Brush-Mineral Features:
A guide to using organic matter and soil for multi-functional benefits in drylands

April 2020

The Brush-Mineral toolbox is a diverse and highly adaptable set of low-cost, shovel ready methods for using organic debris and mineral soil beneficially to improve your landscape, the broader community, and ecosystems within which you live.

terrasophia

Brush-Mineral Features:
A guide to using organic matter and soil for multi-functional benefits in drylands

April 2020

TerraSophia LLC
Jeff Adams, Owner
P.O. Box 571 Moab, UT 84532
(415) 306-6618
www.terrasophia.com

RT Permaculture
Neil Bertrando, Owner
413 Matterhorn Blvd., Reno, NV 89506
775-830-8822
https://www.rtpermaculture.com

About the authors:

Jeff Adams is founder and principal of TerraSophia LLC, an ecological design consulting, education, and landscape contracting firm based in Moab, UT. With close to 20 years of experience in the field, Jeff builds capacity to regenerate the health of our watersheds and communities by engaging citizens, agencies, and organizations. He is a co-founder and board member of the Resiliency Hub, and director of the Canyonlands Watershed Council.

Neil Bertrando is owner-operator of RT Permaculture, a regenerative design and consulting firm based in Reno, NV. Neil works with homesteaders, farmers, non-profits, and agencies to empower ecological lifestyles and food systems. He is a co-founder and board member of Reno Food Systems, working to improve local food systems through ecological farming and participation in the local food movement.

Cover: This organic matter – mineral berm provides privacy and windbreak while hosting a diversity of wildflowers in Moab, UT.

Table of Contents

Statement of Purpose

This primer is intended to inspire action to use more organic materials on-site or in your community as an alternative to landfilling or burning this valuable material. Likewise, these techniques can be used to offset the need to purchase materials such as masonry blocks, concrete or other materials that are conventionally used for the same application, but have higher embodied energy[1]. As a simple and cost-effective strategy, multiple benefits can be realized when integrated with sound landscape design and stewardship to increase multi-functionality, yields, and aesthetics.

Acknowledgements

We would like to acknowledge the ecological processes and cycles, flood deposits, forest floors, beavers, fungi, indigenous peoples, and permaculturists for real world confirmation that this general pattern of materials usage can produce a suite of ecological functions and socio-economic benefits.

We'd like to thank everyone who provided feedback and made this guide more user friendly for all. These people include Javan Bernakevitch, Claire Core, Susan Cosineau, and Jay Nethercott.

TerraSophia thanks our clients and collaborators who have supported these techniques being applied on their property and are now running with them, and all our teachers and inspirations over the years. We specifically thank Jay Nethercott for continual inspiration, adaptation, and experimentation creating some massive landforms and unique structures with his own and other people's "waste".

RT Permaculture thanks our teachers and mentors for their patience, guidance, and leadership, our clients and collaborators for their passion and support, and to people worldwide adopting and adapting the skills and techniques necessary to re-story our cultures into an ecologically beneficial society.

If you put any of these techniques into practice or have additional techniques or considerations not included in this guide, we'd love to hear from you! Please feel free to contact the authors via the information at the beginning of this guide. Thank you!

Disclaimer

This primer and the projects highlighted are provided for education and inspiration purposes only. It is up to each individual who chooses to apply these ideas to ensure proper placement and construction to obtain the benefits presented herein and prevent unintended consequences. Knowing and following any applicable codes, and obtaining any

[1] https://en.wikipedia.org/wiki/Embodied_energy

permits that may be required, is the responsibility of the individual practitioner and these jurisdiction specific requirements are beyond the scope of this guide.

In particular, precaution must be taken on steep slopes, unstable geology, and other potentially adverse site conditions. Consultation with a professional engineer or geologist may be necessary in certain contexts or projects, and it is up to the individual to obtain professional consultation when necessary. When in doubt, ask a professional.

As with most new techniques, it is recommended to start with small trials and in areas where the risks of any unintended consequences are low, and then expand from there. Revegetation such as seeding, planting plugs or live stakes of woody plants e.g. Sloping Agriculture Land Technology (SALT[2]) may be less risky on steep slopes than brush-mineral features.

Managing invasive weeds and plant community dynamics is a complex scenario beyond the scope of this document. We recommend Tao Orion's book *Beyond the War on Invasive Species*[3] for a more thorough discussion of the topic and list of options for management.

Introduction

Brush-Mineral features are a low-cost method of using organic debris beneficially in conjunction with mineral soil. Some of the triple bottom line benefits of these techniques include

- promoting soil health
- offsetting hauling and landfill costs
- enhancing water holding capacity
- working collaboratively in your community

The strategic placement and integration of brush-mineral features into a landscape provides additional site-scale beneficial functions such as improving site access and modifying micro-climates, as well as community scale benefits such as holistic materials management and watershed rehabilitation through erosion control and gully repair. Brush-mineral features can be very cost effective to implement because opportunities exist to source materials on-site or in each community and processing requirements are minimal. Using more of our biomass constructively helps us think more critically about how we approach "weeds" and "invasive species", and find ways to turn these "problems" into a solution. Taking advantage of this annual (or multi-year) harvesting and conversion of solar energy into biomass, these techniques achieve sequestration of atmospheric carbon into terrestrial systems. Brush-mineral features are a shovel-ready solution that holds vast potential for becoming an important part of the tool box for building resiliency and mitigating projected impacts of changing climatic conditions.

[2] https://www.echocommunity.org/en/resources/2b54ae98-cea1-407d-9fc3-b7b0394102c3
[3] https://www.chelseagreen.com/product/beyond-the-war-on-invasive-species/

Assumptions, Lessons Learned and Open Questions

As the methods of brush-mineral features are newly emerging and continuing to be adapted to specific applications and contexts, there are certain assumptions and open questions remaining. There have also been lessons learned along the way so far that will provide useful insight through the continuing evolution of this body of techniques.

Assumptions

- Current management of organic debris and mineral resources is typified by disposal, either by landfilling or burning, and underutilization of resources as a waste product
    - Brush-mineral structures provide multiple onsite and bioregional benefits by diverting these resources to more beneficial use
    - Burning organic materials releases carbon and particulates into the atmosphere, and adds to poor air quality and climate change
    - Landfilling minerals and organics uses excess carbon for transport (fossil fuels) and reduces landfill lifetime. Landfills are typically not focused on managing these materials for optimal carbon sequestration or revegetation
- A movement towards carbon sequestering landscape practices which increases carbon and water storage in soils and living organisms benefits both local ecologies and communities
- Brush-mineral structures are by nature hybrid structures and highly adaptable and variable in design and construction. There exists a diversity of allied and hybrid structures that blur distinctions between individual practices. Building them to meet desired functions and fit the context of the site and users is more appropriate than re-creating a 'textbook' structure
- Fear no plant or 'weed'. Just work with it. If 'weeds' are onsite already, seed banks exist. Our focus is to increase soil organic matter, soil water storage, and photosynthesis while being active stewards of the land to direct plant succession and site micro-climates in a desirable direction over time

Lessons Learned

- Additional upfront investment of time and materials results in more stable structures that can be vegetated quicker
- Lower bulk density and higher ratios of organic matter increase rates of settling
- Rates of decomposition increase with proper moisture content, proper C:N ratios, higher organic matter content, and proper bulk density through mineral soil
- People and companies love a free place to drop off their organic debris and excess materials
- Burying 'weeds' on a site where they already exist can benefit the soil and improve conditions to move succession toward more desired vegetation communities
    - If brush-mineral structures are kept moist there will likely be revegetation. Desired plants can be promoted while 'weeds' can be harvested to continue building more brush-mineral structures

Open Questions

- When having materials hauled to a site, are we sequestering more carbon than is used to import materials to a site?
- What is the carbon balance of brush – mineral features under various amounts of transportation fuel usage compared to the alternatives of landfilling or burning?
- What are ideal or acceptable rates of decomposition and settling for each feature type or intended function? How frequently will re-application be required?
- What are effective methods to engage the community in applying brush-mineral structures on their own individual sites?
- How do we organize a community logistically to manage the streams of organic and mineral resources effectively and encourage multiple sites to implement brush-mineral structures?
- When, if ever, is burning[4] an optimal or acceptable use of time and collected materials?

The Multiple Functions of Brush-Mineral Features

There are multiple functions that brush-mineral features can be created to perform. In many contexts, any application of these techniques will result in a multi-functional feature.

Figure 1: Brush-mineral features can be an effective way to achieve multiple functions, including managing Sectors. The home's living room window and covered porch was exposed to passers-by as well as wind (left). Building a brush-mineral berm with additional rocks, log rounds, and vegetation has created more privacy, blocked the wind, and created habitat and forage (right).

[4] This is specific to materials that have already been managed, collected, processed, and/or concentrated on a site and does not refer to prescribed burning as a landscape restoration tool.

Primary functions of brush-mineral features include

- Optimize land management activities
    - Manage all sources of organic material for beneficial uses, including 'weeds', prunings, clippings, and large woody debris
    - Improve site access
    - Increase usable or fertile land area
    - Minimize the fossil fuels used to transport and process organic materials
    - Modify micro-climates and manage sectors

- Provide ecological benefits
    - Harvest water and store subsurface water in high organic content soils
    - Stabilize slopes, control erosion, and repair gullies
    - Sequester carbon
    - Build healthy, living soil[5]
    - Revegetate degraded or challenging sites
    - Increase soil cover[6]
    - Decrease burning of organic materials and release fewer combustion by-products[7]

The multiple functions of brush-mineral structures should be considered within an integrated design context to better understand the trade-offs that are inherent in this technique. Some activities which provide ecological benefits may require more labor, or the cost to import mineral soil to achieve bulk density may outweigh the cost of more frequent applications to maintain a new path that settes. The common practice of burning materials can be quick and easy with low labor inputs, however, valuable materials for improving site and soil conditions are lost and regional air quality is affected. These types of trade-offs and others should be put into context for your specific project and site through integrated design.

Integrated Design Context

Permaculture design and common sense are the guiding frameworks in the development of brush-mineral techniques. A full discussion of permaculture design is beyond the scope of this guide, and readers looking for more depth on permaculture are encouraged to review the growing body of permaculture literature. A few specific titles include *Gaia's Garden* by Toby Hemenway and *Practical Permaculture* by Jessi Bloom and Dave Boehnlein.

[5] https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/
[6] http://soilquality.org.au/factsheets/benefits-of-retaining-stubble-in-qld
[7] Local burning practices frequently diminish air quality dramatically, particularly in areas with inversion layers

Some key considerations are highlighted to help people optimize the location, selection, implementation and management of brush-mineral structures within an integrated design context for the specific site and broader community or region.

Climate

All good design is rooted in climate. Specific to brush-mineral features, your climatic conditions will influence:

- Rates of decomposition
- Ease of revegetation
- Amount of supplemental water that may be needed for effective decomposition
- Availability of on-site and external sources of organic materials

One way to assess your site's climate is to determine the Koppen-Geiger Climate Classification for your site. **Our experiences used to draft this manual are based on trials in *B* and *Cs* climate classifications.**

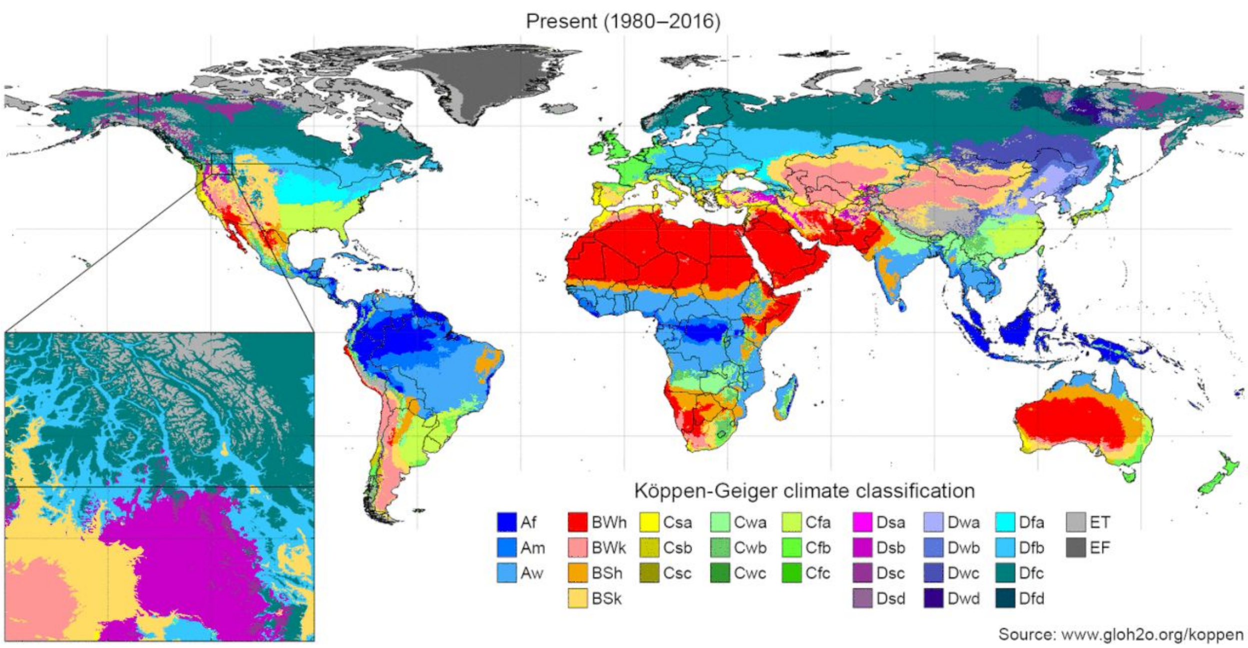

Figure 2: Koppen-Geiger climate classification map of the work based on data from 1980-2016.

Bioregion

For projects that require additional organic matter or mineral earth beyond what is available on-site, it is important to consider the bio-regional context to identify potential sources of material. This includes

- Your neighbors
- Municipalities
- Land management agencies

- Utility companies
- Agriculture operations
- Businesses
- Natural resource related industry
- Any other potential source of materials

The relative location of your project to various external sources of materials will influence

- Costs
- Labor requirements
- Fossil fuel use footprint of your project

Site Specificity

Conducting a site assessment and analysis of your project site to understand site-specific conditions and needs should be accomplished through the existing permaculture toolbox. Strategies such as zone and sector analysis, microclimate mapping, and circulation can greatly inform the design process.

Integrating brush-mineral features into the holistic design context informs strategic placements to

- Work with sectors
- Modify microclimates
- Improve site circulation
- Create more usable spaces

Project Goals

An essential step for any project is to establish goals.

- What are your desired outcomes for the project?
- How does the project meet the needs of your site design and management goals?
- What are your desired functions for the structure?
- How does a brush-mineral feature fit into the larger context of your site or project goals?

Taking some time to reflect on your goals, desired functions and outcomes will help in prioritizing projects and selecting the most optimized approaches.

Design-Build Process

With a better understanding of the big picture context of your climate and bioregion, and your site-specific goals and needs identified, it is time to get specific with what it will take to accomplish your project. Given the flexibility and adaptability of this approach, we recommend a design-build process is followed during implementation whereby a general vision of the outcome is developed, logistical details are considered, and adaptive management is applied during installation to adjust work as needed to specific conditions, materials availability, and creative inspiration. Specific considerations on materials are described on page 32 and the steps of implementing a brush-mineral feature are described starting on page 42.

<u>A Design-Build Process</u>

The design-build process we recommend follows these general steps

1. Develop a general vision of the project outcome
2. Consider options and plan logistical details
3. Apply adaptive management during installation to adjust work as needed based on
    a. Site and Project specific conditions
    b. Availability and sources of materials
    c. Creative inspiration

Beginning with an integrated design context for your project, and following an adaptive design-build process for implementation allows for optimization and adaptability in the applications of Brush-mineral features used. Understanding the range of applications for Brush-mineral features will help to determine when and where these techniques are appropriate for meeting your specific goals.

Applications

Brush-mineral features can be used for a range of applications with minimal processing. The applications and functions of brush-mineral features vary depending on site needs, design context, and available resources .

Many features will serve multiple functions, such as a path located on contour to function as a water harvesting berm.

Current applications include

- Access
- Infill
- Berms and borders
- Terraces
- Bank or hill re-construction
- Gully plugs
- Landform creation
- Creating topsoil

Access (Paths and Ramps)

Brush-mineral features can be placed on steep slopes or flat ground to create stable pathways, or used to create ramped features to gain access where elevation change is significant. Pathways with high organic content help to harvest and hold moisture. They can also act as mycelial highways, connecting various parts of a site to support nutrient exchange and plant health.

Figure 3: Woody materials from a fire damaged landscape are laid across the slope and covered with a soil-wood chip mix creating a path that harvests runoff and stops erosion.

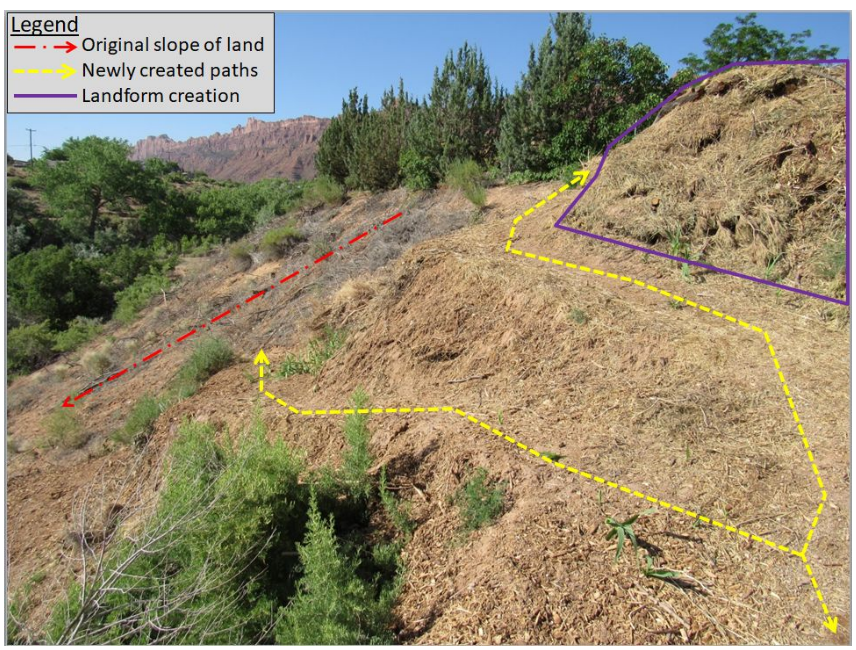

Figure 4: Paths and switch backs can be created to provide access on steep slopes. See Figures 5, 22 and 23 for additional perspectives on the landform creation.

Figure 5: In the early stages of this path system a backhoe was used to anchor large logs into the hillside and deposit bulking materials. This log is now covered in 10-15 feet of material and the flat top access is protruding 30-40 feet out from the original top of slope.

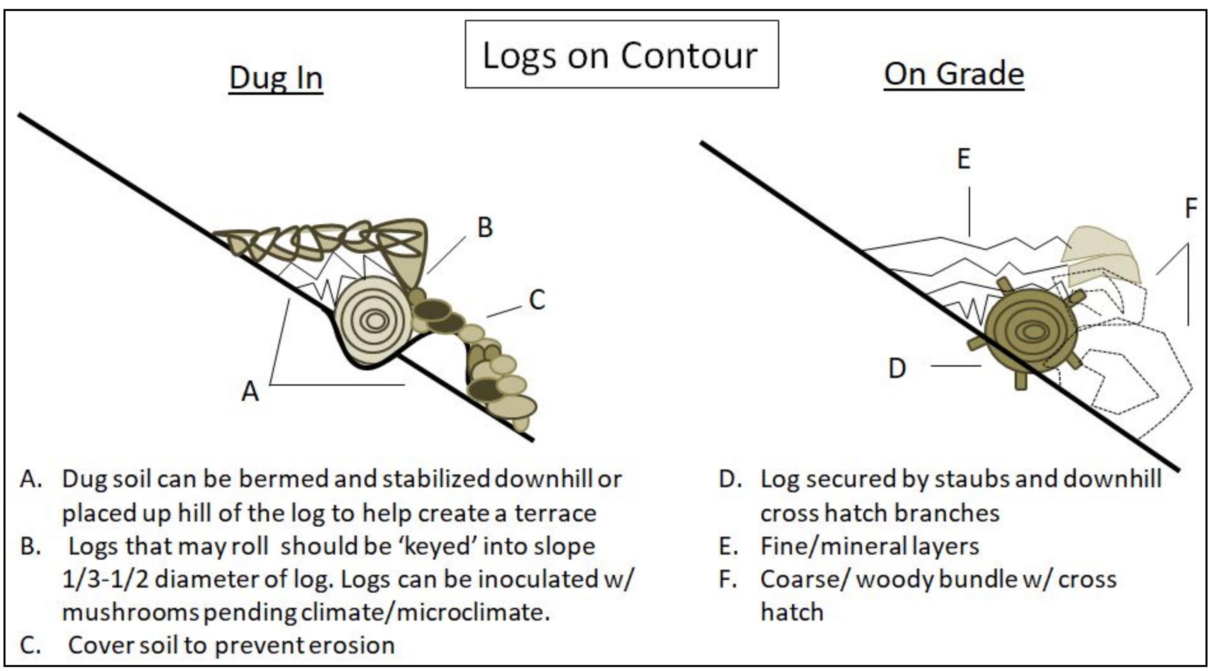

Figure 6: Logs can be used on sloped sites by keying them into the slope (left) or using a log with staubs and installing a stable cross hatching of branches to prevent rolling (right). Staubs are short lengths of branches left on the log lock the log into place.

Figure 7: A rock wall made access to part of the property difficult (left). Densely layered brush and soil (center) are used to create a ramp that provides easy access to this area of the property (right).

Infill

Infill is most appropriate on fully vegetated sites with few opportunities to apply other brush-mineral feature types. It is generally used when there is an excess of materials, particularly coarse woody prunings, and it offers a way to manage them beneficially on site close to where they are produced. It can be applied in many locations including building up on existing soil surfaces, extending berms and borders, and filling in excavated basins. Infill structures tend to have lower bulk density and higher percentages of organic materials. As a result, they tend to settle back to near ground level over the course of 1-2 years. This occurs even in dry climates and with moderately tall initial infill structures e.g. 3-4 feet tall. When infill is applied in a basin, settling and decomposition tend to occur even faster due to concentration of water. Whenever possible, infill should be built on contour across the slope to harvest water or perpendicular to the prevailing winds.

Figure 8: 3 stages - woody uncovered, woody covered 6 months, woody covered 16 months

Figure 9: These swale basins between hedges of woody perennials are infilled annually with the prunings and covered with horse manure and stable bedding to allow use as a foot and wheelbarrow path. Red oval marks the same tree in all photos.

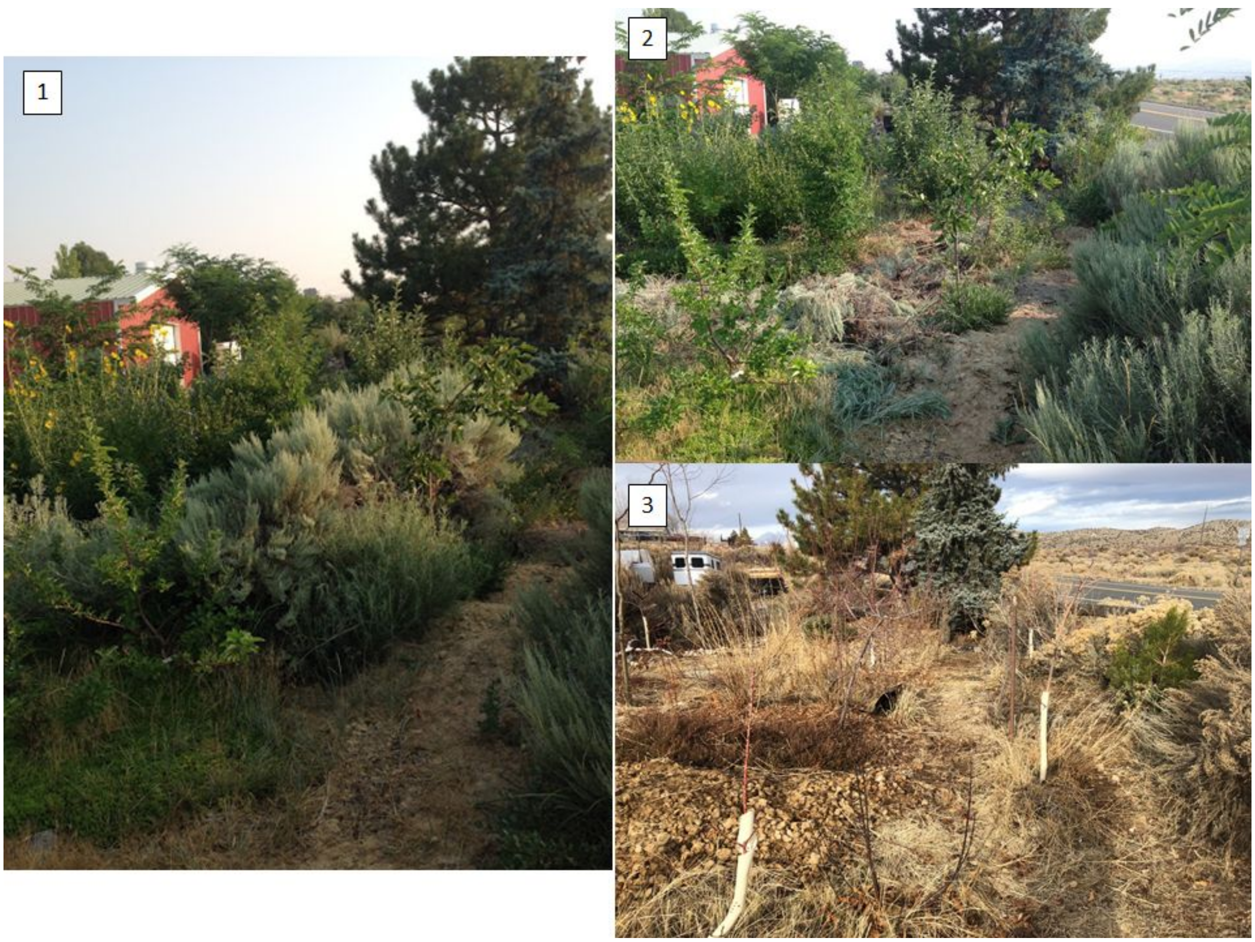

Figure 10: A native perimeter hedgerow was created by layering of the internal shrubs into a brush-mineral path.

Berms and Borders

Berms can be created and located to provide a range of functions from water harvesting to microclimate modification. A strategically located berm can increase privacy, block an undesired view, provide a windbreak, and/or increase the starting height for vegetation to be established on top of it. Berms can also be used to delineate outdoor spaces, enhance outdoor living and work spaces, or provide a visual and physical barrier along the edge of a parking space or road.

Building berms using this technique is analogous to building Hugelkultur[8]. The only difference may be the types of materials used, particularly structures which lack large woody debris.

Figure 11: Brush-mineral berms can be located to enhance and/or create additional microclimates on a property. Orange outline shows an area of increased sunny microclimate, with the area of increased shady microclimate helping to improve snow storage and harvesting.

[8] https://en.wikipedia.org/wiki/H%C3%BCgelkultur

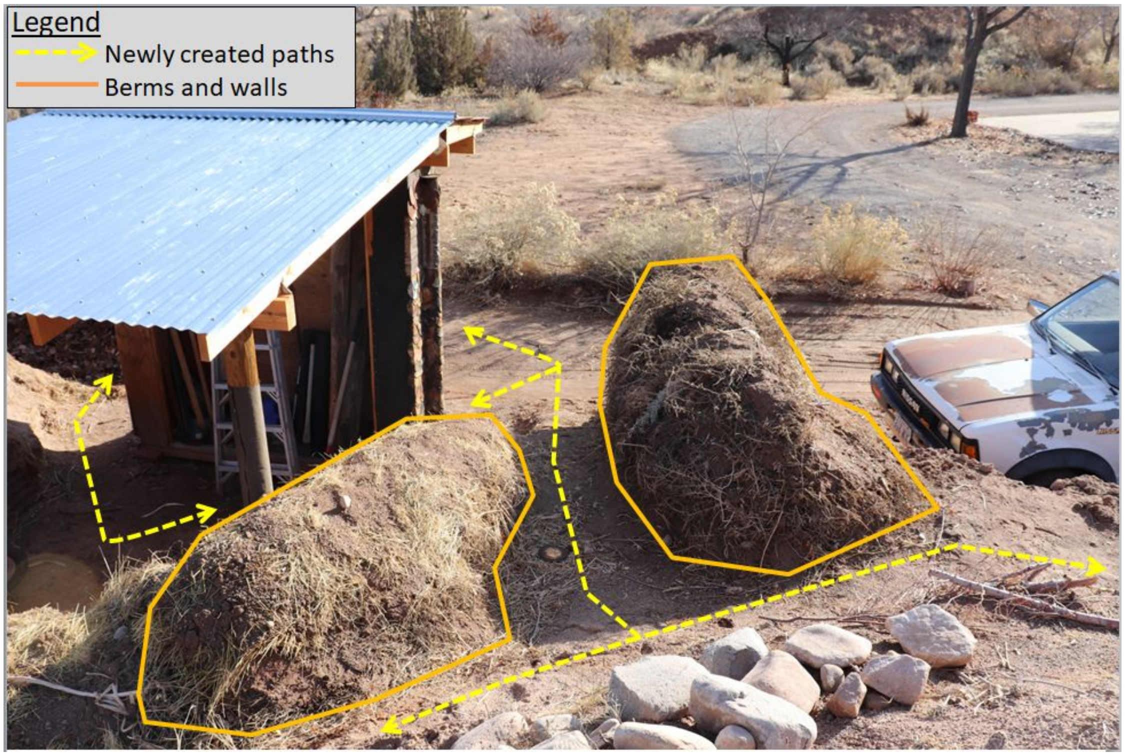

Figure 12: Berms created with increased height and closer to vertical can form walls that help define outdoor activity spaces, such as these brush-mineral walls partially enclosing a shade structure and storage shed.

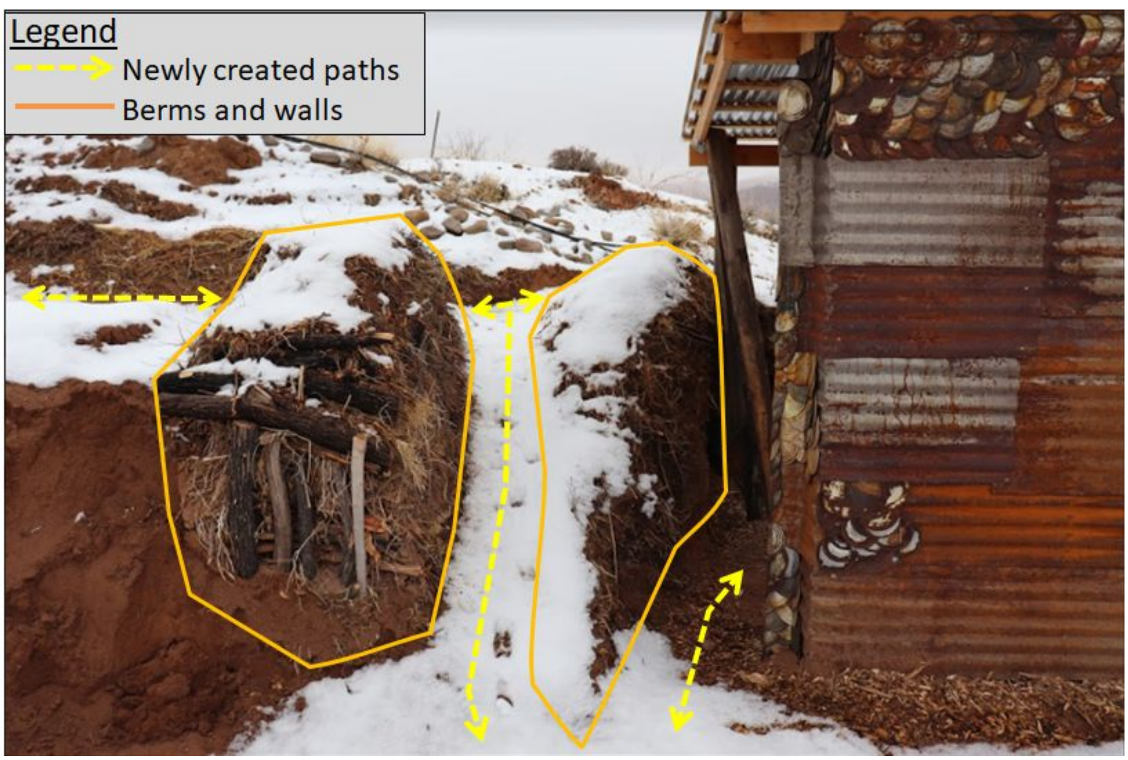

Figure 13: Another perspective of the brush-mineral walls and paths shown in Figure 11, helping to enhance the usability of the shed by improving access and buffering the wind.

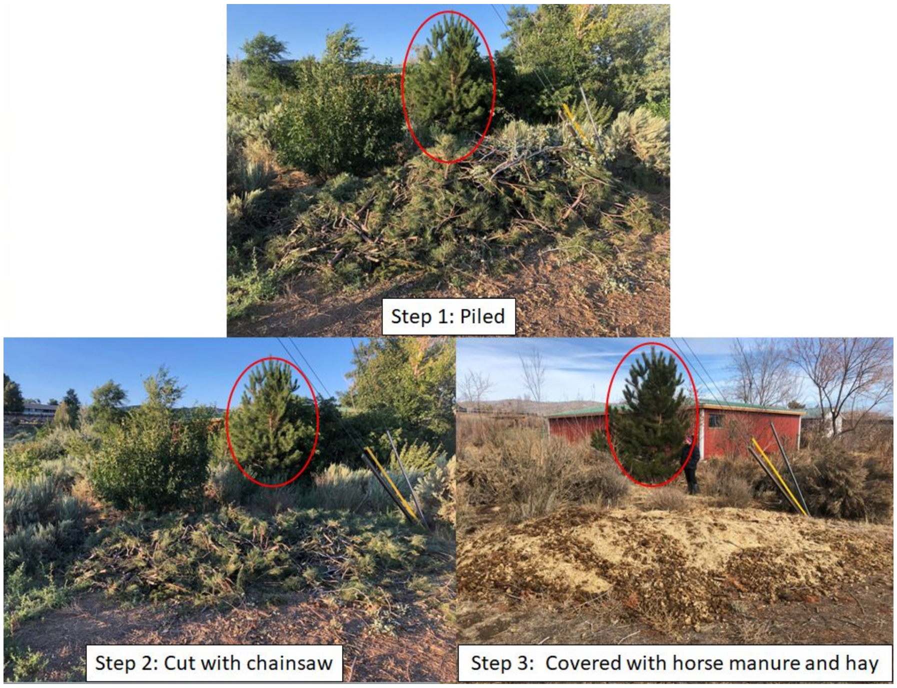

Figure 14: Small windbreak berm created with pine trimmings layered with horse manure and stable bedding. Ready for a second layer of brush to increase berm height over time. Red oval marks the same tree in all photos.

Wood Chip Berms

Wood chip berms can be an effective way to harvest sediment, water, and organic detritus. Wood chip berms pair well with forest thinning projects and are installed on contour with the ends extending to a higher elevation to promote even spill over as sheet flow. Wood chip berms can be as simple as a berm of wood chips 1-2 feet wide and up to 1 foot high. The wood chips will settle over time so the finished berm height is more typically 6 to 9 inches.

Figure 15: A wood chip berm built by Christian Meuli in NM harvests water, sediment, and organic detritus during a monsoon rain event. Water is retained for infiltration and eventual sheet overflow across the level top of berm (left). A close-up view of the wood chip berm shows sediments embedding the wood chips (right). Sediment-detritus line mirrors the high water mark and shows the relatively even spill over.

Figure 16: Wood chips created during a fuel load reduction project are laid out in a fish-scale pattern to harvest water and reduce erosion.

Terraces

Using brush-mineral structures to create terraces can be an effective way to stabilize sloped sites and create more flat areas to grow plants, provide access, and hold onto moisture. Cross hatching and bundling of branches can be used on the down gradient portion of the terrace to create a stable base that integrates with the hillside. Using logs for the base course of terraces may require that the logs are keyed into the slope ⅓ to ½ of the log diameter for increased stability as shown in Figure 6. See figure 32 for a schematic of considerations when integrating brush-mineral structures into a hillslope.

Another terrace building method comes from the SALT method of contour based agroforestry on slopes.[9] This method begins with planting closely spaced trees on contour in single or double rows. Generally fast growing nitrogen-fixing trees are used. Prunings are laid along the contour on the uphill side of the trees and over time these collect sediment and organic matter building up small terraces. Rocks or gravel can be added to increase the speed of terrace formation and increase water harvesting.

[9] https://www.echocommunity.org/en/resources/2b54ae98-cea1-407d-9fc3-b7b0394102c3 figure 8 in linked SALT doc for example

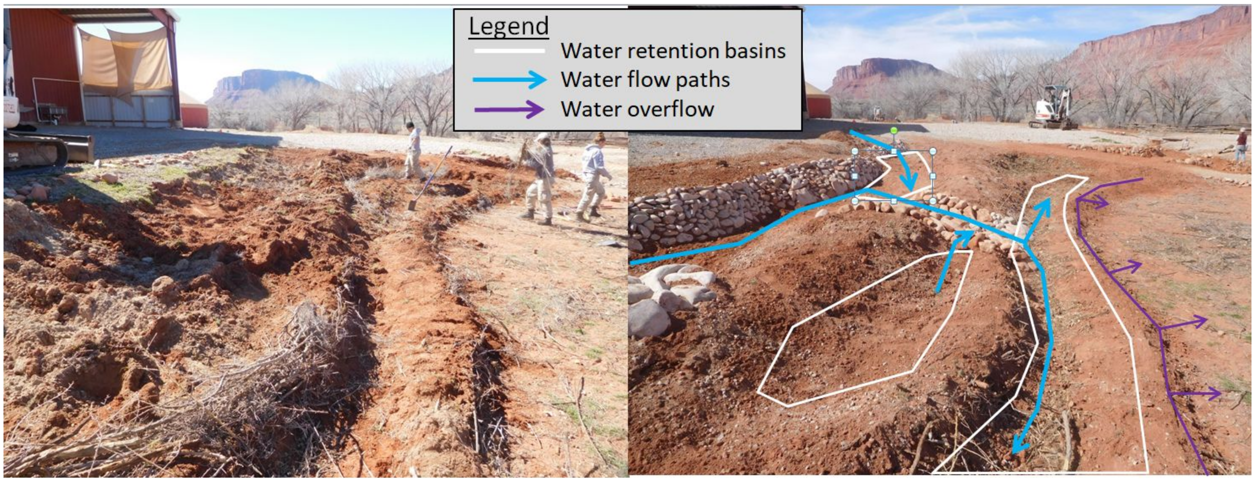

Figure 17: Brush-mineral structures are highly adaptive for creating terraces on sloped areas. Terraces were roughed in with a mini-excavator with a youth corp crew using on-site brush to stabilize the downhill portions of the terraces (left). In this application, basins and swales were included with rock armored spillways in sequence with the terraces to manage stormwater runoff (right).

Bank or Hill Reconstruction

Land use patterns often leave eroding steep cut banks or increase hydrologic loading that results in gully formation. Brush-mineral structures can be used to stabilize cut banks by re-creating more stable landforms, which results in less erosion and more usable area for plants or people. See Figure 32 for examples of how to create stable shapes and landforms using brush-mineral techniques. Careful placement and shaping of brush-mineral features may be used to re-shape gully banks and provide water harvesting opportunity in *low energy intermittent channels* and **is not** an appropriate technique for high-velocity or year-round streams.

Figure 18: A sloped perimeter of this non-profit radio station property was eroding, hard to use, and growing opportunistic plants (left). As an alternative to the conventional approach of removing all the weeds and throwing them in the landfill or burning them, these organic materials were collected and used in conjunction with a mix of mineral earth and wood chips to stabilize this slope (center). Several layers of materials were added and covered with a final layer of wood chip mulch to expand the usable area of the property (right).

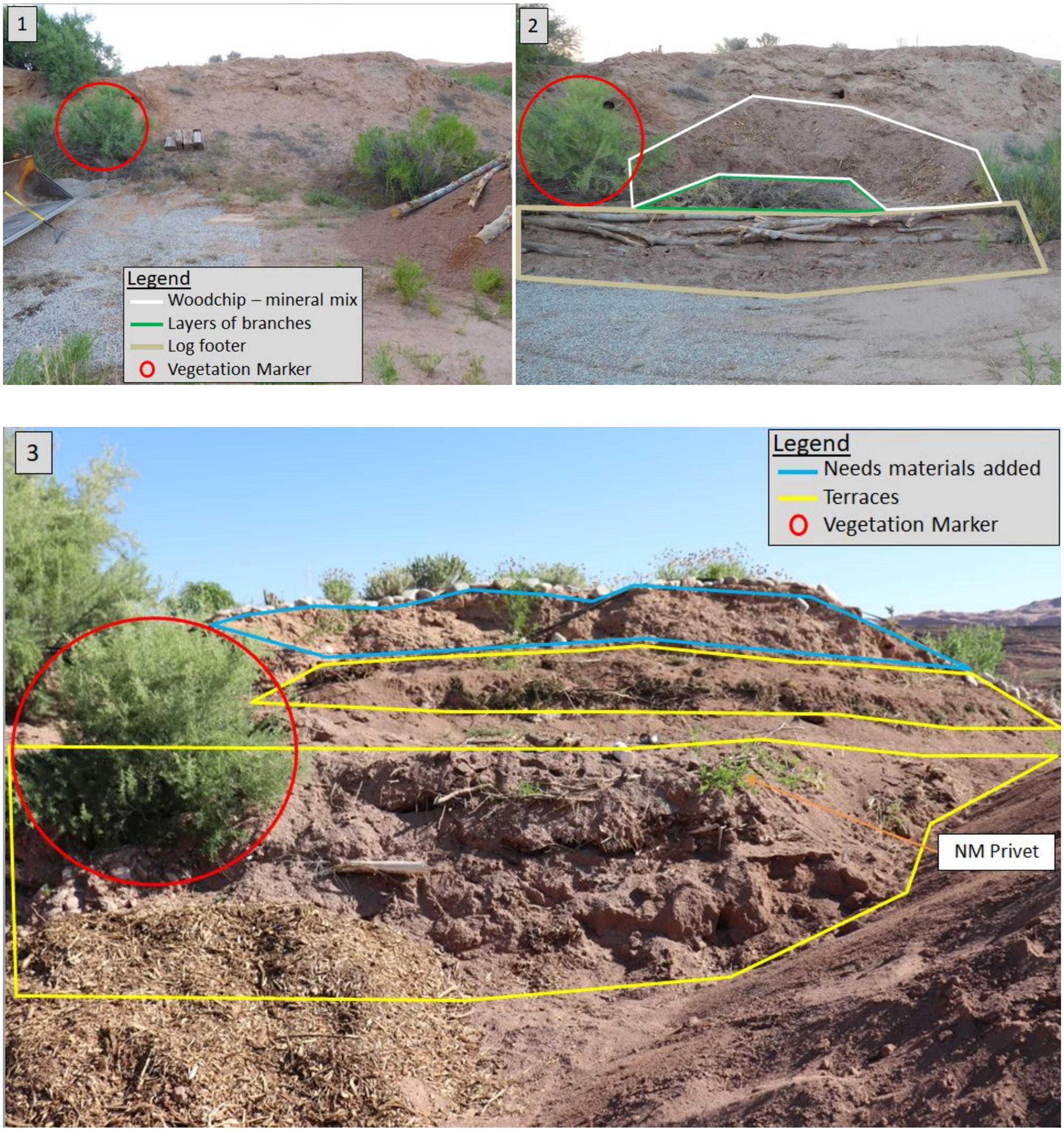

Figure 19: During the development of this neighborhood decades prior, a hillslope was bulldozed to create a building pad, leaving behind steep, unstable and eroding soils. Recently a backhoe was used to stage materials and rough out the structure (photos A and B). Terraces were installed (photo C) using logs from a local tree service as a stable footer, layers of branches, and a wood chip-mineral earth mix. Materials used in the lower terrace included dormant prunings of New Mexico privet (*Foresteria neomexicana*), which have sprouted leaves and grown for the past 2 seasons.

Gully Plugs

Brush-mineral features can be used similar to Beaver Dam Analogs (BDAs)[10] to restore hydraulic functions to degraded gullies. *Brush-mineral structures* ***should only be used*** *in low energy intermittent channels*, whereas more robust BDAs may be suitable for other channel systems.

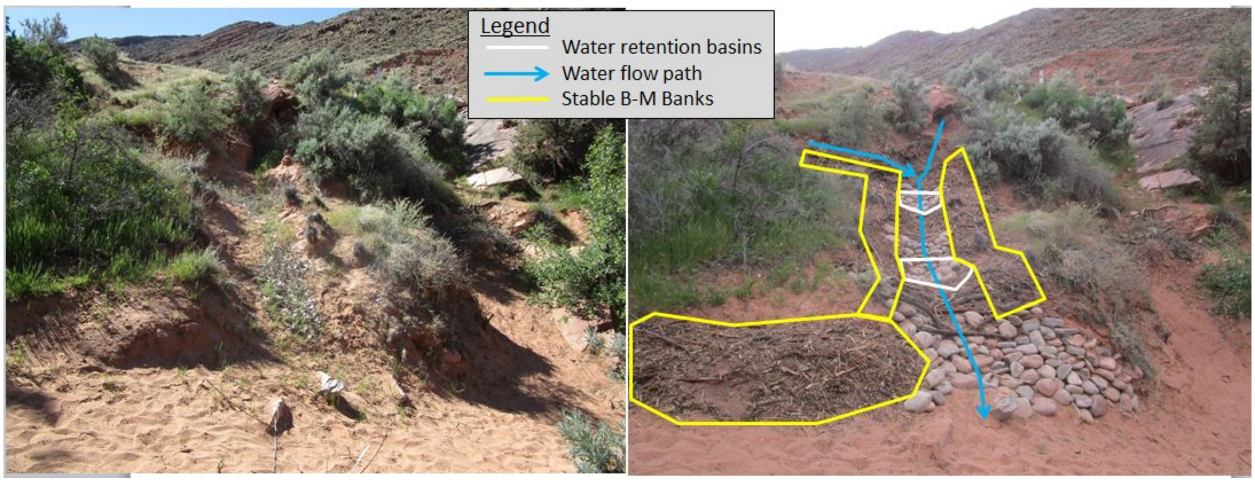

Figure 20: A social trail on public lands has intercepted runoff and created a gully, adding sediments to the nearby creek and stressing surrounding plant communities (left). Brush from a Russian olive removal project, in addition to a mix of mineral earth and wood chips, was used to create stable banks as well as a rock reinforced flow path for future runoff events. Retention basins were added to mimic a step pool system.

Figure 21: A former 2 track road turned into a social trail has eroded into a gully that discharges sediments into the nearby creek (left). A combination of Russian olive branches and mineral earth-wood chip mix was used to create several plugs along the length of the gully and re-contour the eroded banks, both managing water beneficially and discouraging continued use as a path per the goals of the land management agency (right).

[10] see this site for a defnition and explanation of BDAs http://www.anabranchsolutions.com/beaver-dam-analogs.html

Landform Creation

The most ambitious application of brush-mineral techniques is in creating new landforms that create usable spaces out of thin air. Through extensive layering of organic and mineral materials, new landforms can be created. These are highly materials intensive, subject to settling, and generally going to be a multi-year process.

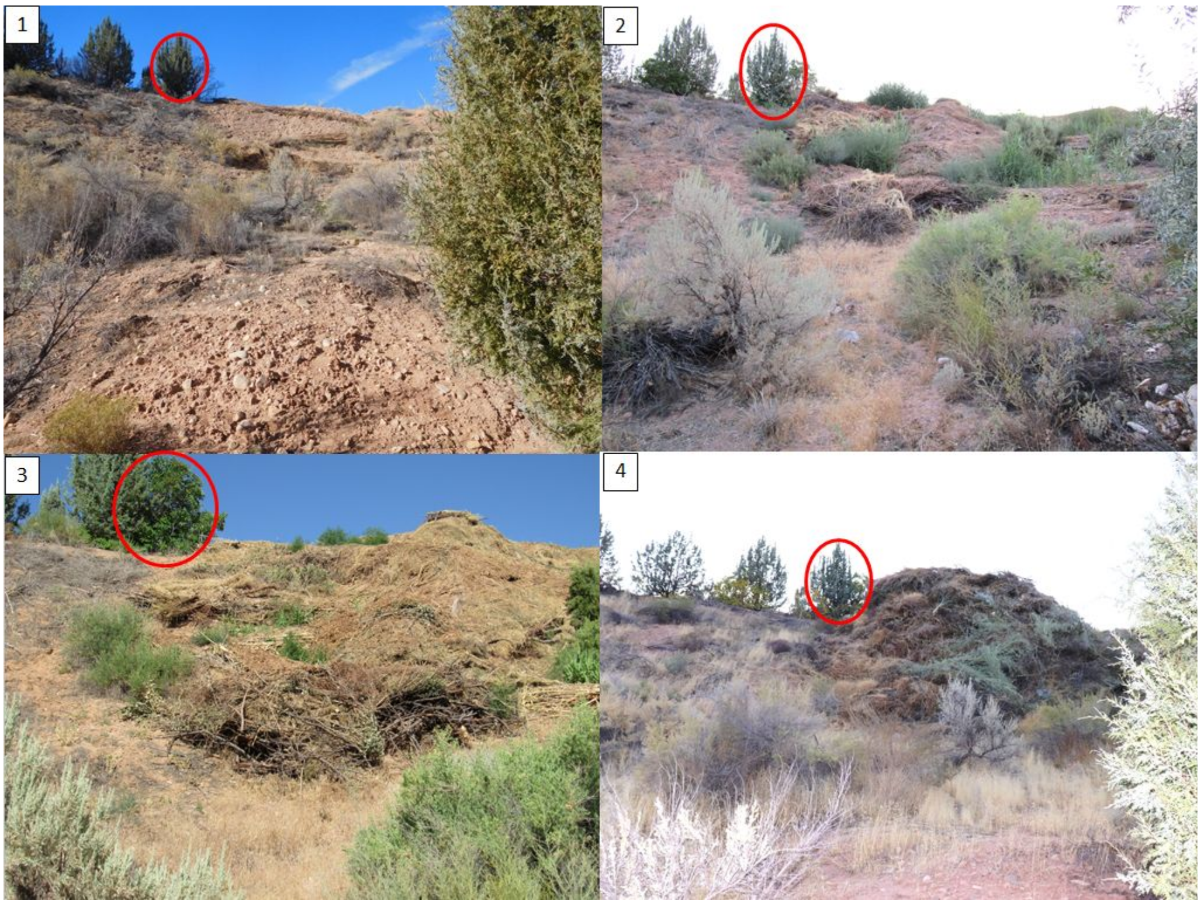

Figure 22: This series of photos shows the evolution of a new land form over the course of 3 years. Red oval marks the same tree in all photos.

A steep eroding hillside was nearly impassable prior to installing brush-mineral paths with switchbacks in 2016 (1). With an increase in materials being delivered from the community, we widened the initial paths and created expanded flat areas at each switchback (2). By 2018, the frequency and volume of organic materials being delivered increased dramatically, and this was the easiest place to use these materials given available labor and site access. This led to a shift in the trajectory of the hillside to an experiment in creating a new landform and significantly modifying local microclimates (3 and 4). This new landform continues to evolve and expand in accordance with available materials. As a result the path system has shifted, and a new vision for what is possible is emerging (Figure 23).

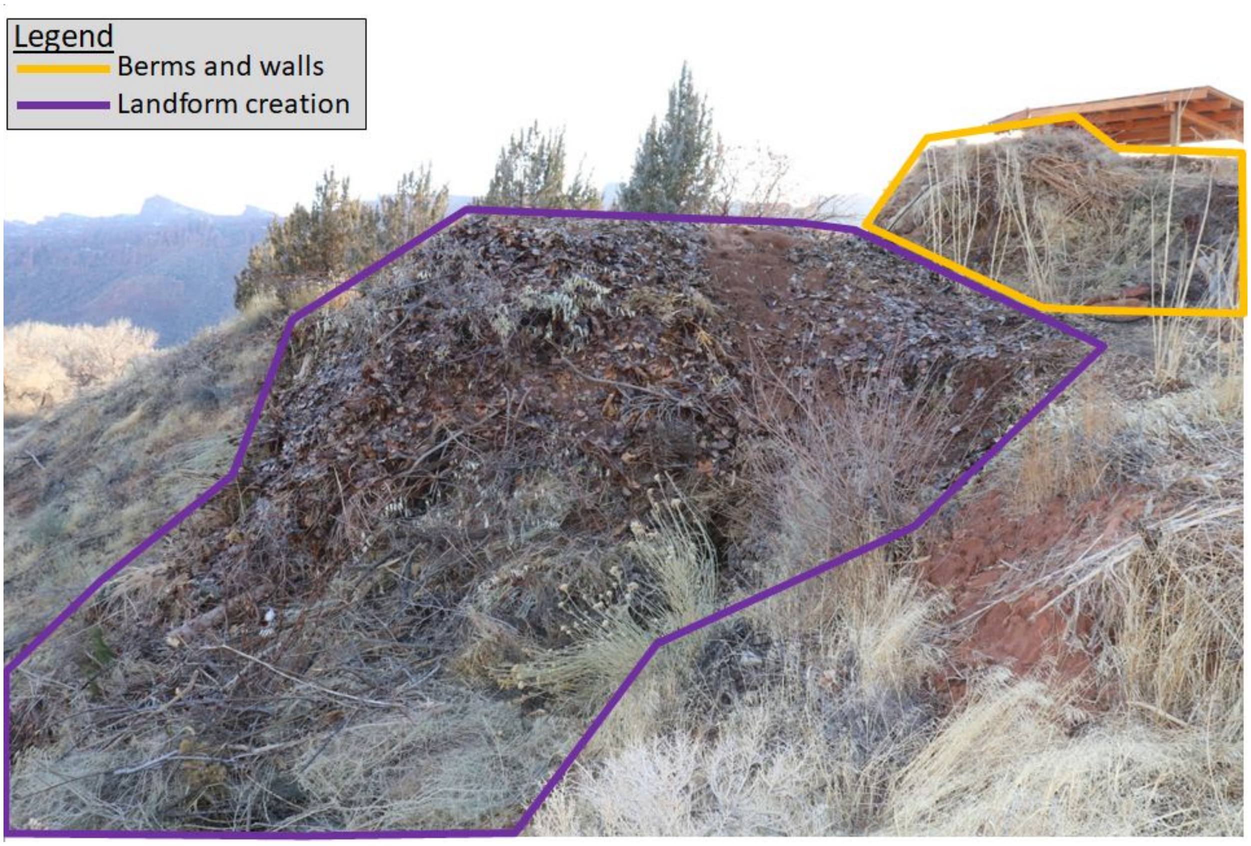

Figure 23: The new landform has evolved in response to an increased availability of organic materials, and a berm was added to modify the microclimates of the adjacent shed in addition to structures shown in Fig. 12

Heavy equipment was used on a few occasions to increase the mineral component and help form the overall shape of this structure, thereby increasing stability, bulk density, and topsoil formation. See Figures 4 and 5 for earlier views of this area.

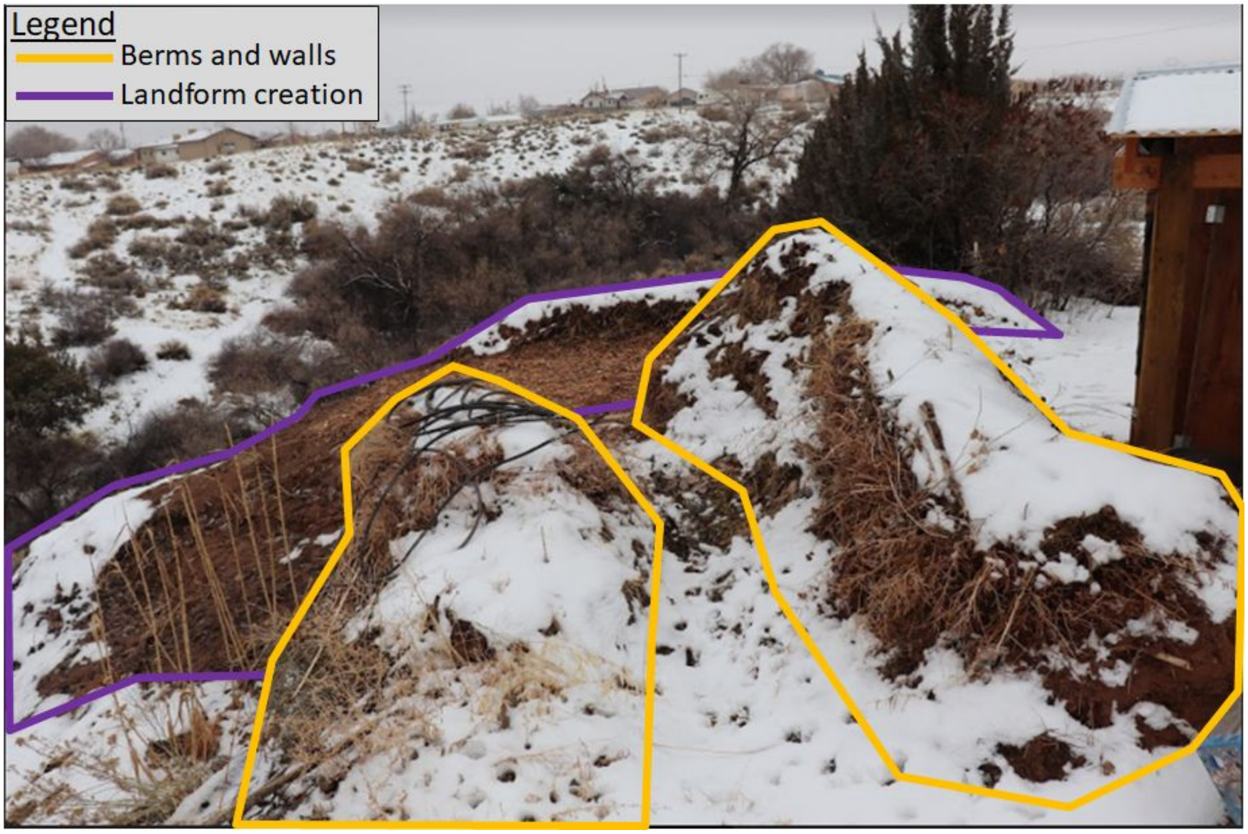

Figure 24: Brush-mineral walls around a shed create privacy and block the wind. These are the same walls from Figure 23.

Creating Topsoil

Layers of organic material and mineral earth can create topsoil in 1 to 2 years when kept moist. Inoculating the pile with compost or living soil introduces the biology that is essential for decomposition and topsoil formation. Decomposition is also accelerated by finer materials or taking time to chop material into smaller pieces. Selecting the right types of materials will also influence the soil building process. Herbaceous vegetation breaks down quicker than woody materials, and a combination of fresh green and dried brown materials is ideal.

When it is time to harvest and use your new topsoil, digging into the pile from the side will leave the top layer of partially decomposed material and seed bank in place.

Allied Strategies

There are similarities and differences in materials, construction, and applications between the brush-mineral features contained in this guide and allied strategies including Chop and Drop, Sheet Mulching, Brush Swales, Hugelkultur, and Beaver Dam Analogues.

Table 1: Brush-mineral (B-M) features are compared and contrasted with allied strategies.

Strategy	Similarities	Differences
Chop and Drop (CnD) (a.k.a Lop and Scatter)	• Use prunings and clippings on-site, close to where they are generated, to build soil and minimize erosion	• CnD used to create a mulch layer, B-M used for a range of applications and includes adding mineral component • B-M typically does not include much additional chopping to minimize size of pieces
Sheet Mulching (SM)	• Layer materials to promote soil building	• SM main function is to suppress weeds and build soil • SM does not use coarse woody materials
Brush Swales (BS) and Brush Mulch	• Pile and process prunings and woody debris to harvest water, mitigate erosion, and promote decomposition	• Does not include a mineral component
Hugelkultur (HK)	• Used to build healthy, spongy soils by encouraging decomposition • Modify micro-climates and increase growing surface area by building berms or mounds	• HK is almost always used as a growing bed, while B-M has a wide range of applications • HK uses more compost and high nitrogen materials, B-M uses whatever is available • HK may involve digging below ground surface if soil is needed or warranted by design conditions, B-M often built up with minimal if any digging
Beaver Dam Analogs (BDAs)	• Layers of branches and mud/rock • Functions to slow and spread water	• B-M features are for intermittent, low energy channels, while BDA's can be appropriate for perennial and higher energy systems

A detailed discussion of these allied strategies is outside the scope of this guide. For additional information on allied strategies see the References section at the end of this guide.

Each type of application has various costs and benefits to be considered in selecting which will be most effective in meeting your project goals within the specific considerations of your holistic context.

Costs and Benefits Considerations

Brush-mineral structures have various costs and benefits to be considered in deciding on the best approach. The specific costs and benefits will be informed by a range of factors such as project goals, materials availability and sources, and specific context. These costs and benefits may be attributed to the specific site, community, and/or larger bio-region.

Costs

The costs associated with Brush-Mineral features can be divided into Materials, Labor, Transportation, and Processing. The specific amounts and sources of each of these line items will impact the relative cost of a project. There are trade-offs in terms of how quickly a project can be completed (having enough of the right materials and labor on-site and ready to go all at once) and the overall costs in money and resource usage, including fossil fuels.

Table 2: Costs associated with brush-mineral features are broken down into materials, labor, transportation & distribution, and processing.

Cost Category	Types of Costs in each Category
Materials	• On-site products of land stewardship • Free materials - Delivery or Pick-up • Purchased materials – Delivery or Pick-up
Labor	• Do-it-yourself vs Hired laborers vs Contractor • Hand vs Machine • Transportation of materials • Processing of materials • Implementing features • Follow-up work to maintain or expand
Transportation & Distribution	• Vehicle use and fuel for importing materials • Delivery • Loading and unloading • On-site staging and movement • Machine
Processing	• Fuel • Equipment • Labor

Benefits

The use of Brush-mineral features has triple bottom line benefits at the site and community scale. Table 3 provides a list of Economic, Ecological, and Social benefits for clarity of presentation, and many of these outcomes provide benefits across multiple sectors. For example, building topsoil is an economical way to gain access to growing healthy food and provides a great opportunity to work collaboratively with neighbors. As water is harvested to help grow trees that provide shade and fruit, additional cost savings can be obtained from the passive shading provided and fruit grown. This also supports wildlife and pollinators while improving your neighborhood by addressing heat island and storm water runoff issues and increasing beauty.

Table 3: Brush-mineral features provide triple bottom line benefits at the site and community scale

Domain	Types of Benefits
Economic	● Avoid hauling time, vehicle use, and tipping fees at landfill ● Prolong useful life of landfills ● Use in-lieu of purchased landscape materials
Ecological	● Develop a mycelium highway ● Develop soil structure, feed soil food web, and build topsoil ● Cycle nutrients ● Harvest, Hold, Infiltrate, and cycle water ● Erosion control ● Pollinator and wildlife habitat ● Carbon positive landscaping – minimize hauling and processing, maximize soil carbon content
Social	● Opportunity to collaborate with neighbors to source materials and implement projects ● Build site and community resilience ● Cultivate a local network of regenerative businesses ● Air quality (from decreased burning and dust control) ● Improve site access and create spaces ● Beneficial use of trimmings, yard waste, and invasive plant materials

Assessing Tradeoffs

Every decision regarding the various categories of costs has some cost-benefit trade-off. For any application of brush-mineral structures, these decisions should be considered within the specific context of your site and system.

Some questions to consider are

- Do you want or need to get the project done all at once, or can you build it over time as materials become available?
- Are you building your feature to expand the usable area for access and work spaces, or do you want to grow plants on it?
- How large is your staging area? How easy is it to move materials from there to their point of use?
- Do you have the labor and equipment necessary to move the materials easily?

In deciding whether to use free, purchased, or some combination of materials sources it is important to consider what materials you have available and what your goals are for the project. Your specific site needs and resources combined with your bioregional network to various other materials will be driving factors in the costs associated with your project.

There are trade-offs in using free materials compared to purchased materials. Free materials may be labor intensive to transport and load/ unload, though may provide more opportunity to unload closer to where they will be used. Gathering free materials is a great way to network in the community, and is often appreciated by the person or entity seeking to give the materials away.

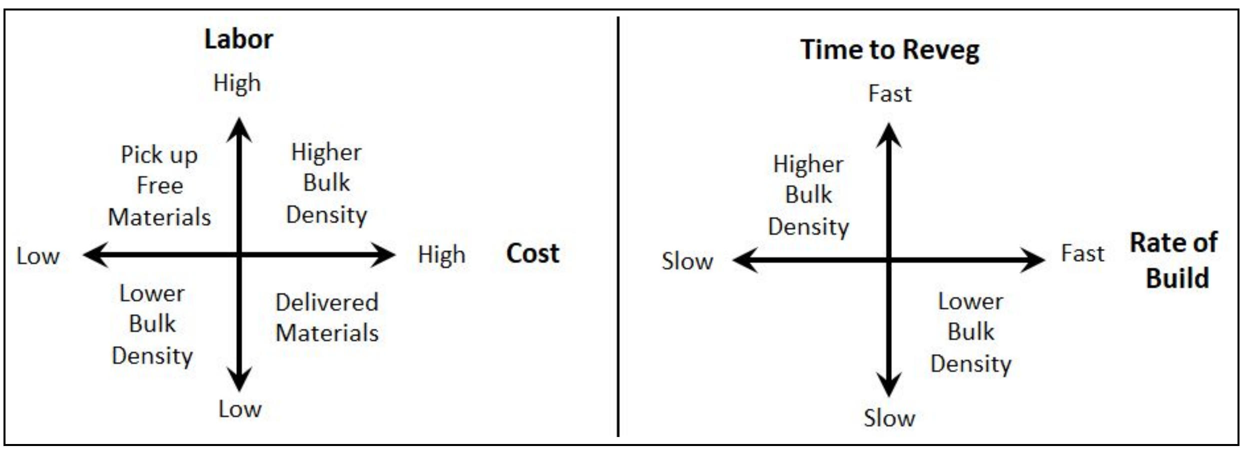

Figure 25: There are trade offs between the amount of labor and the cost of building structures (left), as well as the time typically required to establish vegetation on a new brush-mineral structure compared to the rate at which the structure is built (right).

Purchasing materials can accelerate feature building, increase bulk density of layering and thereby enhance stability and decomposition, and/or provide suitable materials for use as a surface cover. Commonly purchased materials include wood chips, mineral earth, topsoil, manure, and compost.

Hand labor generally has a lower carbon footprint and provides more opportunity for people to work together. Machinery is beneficial for moving large amounts of materials directly onto a structure or for staging, and can be essential to compressing and shaping larger features and those that may not have been layered as well as possible, such as a large burn pile that has been redirected into a brush-mineral structure.

Because burning is a common and traditional method of managing excess organic materials, it deserves a bit more attention here.

The benefits of burning woody debris[11] include

- minimizing labor required to manage this material
- generating wood ash which has a variety of uses
- decreasing the fuel loads on-site

The drawbacks include

- risk of fire escaping
- release of particulates into the air
- loss of carbon and other volatile nutrients from the terrestrial ecosystem
- potential health effects

Creating biochar is an alternate process of burning material that minimizes the drawbacks listed but is more labor intensive. A description of the process of creating biochar and its uses is beyond the scope of this document.

Another alternative for dealing with organic materials is the Jean Pain Compost method[12] which uses large piles of woody biomass to generate heat and gas for cooking fuel, then provides finished compost for soil building applications. It is both labor intensive and requires technical knowledge.

The drawbacks of using woody debris in brush-mineral structures include

- increased labor to both plan a structure then to move and process the material
- a need to source additional materials to integrate into the structure

The benefits depend on how well the structure functions, frequency of use, and proximity of the source of woody materials and the placement of the structure.

Looking at your project holistically and within the context of your specific goals, needs, and resources will help in weighing the alternatives and deciding on a strategy that is right for you. With an understanding of your integrated design context, and cost-benefits of your potential applications, it is time to consider specific materials to use in your project.

[11] The benefits and drawbacks listed here do not include burning for cooking or heating a home. This type of burning generally requires more labor to process the wood into manageable materials, may offset other forms of combustion for the same purposes, or may be the only viable option for cooking or heating.
[12] https://www.jean-pain.com/en/mjp.php

Materials

Many different materials are useful for creating brush-mineral features. Brush-mineral structures are widely adaptable based on the available materials, specific application, and the creativity of the individual builder.

Table 4: Materials are generally described as coarse, fine, or mineral, and can be sourced with various levels of processing. Some commonly used materials are listed here.

<table>
<tr><th>Type</th><th>Sub-Type</th><th>Examples</th></tr>
<tr><td rowspan="3">Organics</td><td>Coarse and Woody Materials</td><td>● Logs
● Branches, tree/shrub trimmings
● Bamboo, canes, and other grass stalks</td></tr>
<tr><td>Fine Materials - Unprocessed</td><td><u>Carbon</u>
● Leaves
● Cardboard/paper
● Dried out grass clipping or weeds
<u>Nitrogen</u>
● Grass clippings
● Weeds
● Manures, including bedding materials</td></tr>
<tr><td>Fine Materials - Processed</td><td><u>Carbon</u>
● Wood chips
● Saw dust
<u>Nitrogen</u>
● Compost
● Manures, if composted</td></tr>
<tr><td>Minerals</td><td>Mineral</td><td>● Fill dirt
● Topsoil
● Reject sand or other gravel extraction by-products</td></tr>
</table>

When using weedy species as a source of materials, it is ideal to harvest this material prior to setting or maturing of seeds. By timing land management activities to harvest weedy species prior to setting seeds, it helps to both deplete the seed bank of the site and minimize the chances for undesired species being introduced through your project. If weed seeds are imported, consider creating a windrow thermal compost to cook the seeds and provide finished compost for application on site or be ready to manage any sprouts as a new on-site source of organic materials.

Having reviewed the types of materials commonly used in Brush-mineral structures, the next section will explore the variety of possible materials sources.

Sources of Materials

There are many potential sources of materials, from on-site trimmings to landfill-bound materials that can be diverted from the waste stream and cycled into a productive, multi-functional use. Some common sources of materials are included in Table 5 below.

Table 5: Common sources of materials can come from On-site, Neighborhoods, Government entities, Businesses, and Industries.

On-site	Neighborhood or Government	Business or Industry
• Vegetation - Pruning and weeding • Grow your own biomass • Your waste stream – e.g. paper products, composted food scraps, manures	• Other people – yard waste or animal manures • Agency invasive weed management – biomass • Fire thinning – woody debris • Recycling centers – cardboard • Municipal composting	• Tree companies, incl. power companies – wood chips • Landscapers – biomass and fill dirt • Furniture stores, warehouses, bike shops – cardboard • Woodworking studios/ lumber yards – sawdust and wood scraps • Animal husbandry – manures • Construction – fill dirt and wood scraps

Any source of organic materials can be used for something - be creative!

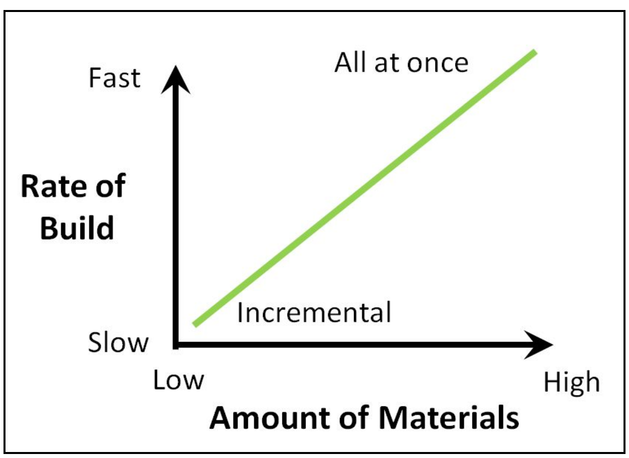

Figure 26: The rate of building varies based on the amount of materials available in relation to the amount of materials needed for a structure (right)

When sourcing materials, consider the composition of these materials to ensure a balance of coarse, fine, and mineral materials, and set some criteria for which materials you will and won't accept. When using a material or source for the first time, particularly if you're having it delivered to the site, it's valuable to inspect the material before it arrives on site. Having a plan for how you will process, store, and use your materials is an important step as you start to use on-site materials or import additional materials.

Figure 27: A landscape maintenance company happily drops off a load of organic matter that was otherwise bound for the landfill.

Processing, Storing, and Using Materials

How you manage materials critically influences the costs and labor of building and the functional effectiveness of Brush-Mineral structures. In many cases, a well thought-out structure can integrate processing, storing, and using the materials as they come in, which can simplify workflows and decrease labor needs.

Key considerations discussed in the following section include

- pile management
- designated areas of use
- timing
- moisture trapping
- cardboard, paper, and junkmail

Pile Management

You should consider the weight of materials, rate of use, temporary storage (very quick use), long term storage (annual or seasonal use), and delivery methods and space needed.

The closer you store materials to their final point of use, the less time and energy it will take to move it. Distance needs to be balanced with delivery methods and accessibility of the material.

Let gravity be your friend. It's easier to haul materials downhill if you can stage resources at the top of a site.

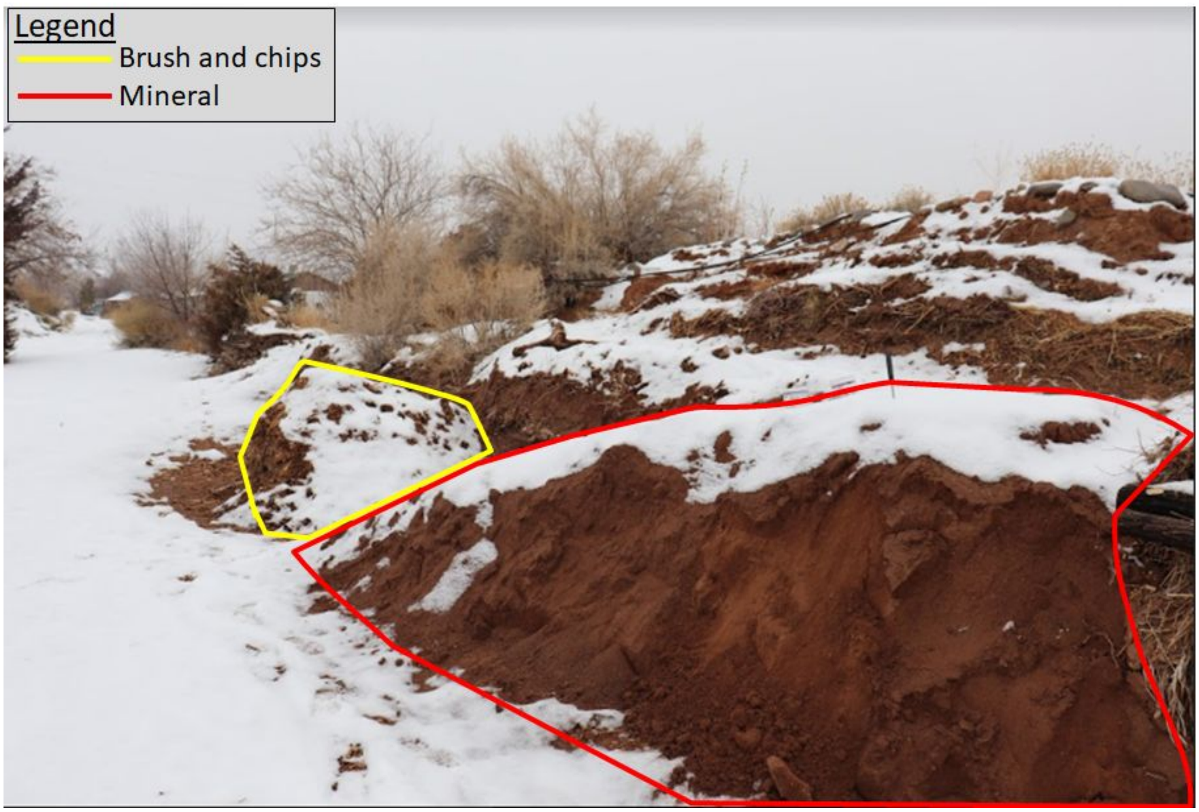

Figure 28: Bulk piles of purchased mineral and wood chips are staged for easy access by wheelbarrow or truck. Access is kept open for other deliveries and site activities

Designated Areas of Use

Having designated areas to apply materials as they are harvested from a site can expedite work flows. Consider the trade-offs of having multiple areas close to where materials are harvested compared to one target area to get a bigger project completed. Ideally materials are stored in the location they will be used or directly applied to one or more in-progress structures.

Figure 29: This aerial view shows the integrated design of many brush-mineral features (Figure 30).

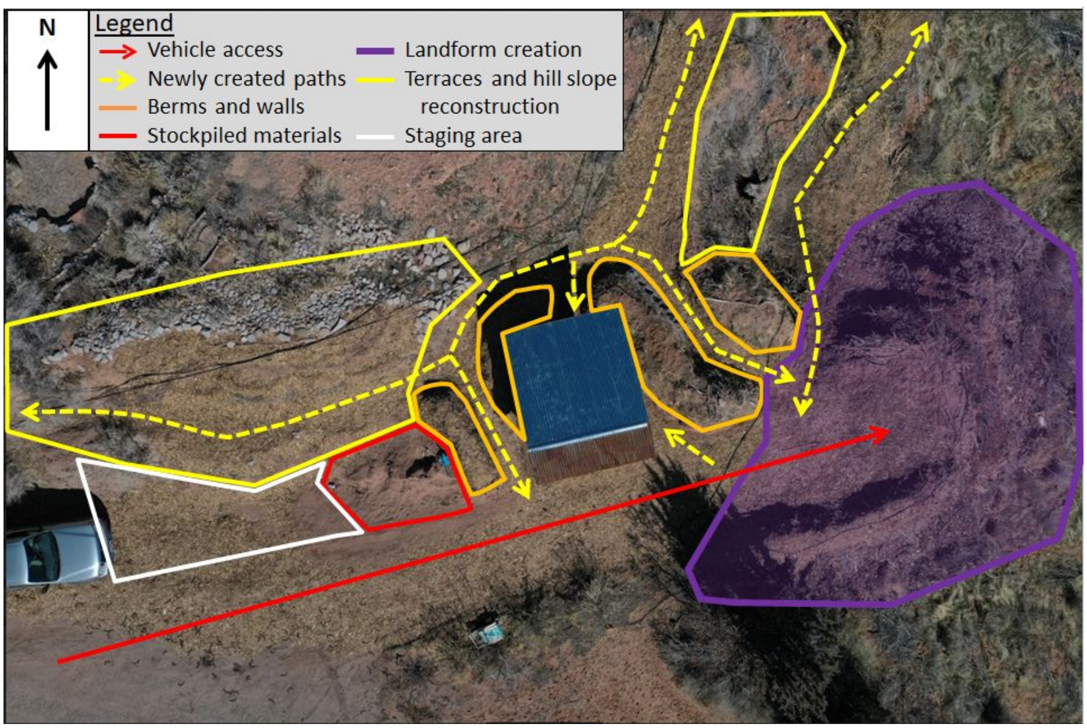

Figure 30: Brush-mineral features are integrated to manage sectors, provide access, create microclimates, and support vegetation and erosion control. Truck access provides an easy way for additional material to be added to this new landform, or deliver bulk materials (Figure 28). This new landform creation is a work in progress and can be seen in Figures 4, 5, 22, and 23. Berms and walls enhance a favorable microclimate around the shed (Figures 12, 13, 24); Terraces and hillslope reconstruction halt erosion and increase vegetative cover (Figure 19).

Timing

The rate materials that are generated on site and/or delivered should be matched to the rate and location of structure building.

For on-site harvested materials, this becomes part of an overall weedy species and biomass management strategy. Do you want to harvest plants when they are smallest and require less work to move or wait until they are larger to maximize the biomass available for your project? You may want to consider timing the harvest of undesired species before they go to seed and desired species after they go to seed.

For example:

- if building layers of chips and fill soil, you may consider having a pile of each delivered for effective mixing during application, or if the scale of the project permits or space is limited consider having them delivered in an alternating sequence of chips-soil-chips-soil
- if cleaning animal stalls or pens, try to generate layers of prunings and woody debris at the same rate that you can cover them with manure and bedding

Moisture Trapping

By timing applications to follow snow or rain events you can increase the amount of this moisture that is held in the materials while also increasing trail usability in snowy or muddy conditions.

This is a great way to use fine materials such as wood chips, straw, hay, and leaves.

This approach can be used in chicken runs or animal pens to mitigate erosion and leaching, and increase decomposition.

Cardboard, Newspaper, and Junk Mail

These common materials can be collected from your personal waste stream and used within structures.

Paper waste is one of the most effectively recycled materials. Depending on your level of concern about possible contaminants in the paper and your locally available recycling options, you can choose to include it in your Brush-mineral features or to recycle it.

With a good sense of what materials you have available, where you will source additional materials from, and how you will manage these materials on your project site, it is time to start building!

Considerations During Implementation

Brush-mineral structures are inherently adaptable and ready for creativity and experimentation. Your creativity and ability to work with your available materials and circumstances provides opportunity to build structures that are fit to a specific context, rather than trying to work with dimensional, more rigid materials, or a preconceived notion of what should happen. It is important to be adaptive in the specific size and shape of your structures, use the materials that are available or most readily obtained, and pay attention to creating stable features.

Key structural considerations include

- The bulk density of each layer
- The shape of each layer and the structure
- How well the structure is integrated into the existing site conditions, particularly slopes and flow paths

Bulk density[13] refers to the amount of dry mass in a feature relative to the volume of the feature. It is often calculated in g/cm^3. A pile of branches has a low bulk density due to the large amount of air between each branch. A pile of earth generally has a high bulk density due to higher levels of mass relative to air space. As decomposition and compression occur, bulk density generally increases. The bulk density of a structure will influence how much settling occurs through gravity and decomposition, and impacts when planting can occur. A well layered brush-mineral feature using combinations of coarse, fine, and mineral materials can achieve a high bulk density right from the beginning. A high bulk density similar to standard soil bulk density is needed for establishing vegetation and will experience the least settling overtime. Areas of low bulk density within a structure are potentially prone to differential settling and creating weak areas that may slump or sluff off the structure if not properly integrated (See Figure 32 for examples of stable structures).

The shape of a brush-mineral feature is important to its stability. Working with gravity, slopes, and forces is important to consider. Brush-mineral structures have been created with nearly vertical sides by careful placement of materials and dense layering. Structures are ideally built in layers, or lifts, of 6 to 9 inches, with each layer having good bulk density and a level top (Figures 30 and 31). Having each layer be installed roughly level helps to provide a solid base for the next layer and helps to prevent potential pitfalls such as erosion, runoff, and sloughing. Using coarse and woody materials along the outer edges of structures helps to provide added stability and contain finer and mineral materials. The coarse material on the outer edges, along with relatively consistent materials within each layer, helps to prevent differential settling or decomposition which may result in a structure falling over.

[13] https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053256.pdf

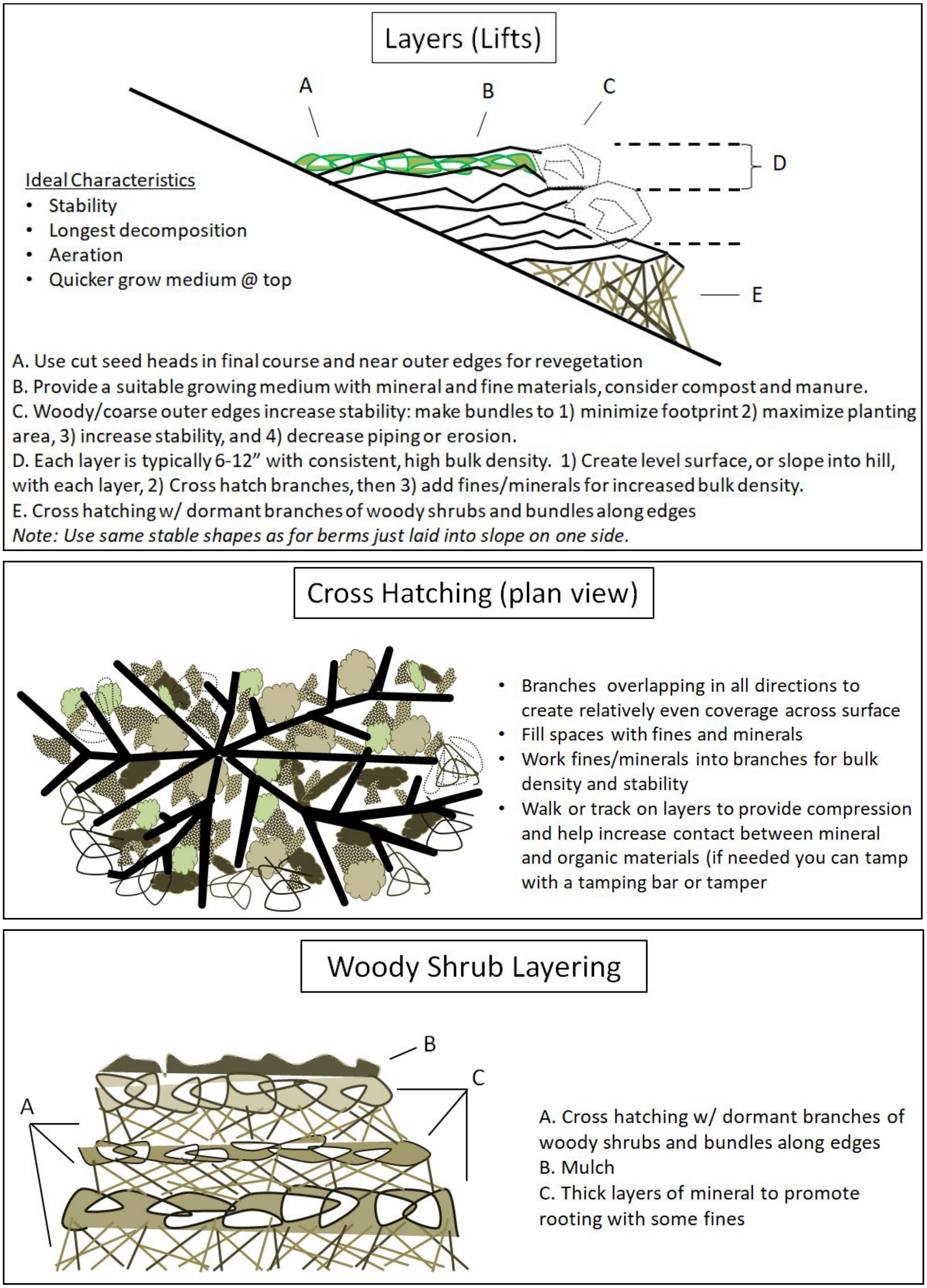

Figure 31: Building structures in lifts (top) and using woody branches for cross hatching (center) helps to make stable structures. Live, dormant cuttings of certain woody vegetation species can be included to promote revegetation (bottom).

Stable Structures

A properly built structure has higher stability. More stable structures generally take longer to build than just rapidly piling up materials. This added time in the initial construction phase results in a structure which requires less maintenance over time and is more easily vegetated. The rate of structure building is influenced by the rate of materials acquisition and the amount of labor available. Be careful of generating more material than you are able to use effectively. Having more materials than you have time to use productively can result in disappointing structures that are not stable and/or not suitable for plant growth for a very long time. Also, if you are unable to use materials in a reasonable timeframe, these resources can turn into excessive materials crowding your project site until used. The general characteristics of brush-mineral structures are outlined below.

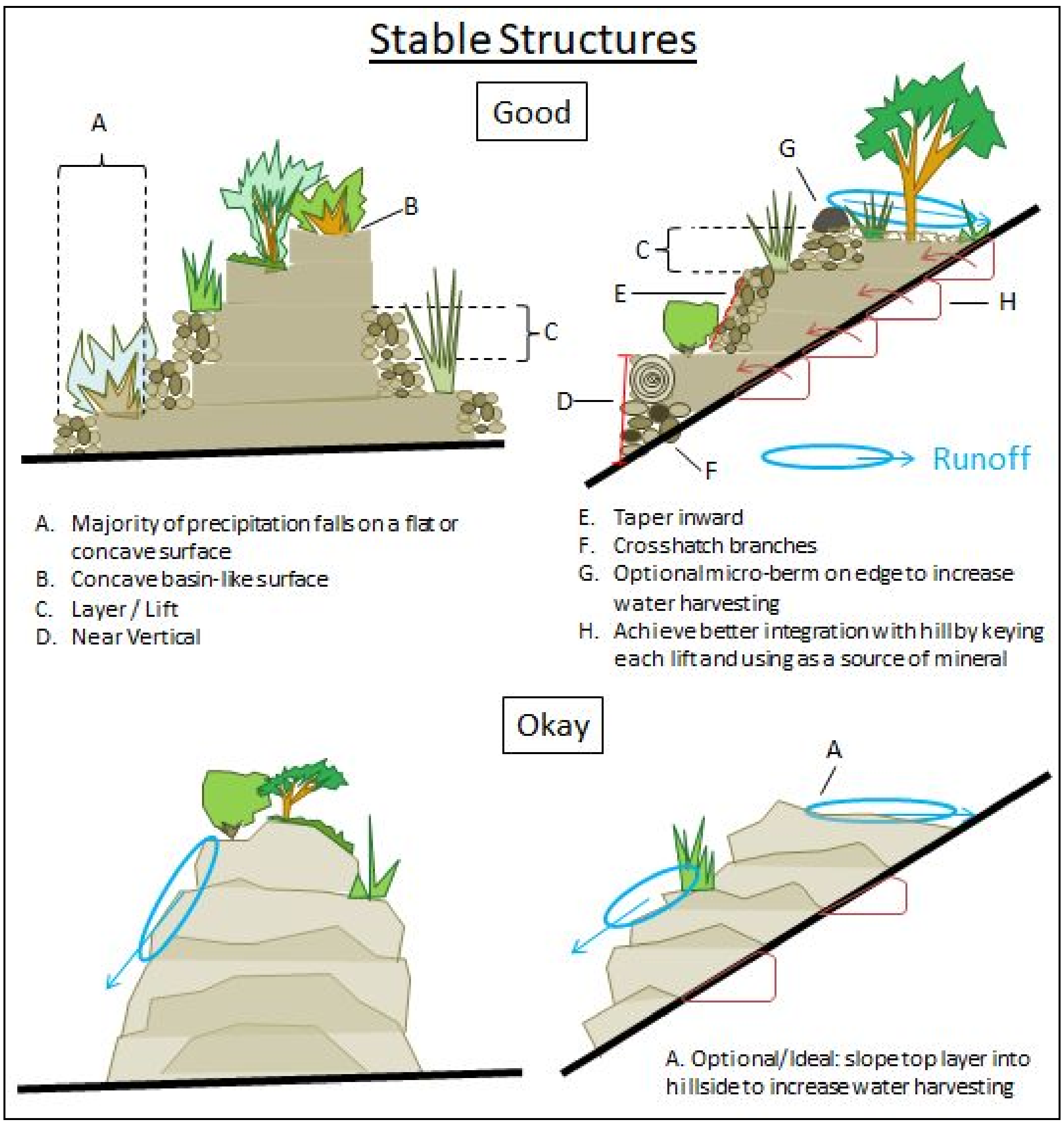

Figure 32: Schematics of brush mineral structure built on flat land and sloping terrain showing a range of quality in construction, including likely points of failure and runoff.

Good structures

- Each layer is level, tapered inward, or concave
- Sufficient bulk density to minimize settling and maximize reveg
- Stable outer edges have coarse or woody materials, or are reinforced with rocks
- Layers built in stair steps to create planting shelves for vegetation
- On sloped projects, each lift is keyed or integrated into slope

Okay structures

- Layers may be mounded
- Outer sloped edges may be prone to light runoff though should resist erosion
- Some slope may be hard to vegetate due to minimal planting shelves
- Lifts may or may not be integrated into the existing slope

Unstable Structures

Several factors can lead to structures that are less stable, and therefore less likely to achieve multiple functions. Factors that may lead to instability range from variations in bulk density, uneven stacking of lifts within a structure, the overall shape of the structures, or other forces impacting the project area. Uneven layers may settle or decompose at different rates or experience sloughing due to water, wind, or their own weight. Unstable structures can be generally described as Marginal or Poor.

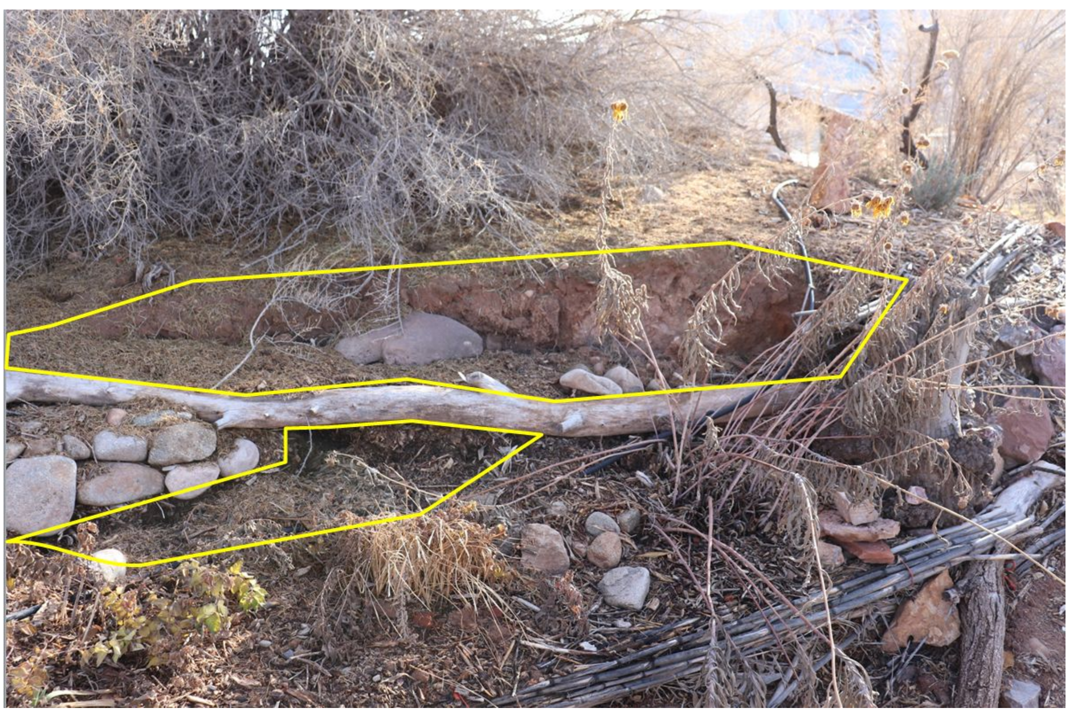

Figure 33: Brush-mineral structures that are not implemented with a high bulk density are more prone to settling and may be difficult to establish plants on. Low bulk density areas are settling above and below the horizontal log (yellow outline), while vegetation has been established just below these areas due to increased mineral soils added to the layers.

Marginal structures

- Irregular shapes prone to runoff, erosion, and slough
- Low or irregular bulk density
- Cantilevered materials

Poor structures

- Low bulk density or high woody branch layers with air gaps that are prone to settling or wind displacement
- Top heavy or cantilevered layers
- Variable bulk density and layers with voids or large air gaps leading to major settling or weakly built layer

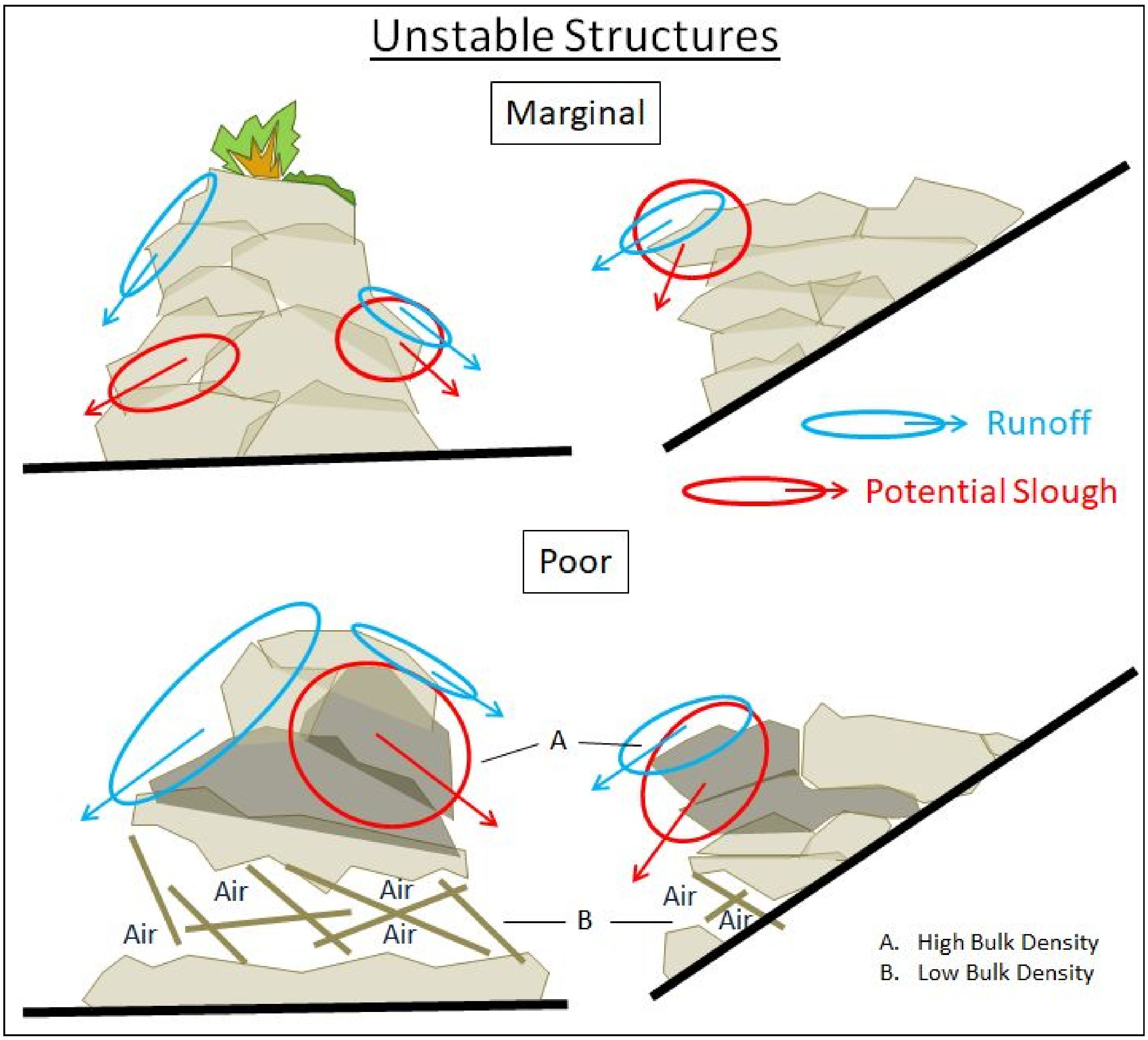

Figure 34: Schematics of brush mineral structures built on flat land and sloping terrain showing a range of quality in construction, including likely points of failure and runoff.

General Steps to Installing a Brush-Mineral feature

1. Read the landscape and assess your site. See the permaculture body of literature for more depth on site assessment and analysis

2. Identify possible locations for structures and determine specific functions for the structure to provide
    a. Determine goals and desired outcomes for each location and structure
    b. Compare these with the overall site goals and context
    c. Prioritize locations and structures. Which create short term yields and/or improve areas you use daily? Which improves long-term site stability and yields?
    d. Take any measurements needed to estimate materials (height, width, etc)

Figure 35: Identifying a suitable location and desired functions is an important first step.

3. Assess available materials and approximate volumes
    a. Sources - onsite and imported
    b. Characteristics - organic and mineral, coarse and fine, nitrogen and carbon
    c. Quantity – How much of each type of material is needed? How much of each type of material is available?
    d. Consider the four variables affecting costs: materials, labor, transportation, processing

4. Refine your structure design and implementation priorities based on your materials and costs assessment. This is also part of the adaptive management that happens once you begin to build your structure – it is likely to evolve, so be ready to adapt and be creative.
    a. Determine final location, size, and shape of structure

5. Procure and stage materials
    a. Pile management

Figure 36: Procuring and staging materials close to the structure makes building more efficient.

6. Layout and mark the site for the structure
    a. Take any final measurements needed to be ready to start building (e.g. survey contours or elevations)
    b. Mark the base of the structure location with flags, stakes, paint, or a scratched line on the ground

7. Lightly grade the area (if needed) to establish a solid footer on a sloped surface or shaping to enhance water harvesting

8. Layering materials (Figures 30 and 31)
   a. Start with large woody debris, branches, and trimmings
      - Cross hatched layers of branches become very strong
      - Outer edges of features should have longer, sturdy materials such as logs, branches, or bamboo to provide solid structure
   b. Add finer organic materials
   c. Cover with a layer of mineral earth or soil
      - Note: the more effectively you fill the space between branches and large woody debris, the higher the bulk density of the material will be and the more stable it will be. Remember, high bulk density is necessary to support plant growth
   d. Repeat
   e. Keep adding layers in 6-9 inch lifts and expanding on your structure until you feel satisfied it is done. This may be a couple hours of work or something that is built slower over many years as on-site materials are available

Figure 37: Building the structure in lifts of organic and mineral materials increases bulk density and stability of the structure, allowing for more rapid vegetation.

9. A final coating of wood chips or leaves adds an aesthetic touch and provides an effective mulch on the surface of the structure. Rocks can also be added for additional stability, heat absorption, and/or aesthetics.

Figure 38: Rock armoring was added to further stabilize the structure and provide for an aesthetic finish.

10. If you want to accelerate soil building and decomposition, then keep your brush-mineral structure moist. This can be done by locating it where it will receive additional runoff, receive irrigation, be accessible for a periodic hose drench, or is an outdoor pee spot

Figure 39: Watering your structure can increase decomposition and promote vegetation establishment

Figure 40: A diverse seed mix was used to establish vegetation on top of this berm.

11. Continue to add to and adapt your structure over time to maximize benefits

Figure 41: Structures can continue to evolve over time, like the log rounds and rocks used to increase the height of this berm and provide a suitable micro-climate for plant growth.

Additional considerations to create the best brush-mineral features possible:

1. For projects on sloped ground, make sure the bottom course is well seated through a combination of light grading, keying in, and materials selection
2. Create stable shapes – consider side slopes; starting with a broader base to allow for slope is useful for bigger structures, though we have had success building very stable nearly vertical berms and embankments when materials are suitable and sufficient mineral earth is used
3. Add enough mineral earth to achieve a solid bulk density. Walking on or tamping each layer can help to eliminate voids and enhance contact between the materials, which will accelerate decomposition and minimize settling
4. Having multiple places to add organic materials as it becomes available on site allows you to move materials the least distance practical, and results in structures that are generally built more slowly

Like all aspects of living systems, brush-mineral features will require some amount of maintenance and managing for re-vegetation and to keep them performing optimally.

Maintenance and Management

The amount of maintenance required for a brush-mineral feature is closely related to how well it was built and the bulk density. A brush-mineral feature that is built with a high initial bulk density for immediate re-vegetation may take no additional maintenance outside that required for the vegetation and any surface mulching. Features such as paths and ramps that become compressed through use and may be built initially with a lower bulk density (faster build with less mineral earth) have been found to need a reapplication of materials after 2-3 years, which can be accomplished with an additional layering materials or a thick layer of wood chips. Features created for functions such as privacy or windbreaks may need additional materials layered periodically to maintain the desired height, or can be topped with vegetation.

When building features incrementally, like terraces or new landforms over several seasons, it is best to leave each layer stable and ready to receive the next round of materials. Projects where large amounts of organic materials exceed the available labor to effectively apply them into stable structures may require follow-up work by hand or with a machine to compress the materials for increased bulk density and/or shape the outer edges to avoid creating slip-slopes between layers that may lead to sloughing.

Settling, Decomposition, and Reapplication of Materials

Organic materials and uncompressed mineral earth will settle over time through gravity, decomposition, and any surface use (for example walking on a brush-mineral path). Settling can be minimized through increasing bulk density, as well as by working in the mineral earth of each layer with a shovel, water, or light compression to fill the gaps between organic materials. Watering in each layer, or every couple layers, can help to settle the materials and achieve even moisture levels throughout a structure.

Some settling should be anticipated in all structures. It is good to either build the structure bigger to account for settling, plan to add more materials over time, or accept the new size of the structure once settling has occurred. Decomposition will decrease the size of your structure over time similar to settling, but it is a desired outcome of these techniques in order to build soil organic carbon and support the soil food web. It also helps provide a recurring place to use materials beneficially on-site when applicable. The moisture content of the brush-mineral feature directly influences the rate of decomposition.

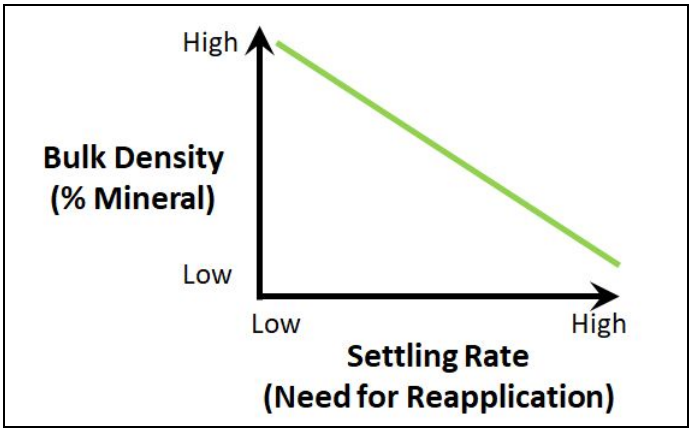

Figure 42: This graph shows the inverse relationship between bulk density and settling rate. The higher the initial bulk density the lower the settling rate.

Establishing Vegetation

Brush-mineral structures can become vegetated through several pathways – planting, seeding, and layering. The seeds and layering techniques become part of, and in some instances a by-product of, the structure building process. Using species known to layer or seed readily can be an effective strategy to vegetate structures. How the structure is built will influence how readily it can be vegetated. Structures that have a higher amount of mineral earth, topsoil, or compost mixed in will generally be easier to vegetate than a structure that has large air pockets between branches and thick mats of leaves or grass clippings that take longer to break down. Additionally, the steeper the slope, the more difficult it is to establish plants, particularly by seed, so layering is likely to be more effective in these cases.

Going Forward

Brush mineral features are part of a growing toolbox of techniques for building resilience and optimizing land management activities. With both site and community scale benefits, these low cost, shovel ready solutions are ready to be deployed at scale. As a highly adaptive technique, the door is wide open for further innovations. So put these ideas to work, taking what works for you as you start playing, innovating, and creating brush-mineral features on your property and in your community!

Resources

Some relevant resources for topics discussed in this document.

Beaver Dam Analogues
https://www.beaverinstitute.org/management/stream-restoration/
http://www.anabranchsolutions.com/beaver-dam-analogs.html

Beyond the War on Invasive Species by Tao Orion
https://www.resiliencepermaculture.com/

Biochar
https://regenerationinternational.org/2018/05/16/what-is-biochar/

Edible Forest Gardens: Volumes 1 and 2 by Dave Jacke and Eric Toensmeier
http://www.perennialsolutions.org/

Gaia's Garden: A Guide to Home-scale Permaculture by Toby Hemenway
https://tobyhemenway.com/

Jean Pain Compost Method
https://www.jean-pain.com/en/charge-mjp.php
https://www.jean-pain.com/en/mjp.php

Practical Permaculture by Jessi Bloom and Dave Boehnlein
https://www.nwbloom.com/
https://terraphoenixdesign.com/team_daveboehnlein.php

Rainwater Harvesting for Drylands and Beyond: Volumes 1 and 2 by Brad Lancaster
https://www.harvestingrainwater.com/

Sepp Holzer's Permaculture by Sepp Holzer
https://www.seppholzer.at/english