COMPOST USE
IN FOREST LAND RESTORATION

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Introduction

Federal land management agencies, including the USDA Forest Service and USDI Bureau of Land Management, have made watershed restoration an integral part of land management. Many past activities have had negative impacts on forested watersheds that have resulted in widespread degradation of terrestrial and aquatic ecosystems. These activities include logging and associated road construction, mining, and recreational activities.

Forest roads can have many negative impacts on forested watershed, including increasing the magnitude and frequency of peak flows in streams and rivers, increasing the risk of landslides, and increasing fine sediment production. Many roads needed for access and travel management have environmental concerns. Existing roads may still be prone to surface erosion and ravel, plugged drainage features, cutbank failures, and landslides (mass wasting). These problems may be stabilized using soil improvement and bioengineering techniques. Other roads may no longer be needed due to reduced timber harvest levels. Road closure and obliteration is one of the most important methods to treat these roads. Road obliteration is the process of removing and treating roads, resulting in partial to complete recontouring of the site with the surrounding natural terrain.

Mining on National Forest and Bureau of Land Management lands has resulted in mine tailing piles that require remediation to mitigate environmental pollution. Many of these sites benefit from the vegetative establishment in order to reduce erosion and restore the plant community. The Surface Mining Control and Reclamation Act of 1977 requires that the land be restored in order to establish permanent vegetation that is native to the area and capable of plant succession.

A third type of disturbance occurs with the heavy use typical of recreational sites, particularly camping areas, which may result in compacted soils denuded of vegetation. These areas result in increased risk of erosion.

The primary factors limiting the re-establishment of native plants in these environments are poorly structured soils, the lack of water holding capacity, low soil nutrient concentrations (especially nitrogen), and steep slopes prone to ravel. The lack of organic matter in the soils of degraded sites may seriously limit the establishment and growth of vegetation or may hinder or prevent succession towards mature native plant communities (Bradshaw and Chadwick 1980).

The stated goal currently in land management Federal agencies is to cost-effectively reproduce the natural soil conditions and promote rapid native plant establishment and growth. The long-term goal of ecosystem restoration is best achieved through soil treatments that favor the succession and maintenance of native plant communities. Native plant species are desirable in the revegetation of disturbed sites because they are better adapted to local site conditions, and to long-term survival without maintenance. These species also provide better habitat conditions for wildlife and greater ecosystem diversity than non-native plants.

Objectives of this Handbook

This handbook is primarily intended for use in restoration of lands disturbed by forest management activities in the Pacific Northwest. The goal is to share information and to provide examples of successful restoration projects using compost. Many of the ideas presented here can be expanded for use in other environments with consideration for local site conditions. Specific objectives are:

- To increase understanding of the value of organic soil amendments in restoration of forest sites,
- To address environmental concerns about use of composts and other organic residues,
- To identify target forest areas which can benefit from the use of organic amendments,

- To provide guidance for planning and design of a project, then how to assess success of a project, and
- To present some examples of successful projects

Why Use Compost and Organic Soil Amendments

Compost is the product of controlled decomposition of organic matter by bacteria, actinomycetes, and fungi. Examples of organic materials typically used to produce compost include yardwaste, manure, and biosolids. Mature compost, which has gone through a time and temperature dependent process, is made of stable organic matter. Further decomposition by microbes after the compost has been applied to the soil releases nutrients slowly and makes the nutrients available for plant uptake. Compost interacts with the soil in several ways, as shown in Figure 1.

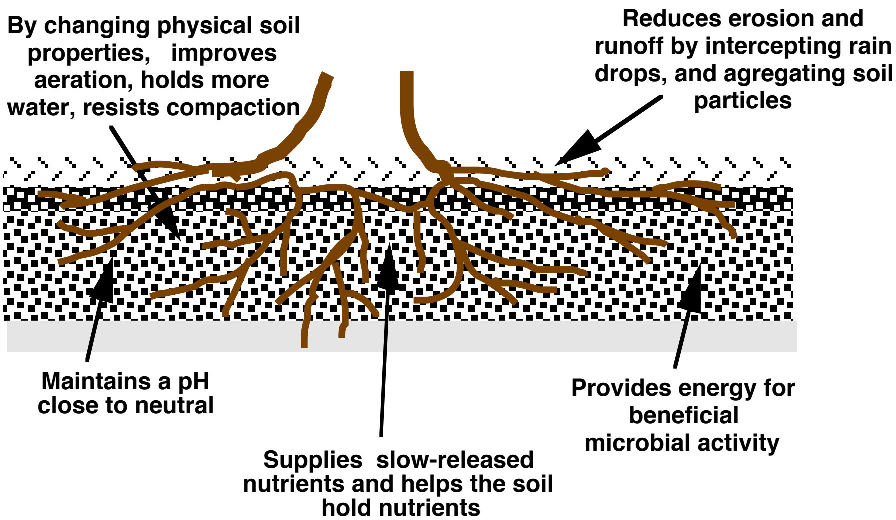

Figure 1. Major interactions of compost with the soil.

Improves the physical soil characteristics

The addition of compost to soils in restoration projects may provide many benefits over that provided by fertilizer applications. The additon of organic matter to soil has been shown to improve water-holding capacity, cation exchange capacity, aggregation and bulk density, buffers pH changes, and increase microbial diversity and activity (Hudson 1994, Brady and Weil 2000, Singer and Munns 2002). In clay textured soils, compost reduces the bulk density and increases the porosity of soils, thus improves the exchange of air and water through the soil. In soils that are predominantly sand, compost will increase the water holding capacity and soil aggregation, as illustrated in Figure 2. This addition of organic matter to ameliorate harsh soil conditions as part of restoration is recommended to improve the vegetative establishment and increase the rate of community succession (Bradshaw and Chadwick 1980).

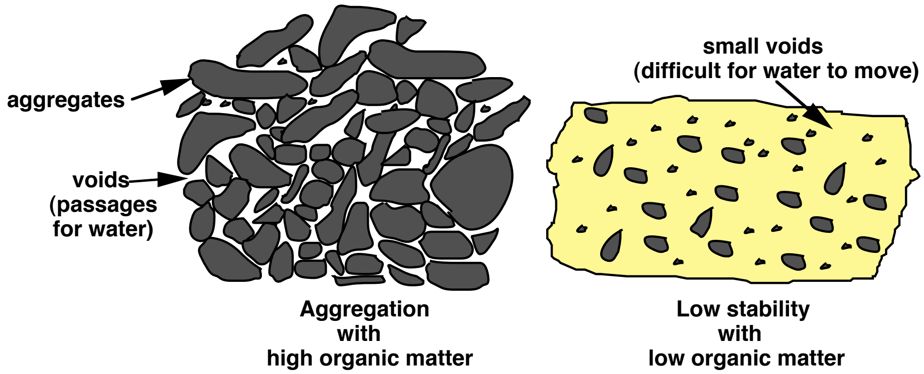

Figure 2. Aggregation in the soil is enhanced when organics in the soil are present, because soil microbes and biota are more active. Greater aggregation, in turn, enhances permeability.

Supplies macro and micronutrients

A mature compost can supply virtually every nutrient needed for plant growth in an available form, especially nitrogen. Composting alters the availability of nutrients from the feedstock (raw materials). During the process, available nutrients (or those that become available due to decomposition) are used by microbes decomposing the carbon-rich bulking agent (e.g., sawdust or yard trimmings). Thus, there are usually less available nutrients per unit of compost compared to the feedstock. This can be considered a positive attribute of compost, however, as it allows a higher application rate -- more organic matter can be incorporated as part of the renovated soil.

The nutrients available for plant growth are dependent upon two factors: 1) the characteristics of the bulking agent, and 2) the stability of the compost. Sawdust has virtually no nitrogen, and in decomposition of it, a significant amount of nitrogen is needed. In contrast, yard trimmings (especially if grass clippings are present) have a fair amount of nitrogen, usually need no nitrogen from other materials, and in some cases release some of their nitrogen into the soil.

A truly stable compost has reached an equilibrium between carbon and nitrogen. That is, there will be neither great demand for nitrogen, nor considerable nitrogen released from the compost. The time required to reach this equilibrium and for a compost to become stable (or mature) varies for different composts. For instance, a yard trimmings compost may become stable sooner than a coarse sawdust compost because much of the organic compounds are readily decomposable. Coarse sawdust decomposes slowly because the particle size is fairly big and very deficient in nitrogen *within* the chip.

Contributes organic matter

Compost adds organic matter to the soil. This organic matter does a number of things. It stores and slowly releases nutrients; it has a high moisture holding capacity; it enhances movement of water through the soil; and it has a high cation exchange capacity (i.e., it attracts and retains cations -- positive charged nutrients). Many potential sites are devoid of organic matter; addition of organics has the potential to greatly improve soil productivity.

Additionally, the organic matter in compost greatly influences aggregate formation and stability. The importance of this property is evident in Figure 2. Where organic matter is present, the soil particles are "bound" together, i.e., aggregated, and voids are present in the aggregated soil compared to the soil low in organic matter. These voids are the "pipes" for water flow (percolation).

Aggregation also decreases erosion. Sediment movement by rainwater is reduced when soil particles are larger. Organic matter which binds soil particles together, greatly reduces the potential for movement of these particles into streams. Organic matter not only retains (absorbs) more water than soil, but can also increase permeability of soil by increasing pore space in the soil. This means that the water will pass through the soil rather than flow over the surface of the soil. Largely because of all these characteristics, in many instances water quality can be improved by the use of compost.

Supplies beneficial microorganisms to soil

Organic matter is the energy source for soil microorganisms and the population of fungi, actinomycetes, and bacteria increases with the addition of compost. These soil microbes are responsible for the decomposition of compost and thus the nutrient cycling, and are essential for healthy plants. They also compete with soil pathogens. In a number of cases it has been shown that use of compost suppresses plant diseases, as described in the literature reviews *Technical Information on the Use of Organic Materials as Soil Amendments* (Henry 1991), and *Status of compost-amended potting mixes naturally suppressive to soil-borne diseases of floricultural crops* (Hoitink *et al.*, 1991).

Improves and stabilizes soil pH

The pH of the soil can be changed through the addition of compost depending upon the pH of the soil and compost. Compost with a typical pH (6-8) may be able to replace or reduce the use of lime for acidic soils. For very acidic soils, lime may also be added to compost. In addition, compost can provide buffering capacity to stabilize soil pH, making the soil more resistant to changes in pH.

Can bind or degrade specific pollutants

Compost has the ability to bind heavy metals, pesticides, herbicides, and other contaminants, reducing their leachability and uptake by plants (Brown et al. 2004, Fogarty and Tuoviea 1991). The soil microorganisms that compost supports also help break down pesticides, fertilizers, and hydrocarbons.

Improves water quality

The characteristics of compost mentioned above have the potential to improve the quality of water coming from watersheds. The three main reasons for this are: 1) sediment movement is reduced, 2) the soil binds and retains nutrients and other elements, and 3) plant growth is enhanced.

Soil erosion. When raindrops strike bare soil, the soil will erode and may enter streams. Initially, fine particles can be dislodged due to the energy of impact of the raindrops. Then, when rainfall intensity exceeds soil infiltration rates, energy of flowing water over the surface of the soil can erode particles along its path. The potential for erosion is greater with both higher flows and higher velocity of flow. As discussed earlier, organic matter will: i) bind soil particles together, making them harder to dislodge (requiring more energy), ii) hold more water, reducing the rate of runoff, and iii) increase permeability of the soil, again reducing the rate of runoff.

*Soil as a treatment mechanism***.** Once water is in the soil, the soil "micro ecology" can be viewed as a natural treatment system, utilizing or retaining the nutrients which would otherwise pass into streams or lakes. There are many mechanisms that reduce movement of nutrients either into ground water or surface water. These include immobilization by microbes (the use of nutrients in synthesis of new microbial biomass), uptake by the roots of plants, and chemical attractions and transformations. Many of the nutrients and trace elements are cations (positively charged ions), and electrostatically attracted to the cation exchange sites (negative charges of soil clays and organic matter). This mechanism greatly restricts movement of the cations, yet they are available for plant uptake. However, some of the nutrients are more mobile in the soil, especially the anions (negatively charged ions), such as NO_3^-, Cl^-, and SO_4^{2-}. Although phosphorus also is prevalent as an anion (PO_4^{3-}), it is often strongly held in the soil as a precipitate of calcium, aluminum or iron.

These mechanisms in the soil have been shown to be effective, such as in recent studies in a steep, forested watershed in western Washington, where it was found that phosphorous and ammonium N were not increased during runoff events following biosolids application (Grey and Henry 2002). A relationship between nitrate N and runoff was found although the nitrate losses from the biosolids amounted to less than 1% of the original mass of nitrogen that had been applied.

Plant response. Enhanced soil moisture conditions and availability of nutrients will enhance both plant establishment and growth. Enhancement of both trees and the understory vegetation decreases the potential for surface runoff and subsequent sediment movement into streams. This is a result of interception and dissipation of the energy of raindrops, disruption of any runoff patterns of overland flow, increase in infiltration through macropores formed by old roots, and binding the soils by root balls.

Environmental Concerns

The different types of compost materials each have different types of environmental concerns. The primary concerns with yard-waste composts include weed seeds, herbicide or pesticide persistence from the base material, and plant pathogens. Even the nutrients in yardwaste compost can have adverse environmental impacts if not managed properly. In contrast, concerns regarding biosolids include trace elements, trace synthetic organics, and pathogens. All of these constituents, if found in excessive amounts, have the potential to degrade the environment and affect human and animal health.

The environment is protected against this potential degradation in at least three ways: 1) Compost quality is high, due to industrial pretreatment of wastewater and hazardous waste programs, keeping the contaminants out of biosolids and other composts; 2) Proper management practices for compost and organic residuals are used including calculating appropriate application rates, maintaining buffers from waterways and conducting environmental monitoring; and 3) Characteristics are present in the soil, composts and biosolids to "treat" and bind contaminants.

Weed introduction

Weed seeds may potentially contaminate yardwaste compost materials through the base material or through other sources, such as wind-blown seeds. Commercially produced composts are generally allowed to reach temperatures exceeding 54 to 65 degrees C in order to destroy weed seeds. Grundy et al (1998) tested eight types of weed seeds that had been buried in packets in municipal yardwaste compost. The study found that all of the weed species were destroyed when the temperatures were allowed to reach 55 degrees C for three days. However, weed seeds could still survive if there are any cooler spots due to inefficient turning of the pile or if wind-blown seeds reached the outer portion of the pile following this process. Weed species that regenerate following fire may survive temperatures exceeding 55 degrees C and be able to germinate.

Change in site conditions to favor non-native vegetation

Non-native plants have been shown to substantially change the natural ecological succession, community structure and vegetative composition and diversity of native ecosystems. These species generally have evolved to thrive in moderate to high soil nutrient content, and may be expected to perform better with the addition of compost. Contrary to this expectation, results of a study on the effect of compost on native plant establishment and growth indicated favorable growth of native plants resulting from enhanced soil nutrient levels and improved physical soil conditions (Bergeron 2003). Other studies with compost have found similar results. Meyer et al.

(2004) found establishment of native species for four years using compost after following a high severity fire.

Nutrient management

Although the common perception of biosolids is that it contains large amounts of contaminants, surprisingly it is the nutrients (primarily nitrogen) contained in biosolids and other organic residuals that restrict application rates. Many studies have documented this; seldom have heavy applications posed problems from contaminants, whereas over-application will invariably cause nitrate leaching. Proper nutrient management – controlled application rates such as that used for any fertilization – will reduce risk of it occurring. Figure 3 shows actual data from a biosolids-applied site. For comparison purposes, both Douglas-fir stands and red alder stands are also show. Red alder is a nitrogen fixer, and typically adds significant amounts of nitrate to ground and surface waters. Current research is focused on nitrogen management, continually providing more accurate design of application rates. Secondly, site monitoring provides information to fine tune site specific application rates.

In many cases, phosphorus is used by plants at the same rate as it is supplied by the biosolids when application rates are based on nitrogen. This is because there is a fairly consistent ratio of nitrogen to phosphorus in most organic residuals. However, phosphorus content in biosolids may contain 2-3 times the P required by plants when applied at the N rate. If this is the case, excess P may occur. Excess phosphorus not used by plants usually precipitates (as described earlier) and is no longer soluble. The capacity of the soil to remove P is high in most forest soils in the western US, resulting in phosphorus rarely being a problem in an land application system. This may not be the case in other areas in the US, especially where frequent applications of manures have been applied.

Thus proper nutrient management will reduce risk of other environmental concerns to insignificant levels. A more complete discussion of nitrogen management can be found in ***Managing Nitrogen from Biosolids*** (Henry 1999).

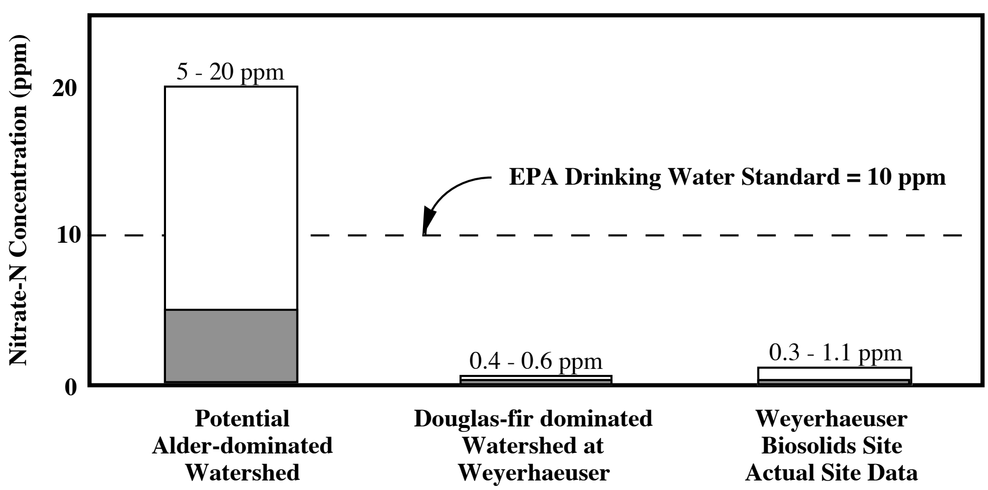

Figure 3. Comparison of nitrate-N concentrations in streams from different forests (Henry 1995).

Trace elements

Our soil contains trace elements (often referred to as "heavy metals"). Some of these are present naturally in rocks that decompose into soil, some may be from atmospheric deposition, and some from substances that humans apply to it. Biosolids and other organic materials contain trace elements from domestic, storm water and industrial sources that enter the sewage system. Some of these at high concentrations can be toxic to plants or animals. Several of these elements are also necessary plant or animal nutrients, meaning their lack is detrimental to the health of associated plants or animals. Necessary trace elements include V, Cr, Mo, Mn, Fe, Co, Cu, Zn and Se. Deficiencies of all of these elements have been noted in nature. Plant or animal toxicity of several of these elements sometimes limit biotic productivity in nature, including Cd, Ni, Zn, Cu, Pb, Cr, Mn, As, Mo and Se.

Over the years, the quality of biosolids has improved dramatically as a result of industrial pretreatment programs, household hazardous waste education and changes in water supply management. Secondly, trace elements are not all in forms that react with the environment. In other words, there are many mechanisms within soils and biosolids that reduce or eliminate their availability. Figure 4 shows these mechanisms, which are both chemical and biological in nature. In order for an element to move with water through the soil, it must be in a soluble form; in order for it to be available to plants it must be either soluble or exchangeable. By far the majority of elements in biosolids/organic residuals/soil are not in these forms, and research has shown that they become even less available with time (favored transformations are indicated by the heavier arrows in Figure 4). In some cases, addition of biosolids to soils may actually reduce the availability of the natural occurring trace elements.

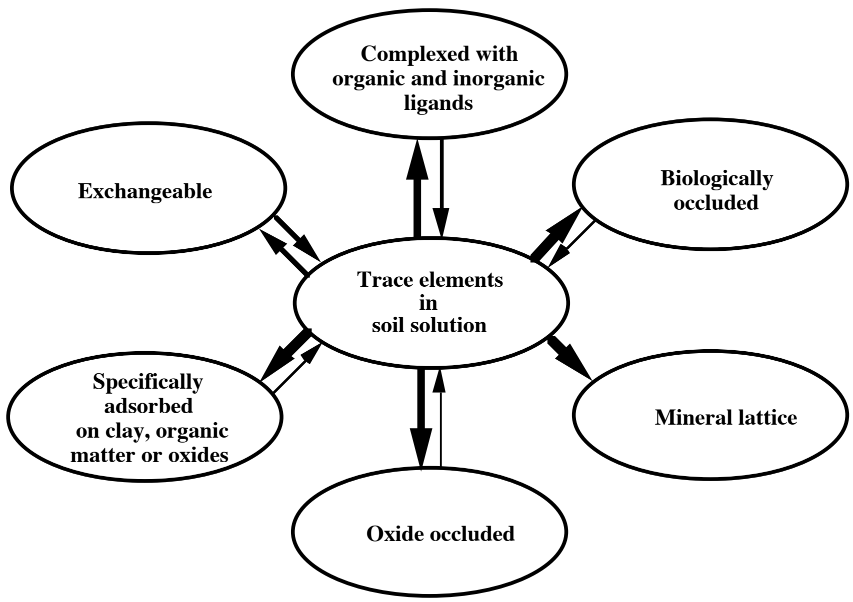

Figure 4. Processes by which trace elements found in biosolids are retained by the soil. Heavier arrows indicate general favored transformations. These element/soil/biosolids interactions restrict movement with water and uptake by plants.

Our environment can assimilate certain levels of these elements beyond the concentration that is required for plants. This level is included in the U.S. EPA standards for safe use of biosolids (40 CFR 503), as a result of an extensive exposure risk assessment methodology. Exceptional quality biosolids have concentrations below the following:

Metal	Concentration
arsenic	41 mg/kg
cadmium	39 mg/kg
copper	1500 mg/kg
lead	300 mg/kg
mercury	17 mg/kg
nickel	420 mg/kg
selenium	100 mg/kg

zinc	2800 mg/kg

Biosolids, biosolids composts and other organic residuals are typically well below these regulatory limits.

Trace synthetic organics

Trace synthetic organic compounds have not been found in biosolids at concentrations even remotely posing significant risk, and therefore not a problem in land application systems. Organic compounds are readily sorbed to the organic surfaces of the soil system and thus have limited mobility through the soil profile. In that these organic compounds are typically biodegradable, they will not accumulate to any extent in the soil.

In addition, concentrations of many organics in biosolids were dramatically decreasing as the result of industrial pretreatment, household hazardous waste programs, and halting production of the most toxic chemicals (such as PCBs). Synthetic organics also pose little risk because they are difficult to assimilate. The main exposure route for humans and other animals is by direct ingestion of soil containing biosolids or consumption of fat from animals that ate soil. Plants take up insignificant amounts of organics as they are strongly adsorbed to soil particles, especially by the organic fraction of biosolids. Studies have shown that PCBs and dioxins/difurans pose little risk, despite their high toxicity.

Pathogens

The EPA has developed standards for the level of pathogens in biosolids and biosolids products. Class A means that the treatment process results in a biosolids or biosolids product that has indicator organisms below the limits of detection for the methods specified in Part 503. is essentially pathogen free. The Class B means that, whereas most of the pathogens have been killed, a few (<1%) may survive. Class B biosolids have undergone a Process to Significantly Reduce Pathogens (PSRP) and that do not pose a threat to public health and the environment as long as actions are taken to prevent exposure to the biosolids after use. (An example is the restriction of public entry in applied areas immediately following application. Full details of these restrictions are outlined in the regulations.) The remaining pathogens are initially filtered out by the soil and forest floor and then replaced by the native organisms of the soil. The survival time for most microorganisms following land application is typically very short but is dependent on a variety of soil and climatic conditions including temperature, moisture content and pH. Bacterial pathogens will generally die off to negligible numbers within 2 to 3 months following application. Viruses can survive up to 3 months, while protozoa will survive for only a few days (Kowal 1985). In any case these microorganisms will not leach through the soil system to present a public health problem for the receiving ground waters. They will remain in the surface soils for the duration of their survival period. Where surface runoff occurs pathogens will be filtered out by the fine particles in the forest floor and soil within the buffers and be kept from entering into receiving water bodies. Generators and contractors are familiar with these restrictions and can make sure that application is in compliance with the regulations.

In contrast to Class B, Class A materials have undergone a Process to Further Reduce Pathogens (PFRP), such as high temperature digestion, composting or heat drying. This means that the concentration of fecal coliform is less than 1000 per g dry solids or *salmonella* is below the detection limit. Properly managed, a compost will be a Class A product.

Applications in Forest Land Restoration

Potential sites for compost use

Generally, to be consistent with restoration objectives, site characteristics desirable for compost use in forested environments are those with bare soil, and those where there is a plan to establish vegetation. These include cut and fill slopes, roadways to be abandoned, landings, and other areas of bare soil caused by either natural or human disturbance. Areas that should be avoided include those with excessive slopes (defined later), bare rock, and adjacent to flowing water.

Road obliteration

Road closure and obliteration is one of the most important methods used to improve and protect watersheds within the National Forests of the Pacific Northwest. These are generally compacted, have little sideslope, and usually have grades less than 15%. Road obliteration is the process of removing and treating roads, resulting in partial to complete recontouring of the site to match the surrounding natural terrain.

The main objectives of forest road obliteration are to restore hillslope hydrology, decrease surface erosion and the risk of mass wasting, and promote the re-establishment of native vegetation. The primary factors limiting the re-establishment of native plants in this environment are poorly constructed soils, the lack of water holding capacity, and low soil nutrient concentrations (especially nitrogen). Road obliteration is a restoration tool used to meet the goal of promoting long-term vegetative succession. However, the lack of organic matter in the soils of obliterated roads may seriously limit the establishment and growth of vegetation, and may hinder or prevent succession towards mature native plant communities (Bradshaw and Chadwick 1980). Thus, compost application can significantly increase restoration success.

Due to their compacted surface, it is highly desirable to rip the surface following compost application to facilitate movement of water into the soil and allow root penetration. Design considerations include: 1) compost application rate, and 2) existence of waterways, 3) runoff control.

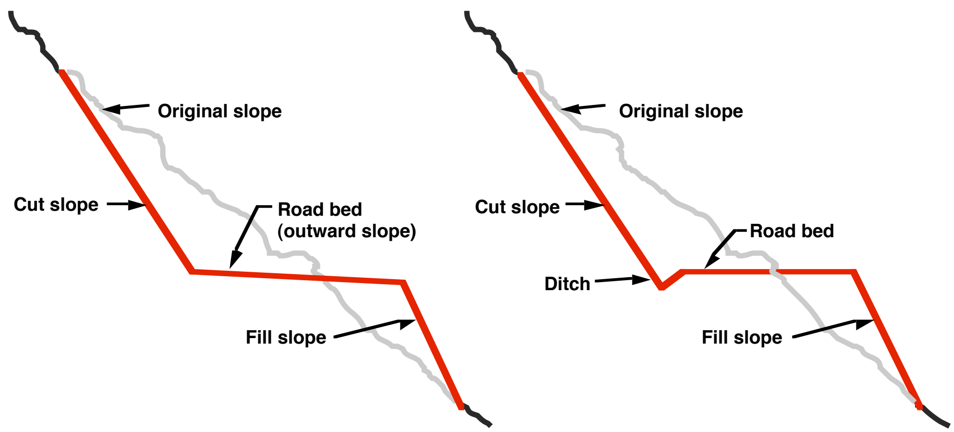

Figure 7. Typical road sections cut into hillside, with and without ditch for water conveyance.

Landings

Similar to roadways, landings are excellent opportunities for compost use, and have similar design considerations. Landings may also have substantial piles of logging debris. This material can easily be pulled back into the landing and help stabilize soil after application and ripping. Compost may even accelerate decomposition of the big woody debris by adding nutrients, holding moisture, and encouraging plant growth.

Natural eroded surfaces

Areas may exist which have eroded by natural causes, or indirectly from prior logging activities. These include slope failures or erosion from flooding. Some of these areas may be appropriate for reclamation using compost. However, as these areas failed under natural (or "altered natural" conditions), it is highly likely that they will fail again in the future regardless of efforts of restoration. Thus, a major consideration for this type of reclamation is whether the benefit outweighs the potential future failure. In some cases a delay or reduction of future erosion warrants the use of compost on this type of site. However, failure which allows a significant amount of compost (with associated nutrients and trace elements) to enter flowing water is not desirable.

Roadside restoration

Numerous state agencies have begun incorporating compost in roadside and highway restoration projects (US Compost Council 2003). Compost has been used in traditional landscape applications and expanded use to erosion and sediment control, reclamation, bioremediation, store water management and wetland restoration. The ability of compost to improve soil structure has resulted in reduced road maintenance costs in the long-term when compared with traditional engineering approaches.

One approach that has been developed lately for sediment-trapping and filtration devices is the use of composted materials encased within mesh bags (Faucette 2004). These proprietary netting products have had success in projects for erosion control and storm water management.

Mine restoration

Soil conditions on mine tailings represent conditions that are similar but significantly harsher than the mineral soil conditions characteristic of obliterated roads. Mine tailings generally have low pH and insufficient levels of nitrogen phosphorous and potassium, and high metal solubility. Biosolids compost and other organic amendments have been shown to improve soil properties on mine tailings (Bradshaw 1983, Brown et al. 2003, Cocke and Brown 1987, Harrison et al. 1995, Hudson 1994). This improvement has been demonstrated to be a result of: 1) an increase in the soil pH in acidic soil; 2) improved available water capacity; and 3) increased nitrogen, phosphorous and micronutrients. The result of these soil applications is an improved success of revegetation efforts.

Campsite restoration

Heavy recreation use often results in severely compacted soils with a loss of vegetation. This combination may result in soil erosion, further deteriorating the resources. In an effort to assess the effectiveness of campsite restoration, the Forest Service (USDA Forest Service 2001), initiated a study of restoration treatments in sub-alpine forests in northeastern Oregon. The restoration treatments included scarification, amending the soil with composted biosolids and a native soil innoculum, followed by planting native plants. When compared to untreated sites, or sites without soil amendments, there was a substantial improvement in seedling growth and survival. The authors anticipated complete recovery of the fully treated sites within five years compared to over 100 years for sites that had been scarified but not amended nor planted.

Restoration of wildfire sites

High intensity wildfires can detrimentally alter many ecosystem functions. Loss of vegetation, and especially the organic duff covering the forest floor can change infiltration rates during heavy rainfall, leading to heavy runoff and subsequent erosion. Composted biosolids have successfully been used to accelerate revegetation and reduce particulate movement into water bodies (Meyer et al. 2001 & 2004). Plant biomass and percent cover were both shown to increase, and corresponding runoff quality improved.

Elements of a Project

Obtaining Soil Amendments

Yardwaste composts

Municipalities and counties often have yard waste composting programs, which can be obtained through public works or other offices. Yardwaste composts are commercially produced that are generally made from yard waste with small amounts of wood waste, and can include grocery-produce waste. The temperature of the materials are allowed to rise above 130 degrees F in order to reduce weed seeds and plant pathogens. You can also make your own on-site from shredded/chipped yard waste from maintenance activities of parks or other facilities.

Biosolids composts

Biosolids are the residual materials from primary and secondary wastewater treatment. This material contains: a) organic matter, b) inorganic matter, including sand and ash, c) macronutrients, such as nitrogen and phosphorous, and d) micronutrients, such as iron and zinc.

Biosolids composts are produced by combining carbon-rich material, such as sawdust or woodchips, with biosolids. Both high and low N biosolids may be used as part of the feedstock for producing composts. Composting can be a portion of a municipalities biosolids program, either done by the municipality or by a private company. Finished compost is generally produced for the home gardener or landscaper so that the final product needs to be highly stable and screened to a small particle size. As a result of this, composts tend to be the most expensive of all types of biosolids so that the use of compost in restoration may not be the most cost effective option. Composts tend to have low fertilizer value and are used primarily as a soil conditioner. However, they can also be used to create a new soil horizon. High rates of compost are required for restoration (generally applying 3" of material is sufficient to create a new soil horizon). They are appropriate for use in high population areas and in areas bordering roads and streams where potential erosion of less stable materials is a concern. They can also be used as a border in projects that primarily use biosolids. Composts are also highly effective for use in wetland restoration or construction. They are stable, highly organic materials that are similar to the muck found in naturally occurring wetlands.

One way to lower the costs associated with compost use is to use compost that has not been screened or completely cured, as both long detention times and screening add significant costs to the process. These less stable materials are much cheaper to produce and can be obtained by working with a municipality or composting operation to specify the type of product that you require.

As an alternative, a relatively low-tech and cost effective way to produce compost from biosolids is by use of a static pile on site mixed with carbon-rich material at hand (logging waste, logyard waste, hog fuel, etc.). Biosolids can be set in piles and left to cure for 4 or more months. Little odor will be created except at pile building, and some amount at extraction of composted material for land application.

On-site Materials (residual logging debris)

Logging residuals, such as foliage, branches, and log decks, remaining on site after timber harvest, have tremendous potential for use in restoration projects. These materials are typically burned following timber harvest or thinning although increasing concerns about air quality

Lopped and chipped slash was combined with fertilizer in study of road restoration western Montana (Bradley 1997). The combination of scarification of the road surface and mulching produced a much higher vegetative biomass, seed germination, and seedbed density compared to the scarification or mulching alone. The combination of scarification and mulching also produced the greatest improvement in soil physical properties.

Their Cost

The additional cost of compost in restoration is a frequent concern. However, studies conducted by state highway departments (US Composting Council 2003) have shown that long-term costs in roadside construction have been reduced as a result of lower maintenance costs. The decision whether to use composts needs to be based upon the objectives of the restoration project. If a project fails because of lack of organic matter, then the project is not cost effective.

Nationwide, yardwaste, manure, and biosolids compost costs are typically $9-$15 per cubic yard. In addition, transportation to the restoration site and application of the materials need to be factored in to total costs. Materials found on-site, such as logging residues, may require a chipper in order to break down the material into a size suitable for application.

Under the Clean Water Act, all municipalities that generate biosolids are responsible for their management—use or disposal. Beneficial use for agriculture, silviculture, and restoration are recommended end-uses for biosolids under this act. Generally, a municipality will have developed a range of beneficial use options or will have paid a contractor to develop a beneficial use program. In all cases, the municipality has costs associated with biosolids use or disposal. It is also the goal of all municipalities to reduce these costs. In certain cases, the municipality or contractor will willingly provide and incorporate biosolids at no charge. In many cases, a token payment will be required.

The cost to treat a 2.5 km long road rehabilitation project on the Mt. Baker-Snoqualmie National Forest was estimated to be approximately $2600 for 2 inches of biosolids compost. However, the results of a two-year study of vegetative growth and biomass on this site indicate that a one inch application combined with winter wheat seed produced the most cost effective treatment combination.

Design and Permitting Process

Site suitability considerations

Often the disturbed areas, and thus the potential sites for compost use, exist in extreme conditions. These include excessively steep slopes (such as those occurring as a result of road building), severely compacted soils (old road beds or landings), areas that have been disturbed or eroded by heavy spring runoff, or areas where little or no soil exists for vegetation to establish. Potentially, these are the sites that can benefit the most from compost use.

However, the extreme sites are also those which stand the greatest chance of failure to meet the goals of restoration. For instance, compost may not be retained on excessively steep slopes, compost entering waterways may cause eutrophication, or vegetation establishment may be only temporary and may erode away in the future. In the following sections guidelines are shown for slopes and buffers from waterways based on field research and experience. The guidance provided here also requires the use of field common sense, as well as appropriate evaluation of results in when the compost is used in new situations.

Application rate

If one were to look at a native soil in the forest (schematic as shown in Figure 8), typically you would see an organic layer (O horizon) on top, followed by a dark mineral horizon (A horizon). When these have been disturbed, many desirable characteristics of soils have been lost, such as the organic matter, the nutrient bank, moisture holding capacity and porosity. This is especially true for old roadbeds, where the organic matter has purposely been removed. The goal of applying organic matter is to recreate these horizons, so that good soil characteristics can be reestablished.

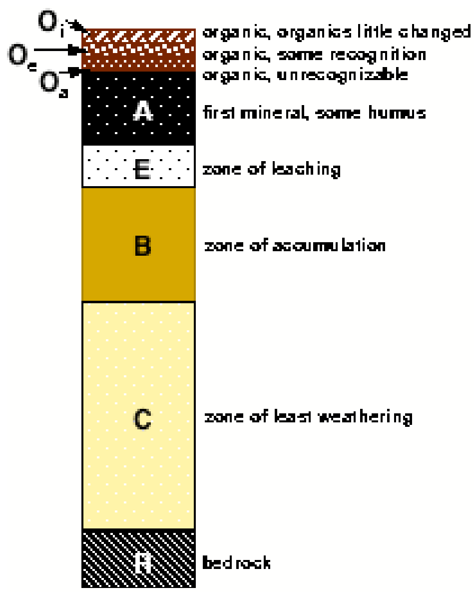

Figure 8. Typical soil profile and horizons.

Experience tells us that more of an organic amendment is generally better – and most of the benefit is when the material is in the rooting zone (top 6 inches). How much to apply is largely a balance between cost and benefit. Recommendations provided here are what may be considered conservatively low application rates; ones that can get the job done but consider the economics.

In these recommendations it is assumed that a "nutrient balanced" compost has been manufactured. In other words, the compost amendment should not have nutrients either deficient nor in excess. If a high nitrogen containing material is used in the reclamation project, excessive N could leave the site. Good guidelines exist to calculate application rates based on N (Henry 1999).

Roads and landings (compost incorporated). Where the compost is applied and incorporated into the soil, a 2-3 inch application is recommended. This is equal to about 100 tons/ac dry matter, and if we assume it is incorporated into the top 6 inches of soil, it will result in up to 10% organic matter in this layer. In a few years, decomposition will probably reduce this to about 5%, which is a good target for a topsoil. This target rate may be high for some areas, such as the semi arid/arid regions of the PNW, where "relatively productive" surrounding soils may be considerable less than 5% organic matter.

Slopes and natural erosion areas (compost surface applied). In areas with slopes too steep for equipment to incorporate the compost, it can be surface applied. In a sense, this is like creating an instant duff layer similar to litterfall. Research to date suggest that a surface application of one inch of biosolids compost combined with winter wheat seed as a cover crop resulted in substantially improved vegetative cover and native plant biomass (Bergeron 2003). The single application of organic matter has shown to promote plant growth over a two-year period and eventually, as the plants die and decompose, the soil properties should continue to improve.

Slope criteria

Recent research has shown no movement of compost over a winter and following spring with slopes up to 40%, and little movement (but still complete coverage of the soil with compost) at slopes up to 65%. Using these results, acceptable slopes have been recommended to include those up to 50%. Where terraces are constructed, erosion potential is reduced, so average slopes exceeding the value shown in Table 1 may be applied, but only to the actual terrace. Bare smooth rock will probably not hold compost for a significant period of time, and thus are not recommended for application.

Table 1. Recommendations for applications of compost to slopes.

General criteria for surface application	
Average <50%	apply to the whole slope
Average >50%	do not apply
General criteria for incorporated application	
Average <50%	apply to the whole slope
Average >50%	do not apply
Terraced slopes	apply to terraces
Rocky slopes	
solid rock	do not apply
soil with solid rock portions	apply to soil portion only
broken rock (ave. <3" dia)	apply to the whole slope
Hard packed soil on slopes	rough up surface of soil

Buffers from flowing water and ditches

Our objective in compost use is to rehabilitate the soil for a net reduction of erosion. Buffer recommendations were developed consistent with this objective and for the following purposes: 1) to provide a factor of safety against errors even when proper application and management techniques are used, and 2) to absorb constituents and filter runoff from waste-applied surfaces. Depending upon compost application method, material can be placed pretty close to where we want it, and waterways can be identified fairly easily in these disturbed areas. The recommendations of minimums of 33' from continuously flowing water were made to be consistent with EPA's 40 CFR 503 biosolids regulation. In some cases, "waters of the U.S." may include intermittent streams and in some cases dry stream beds. To have set backs less than the 33' foot requirement, the permitting authority may have to be consulted.

Although it may be possible to reduce erosion by using compost immediately adjacent to a waterway, erosion of the compost is highly likely in some conditions. The purpose of Table 2 is to give guidance to minimize the potential for loss of compost or nutrients to the waterways. Figure 9 shows some of the buffers for typical situations.

Application to cut slopes where there is a ditch at the bottom should generally not be made even though we have recommendations for buffer distance (Figure 9), because invariably some of the compost will enter the ditch, and it, or the nutrients in it, will be transported downstream during rainfall events. One alternative is to eliminate the ditch, and slope the road as shown in the first part of Figure 9. This will effectively eliminate concentration of flowing water, and distribute it on the downslope side of the roadbed. Any channeling in the road should be buffered as recommended in Table 2.

Water bars should be incorporated into road closures to channel flow and reduce erosion from water running down the center of the road. Figure 10 shows recommended buffers or compost from water bars. If one or more of the sides are bermed in water bar construction, the compost may be applied to the outside top of the berm.

Table 2. Buffer recommendations for applications of compost.

Slope and Application Method	Continually Flowing	Ditches*
Slope <5%		
Surface applied	33'	10'
Incorporated	33'	5'
Slopes <50%		
Waterway downslope, buffer vegetated		
Surface applied	50'	25'
Incorporated	33'	10'
Waterway downslope, buffer bare soil		
Surface applied	100'	50'
Incorporated	50'	25'
Terraced	33'	10'
Waterbar		
With berm		to berm
Without berm - surface applied		10'
Without berm - incorporated		5'

* May need consultation with the permitting authority.

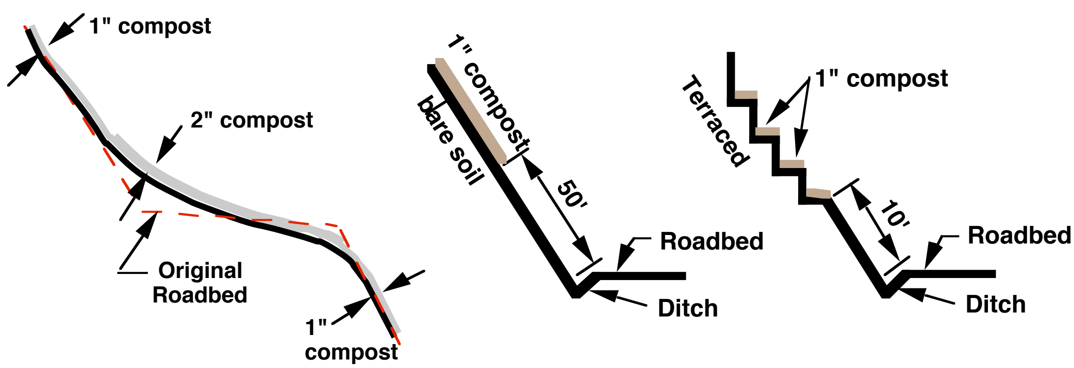

Figure 9. Compost and buffer recommendations for road sections and from ditches.

Sites with characteristics outside these guidelines

As mentioned, these guidelines are purposely conservative, and we expect there are many potential uses/situations that lie outside of the "acceptable limits" as defined by these guidelines. Additional potential opportunities should be evaluated on a case-by-case basis so that the successful use of compost can be expanded. Those with a relatively high potential will be developed as a small monitored research project, where the results can be used to modify these guidelines in the future.

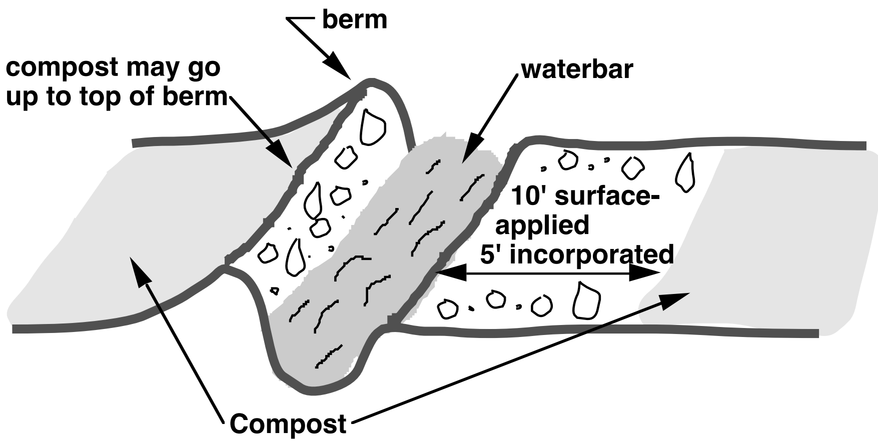

Figure 10. Buffers recommended for compost application near water bars on abandoned roads.

Permitting process

Permits are generally required for all biosolids applications with the exception of small scale biosolids compost use. Use of biosolids for reclamation is a recommended practice in US regulations. A provision is made within the regulations for application in excess of agricultural rates for restoration objectives: 503.14(d) "Bulk sewage sludge shall be applied…. at agronomic rates…unless, in the case of a reclamation site, otherwise specified by the permitting authority." Permits may be required on several levels, depending on the particular region of the country. Generally, the permitting process is best left to the experts. If biosolids are being obtained through a municipality, generators can often walk the necessary permits through. Another way to obtain appropriate permits is by working with the regional/state biosolids coordinator.

Federal regulations -- 40 CFR 503

Contaminants – metals and organics. The national regulations that define appropriate use of biosolids are detailed in 40 CFR part 503. The basis for 40 CFR 503 is an exposure risk assessment that used a "highly exposed individual" pathway approach to evaluate potential negative impacts from contaminants as a result of biosolids use. Although the data for the assessment was primarily from agronomic use of biosolids, soil reclamation was also considered. As part of the regulation, EPA defined as exceptional quality biosolids, where the maximum metal concentrations meet or exceed those described earlier in **Environmental Concerns: Trace elements**. These materials may be used without restriction. Currently the vast majority of biosolids produced in the country have metal concentrations well below these limits, especially when the biosolids have been mixed with other residuals and composted. Organic contaminants are not regulated under 40 CFR 503 as concentrations of these materials were well below concentrations that were deemed to pose a potential risk. (For the technical basis for 40 CFR 503 see EPA 1995.)

State regulations

The 40 CFR Part 503 regulations are the minimum standards for biosolids application. Each state has the freedom to apply more stringent standards above and beyond those outlined in 503. The EPA regional biosolids coordinator will be familiar with any additional regulations. Many additional regulations relate primarily to agricultural use of biosolids. Use of material for restoration purposes (generally a one-time application) may be exempt from these additional regulations.

Social Acceptance

While the use of yardwaste compost in restoration is seen as a progressive use of recycled materials, the use of biosolids compost can still raise some concern. In the use of straight biosolids, a successful project usually requires a pro-active approach. It is necessary to be very open with local citizens groups about the nature of the restoration project. This includes being straightforward about the materials to be used as well as their origins. Low-keyed informational meetings (as opposed to formal public meetings or hearings) and articles in local papers are very effective means for gaining public acceptance. A large body of educational materials exists that is excellent for use in public meetings. These include videos and pamphlets that describe what biosolids are, the regulations governing their use, and the benefits associated with biosolids use. The generator or contractor providing biosolids for a project may have access to these types of materials. The Northwest Biosolids Management Association (NBMA - contact Maile Lono 206 684-1145 www.nwbiosolids.org) is also an excellent source of general educational material and can also provide detailed literature reviews on the environmental effects of biosolids use.

One major advantage of the use of composted biosolids, is that is normally looks good and doesn't have an objectionable odor. In most cases it can be used without the extensive social acceptance effort that straight biosolids requires.

Application Techniques

Application of compost usually requires special equipment to match the characteristics of the compost to the individual site. The amount of moisture in residuals and composts, commonly reported as % solids (a weight measurement of the amount of solids and water in a biosolids sample), is the predominant characteristic that dictates the type of machinery required, the application procedures and application timing. The solids content of compost vary from about 40 to over 60% solids (60 to over 40% moisture), as compared to biosolids that vary from a dark liquid at 2-3% solids to a semi-solid moist cake-like material at up to 40% solids. Dewatered biosolids, sometimes called cake, have had polymers or lime added prior to belt filter press or centrifuge processing to achieve a 15-30% solids content. They are generally the consistency of gelatinous mud.

Application rates are typically calculated on a dry weight basis. This means that, for an average compost (at 50% solids), application of 100 dry t/ac would involve applying 200 wet t/ac of material. This is a significant amount of material at 2-3" deep. This quantity suggests simplicity and speed -- a feature of direct spreading! A variety of equipment technologies are available to perform direct spreading including farm manure wagons, all terrain vehicles with rear tanks and dump trucks.

Heavy applications such as this can be accomplished using two basic techniques, both of which are relatively easy in concept and relatively inexpensive.

- **Single application**. The fastest and most cost-effective method is to make the total application in a single lift. Once applied, normal farm disks can be used to incorporate compost into the subsoils.
- **Multiple lifts**. In some cases using materials with low percent solids and with some equipment, it may be easier to apply in smaller "lifts", or partial applications. For example, applying a low percent solids material like biosolids or manure means that a much greater depth of material. That may require either incorporation or drying between applications. Another example is using a manure spreader that is designed for 3-10 tons per acre may require repeated passes. In the case of multiple heavy applications needed within a short period of time, working the soil becomes a definite challenge, as repeated applications following by mixing without drying will turn the soil into a deep quagmire (potentially far

deeper than the actual depth of material added). Because the soil is worked many more times in this method, costs will be significantly higher.

There are several technologies that are effective for applying and even incorporating these rates of materials. Site topography, soil strength, evenness (including debris), and waterways are the physical features that affect equipment selection. Easy access, stable soils and a clear site favors the simple methods, while obstructions or steep slopes require specific equipment. Also important is the application rate, as light applications require a more precise method. The following table summarizes the common types of equipment available to make applications to disturbed soils.

Table 3. Comparison of different application systems used in remediation sites.

System	Range	% Solids	Relative Costs	Advantages	Disadvantages
Dump truck discharge, spreading with dozer	10'	> 12%	Low capital, low O&M	Simple to operate, fast for high application rates	Need cleared, relatively flat site, acceptable to heavy equipment, difficult to get even applications for low application rates
Application vehicle with mounted cannon	125'	< 12%	Moderate capital, high O&M	Can make even applications for low rates, any terrain.	May need special trails with strength for repeated trips, slow.
Application vehicle with rear splash plate	10'	15-35%	Moderate capital, moderate O&M	Can make even applications for low rates, moderate terrain.	May need special trails with strength for repeated trips, slow.
Application vehicle with side discharge	200'	15-50%	Moderate capital, moderate O&M	Can make even applications for low rates, any terrain.	May need special trails with strength for repeated trips, moderate speed.
Manure-type spreader - rear discharge	10'-30'	> 25%	Low capital, low O&M	Can make even applications for low rates, moderate terrain.	Limited to high % solids, trails may need to be close together, moderate speed.

Dump truck and dozer

The most basic (and simple) application technologies use dump trucks and bulldozers. Dump trucks can transport materials directly to the application site and end dump in piles placed evenly throughout the site. If the soils can not withstand heavy trucks, either dump trucks or other

equipment with high flotation tires can be used between the point that the long-haul vehicles can access and where the amendment will be used. This equipment may be available from the POTW that supplies the compost or biosolids, potentially for the price of transportation and a small fee.. The capacity of the dump truck combined with the loading or application rate can be used to determine how much ground one load of material should cover. A bulldozer can then spread the amendment evenly over the ground. With the right kind of ground (level to gently sloping and sufficiently dry soils, this can be a quick and cost effective application technology. The bulldozer will have sufficient traction to drive on ground that has already received application. The process should be staged so that the dump trucks (which will not have sufficient traction) dump at the far end of the site first, then move forward.

Application vehicle with cannon

An application system suited to liquid amendments is a vehicle with a tank and spray nozzle mounted on the rear. Depending on the site needs, a specially designed all-terrain vehicle may be used or a simple heavy-duty truck chassis with rear mounted tank may be acceptable. Each of these types of systems has been demonstrated to be effective in the Pacific Northwest. The operation of these systems is relatively simple. A biosolids source, where biosolids are transferred into the application vehicle, is available either at the treatment plant, through a delivery truck or from onsite storage. Once full, the vehicle moves into the site and unloads the biosolids in uniform layers while the vehicle is moving or stationary. When empty, the vehicle returns to the biosolids source for a refill and repeats the cycle.

Application vehicle with rear discharge

There are also vehicles that have been specifically designed to apply amendments to agricultural sites. These typically have flotation tires and a carrying capacity of about 10-18 yards of material. They spread biosolids or manures from the rear of the box with a fan or splash plate. The width of the spread is comparable to the width of the vehicle. Changing the speed of the vehicle as well as the speed of the fan can alter application rates. These vehicles are excellent

for operating on wet soils. The flotation tires give generally excellent traction and enable access to areas that may not be possible with conventional equipment. They can spread high or low rates of amendments onto the surface of a soil. In cases where incorporation is required, additional equipment is required. Rear-discharge application vehicles can also be set up with sub-surface injection equipment. Sub-surface injection requires a low solids content to function properly. Water can be added to the amendment before application to achieve sufficiently low % solids. It may be appropriate for reclamation projects with relatively low application rates.

Side cast spreader

Another type of application vehicle is a side cast spreader, capable of throw distances of up to 200 ft. Throw distance is dependent on the moisture content of the amendment, with wetter

material (that clumps together) having a greater throw distance than drier materials such as composts. Application rates can be controlled with this spreader by adjusting the speed of the vehicle as well as the speed of the fan. The spreader can be mounted on a range of vehicles, ranging from simple truck chassis to agricultural application vehicle with high floatation tires to all-terrain logging forwarders. Reclamation efforts at mine sites have used an Aerospread mounted on surplus army vehicles. The type of vehicle that is required is especially useful on very steep or debris-filled sites.

Manure-type spreader

Farm equipment that has been designed for manure spreading also works well for many types of soil reclamation projects. A common design is a wagon pulled by a tractor. Typically, these discharge out the back with a big rotary brush. Application rates using this type of equipment are usually relatively light, so repeated applications are usually required.

Incorporation

Incorporation of high rates of amendment mixtures similarly requires the proper equipment and equipment operators. The low % solids of some amendments means that when you are making a 100 dry t/ac application, you may actually be applying up to 500 wet t/ac of material. Generally a large track bulldozer (such as a Caterpiller D7) pulling a 36" disk is required. Smaller equipment may just float on the surface of the biosolids mixture. Large chisel plows also exist that are capable of incorporating the amendments. When you are incorporating high rates of amendments it will not be possible to achieve a completely homogenous mixture. However, the effectiveness of the amendment is usually better when mixed as evenly as possible.

Subsoiler with brush rake attachment

A special subsoiler with brush rake attachment was designed by Mike Karr and Jim Archuleta on the Diamond Lake Ranger District, Umpqua NF. Wood chips and biosolids were applied to the soil surface area prior to subsoiling. The ripper teeth on the end of an extended arm then can both break up the compacted roadbed and incorporate the amendment at the same time.

Excavator

An excavator has been used with excellent results decommissioning logging roads along the I-90 corridor in Washington. First, the excavator rips the roadbed, then pulls up the fill material, placing it in the road prism; the goal is to recreate the original slope. The excavator bucket then grabs compost that has been placed evenly in plies along the road, and distributes it in about a two inch layer. In this case, volunteers seed with a sterile winter wheat, and then cover the whole area with weed-free straw for immediate erosion protection.

Monitoring to Assess Success

Monitoring is often overlooked in the planning stage of restoration projects. The monitoring plan should be written before the project is implemented and the project objectives should be clearly identified.

Vegetative response

Vegetative establishment measurements

The primary vegetation measurements methods include vegetative cover, plant biomass, plant density, and plant diversity. Two excellent references for measuring and analyzing vegetation include *Canopy Coverage Method of Vegetation Analysis* by Daubenmire (1959) and Aims and *Methods of Vegetation Ecology* by Mueller-Dombois and Ellenberg (1974). In addition to quantitative methods list below, color photographs and observations of the site conditions can be invaluable to reporting results.

Vegetative Cover

Vegetative cover is the percentage of ground surface covered by vegetation and is important in evaluating soil erosion. It is generally best suited for plants smaller than 3 ft in height. It is considered to be a better indicator of ecological significance than plant density (Dabenmire 1959), and allows for consecutive measurements trends in plant growth over time without disturbing the plants. Cover changes through the growing season and subjectivity of the measurement can be reduced by taking the measurement at the same time of year.

Plant biomass

Plant biomass is considered to be a better estimate of plant productivity than vegetative cover for evaluating the long-term effects of the treatments on plant growth. However, this is a destructive method that requires harvesting the plants. The above-ground plant biomass is harvested by cutting the stem at the soil surface, sorted by species, and dried in a 70° C oven for 24 hours. The final biomass weight is then recorded by species for each plot. It is labor intensive and costly.

Plant density

Plant density is the number of plants per area used to measure the size of plant populations within a study area. It is the most sensitive technique to changes caused by mortality or recruitment. The number and size of plots within a larger study area is determined based upon the size of plants and the size of the study area. Generally, plots 10 ft^2 are used and methods for locating sample plots are discussed in detail in Muller-Dubois and Ellenberg (1974). The plots are located using either random or stratified selection methods. The stems within the plot are counted and recorded for each species. This information can then be averaged for each treatment and compared between treatments.

Plant diversity

Measurement of plant diversity is another non-destructive method. Species diversity compares the evenness of abundance among species. Unlike other methods of abundance (e.g. density, biomass), each species' frequency of occurrence is the contribution to the overall species richness. The supply of the most limiting resource can control species diversity. Two indices used to compare data are the Shannon-Weiner diversity index and the MacArthur-Wilson diversity index.

Physical Soil Measurements

Soils with high organic matter generally have higher soil porosity, increased pore volume and decreased bulk density, resulting in increased infiltration capacity (Linsley et al. 1982). These measurements can be made prior to restoration and periodically following restoration to examine the effects of the treatment.

Soil-water infiltration capacity

Infiltration capacity is the maximum rate of water entering the soil surface (Dunne and Leopold 1978). This rate is dependent upon many factors including the soil texture, soil structure, moisture content, shrink/swell properties, and organic matter. Cylinder infiltrometers can be used to measure the rate at which water enters the soil.

Bulk density

Bulk density is the ratio of the mass of dry solids to the bulk volume of the soil occupied by the dry solids (Hillel 1998), usually measured in situ. High bulk density will impede water infiltration and plant rooting, thus effectively reducing plant productivity. Incorporation of compost into soil reduces the bulk density.

One way of measuring bulk density is using a cylindrical metal sampler with coring devices driven into the soil. The soils are dried for 24 hours in a 100 degree C for 24 hours and then weighed. The volume of soil within each core is directly measured and calculated. When large rocks are in the soils, or the soils are very compacted, this method doesn't work. Another method is to excavate a hole and determine the volume of the hole by filling it with measured amounts of sand. The material excavated is saved, dried and weighed.

C:N ratio

The carbon to nitrogen ratio (C:N) represents the current status of carbon decomposition processes and nitrogen availability. If the compost being added to the soil has a high C:N ratio (>30:1), then decomposition is retarded. If the material added to the soil has a low C:N ratio, the loss of nitrogen occurs from mechanisms like nitrate leaching, volatilization or runoff. As compost decomposes, the C:N ratio in the soil changes, affecting the availability of nitrogen to plants. Measurement of carbon and nitrogen is done in the laboratory. Measurements can be arranged with a local extension service or local soils laboratory.

Successful projects

Chelan Road Adjacent Cutsopes, WA

Project Sponsor: Washington State Department of Transportation.

Location: Chelan, Washington. State Route 971.

Description: The project involved stabilization of a road adjacent cutslope that had a history of chronic surface erosion with rilling and associated accumulated debris in the ditchline. The project involved re-shaping the slope to 1.5:1 slope and constructing bender board fencing terraces, and application of <1: Class A biosolids compost, and revegetation. The biosolids compost was incorporated into the top soil surface. Native plants used in revegetation included service berry (Amelanchier alnifolia), snowberry (Symphoricarpos albus), blue elderberry (Sambucus ceulea), mock orange (Philideloophus lewisii), Ponderosa pine (Pinus ponderosa), squaw current (Ribes cereum(, and a native seed mix.

Size of Project: 630 feet long by 70 feet wide.

Implementation: The project began in November 1999, with the majority of the work completed by April 2000.

Objective: The objectives were to accelerate native plant establishment and provide long-term site recovery.

Site Description: The site is located on the Eastside Cascade Mountains near Chelan, Washington.

Monitoring Results: Biosolids compost was applied to two-thirds of the slope with the remaining one-third of the slope left untreated as a control. During construction, the field crew noticed a large difference between the treated and untreated areas in the ability to construct the terraces and pound in rebar. The soil was much easier to work in the areas treated with biosolids compost.

Two months after completion (June 2000), the bender board appeared to have stabilized the slope and dramatically reduced erosion.

Umpqua, OR

Project Partners:
Bureau of Land Management -Roseburg, Oregon
Umpqua National Forest –Roseburg, Oregon
Oregon Department of Environmental Quality-Roseburg, Oregon
Northwest Biosolids Management Association- Seattle, Washington
City of Medford-Water Restoration Facility, Oregon
Weyerhaeuser Company-Wilbur Oregon

Location: Little Rock Creek, Oregon

Description: Research plots were established on an abandoned road surface to compare soil restoration treatments. Treatments included subsoiling (deep ripping), subsoiling through 3" of woodchips, and subsoiling with 3" woodchips and biosolids (140 N-lbs/acre). The plots were then seeded with Elymus glaucus and planted with Douglas-fir seedlings.

Size of Project: 7000 m^2

Implementation: The project was implemented to demonstrate the benefits of utilizing slash piles after harvest and recycling biosolids from municipal treatment plants to help activate and restore the belowground processes to severely impacted soils. The findings from this project will help managers during road, landing, yarding or mine tailing restoration. The project was implemented in the spring and fall of 2001.

Objective: The project objective is to recycle and utilize municipal biosolids and material from wood slash piles as a soil amendment to improve soil tilth, reduce erosion, and improve the water holding capacity, and nutrient holding capacity.

Site Description: The study site is located on the Westside Cascade Mountains at 4,000 feet elevation. Many of the problems associated with revegetating disturbed sites at this elevation are due to temperature and moisture extremes.

Monitoring Results: Initial visual observations indicate improved vegetation cover compared to a control. There appears to be a significant increase in Microarthopod activity on the sites treated with both biosolids and wood chips.


Road (control)

Road treated with biosolids


Hansen Creek Road Obliteration, WA

Project Partners:
Mt. Baker-Snoqualmie National Forest, Snoqualmie Ranger District
Mountains to Sound Greenway Trust

Location: South Fork Snoqualmie watershed, located 47 miles east of Seattle.

Description: Restoration consisted of obliteration of forest logging roads through removal of all culverts and associated fill materials, and ripping and outsloping of the road surface. An application of 5 cm of biosolids compost, 5-10 cm of hay mulch, and winter wheat seed was immediately applied following restoration in August 2000. The road was outsloped to match the natural slope and averaged 58% slope gradient.

Size of Project: Three miles of forest logging road, with a total restoration of approximately nine acres.

Implementation: The project was implemented through a partnership with the Mountains to Sound Greenway Trust. The Greenway Trust is a non-profit conservation group of citizens, businesses and government agencies. The roads were obliterated in July 2000 and immediately treated with biosolids compost, hay and winter wheat seed.

Objective: The project objectives were to reduce the risk of mass failures, improve soil water infiltration rates, reduce surface erosion, and provide conditions that would favor the re-establishment of native vegetation.

Site Description: The elevation of the study site is 951 meters with an eastern aspect. The geology of the site is intrusive granitic rocks on steep sideslopes. The area receives approximately 250 cm of precipitation annually, with much of this in the form of snow.

Monitoring Results: A two-year study was initiated along a 700 meter section of road to examine the effects of the use of organic soil amendment, seed, and hay mulch treatments in road obliteration (Bergeron 2003). Biosolids compost and winter wheat seed application resulted in substantially improved vegetative cover and biomass. The single application of organic matter was shown to promote plant growth, and eventually, as the plants die and decompose, the soil properties are expected to continue to improve.

Hansen Creek Road Obliteration: Two years following restoration.

Buffalo Creek Fire Site

Project Partners:
Colorado State University
U.S. Environmental Protection Agency Region 8
Denver Metro Wastewater Reclamation District
USDA Forest Service, Pike National Forest

Location: Buffalo Creek fire site in Pike National Forest, approximately 14 mi. SE of Pine Junction.

Description: Restoration consisted of application of biosolids compost to a severely burned, previously forested site near Buffalo Creek, CO. to assess ecosystem recovery. In May 1996, a high-intensity, fast-moving, stand-replacing crown fire burned approximately 4900 ha of forested land.

Size of Project: Approximately 24 ha.

Implementation: The project was a cooperative study among Colorado State University, U.S. Environmental Protection Agency Region 8, Denver Metro Wastewater Reclamation District, and USDA Forest Service, Pike National Forest. Denver Metro Wastewater Reclamation District prepared the plots first with a dozer, than applied the compost at rates of 0, 5, 10, 20, 40 and 80 Mg ha-1 . After compost application, the plots were disked, and seeded with a grass mixture at the rate of 34 kg ha-1 by the Forest Service.

Objectives:

Study 1: To determine the effects of a one-time application of up to 80 Mg ha-1 dry composted biosolids on ecosystem recovery as measured by changes in plant canopy cover, biomass production, plant tissue and soil concentrations of N, P, and Zn, and total soil C and N contents (Meyer et al. 2004).

Study 2: To determine runoff quantity and runoff quality from a burned site as affected by biosolids application rate (Meyer et al. 2001).

Site Description: The elevation of the study site is 2235 meters. The area receives approximately 520 mm of precipitation annually, with 75% occurring in spring and summer. Mean annual temperature is 8°C. Soils at the study site are developed from Pike's Peak granite, and are contained in the Sphinx soil series.

Monitoring Results: Total plant biomass generally increased with increasing compost application rate, while bare ground generally decreased with increasing rate. Biosolids application rates did not significantly affect mean total runoff. Sediment concentrations were greater from the control plots compared with the plots that had received compost. The increase in productivity and cover resulting from the use of biosolids can aid in the rehabilitation of wildfire sites and reduce soil erosion in ecosystems similar to the Buffalo Creek area.

Lessons Learned

Thoughts from: David McDonald, Seattle Public Utilities

How would nature do it? Restoration projects in urban, sub-urban, managed forests and true wildland areas all have a common requirement: successful plant establishment (and the resulting long-term erosion control, habitat benefits, etc) depend most of all on placing site-adapted plants in an optimal soil environment. The best way to select an effective soil preparation strategy is to ask three questions:

1) "What's the soil like on the site now, especially with respect to compaction, drainage, particle size, and organic content at the surface, root zone, and below the root zone?"
2) "What are the soil conditions like where the plants selected for restoration thrive in the wild?"
3) "What's the most cost-effective strategy to make the site's soil environment optimal for these selected plants?"

Some general observations emerge from a variety of restoration projects around the Northwest:

Right plant, right place, right soil. Most plants used for restoration in the Northwest, whether woodland, wetland, or meadow species thrive in a high organic content soil, and adding organic matter to disturbed/degraded sites is usually critical to success. But some plants like bare rocky slopes or beach sand. Always observe site and soil conditions where that plant thrives, and try to match them.

Lousy soil plus organic matter plus time creates healthy soil, which supports healthy plants. Organic matter, in nature and restoration, feeds the soil organisms that create:

- Soil structure (air, water, and root penetration, and resistance to compaction)
- Nutrient cycling and plant availability of nutrients, endlessly (since terrestrial life began)
- Plant disease protection (through competition, predation, and systematic induced resistance)
- Soil erosion resistance, fine sediment capture, and biofiltration of introduced pollutants.

Mix organic amendments into rooting zone where possible, surface apply where not. Degraded, compacted soils are most quickly improved by mixing from 10% to 25% organic amendment by volume into the whole site before planting. But if there are existing tree roots to preserve, or the site is steep, it's better to top-dress with several inches of coarse textured organic matter, and let the soil organisms incorporated it over time.

Amend the existing site soil with organic matter, rather than bringing in soil mixes, wherever possible. Use the on-site mineral component and amend it with organic matter, to avoid the weed seeds and incompatible soil texture problems (excess fines) often associated with imported soil mixes.

Composted materials are the best for soil incorporation. Composting ties up free soluble nutrients into forms that don't readily wash off but are slowly made available to plants by the soil food web. Composting buffers pH and mineral imbalances. And composting reduces weed seeds and plant pathogenic organisms, while greatly increasing plant-protective organisms. Un-composted woody materials may use up soil nitrogen temporarily when incorporated-they're better used a surface applied mulch. And un-composted materials are more likely to introduce weed seeds.

Some woody plants establish better with loose, low-organic soil and lots of organic mulch on the surface. Again, look at the actual soil organic content and structure in sites where that plant thrives.

Coarse woody mulches are better than fine textured materials. Chunky mulches let more air and water in, whereas fine-textured mulches (where most of the material would pass through a 1/2 inch screen) are more likely to crust and impair penetration.

Native lowland Northwest plants compete in a higher carbon, lower nitrogen soil mix, compared to introduced horticultural and weed species. Compost for landscape/horticultural uses should have a carbon/nitrogen (C:N) ratio below 25:1. But Northwest natives which evolved in the high carbon environment of rooting forest duff grow better where compost or other organic amendments have a C:N ratio as high as 35:1. Practically, that usually means more wood in the mix. At the other extreme, many introduced annual or perennial "weed" species thrive in high nitrogen conditions.

Generally, yard waste or wood waste derived composts will have lower soluble nitrogen and phosphorous than biosolids or manure derived composts. But that depends on how much woody or other high-carbon material it was mixed with and how long and completely it's been composted. Soluble nutrients are obviously a concern close to sensitive water bodies, whereas nutrients that are well bound in the organic compost matrix are unlikely to be released at rates that create a water pollution problem.

Compost berms and blankets are cost-effective erosion and sediment control strategies for restoration sites as well as development sites. Several inches of coarse-textured compost (a "blanket") has proven to be often more effective than straw, jute mats, or other traditional surface erosion control measures, as well as being more compatible with restoration sites while providing soil improvement and plant establishment benefits. Compost "berms" 12-24 inches high are often more effective than traditional silt fence in site sediment control, as well as bio-filtering road runoff and other pollutants. They can be scattered or left on-site, again providing soil and plant benefits.

Small amounts of native soil and duff may have value as inoculants and seed sources. Almost all terrestrial plants require specific micorrhizal fungi to thrive and sometimes certain bacteria or other soil organisms. When establishing natives on very damaged/degraded sites where native plants have not grown in recent years, it *may* be worth inoculating the site with a small amount of soil from a location where these plants thrive, to reintroduce the needed micorrhizal species.

Fit the strategy to the site. In smaller wildland restorations, especially remote from roads, it may be possible to harvest duff from nearby sites to introduce the full array of site-adapted plant seeds to the site. Larger organic material such as logs and branches can also often be salvaged near small remote sites, and may be more effective in redirecting human traffic than obtrusive strings and signs on these sites. This is just one example of an observant, cost-effective strategy that starts with the right question: **"How would nature do it?"**

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