- **<u>Soil Sampling:</u>** At each site a composite soil sample from the 0-15cm and 15-30cm soil layers was collected, along with a single surface bulk density sample. The composite samples were analyzed in an automated dry combustion apparatus to determine soil carbon concentration (%C by mass). Carbon concentration was used with the bulk density estimate to calculate site-level carbon storage in each soil layer (Mg C ha^{-1}). The carbon storage data was then subjected to statistical analysis to examine the effect of the site history factors on soil carbon storage, including the effect of biosolids treatment.

Table 1: Mine areas sampled in this study.

Location	**Mine type**	**No. conventional sites**	**No. biosolids sites**	**Max age**
Central Washington	Coal	23	12	17
Coastal BC	Sand & Gravel	N/A*	25	9
Inland BC	Copper/Molybdenum	7	14	8
Inland Massachusetts	Sand & Gravel	2	7	7
S. and Cent. Pennsylvania	Coal	9	19	27

*Conventional C storage estimated from measures of mine tailings and stockpiled topsoil.

Results of Field Study

- **<u>Soil carbon storage increased:</u>** At every mine area studied, sites reclaimed with biosolids stored more carbon in soils than similar conventional sites. The increase in soil carbon storage with biosolids was significant across the range of mine areas sampled, site ages and biosolids application rates. Statistically significant differences were typically only observed in the upper 15cm soil layer (Fig. 1). Mean increases in the 0-15cm layer ranged from 15.46 to 87.46 Mg C ha^{-1} compared to control sites.

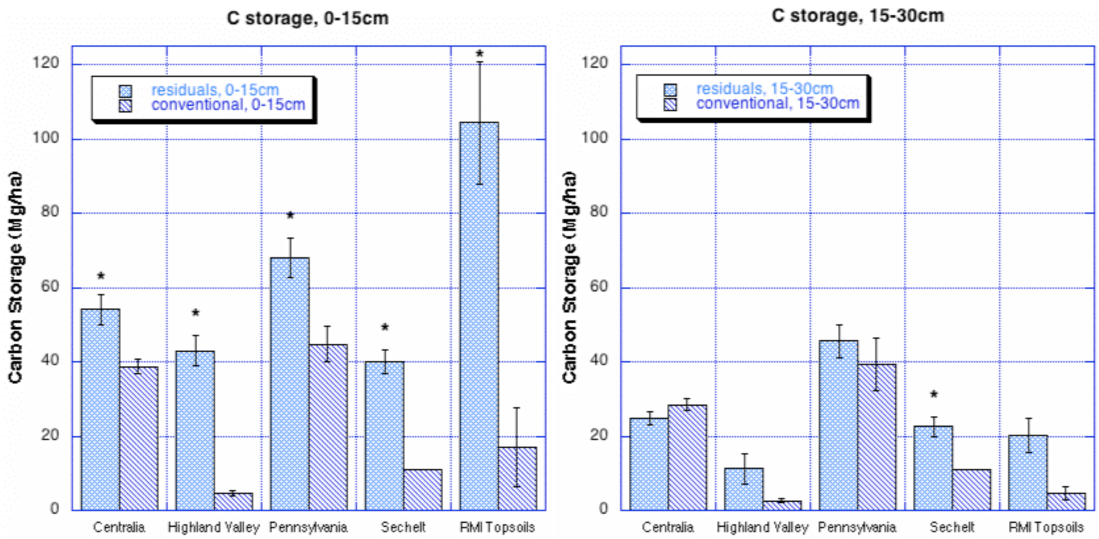

Fig. 1: Carbon storage in 0-15cm (left) and 15-30cm (right) soil layers, by treatment. * indicates statistically significant difference ($p < 0.05$) to local conventional mean.

- **<u>Positive Response to Treatment:</u>** The gross amount of carbon stored and the size of the soil carbon increase with biosolids varied substantially between mine areas, likely a product of site-specific factors and replacement topsoil quality. A response variable was calculated to normalize soil carbon storage against the appropriate local conventional site mean (mean response in conventional sites = 1.0). Response to biosolids amendment ranged from 1.40 to 6.16 times more carbon in the 0-15cm layer. The response variable also showed non-significant elevation at most mine areas in the 15-30cm layer (Fig. 2, below).

- This finding indicates that biosolids had a positive but variable effect on carbon storage across mines, with most increases occurring in the top 15cm but with smaller increases probably occurring in the 15-30cm layer.

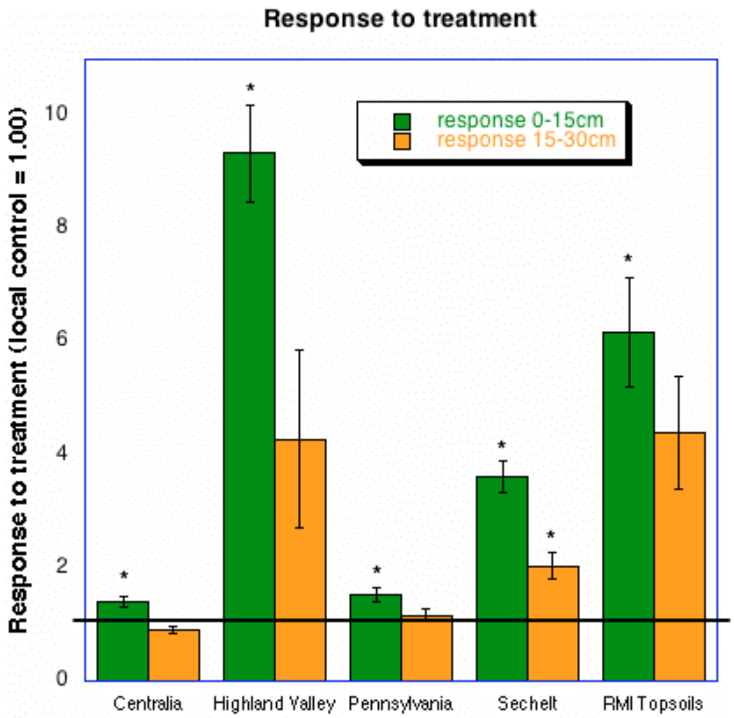

Fig. 2: Response to treatment in biosolids applied sites, 0-15 and 15-30cm layers. Bar indicates mean response in local conventional sites.

- **Carbon Storage efficiency:** C storage efficiency is the amount of carbon storage gained per Mg of biosolids/residuals applied. In the 0-15cm layer, where increases were significant, C storage efficiency ranged from 0.03 to 0.31 Mg C gained per Mg of biosolids applied.

- Greater storage efficiency appeared to occur in sites with lighter biosolids application. This finding may indicate that the C storage increase did not strongly correlate with increased application rate (i.e. C storage benefits were realized even at lower rates, while heavier application did not further increase C storage by a great deal).

- **Carbon accumulation rate:** Though this study did not directly measure C accumulation rate across the site history, it was possible to distribute the C storage increases against the age of the biosolids-treated sites. In the 0-15cm layer, biosolids-treated sites accumulated carbon at an effective rate of 0.91 to 41 Mg C ha^{-1} yr^{-1} over their local controls (generally below ~7 Mg C ha^{-1} yr^{-1}). Older sites showed lower net accumulation rates than younger sites.

- This finding may indicate that conventionally reclaimed sites could eventually "catch up" to similar biosolids-treated sites when both reach their long-term equilibrium C storage levels. However, this equilibrium had apparently not been reached even after 20-30 years of reclamation. Increase in biosolids C storage is therefore apparently persistent over the scale of at least a few decades.

Life Cycle Assessment of Biosolids in Reclamation

- **Scenarios considered:** A Life Cycle Assessment (LCA) of greenhouse gas emissions with biosolids use in reclamation was conducted to model the net climate impact of biosolids and post-reclamation land-use endpoints in the King County region of Washington state. Three different biosolids and land-use endpoint scenarios were considered to model the climate change impact of the CO_2, methane (CH_4) and nitrous oxide (N_2O) emissions due to biosolids use in reclamation on a hypothetical 1ha plot located in the Snoqualmie pass region over a 30 year time horizon. The scenarios modeled were:

    1) Biosolids reclamation, in which a biosolids unit of 100 dry Mg is applied during reclamation and the site is returned to typical forest cover;
    2) Conventional reclamation, in which the site is returned to forest cover and the biosolids unit is applied to wheat fields in eastern Washington; and
    3) Suburb, in which the site is developed with housing and road cover typical for low-density residential areas, with the remaining area reclaimed to forest and the biosolids unit applied to wheat fields.

- **Processes modeled:** The LCA model accounted for emissions from the following processes: biosolids handling and transport; equipment use in reclamation; construction, maintenance, and use of houses and roads; induced N_2O emissions from N application to soil; production of necessary NH_3 fertilizer and diesel fuel; and organic carbon storage increases in soil and biomass post-reclamation.

Results of LCA

- **GHG emissions highest in Suburb scenario:** Net global warming potential (GWP) impact was highest under the assumptions of the Suburb scenario, at 2464 Mg-CO_2-eq. (sum of the effect of emissions of CO_2, CH_4, and N_2O). The large impact on GWP under Suburb was mainly the result of high CO_2 emissions related to construction use and maintenance of roads and houses, as well as the diminished carbon sink due to loss of recovering forest cover (Fig. 3).

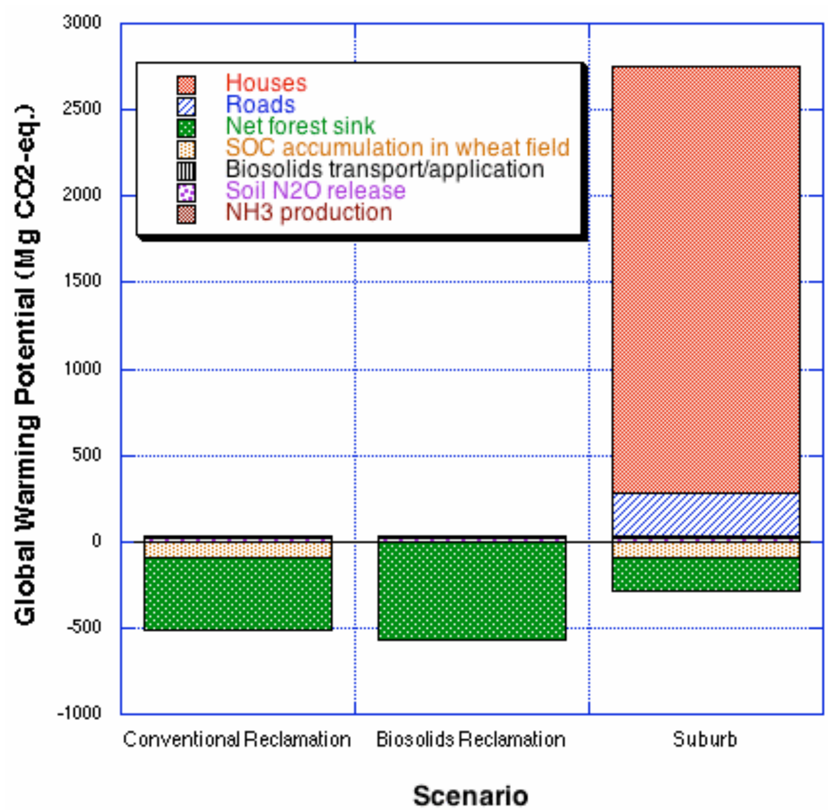

Fig. 3: Net global warming potential by process in each modeled scenario.

- **Biosolids in reclamation a net GHG sink:** The biosolids reclamation scenario had a GWP of -539 Mg CO_2-eq. (a net sink of GHG), while the conventional scenario had GWP of -477 Mg CO_2-eq. (summarized in Table 2). The net carbon sink in regrowing trees and in soils applied with biosolids was larger than the net sink under conventional reclamation due to faster tree growth and greater soil carbon storage. Ancillary GHG emissions due to biosolids transport, soil N_2O emissions, and NH_3 fertilizer displacement were minor compared to carbon storage increases gained with biosolids.

Table 2: Estimated global warming potential by process (in Mg CO_2-eq).

Process	Conventional Reclamation	Biosolids Reclamation	Suburb
House construction/use/maint.	0	0	2474
Road construction/maint.	0	0	245
Net forest sink	-422	-568	-199
Biosolids transport/handling	16	5	16
SOC accum. in wheat field	-91	0	-91
Soil N_2O release (BS)	19	24	19
Fertilizer production	0	0.2	0
Net GWP	**-477**	**-539**	**2464**

Other Ecosystem Services Affected by Reclamation

- Ecosystem services describes to the valuable products and services produced by natural ecosystems that contribute to human well being, such as providing fuel, stabilizing climate, and providing opportunities for recreation (Costanza et al., 1997). The impact of the LCA reclamation scenarios on three other classes of ecosystem services in addition to climate stabilization were evaluated: Rainfall capture and filtration; potential for tourism revenue; and biodiversity preservation.

- A review of the literature showed that complete reclamation of the 1ha unit plot of land in the LCA scenarios would likely lead to greater output of ecosystem services than conversion of some of the area to suburban land use (summarized in Table 3). Biosolids use in reclamation would likely result in similar output of these services relative to conventional reclamation.

Table 3: Ecosystem services output over 30 years based on reclamation scenario.

Scenario	GWP (Mg CO_2 eq.)	ML of water filtered	Tourism/recreation value	Biodiversity changes
Conventional Reclamation	-477	646	$3,150 - $31,500	+
Biosolids Reclamation	-539	646	$3,150 - $31,500	+
Suburb	2464	452	$1,470 - $14,700	–

Conclusions

- Soil carbon storage was greater in mine areas reclaimed with biosolids compared to similar areas reclaimed with conventional techniques. Results from this sampling suggest that use of biosolids, either singly or as part of a manufactured topsoil, results in higher carbon storage than use of high rates of topsoil for restoration. The increases in carbon storage were significant even 20-30 years after reclamation.

- Life cycle assessment of biosolids in reclamation in the King County region suggests that the use of biosolids in reclamation (with reforestation) would have a lower global warming impact over 30 years than conventional reclamation with reforestation. In comparison, conversion to low-density residential use would lead to much larger greenhouse gas release.

- Reclamation with reforestation, including with land-applied biosolids, would likely lead to greater provision of ecosystem services, including climate change mitigation, provision of useable water, generation of tourism revenue, and increasing biodiversity reserves.

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