Riparian Monitoring in New Mexico:
A Practitioner's Handbook

New Mexico
Forest and Watershed
Restoration Institute
New Mexico Highlands University

NMFWRI • ECOLOGICAL MONITORING PROGRAM

Riparian Monitoring in New Mexico: A Practitioner's Handbook

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And special thanks to

Dierdre Tarr, Claunch-Pinto Soil and Water Conservation District/Greater Rio Grande Watershed Alliance

With contributions from

Bonfantine, K., J. Zebrowski, and A. Egan. 2011. Guidelines and protocols for monitoring riparian forest restoration projects. A publication of the New Mexico Forest and Watershed Restoration Institute. Available at: www.nmfwri.org

Bonfantine, K., J. Zebrowski, and A. Egan. 2011. Field handbook for monitoring riparian forest restoration projects. A publication of the New Mexico Forest and Watershed Restoration Institute. Available at: www.nmfwri.org

Mahan, K.R., Melendez C., May, C., Prentice, M. 2024. Field Manual for Monitoring Upland Forests. A publication of the New Mexico Forest and Watershed Restoration Institute. Available at: www.nmfwri.org.

Citation

Gaglianese-Woody, J., Han, A., Mahan, K. R., Goetsch, P.C., Schlosser, T., and Vispo, V. 2026. *Riparian Monitoring in New Mexico: A Practitioner's Handbook.* A publication of the New Mexico Forest and Watershed Restoration Institute. Available at: www.nmfwri.org.

Front Cover Photo

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Dedication

To all who strive for adaptive management.

Feedback

Speaking of adaptive management – do you have feedback on this manual? Please share it! Contact us through nmfwri.org or call 505-426-2080.

This publication was produced by New Mexico Forest & Watershed Restoration Institute (NMFWRI) in partnership with the USDA-Forest Service Region 3, Claunch-Pinto Soil and Water Conservation District, and the Wildfire Resiliency Training Center, with funding from New Mexico Finance Authority Water Trust Board, USDA NextGen and the Cooperative and International Programs of the U.S. Forest Service, Department of Agriculture, under the Southwest Forest Health and Wildfire Prevention Act. In accordance with Federal law and U.S. Department of Agriculture policy, NMFWRI is prohibited from discriminating on the basis of race, color, national origin, sex (including gender identity and sexual orientation), religious creed, disability, age, political beliefs, and prohibits reprisal or retaliation for prior civil rights activity. Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at 202-720-2600 (voice and TDD). To file a complaint of discrimination, write to USDA, Director, Office of Civil Rights, 1400 Independence Avenue, SW, Washington, DC 20250-9410 or call (800) 795-3271 (voice) or (202) 720-6382 (TTY).

Published by the New Mexico Forest and Watershed Restoration Institute, 2026.

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1.0 Introduction

Figure 1. Monitoring of wetland ecosystems, like this lush area of the Rio Grande watershed, is crucial for making beneficial management decisions. *Photo by Jax Gaglianese-Woody.*

Riparian ecosystems are ribbons of life that stitch together New Mexico landscapes and communities. The centuries-long transformation of the valley bottoms and floodplains of the southwestern United States into agricultural systems and urban centers has dramatically altered the hydrology and vegetation of these ecosystems. Approximately 90% of the historical riparian habitat of the Southwest has been destroyed or severely damaged and restoring remaining riparian ecosystems to their historic condition may not be possible due to river impoundment, urbanization, agricultural conversion, and associated hydrologic and ecological changes. However, resilient riparian ecosystems provide critical wildlife habitat and ecosystem services that help mitigate the extremes of flooding and drought. Decades of ecological monitoring have helped to identify appropriate and effective methods for nudging riparian ecosystems towards health. By tracking the structure and function of riparian ecosystems, monitoring chronicles ecological trajectories to support informed decision-making and course correction to shift ecosystems towards more desirable outcomes.

This handbook offers guidelines and protocols for monitoring riparian restoration projects. Protocols are derived from the synthesis of NMFWRI's experience as a monitoring program, and a broad range of existing

literature on the assessment of riparian vegetation and wildlife habitat into a methodology that is efficient, objective, and quantitative. Additional resources are also suggested for measuring variables such as hydrology, water quality, and aquatic habitat. Rather than creating new monitoring protocols, this document provides context and comparisons to help practitioners select and implement efficient and effective ecological monitoring.

Figure 2. NMFWRI crews have more than 15 years of experience monitoring riparian sites, like this canyon near Lamy. *Photo by Kathryn Mahan*

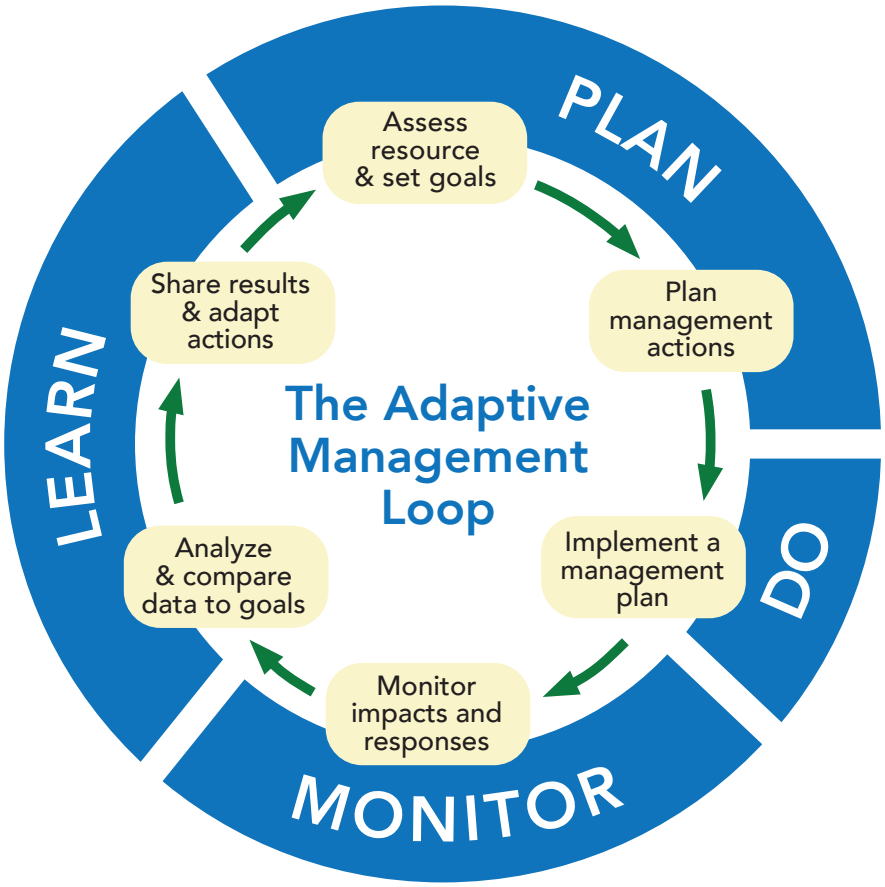


Figure 3. The Adaptive Management Loop. Environmental restoration and management are integrative and iterative processes. Monitoring the environmental impacts and responses following restoration can provide insights that practitioners can use to adapt management practices and meet restoration goals. While this handbook focuses on monitoring and data analysis, it also provides key considerations for planning, implementing, and learning from monitoring data.

Note. Diagram is adapted from Adaptive Management: The U.S. Department of the Interior Technical Guide (Williams et al., 2009).

Full citation: Williams, B.K., Szaro, R.C., and C.D. Shapiro. 2009. Adaptive Management: The U.S. Department of the Interior Technical Guide (2009 edition). The U.S. Department of the Interior.

1.1 Welcome to NMFWRI: About Us

Figure 1. Rio Ojo Caliente and its neighboring riparian habitat. Photographed during a field visit. *Photo by Alex Makowicki*

The New Mexico Forest and Watershed Restoration Institute (NMFWRI) is a Research and Public Service Program (RPSP) based at New Mexico Highlands University (NMHU) in Las Vegas, NM. NMFWRI has staff with expertise in geospatial information systems, ecological monitoring, outreach, education, and collaboration that work alongside partnering organizations around New Mexico to build capacity and develop projects that lead to healthier ecosystems and communities.

NMFWRI Institutional Alliances and Partnerships

The NMFWRI is one of four Southwest Ecological Restoration Institutes (SWERI), which also include the Ecological Restoration Institute (ERI) at Northern Arizona University (NAU), the Colorado Forest Restoration Institute (CFRI) at Colorado State University (CSU), and the Nevada Forest and Woodland Restoration Institute (NFWRI) at the University of Nevada, Reno (UNR).

The SWERIs collaborate with a diverse set of partners and affected entities to build capacity in forest restoration, and these institutes support cooperative efforts such as shared stewardship. The SWERIs collaborate with and serve land managers and regulators, including federal, state, local and Tribal agencies; interested or affected stakeholders; concerned citizens; organizations representing natural resource users; traditional groups including land grants and acequias; state and local representatives; and political subdivisions of states, such as soil and water conservation districts. SWERI administrators and staff respond to the current needs of partners and affected entities while also anticipating and preparing for future challenges.

NMFWRI Statutory Purposes and Duties

The NMFWRI began operations in 2005. The SWERI Act (PL 108-317, https://sweri.eri.nau.edu//wp-content/uploads/2018/10/sweri_act.pdf) defines the purposes and duties of the SWERIs and creates a framework for the Institutes to align their operations, cooperate with federal agencies, collaborate with partners, and serve affected entities.

The general purposes and conditions of the SWERIs listed in the SWERI Act are:

1. Promote the use of adaptive ecosystem management.
2. Reduce the risk of wildfires.
3. Restore the health of forest and woodland ecosystems in the Interior West.
4. Promote the use of collaborative processes.
5. Prepare an Annual Work Plan that ensures the proposed work of the Institute serves the informational needs of affected entities.

The duties of the SWERIs as defined in the SWERI Act are:

1. Develop, conduct research on, transfer, promote, and monitor restoration-based hazardous fuel reduction treatments to reduce the risk of severe wildfires and improve the health of dry forest and woodland ecosystems in the Interior West;
2. Synthesize and adapt scientific findings from conventional research to implement restoration-based hazardous fuel reduction treatments on a landscape scale using an adaptive ecosystem management framework;
3. Translate for and transfer to affected entities any scientific and interdisciplinary knowledge about restoration-based hazardous fuel reduction treatments;
4. Assist affected entities with the design of adaptive management approaches (including monitoring) for the implementation of restoration-based hazardous fuel reduction treatments; and
5. Provide peer-reviewed annual reports.

NMFWRI Mission Statement: The New Mexico Forest and Watershed Restoration Institute works to reduce catastrophic wildfires and restore resilient, fire- and climate-adapted ecosystems. We collaborate with partners and engage communities to bridge scientific and local knowledge and build capacity in landscape-scale adaptive management.

NMFWRI Vision Statement: The New Mexico Forest and Watershed Restoration Institute envisions a fire- and climate-adapted New Mexico that prioritizes cross-boundary collaboration for healthier human and ecological communities, sustainable economies, and social justice.

NMFWRI Ecological Monitoring Program: Ecological monitoring data provides the scientific basis for restoration treatments and is critical for adaptive management. The NMFWRI's Monitoring Program

Figure 2. The 2026 NMFWRI monitoring crew during training. Some staff in the Monitoring Program are full-time professionals while others are student interns or seasonal technicians gaining experience in the field of natural resources. *Photo by Kathryn Mahan*

maintains a professionally managed field crew to collect data on short- and long-term ecosystem response to restoration treatments and other disturbances. The field crew also provides hands-on internship opportunities for students and recent graduates to help build New Mexico's forestry workforce. Staff collect data on partner needs and opportunities related to monitoring and adaptive management and respond to those needs through initiatives and projects such as: creating a statewide monitoring data repository and suite of analytical tools, building a network of groups participating in ecological monitoring, and building statewide capacity for ecological monitoring and restoration work through monitoring protocol trainings and technical support.

Our goal is to become a long-term, capacity-building force within the restoration economy with a focus on assisting our partners in overcoming obstacles that currently limit the use of an adaptive management model.

Projects of the Ecological Monitoring Program include:

- Monitor forested and riparian ecosystems throughout New Mexico. Provide quality, hands-on internship opportunities for college students and recent graduates in natural resource management to help build New Mexico's forestry workforce.
- Develop a database of partners working in ecological monitoring statewide; survey needs across partner organizations and develop strategies to meet those needs.
- Establish NMFWRI as a repository for ecological monitoring data collected across the state, building from our own dataset. Co-develop data pipelines and suites of analytical tools suited to partner needs.
- Conduct database analysis to investigate program-level and landscape-level trends in forest and watershed health and the impacts of restoration efforts. We are uniquely situated to do this because of our own long-term monitoring datasets as well as our network of partners.

- Provide on-demand technical assistance and training in restoration and monitoring methods, protocols, and analysis to build capacity among partners and communities.
- Support the development of professional monitoring and restoration capacity across the state by expanding access to formal training (in-house or contracted) and developing accessible training materials (manuals, videos, brochures) on monitoring and restoration methods. We envision a network of professionally trained crews available to contract with agencies.
- Regularly report on and share our findings with partners and the public; set up a library of equipment, technical literature, and herbarium specimens and develop a system for providing managed access to local students and professionals.

About this Resource: This handbook builds on nearly two decades of riparian and ecological monitoring experience by NMFWRI. It was developed to document some of the methods, lessons learned, and practical considerations that have emerged through long-term monitoring, and to build on and update the resources from our 2011 guide, Guidelines and Protocols for Monitoring Riparian Forest Restoration Projects. Like our 2026 upland companion *Guidelines and Protocols for Monitoring Upland Forests Field Manual*, Version 2, this resource is intended to support practitioners, partners, students, and land managers by providing science-based guidance while recognizing that monitoring protocols and restoration practices continue to evolve through adaptive management.

How to Use this Handbook: The handbook can be read from beginning to end, but we suspect most users will find it most valuable as a reference to return to throughout the planning, field, and data analysis phases of a project. The chapters are organized to support you through the monitoring process from planning to adaptive management. They introduce key concepts in riparian ecology, restoration, monitoring design, data management, and analysis. The case study demonstrates how these principles have been applied through NMFWRI's long-term monitoring partnership with the Greater Rio Grande Watershed Alliance (GRGWA).

The supplements are intended as practical field and office references. They include plant identification resources, mapping guidance, field safety and operations, data management tools, detailed monitoring protocols, instructions for common field equipment, and lots of additional resources to support further learning and application!

A Note on Units: This guide uses English (U.S. customary) units because they remain the standard in much of U.S. forestry practice and are familiar for many land managers. Some formulas, references, and resources may be in metric (SI) units because of their international use. Both systems are valid for this work.

A Living Resource: This handbook will continue to change over time. We recognize that errors or omissions may exist, science and best practices will advance, and web links and other resources will change, etc. We welcome feedback, corrections, and suggestions to help improve future editions.

2.0 Riparian Ecology and Restoration

Figure 1. Riparian ecosystems are hot spots of biodiversity (and color) in otherwise arid southwestern landscapes. Photographed during a field visit. *Photo by Jax Gaglianese-Woody*

Bright spots in a brown landscape, southwestern riparian areas serve as biodiversity hot spots, shade structures, wildlife corridors, water storage and distribution systems, and flood mitigation infrastructure. These critical ecosystem services are compromised by shifting disturbance patterns that often favor exotic species. Altered hydrology and fuels drive a negative fire feedback loop that pushes native species further beyond the ecological boundaries that defined their existence for millennia.

Riparian ecosystems may shape and be shaped by the surrounding landscape so riparian restoration may target aquatic and/or terrestrial processes. Both in terms of project design and evaluation, it is challenging to disentangle cause and effect in an ecosystem that is naturally variable and altered across multiple physical and biological dimensions. Despite their complexity, restoring natural processes in riparian systems offers a high return on investment since their elasticity can buffer ecological and human communities against the ravages of a wetter wet and drier dry climate. Successful restoration actions are generally those that nudge the riparian ecosystem towards greater resiliency.

"On upland areas, site characteristics, such as overall climate and general landscape and soil features, normally remain relatively stable over time. One can select an appropriate monitoring site and be relatively confident that most changes in the vegetation on that area, over time, can be related to whatever management is being applied. However, in riparian areas there often is a continual process of change. One must use caution in accounting for vegetation changes caused by naturally occurring site changes compared to changes due to specific management activities."

(Winward, 2000, p. 5)

2.1 A Brief Review of Riparian Ecology in New Mexico

Figure 1. A classic "bosque" scene with a tall cottonwood overstory and limited understory vegetation. *Photo by Kathryn Mahan*

Riparian ecosystems occur along the margins of streams, rivers, and arroyos across New Mexico. The terms "riparian" and "wetland" are used interchangeably in some contexts but in this document, "riparian" will be used generally to describe all streamside vegetation and "wetland" is defined more specifically. Riparian areas may also be called "riparian forests" or "bosque" (a Spanish word for forest) but in these restoration monitoring guidelines, we consider the bosque to be a specific type of riparian ecosystem and thus use the term sparingly, preferring "riparian ecosystem" to include the full range of riverside communities.

Wetlands and riparian areas comprise approximately 0.6 percent of all land in New Mexico.[1] Approximately two thirds of all bird species in the Southwest depend on riparian ecosystems for at least part of their lives[2] and approximately 80% of all sensitive vertebrate species in New Mexico depend upon riparian or aquatic habitats at some time during their life cycle.[3] These diverse, highly productive ecosystems also absorb floods, filter sediment and pollutants, sequester carbon, sustain streamflow, and recharge aquifers.[4] They also nurture important medicinal and food plants, provide recreational opportunities, and foster deep cultural connections to the land.

Every ecosystem exists in a dynamic equilibrium maintained by a natural disturbance regime. Historically, riparian ecosystems in the Southwest were frequently transformed by the power of water through seasonal

flooding and the resulting movement of debris, vegetation, and sediment. This disturbance maintained both landscape and species diversity. Now that the power of water has largely been removed or modified through diversions and flood control infrastructure, flooding no longer acts as the primary agent of disturbance in many riparian systems. Species adapted to massive floods, shifting substrate, and periodically saturated soil now cope with dry soil, a disconnected water table, and a lack of flooding. The lack of flooding and inundation

Figure 2. Above: Humans have altered natural water flow patterns, leading to incised rivers and disconnected floodplains as seen here. *Photo by Kathryn Mahan*

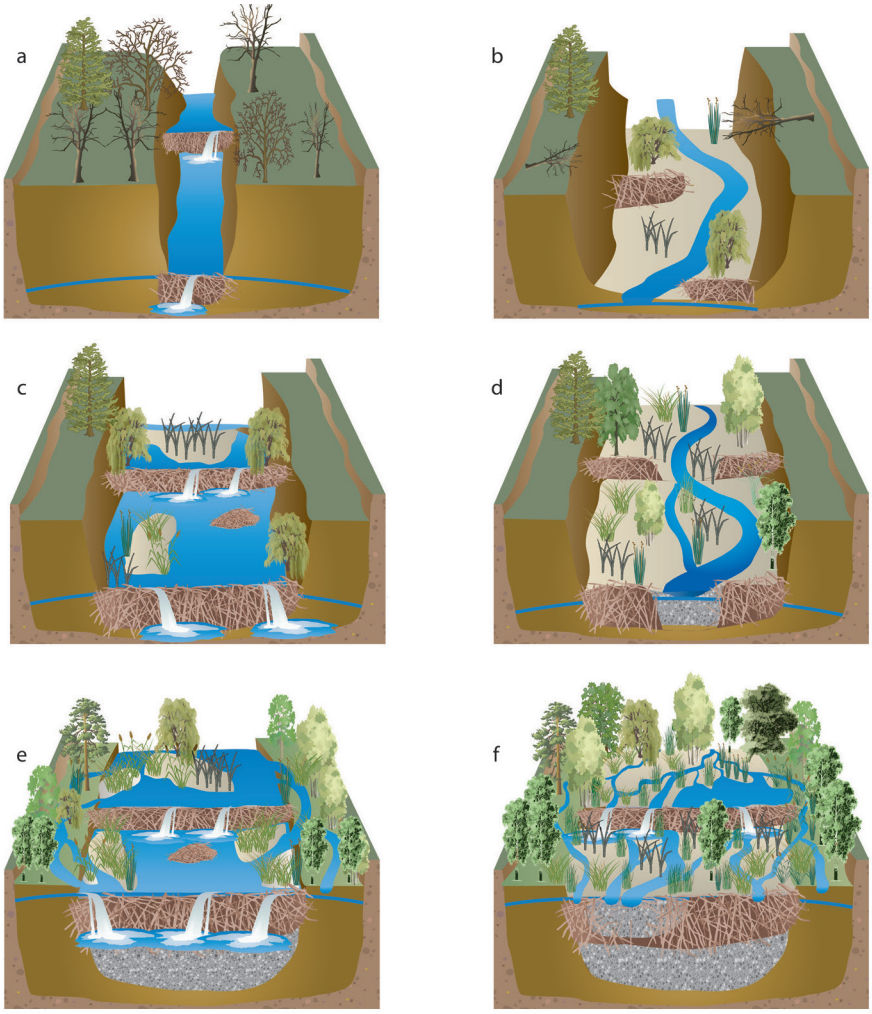


Figure 3. Stream evolution with beaver dams. Reproduced from Pollock et al. (2014), public domain (U.S. government work).

Pollock et al., 2014, Using beaver dams to restore incised stream ecosystems. BioScience, 64(4), 279-290.

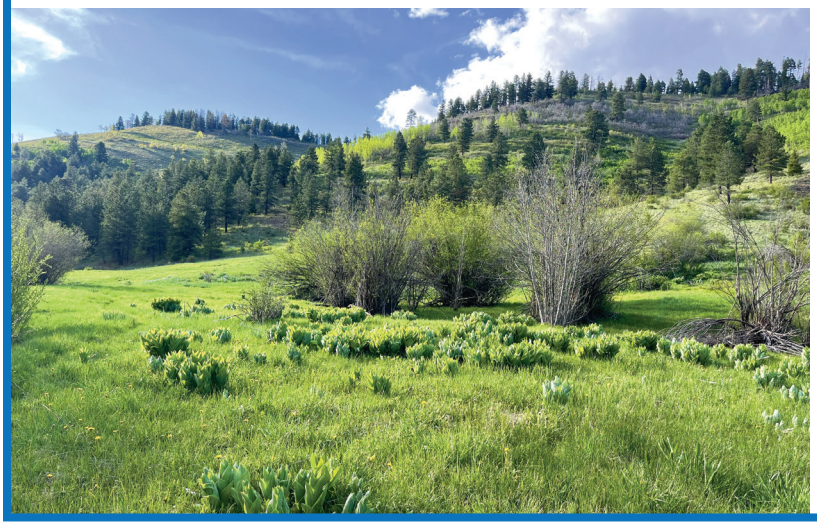
What is a Wetland?

Wetlands are ecosystems that are saturated with water at least part of the year. They may be watered from below (by groundwater) or from above (by surface water) and may be ephemeral (temporary) or perennial (permanent). Because wetlands provide critical ecosystem services and habitat, they have special protections. Following the national accounting of wetland status and loss in the 1980's, the U.S. Environmental Protection Agency (EPA) established a "no net loss" policy to prevent further wetland destruction and enhance restoration. This policy remains in place despite shifting federal protections and regulatory definitions of wetlands through the years. Wetland regulations generally center on a biological definition that describes three defining features of wetland ecosystems:

- Hydrology - Periodically saturated with water
- Soils - Saturated soils
- Vegetation - Water-loving plants

Figure 4. Wetland is a broad term for all ecosystems with periodically saturated soils dominated by water-loving plants. They may range from swamps with dense trees to wet meadows with little to no woody species. *Above photo by Kathryn Mahan, below by Jax Gaglianese-Woody*

At the federal level, all three criteria must be met while New Mexico regulations allow wetlands to be identified by one characteristic. The easiest clue to identify a wetland during the growing season is the presence of water-loving or hydrophytic vegetation. Some familiar wetland plants, like cattails (*Typha* spp.), are associated with obvious water sources like ponds while others, like yerba mansa (*Anemopsis californica*), may serve as the only clue to the presence of water. If hydrophytes are present, the site is probably a wetland in New Mexico! The US Army Corps of Engineers maintains a National Wetland Plant List that characterizes individual plants by how often they occur in wetlands. These wetland indicator statuses can be viewed in the PLANTS database (https://www.plants.usda.gov).



What is a Phreatophyte?

Most woody riparian species are phreatophytes, meaning that they depend on groundwater. Native species such as cottonwoods and willows are considered obligate phreatophytes, whose roots must reach the water table for them to survive. In contrast, tamarisk (*Tamarix* spp.), also known as saltcedar, is considered a facultative phreatophyte. As a facultative species, tamarisk will utilize groundwater when available, but it does not require continual contact with the water table. Tamarisk can also extract water from drier soil (obtain water at lower plant water potentials) than many natives. By doing more with less (higher water use efficiency), tamarisk is a highly successful and abundant colonizer of the new, flood-free riparian ecosystem. As sites dry out, native plant communities often fail to regenerate, and are replaced by tamarisk/saltcedar (*Tamarix* spp.) and Russian olive (*Elaeagnus angustifolia*). In many cases, the exotics are better suited to the current conditions, able to out-compete natives, and are difficult to eradicate.

Figure 4. Saltcedar (*Tamarix* spp.) and Russian olive (*Elaeagnus angustifolia*) have jointly moved in to ecosystems where native species are unable to compete under changing conditions. *Photo by Kathryn Mahan*

Figure 5. Above left: Saltcedar (*Tamarix* spp.) dominating a riparian ecosystem in central New Mexico. *Photo by Kathryn Mahan.* Above right: Russian olive (*Elaeagnus angustifolia*) alters ecosystem function by creating dense and impenetrable stands. *Photo by Abigail Han*

has impacted not only moisture availability but also seed dispersal patterns, recruitment, and nutrient cycling. Many floodplains are now high and dry, suspended above the adjacent channel, deprived of the valuable sediment inputs brought by floods, and choked by the tree and shrub litter no longer carried away. Salt that naturally accumulates on the soil surface as groundwater wicks upward and evaporates is no longer flushed by flood water. In many cases, these alterations have created conditions more suitable for colonization by generalist exotic plant species rather than native specialists.

Figure 6. A streamside willow pruned to boot height is barely visible among the grass. *Photo by Krista Bonfantine*

Historically, fire was a less common agent of disturbance in riparian zones but fire is becoming more frequent and severe due to changes in hydrology and vegetation coupled with a warmer, drier climate.[5,6] High fuel loads are common in riparian ecosystems due to the greater biomass, stocking, stand density, and rates of production.[7] Fuel loading and flammability are further enhanced in nonnative stands which also possess continuous fuel beds that readily carry fire horizontally and vertically.[5] The effects of fire on riparian resources depend on fire size, severity, intensity, and frequency coupled with the characteristics of the affected riparian area.[8]

Profound changes in southwestern riparian ecosystems have also resulted from the removal of another important natural disturbance agent, the North American beaver (*Castor canadensis*). Although these native mammals were largely killed off before formal record-keeping began, accounts by early trappers suggest that beaver were present along most perennial waterways and wetlands in the Southwest.[9] By building dams and lateral channels, beaver expand their habitat, enhance their food supply, and gain protection from predators.[10] Together, these hydrologic modifications slow and spread water, creating wider, wetter, more diverse riparian ecosystems[10,11] that are more resistant to fire.[12,13]

In many parts of New Mexico, beavers are unable to help store water and mitigate fire risk because they struggle to compete with livestock for access to their favorite foods, such as willows.[14] Without beavers and healthy wetlands, many high-elevation watersheds in New Mexico are shedding instead of storing valuable water.

The pressures on riparian ecosystems continue to mount as the planet warms. Average temperatures across New Mexico are expected to be about 3-7°F warmer than the late 20th century.[15,16] With warmer temperatures come sharp declines in snowpack, earlier spring melting, less surface runoff, and reduced aquifer recharge[15,17] even as groundwater pumping increases to meet agricultural and urban water demands. Humans may continue to chase the retreating water table but vegetation, particularly native vegetation, will struggle to keep up. Extreme events with heavy precipitation, higher rainfall intensity, and deeper droughts are increasing in frequency and pose additional challenges for ecosystem survival.[18]

Types of Wetland Plants

The tolerance of plant species for saturated or dry soil conditions exists on a continuum. Most plant species in the United States are assigned a wetland indicator status which categorizes plant species according to the likelihood of their occurring in wetlands. Wetland indicator status is assigned by U.S. Army Corps of Engineers regions, which in New Mexico include Arid West, Great Plains, and Western Mountains, Valleys, and Coast. The wetland indicator status for each species can be found in the USDA PLANTS Database (https://www.plants.usda.gov).

Wettest

Driest

	Indicator Code	Wetland Type	Comment
Hydrophytes	OBL	Obligate Wetland	Occurs almost always (estimated probability 99%) under natural conditions in wetlands
	FACW	Faculative Wetland	Usually occurs in wetlands (estimated probability 67%-99%) but occasionally found in non-wetlands
	FAC	Faculatitve	Equally likely to occur in wetlands or non-wetlands (estimated probability 34%-66%)
Non-hydrophytes	FACU	Facultative Upland	Usually occurs in non-wetlands (estimated probability 67%-99%) but occasionally found on wetlands (estimated probability 1%-33%)
	UPL	Obligate Upland	Occurs in wetlands in another region, but occurs almost always (estimated probability 99%) under natural conditions in non-wetlands in the regions specified. If a species does not occur in wetlands in any region, it is not on the National List.

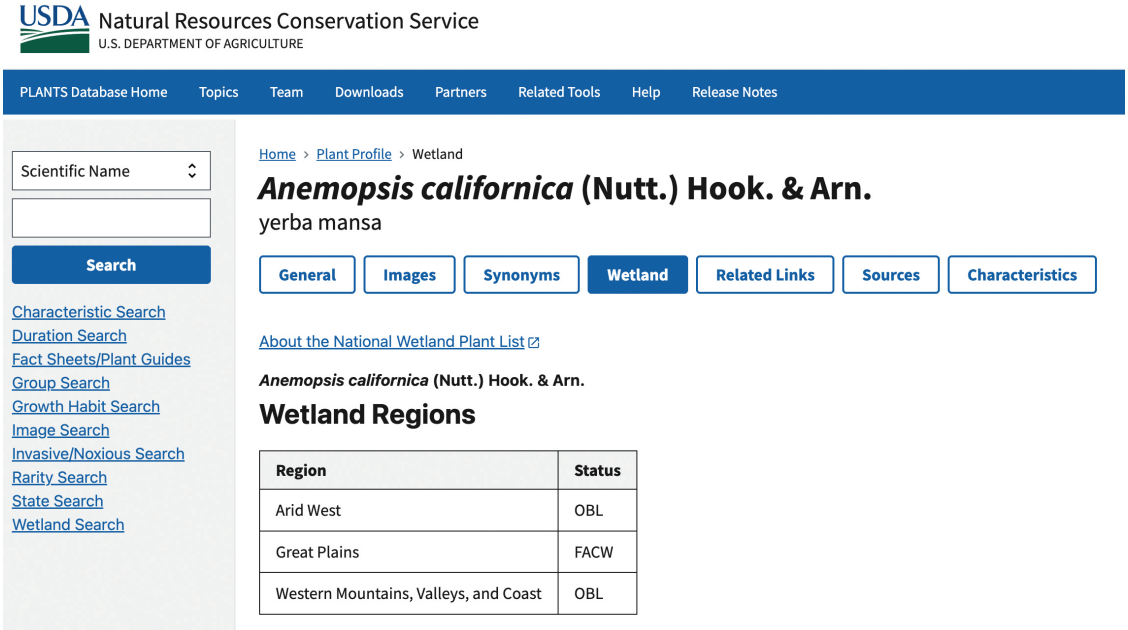


Figure 7. Above: An example of the information on the wetland tab in the USDA PLANTS database for yerba mansa (*Anemopsis californica*), a native wetland obligate species.

2.2 What is Restoration?

Figure 1. Fencing can restrict grazing access to sites, allowing overgrazed vegetation to recover and creating bands of larger plants with deeper roots that catch and store water. When done for the purpose of restoration, these structures are called exclosures. Both fencing and exclosures can be important parts of grazing management. *Photo by Jax Gaglianese-Woody*

The Society for Ecological Restoration defines ecological restoration as the process of assisting the recovery of a native ecosystem that has been degraded, damaged, or destroyed. Typically, restoration projects use historic conditions as a benchmark and target for intervention. Riparian restoration projects are unique because, in many cases, a fundamental ecological disturbance process, flooding, cannot be returned to the system. Meanwhile, fire is becoming a more frequent and severe agent of riparian disturbance despite its minor role historically.[1] Both flood and fire regimes are now shifting beyond their historical ranges of variability, driven by an increase in extreme events associated with a warmer, wetter atmosphere.[2]

As baselines shift, there is increasing attention on restoration actions that support ecological resilience. Resilience is defined as the amount of change that a system can undergo in response to disturbance while maintaining a characteristic and self-sustaining regime of processes, functions, and feedback loops.[3] Projects whose primary goal is fuel reduction may be difficult to define as restoration efforts because the preservation of ecosystem composition and structure may be limited. Terms such as "rehabilitation" or "reclamation" sometimes distinguish projects with restoration constraints but "restoration" is generally appropriate as some ecological

What Restoration Looks Like

Above: Low-tech structures built in stream beds can encourage stream "meandering" and reestablish patterns akin to those formed by natural geomorphic processes. *Photo by Jax Gaglianese-Woody*
Below: Thinning can improve habitats and reduce the risk of fire. *Photo by Barb Odell, WRTC Photographer*

Heavy machinery used to remove and masticate non-native phreatophytes along the Rio Grande in Central New Mexico. *Photo by Kathryn Mahan*

Topical herbicide applied directly to stumps shortly after cutting is an effective and targeted approach to invasive species control. *Photo by Kathryn Mahan*

Shrubs planted along the Rio Grande as part of restoration efforts in areas affected by the canalization project. *Shrubs for Rio Grande Canalization Project, United States Section of the International Boundary and Water Commission, Public Domain,* https://www.fws.gov/media/shrubs-rio-grande-canalization-project

processes and functions can be reestablished even if the historic ecosystem cannot be recreated under current conditions.[4,5]

Projects that seek to support riparian resilience may employ techniques that target specific ecosystem elements. Restoration approaches may be defined on a spectrum from passive to active techniques. Some terminology, such as nature-based restoration, may have different interpretations across various practitioners. A process-based restoration strategy aims to reestablish natural rates and magnitudes of physical, chemical, and biological processes that sustain river and floodplain ecosystems.[6] Examples of processes that can be targeted include sediment delivery, seedling establishment, and beaver dam building. Another set of restoration techniques centers on modifications to stream channel morphology. In a form-based restoration strategy, in-channel structures are designed to reestablish natural stream geomorphology and restore floodplain access.

In addition to these techniques for restoring adjacent rivers and streams, riparian restoration projects may include terrestrial activities such as grazing management, terrace lowering, removal of non-native species, thinning for fuels reduction and habitat improvement, and planting and reseeding of desirable native vegetation. Planting and reseeding are particularly common in projects that involve removal of non-native phreatophytes, but successful revegetation generally requires changes to the underlying hydrology. For example, cottonwood and willow plantings may not survive unless soil is removed from the planting site to lower the elevation and bring the vegetation within reach of the water table. Vegetative restoration is often accompanied by other non-vegetative restoration activities designed to control erosion, stabilize stream banks, or other measures designed to improve riparian condition. Techniques that are appropriate for remote, headwater ecosystems may not be possible in lowland areas that are heavily channelized, urbanized, or cultivated. To address the project realities and shifting conditions, the development of effective riparian restoration practices should include diverse input based on local and Indigenous knowledge, previous lessons learned, and scientific research.

Figure 2. Seed balls for reseeding a restoration project area with native vegetation. *Photo by Jax Gaglianese-Woody*

3.0 Riparian Monitoring

Figure 1. The many factors impacting riparian ecosystems leads to highly localized habitats. This makes the selection of appropriate monitoring techniques important—and challenging. *Photo by NMFWRI field crew*

As discussed in the preceding chapters, riparian ecosystems are among the most dynamic landscapes to restore and manage. Their condition is shaped by the interaction of vegetation, streamflow, groundwater, sediment movement, wildlife, climate, and human activities, all of which can vary across seasons, years, and even individual reaches of a stream. Because these systems are constantly changing, restoration is not complete when implementation is finished.

Monitoring is critical for understanding how riparian ecosystems respond over time, determining whether restoration objectives are being met, and providing the information needed to adapt management activities as conditions change. Selecting meaningful monitoring begins with understanding the ecological processes driving change and the management decisions the monitoring is intended to support.

Monitoring strategies should be developed collaboratively whenever possible to meet the needs of land managers, partners, regulatory agencies, and other stakeholders while avoiding unnecessary duplication of effort. Well-designed monitoring efforts generally include planning, data collection, data summary (i.e. analysis and interpretation), and support for decision-making. These activities can occur concurrently, with monitoring results used to evaluate restoration effectiveness, improve future project design, and support adaptive management.

Perhaps most importantly, monitoring should be designed to answer the questions that matter most for management. Consider how monitoring data will be used to inform future decisions, what resources will be needed to sustain monitoring over the short and long term, and how monitoring efforts can build on existing datasets to maximize their value. Thoughtful planning at the outset helps ensure that monitoring produces meaningful information that can be integrated into management decision-making with confidence.

The following chapter provides more information on developing a monitoring plan that is practical, scalable, and aligned with your restoration and management goals. A checklist of best practices is also available at the end of this chapter.

3.1 Developing a Monitoring Plan

Figure 1. Pre-treatment visits that involve landowners, management and monitoring contractors, and other stakeholders can help establish a shared vision and understanding of a project's goals. *Photo by Kathryn Mahan*

A monitoring plan must be based on an understanding of what should be monitored and why. With a full understanding of the purpose of the monitoring and the indicators to be measured, a plan can be developed that identifies how the monitoring will be accomplished. Being clear on the project objectives, available resources, and organizational capacity are also fundamental to any monitoring project.

WHY: Why should we monitor?

Monitoring measures change over time. Monitoring pre- and post-treatment evaluates whether the project was implemented as planned. Broader, long-term monitoring measures the trajectory of ecological attributes so land managers can assess the impacts of project activities, adjust activities if necessary (adaptive management) and improve future restoration efforts. A comprehensive monitoring plan can include the identification of thresholds or "watchouts" where monitoring results for specific parameters within or outside of certain ranges trigger changes in management activities; this can help ensure that decision-making is supported by data. Although monitoring can be expensive and time-consuming, it is fundamental to improving our understanding of potential impacts of project actions on the habitat and populations of target species. Well-designed monitoring that quantifies the effects of riparian treatments on fuel loads, fire risk, and ecological effects can help to optimize treatments to balance complex ecological processes.

WHO: Who should participate in monitoring?

Riparian ecosystems occur across the state, and are managed by partners with differing social, economic, and

cultural values. An inclusive monitoring team can support collaborative processes, contribute to the project success and impact stakeholder engagement and investment in the outcome. This selection process may start from questions such as "Who is affected?" and "What support is needed?". When done well, monitoring can help facilitate cross-boundary partnerships by providing opportunities to develop a shared understanding of specific terminology, build consensus around management decisions, and share the cost and capacity requirements associated with a sustained and effective monitoring program.[1]

Effective communication and coordination are essential for achieving shared objectives when multiple stakeholders with differing interests are involved. Ecological monitoring depends on the timely transfer of accurate information among land managers, monitoring crews, funding entities, and other partners. Attention to detail is required to maintain data integrity when multiple parties are involved.

Monitoring teams are rarely the only parties working within a given riparian system. Proactively engaging with other practitioners and organizations active in the same area can improve efficiency and reduce duplication of effort. Collaboration and data sharing, where appropriate, can save time and resources while strengthening the collective understanding of site conditions *(See Supplement B3 Spatial Data Resources for information on additional datasets)*. In addition to formal datasets, experiential knowledge held by other practitioners working on the landscape can provide valuable context for interpreting monitoring results.

NMFWRI recommends that monitoring teams prioritize understanding land managers' questions, management objectives, and perspectives, while clearly communicating their own goals, methods, and on-site conduct. Transparency and trust-building can lead to land managers sharing valuable contextual information, including land-use history, prior management actions, and site-specific observations. In many cases, this collaborative relationship can also improve site access and logistical efficiency because the monitoring effort becomes relevant and beneficial from the land manager's perspective. This approach is particularly important in New Mexico, where formal records of land-use history and landscape conditions may be incomplete or of variable quality. The extensive place-based knowledge held by land managers—derived from sustained observation of landscape change—can provide critical insights that are frequently underrepresented in formal scientific datasets. When working on private land, the inclusion of landowners in monitoring leverages their expertise, ensures buy-in, and supports long-term observations. Respect and cultural awareness are critical components of the process, particularly when working with private landowners, Tribal partners, and land grants. Many communities in New Mexico have a history of being forcibly separated from their land. Tribal Nations are sovereign governments; projects conducted on Tribal lands must adhere to Tribal laws, protocols, and cultural expectations. Tribal governments retain full authority over access, data sharing, and acceptable conduct on their lands. Many land grants and acequias have status as political subdivisions and are managed differently from private lands. Monitoring teams should approach these partnerships with respect, cultural awareness, and a commitment to complying fully with requirements laid out by Tribes, land grants, or other landowners.

One more consideration in collaborative projects is the level of technical expertise required to generate decision-relevant data. For example, working with volunteer or student groups may be an ideal way to meet community engagement or educational goals while also collecting field data. In other cases, investing in a professional monitoring crew may yield greater methodological consistency and analytical objectivity. If working with professional crews, involving youth, policymakers, and community members through field tours, workshops, or demonstration workdays can be effective for building understanding and support. Direct

Figure 2. Because of the wide range of important metrics, riparian monitoring may necessitate the use of a wide range of specialized techniques and equipment. *Photo by NMFWRI field crew*

exposure to field methods and on-the-ground conditions can communicate the importance of monitoring and management actions more effectively than written or verbal explanations alone, while also advancing broader science communication goals.

WHAT: What should we monitor?

Riparian restoration projects involve a suite of biotic and abiotic factors that are often not considered in upland ecosystems. These factors include soil moisture dynamics, geomorphology, nutrient cycling, and groundwater connectivity. In many cases, that means that a broader group of individuals with a wider range of expertise should be part of a riparian restoration monitoring team. Potential impacts on hydrology, geomorphology and threatened and endangered species may necessitate participation from multiple resource specialists and monitoring additional variables in riparian systems may be helpful in explaining observed changes. However, time and personnel are always limited and more disciplines at the table means more variables to monitor.

Several techniques have been developed that incorporate a broad range of parameters to evaluate the condition and functionality of riparian ecosystems. Here we provide an overview of monitoring metrics or indicators to consider. The selection of monitoring indicators should also consider project goals and existing monitoring data or efforts. A restoration monitoring program should aim to collect measurements that track project goals as efficiently as possible. Alternatively, other relevant protocols are listed in the *Supplement E1 Additional Monitoring Methods.*

Project Goals	Monitoring Indicators	Frequency	Season
Increased understory grasses and forbs	Percent understory cover Plant species diversity	Annual	July-Sept
Reduced threat of crown fire	Density, species, and size of live trees Basal area Height to live crown Canopy cover Surface fuel loading Vegetative community structure	Annual	Any Cover: May-Oct
Improved habitat for Southwestern willow flycatcher	Density, species, and size of live trees Basal area Canopy cover	Annual	Any Cover: May-Oct
Retention of snags	Snag density	Annual	Any
Retention of large trees	Density of trees >16" in diameter	Annual	Any
Reduced soil erosion	Soil disturbance	Biannual or following event	Any—consider timing relative to monsoon season

Table 1. Monitoring Indicators by Project Goals.

A consistent, simple set of monitoring indicators that can be implemented through time by different people should form the backbone of a monitoring program. In general, more detail takes more time. In Table 1, monitoring indicators relevant to various project goals and their frequency are shown.

Live And Dead Tree Density: Tree density is an estimate of how many trees there are per area in the forest. It is valuable information for restoration work, since many sites have a much higher density of trees than would be considered "natural" in southwestern forests. Many riparian ecosystems have high densities of non-native trees. Small trees can serve as ladder fuels to carry fire into the crown of mature trees. Snags (dead standing trees) are good wildlife habitat, are often scarce, and should be protected during treatments.

Live And Dead Tree Size: Measuring tree size (and density) helps identify if there is a healthy mix of young and old trees or if the area is dominated by small, competing, or non-native trees. In a riparian ecosystem, large trees provide additional benefits as flood-resistant anchors that stabilize streambanks and provide shade. Unless large non-native trees, such as elm, are targeted for removal, the average tree size should increase after treatments remove many small trees.

Crown Base Height: Crown base height (CBH) is the distance between the ground and the lowest live branches in the crown of a tree. This indicator is important to determine the likelihood of surface fire moving into the canopy. CBH for individual trees are then averaged to determine the crown base height for the area sampled. Since many small trees may be cut in restoration treatments, average CBH for a stand usually increases. An increase in CBH can represent a reduced fire risk.

Species Composition

Overstory Species Composition: Overstory refers to the upper layer, or canopy, of a forest. Overstory species are those trees or shrubs that are likely to belong to the overstory when mature. These tree species reflect the longer history of the site while seedlings describe more recent conditions. Recording information about overstory species composition (at all life stages) is valuable in part because these woody species differ in their habitat quality and suitability for birds and other wildlife. The presence or absence of certain species may also be an important metric to describe the ecological trajectory of a site.

Understory Species Composition: The understory is the area below the forest canopy and is comprised of shrubs, small trees, and herbaceous plants. In many ecosystems, the dominant forb or grass species might naturally shift year to year regardless of the management practices in use. Because of this, identifying and measuring understory plants at the species level may not inform decision-making or be an efficient use of time. Therefore, the decision to monitor understory plants at the species level should be made at the project inception based on the presence of culturally or ecologically important species, management goals, crew expertise, and funding so that it can be sustained and not cast off when required by a budget crunch. If the most important understory species are the introduced species, crews may be trained to identify noxious weeds and record their cover by species while measuring other plant cover without considering differences in species.

Surface Fuel Loads: Because surface fuels like logs and branches can burn hot and carry fires into tree crowns, the amount of dead and down surface fuels is an important measure of how vulnerable the forest is to crown fire. In riparian ecosystems, non-native trees can produce large amounts of dead and down wood that increase the risk of crown fire. The reduction of surface fuels is an important restoration goal. Dead and down wood fosters wildlife and understory growth and some should be left on the ground.

Overstory Canopy Cover: Overstory canopy cover is a measure of the amount of leaves or needles in tree branches overhead. If the overstory canopy cover is very dense, it means that tree crowns are close together and are likely to carry an intense fire from tree crown to tree crown. When the canopy is more open, there is more space between tree crowns and the crown fire risk is reduced. Also, a more open canopy means that more sunlight reaches the forest floor, allowing a healthy understory of grasses and forbs to grow. Some level of canopy cover is good for wildlife habitat, however, especially when large trees are left in clumps. Riparian overstory vegetation supplies critical, cooling shade for adjacent aquatic ecosystems. Since many restoration treatments remove trees, percent overstory canopy cover is expected to decrease.

Understory Cover: The understory of grass and small plants under the forest canopy is a good indicator of forest health. The understory has many ecological functions, including providing habitat for wildlife, protecting soil from erosion, and carrying low-intensity fires. Where trees have an unnaturally high density, the plant cover on the ground is usually sparse. Thinning the trees results in an increase in understory plant cover over time, but a substantial recovery may take some years.

Vegetative Community Structure: Vegetation community structure is an important component of riparian wildlife habitat. Structure classifications are based on the amount of vegetation at different layers of the canopy. Community structure types were developed by Hink and Ohmart[2] to describe patterns of vegetation communities along the middle Rio Grande *(see Supplement E4.7 Hink & Ohmart Structure Types*). Although the composition of species will differ for other systems, the structure classes and height cutoffs can still be applied. Generally speaking, greater structural diversity is associated with greater wildlife diversity.

Depth to Water Table: It is important to monitor the depth to the water table and soil properties in order to set reasonable expectations for a restoration project. As discussed in Chapter 2, the current hydrology of a site can be very different from the historical condition. By measuring the depth to groundwater, the manager can determine what portion of the project area should be considered a riparian area and what portion should be treated as an upland site. When non-native phreatophytes dominate a site, their removal is often followed with seeding or planting of native species. Determining what plant species and stock type is appropriate for revegetating a site and promoting their successful establishment requires an understanding of site hydrology. Field methods for measuring depth to water table can be found in the *Supplement E3 Groundwater Monitoring & Installing Shallow Groundwater Wells.*

Soils

Soil Salinity: When a project involves revegetation, soil properties should also be measured. Saline soil in riparian ecosystems can affect the soil-water balance and limit the range of species suitable for the site. Salts can accumulate at the soil surface as water evaporates from bare soil. Leaf litter may also contribute to soil salinity, as some riparian species—such as saltcedar and fourwing saltbush—accumulate salt in their leaves.

Soil Texture: Sand, silt, and clay are the three particles that make up soil. The amount of each particle in the soil determines its texture. Each soil texture stores water differently, contains varying levels of nutrients, and provides varying levels of aeration, which influence microbial activity and plant root growth. Soil texture can be a factor in appropriate species selection because some plant species are tolerant of a wide range of soil textures and others are more specific. In riparian ecosystems, soil texture is influenced by sediment movement, as well as parent material and weathering.

Soil Disturbance: Soil disturbance is a measure of changes to the soil surface caused by ground-disturbing activities such as vehicle traffic, heavy equipment use, livestock trampling, severe fire, or concentrated foot traffic. Such activities can compact the soil, reduce water infiltration, increase erosion, and negatively impact vegetative cover. Disturbed soils may also contribute sediment to nearby streams or channels, affecting water quality and aquatic habitat. Some soil disturbance may occur during restoration treatments and management activities; minimizing unnecessary disturbance and monitoring recovery are important for maintaining long-term soil health and site resilience. More information on protocols that include measurements of soil disturbance, such as the USFS Forest Soil Disturbance Monitoring Protocol, New Mexico

Rapid Assessment Method (NMRAM) and National Water-Quality Assessment Program (NAWQA), can be found in the *Supplement E1 Additional Monitoring Methods and Protocols*.

Channel Shape: Channel shape describes the width, depth, slope, and overall form of a stream channel. It influences how water moves through the system, how sediment is stored or transported, and how streams respond to floods. It may be helpful to document or monitor the characteristics of the stream channel by collecting information on the longitudinal and cross-sectional profiles of the stream. Restoration treatments that improve vegetation cover, bank stability, or floodplain connection may gradually influence channel shape over time. If any previous stream monitoring has taken place, the methodology and locations should be followed as closely as possible. For an introduction into understanding bankfull, learning about width:depth ratios, and taking cross-sections, we suggest the training and protocols associated with the New Mexico Rapid Assessment Method (NMRAM) or New Mexico Environment Department's Physical Habitat SOP. More information on these and other protocols that include measurement of channel shape can be found in the *Supplement Protocols E1 under Additional Monitoring Methods and Protocols*.

Streamflow Estimation: Streamflow is a measure of the amount of water moving through a stream channel over time. Estimating streamflow helps managers understand water availability, seasonal variability, and the ability of a stream to support riparian vegetation and aquatic habitat. High flows transport sediment, recharge floodplains, and shape channel features, while low flows may limit habitat quality and plant establishment. Changes in streamflow can result from drought, watershed disturbance, water withdrawals, or restoration actions that improve infiltration and watershed function. Monitoring streamflow trends helps place other restoration outcomes in context. More information on protocols that include measurement of streamflow, such as New Mexico Environment Department's Physical Habitat SOP and National Water-Quality Assessment Program (NAWQA) can be found in the *Supplement Protocols E1 under Additional Monitoring Methods and Protocols*.

Water Temperature: Water temperature is a useful indicator of stream health because it strongly influences aquatic species, dissolved oxygen levels, and overall ecosystem processes. Many native fish, amphibians, and aquatic insects depend on cool water, especially during warm seasons. Water temperatures may increase where streamflow is reduced, channels are widened, or riparian shade is lost. Healthy riparian vegetation can moderate stream temperatures by shading the water and supporting cooler microclimates. Monitoring water temperature helps evaluate habitat conditions and the effectiveness of restoration actions that protect streamside vegetation and hydrologic function. Field methods for measuring water temperature can be found in the *Supplement Protocols E2 under Additional Monitoring Methods and Protocols*.

WHEN: When should we monitor?

Ideally, the same site should be monitored during the same month or season each year to provide consistent measurements of abundance and cover. This consistency can help separate short-term seasonal variations from long-term trends in ecological condition. Photos will also be easier to interpret and compare if they were captured at a similar time. In riparian ecosystems, deciduous trees should be fully leafed-out for accurate estimates of overstory cover. Likewise, for understory vegetation, it is important to collect measurements at the same time of year, ideally during the growing season, when plants have reached their maximum coverage.

How frequently a site will be monitored should be determined based on the expected response timeline, seasonal factors, partner resource availability, and cost. Vegetation can change more quickly and should be monitored more frequently than soil properties, for example . If a site can only be accessed outside of the growing season, it may not be worth putting much time into cover measurements that will not be accurate.

WHERE: Where should we monitor?

It is important to choose monitoring sites that will remain accessible for the duration of the restoration project, and ideally for several years after. It may be helpful to draft an agreement with the public land manager or private landowner to document that access has been granted for monitoring activities to be conducted for some number of years. Although the agreement won't be legally binding, it can provide some

Figure 3. The location of plots or transects established using GIS may need to be shifted in the field, for example if they fall within channels or near project boundaries. *Photo by Kathryn Mahan*

continuity. Once the indicators and conditions to be monitored are established, a site map of the project area should be prepared. The site should be stratified into similar units and a sampling plot placement scheme and a plot layout design should be developed.

Locating Plots

Objective sampling ensures that the data collected are both unbiased and representative of the unit being measured.

Systematic Plot Placement

There are a number of different ways to objectively place plots within the project area according to some sort of pattern. By one method, a network of plots on a grid can be placed on the map manually or by using a regular point generator in ArcGIS or other GIS platform. Points that fall on or very near a project unit boundary should be offset into the project area by a distance that will allow the entire plot to fall within the project area.

Another systematic way to locate plots on a landscape is to position them at some set distance from a fixed feature such as a road or fence line. Similarly, sample units can also be placed perpendicular to major topographic and physiographic features—such as contours—which allows investigators to capture attribute variability along inventory lines and more confidently use systematic, rather than strictly random, plot location methods.

One advantage of systematic plot placement is that the plot locations can be more easily reproduced if plot markers are destroyed or misplaced during the project.

Random Plot Placement

As an alternative, plots may be located randomly across the project area. The "Create Random Points" tool in ArcGIS allows users to set the number of points desired within each polygon and buffers from polygon boundaries. Other GIS platforms have similar tools. As in the case of systematic sampling, points that fall on or very near a project unit boundary should be offset into the project area by a distance that will allow the entire plot to fall within the project area.

Plot layout options

Depending on the type of vegetation, size of the project area, width of channel, project goals, and access issues, one plot layout approach may be better suited to a particular project than another. Plot shape and size are frequently determined by the history of the project or the requirements of the managing entity. An example of a monitoring layout for a small, non-native tree removal project is provided in Table 2. In this example, all cottonwood trees were measured and tracked individually across the site while other trees were monitored using belt transects placed at regular intervals across the channel. Plots should be laid out with crew efficiency and ecology in mind.

- Plot shape and size can vary as long as the values are consistently converted to a common unit of area, such as acres.
- In some narrow riparian corridors, it may be challenging to place an adequate number of circular plots.

- For small, ephemeral channels, a belt transect or line point intercept that spans the channel can monitor both streambank vegetation and channel dynamics.
- Transect length should be based on the width of the riparian area. Transects should extend beyond the current riparian vegetation in case the riparian area expands over time.
- Additional transects may be required to adequately track vegetation if sections of each transect and the sampling points they contain fall in the channel.

Variable	Description	Method	Size	Position	Measurement Details
Native trees	Location and size of all cottonwoods	Individual trees	N/A	Entire project area	Each individual tree geolocated and recorded by species and DBH
Woody species density	Elm, juniper, cottonwood	200 ft transect	10 ft wide belt	Transects perpendicular to thalweg, every 200'	Tally stems by size class for woody species, excluding willows
Understory cover	% understory cover % bare soil exposure	Line point intercept	Anytime Cover: May-Oct	1 north and 1 south from thalweg	Plant intercepts. Includes noxious weeds, identified by species, and willow cover.

Table 2. Example of monitoring indicators and methods for a riparian restoration project.

3.2 Best Practices for Ecological Monitoring

Figure 1. "Boots on the ground" fieldwork, while the most visible and perhaps time-consuming stage, is only a portion of any full monitoring plan. *Photo by Vince Vispo*

What follows is a very brief overview of the monitoring process. We have included suggestions of things to think about based on our lessons learned in doing this work.

First Steps

- ☐ Determine project goals and interests.
- ☐ What are your scientific question(s) of interest?

Determine what indicators to monitor

- ☐ What indicators will give you information to evaluate each goal? Examples of indicators may include basal area, seedling density, or surface fuel loads. See What: What should we monitor? section of Chapter 3.1.

Select appropriate data collection procedures

- ☐ What methods are needed for the indicators selected?
- ☐ What statistical tests or analyses will be used?
- ☐ What are your measurement quality objectives?

Establish spacing and number of measurements throughout the project

- ☐ Consider the scale at which you are monitoring; project vs landscape, etc. For instance, if your monitoring is intended to quantify landscape-level trends then your sampling design should include randomly selected sites from across the landscape of interest.
- ☐ Spacing and density of measurements may be determined by indicator and analysis method for statistical validity and stratification by vegetation communities or treatment units.
- ☐ Consider how to minimize impacts of limited access to the site.

Determine when and how often to take measurements

- ☐ Be aware of the impact of season and sensitivity of your indicator.
- ☐ Gather baseline data before the project begins.
- ☐ Repeat the same measurements after the project is completed.
- ☐ Repeat the same measurements at regular intervals after project completion (5, 10, 20 years).
- ☐ Repeat the same measurements post-disturbance (e.g. wildfire).
- ☐ If appropriate, stratify your sample area into treatment units or distinct vegetation communities, and sample randomly within stratified units. This will reduce unexplained noise in later statistical analysis and facilitate understanding the effects of treatments
- ☐ Have your measurement locations permanently monumented whenever possible.

Establish who will take measurements

- ☐ Consistency is key; try to keep the same person involved throughout a project.
- ☐ Ensure your team has had rigorous training and access to training materials in the field.
- ☐ Have a clear QC process to identify and address concerns with the data.

Establish when and how to analyze data

- ☐ Understand how to analyze your data and when it is useful to do so.
- ☐ Consider different analysis options: When might you want to utilize photo comparisons vs statistics to best communicate a change?

- ☐ Use software or coefficient sets appropriate to the project area (for instance, make sure the formulas used in summary calculations include constants developed for the habitat or region in which you are working).
- ☐ Seek assistance if needed in interpreting results.
- ☐ Preliminary and historic data are useful in identifying trends or immediate treatment impacts; long-term data may highlight other trends or information on treatment longevity/need for maintenance.

Establish where and how to store data

- ☐ Determine which data points are required for the monitoring methods used by your project as well as what additional information you will want to collect/document.
- ☐ Make sure all relevant information is documented (monitoring methods used, treatment information, etc.) and make it as easy as possible for anyone else to pick up where you've left off.
- ☐ Reduce risk of loss through proper data management. Work with a data manager to outline a management plan and organizational system for your project.
- ☐ Determine how to keep your data safe, available, and understandable to others.
- ☐ Consider uses and limitations of paper data versus electronically collected data. For example, using paper datasheets may be faster in the field, but requires additional labor to enter the data later. Using electronic data collection allows for opportunities to build in QC checks to catch potential entry errors but is more time- and equipment-intensive.
- ☐ Ensure multiple copies of data are stored (e.g. scan your paper datasheets, make backups of electronically collected data, etc.)
- ☐ Establish a data-sharing protocol with partners.

Encourage adaptive management

- ☐ Monitoring results are useful ONLY when they are analyzed, interpreted, and shared with managers to provide lessons-learned and inform future design-making.
- ☐ Consider establishing adaptive management "watchouts" with managers during the monitoring planning process. Identify thresholds or indicators that, when present in the monitoring data, can drive a change in decision-making /management. Identify how often the results will be reviewed for these watchouts.
- ☐ Identify target audience(s) and make efforts to share data, reports, and implications with them.

4.0 Working with Your Data

The primary goal of most monitoring efforts is to inform adaptive management decisions. Not only can monitoring data help to understand a site's current conditions when considering a treatment, it can also be used to evaluate the impact and effectiveness of a particular treatment or disturbance and inform planning for the future.

The following sections will provide suggestions to improve data quality in the field, step through the data analysis process, and provide a brief overview of the management implications that may be drawn from analysis results.

In this chapter, we will cover five topics, including:

- 4.1 - Data Quality Assurance in the Field
- 4.2 - Data Quality Control
- 4.3 - Data Analysis
- 4.4 - Interpreting and Communicating Data
- 4.5 - Sharing Data

In section 4.1, we discuss how to prevent errors during data collection in the field—this is called data quality assurance. In section 4.2, we discuss how to detect and fix data errors once back in the office—this is data quality control. Both are critical to making sure the data collected is of the highest quality.

Section 4.3 provides an overview of the data analysis process, including how to determine what analyses to perform, understanding analysis methods and calculations, and preparing your data for analysis. Once those calculations are complete, those results drive the discussions in reports and how land managers interpret monitoring data as covered in section 4.4. Resources and suggestions for sharing your data with others is covered in section 4.5.

This chapter does not explicitly address data organization. However, developing a data management plan is just as important as selecting protocol methods. Consider whether data will be recorded on paper or electronically, how it will be backed up, what software will be used, and who will have access to the data. Addressing these questions early in the process is essential to support the ultimate goal of helping land managers make informed decisions. For best practices in data management and file naming conventions, refer to *Supplement D Data Management and Quality Control.*

4.1 Data Quality Assurance in the Field

Ensuring quality data collection requires deliberate steps to check data during collection and before leaving each plot. These methods apply to both paper datasheets and electronic data entry. We recommend assigning two crew members to review the data to ensure completion and accuracy before leaving the monitoring plot. Some best practices for on-plot quality assurance (QA) are listed below:

1. Is data being collected consistently?

- ☐ Ensure all technicians are following all established protocols (i.e., DBH is taken from the correct height; any trees located near the edge of a plot are carefully measured with a tape; fuels transects are laid out to match photos of previous transects).
- ☐ Before collecting project data, conduct practice training sessions at a designated practice site. Cross-check practice data with an experienced crew member to identify inconsistencies and determine where additional practice is needed. For more details, see 4.1 subsection "Measurement Quality Objectives." We recommend taking the time to evaluate your own crew's performance against these or similar metrics before using your data for analysis and decision-making.

2. Are all protocols completed?

- ☐ Have all types of data been collected?
- ☐ If using computer/tablet data entry, ensure every protocol tab is filled out completely.
- ☐ Confirm all photos are present on the camera.
- ☐ Confirm GPS location is recorded on GPS unit and in datasheets/data entry forms.

3. Within protocols, are all required data present?

- ☐ If using paper datasheets, ensure every box is filled in. If no trees/seedlings/fuels were present, a line through the box or comment should indicate that this protocol was completed. Do not leave anything blank.
- ☐ Are the plot center coordinates and elevation recorded?
- ☐ On paper datasheets, are final tallies counted and circled?
- ☐ Have another person verify that all information has been recorded. Does anyone else on the crew have anything to add to the comments section?

4. Scan through data. Does everything make sense?

- ☐ Are there any trees that are too tall or wide? (Do DBH and height measurements make sense?)

- ☐ If a total is supposed to equal 100%, do all the percentages add up?
- ☐ Are there any noticeable outliers or strangely large or small numbers?
- ☐ Is all written data legible?

Measurement Quality Objectives

Measurement Quality Objectives (MQOs) are threshold values that define the acceptable limits of quality for selected parameters. Monitoring crews use MQOs as guidelines for collecting complete, accurate, and reproducible data. These standards, set during the planning phase, increase data reliability and ensure results can confidently support management decisions. MQOs also help confirm that the selected monitoring methods are appropriate for tracking project goals and objectives. When evaluating the effectiveness of restoration practices, it is important to remember that long-term datasets often span different time periods and site locations and involve multiple crews. Adhering to consistent MQO metrics improves data reliability and ensures confident comparisons and analyses.

Figure 1. Quality assurance in the field is a critical step in the data collection process. It requires cross-checking with crewmates, clear communication, and ensuring all crew members are familiar with the data collection and in-field QA process. *Photo by Jax Gaglianese-Woody*

There are several key steps to establishing MQOs for monitoring: (1) clarifying monitoring objectives, (2) determining how the data will be used, (3) selecting parameters that align with project goals, (4) choosing appropriate data collection methods, (5) setting data thresholds to ensure quality, and (6) documenting MQO metrics. Clear and accessible documentation of MQOs ensures monitoring crews can consistently compare and validate data over time. Additionally, MQOs might be protocol-specific or generalized across all monitoring activities.

Cross-checking the accuracy of data collected by a production crew should be conducted during training, as described above. NMFWRI operates a part-time Quality Assurance (QA) crew throughout the regular field season. This crew is made up of the most experienced and dependable field staff. NMFWRI aims to re-sample at least ten percent of data collected by a production crew, distributed evenly across the sampling period for a project. The data from the production crew is then weighed against the metrics from the QA crew to determine whether these values are within the set tolerance. This tolerance is usually a percentage of the QA crew's value, unless otherwise stated. For example, cover data is recorded as a percentage; thus, the tolerance refers to the absolute value of the metric. NMFWRI data must be within the tolerance 90% or more of the time in order to meet MQOs.

NMFWRI recommends that QA re-sampling take place within a few days of the initial production crew sampling, up to two weeks at a maximum. This is to ensure that areas of concern can be addressed and corrected

as soon as possible, but also that metrics such as tree seedling count are not skewed by the natural progression of the growing season. Similarly, lightweight surface fuels may shift during precipitation events, especially during monsoon season. If it is at all possible that an observed metric has shifted, consider excluding from your MQO evaluations.

NMFWRI's Measurement Quality Objectives

Measurement	Tolerance	MQO Standard %
Slope	± 5% absolute	90%
Azimuth and Aspect	+/- 10°	90%
Cover estimations	± 10% absolute ± 1 class (seedlings)	90%
Heights	± 10% ± 1 class (seedlings)	90%
Diameters (DBH/DRC)	± 0.1in per 20in ± 1 class (saplings)	95%
Duff/Litter Depths	± 0.5in	90%
Damage Severity	± 10% or 1 class	90%
Decay Class	± 1 class	90%
Seedling/Sapling Count	± 20%	90%
Nail of tagged tree at 4.5ft	± 1in	90%
Canopy cover (w/ Densiometer)	± 10% (or 2 squares)	90%
1, 10, 100, 1000-hour fuel counts	± 20%	90%
Species/status/tag #/plot #/etc.	No tolerance	90-99%
No trash or equipment left on plot	No tolerance	99%

Table 1. The MQO Standard % represents our expectation of what percentage of measurements taken by our crews fall within these tolerances when compared against quality assurance checks. Please note that these MQOs are intended for professional, experienced crews.

4.2 Data Quality Control

Following field quality assurance, quality control (QC) practices are necessary to ensure all data errors are corrected before analysis. Data QC validates the data and ensures datasets are clean, with minimal to no errors, such as missing or inconsistent data, erroneous data, or transcription mistakes.

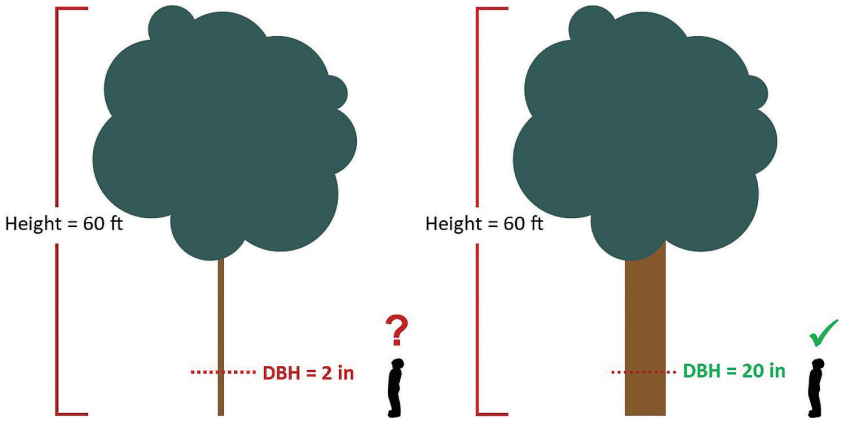


Figure 1. It can be easy to incorrectly transcribe data in the field or incorrectly enter data into a digital format. In this case, a tree with a DBH of 2 inches and a total height of 60 feet should be flagged and checked for possible data entry errors. *Diagram by Jax Gaglianese-Woody*

Errors can occur at any point in data collection as a result of numerous factors, such as improperly calibrated equipment or equipment failure, observer errors (e.g., misidentified species or inaccurate cover estimates), or improper/poor data transcription (e.g., duplicate data entries, incorrect unit conversions, or illegible handwriting). Data errors can cause misrepresentative results, misinterpretation of results, and inappropriate management decisions. Furthermore, high-quality data is reliable and reproducible and is therefore more useful to the wider ecological and restoration community than poor quality data.

While data QC can seem daunting—especially with large, multi-scale monitoring datasets—there are tools and software that can help reduce the stress of the QC process. Additionally, the long-term benefits of proactive QC outweigh the consequences of error-ridden datasets. While QC is easiest when done before data analysis, it is important to diligently scrutinize results throughout the dataset's life to verify errors were not missed early in the QC process. There are multiple methods that can be employed in the quality-control process, and the most effective quality control employs a combination of these methods.

Quality control by visual review

QC can be performed by visually reviewing the database, sorting data values, and comparing entered data to paper datasheets. Reviewers should look for missing data, unlikely or incompatible values, typos, and incorrect plot sizes or transect lengths. For example, a Rio Grande Cottonwood (USDA PLANTS code of PODEW) with a DBH of 2 inches and a height of 60 feet should be flagged for further review and checked against the paper datasheets. Similarly, if there is a crown base height for a dead tree, there must be an error in either the tree status or the crown base height.

Several online resources guide users through the process of organizing and formatting example datasets to help with QC by visual review in a spreadsheet. An example can be found here: https://datacarpentry.github.io/spreadsheet-ecology-lesson/aio.html. *See Supplement D3 for an example of a visual review QC checklist used by NMFWRI.*

Quality control by script

Programming languages can be used to create scripts that detect and flag potential errors in a dataset. These scripts efficiently check all data for common errors, such as heights, DBH values, plot sizes, or transect lengths that do not meet established criteria.

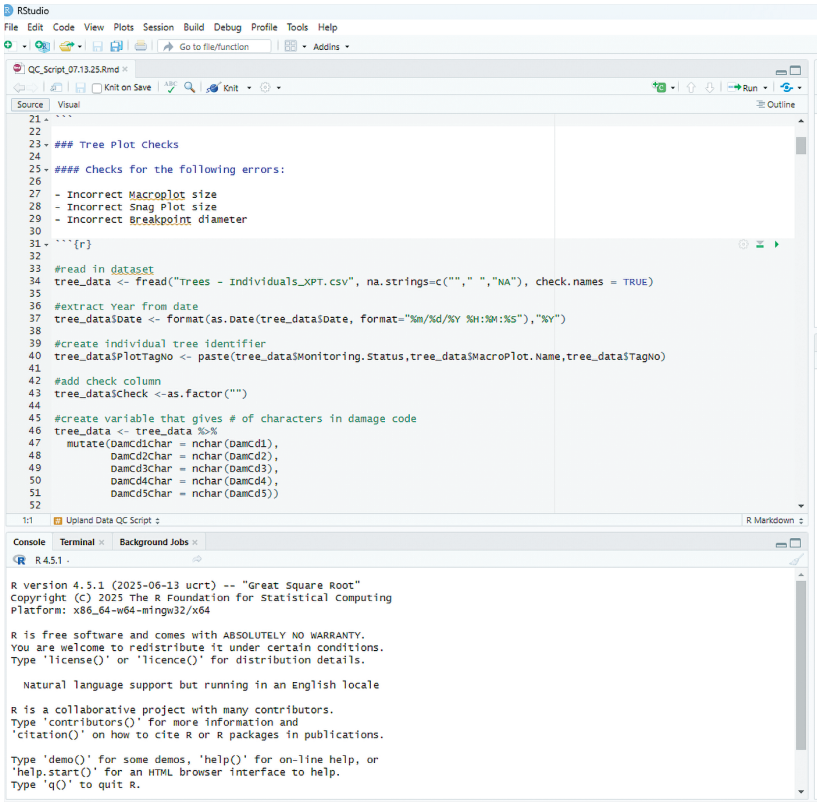


Figure 2. An example of a complete QC script in R can be provided by NMFWRI upon request. Additionally, NMFWRI maintains a github site that hosts a Python QC script (https://github.com/NMFWRI).

They can also catch more subtle errors that are difficult to spot by eye, like a damage code entry that does not match any established codes or ground cover values that do not add up to 100%. However, some errors, such as misidentified plant species or incorrect sampling dates, still require manual review, as they cannot be reliably detected by automation alone.

Quality control by data analysis

Data analysis is another powerful tool for identifying errors overlooked during initial quality control checks. Analysis of summary statistics is the most common analysis approach in the data quality control process. Summary statistics concisely describe three key characteristics of a dataset: central tendency (e.g., mean and median), variability/spread (e.g., range, variance, and standard deviation), and data distribution/shape. These simple statistical analyses summarize raw data and can indicate anomalies such as outliers, skewed data, and missing data. Visualizing summary statistics as boxplots, histograms, and scatterplots can also reveal data anomalies. Significant changes in data values across measurement periods, especially those without an apparent ecological explanation, should be investigated further and can be detected through analysis and visualization. For example, a substantial decrease in basal area or tree density after no treatments or known disturbance might indicate missed trees or errors in plot size. Additionally, plot photos are useful for validating trends or revealing possible errors when compared to summary statistics.

4.3 Data Analysis

Monitoring data is collected so that it can be learned from. However, raw data is too detailed to learn from and needs to be organized, processed, and packaged before it can reveal clear insights. Data analysis is the conversion of raw and unorganized data into meaningful information. This can then provide evidence-based insights that help managers spot trends, judge the success of restoration efforts, and make decisions.

Determining what analyses to perform

As with data collection metrics, data analyses should address the project goals, interests, and questions established in the design phase of a monitoring project. You should have a full understanding of the underlying calculations and how to interpret the results of analyses.

Data analysis calculations and explanations for the metrics presented in Chapter 3 can be found in the Example Data Analysis Calculation later in this section.

Analysis starts even before data has been collected, because the methods that can be used and the types of questions that can be answered depends on the type and structure of the data. Knowing what the goal of the project is and what sort of statistics will be required to meet that goal is the first step. Certain elements hold true no matter the project specific goals, and that is what this section attempts to cover: the basics of statistics that will help no matter the context.

For every project, samples are collected when it is uneconomical to collect data on an entire population. For example, the population of interest might be trees in a project area and the parameter of interest might be the mean diameter of that population. If the resources exist to measure every single tree, great! There is no need for statistics—it is certain that the mean calculated from the measurements taken is the mean of the population, because the whole population was measured. In practice, however, a full population census is rarely feasible—and often would be an inefficient way to use resources. If instead a subset of the population—a sample—was measured, then any number calculated from that sample is a statistic. A statistic is to a sample as a parameter is to a population. The goal a monitoring project is to estimate the population parameter, using a statistic from the sample.

It can then be seen why one of the primary concerns with statistical estimations is how well the sample represents the population. For a statistic to be valid, the sample must have the same characteristics as the population. One of the most important ways to ensure that a sample is representative of the population is to make sure that it is random. There are numerous ways to select a random sample:

- In a simple random sample, all members of the population are equally likely to be chosen. Imagine if each tree in the project area was assigned a number, and then a sample of numbers were drawn from a hat and those trees were measured.
- A stratified sample first splits the population into groups, which are then sampled randomly. The number of measurements taken in each group should be proportionate to the group size. If the project area is composed of distinct habitat types, it might be appropriate to first delineate these and

Glossary Of Important Statistical Terms	
Statistics	Tools for learning from data.
Statistic	A number that shows something about data (e.g., an average).
Descriptive Statistics	Summarizing data.
Inferential Statistics	Tools that we use to learn about relationships, causes, and patterns in data.
Population	The entire group of people or things being studied.
Sample	A small (usually very small) part of the population, from which data is collected.
Data	Information collected about a sample. A record of values linked to observations about the sample.
Parameter	A number that shows something about an entire population. A statistic is an estimation of a parameter.
Variable	A characteristic of the sample. Each person or thing being studied is measured to record the value of that characteristic. Each variable is a column when data is recorded.
Observation	When a variable is recorded, it creates a row. Each row is an observation. An observation may link a member of the sample to many different variables, or be simply a single value with a unique identifier.
Value	A single data point. An observation consists of one or more values recorded for one or more variables. Values can be numbers or words.
Qualitative Data	Information that categorizes or describes a sample, for example, the species of trees found on plot. Otherwise known as categorical data. Usually but not always words.
Quantitative Data	Always numbers. Information from counting or measuring a sample. Can be discrete or continuous.
Discrete Quantitative Data	The result of counting. Can only take certain numerical values. For example, a tree may have 4 stems but it will never have 4.37 stems. Sometimes categories are represented as discrete values, for instance alive (1) or dead (0).
Continuous Quantitative Data	All other numerical data that is not necessarily the result of counting. Often includes fractions or decimals. Continuous data is the result of measurements, such as the diameters of trees.

then choose trees randomly within each habitat to make sure that all plant communities present are represented in the final statistic. To avoid creating biases, the number of trees sampled from each habitat must be proportionate to the size of that habitat.

- A cluster sample starts like a stratified sample by first delineating groups, but then groups are randomly selected and every member of those groups is measured.

These methods are all in contrast to convenience sampling, whereby the sample is not chosen randomly but instead, as the name suggests, because of some characteristic that makes it easier to reach. Convenience sampling

might mean that the trees measured are near a road or on the edge of a field. Access must of course be considered when choosing a sample, but be very careful when straying from random sampling procedures. Under certain circumstances – the stand is uniform and the trees next to the road have the same characteristics as those down at the bottom of the arroyo – the sample will still be representative. But more often, particularly with biotic variables, the same factors that make a particular sample easier to reach will also influence its statistics.

Preparing data for analysis

The process of preparing data for analysis is an iterative and continuous process that spans the data life cycle. The process depends on your project goals and the analyses you plan to conduct. To streamline this process, it is helpful to develop and follow a project workflow that outlines the entire life cycle of your data. This should be informed by questions addressed in your monitoring and data management planning, such as: How and where will you store your data (e.g., scanning and archiving datasheets, building or using centralized databases)? How will you keep records of relevant metadata (such as landowner information, monitoring dates, project status, etc.)? What steps will you take to standardize your data, and which file formats are required for your analyses? For more information, *see Supplement D Data Management and G Additional Resources.*

Data prep considerations:

- To ensure analysis results are valid and are not inappropriately influenced by errors, you should have a strong grasp on your raw data and perform proper data QC. *See Chapter 4.2 for more information.*
- Standardize parameter units and plant names. For example, if you are collecting information on vegetation, use USDA plant codes (*see Supplement A Vegetation*). Analysis can become frustrating if data is not recorded or transformed into a standard format.
- Organize and sort data into a consistent and understandable structure, ensuring data is properly matched with dates and locations.
- Consider the file format required for the analysis software you intend to use, such as .csv or .txt files for R, shapefiles for ArcGIS, and .kml for Google Earth.

It should also be determined what tools will be used to perform that analysis. Some options include:

- **Excel**, which remains the standard software for spreadsheets. It is a relatively user-friendly platform that can be used to organize, clean, and format data as well as create diagrams and perform many standard statistical calculations and tests. However, the features included in the program differ significantly between Windows and Mac, as well as between the browser and desktop versions. Some of the statistical features available also depend on the type of license purchased. Another concern is the "black-box" nature of analysis in Excel: the program is not designed to track the steps taken, and many calculations are performed "behind the curtain" and hidden from the end user. This can create issues with replicability as well as hinder understanding of the logic behind the tools it offers.
- **Google Sheets**, a free online alternative to Excel. Although perhaps not as powerful, it can do most of the same basic tasks necessary for analysis. Sheets has the same weakness as Excel in that many of the calculations being performed are hidden from the user, but it at least has only one version that anyone with a computer and internet connection can access. Sheets is a great place to begin.

- **R**, a programming language used widely for statistical computing by natural scientists. Unlike Excel or Sheets, the user does not manipulate the data with their mouse, and instead using code to manipulate and analyze the data. Secondary programs such as **RStudio** improve the accessibility of the coding language, but becoming proficient is still a hefty task. It may be well worth investing this time initially, however, if a project requires substantial statistics. Scripts can document every step taken and these can greatly improve efficiency if the same analysis must be performed multiple times on different datasets. Any visuals created in R are also highly customizable.

Analyzing

The goal of analyzing data is to understand what it is showing you. The first step to any analysis is getting a "feel" for your data with descriptive statistics.

Descriptive statistics

Otherwise known as summary statistics, descriptive statistics provide an overview of your data. They make large datasets digestible and interpretable. Summary statistics include measures of the central tendency of the data (mean, median, and mode), how closely the other observations are grouped around this center point (variance, standard deviation, and range), and how those observations are distributed (skewness, kurtosis). There are a huge variety of visual tools available to help get a sense for data. Just a few include:

A few important descriptive statistics equations	
Sample Mean	$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$
Sample Variance	$s^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \overline{x}\right)^2$
Sample Standard Deviation	$s = \sqrt{s^2} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \overline{x}\right)^2}$
Z-score of a sample (#of standard deviations from the mean)	$z = \frac{x_i - \overline{x}}{s}$

Table 1. $\mathbf{n}$ is the number of observations in the sample. $\mathbf{x_1}$ is a single observation from the sample. Each observation can be represented by an $\mathbf{x_1}$ with a subscript, for example $\mathbf{x_1}$, $\mathbf{x_2}$, $\mathbf{x_3}$,... all the way up to $\mathbf{x_n}$, the final observation.

- A **stem-and-leaf graph**. These work best when datasets are small and the measurements themselves do not have a wide range. To construct a stem-and-leaf graph, divide each observation into a "stem," all digits before the last, and a "leaf", the last digit. All observations must have the same number of significant figures. For example, a diameter measurement of 8 would have a stem of 8 and a leaf of zero. An observation of 12.3 would have stem 12 and leaf 3. To construct the plot, all stems that

occur in the dataset are placed in order in a column (once, even if they occur several times) and then every leaf is placed next to the stem it came from. This creates a simple but effective visualization of the distribution of observations.

- A **bar or line graph**. If the data is qualitative or discrete, it can be presented simply using one of these graphs. Both of these can be created by hand, but are easier done with a computer program. Categories are typically arranged on the x-axis, and the total count of observations in each category becomes the height of the bar or line above that category.

- A **histogram** is like a bar graph for continuous data and is typically used to represent a large dataset. The first step to constructing a histogram is to decide how many bars it will have and what values divide the bars. A rule of thumb for readability is to have between 5 and 15 bars. Subtract the lowest value in the data from the highest and divide by the number of bars, then round up to the same level of precision as the data to determine how wide each bar will be. For example, if the smallest tree on a plot has a diameter of 7 and the largest one of 18.5, and the histogram will have 10 bars, each bar needs to encompass values in a 1.2-inch wide group ((18.5 – 7)/10 = 1.15 rounded up). The starting point for the first bar must be less than the smallest value in the dataset, and it is often convenient for it to have one more decimal place than the most precise value in the set, to ensure that no values fall on division points. For example, if the smallest trees on plot had a diameter of 7 and the most precise values have one decimal point, the first bar of the histogram representing this data could start at 6.95. This first bar would extend 1.2 inches to 8.15, the next would extend from 8.15 to 9.35, and so on.

One of the most basic but useful ways to describe data is by determining its center. There are several ways to approach this task. "Average" technically means central location, and there are a few statistics that represent this. What is generally referred to as the average is more precisely known as the arithmetic mean: the result of adding all the numbers in a series and dividing by the count of values in the series. The mean of a sample is represented by $\bar{x}$; the mean of a population by μ. The other common statistic for the central location is the median. This is the value at the center of the dataset when the observations have been ordered from smallest to largest. If there is an odd number of values the median will be an actual observation from the data, but if the count of values is even the median will be half-way between the two central values. Median is often represented by an *M*. Another measure of central location is the mode. This is simply the value(s) that occurs most frequently in the dataset.

Mean and median can represent more about a dataset than just its center. Comparing these statistics can also shed light on the *skewness* of the data. If the data is perfectly symmetrically distributed, the mean and median will be the same. However, because the mean is affected by extreme values while the median is not, the mean will get "pulled" in the direction of the extremes. If there are several very low values, for example, the mean will be lower than the median, and the data is considered "skewed to the left" because there are more values in the left tail of its distribution. Mean and median may be similar but they serve different functions. When analyzing how much biomass is in a project area, for example, the appropriate statistic is the mean. It gives the really big trees the importance they deserve: they contribute a large portion of the biomass, and the mean reflects that. If instead the goal is to understand what the "normal" or "typical" tree in the area looks like – perhaps for habitat modeling purposes – the median would be the better statistic.

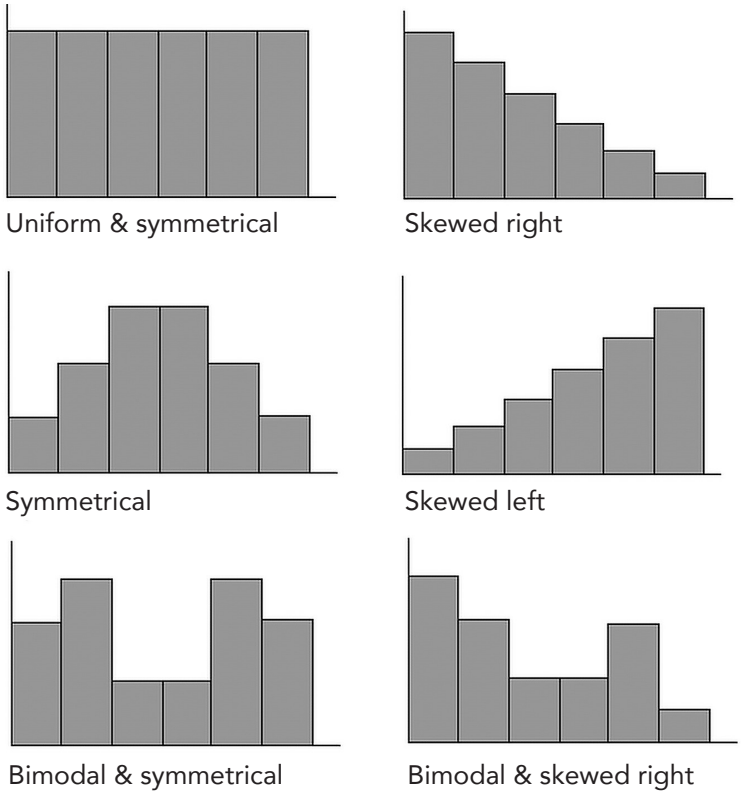


Figure 1. Histograms are valuable because they give a sense of the "shape" of a dataset that can get masked by single-number statistics such as means. For example, the mean of tree diameters from a symmetrical sample might be good to know if management decisions are being made in the interest of the "average" tree. If the sample was bimodal, however, making decisions for the average tree might be detrimental, since in fact the majority of trees are much smaller or larger than the average. The means might be the same for both these samples, despite the fact that the actual structures underlying the statistics are very different. *Credit: Ling, D.L. (2020). Introduction to Statistics Using Google Sheets (6.1). College of Micronesia-FSM.*

One way to get a sense for the location of data in more detail than a mean or median is with **quartiles** or **percentiles**. Both approaches involve ordering the data from smallest to largest, then finding the values that divide the data into equal parts: four parts for quartiles, one hundred for percentiles. The value in these divisions is not necessarily a value in the dataset. For example, if the data consists of the whole numbers 1 through 10, the division between quartiles 2 and 3 would be 5.5. These tools are useful to determine the shape of data. For example, if the first quartile ends at 40, the second at 50, and the third at 85, this means not only that the center of the data is at 50, but also that the observations below 50 are more tightly grouped to the median than those above it, and thus the distribution of the data is skewed to the right – the histogram of this data would have a longer tail on the right side of the plot. Another way to look at this is that 25% of the observations are between 40 and 50, a range of ten values, while another 25% are between 50 and 85, a range of 35 values. For this to be true, the observations in the third quartile must be spread more "thin" than those in the second. Quartiles are often represented using box-and-whisker plots.

Using quartiles also helps identify potential outliers in the dataset. The interquartile range (IQR) is the set of values between the beginning of the second quartile and the end of the third. By definition, this range includes 50% of the observations. Values are typically identified as possible outliers if they are more than 1.5 times the IQR above the end of the third quartile or below the beginning of the second. While it is often worth examining

What is a boxplot?

A boxplot provides a snapshot of data distribution. The display includes the following (from Minitab):

Outlier (*) - Observation that is beyond the upper or lower whisker

Mean symbol (⊕)- Average value

Upper whisker -Extends to the maximum data point within 1.5 box heights from the top of the box

Interquartile range box - Middle 50% of the data

Top line - Q3 (third quartile). 75% of the data are less than or equal to this value.
Middle line- Q2 (median). 50% of the data are less than or equal to this value.
Bottom line - Q1 (first quartile). 25% of the data are less than or equal to this value.

Lower whisker - Extends to the minimum data point within 1.5 box heights from the bottom of the box.

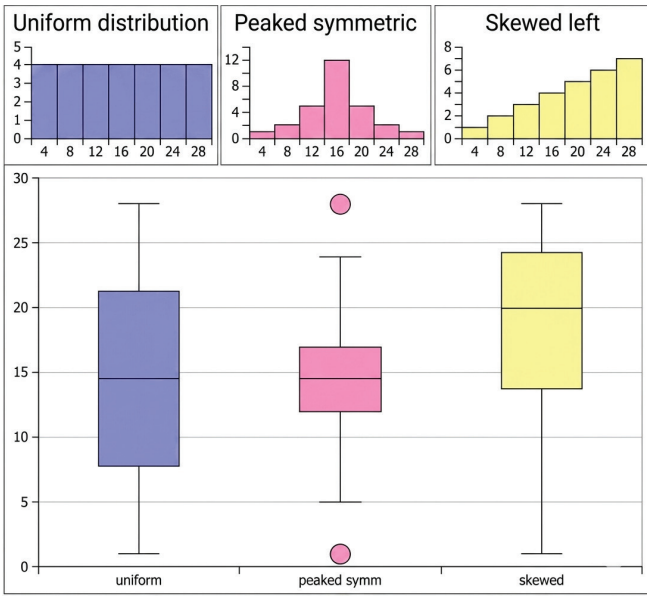


Figure 2. Box-and-whisker plots represent the quartiles of a dataset and can give clues as to the distribution of observations. A "univalue" dataset, in which all observations are the same, would appear as a single line. Uniform data where the distance between each value is the same would have quartiles of equal sizes. In peaked symmetrical data most of the values occur around the mean, and so the interquartile range is small compared to the whiskers. If the data is skewed, the quartiles might all be different sizes. In this graph, the dots represent likely outlier values. *Credit: Ling, D.L. (2020). Introduction to Statistics Using Google Sheets (6.1). College of Micronesia-FSM.*

outliers, for instance to make sure a measurement of 10.9 inches was not entered into the database as 109 inches, it is generally not recommended to exclude data from analysis solely because it is far from the mean.

Standard deviation is the typical statistic used to represent data variation. Think of variation this way: two plots may both have the same mean tree diameter, say 9.5 inches. But if plot one has a standard deviation of 0 inches, that shows that *all* of the trees on that plot are 9.5 inches while if plot two has a standard deviation of 2 inches, evidently plenty of trees are smaller or larger than 9.5 inches. Means alone would not show that the community structures on these plots are different. In a normal distribution (think a nice classic bell curve) approximately 68% of all observations fall within one standard deviation and 95% within two.

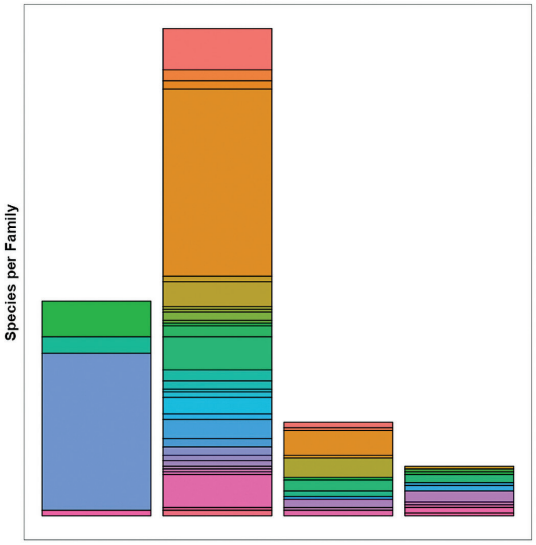
Deviation is the distance of any observation from the mean ($x - \bar{x}$ for a sample, $x - \mu$ for a population). **Variance** (s^2 or σ^2) is the average of the squares of the deviations, and **standard deviation** is the square root of variance. The standard deviation of a sample is represented by s, while that for a population is σ. In practice s is rarely calculated, but s is a good estimation for it if the sample and population have the same characteristics.

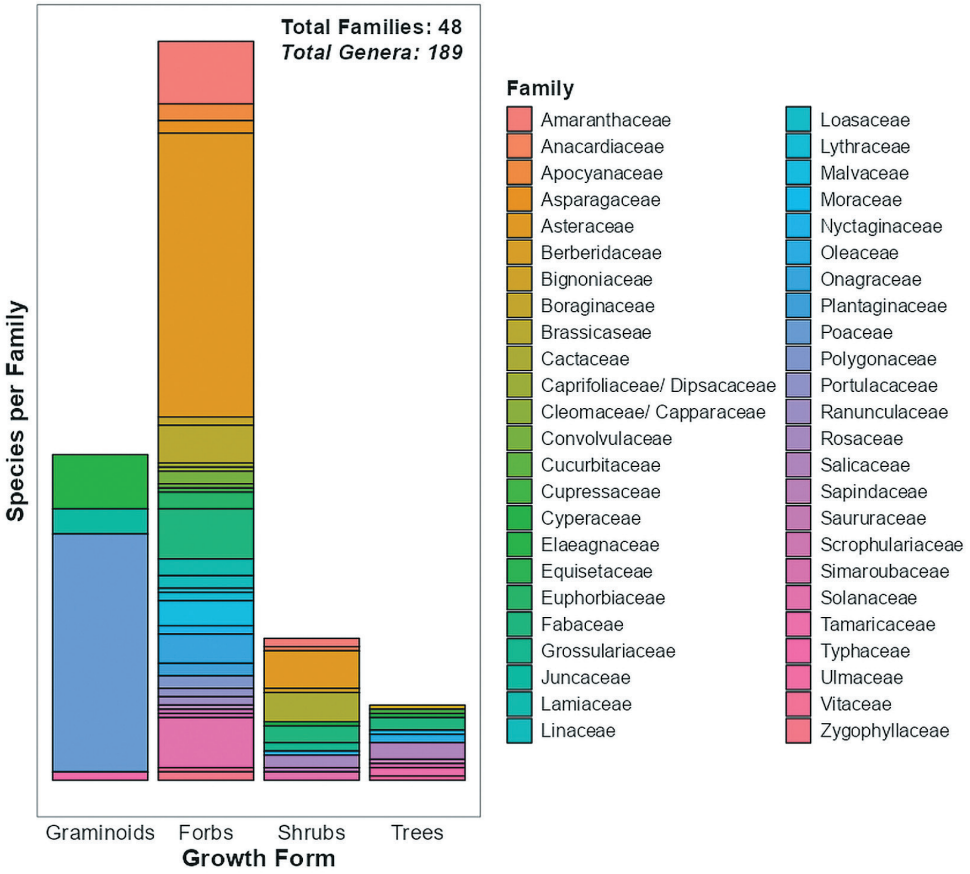
A **z-score** is a standardized metric that represents how many standard deviations from the mean an observation is. It is the distance of a given observation from the sample mean, divided by the sample standard deviation. This value can be useful because it allows comparing datapoints between datasets even if the datasets have different means and standard deviations.

Key Components of Graphs

Figure 3. Two graphs showing species composition by growth form. Although both figures present the same data, the first graph lacks key components needed for interpretation, including x-axis labels, an x-axis title, and a legend. The bottom graph includes these elements, making it more comprehensible. Note: Neither figure is designed to be color-blind accessible, which should be considered when creating figures for public communication.

Graphs by Taryn Schlosser





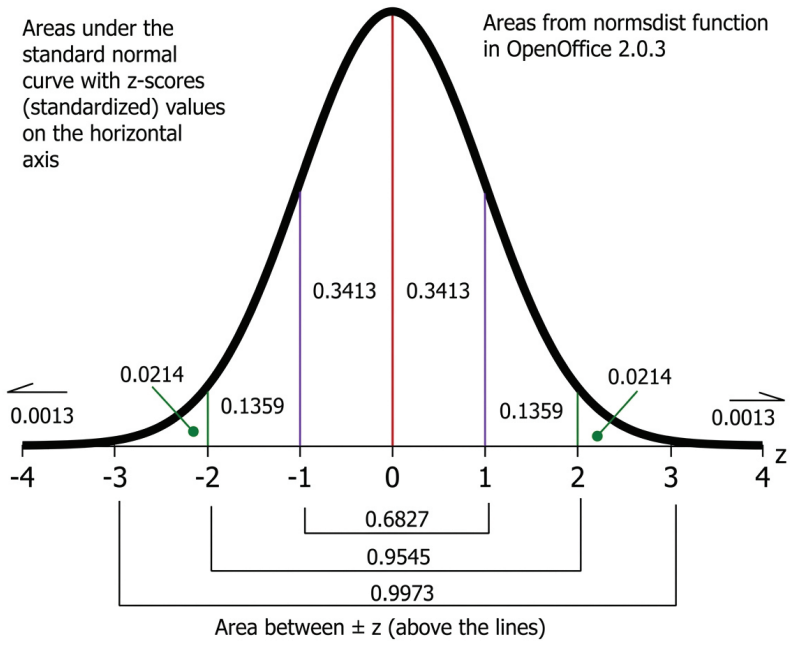


Figure 4. This graph shows areas under a normal distribution based on distance from the mean (z-score). Values above the x-axis are for only that area – for example, 13.59% of the area is between z-scores 1 and 2 on the right side of the distribution. Values below the x-axis are cumulative; e.g. 95.45% of the area below a normal curve is within 2 z-scores of the mean. *Credit: Ling, D.L. (2020). Introduction to Statistics Using Google Sheets (6.1). College of Micronesia-FSM.*

The reason for the careful distinction between sample and population is because the formulas for variance and standard deviation actually change slightly depending on whether the data comes from a sample or population. In almost all applied cases data comes from a sample.

Inferential statistics

Depending on your goals, descriptive statistics may sometimes be sufficient. They are the rawest form of analysis. They allow you to say *what* you found, but using them to say anything more should be done with caution; they tell you very little about what your data actually *means* .

It is typically only possible to get information about a sample. This creates the danger that the sample taken might just be strange—it may not represent the population. For example, a sample of adult heights might have an average of 4'1" or 6'8" simply because of the individuals that were measured. Inferential statistics is a set of tools that show how likely such a sample is to be selected given the study protocols. This guards against the potentially costly or dangerous error of thinking that a sample is representative of a population when in fact it is not. Inferential statistics is accepted by the scientific community as the way to prove things with data—scientific journals will not accept research papers that do not use inferential statistics to support their results.

Comparison to other projects or a desired state might be all that is necessary to inform management goals, but without inferential statistics such a comparison can only remain anecdotal. Is the difference seen between these projects real or because of random sampling? Was this treatment more successful than that one? Is the observed increase in water temperature because of non-native tree removal, or just because the post-treatment sampling

year was hotter? And perhaps most commonly asked, is there a difference in site characteristics now compared to before the treatment? These are the sorts of questions inferential statistics can help to answer.

The tools used range from straightforward to incredibly complex depending on the data and the question to be answered, but all methods are based on probability reasoning. They use extrapolation to estimate the likelihood that a finding from a sample is true for the entire population, or instead the product of random chance. The simplest inferential statistics tool is known as a **t-test**. T-tests reveal the probability that an observed difference between the means of two groups (for example, mean tree diameter on plot before a treatment, and after) is the outcome of a null model where there is actually no difference between the groups. By convention, when this probability is very small it is concluded that the difference is meaningful.

The theory behind inferential statistics is unfortunately outside the scope of this text. This is not because the topic is unimportant, but rather the opposite. The subject is admittedly daunting at first, and an incomplete explanation risks making it seem even more confusing. Anyone at all interested in the topic is highly encouraged to refer to the materials at the end of this section. Statistics is not a tough subject at all when it is broken into manageable chunks, and in fact it can be satisfying to progressively build an understanding of the logic behind the common tests. Once an understanding has been gained, it will also be seen that statistics are all around us in our everyday lives. Understanding how they are used (and mis-used) can make us better citizens, as well as environmental professionals.

Inferential statistics are powerful, but specialized. Generally NMFWRI sticks to descriptive statistics outside of research contexts. The following section presents the conversions often employed in our reports.

Further resources:

Needless to say, actually applying statistics to a project requires a more complete understanding of the theory and methods than can be presented here. A few resources might be helpful for those interested in the subject:

Illowski, B., Dean, S., Birmajer, D., Blount, B., Boyd, S., Einsohn, M., Foreman, N., Helmreich, J., Kenyon, L., Lee, S., & Taub, J. (2023). Introductory Statistics (2nd ed.). https://openstax.org/details/books/introductory-statistics-2e

The information from this chapter was summarized from this excellent, free online textbook. For those interested in deepening their understanding of statistics this is a perfect starting point

Healy, Y. H. and C. (n.d.). From data to Viz | Find the graphic you need. Retrieved April 24, 2026, from https://www.data-to-viz.com/data-to-viz.com

This chapter could only include a few examples of graphs, but there is an almost endless variety of ways to display data. This webpage is great for inspiration. It can help with choosing the right graph for the data, and presents important caveats and things to consider about each graph type.

Holtz, Y. (n.d.). The R Graph Gallery – Help and inspiration for R charts. The R Graph Gallery. Retrieved April 24, 2026, from https://r-graph-gallery.com/

If R is being used to create graphs, this site can help by providing examples of graph types and the code used to create them. Use the Data Viz site to choose the right graph, then use this one to find the code to make it.

Ling, D.L. (2020). Introduction to Statistics Using Google Sheets (6.1). College of Micronesia-FSM.

Introductory statistics geared towards users of Sheets, with examples of figures and the formulas required to replicate them.

Pearl, J., & Mackenzie, D. (2019). The book of why: The new science of cause and effect. Penguin Books.

This text is aimed for audiences somewhere between the general public and professionals. It can provide a bridge into more advanced topics, but is probably not suitable for a complete beginner.

Zuur, A. F., Ieno, E. N., Walker, N., Savel'ev, A. A., & Smith, G. M. (2009). Mixed Effects Models and Extensions in Ecology with R. Springer New York. https://doi.org/10.1007/978-0-387-87458-6

A textbook that goes into the "nitty-gritty" of statistical modeling using R for environmental applications. It uses real-world examples to enforce concepts.

Example Data Analysis Calculations

Below, find data analysis calculations and recommendations for the metrics presented in Chapter 3.1. These summaries and statistics can be performed using a variety of tools and methods, from pencil and paper through sophisticated ecological data analysis tools. This section describes the statistics that need to be generated and suggest some ways to present that information. These metrics will also be discussed in Chapter 4.4.

Live and Dead Tree Density

Density (trees per acre):

$$TPA = \frac{n}{area}$$

The density of trees is generally reported as the number of trees per acre (TPA). This is first calculated at the plot level as the number of individual trees divided by the area of the plot in acres (equation 5). To calculate a project-level mean, the plot level TPA is averaged (not shown).

Mean basal area:

Basal area represents the area of a forest that is covered by tree boles, and is calculated based on DBH (diameter at 4.5 ft off the ground). Typically, basal area is reported as the square feet of tree bole per acre of forest. To calculate the basal area for a plot we first calculate the basal area (in inches) of each tree (measured in inches) as the DBH squared times 0.005454 (equation 3). Then we sum basal area of trees within the plot, and divide by the area of the plot in acres – for reference the area of a 37' 3" plot radius is 0.1 acres. Finally, to get a project mean DBH we average across the plots (not shown).

$$Basal\ Area = DBH^2 * 0.005454$$

Live and Dead Tree Size

Quadratic mean diameter:

The quadratic mean diameter (QMD) is meant to represent the average tree diameter and is used over an arithmetic mean for historical reasons *(see:* https://www.fs.usda.gov/pnw/olympia/silv/publications/opt/436_CurtisMarshall2000.pdf*)*.

The QMD for a plot is calculated by summing the squared DBH values, dividing by the number of trees and taking the square root as in equation 4. To calculate the QMD at the project level we then take the arithmetic mean of the QMD for the plots (not shown).

$$QMD = \sqrt{\frac{\sum_i^n DBH_i}{n}}$$

Mean height (can be used for tree height or live crown base height):

The mean height and live crown base height of trees may be reported at the plot or project level. When calculating mean heights (Hplot) at the plot level sum all individual tree heights (Hi) within a plot and divide by the number of trees in the plot (n) following equation 1. When reporting mean heights at the project level (Hproject) we typically average the means of the plots by summing the mean heights across the plots and dividing by the number of projects (p). Note that taking the mean of the plot means may yield a different project level value when there are different numbers of trees among the different plots (not shown).

$$H_{plot} = \frac{\sum_i^n H_i}{n}$$

$$H_{project} = \frac{\sum_i^p H_{plot}}{p}$$

Species Composition

Overstory species composition:

Species composition compares the abundance of different species within a forest. It is typically calculated based on either TPA or basal area of species and could be graphed as a bar graph.

Understory species composition:

If species data is collected as part of cover, this data can be summarized by species, form (e.g. tree, shrub, graminoid, forb), or in other ways (for example, native vs exotic). In this case, including a plant list is standard.

Surface Fuel Loads

Downed Woody Debris (From Brown 1974):

Formula for Computing Tons per Acre:

1, 10, 100-hr size classes: 0-3 in: (tons/acre) = $(11.64 * n * d^2 * s * a * c)/N_t$

1000-hr size classes: 3+ inches: (tons/acre) = $(11.64 * \sum d^2 * s * a * c)/N_t$

$$c = \sqrt{1 + \left(\frac{\text{Percent slope}}{100}\right)^2}$$

Table 1.--*Slope correction factors for converting weight/acre on a slope basis to a horizontal basis*

Slope	Correction factor	Slope	Correction factor
Percent	*c*	*Percent*	*c*
0	1.00	60	1.17
10	1.00	70	1.22
20	1.02	80	1.28
30	1.04	90	1.35
40	1.08	100	1.41
50	1.12	110	1.49

(From Brown 1974)

Where:

c = slope correction factor

n = total number of intersections over all sample points (for each of the 1-hr, 10-hr and 100-hr samples), aka the number of pieces you tallied

d_2 = squared average diameters

For 1, 10 and 100-hr fuels these have been measured in the field and constants for different species and systems have been derived. For our purposes, we use the following (non-slash composite values from Brown 1974):

Hour Category	1-hr	10-hr	100 -hr
Diameter class (inches)	0 – 0.25	0.25 - 1	1 - 3
d^2 (inches^2):	0.0151	0.289	2.76

For 1000-hr fuels (3+in), the actual diameters of each piece are squared and added together to get Σd^2

s = specific gravity of the materials

Approximate Specific gravities for conifers given by Brown (1974) were:

Hour Category	1-hr	10-hr	100 -hr	1000-hr sound	1000-hr rotten
Diameter class (inches)	0 – 0.25	0.25 - 1	1 - 3	3+, decay class 1, 2, or 3	3+, decay class 4 or 5
specific gravity	0.48	0.48	0.40	0.40	0.30

a = the nonhorizontal angle correction factors

- The correction factor adjusts weight estimates for the fact that all particles do not lie horizontally as assumed in the planar intersect theory.

  0 to 3 inches: 1.13

  3+ inches: 1.00

- Brown provides the following:

N_l = the total length of the sampling line

These lengths are different for different protocols. In our protocol:

Fuel Size Class	Length of Transect Sampled
5-hr	6ft
10-hr	6ft
100-hr	35ft
1000-hr	60ft

Litter and Duff:

Litter and Duff loadings are calculated by multiplying the average depth by the bulk density of litter (or duff). Use bulk density values of 2.75 lbs/ft^3 for litter and 5.5 lbs/ft^3 for duff. Note that you will need to convert to tons/acre.

Full Formulas:

$$Fuel\ loading\ \left(\frac{tons}{ac}\right) = avg.depth(in)x\ bulk\ density\left(\frac{lb}{ft^3}\right)\left(\frac{1ft}{12in}\right)\left(\frac{1ton}{2000lb}\right)\left(\frac{43560ft^2}{1ac}\right)$$

Or

$$Fuel\ loading\ \left(\frac{tons}{ac}\right) = \frac{avg.depth(in)xbulk\ densityx43560}{24000}$$

Or

$$Fuel\ loading\ \left(\frac{tons}{ac}\right) = avg.depth\ (in)xbulk\ densityx1.815$$

Calculate average depth in inches for your entire site.

B = H * C * BD

Where:

B = biomass (kg/sq. m)
H = height (m)
C = percent cover/100
BD = bulk density (kg/cu. m)

Bulk density used for the herbaceous and shrub components are 0.8 kg/m3 and 1.8 kg/m3, respectively.

For more information on the topics covered on this and the next page see also Chapters 3.1 and 4.4.

Overstory canopy cover:

Canopy cover is typically reported in percent cover, based on the readings taken with the densiometer or other tool. These are averaged across the project. In general, overstory canopy cannot exceed 100% cover.

Understory cover:

Understory cover (ground or aerial cover) is typically represented in tables or as pie charts showing the proportions of cover across various categories. This can be done by plot but typically is also reported by project, as an average of the plot-level covers.

If Daubenmire coverage class is used the average is not determined. Instead, a table can be created and the general trends can be described in the body of the report.

Vegetative community structure:

Because community structure is a qualitative determination, it cannot be described with detailed statistics. A simple table showing the community structure of each plot can be built. A summary paragraph can also be written that mentions the majority and minority community structures and discusses any trends and patterns for the entire project area.

Depth to water table:

Depth to groundwater is a specific determination, so it is not summarized for the entire project area.

Soils

Soil Salinity:

Soil salinity electrical conductivity (EC) measurements can be reported at the sample level; because this is a specific determination, it is not summarized for the entire project area.

Soil Texture:

Because soil texture is a qualitative determination, it cannot be described with detailed statistics. A simple table showing the textures present on each plot can be built. Soil texture should not be generalized across the project area. A spreadsheet to help with calculations from the USDA is available here: https://www.nrcs.usda.gov/resources/education-and-teaching-materials/soil-texture-calculator

Soil Disturbance:

Depending on the protocol, soil disturbance can be presented as an estimated percentage of the total project area impacted, or the results of the scoring from an assessment rubric. A brief summary can also be written that outlines the causes of disturbance.

Channel shape:

Channel shape is often represented graphically. There are free downloads of Excel workbooks available to assist with this graphing, such as the reference reach spreadsheets available here: https://dep.wv.gov/WWE/getinvolved/sos/Pages/Scores.aspx and here: https://stream-mechanics.com/resources/

Streamflow Estimation:

Calculating flow is not particularly complicated, but it involves several steps and some important considerations. For a good how-to refer here: https://archive.epa.gov/water/archive/web/html/vms51.html

Water Temperature:

Water temperature is reported in degrees Celsius (°C) and Fahrenheit (°F), and temperature data analysis depends on the measurement methods used. For example, calculating daily, seasonal, and annual statistics is best suited for continuous temperature datasets from long-term datalogger and sonde deployments. These statistics include the maximum weekly average temperature (MWAT), as well as daily mean, median, maximum, and minimum temperatures. Continuous data can also be visualized as a time-series graph, with time on the x-axis and temperature on the y-axis. Temperature data should be separated by measurement site before analysis.

General notes on riparian measurement metrics: When comparing forest measurement metrics between projects or sampling periods, it is important to understand the underlying methods that were used to collect and summarize the data. A few considerations are discussed here:

- Breakpoint diameters that determine whether a tree is counted as a "tree" or "sapling" are an important part of a classification scheme. Two sampling protocols that use different breakpoints can end up having different values for these metrics because changing the breakpoint can change how trees are counted, and how many small trees effect the values like average height and QMD.
- At NMFWRI, to get project level averages, we typically average at the plot level and then average across plots. Metrics such as height, DBH, and live crown base height may also be reported as grand means at the project level. Be cognizant that the values of these two methods can differ and be sure to report the method used.

Photos can be informative sources of information. Spend time training new crew members on proper photo-point methods and be patient when taking photos to ensure you are capturing all important information. *See Supplement E4.1 Photopoint and Photo Management Best Practices for more information.*

4.4 Interpreting and Communicating Data

The next steps in the monitoring process are creating accessible summaries of the data, interpreting the results, and discussing the implications of these results for adaptive management with decision-makers. This section focuses on the management implications of monitoring results in an ecological context and provides suggestions for communicating results to different audiences.

REPORTING METRICS

Live and Dead Tree Density

Density:

Tree density, reported as trees per acre, reflects the degree of tree crowding within a project area. It can be used to assess the level of tree competition, risk of high-severity fire, and vulnerability to insect and disease outbreaks within a stand. Tree density is a measure of the number of trees per acre irrespective of size, so considering basal area alongside density gives further information on stand trends. Similar to basal area, tree density values can be compared to historic ranges of variability to inform treatments and assess outcomes.

Basal area:

Basal area incorporates stand density and tree diameters and can be used with other metrics to assess forest trends. For example, if basal area increases while tree density decreases five years after a fire, remaining trees can be assumed to be gaining diameter, likely due to decreased competition. Basal area values can be compared to historic ranges of variability to assess risk of high-severity fire, inform treatments, and assess treatment effectiveness.

Live and Dead Tree Size

Quadratic mean diameter (QMD):

Quadratic mean diameter provides information about the average tree size in a project and is directly related to basal area. An increase in quadratic mean diameter over time may indicate tree growth or the selective removal of smaller trees. As retaining fewer, larger trees is generally the target of thinning treatments, an increase in QMD immediately post-treatment is expected.

Mean height:

Mean tree height provides information on site quality, tree growth, and wildlife habitat. An increase in mean tree height often signals tree growth. If mean tree height increases while tree density decreases after thinning or fire, this suggests selective retention of taller trees. Conversely, a decrease in mean tree height may result from by an increase in the number of small trees at the site.

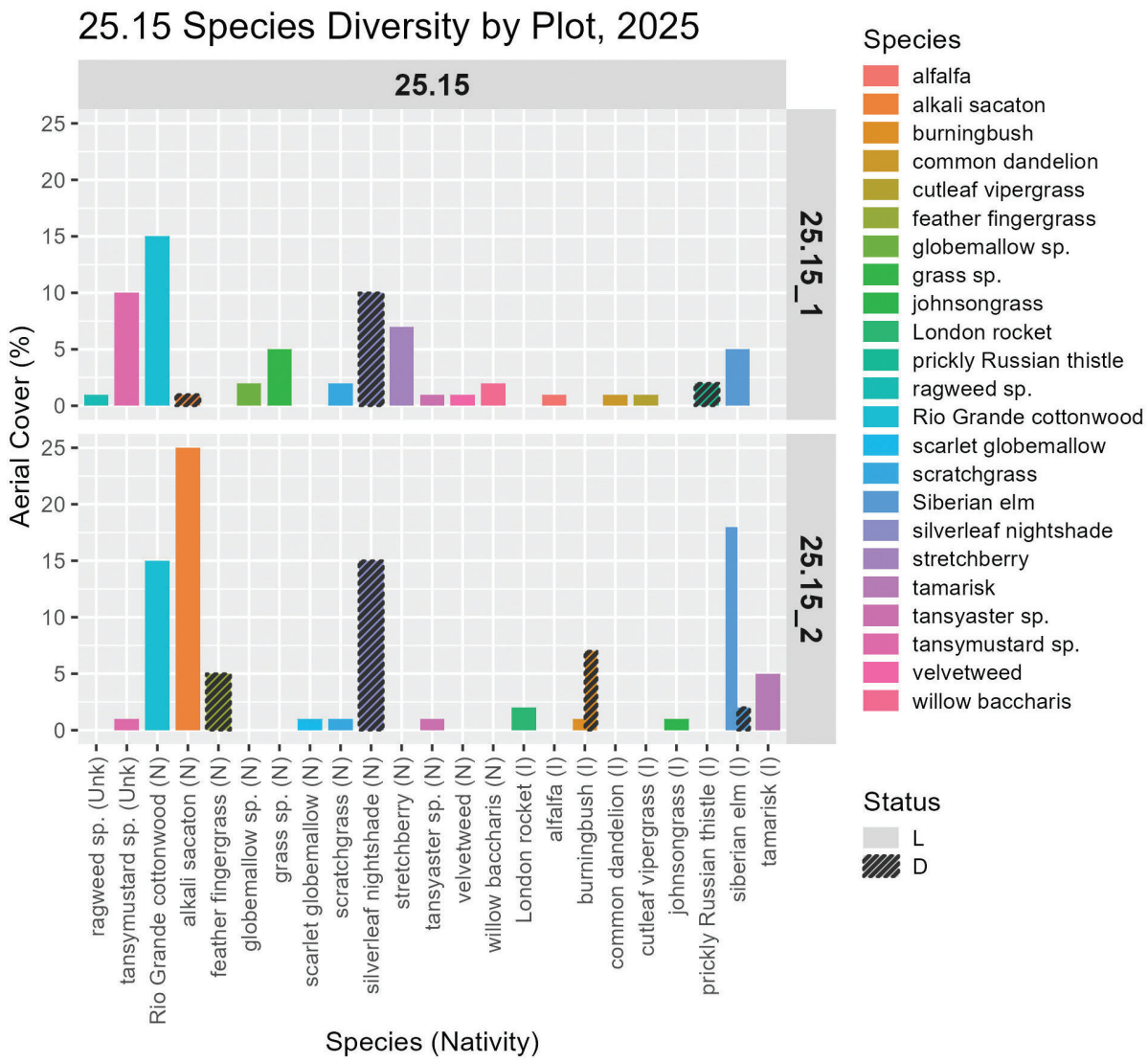


Figure 1. Aerial cover percent by plot, species, and status (Live or Dead). *Diagram by Jax Gaglianese-Woody*

Crown Base Height

Live crown base height:

Mean live crown base height provides information about the susceptibility of a stand to crown fire, and an increase in mean live crown base height can indicate decreased risk of crown fire in the measured project area, usually following treatments or fire. A decrease in live crown base height over time often indicates the in-growth of smaller trees with lower live crown base heights drawing the overall stand mean lower.

Species Composition

Overstory species composition:

Species composition and change in species composition over time are important parameters to report to understand forest type classification, assess wildlife habitat factors, and determine impacts of treatments and other activities on biodiversity. Shifting species dominance in a stand is often included in management

goals when planning restoration treatments. For example, a treatment may target the removal of salt-cedar and Russian olive from the bosque or to seek increase the dominance of Rio Grande Cottonwood or coyote willow to reflect historic species compositions in the area. Species compositions of the regeneration class can provide valuable information about the trajectory of the stand species composition over time.

Understory species composition:

Understory species respond more rapidly to disturbance than overstory species. Understory species composition can change seasonally but may also respond to management actions, such as grazing management or invasive species removal. Shifts in riparian understory plant composition can also indicate changes in hydrology. Examples include changes from natural flood events, changes in water table depth, or in-stream restoration work. Understanding the balance of plant communities between native and exotic species, as well as between upland and wetland species, can help managers determine whether restoration and management efforts are meeting their objectives. See Figure 1 for an example of species composition data visualization.

Fuel Loads

Surface fuel loads:

Surface fuel loads, most often reported in tons/acre, can tell managers a lot about expected fire behavior, forest structural diversity, quality of wildlife habitat, carbon sequestration, nutrient cycles, and more. In most cases, projects that include surface fuel targets have the objective of reducing surface fuels to safe levels. Too much surface fuel can burn hot enough to carry fire into the canopy of the trees; however, some surface fuels are valuable for wildlife habitat and for providing wetter sites where tree seedlings and understory plants can germinate. Restoration should not aim to remove every scrap of surface fuels, or to create a very "clean" forest floor. The results of the surface fuels measurement may vary considerably depending on treatments and forest type. For example, some sites have little surface fuels before treatments, but more when debris remains on the ground after trees have been cut down and partially removed, masticated, or mulched.

Surface fuel loads typically increase after thinning and decrease immediately after fire. Flooding can have varied impacts by redistributing fuel loads, including scouring fine fuels and depositing debris. Very low fuel loads may suggest recent fire, flooding, and/or heavy fuelwood utilization. Examining how 1000-hour fuel-decay classes are distributed can reveal information about habitat diversity, fire history, and recruitment patterns. For instance, if the majority of logs fall into decay classes 1-2, it likely means they were recently recruited (e.g. thinning, blowdown).

Overstory canopy cover

Changes in overstory canopy cover, often reported as percent cover, can indicate long-term shifts in vertical structure, bosque health, and disturbance frequency. These changes also impact other parts of the system, such as soil moisture, light available to the understory, and the temperature of the ground or stream beneath. Overstory canopy cover typically decreases after events such as tree clearing, removal of invasive species that involve larger individuals, fires in the bosque that kill mature trees, or as cottonwood forests mature, experience drought, or face reduced streamflow. Canopy cover may increase in the long-term following conditions that that allow for cottonwood or willow establishment, such as natural overbank flow events, in-stream restoration activities, planting, or grazing management. See Figure 2 for an example of canopy cover data visualization.

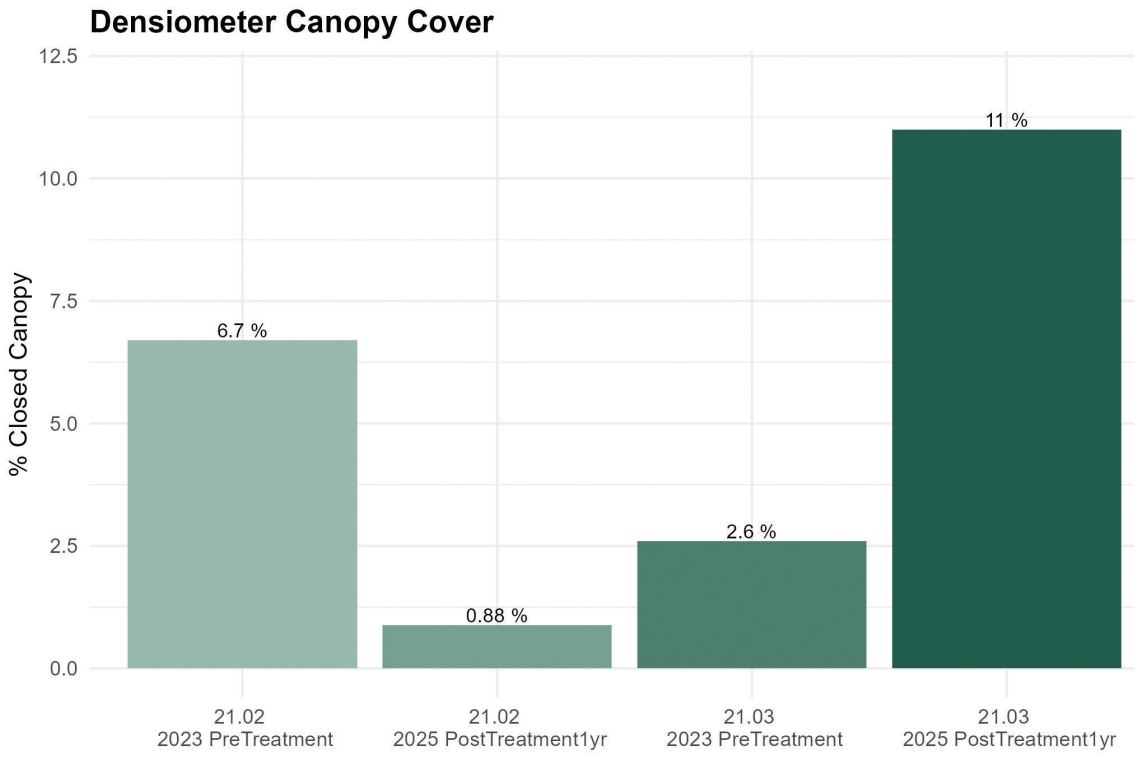


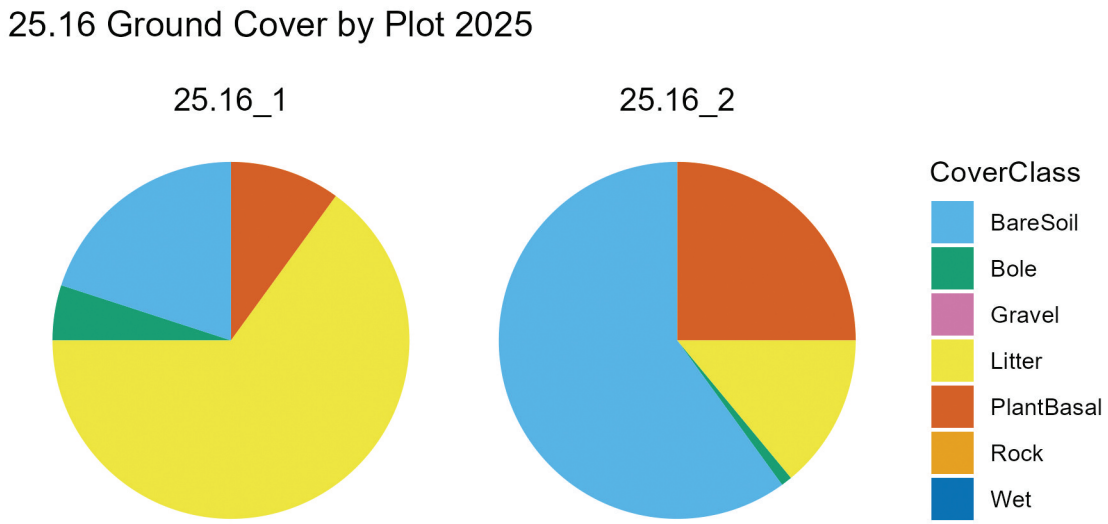
Figure 2. Percent canopy cover (% Closed Canopy) by project and treatment status. *Diagram by Emily Yannayon*

Understory cover

Understory cover, reported as the percent of ground covered by vegetation or other substrates (e.g. rock, litter, bare soil), is useful for understanding disturbance and recovery processes. For example, an initial increase in bare ground/ decrease in vegetative cover is often expected following management activities using heavy equipment, heavy grazing by wildlife or livestock, or following flooding that includes scouring or sediment deposition. An increase in vegetative cover/ decrease in bare ground is expected when cottonwoods drop their leaves in the fall (like many of these measurements, season is important), but it can also indicate establishment of understory vegetation and reduced potential of soil erosion. See Figure 3 for an example of Understory Cover.

Vegetative community structure

Tracking change over time using the Hink and Ohmart structural classes provides a way to quantify vertical complexity. Changes in a site's structural classification may result from natural succession, disturbance such as fire or flood, or management activities. For example, initial removal of all salt cedar may reduce the vertical complexity of a site; if plantings of species such as willows or New Mexico olive are successful, the structural classification may become more complex over time. Because community structure is a qualitative determination, it cannot be described with detailed statistics. A simple table showing the community structure of each plot can be built. A summary paragraph can also be written that mentions the majority and minority community structures and discusses any trends and patterns for the entire project.



Project ID	Plot ID	Cover Class	% Cover
25.16	25.16_1	Wet	0
25.16	25.16_1	PlantBasal	10
25.16	25.16_1	Bole	5
25.16	25.16_1	Litter	65
25.16	25.16_1	BareSoil	20
25.16	25.16_1	Rock	0
25.16	25.16_1	Gravel	0

Project ID	Plot ID	Cover Class	% Cover
25.16	25.16_2	Wet	0
25.16	25.16_2	PlantBasal	25
25.16	25.16_2	Bole	1
25.16	25.16_2	Litter	14
25.16	25.16_2	BareSoil	60
25.16	25.16_2	Rock	0
25.16	25.16_2	Gravel	0

Figure 3. Percent ground cover by plot and cover class. *Diagram by Jax Gaglianese-Woody*

Depth to water table

Depth to water table, reported in feet or meters, can provide information about the hydrology and site potential (e.g., likelihood of planting success or establishment of riparian obligate vegetation). Understanding trends in depth to water table is important for evaluating the feasibility of management objectives that depend on hydrologic conditions. Generally, an increase in the depth to water table can be caused by groundwater extraction, drought, channel incision, or decreased surface or stream flows. In contrast, a decrease in the depth to water table can indicate higher stream flows or improved hydrologic connectivity from management activities. Over time, these changes will also be reflected in the vegetation present on-site.

Soils

Soil salinity:

Soil salinity, commonly reported as the electrical conductivity (EC) of the soil, can be influenced by evaporation of water containing salts and mineral weathering, among other factors. Increase in soil salinity over time indicates that salts are accumulating more quickly than they are being removed, often associated with environmental degradation. Different plant species tolerate different salt concentrations, and understanding the salinity can be critical to planting success. NRCS and extension offices often have information about salinity tolerances for various plants. See also Table 1 on site suitability for native revegetation based on soil properties.

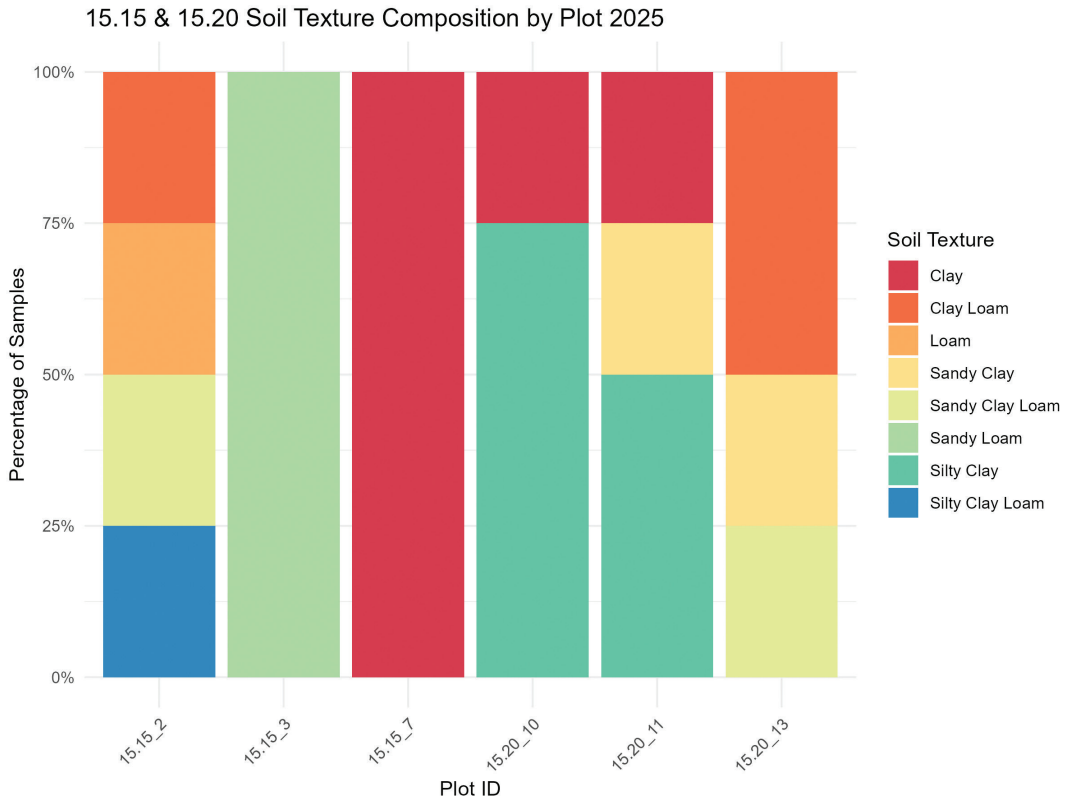


Figure 4. Soil texture by plot and soil texture composition type. *Diagram by Abigail Han*

Soil texture:

Soil texture is reported as texture type (e.g. clay loam) and can provide information about sediment sources, site stability, and depositional processes. For example, sites that regularly experience overbank flow may show changes in soil texture between monitoring visits due to sediment deposition or erosion. Soil texture strongly influences the types of plant communities that can thrive at a site. Understanding soil texture can also guide management decisions about which species to include in seed mixes or planting efforts. See also the suitability table, below. See Figure 4 on an example of soil texture data visualization and Table 1 on Site suitability based on soil properties.

Soil disturbance:

Soil disturbance is commonly reported as the type and extent of surface impacts such as compaction, rutting, displacement, erosion, or loss of protective ground cover. Changes in soil disturbance over time can provide information about site stability, treatment impacts, and recovery processes. An increase in soil disturbance may indicate concentrated vehicle traffic, livestock use, severe fire effects, flooding, or other activities that disrupt the soil surface. Excessive disturbance can reduce infiltration, increase erosion, and limit plant establishment. In contrast, a decrease in soil disturbance over time often suggests successful revegetation, improved ground cover, and recovery of soil function. Understanding patterns of soil disturbance can help managers evaluate whether restoration activities are meeting objectives while minimizing unintended impacts to long-term soil health.

Site suitability for native revegetation based on soil properties

Soil Property	Suitability			
	Good	Fair	Marginal to Fair	Very Poor
pH	6.0 - 8.4	5.5 - 6.0 or 8.4 - 8.8	5.0 - 5.5 or 8.8 - 9.0	< 5.0 or > 9.0
EC (dS/m or mmhos/cm)	0 - 4 Growth of salt-sensitive species may be limited	4 - 8 Growth of many plants is limited	8 - 16 Only salt-tolerant plants grow satisfactorily	< 16 Only a few, very salt-tolerant plants grow satisfactorily
Texture	sandy loam, silty loam, sandy clay loam	clay loam, silty clay loam, sandy clay, loamy sand	clay, silty clay, silt, sand	parent material
SAR	< 6	6 - 10	10 - 15	> 15
% Organic	> 1	0.5 - 1	< 0.5	0
Nitrogen (NitrateNO_3)	> 200 ppm (> 0.2%)	100 - 200 ppm (0.1 - 0.2%)	50 - 100 ppm (0.05 - 0.1%)	0 - 50 ppm (0 - 0.5%)
Phosphorus	> 100 ppm (> 0.1%)	60 - 100 ppm (0.05 - 0.1%)	30 - 60 ppm (0.02 - 0.05%)	0 - 30 ppm (0 - 0.02%)

Table 1. Soil property thresholds for native revegation to evaluate potential success on a site.[1]

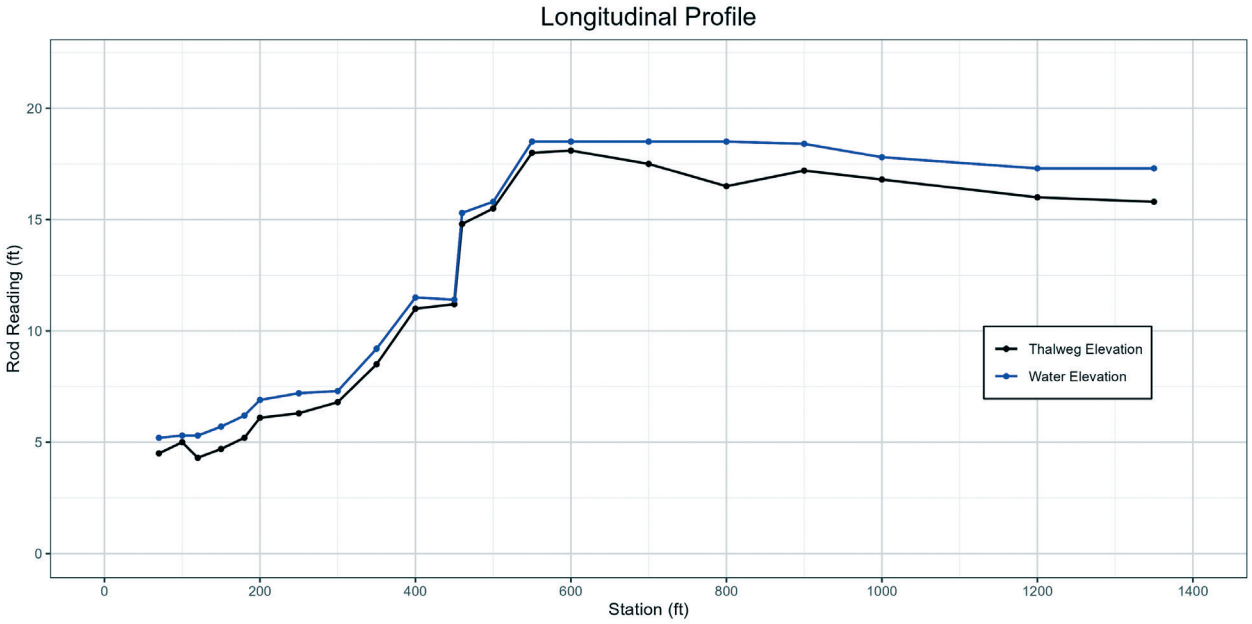
Channel and Instream Conditions

Channel shape:

Changes in channel shape, detected in re-measurements of cross-sections or longitudinal profiles, can be caused by flooding, restoration efforts, or other management actions. Channel shape influences flood frequency and intensity, in-stream and bank habitat, water table depth, and more. Channel shape can also be used to evaluate connectivity of a stream to its floodplain and the stability of that river system. These measurements are necessary for designing in-stream structures, assessing restoration performance, and they are often required for in-stream work permits. These metrics can be used to calculate slope, sinuosity, width-to-depth and entrenchment ratios, and flood-prone widths. These results support classification of the stream channel into a Rosgen (1994) type and to help guide future management actions. See Figure 5 for an example of visualizing channel shape.

Streamflow estimation:

Streamflow is a measure of how much water is moving, how fast, in units of volume per unit time. While stream velocity is measured at a single point, some measurement of channel area is needed to estimate streamflow. Streamflow can be impacted by many factors, including precipitation locally or upstream, water management activities, channel shape, and more. Examining trends in streamflow can provide useful information on variability within the river system and can be used to evaluate whether particular management actions are appropriate for particular flows. Streamflow can be measured by tracking the time it takes an object to float from one point to another or by using specialized instruments such as propellers,



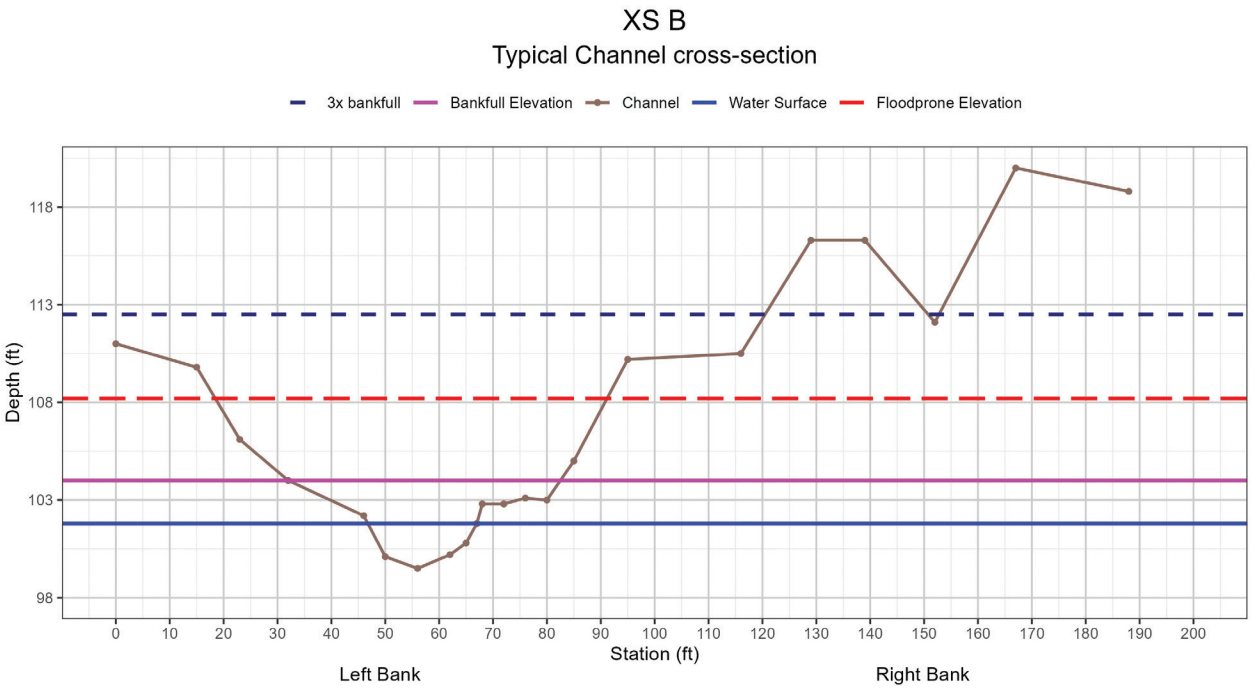


Figure 5. Top: Longitudinal channel profile showing water surface elevation and thalweg elevation. Rod readings (feet) are plotted on the y-axis, and station distance (feet) from the measurement starting point is on the x-axis.
Bottom: Channel cross-section showing 3× bankfull, bankfull elevation, channel depth, water surface, and flood-prone elevation. Depth (feet) is plotted on the y- axis, and channel width (feet), from left bank to right bank, is on the x-axis.
Diagrams by NMFWRI Monitoring Crew

together with an estimate of the channel dimensions. Analyzing streamflow trends provides valuable insight into how the river system varies over time and helps determine whether particular management actions are suitable for particular flow conditions.

Water temperature:

Water temperature (often collected with an in-stream sensor) is a critical component of aquatic habitat in part because higher temperatures reduce dissolved oxygen levels. Higher or increasing temperatures may indicate a loss of streamside overstory canopy cover, the channel becoming wider, or reduced flow, while lower temperatures can indicate groundwater connectivity, presence of contiguous streamside vegetation (shade), a narrower channel, or higher stream flows. *See Supplement E.2 on Surface Water Quality.*

Best practices for reporting and communicating results

After selecting reporting metrics and conducting analyses, the next step is to decide how to communicate the results. Summarizing monitoring results in reports and presentations is essential for documenting and communicating management outcomes. Pre-treatment monitoring data will inform the development of treatment prescriptions. Short-term, post-treatment monitoring data will be used to evaluate whether the treatments were implemented as prescribed. Longer-term post-treatment monitoring data can provide information on treatment longevity. These data also serve as an important historical record of the project area. They may be used to evaluate ecological change over time and to help evaluate treatment effectiveness. One of the most common and important uses for data summaries is to support collaborative discussions where all parties can co-evaluate monitoring results and outcomes, and adjust management practices accordingly.

General Recommendations:

Many resources exist to further support science communication. We offer a few recommendations, but encourage consulting some of the following resources for additional guidance:

- https://www.aaas.org/resources/communication-toolkit
- https://civis.eu/storage/files/guidelines-of-best-practices-in-citizen-science-and-science-communication.pdf
- https://nwfirescience.org/sites/default/files/Best%20practices_NWFSC.pdf

Know the audience:

The intended audience has a significant impact on the language choice, tone, length and format. Potential types of audiences may include communicating with internal staff, external partners, the general public, K-12 students, or subject matter experts. In some cases, a document may have multiple audiences. Communicators can change the level of detail and style of writing to make the topic more or less accessible to a wider range of people. For example, a document may not need to explain the concept of "live crown base height" if it is assumed the audience are subject matter experts; in another document intended for K-12 students, that concept would be described and a diagram might even be provided.

Explain why it matters:

When communicating monitoring results, it is important to explain why they matter. Assume the audience is asking the question "Why should I care?". It can be helpful to offer actionable recommendations when presenting

information to managers and decisionmakers, while a general audience may connect more easily with information presented as storytelling with simplified technical detail.

Products should be accessible:

When reporting results for a general audience, avoid technical terms and jargon that may be inaccessible to the average reader. Define acronyms or technical terms that are used. Create clear figures that show data trends visually and refer to these figures when describing results. Provide a general summary of data trends and management implications at the beginning of the report. Try to integrate the understanding across the different types of data to create a common-language narrative of what is happening.

Additionally, consider the different accommodation needs of the audience; for example, those with visual impairments who may need to use a document reader. Additional guidance on accessibility for various products can be found at the Section 508 website https://www.section508.gov/create/.

Provide context:

When reporting results, it is important to make results relevant in the context of the history and geography of a project area. Provide maps of treatments, plots, and project boundaries. Include a timeline of treatments, fires, and other disturbances, with details on the intended outcomes and goals of any treatments completed. Consider any other information needed to understand the results in an ecological context, and if reporting to a general audience, do not assume prior knowledge. For example, in addition to reporting the measured fuel loading, include an estimate of what would be considered healthy for the ecosystem. *See Chapter 3.4 for more resources.*

Note limitations:

When reporting monitoring results, always clearly describe any limitations in the data analysis or data quality. For example, if only a subset of monitoring plots were re-measured in a particular year, this could influence results and should be noted clearly in the report wherever applicable. If monitoring protocols changed over time, detail these changes and any effects they may have on data trends. Note where direct comparisons should not be made over time due to changing protocols or seasonal effects.

Reminder: Importance of Record-Keeping!

Always retain the original field sheets and digital files in a safe location. Make sure they are clearly marked with the project name and date. In many cases, the final report and accompanying data are the legacies of the monitoring project. *See Supplement D1 for more on data management.*

Select the Format:

A few of the formats NMFWRI and our SWERI partners commonly use include:

- **Written reports of various lengths**

  Examples of project-level reports can be found here: https://nmfwri.org/resources/monitoring-reports/ or here: https://nmfwri.org/monitoring/2022-hermits-peak-calf-canyon/

  A longer report written to support NEPA clearance in a forest can be seen here: https://nmfwri.org/wp-content/uploads/2020/07/WalkerFlats_FinalReport_RioDeLaCasa_web.pdf

Example of a write-up focused on community program-level results to a more general audience: https://nmfwri.org/wp-content/uploads/2020/08/Investigating_CFRPs_Ecological_Legacy_newsletter.pdf

- **Photo comparison documents**

  Photo comparison documents explain the change over time and current state of a project quickly. "A picture is worth a thousand words" is utilized here for quick, effective communication that relays information to most practitioners without sifting through a dense report.

  Example: https://nmfwri.org/wp-content/uploads/2020/07/Santa-Fe-Pojoaque-11.04-Site-2-5-year-Photo-Comparisons.pdf

- **Storymaps**

  Storymaps are easy-to-build websites through the ESRI platform that can integrate maps, text, photos, and videos in one place to tell a story. The format is user-friendly, aesthetically pleasing, and best used to describe big-picture projects.

  Example: https://storymaps.arcgis.com/stories/5bc9a325830040468a49127c40adb1a6

- **Webmaps**

  Webmaps are built through the ESRI platform and display geographic information. This is a helpful tool for quickly showing the scope and size of a project and sharing geographic data.

  Example: https://experience.arcgis.com/experience/6ddc7544a55946ea93329efdef3b449b/

- **Wall maps**

  Physical versions of maps are a way to showcase project work at conferences, meetings, and other shared spaces. It can also be a way to create accessible information for audiences with limited access to the internet or technology.

  Example: https://nmfwri.org/wp-content/uploads/2025/07/GRGWA_final-map.pdf

- **Posters**

  Posters are used to summarize results from discrete projects visually through maps and photos, as well as using summarized data and descriptive text. The poster shown in figure 6 provides an example of this.

  Example: https://nmfwri.org/wp-content/uploads/2020/07/Using-LIDAR-for-Greater-Rio-Grande-Watershed-Alliance_sm.pdf

- **Oral presentation, with or without slides**

  Oral presentations are an important avenue for sharing information to a live audience or via virtual meeting space. Presenting project story-telling and data verbally allows for feedback with the audience during Q&A and can create opportunities for collaboration between groups.

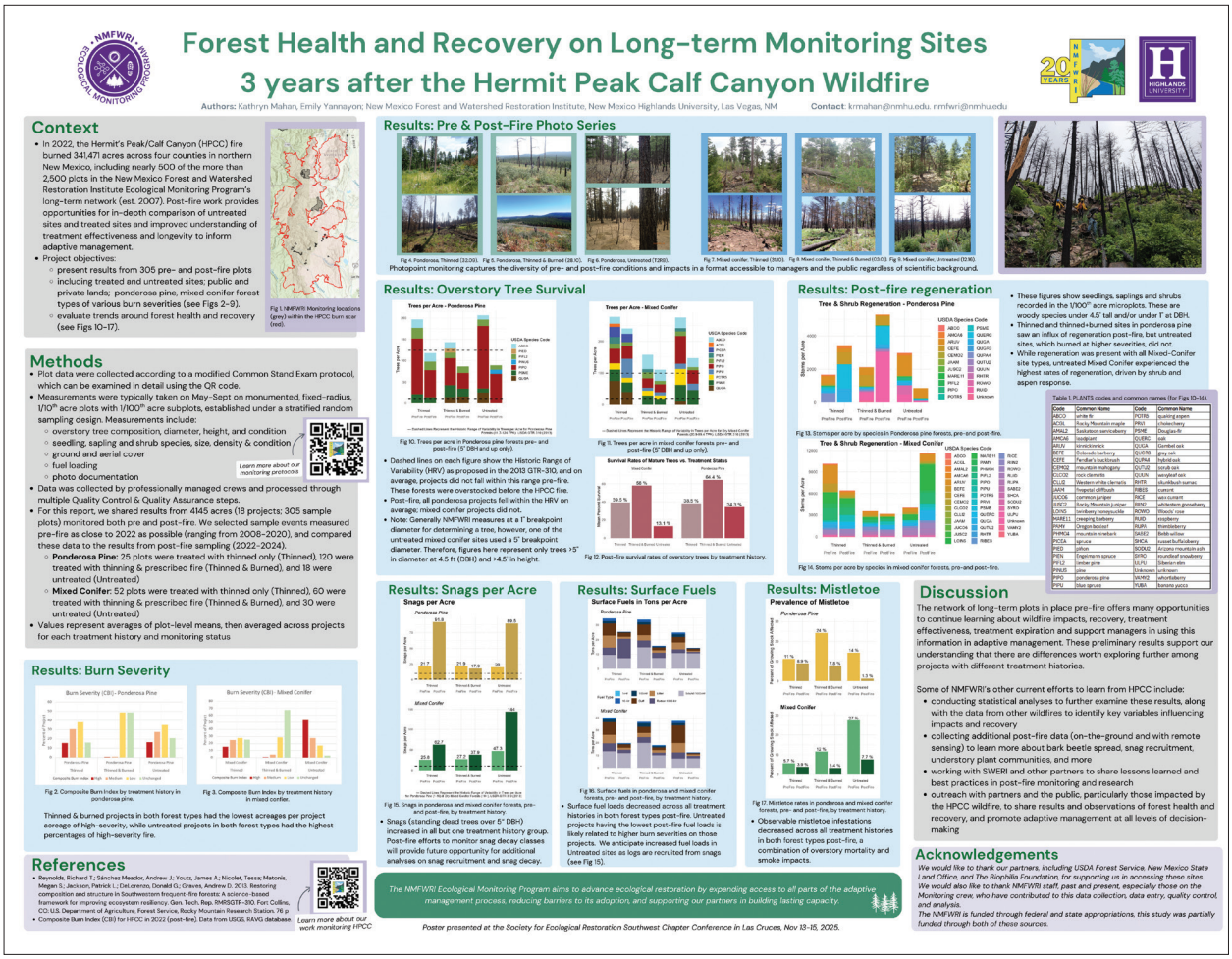


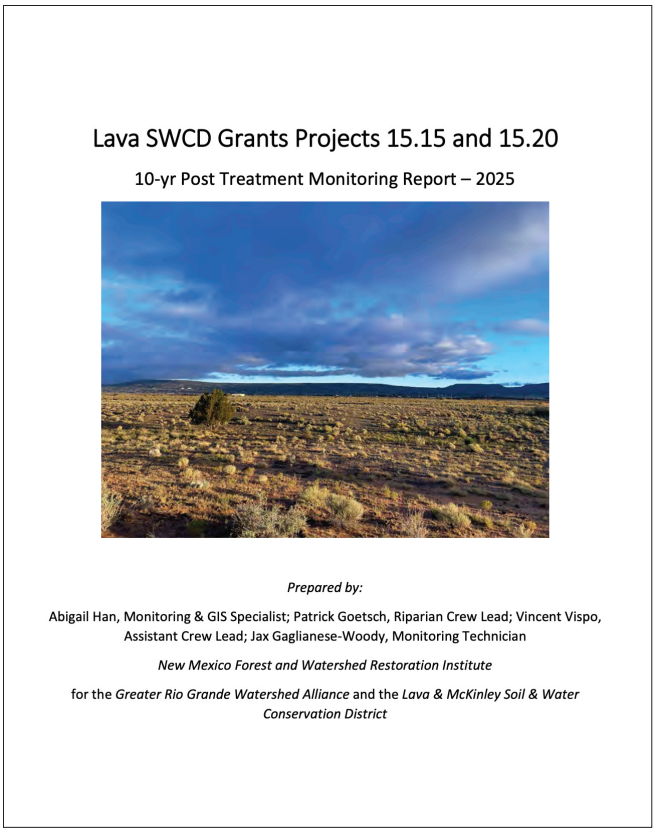
Figure 6. Scientific posters distill a project's context, purpose, methods, results, and implications into a digestible and engaging format for a broad audience. *Poster by Kathryn Mahan & Emily Yannayon*

In Chapter 5.3, we provide other examples of how NMFWRI shares and presents data.

Written Reports

Writing a final report is common practice for monitoring efforts. When creating a written report, the report should, at a minimum, include:

- Project and site description.
- Responsible organization (e.g. grantee).
- Project location, including name of the administrative unit (e.g. land manager).
- Names, roles, and affiliations of all persons involved with the monitoring.
- When the monitoring was accomplished.
- A map showing the monitoring location and a table showing the geographic coordinates of each plot.
- Data summaries.
- Conclusions, observations, and recommendations.



Lava SWCD Grants Projects 15.15 and 15.20

10-yr Post Treatment Monitoring Report – 2025

Prepared by:

Abigail Han, Monitoring & GIS Specialist; Patrick Goetsch, Riparian Crew Lead; Vincent Vispo, Assistant Crew Lead; Jax Gaglianese-Woody, Monitoring Technician

New Mexico Forest and Watershed Restoration Institute

for the *Greater Rio Grande Watershed Alliance* and the *Lava & McKinley Soil & Water Conservation District*

Figure 7. Reports are comprehensive documents that contextualize a project, detailing project background, purpose, management goals, management practices, monitoring methods, results, and management implications. These document are created periodically to keep project partners, landowners, and contractors informed on project progress. *Report by NMFWRI Monitoring Crew*

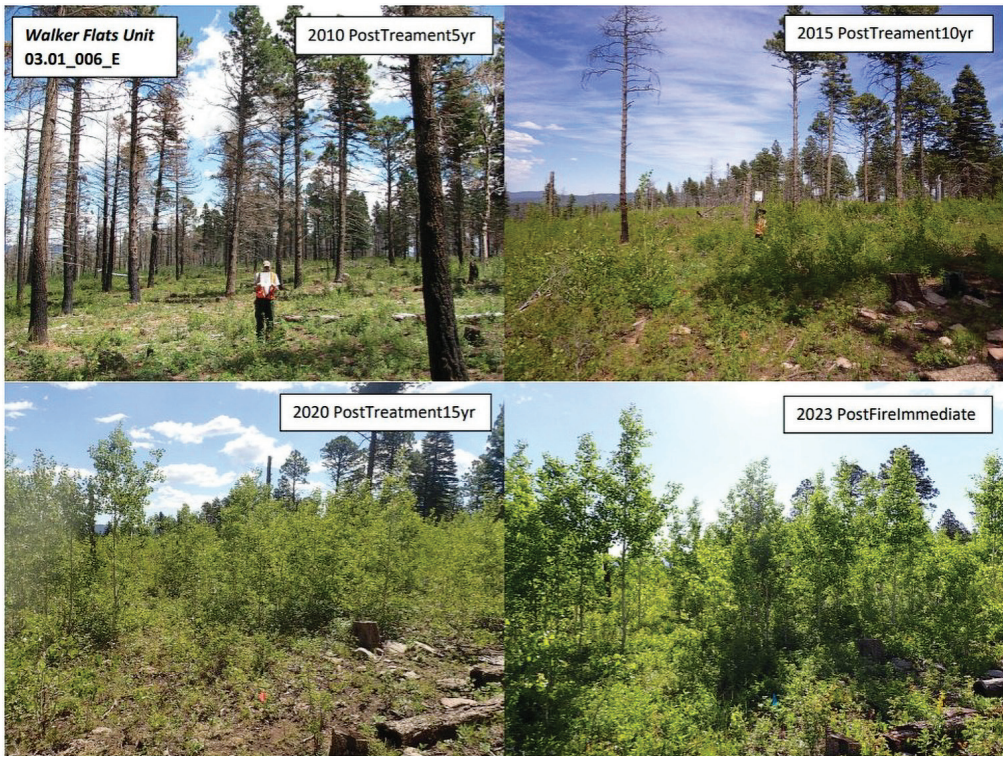


Figure 8. Above is a photo comparison document showing the same area 5-years, 10-years, 15-years, and immediately after the HPCC wildfire in 2023. Relaying information in this format is an efficient and accessible way to illustrate site changes over time. *Photos by NMFWRI Monitoring Crew*

The report should be well organized. It should include a table of contents and the pages should be numbered. Create a folder or binder with the report, a copy of all field sheets, electronic copies of data analysis spreadsheets, maps, plot and other documentary photographs, and geographic information systems data files. All electronic files should use a simple, but descriptive naming convention.

Evaluation: Closing the Loop

The ultimate purpose of monitoring is to go from raw data to actionable knowledge that supports locally relevant, informed management decisions. Accordingly, the final step in the adaptive management process is to evaluate the information collected and determine whether management actions achieved the stated objectives, and whether the existing goals, values or desired conditions should be revised. Quantitative monitoring data—such as measurements of channel shape or understory species diversity—are used to assess progress toward project targets and to guide refinement of management practices. Consistent tracking of results over time allows managers to detect trends and respond to changing conditions.

In Chapter 5.4, we describe an example of adaptive management of how data impacted management practices.

4.5 Sharing Data

Now that you have collected your data and communicated the results and management implications with stakeholders, one further step in the monitoring process can include sharing your raw or summarized data with partners who are working on similar efforts or at larger scales.

Why consider sharing data?

Sharing data enables reproducible research, supports organizations with fewer resources, and generally creates more opportunities for everyone to understand the adaptive management process. Sharing good data can lead to good decision-making!

Sharing data can also be a way of archiving it outside of an individual organization.

How does data sharing work?

There are many different methods, but generally the goals are to supply the data set in a most user-friendly form and supply metadata/instructions for properly using the data.

Sharing data with others requires solid data management and organization *(see Supplement D Data Management and Quality Control)*.

Where can data be shared?

Digital data may be stored and shared in different places and formats depending on the purpose of the program. Maps, or spatial data resources can assimilate data from many sources. Data exchange is facilitated by central clearinghouses, known as repositories, where data can be effectively stored and shared across programs, institutions, and countries. This is not an exhaustive list, but a few options include:

Ecological Data Initiative (EDI)

This is an NSF-funded repository based at the University of New Mexico and the University of Wisconsin. EDI is focused natural resources research.

https://edirepository.org/about/about-edi

Treatment and Wildlife Interagency Geodatabase (TWIG)

If your work involved fuels treatments, you could share your data with the **New Mexico Vegetation Treatment Geodatabase** or Treatment and Wildfire Interagency Geodatabase Viewer (TWIG, the national version).

https://reshapewildfire.org/twig/layers

NMFWRI

Our monitoring repository can consume data recorded in all versions of FFI, and we can provide templates for plot-based CSE and Fuels measurements (and maybe data entry platform).

https://nmfwri.org/

GitHub

GitHub is a site that allows sharing of data repositories privately with a team of partners or with the public.

https://docs.github.com/en/repositories/archiving-a-github-repository/about-archiving-content-and-data-on-github

Zenodo

Zenodo is another way of archiving research data. Data are stored within the CERN Data Centre. Zenodo can integrate with GitHub.

https://zenodo.org/

New Mexico Water Data

A collaborative effort to improve quality and access to New Mexico water data for management and planning.

https://newmexicowaterdata.org/

5.0 Case Study: NMFWRI Riparian Monitoring with GRGWA

The purpose of this section is to present a case study of one monitoring effort with partners, from beginning to end, highlighting one of NMFWRI's longest-standing riparian monitoring partnerships with the Greater Rio Grande Watershed Alliance (GRGWA).

We aim to present an overview of our partnership and offer our lessons learned from working with a variety of land managers; the evolution and use of our protocols with explanation of how they have changed over time; examples of how we manage and report the data collected, and how the GRGWA effort has been able to utilize this data in decision-making.

5.1 The Partnership

Figure 1. Treatment contractors visiting a site prior to submitting bids. *Photo by Kathryn Mahan*

According to NMFWRI records, as of March 2024, GRGWA has completed 119 projects across 3,863 acres, from Abó to Ojo Caliente.

Most projects focus on the removal of non-native species such as saltcedar, Russian olive, Siberian elm, and tree of heaven. Work done to remove these species can help to reduce fire risk, preserve native vegetation, and complements other efforts to restore the bosque and the watershed as a whole to a more natural and functional ecosystem. Individual Soil and Water Conservation Districts (SWCDs) submit project proposals to the GRWGA. Tribal partners and private landowners are sponsored by SWCDs. Once with GRWGA, the Technical Committee visits all sites and completes an evaluation of the opportunities and challenges present with each proposed project. If GRGWA receives Water Trust Board funding, the Alliance meets and prioritizes the project proposals that could be accomplished within their budget. Next, they put out a request for proposals (RFP) and host site visits for treatment contractors. Treatment contractors submit their bids, and GRGWA selects projects and contractors to proceed. At this point, NMFWRI collects pre-treatment monitoring data on that site before the treatment contractors begin work.

Treatment plans are created with each individual collaborator to decide on the most effective treatment method for invasive species removal. GRGWA projects employ a variety of techniques including extraction, mastication, aerial, basal, foliar and cut-stump herbicide applications, and planting grass, shrubs and trees. Contractors follow community, state, and national conservation management plans, while also monitoring the effectiveness of restoration efforts. In addition, GRGWA has funded NMFWRI to develop literature reviews on topics such

as invasive species control methods and the impacts of bosque treatments on wildlife to better understand the impacts of their efforts.

GRGWA is committed to monitoring their treatments to make their funds go as far as possible. NMFWRI has been contracted to do this monitoring since 2011 and has since established over 280 monitoring points (plots and/or photopoints). Monitoring efforts help illuminate changes in the landscape over time, allowing NMFWRI to document which treatments of invasive species are proving most effective in which ecological site types, and aiding in the creation of future land management plans.

Monitoring is ideally conducted before and after treatment occurs. There are also timelines on continuing projects where monitoring is conducted every 5 years. By conducting long-term monitoring, the most effective treatments can be chosen to optimize maintenance efforts and future management plans.

Planning for monitoring begins long before the crew heads into the field to accommodate the needs of GRGWA, NMFWRI, and each individual partner involved in the work. This requires frequent communication and coordination between multiple parties such as landowners, contractors and the GRGWA Technical Committee.

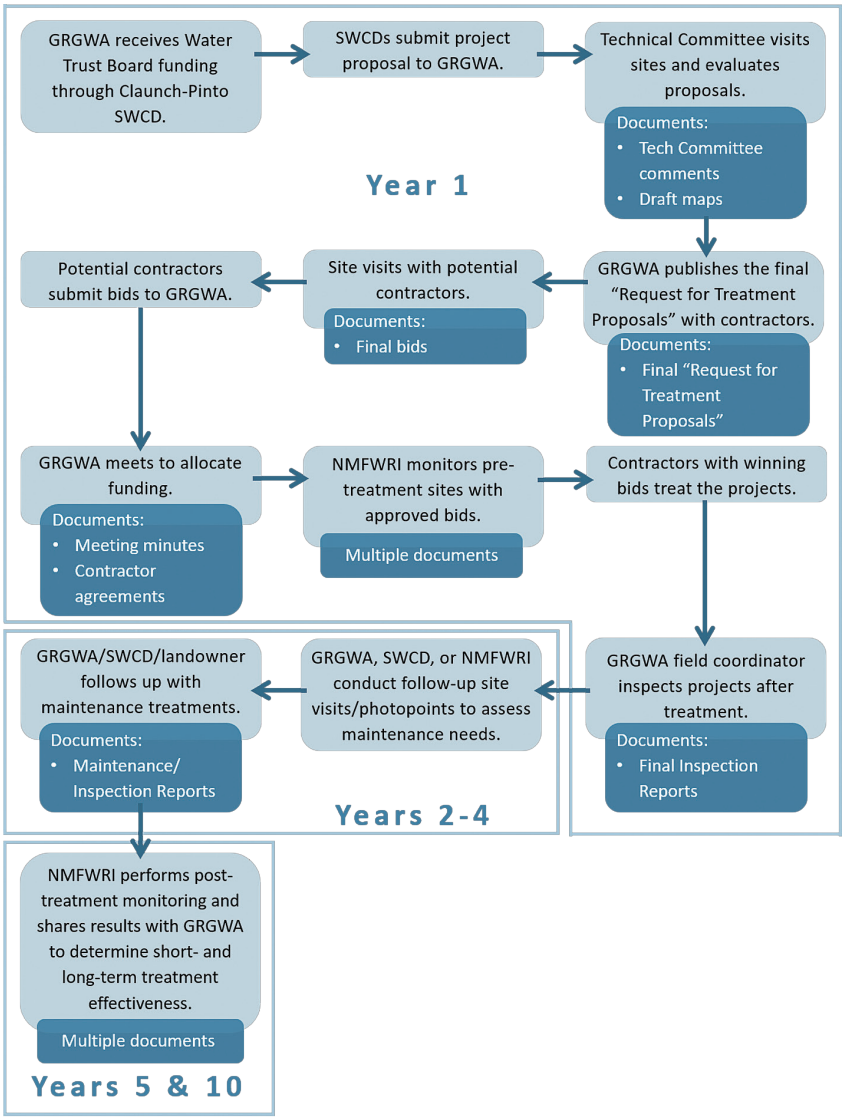
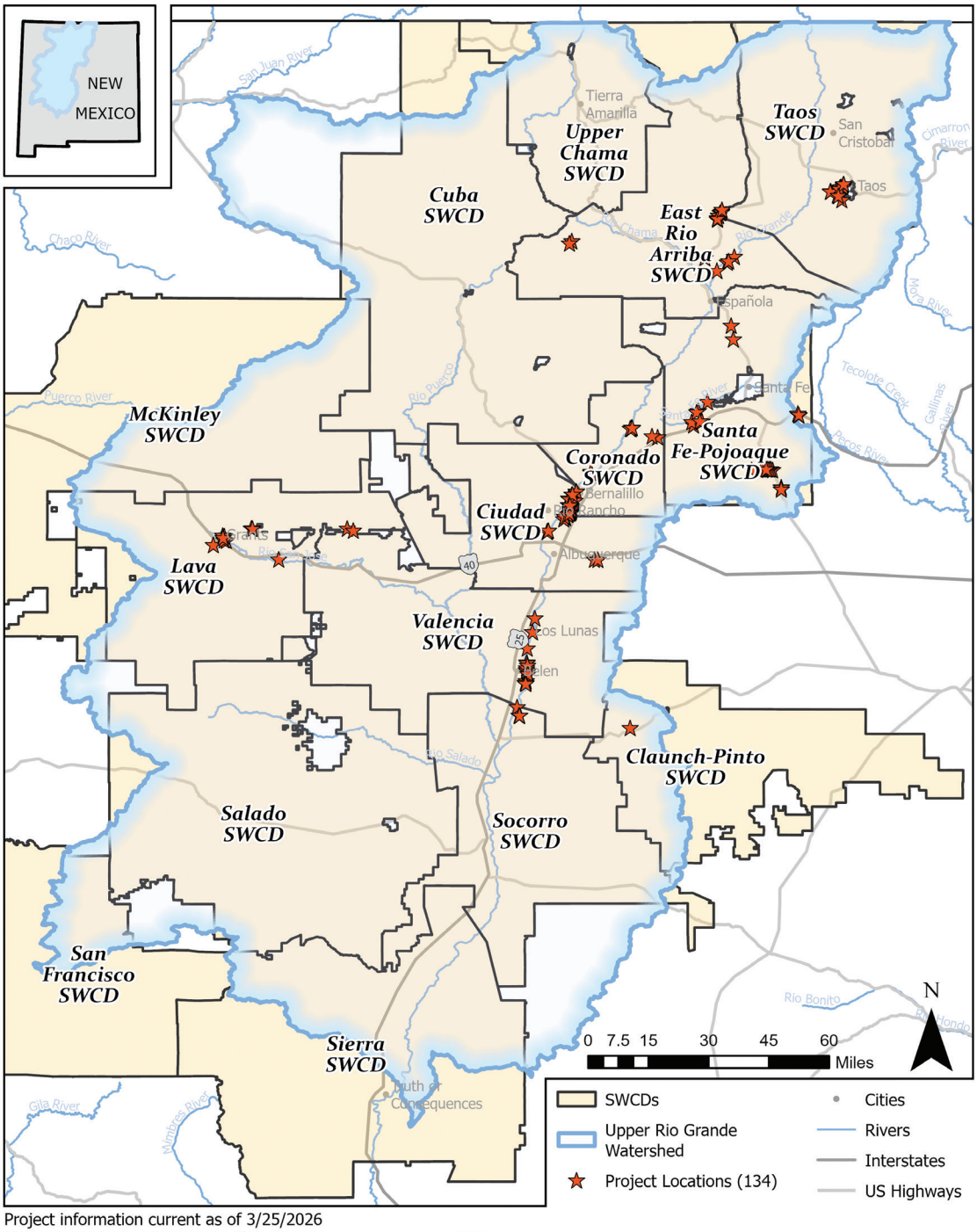


Figure 2. Illustrative flowchart of the collaborative process between GRGWA, NMFWRI, and SWCDs to implement restoration projects and monitoring.

Greater Rio Grande Watershed Alliance Projects 2011-2025



Project information current as of 3/25/2026
Map created by Jax Gaglianese-Woody

SWCD Boundaries: RGIS, NM Dept. of Agriculture
Project Points: GRGWA
Watersheds: USDA-NRCS, USGS, and EPA
Interstates & Highways: NMDOT
Inset map: Dept. of Commerce, U.S. Census Bureau, Geography Division

Basemap (main & inset): ESRI Light Gray Canvas
Coordinate System: NAD 1983 UTM Zone 13N
Projection: WGS 1984 Mercator (Auxiliary Sphere)

NMFWRI • ECOLOGICAL MONITORING PROGRAM •

New Mexico Forest and Watershed Restoration Institute
New Mexico Highlands University

5.2 Monitoring Considerations

Over time, the monitoring protocols used by NMFWRI for GRGWA have evolved in response to project needs and implementation realities. As with any long-term effort, challenges are best seen as opportunities to refine methods through adaptive management.

In 2011, NMFWRI used plot protocols selected from the 2011 Guidelines and Protocols for Monitoring Forest Restoration Projects. The primary constraint that year was timing: data collection often occurred immediately ahead of treatment contractors, and in some cases while contractors were already on site. As a result, much of the first year's data was collected outside the typical field season (e.g., in December–January).

In 2012, an environmental consultant developed a new monitoring plan for GRGWA. The plan called for an adapted version of the New Mexico Environment Department's New Mexico Rapid Assessment Method (NMRAM) to be implemented on every site, along with modified versions of Breeding Biology Research and Monitoring Database (BBIRD) and Bosque Ecosystem Monitoring Program (BEMP) plots and shallow groundwater well monitoring on a subset of sites. When NMFWRI began implementing this plan in 2013, however, some practical and methodological challenges became apparent:

- Private landowners generally did not grant permission to install shallow groundwater wells or other permanent plot monuments on their properties.
- Coordinating among multiple partners continued to constrain the time available for pre-treatment monitoring. By the time project plans were finalized and access was secured, treatment contractors were often ready to begin work, leaving insufficient time to complete both NMRAM assessments and BEMP/ BBIRD plots.
- The consultant's monitoring plan applied the NMRAM outside its intended use, creating several methodological concerns. For example, monitoring areas were defined by ownership boundaries or invasive species extent rather than by hydrologic conditions, as required by the protocol, which invalidated portions of the scoring system. Defining the monitoring area as the entire project also made scores highly sensitive to changes in project boundaries between pre-treatment monitoring and project completion, complicating meaningful interpretation of results.

Rather than viewing these challenges as setbacks, NMFWRI and GRGWA used them to strengthen the monitoring program through adaptive management. As new technologies became available and experience accumulated, monitoring methods were refined to better meet project objectives while remaining scientifically rigorous and practical. For example, following the 2014 statewide LiDAR acquisition, NMFWRI incorporated additional remote sensing into its monitoring approach and developed methods to derive vegetation classifications from LiDAR data.

In 2016, NMFWRI completed 5-year post-treatment remeasurements of the 2011 plots and analyzed changes in the presence and abundance of target species. The results highlighted not only the importance of maintenance treatments to long-term project success, but also the value of plot-based monitoring for evaluating restoration outcomes; GRGWA adopted the plot-based methods presented below as the primary monitoring approach.

Several advantages of plot-based monitoring became apparent through this adaptive process:

- Changes in project boundaries can be more readily accommodated during data collection and analysis.
- Appropriate sampling designs allow for robust statistical analyses of treatment effects.
- Plot-based methods are generally simpler to understand and interpret.
- Standardized plots facilitate more meaningful comparisons across time, projects, and partners.

The monitoring program continued to evolve as new challenges and opportunities emerged. In 2020, COVID-19-related logistical constraints limited field operations, and NMFWRI relied on National Agriculture Imagery Program (NAIP) imagery and LiDAR-derived products to document site conditions where possible. Although additional LiDAR acquisitions were not available for post-treatment monitoring, these remote sensing products helped maintain continuity in data collection during an unprecedented disruption.

More recently, NMFWRI developed land stewardship data collection forms (*see Supplement E4.11, NMFWRI Data Collection Forms*) to document stewardship practices that influence treatment outcomes. Integrating these into NMFWRI's database alongside field monitoring data, treatment records, and site characteristics provides valuable context for interpreting restoration outcomes. This integrated approach supports more holistic analyses and reflects the program's continued commitment to adaptive management and continuous improvement. The lessons learned through this evolution have helped identify several key considerations that contribute to a successful long-term monitoring program. While every restoration project is unique, the principles below have consistently improved the quality, usefulness, and longevity of monitoring efforts.

Key Considerations for Successful Monitoring

Long-term monitoring sites are a valuable source of data on the continuing effects of treatments. This data fills gaps in the knowledge left by short-term monitoring for short-term goals and helps managers understand landscape level effects in the process. A strong partnership is critical in order to maintain long-term datasets on a given site for many years. Challenges will inevitably arise, but if the organizations involved share an understanding of the importance of their work these can be resolved with minimum friction.

Communication and Coordination

To make the monitoring and adaptive management process most efficient, both NMFWRI and GRGWA focus resources on projects that will allow long-term access for repeated monitoring and ensure that we have as complete as possible information on all projects. Coordination among partners is critical for scheduling pre-treatment, treatment, treatment inspection, and post-treatment visits to guarantee that the most useful and relevant information is collected and stored for long-term handling and processing.

Monitoring Schedule

The efficacy and efficiency of monitoring a project relies largely on timing. Ecosystems move with or without eyes looking at them, often leaving only a small window available to capture the information most vital to understanding treatment outcomes. For this reason, it is important that pre- and post- treatment visits and inspections are done in a timely manner. Pre-treatment visits should be scheduled close to the treatment, and inspection reports should be finished soon after the treatment to confirm proper treatment application. These inspection reports should be available for the monitoring crew's post-treatment visit. Projects that meet the criteria laid out below should be considered for long-term monitoring (at 5-year intervals in most cases).

Post-treatment revisits (5-year, 10-year, 15-year etc.) should take place within a two-week window of the original post-treatment visit date, to ensure the seasonal differences are minimal. To make those long-term monitoring sites more viable, it is an excellent practice to get land managers and owners involved and invested in the monitoring process so that they can coordinate access to the site and provide additional support. New projects will use the plot-based protocols outlined in this document, but existing projects will use plot-based protocols in addition to the previous protocols used in the pre-treatment visit (i.e. NMRAM, BEMP protocols).

Additionally, remote sensing should be mentioned as a work around for some access issues. There is a lot of data available online through ESRI or other sources and can help fill gaps when access isn't possible. Remote sensing isn't a replacement for much of the data NMFWRI collects, but it should not be forgotten as a useful tool when limitations arise.

Prioritize Projects

For long-term projects, it isn't always possible to re-measure all sites. Instead, prioritize projects that:

- have good access, (and will remain accessible, which includes matters of safety)
- have certain characteristics (e.g. land history, management) relevant to the treatment being studied
- are feasible given technical constraints (e.g. site safety, specialized equipment needs)

Other factors include:

- landowner/manager cooperation and interest,
- landowner/manager documentation of management and land tenure,
- previous data of high quality or ecological importance,
- sites within ecological groups/landforms that can be compared,
- sites that will have enough time to re-measure effectively,
- and projects that can be reasonably sampled in the season they need to be, and represent a diversity of ecological settings.

Data Management, Standardized Forms and Data-Sharing

One of the key components of a successful monitoring program is good data management. It is important to have standardized methods of data collection, sharing, processing, QC, analysis, and reporting.

For all partners involved, a thorough and standardized set of forms should be used for all data collection and quickly processed and stored to ensure data quality and funding effectiveness.

To this end, NMFWRI has utilized various methods of file-sharing with GRGWA, including email, ftp sites, DropBox, SharePoint, and Box. The key components have been:

- A simple file-sharing platform that does not restrict file name lengths.
- Accessible by all partners.
- Commitment by all parties to share information in a consistent and timely format.

The NMFWRI Ecological Monitoring Program primarily uses custom databases and protocols within Excel, FFI, and Microsoft Access to manage GRGWA data, as well as custom R Scripts for data QC and analysis.

Complete Information

For the purposes of improving our understanding of treatment effectiveness, we need detailed records on the treatment applied, which should include method of treatment—broadly categorized as mechanical (mastication), mechanical (extraction), mechanical (hand crew), chemical (foliar), chemical (stump spray/paint)—how many projects of each type, the project acreage, the month and year treated, who performed the treatment, and information on any retreatments, including when and by whom, to see if there are any broad trends.

Whenever possible, request that data on land use be collected for projects, such as known fire impacts on site, current land use, history of land use, primary land use after treatment, any impacts on non-target vegetation due to treatment, livestock use after treatment and intensity, and native plant response. This has been made into a Landowner and Contractor Survey (*see Supplement E4.11 NMFWRI Data Collection Forms*). It is also advised to ask landowners/managers for permission to monument plot locations with rebar whenever possible for ease of repetition in remeasurement and photopoint accuracy.

Adaptive Management

Monitoring provides the feedback needed for adaptive management. By documenting treatment implementation, ecological response, and land stewardship over time, managers can evaluate what worked, what did not, and adjust future restoration strategies accordingly. This applies not just to the work of the GRGWA but the work of other organizations or individuals that could benefit from the lessons learned by GRGWA's history of restoration efforts.

To help facilitate this learning, NMFWRI shares all data collected (with the exception of confidential Tribal data) with partners and the public. For instance, the GRGWA project reports are made available on NMFWRI's website. GRGWA can use these summary reports to obtain a better understanding of treatment effectiveness and provide oversight of restoration projects in the future. Other organizations can also access the data and summary reports, as well as reach out to the NMFWRI Ecological Monitoring Program for further consultation.

NMFWRI also strives to facilitate adaptive management by collecting information on projects beyond just the on-the-ground data. This information (such as that included in the Landowner and Contractor survey) can be used for cross-project queries such as, understanding more about the importance of retreatments and the interval within which projects escape, which treatments may be most effective in which ecosystem types; etc. The NMFWRI Ecological Restoration Data System (or NERDS) was developed to store datasets in a publicly accessible space and provide query services within the database for exploration of the data by staff, partners, and the public.

NMFWRI regularly updates the processes and the technologies utilized to provide these services. Moving forward, NMFWRI aims to support GRGWA's adaptive management decision-making, so that the "lessons learned" from previous seasons inform the management actions planned for future projects. Additionally, NMFWRI is working on using the NERDS to help look at landscape-level questions around treatment effectiveness and longevity and the results with partners across the Southwest.

5.3 Data Management and Sharing

The basic components of NMFWRI's approach to data management and sharing are outlined below.

Data Management Plans

NMFWRI has a data management plan (DMP) that outlines and directs how monitoring data is handled. This is a comprehensive document that outlines the how, where, when, who, and what of data storage, back-ups, processing, naming, and archival process.

NMFWRI's DMP is available on our website, https://nmfwri.org/wp-content/uploads/2026/04/Ecological-Monitoring-Data-Management-Plan-v1.0-2026.pdf. *See Supplement D1 Data Management Best Practices for more on how to create a data management plan.*

File Naming

A standardized file naming convention allows NMFWRI staff to quickly and accurately identify files. NMFWRI uses the following file naming convention:

1. Year
2. Project ID
3. Name
4. Soil and Water Conservation District (SWCD)
5. File Type

These metadata provide enough information for the user to determine the file's date. A file name is written as:

Year_ProjectID_Name_SWCD_FileType

NMFWRI's file naming convention defines all commonly used acronyms and abbreviations to create a shared language. For example, "InsptRpt" is an abbreviation for "Inspection Report" and indicates a file type in a file name.

Certain files, such as plot photos, use a separate file naming convention that is laid out in a similar format but includes additional plot-specific metadata. File naming conventions can be flexible depending on the information that needs to be communicated to staff and external partners.

See Supplement D2 File Naming Convention Worksheet on creating a file naming system.

File Management

NMFWRI primarily uses Sharepoint for internal file management. Below is an excerpt from our file management schema that guides our folder organization:

Use "Year" as main organizing folder system for DATA COLLECTION + REPORTING in GRGWA Sharepoint.

Year

- Project 1
  - Datasheets
  - Photos
  - Maps
  - Inspection Reports
  - Landowner Information
  - Project boundary and shapefiles/and or link to AGOL
- Reports
  - Project 1
    - Draft
    - Figures
    - Final

Create specific "Administrative" folders for NON-DATA COLLECTION & NON-REPORTING activities.

Presentations & Workshops

- Year_Name
  - Planning Documents
  - Meeting Notes

Invoices

- Year_Name
  - Documents

Master Monitoring Documents

- Archive
- Most Updated
  - Blank Datasheets

And much more!

Geospatial Data Management

Alongside monitoring plot data, NMFWRI organizes geospatial data primarily through ArcGIS Online (AGOL). Large, on-going projects are placed into labeled groups and shared with the appropriate staff. All GIS data that pertains to projects are placed in their respective group on AGOL. Back-ups of shapefiles and geodatabases are stored on an internal cloud-based website.

NMFWRI Ecological Restoration Data System (NERDS)

In addition to using FFI and Excel, the Monitoring Program has developed a Microsoft Access database called NMFWRI Ecological Restoration Data System (or NERDS).

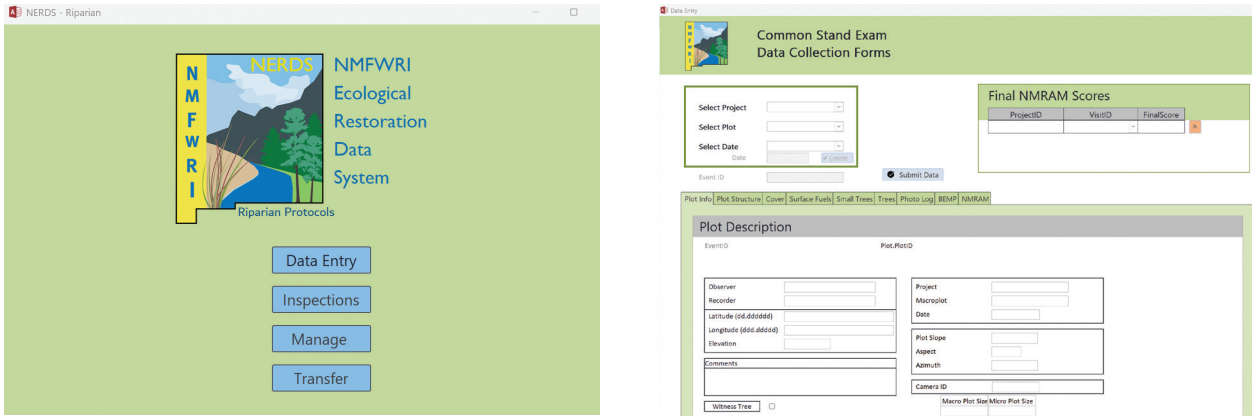


Figure 1. Screenshots of the NERDS database.

Data Sharing

NMFWRI communicates monitoring results in various ways. For example, raw data is shared with the GRGWA as Access databases, Excel files, jpegs, and scans of datasheets and field notes using file-sharing platforms such as SharePoint, Dropbox, and Box. When allowed, this raw data is also available to other partners upon request. Additionally, we post project reports with data summaries on our website and send digital or hard copies to the GRGWA, SWCDs and other stakeholders.

Below are links to a few examples of how NMFWRI communicates the GRGWA results digitally—including a public-facing story map that outlines the partnership, a web map that

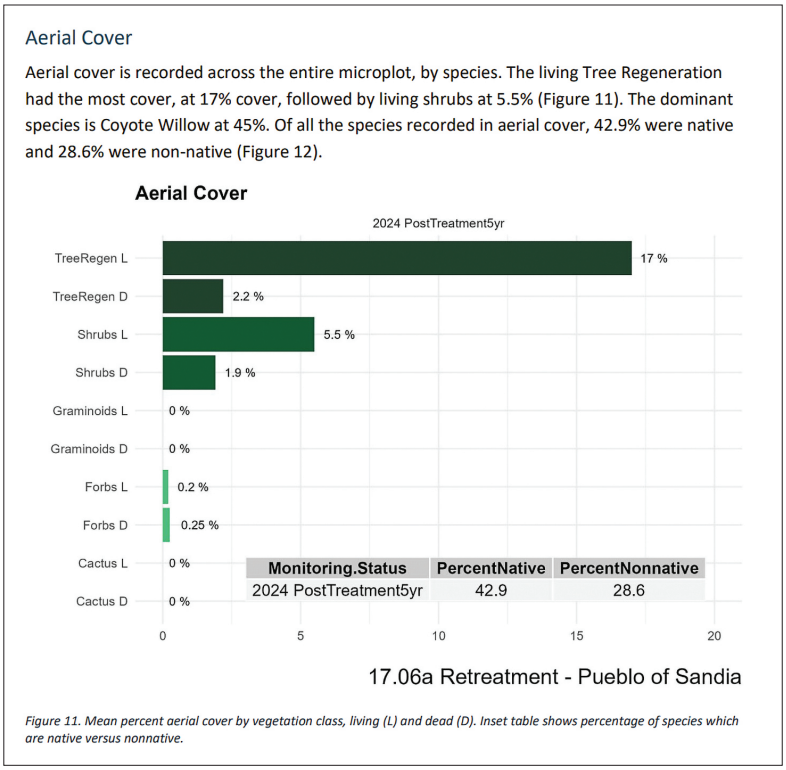
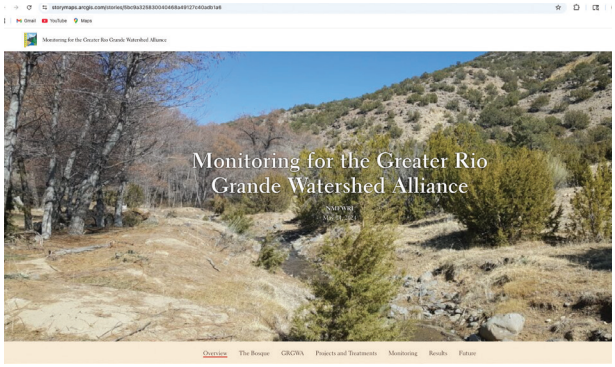


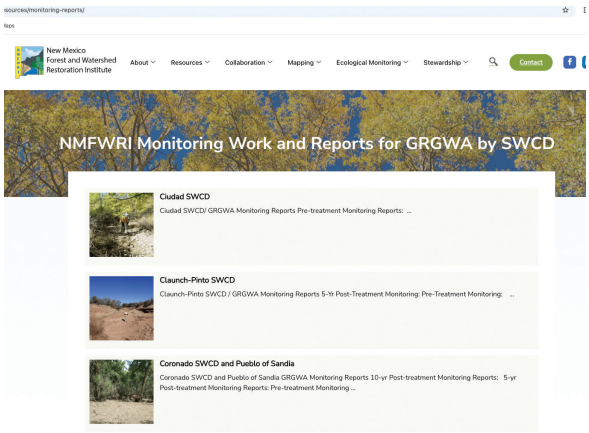
Figure 2. Example of graph and narrative text from NMFWRI's reports.

displays all riparian monitoring locations, and a library of reports and photo-comparisons that are provided to partners. NMFWRI also provides resources on relevant topics through literature reviews, cross-project summaries, guides, and protocols (see https://nmfwri.org/resources/other-docs/). *See Ch 4.4 for more information on different formats for communicating results.*

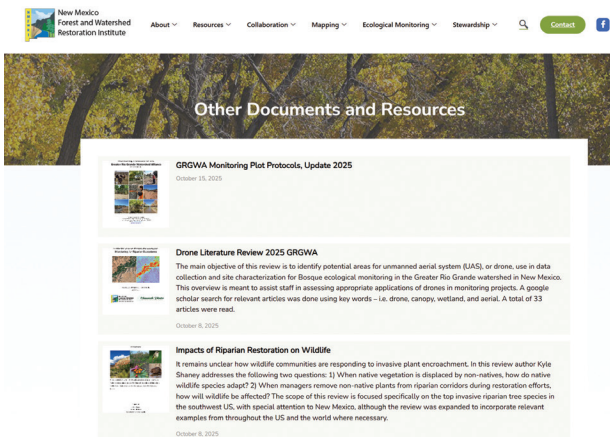
https://experience.arcgis.com/experience/6ddc7544a-55946ea93329efdef3b449b/



https://storymaps.arcgis.com/stories/5b-c9a325830040468a49127c40adb1a6



https://nmfwri.org/resources/monitoring-reports/



https://nmfwri.org/resources/other-docs/

As discussed in 5.2, photos are taken at each plot. For 5- and 10-year revisits, this process is repeated. NMFWRI can place matching photos side-by-side to visualize change over time. This product also demonstrates the importance of data management—in order to show site change visually over time, accurate GPS points and photos need to be taken during fieldwork, named, and stored so that in five years staff can find old data and create these documents to communicate what has changed (*See Supplement D Data Management and Quality Control*). From experience, the photo comparison documents are often the most popular when communicating results to a broad audience due ease of accessibility and visual component.

While reports provide comprehensive data summaries as graphs and paragraph explanations, photo comparison documents tend to be more accessible to the general public. Photo comparisons convey similar information quickly without the need for a graph or explanation. A photo can show changes in vegetation density, dominant vegetation type, and topography.

Figure 3. Examples from NMFWRI's photo comparison documents.

Case Study: NMFWRI with GRGWA

5.4 From Monitoring to Management

Adaptive management depends not only on the data, but also on strong partnerships, meaningful communication, and a willingness to adjust practices based on what is learned. Through its long-standing partnership with GRGWA, NMFWRI has had the privilege of seeing monitoring results directly influence restoration planning and implementation.

The value of long-term monitoring became especially apparent in 2016, when NMFWRI completed its first five-year remeasurements of projects initially monitored in 2011. During the annual GRGWA meeting, NMFWRI presented results from 45 monitoring plots distributed across 11 riparian restoration projects in three Soil and Water Conservation Districts. All 11 projects focused on the removal of invasive phreatophytes, including saltcedar, Russian olive, and Siberian elm. Because some projects had received follow-up maintenance treatments while others had not, the remeasurements provided one of the first opportunities to compare long-term treatment outcomes across multiple projects using a consistent monitoring approach.

Figure 1. Site that had received maintenance treatments. *Photos by NMFWRI monitoring crew*

The analysis demonstrated that projects receiving maintenance treatments had substantially lower relative abundance of target invasive species five years after treatment, while projects without maintenance treatments generally showed little improvement or increases in invasive species abundance. These findings were reinforced by repeat photo comparisons and field observations from the Claunch-Pinto Soil and Water Conservation District field crew, all of which highlighted the importance of timely maintenance retreatments for sustaining restoration success.

Figure 2. Sites that had not received any maintenance treatments. *Photos by NMFWRI Monitoring crew*

The results of this analysis directly informed management decisions within GRGWA. Additional funding was allocated to prioritize maintenance treatments during the first, second, and third years after initial treatment, and NMFWRI collected additional photopoints on those sites in the following years to help capture information on resprouts and invasive species presence. Since 2016, GRGWA's maintenance treatments have increased by approximately 18 percent, and it has become standard practice for treatment projects to receive follow-up maintenance through herbicide application, browsing, or other appropriate methods. These maintenance treatments are also inspected and documented.

This example illustrates the adaptive management cycle in practice. Long-term monitoring identified an emerging pattern, effective communication translated those findings into actionable information, and strong partnerships allowed restoration practices to evolve in response. The greatest value of monitoring lies not simply in collecting data, but in using that information to improve future decisions. Through continued collaboration, GRGWA and NMFWRI have demonstrated how long-term monitoring can strengthen restoration strategies, increase treatment effectiveness, and support healthier, more resilient riparian ecosystems.

6.0 Glossary and Basic Concepts

Abiotic factors – non-living components of an ecosystem.

Adaptation – a change in an organism that makes it more suitable to its environment.

Adaptive management – learning from experience; an iterative approach that relies on monitoring data and other feedback to evaluate and improve management strategies.

Aquifer – saturated, permeable underground geologic formation that stores and transmits groundwater to springs and wells.

Arid – dry. Arid ecosystems generally contain less biomass than mesic or wet systems.

Biotic factors – living things in an ecosystem.

Channel morphology – study of the shape and pattern of a stream or river channel that affects how water, sediment, and vegetation interact.

Climate – long-term average weather conditions over many years.

Condensation – conversion of vapor or gas to a liquid.

Diameter at Breast Height (DBH) - diameter of a tree as measured at 4.5ft on the uphill side of a tree.

Diameter at Root Collar (DRC) - diameter of a tree at the base, where the root system meets the aerial stem.

Diameter tape – a measuring tape that has a scale calibrated to read a tree's diameter when wrapped around the tree's circumference; uses the value of pi.

Disturbance – any process that removes biomass from an ecological community or changes the ecosystem trajectory.

Drought – a period with little or no rain or less than average, insufficient precipitation. Unusually dry weather means different things in different ecosystems.

Ecology – study of living and non-living things in an area which function together as an ecological unit.

Ephemeral stream – flows only after precipitation, such as an arroyo.

Erosion – movement of soil or sediment away from an area.

Eutrophication – excessive enrichment of water bodies with nutrients that often leads to algal blooms.

Evaporation – the process of liquid becoming gas.

Forb – an herb, flower, or plant, other than grass.

Forest – an ecosystem dominated by trees.

Geographic Information Systems (GIS) - a system of cataloging, analyzing, and displaying geographically referenced information, using data tied to a unique location on Earth.

Graminoid – grasses or grass-like plants.

Groundwater – water found underground in the cracks and spaces in soil, sand and rock. Groundwater is stored in and moves slowly through aquifers.

Headwaters – small streams, springs and wetlands at the top of the watershed where a river begins.

Hydrology – study of the occurrence, movement, and management of water.

Infiltration – the movement of water from the land's surface into the soil.

Interception – precipitation that does not reach the soil because it is intercepted by the forest canopy and litter.

Intermittent stream – a stream that flows only when it receives extra water from melting snow or seasonal groundwater supplies.

Lentic – relating to or living in still or standing freshwater ecosystems such as lakes, ponds, and swamps.

Lotic – relating to or living in flowing freshwater ecosystems such as rivers, stream, and creeks.

Lowland – flat or low-lying floodplains and valleys.

Overstory – top layer of cover in a forest.

Perennial stream – a stream that flows year-round.

Phreatophyte – a plant that requires access to groundwater.

Precipitation – rain or snow.

Process-based restoration strategy - a strategy that aims to reestablish natural rates and magnitudes of physical, chemical, and biological processes that sustain river and floodplain ecosystems.

Quality assurance – systematic process designed to ensure that standards of quality are met.

Quality control – steps taken to ensure accurate data collection, measurement, and analysis.

Reclamation – reclaiming or restoring a degraded site to a better functioning state.

Rehabilitation – process of repairing a degraded or damaged ecosystem to a more functional condition.

Resilience – the capacity of an ecosystem to 'bounce back' to a similar state of productivity and functionality following disturbance.

Restoration - the process of assisting the recovery of a native ecosystem that has been degraded, damaged, or destroyed.

Riparian – along the banks of a river, stream, or lake.

Runoff – water which flows over the ground (often a paved, burned, or compacted surface) without being absorbed.

Stormwater – water that falls from the sky as rain or snow and flows across impervious surfaces rather than soaking into the ground.

Sublimation – the process where water moves directly from a solid to a gas without passing through the liquid state.

Surface water – body of water on top of the ground that is exposed to the atmosphere; streams, rivers, lakes, and reservoirs.

Understory – vegetation growing below the forest canopy.

Upland – high or elevated land, generally away from water bodies.

Vegetation structure – the three-dimensional pattern and arrangement of all plants on a site.

Watershed – an area of land where all the water drains into a common outlet or particular body of water. Watersheds can be considered at multiple scales from neighborhood arroyo systems to large rivers whose watersheds span several states.

Water table - the upper surface of the saturated zone of underground water.

Wetland – ecosystem that is saturated with water for part or all of the year.

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VEGETATION

A1 Plants to Know

A Few Notes

Species written in blue with EX are considered exotic.

Unless otherwise stated, wetland indicator status applies to all possible regions

Counties listed are only the counties with NMFWRI GRGWA plots and the species. They may exist in more counties around the state.

GRAMINOIDS

Grass Family (Poaceae)

Achnatherum hymenoides, Indian ricegrass

Aristida purpurea, purple three-awn

Arundo donax, giant reed EX

Bromus inermis ssp. *inermis*, smooth brome EX

Distichlis spicata, inland saltgrass

Elymus elymoides, squirreltail

Phragmites australis, common reed

Saccharum ravennae, ravennagrass EX

Sporobolus airoides, alkali sacaton

Sporobolus cryptandrus, sand dropseed

Cattail Family (Typhaceae)

Typha latifolia, broadleaf cattail

FORBS

Amaranth Family (Amaranthaceae)

Bassia scoparia, kochia EX

Salsola tragus, prickly Russian thistle EX

Aster Family (Asteraceae)

Helianthus annuus, sunflower

Lactuca serriola, prickly lettuce EX

Morning Glory Family (Convolvulaceae)

Convolvulus arvensis, field bindweed EX

Legume Family (Fabaceae)

Medicago sativa, alfalfa EX

Loosestrife Family (Lythraceae)

Lythrum salicaria, purple loosestrife EX

Buttercup Family (Ranunculaceae)

Clematis ligusticifolia, western white clematis

Lizard's Tail Family (Saururaceae)

Anemopsis californica, yerba mansa

Nightshade Family (Solanaceae)

Solanum elaeagnifolium, silverleaf nightshade

SHRUBS

Aster Family (Asteraceae)

Baccharis salicina, seepwillow

Olive Family (Oleaceae)

Forestiera pubescens var. *pubescens*, New Mexico olive

Willow Family (Salicaceae)

Salix exigua, coyote willow

Nightshade Family (Solanaceae)

Lycium pallidum, pale wolfberry

Lycium torreyi, Torrey's wolfberry

TREES

Cypress Family (Cupressaceae)

Juniperus monosperma, one-seed juniper

Oleaster Family (Elaeagnaceae)

Elaeagnus angustifolia, Russian olive EX

Willow Family (Salicaceae)

Populus deltoides var. *wislizenii*, Rio Grande cottonwood

Salix goodingii, Gooding's willow

Quassia Family (Simaroubaceae)

Ailanthus altissima, tree of heaven EX

Tamarix Family (Tamaricaceae)

Tamarix chinensis, saltcedar EX

Elm Family (Ulmaceae)

Ulmus pumila, Siberian Elm EX

Graminoids | Grass Family | Poaceae

Achnatherum hymenoides

Photo by Cecelia Alexander

Photo by Credible Corvid

Photo by Gabriel Campbell

Common Names: Indian ricegrass, sand ricegrass, Indian millet, sandgrass

Code: ACHY

Habitat: Found on dry, sandy, well-drained soil. Adapted to habitats like sandy plains or dunes, but can live in moist microclimates in drier environments. Often grows around sagebrush or juniper; common throughout New Mexico. Elevation range 1,500 to 11,000 ft. In Valencia, Cibola, Sandoval, Santa Fe, Rio Arriba, Bernalillo, Torrance, and Socorro counties. Obligate upland species for the Arid West and Western Mtns, Valleys, and Coast regions; facultative upland species for Great Plains region.

General: Perennial bunchgrass, not rhizomatous; 20-70 cm (0.6-2.3 ft) or more tall; stem nodes swollen or brittle.

Leaves: Ligule is membranous; leaf blade margins folded; leaf blades very narrow (less than 2 mm wide) and overlap each other.

Flowers and Fruits: Panicles evenly forking (dichotomously branching), to 20 cm (7.87 in.) long and 15 cm (5.91 in.) wide; lemmas are densely covered with long hairs, awns short (3-5 mm long); seedheads are ivory or black colored. The open, dichotomously branching panicle with long pedicels is unique among our species of *Eriocoma*. The seedhead has the same branching pattern as chicken-wire. Flowers from May to August.

Graminoids | Grass Family | Poaceae

Aristida purpurea

Photo by Cecelia Alexander

Photo by Cecelia Alexander

Common Names: purple threeawn, red threeawn

Code: ARPU9

Habitat: Found on dry plains, slopes, foothills, sandy sites, disturbed ground, found commonly along roadsides. Widespread throughout New Mexico. Elevation range 1,000 to 7,000 ft. In Valencia, Cibola, Sandoval, Santa Fe, Rio Arriba, Bernalillo, Torrance, and Socorro counties.

Similar Species: Some species of *Eriocoma* look similar, but *Aristida* does not have membranous ligules.

General: Densely tufted bunchgrass, perennial, not rhizomatous, 10-100 cm (0.3-3.3 ft) tall; usually unbranched above the base.

Leaves: Ligules have conspicuous hairs; the leaves are mostly basal or mostly cauline, blades are usually rolled but not curled like wood shavings.

Photo by Robert L. Carr

Flowers and Fruits: The glumes (bracts subtending floret) are often light brown to a reddish-purple color and are noticeably unequal in length; lower glume is shorter than the upper glume; three awns per lemma, equal to sub-equal, deeply colored and often purple; central awn occasionally thicker and longer than lateral. Flowers April - October. There are six varieties in NM, all of them widespread.

Graminoids | Grass Family | Poaceae | Exotic

Arundo donax

Photo by Brandt Magic

Photo by Alex Abair

Photo by Brandt Magic

Photo by Matt Lavin

Common Name: giant reed

Code: ARDO4

Habitat: Found as an ornamental, along ditches, culverts, roadsides, stream banks, and in disturbed habitat. Can tolerate high salinity. Grows up to 8,200 ft. Mostly in the southern half of the state but some occurrences northward. In Sandoval, Santa Fe, Bernalillo, Valencia, and Torrance counties.

Similar Species: *Saccharum ravennae*, but *S. ravennae* has prominently pubescent blades near the ligules, and *Phragmites australis* has glabrous florets, hairy rachilla, and generally smaller diameter culms.

General: Mostly rhizomatous perennial; rhizomes thick and knotty; stems hard and fibrous (almost woody), up to 10 m (33 ft) tall; stem internodes hollow.

Leaves: Ligules less than 1 mm long; leaf blades numerous, flat, glabrous or scabrous, 2-9 cm (0.8-4 in) wide, with a wedge-shaped brownish colored area near the base; margins scabrous.

Flowers and Fruits: Panicle dense, erect, mostly 30-60 cm (1-2 ft) long; spikelets with 3-6 florets; rachilla glabrous; florets disarticulate above the glumes; glumes as long as the spikelets, thin, brownish or purplish, 3-5 veined; lemmas 3-5 veined, pilose, midvein ends in an awn; paleas pilose at base, shorter than lemmas. Flowers late summer.

Notes: A form with variegated leaves (cultivar 'VARIEGATA') is an attractive ornamental. Dried stems have been used for thousands of years in the making of reeds for woodwind instruments, as well as for flutes and musical pipes, animal calls, whistles, straws, thatch, mats, baskets, pens and cages, fish traps, furniture, spear shafts and arrows, walking sticks, and fishing poles. It's also planted as a windbreak.

Graminoids | Grass Family | Poaceae | Exotic

Bromus inermis ssp. *inermis*

Photo by Cecelia Alexander

Photo by William Harmon

Common Names: smooth brome, awnless brome, brome inerme, Hungarian brome

Code: BRINI, BRIN2

Habitat: Found on disturbed soils, often pastures and flats, mountain slopes, roadside swales and slopes; throughout the state. Native to Eurasia. Elevation range 4,000 to 11,000 ft. In Cibola, Sandoval, Santa Fe, Rio Arriba, Bernalillo, Torrance, Valencia, and Socorro counties.

Similar Species: *Bromus pumpellianus*, but unlike *B. inermis* ssp. *inermis*, *B. pumpellianus* is hairy.

General: Rhizomatous perennial; stem nodes usually hairless; stems 50-130 cm (1.6-4.3 ft) tall, singly or together, with 3-5 nodes.

Leaves: Leaf blades 11-35 cm (4.3-13.8 in) long, 5-15 mm wide, flat, usually hairless; sheaths usually glabrous, rarely hairy; auricles sometimes present; ligules to 3 mm, glabrous, ends abruptly; margins irregular.

Photo by Cecelia Alexander

Flowers and Fruits: Panicles are 10-20 cm long and branches are mostly ascending; awns 0-3 mm long; spikelets purplish when young and brownish to bronze when mature. Flowers from May to September.

Graminoids | Grass Family | Poaceae

Distichlis spicata

Photos by Cecelia Alexander

Common Names: saltgrass, inland saltgrass, desert saltgrass, zacate espinudo, zacate salado

Code: DISP

Habitat: Found on floodplains, saline soils, swales, salt flats, and marshes. Common throughout New Mexico. Grows at elevations up to 9,000 ft. In Valencia, Cibola, Sandoval, Santa Fe, Rio Arriba, Bernalillo, and Socorro counties. Facultative species for the Arid West region; facultative wetland species for Western Mtns, Valleys, Coast, and Great Plains regions.

General: Rhizomatous to sometimes stoloniferous perennial; 10-60 cm (0.3-2 ft) tall, usually erect

Leaves: Foliage usually exceeding the pistillate panicle but often shorter than the staminate; leaves arranged in two opposite rows and hairless; blades stiff; ligules a short membrane. Leaves are often dusted with salt crystals.

Flowers and Fruits: Spikelets 5-20 mm long and awnless; glumes unequal; lemmas 3-6 mm long. Flowers June to September.

Graminoids | Grass Family | Poaceae

Elymus elymoides

Photos by Craig Martin

Common Names: squirreltail, western bottle-brush grass, bottlebrush squirreltail, cola de ardilla, zacate ladera

Code: ELEL5

Habitat: Found in plains, grasslands, woodlands, forest clearings, and roadsides. Widespread throughout New Mexico and ecologically diverse. Elevation range 2,000 to 11,000 ft. In Valencia, Cibola, Sandoval, Santa Fe, Rio Arriba, Bernalillo, Torrance, and Socorro counties. Facultative upland species for Arid West and Westerns Mtns, Valleys, and Coast regions; obligate upland species for Great Plains region.

Similar Species: *Hordeum jubatum* looks alike but has 3 spikelets per node with more slender and bristle-like awns that lack a central groove.

General: Tufted perennial, not rhizomatous; 15-70 cm (6-2.3 ft) tall; the stems erect but can be bent at a sharp angle; the nodes mostly concealed by the sheaths. Grazed upon when young.

Leaves: Sheaths hairless to densely villous; auricles about 1 mm long; blades 2-6 mm wide, hairless to villous.

Flowers and Fruits: Spikes 5-20 cm long, erect to sharply bent over, with 2-3 spikelets per node; the florets disconnect from their stem and are pulled down; glumes 2-13 cm long; lemmas 6-12 mm long, hairless to hairy; lemma awns 2-12 cm long, flattish and grooved, sometimes split, often purplish or reddish curl outwards when dry. Flowers from late May to July.

Note: Hybridizes with *Elymus canadensis*.

Graminoids | Grass Family | Poaceae

Phragmites australis

Photo by Rob Curtis

Photo by Kallum McDonald

Common Names: common reed, carrizo

Code: PHAU7

Habitat: Found along streams, rivers, drainages, ditches, canals, in wetlands, and on sandbars and islands. Can also be found in wet ground around springs and seeps. Found at elevations up to 7,000 ft. In Sandoval, Bernalillo, Valencia, Rio Arriba, Cibola, and Torrance counties.

Similar Species: *Saccharum (Tripidium) ravennae*, but that species has prominently pubescent blades near the ligules, and *Arundo donax*, but that species has pilose florets, glabrous rachilla, and generally larger diameter culms.

The Situation: *Phragmites australis* has three subspecies, two of which are native. To tell them apart:

- *Phragmites australis* subsp. *americanus* (American common reed, native lineage, PHAUA6): Ligules 1.0-1.7 mm long, leaf sheaths deciduous with age; culms exposed in the winter, smooth and shiny; rarely occurs in a monoculture; sometimes purplish at the nodes and internodes.
- *Phragmites australis* subsp. *berlandieri* (subtropical common reed, Gulf Coast lineage, PHAUB2): Culm smooth and shiny; leaf sheaths not deciduous with age; may occur as a monoculture; likely limited to southern New Mexico.
- *Phragmites australis* subsp. *australis* (introduced common reed, European common reed, introduced lineage, PHAUA7): Culm ridged and not shiny; leaf sheaths not deciduous with age; often occurs as a monoculture.

Efforts to describe morphology have mostly been limited to the more widespread subspecies *americanus* and subsp. *australis*. Here are features that can be used to tell those subspecies apart. It is essential to decide subspecies based on multiple characteristics on multiple plants because using

Photo by Kallum McDonald

Photo by Rob Curtis

only one can be misleading. Several traits do not translate well to photos.

- When approaching a stand, the first thing to look at is the stand as a whole. Subsp. *australis* and subsp. *berlandieri* are more likely to grow in a monoculture than subsp. *americanus*. The native subspecies are more likely to have mixed vegetative communities, and the introduced is likely to be homogenous. *See stand photos opposite page and above left.*
    - Subspecies *americanus* and subsp. *australis* can grow very sparsely or very densely. When growing densely, the introduced subspecies is more difficult to walk through. The native subspecies does not have the weedy tendency of the introduced subspecies. *See stand photos opposite page and above left.*
    - The native subspecies are more likely to have more stem coloration lower down on the plants where dead leaves are present than the introduced subspecies. If there is little variation, it is more likely to be exotic. *See stand photos opposite page and above left.*
    - Look low on the stem. How tightly the sheath remains attached to the stem is diagnostic. On subsp. *americanus*, the sheath is deciduous. Occasionally it can remain attached past winter, but it can be easily removed. On subsp. australis, the sheaths take effort to remove even when they are starting to break down. *See photos above.*
    - Increased sun exposure on the stems causes a reddish/purplish color to appear. This is more common on subsp. *americanus* because the leaf sheaths are deciduous but can also occur on subsp. *australis*. *See stem photos next page.*

Photo by Kallum McDonald

Photo by Kallum McDonald

Photo by Thurman Johnson

Photo by GWT2012

- Look at exposed stems (the sheath may have to be removed). If you feel minimal or no ridges when running a fingernail over the stem and the color is not flat, it is likely one of the native varieties. If you can feel ridges and the color is more flat, it is likely subsp. *australis*.
- All subspecies can get mildew spots, but only subsp. *americanus* can develop distinct black fungal dots. These fungal spots do not always occur.
- The ligule on subsp. *australis* is usually shorter than those of subsp. *americanus*.
- In younger plants:
  - Subspecies *americanus* has leaves that tend to be floppier and come off the stems at a more horizontal angle. They are generally more yellowish-green.
  - Subspecies *australis* has leaves that are stiffer and come off the stem around a 45-60 degree angle. They are generally more bluish-green.
- The introduced subspecies often stays green later into the year but not always.

Note: Neither USDA PLANTS nor POWO have subsp. *australis* occurring in New Mexico, but there are many accounts of it growing in the state. There is also some debate about the nativity status of subsp. *berlandieri*. There are very few resources covering the differences between the three subspecies in New Mexico. None of the photos included for the species were taken in New Mexico.

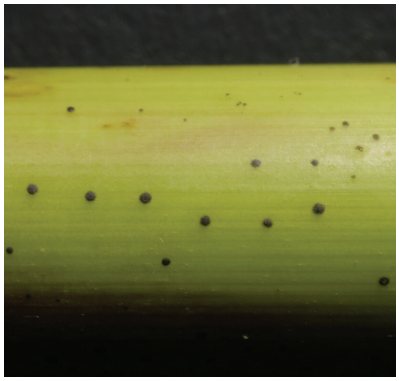

Photo by Brian Daggs

Links to other identification resources:

Guide to Identifying Native and Non-Native Phragmites australis (https://www.lccmr.mn.gov/projects/2013/finals/2013_06a-17_mn_phrag_identification_guide.pdf)

Phragmites—Native or Not? (https://mnfi.anr.msu.edu/pdfs/phragmites-native-non-native.pdf)

Winter Identification of Native and Exotic Phragmites Subspecies in SE Wisconsin (https://prairiebotanist.com/2016/01/30/winter-identification-of-native-and-exotic-phragmites-subspecies-in-se-wisconsin/)

Phragmites Field Guide: Distinguishing Native and Exotic Forms of Common Reed (Phragmites australis) in the United States (https://bugwoodcloud.org/mura/mipn/assets/File/Educational%20Resources/Phragmites%20Field%20Guide.pdf)

Native vs. Non-Native Phragmites (https://www.greatlakesphragmites.net/phragbasics/native-vs-nonnative/)

Fact Sheet: Giant Reed (https://www.invasive.org/alien/fact/pdf/phau1.pdf)

Graminoids | Grass Family | Poaceae | Exotic

Saccharum ravennae

Photo by Sandia Mountain Natural History Center

Photo by Fiana Shapiro

Common Names: ravennagrass, elephant grass, plume grass, hardy pampas grass

Code: SARA3

Habitat: Found in open, disturbed locations at both moist and dry sites, including marshes, ditch banks, seeps, floodplains, rocky hillsides, gravel roadsides, and escaped from yards. Tolerant of cold weather. Elevation range up to 8,000 ft. In Bernalillo and Santa Fe counties. Facultative species for Arid West and Western Mtns, Valleys, and Coast regions; obligate upland species for Great Plains region.

Similar Species: *Cortaderia jubata* (jubata) and *Cortaderia selloana* (pampas grass) are bunchgrasses that look similar, but *S. ravennae* has densely hairy leaf and stem bases,thick and white midveins on the upper side of the blades, and the flowering stems can be reddish.

General: large, tussocky, tufted perennial, not rhizomatous; stems 2-4 m (3.3-14.4 ft) tall; culms and leaves hairless.

Leaves: Leaves born along the stem; blades to 100 cm (3.3 ft) long and 1.4 cm wide, flat; leaf margins are serrated and have a thick, white midvein on the upper side of blades; leaf bases are densely covered with long, fuzzy hairs that typically hide the ligule; ligules a ciliate membrane, about 1 mm long.

Flowers and Fruits: Panicles elevated usually far above the leaves, 40-80 cm (1.3-2.6 ft) long and about 1/3 as wide; spikelets 4-6 mm long and can be stalked or stalkless, the stalkless spikelets are straw colored; florets covered in tufts of silky hairs and are purplish, maturing to silver to tan. Flowers from July to October.

Note: Likely escaped from use as a landscaping plant and the ABQ zoo.

Graminoids | Grass Family | Poaceae

Sporobolus airoides

Photos by Cecelia Alexander

Common Names: alkali sacaton, zacate alcalina, zacate de agua, cresta de gallo, zacatón

Code: SPAI

Habitat: Found on sandy, gravely, clayey plains, flats, mesas, playas, floodplains, throughout the state. Grows in saline and non-saline soils and can often be found in alkaline soils. Floodplains and playa beds can be covered with an almost solid expanse. Elevation range 2,500 to 7,500 ft. In Valencia, Cibola, Sandoval, Santa Fe, Rio Arriba, Bernalillo, Torrance, and Socorro counties. Facultative species.

Similar Species: *Sporobolus wrightii* looks similar, but *S. airoides* has spreading pedicels, branchlets without spikelets to the base, and is usually shorter. *S. cryptandrus* can look similar, but it has flag blades almost perpendicular to the stem and mostly appressed pedicels whereas S. airoides has ascending flag blades and somewhat spreading pedicels.

General: Densely tufted perennial, forming large tussocks to 1 m (3.3 ft) or more across, not rhizomatous; 35-150 cm (1.1-4.9 ft) tall; adventitious roots thick, 2-4 mm diameter.

Leaves: Lower sheaths shiny, becoming straw-colored; sheath apices hairless or only sparsely hairy with long hairs; ligules less than 0.5 mm long; blades to 60 cm (2 ft) long, weeping.

Flowers and Fruits: Panicles 15-45 cm long, very open and diffuse at maturity, the base often included in the sheath; pedicels 0.5-2 mm long; spikelets 1.3-2.8 mm long, purplish or greenish; unequal glumes; no awns; difficult to uproot. Flowers from May to October.

Note: Rattlesnakes seem to like to hide in areas expansively covered by alkali sacaton.

Graminoids | Grass Family | Poaceae

Sporobolus cryptandrus

Photos by Cecelia Alexander

Common Names: sand dropseed, zacate de arena, zacate encubierto

Code: SPCR

Habitat: Sandy or gravelly plains, dry slopes, mesas, roadsides, waste places, and washes throughout the state. It's often in open ground. Elevation range up to 7,500 ft. In Valencia, Cibola, Sandoval, Santa Fe, Rio Arriba, Bernalillo, Torrance, and Socorro counties. Facultative upland species.

Similar Species: *Sporobolus airoides* can look similar, but *S. cryptandrus* has flag blades almost perpendicular to the stem and mostly appressed pedicels while *S. airoides* has ascending flag blades and somewhat spreading pedicels. *S. cryptandrus* is similar to *S. flexuosus* but *S. cryptandrus* has generally persistent panicle branches, and even if they break, they don't leave a spine-remnant.

General: Tufted perennial, not rhizomatous; 30-120 cm (0.9-3.9 ft) tall; stems 1-3.5 mm thick.

Leaves: Sheath margins sometimes ciliate, the apices with conspicuous tufts of long, thin, white hairs 2-4 mm long; leaf blade upper surfaces and margins slightly rough to the touch; flag blades nearly perpendicular to the stem; ligules 0.5-1 mm long.

Flowers and Fruits: Panicles erect, 15-40 cm long, 2-14 cm wide, open in age but often spike-like when young, the branches ascending to reflexed, not entangled; secondary branchlets and spikelets generally appressed along the primary branches; spikelets 1.5-2.7 mm long and brownish-, lead-colored, or purplish-tinged; glumes unequal; lemmas 1.4-2.7 mm long; no awns. Flowers May to September.

Graminoids | Cattail Family | Typhaceae

Typha latifolia

Photos by Radha Veach

Common Names: broadleaf cattail, common cattail, cattail, espadilla, cola de gato, plumillo, maza de agua

Code: TYLA

Habitat: Found growing in wet areas, including freshwater to slightly brackish marshes, ponds, ditches, swales, arroyos, and slow moving river sites. Elevation range up to 8,000 ft. In Bernalillo, Sandoval, Valencia, Socorro, Cibola and Rio Arriba counties. Obligate wetland species.

Similar Species: *T. latifolia* can be distinguished from other *Typha* species by the connecting or only very slightly separated pistillate and staminate parts of the inflorescence.

General: Perennial herb with extensively creeping rhizomes; plants 1.5-3 m (4-9.8 ft) tall,; stems erect, cylindric, and pithy.

Leaves: Leaves alternate, with sheathing bases; 12-16 leaves per stem; sheaths cylindric and open to the base; leaf blades thick and spongy, light green, 6-23 mm wide, about as long as the stems or slightly shorter and nearly flat.

Flowers and Fruits: Staminate and pistillate portions of the spike usually contiguous to each other or sometimes separated 1-4 cm, the pistillate portion 2.5-3.5 cm thick in fruit. Flowers May to July.

Note: All *Typha* species in New Mexico known to hybridize.

Forbs | Amaranth Family | Amaranthaceae | Exotic

Bassia scoparia

Photo by Craig Martin

Common Names: kochia, burningbush, summer cypress

Code: BASC5

Habitat: Found in open, unshaded areas on disturbed ground, roadsides, saline and/or alkaline soils, fields, pastures, rangelands, piñon-juniper woodlands/grasslands/shrublands, desert scrub, and sagebrush. Elevation range 2,000 to 9,000 ft. In Sandoval, Rio Arriba, Santa Fe, Socorro, Valencia, Bernalillo, Cibola, and Torrance counties. Facultative species for Arid West and Western Mtns, Valleys, and Coast regions; facultative upland species for Great Plains region.

Similar Species: *Bassia hyssopifolia* looks similar but is hairier and has a 5-hooked structure on the seeds.

General: Annual herb; dark green when younger and often red in autumn; herbage often covered with long, soft, scattered hairs; stems erect, up to 1.5 m (4.9 ft) tall, much-branched.

Photo by Rod

Photo by Cecelia Alexander

Leaves: Leaves alternate, linear to narrowly lanceolate or oblanceolate, 1-10 cm long; margins entire and fringed with hairs, leaf faces slightly hairy to smooth, lower surface usually hairier.

Flowers and Fruits: Inflorescences of solitary flowers or interrupted spikes, both terminal and in the leaf axils; flowers are inconspicuous; seeds are wedge-shaped, brown, and slightly ribbed; young plants have 3-veined leaves densely covered in long, soft, weak hairs. Flowers June to October.

Note: Summer cypress is a narrow-leaved form sold by nurseries.

Forbs | Amaranth Family | Amaranthaceae | Exotic

Salsola tragus

Photo by Brandt Magic

Photo by Sam Kieschnick

Photo by dfoehring

Photo by Erik Danielsen

Common Names: prickly Russian thistle, Russian thistle, tumbleweed

Code: SATR12

Habitat: Found throughout the state in a wide variety of disturbed habitat. Can be found in alkaline and/or saline soils but not soils that are saturated for extended periods of time. Generally grows at elevations up to 8,000 ft. In Valencia, Cibola, Sandoval, Santa Fe, Rio Arriba, Bernalillo, Torrance, and Socorro counties. Facultative upland species.

General: Annual herb, usually up to 1 m (3.3 ft) tall; rounded, bushy, many-branched stems, branches spreading; stems usually red or purple striped; herbage hairless to somewhat hairy. The leaves, as well as the young plant (up to ~6 in tall) can be eaten.

Leaves: Leaves alternate, stalkless, thread-like, and sharp-tipped; stems and leaves succulent when young and harden with age.

Flowers and Fruits: Solitary flowers located in leaf axils, pink to white, with spiny bracts; mature plant breaks off at ground level and are pushed around by wind; fades to tan to brown. Flowers June to early October.

Note: The diploid species, *S. australis*, may be concealed within our tumbleweed population; they look very similar, and only recently has work been done to shed light on the distinction between the two.

Forbs | Aster Family | Asteraceae

Helianthus annuus

Common Names: common sunflower, Kansas sunflower, mirasol, Hopi sunflower, annual sunflower, sunflower, wild sunflower, girasol, flor de sol

Code: HEAN3

Habitat: Found on open and/or disturbed areas like roadsides, floodplains, yards and gardens, fields, and old homesites. Can grow in dry or moist soil, and is drought-tolerant; prefers full sun but can tolerate semi-shaded locations. Generally found below 10,000 ft. In Valencia, Cibola, Sandoval, Santa Fe, Rio Arriba, Bernalillo, Torrance, and Socorro counties. Facultative upland species.

Similar Species: Is similar to other *Helianthus* species, especially *H. petiolaris*, which is smaller and more slender in all respects, has lanceolate phyllaries, and usually lacks ciliate margins.

General: Annual forb; stems 1-3 m (3.3-9.8 ft) tall, coarse and hispid, simple or branched; when dead, the plant turns to a pale green and eventually tan to brown; the stalk becomes more prickly; the styrofoam-like pith can persist for months after dying.

Leaves: Leaves alternate except for lowermost leaves which may be opposite; petiolate; petioles 2-20 cm (0.8-7.9 in) long; leaf blades ovate to lanceolate-ovate, 10-40 cm (0.3-1.3 ft) long and 5-40 cm (0.1-1.3 ft) wide; margins serrate to coarsely toothed (rarely almost entire); surfaces hispid.

Flowers and Fruits: Flower heads large, showy, and radiate; yellow (rarely reddish or pinkish) ray florets with brown to purplish brown (sometimes yellow) center disk florets, solitary or few at the ends of stems and branches; heads peduncles 2-20 cm (0.8-7.9 in) long; phyllaries 20-30 mm, ovate to lanceolate-ovate, more or less pubescent, margins usually ciliate, apex a narrow tip; achenes glabrous or finely pubescent; pappus of 2 or more awns or scales. Flowers bloom from March to October, in NM most bloom in August.

Photos by Taryn Schlosser

Note: A highly variable species that hybridizes with other *Helianthus* species, including backcrossing between wild and cultivated individuals, which can make it difficult to assign to species. The heads and seeds of cultivated forms are very large. The species has a long history of cultivation. Flowers change color under UV light.

Forbs | Aster Family | Asteraceae | Exotic

Lactuca serriola

Photo by pinkspoonbill

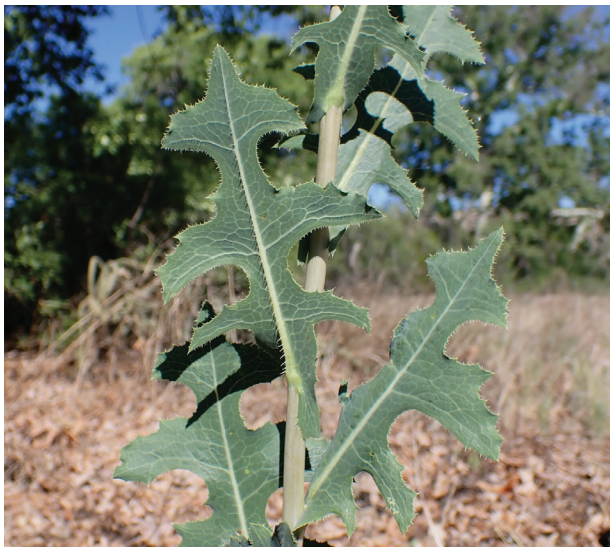

Photo by Radha Veach

Photo by Cecelia Alexander

Common Names: prickly lettuce, wild lettuce, compass plant, China lettuce

Code: LASE

Habitat: Found in fields, gardens, waste places, disturbed areas, and roadsides. Widespread throughout the state in nearly all terrestrial habitats, from desert to high mountainous elevations. Generally found below 9,000 ft. In Cibola, Sandoval, Santa Fe, Rio Arriba, Bernalillo, Torrance, Socorro, and Valencia counties. Facultative upland species for Arid West and Western Mtns, Valleys, and Coast regions; facultative species for Great Plains region.

General: Annual herb; stems 30-150 cm (0.9-4.9 ft) tall, hairless for most of the length but prickly at the bottom; leaves on lower ¾ of stems; produces milky sap.

Leaves: Leaves are twisted at the base to lie in a vertical plane; leaves alternate, stemless, and clasping the stem with two angled or earlike lobes; leaf blades with large prickles on the underside of the midrib and prickly on the pinnately lobed to lobeless margins; undivided cauline leaves oblong to lanceolate.

Flowers and Fruits: Flower heads are yellow, often drying blueish; ray florets only; each flowering head has 6-30 flattened fruits with 5-7 parallel ridges on each side; the fruit is bristly near the top. Flowers from July to September.

Note: A variant spelling is *Lactuca scariola*. Is known to hybridize with garden lettuce. Is edible.

Forbs | Morning Glory Family | Convolvulaceae | Exotic

Convolvulus arvensis

Photo by Rod

Common Names: field bindweed, creeping jenny, European bindweed, morningglory, perennial morningglory, correhuela

Code: COAR4

Habitat: Primarily an agricultural weed. Tolerates a wide range of habitats and grows well on disturbed sites such as roadsides, along railways, fields, pastures, gardens, and orchards. Found in riparian corridors and irrigated areas on tracts once used for agriculture. Generally grows below 9,000 ft. In Valencia, Cibola, Sandoval, Santa Fe, Rio Arriba, Bernalillo, Torrance, and Socorro counties.

Similar Species: Similar to *C. equitans*, which has narrower leaves with longer, narrower lobes at the base.

General: Perennial herb/vine from deeply set creeping rootstocks; exudes a milky sap; stems slender and branching, prostrate or twining, to about 1 m (3.3 ft) long; often forms large patches; herbage glabrous to pubescent.

Photo by Rod

Photo by Robert Eberhardt

Leaves: Leaves alternate along the stem on petioles 3-40 mm long; leaf shape variable; the blades 2-5 cm (0.8-2 in) long, to nearly 4 cm (1.6 in) wide, mostly arrowhead shaped but can be broadly lanceolate, oblong, to broadly ovate in outline, the lobes divergent or not, rounded, angled, to pointed.

Flowers and Fruits: Flowers white to pink, sometimes bicolored, in leaf axils, usually 1-3 flowers per node on long peduncles, calyx 3-5 mm long, corolla of 5 petals fully fused into a funnel shape. Flowers May to September.

Forbs | Legume Family | Fabaceae | Exotic

Medicago sativa

Photo by Dustin Chavez-Davis

Photo by eneecnm

Photo by Ellen Hildebrandt

Common Name: alfalfa

Code: MESA

Habitat: Cultivated as a crop nearly everywhere irrigation is available. Found in old fields, along roadsides, fields, trails, yards, and waste areas. Alfalfa is intolerant of waterlogged soils but requires a lot of irrigation as a crop. Generally found below 10,000 ft. In Valencia, Cibola, Sandoval, Santa Fe, Rio Arriba, Bernalillo, Torrance, and Socorro counties. Obligate upland species.

Similar Species: Other *Medicago* spp. and other clovers, but the purple flowers are fairly distinctive.

General: Perennial (sometimes annual) herb, the herbage obscurely pubescent; stems erect to ascending, very branched, 20-100 cm (0.6-3.3 ft) tall/long; roots deep.

Leaves: Leaves alternate, pinnately trifoliate; leaflets oblong to obovate, 10-25 mm long, toothed towards the apex; stipules entire or dentate proximally.

Flowers and Fruits: Flowers small, greenish-yellow or violet to deep purple, often varicolored with blue, green, yellow; in oval clusters arising from leaf axils; pods unarmed, generally coiled, also nearly straight to hooked, glabrous, indehiscent. Flowers April to October.

Note: Not all individuals produce seeds.

Forbs | Loosestrife Family | Lythraceae | Exotic

Lythrum salicaria

Photo by Michael Burns

This photo and below by A.M.

Common Names: purple loosestrife, spiked loosestrife

Code: LYSA2

Habitat: Found in disturbed wet places, seeps, springs, roadside ditches, and marshes. Grows best in unshaded, newly-exposed, moist soils. Occasionally grown in gardens and escaping. Its range in NM follows the Rio Grande. Elevation range 3,000 to 9,000 ft. In Bernalillo, Sandoval, and Rio Arriba counties. Obligate wetland species.

Similar Species: Similar to other *Lythrum* spp., but other species have 1-2 flowers per bract pair, while *L. salicaria* has many. Looks similar to *Verbena hastata*, but there is very little overlap between ranges.

General: Perennial herbs from creeping rhizomes; the stems 70-300 cm (2.3-9.8 ft) tall, with coarse hairs, especially near the branching inflorescence.

Leaves: Leaves mainly opposite or in whorls of three; stalkless, sometimes with a stalkless base lanceolate to ovate, to 10 cm (3.9 in) long and 2 cm (0.8 inches) wide, pubescent.

Flowers and Fruits: Inflorescence terminal and spike-like, 10-40 cm (0.3-1.3 ft) long, with numerous crowded flowers in the axils of two pointed, hairy bracts, at least two, usually more, flowers per bract axil; flowers heterostylous, bright purple-red, stalkless, with sepals and petals fused together (hypanthium); hypanthium tube 5-8 mm long, coarsely hairy; petals 5-12 mm long. Blooms July to October.

Forbs | Buttercup Family | Ranunculaceae

Clematis ligusticifolia

Photo by Spencer Hurt

Photo by Craig Martin

Photo by Christopher Rustay

Common Names: western white clematis, hierba de chivo, yerba de chiva, old-man's-beard, virgin's-bower, traveler's joy, leatherflower

Code: CLLI2

Habitat: Widespread in somewhat moist sites across NM including forest edges, woods, riparian deciduous woodlands, moist wooded draws, secondary sites derived from these, and clearings and pastures, usually near streams or on moist slopes. Does best in deep soils with good water holding capacity is semi-shade tolerant but grows well in full sun. Elevation range 3,000 to 10,000 ft. In Socorro, Sandoval, Rio Arriba, Bernalillo, Cibola, Torrance, and Santa Fe counties. Facultative species for Arid West and Western Mtns, Valleys, and Coast regions; facultative upland species for Great Plains region.

Similar Species: Similar to other *Clematis* species. Differs from *C. columbiana* by being dioecious.

General: Perennial, deciduous vine; usually herbaceous from a woody base; the stems clambering to climbing or trailing, up to 6 m (19.7 ft) long.

Leaves: Leaves opposite, on long petioles; leaves pinnately compound with 5-7 stalked leaflets; leaflets lanceolate to broadly ovate, lobed or unlobed, 2-9 cm (0.8-3.5 in) long; hairless to sparsely hairy on the under-side; margins entire or toothed.

Flowers and Fruits: Dioecious; inflorescence an axillary long-peduncled cyme, mostly 7-20-or more-flowered; four thin, petal-like sepals widely spreading, white to cream, 6-10 mm long; petals absent; male flowers with many stamens, lacking staminodes; female flowers with staminodes, pistils numerous; styles of female flowers elongate into an achene about 3 mm long, the beaks about 3 cm long; seeds hairy. Flowers from May to August.

Forbs | Lizard's Tail Family | Saururaceae

Anemopsis californica

Photos by deekyn

Common Names: yerba mansa, lizard tail, bear root

Code: ANCA10

Habitat: Found in wet, usually alkaline to saline soils, along streams, in wet meadows, in marshlands, and floodplains. Can tolerate shade. Often forms large colonies. Grows up to 8,000 ft. In Socorro, Valencia, Bernalillo, Sandoval, Rio Arriba, Santa Fe, and Torrance county. Obligate wetland species for Arid West and Western Mtns, Valleys, and Coast regions; facultative wetland species for Great Plains region.

General: Perennial herb/forb; rhizomatous; plants 10-80 cm (0.3-2.6 ft) tall; stems simple, densely pubescent to nearly glabrous, stoloniferous.

Leaves: Leaves large, leathery; basal leaves are elliptic-oblong; blades 1-25 cm (0.4-9.8 inches) long; margins entire, petioles 2-40 cm (0.8-15.8 in) long; stem leaves are located at the single node on each stem and include one sessile, clasping leaf, and 1-3 petioled leaves emerging from the axil of the sessile leaf.

Flowers and Fruits: Flower a fragrant, densely packed, conic spike, 1-4 cm (0.4-1.6 in) long, subtended by white to reddish petal-like bracts, 5-35 mm long; each individual flower in the spike is subtended by a small, round, white bract 3-6 mm long with a narrow claw; as the plant matures, reddish purple blotches appear on the leaves and stems. Blooming from March to September.

Note: Does not contain true petals or sepals and instead contains bracts imitating a perianth.

Forbs | Nightshade Family | Solanaceae

Solanum elaeagnifolium

Photo by Craig Martin

Photo by Jill DeVito

Common Names: silverleaf nightshade, trompillo, whiteweed, white horsenettle, bull nettle, tomato weed, white nightshade, tomatito de buena mujer

Code: SOEL

Habitat: Usually on disturbed ground and roadsides, along or in sidewalks, on or in sandy plains, arroyos, outwash slopes, and overgrazed fields, but not deep sands. Is shade tolerant and drought tolerant. Generally grows below 8,000 ft. In Socorro, Bernalillo, Sandoval, Rio Arriba, Santa Fe, Valencia, Torrance, and Cibola counties.

Similar Species: Can resemble *Croton* species, but *Croton* is never armed and is very shade intolerant.

General: Perennial rhizomatous herb/forb; often armed with stout prickles, but nearly unarmed individuals can be found in wetter sites; 15-100 cm (0.5-3.3 ft) tall, the herbage silvery to grayish-white, densely pubescent with appressed stellate hairs with the rays fused at the center.

Leaves: Leaves alternate, simple, narrowly lanceolate to oblong; to 15 cm (5.9 in) long and 3 cm (1.2 inches) wide; margins entire to undulate or sinuate, sometimes shallowly lobed; the lower surface densely covered in stellate hairs; petioles and leaf midribs prickly with yellowish spines.

Flowers and Fruits: Flowers showy and purple, occasionally white; corolla 5-lobed and flat and roundish; stamens bright yellow; berries round, green with pale green to greenish gray markings when immature, yellow to orange to brownish when mature; fruits containing brown, lens shaped seeds. Flowers March to October.

Note: Roots can grow to 3 m deep, sometimes more depending on the soil. Can spread by root fragmentation.

Shrubs | Aster Family | Asteraceae

Baccharis salicina

Photos by Cecelia Alexander

Common Names: seepwillow, willow baccharis, false willow, Great Plains false willow

Code: BASA

Habitat: Common on stream banks, flood plains, gypsum flats, moist roadsides, along arroyos and streams, and in alkali meadows. Is heat and drought tolerant, shade intolerant, and usually grows in disturbed soils, often in moist or dry, sandy, subsaline soils. Generally found up to 8,000 ft. In Socorro, Valencia, Bernalillo, Sandoval, Rio Arriba, and Santa Fe counties. Facultative wetland species for Arid West region; facultative species for Western Mtns, Valleys, and Coast and Great Plains region.

Similar Species: Similar to *B. salicifolia*, which is more willow-like, sticky, has evenly and finely serrate leaf margins, and the pappus on the achene is shorter. The two often co-occur.

General: Perennial shrub, dioecious; branched from the base, stems erect, 1-3 m (3.3-9.8 ft) tall, glabrous and resinous; branches striate with 5 ridges or nerves; twigs green, strongly striate-angled.

Leaves: Leaves alternate and short-petiolate, well-developed, persistent; blades oblong to oblanceolate; 2.5-7 cm (1-2.8 in) long and 5-10 mm wide; 3-nerved; lower leaf margins coarsely few-toothed, uppermost leaves narrower and often entire; apices acute or obtuse; glabrous and finely gland-dotted.

Flowers and Fruits: Heads in large paniculiform arrays, only disk flowers; involucre cone- or bell-shaped; phyllaries lanceolate, gland-dotted and glabrous, midribs green or reddish, scarious margins, apices greenish or purplish; female florets 25-30, the corolla hidden by long, white hairlike bristles; male florets 20-25, short bristles that extend barely above the involucre, corolla yellow; fruit glabrous, finely but distinctly ribbed, pappus 8-12 mm long. Flowers May to September-November.

Shrubs | Olive Family | Oleaceae

Forestiera pubescens var. pubescens

Photo by Dustin Chavez-Davis

Photo by lhenryunm

Common Names: New Mexico olive, stretchberry, desert olive

Code: FOPUP, FOPU2

Habitat: It grows along stream courses, moist valleys, hillsides, and mesas. Widespread throughout the state. Elevation range 2,000 to 8,0000 ft. In Socorro, Valencia, Bernalillo, Sandoval, Rio Arriba, Cibola, and Santa Fe counties. Facultative upland species.

General: Deciduous shrubs to 2-5 m (6.6-16.4 ft) tall; the young twigs hairy.

Leaves: Leaves opposite, commonly clustered on short shoots, elliptic to oblanceolate, glabrous to pubescent, with minute dark pits on the bottom surface, veins somewhat translucent; the margins commonly crenulate to serrulate, rarely entire.

Flowers and Fruits: Flowers inconspicuous and clustered; fruits elliptic, green when immature, bluish black when mature. Flowers late March to April before new leaves appear.

For Winter: Terminal buds ovoid, acute 2-3 mm long; lateral buds smaller; bud scales opposite, in 5-7 pairs, the lowermost gray-brown; margin ciliate, otherwise glabrous; uppermost bud scale honey-yellow to ochre-colored; surface partly with dead, gray-white lifting epidermis; twigs very slender, below the terminal bud <1 mm diameter, gray to gray-brown, with few pale dot-shaped lenticels; more mature bark has shallow rhomboid-furrows.

Note: The recognition of *Forestiera pubescens* var. *pubescens* is not universal, and both varieties recognized by the USDA occur in NM.

Shrubs | Willow Family | Salicaceae

Salix exigua

Photos by Cecelia Alexander

Photo by Craig Martin

Common Names: coyote willow, narrowleaf willow, sandbar willow

Code: SAEX

Habitat: Found in thickets along creeks, stream-sides, lake shores, sandbars, drainages, arroyos, and roads where there's the right micro-climate. Widespread throughout the state. Elevation range 1,500 to 10,000 ft. In Valencia, Cibola, Sandoval, Santa Fe, Rio Arriba, Bernalillo, Torrance, and Socorro counties. Facultative wetland species.

Similar Species: Young Gooding's willow, but Gooding's willow has more toothed/serrated leaf margins and usually has yellowish young branches and stems.

General: Deciduous, clonal, thicket-forming shrubs (or small trees) to 8 m (26.25 ft) tall, the branches ascending to spreading, gray, red, to yellow-brown, the bark thin and smooth, becoming shallowly fissured in age; the twigs red, gray, to yellow brown, glabrous to finely hairy to silky-hairy with usually spreading hairs; stipules mostly absent to rudimentary, sometimes leaf-like on later growth.

Leaves: Leaf blades narrowly ligulate; 3-14 cm (1.1-5.5 in) long, to 1 cm wide, somewhat glaucous and slightly hairy to glabrous on the top, silvery gray and silky-hairy on the bottom, margins entire or with widely spaced tiny teeth, slightly rolled under towards the midrib.

Flowers and Fruits: Male catkins 2-6 cm long, female catkins 2-7 cm long, the bracts deciduous after flowering; capsules 4-8 mm long, mostly glabrous. Flowers from March to June, with catkins appearing before or during leaf emergence.

Note: Dense thickets have a certain smell.

Shrubs | Nightshade Family | Solanaceae

Lycium pallidum

Photo by JD McCoy

Common Names: pale wolfberry, pale desert-thorn, rabbit thorn boxthorn, desert thorn

Code: LYPA

Habitat: Widespread throughout the state in a variety of habitats, often associated with past disturbance; our most common species, probably present in every county. Found on desert grassland, riparian areas, mesas, rocky slopes of canyons, hills, and mountains, piñon-juniper woodland, plains, along washes and arroyos; commonly grows on sandy or rocky soil. Is tolerant of saline soil. Elevation range 2,000 to 9,000 ft. In Valencia, Cibola, Sandoval, Santa Fe, Rio Arriba, Bernalillo, Torrance, and Socorro counties.

Similar Species: Similar to *Lycium torreyi*, but *L. pallidum* has a waxy glaucous coating on its herbage, calyx lobes 5-8 mm long, and corollas usually 15-20 mm long.

General: Perennial shrub with tough, fibrous roots; drought deciduous; zig-zagging branching pattern, spreading, 1-2 m (3.3-6.6 ft) tall; glabrous to finely pubescent; has sharp slender thorns, 5-10 mm long, bark yellowish, gray, or red to dark purple; branches glabrous to sparsely pubescent, often somewhat flexuous.

Leaves: Leaves short-petioled and in small clusters; clusters alternate; blades ovate to broadly elliptic to spatulate; 1-4 cm (0.4-1.6 in) long, 3-15 mm wide; apex acute or sometimes rounded; base tapering into a short petiole; surfaces glaucous green, and glabrous or nearly so; midvein and primary lateral veins usually visible.

Flowers and Fruits: Flowers pendulous on slender pedicels 6-12 mm long; solitary or in groups of 2-3; calyces bell-shaped, 5-8 mm long; calyx lobes the same length or exceeding the calyx tube; lobes glabrous or blue-glaucous; corollas tubular-funnelform, whitish-greenish and tinged with purple veins, mostly 15-20 mm long, sometimes shorter, glabrous; berries 8-10 mm in diameter, bright red at maturity, sometimes blue-tinged due to glaucescence, edible. Flowers (March-) May to June.

Photo by Cecelia Alexander

Photo by Craig Martin

Shrubs | Nightshade Family | Solanaceae

Lycium torreyi

Photo by Brandt Magic

Photo by Craig Martin

Photo by Ilja Fescenko

Common Names: Torrey wolfberry, desert thorn, boxthorn

Code: LYTO

Habitat: Found in alluvial flats and river bottoms, floodplains, washes, arroyos along the Rio Grande and its tributaries, as well as other watercourses. Commonly grows in dry, silty, sandy, and alluvial soils, and often occupies saline or alkali sites. Generally grows up to 7,000 ft. In Socorro, Cibola, Sandoval, Valencia, Bernalillo, and Santa Fe counties. Facultative species for Arid West and Great Plains regions; facultative upland species for Western Mtns, Valleys, and Coast region.

Similar Species: Similar to *Lycium pallidum*, but *L. torreyi* has no glaucous waxy coating, calyx lobes less than ½ as long as the tube, and corollas 7-13 mm long.

General: Perennial shrub with tough, fibrous roots; drought deciduous; much-branched, spreading to erect, 1-3 m (3.3-9.8 ft) tall, generally glabrous; unarmed or with a few big spines 5-10 mm long; bark yellowish-tan to brown; branches leafy and glabrate.

Leaves: Leaves short-petioled and in clusters of a few; clusters alternate along the stem; blades elliptic to spatulate; 1-5 cm (0.4-2 inches) long, 3-15 mm wide; acute or obtuse at the apex; base tapering to a short petiole; light green and glabrous.

Flowers and Fruits: Flowers 1-3 in the axils; calyces 3-5 mm long and lobed mostly less than ½ the total length; lobes with small fine hairs; corolla, whitish, greenish, purplish, tubular-funnelform, 7-13 mm long; corolla lobes with small fine hairs; berries 6-10 mm in diameter, bright red and juicy at maturity, edible. Flowers (April-)May to June.

Trees | Cypress Family | Cupressaceae

Juniperus monosperma

Photo by Paul Mitter

Photo by Craig Martin

Common Names: one-seed juniper

Code: JUMO

Habitat: Widespread and common in canyons, on plains, foothills, dry mountain slopes, dry hills and mesas, merging into grasslands at lower elevations and forests at upper elevations. Can be found in drier areas in the old floodplain of the bosque. Elevation range 3,000 to 7,500 ft. In Valencia, Cibola, Sandoval, Santa Fe, Rio Arriba, Bernalillo, Torrance, and Socorro counties.

Similar Species: Other *Juniperus* species.

General: Evergreen shrub or tree, 3-8 m (9.8-26.3 ft) or more tall; usually branching from the base with a shrub-like growth form; bark gray to brown to red-brown, peeling off in thin strips.

Leaves: Leaves scale-like; green to dark green; usually with a resin gland on the back.

Flowers and Fruits: Male and female cones on separate plants; pollen (male) cones located at branch tips, can make the whole tree look yellowish when blooming; seed (female) cones located at branch tips, berry-like, can be resinous, green with a waxy bloom when immature, reddish blue to brownish blue when mature; 1 (sometimes up to 3) seed per cone. Pollen shedding February to April, sometimes later.

Photo by David Jeffrey Ringer

Trees | Oleaster Family | Elaeagnaceae | Exotic

Elaeagnus angustifolia

Photo by CK2AZ

Photo by Mark G

Photo by Craig Martin

Common Names: Russian olive

Code: ELAN

Habitat: Found near human disturbance, often around springs, seeps, irrigation ditches, and riparian zones throughout the state. Plant is salt tolerant. Planted as an ornamental and frequently escapes. Elevation range generally 3,000 to 8,000 ft. In Bernalillo, Sandoval, Santa Fe, Rio Arriba, Socorro, Cibola, Valencia, and Torrance counties. Facultative species for Arid West and Western Mtns, Valleys, and Coast regions; facultative upland for Great Plains region.

General: Deciduous shrubs or small trees to 12 m tall; sometimes thorny; 1 to several-trunked; the bark dark brown, smooth when young, becoming fissured and shredding; older stems turn reddish brown; buds are grayish brown, tiny, rounded to oblong, with silvery scales.

Leaves: Leaves alternate; dark green with silvery scales on both sides, but less so on the top side (two-toned leaves); 2-10 cm long, to 4 cm wide; lance-shaped/oblong; margins entire.

Flowers and Fruits: Flowers solitary or in clusters of two-three near leaf axils; flower tubular, silvery outside and yellow inside; fruit ellipsoid, fleshy with an achene in the center, short-stalked, 1-2 cm long, silvery to finally brown. Flowers from May to June.

Trees | Willow Family | Salicaceae

Populus deltoides ssp. *wislizeni*

Photo by Roland Wirth

Common Names: Rio Grande cottonwood

Code: PODEW

Habitat: Widespread throughout the state except the northeast plains. Common in bosques, floodplains, river drainages, town plazas and parks, pueblos, and playgrounds. Elevation range 1,500 to 8,000 ft. In Bernalillo, Sandoval, Santa Fe, Rio Arriba, Socorro, Cibola, Valencia, and Torrance counties. Facultative species.

General: Fast-growing trees to 40 m tall; the trunk slender to massive, to 3.5 m (11.5 ft) diam; the bark reddish to grayish when young, becoming thick and furrowed; twigs glabrous to densely yellowish hairy; buds densely hairy.

Leaves: Petioles 1-9 cm long, ½ to equaling the blade length, flattened near the blade; blades ovate-rhombic to broadly deltoid; 3-12 cm long, about as wide; the bases broadly cuneate, truncate, rounded, to cordate; margins blunt-toothed; bright to pale green.

Photo by Paul Asman

Photo by Jim Boone

Photo by Brandt Magic

Flowers and Fruits: Flowers from late March to early May, with flowers appearing before the leaves.

Trees | Willow Family | Salicaceae

Salix gooddingii

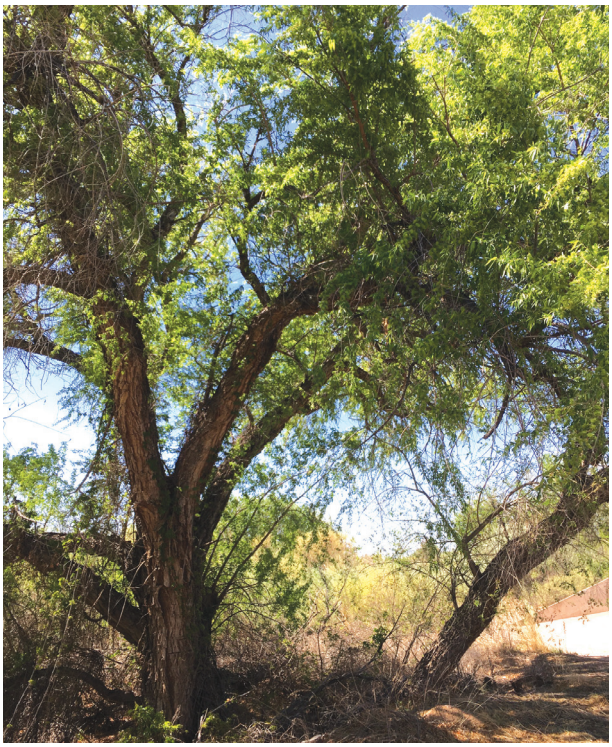

Photo by Devon Cox

Photo by titus9

Photo by titus9

Common Names: Goodding's willow

Code: SAGO

Habitat: Found along stream- and river-banks, arroyos, washes, in canyons, wet meadows, and marshy habitats. Grows in NM from the low plains and deserts up into the mountains. Widespread in the state except for the northeast corner. Elevation range 1,000 to 7,500 ft. In Bernalillo, Sandoval, Santa Fe, Rio Arriba, Socorro, Cibola, Valencia, and Torrance counties. Facultative wetland species.

Similar Species: Can look like coyote willow when young, but coyote willow has less toothed leaf margins and tends to have redder young branches and stems.

General: Deciduous trees 8-20 m (26.3-65.6 ft) tall, most commonly to 15 m (49.2 ft), the trunks to 100 cm (39.4 in) diameter; bark thick and gray, and split into many furrows and ridges; the twigs yellowish (sometimes reddish), generally hairy, often brittle at the base; the bud scales overlapping;

Photo by titus9

Leaves: Leaves alternate along branchlets; leaf blades linear to broadly oblong; 7-13 cm (2.8-5.1 in) long, 1-2 cm wide; upper and lower surfaces green to yellowish-green and hairless; margins finely toothed to serrate.

Flowers and Fruits: Male and female catkins on separate trees; catkins yellowish; male catkins 3-8 cm long; female catkins 3-8 cm long; the bracts deciduous after flowering; capsules 6-7 mm long, generally hairy, the stalks 1-3 mm long. Flowers from March to June, with catkins emerging at the same time as or after leaves.

Trees | Quassia Family | Simaroubaceae | Exotic

Ailanthus altissima

Photo by osodad

Common Names: tree of heaven, ailanthus

Code: AIAL

Habitat: Widespread throughout the state. Found along irrigation ditches and floodplains, roadsides, backyards, occasionally at old homesteads, vacant lots, and any disturbed urban area, including cracks in sidewalks and pavements. Elevation range 2,000 to 8,000 ft. In Bernalillo, Sandoval, Santa Fe, Rio Arriba, Socorro, Cibola, Valencia, and Torrance counties. Facultative upland species.

General: Fast-growing, weedy, deciduous trees, often forming colonies; roots are shallow and widespread; up to 35 m (115 ft) tall, but usually up to 25 m (82 ft); the bark smooth, light-colored, with whitish lenticels; the twigs reddish or grayish brown, glabrate (becoming hairless), with large heart-shaped leaf scars.

Leaves: Leaves odd or evenly pinnately compound; 15-90 cm (0.5-2.95 ft) long, to 30 cm

Photo by Craig Martin

Photo by Laurel Ladwig

(1 ft) wide; the leaflets 2-15 cm (0.8-6 in) long, 4-7 cm (1.5-2.8 in) wide, lanceolate to broadly ovate; green and glabrous (hairless) on top, hairy and glabrate on bottom; the bases rounded, often with basal teeth; margins entire; petioles 2- 15 cm (0.8-6 in) long; the axis of the leaf is reddish. Crushed up leaves smell like rotting peanut butter or something similarly unpleasant.

Flowers and Fruits: Petals 5, greenish yellow (sometimes pinkish), 2-3 mm long; stamens 10; pistils 5, separating in fruit; samaras 4-5 cm long and twisted at the tip. Flowers from June-July.

Trees | Tamarix Family | Tamaricaceae | Exotic

Tamarix chinensis

Common Names: salt-cedar, saltcedar, five-stamen tamarisk, tamarisk

Code: TACH2

Habitat: Found in waterways, ditch banks, arroyos, lakeshores, ephemeral water courses, wetlands, riparian drainages and floodplains, wet pastures, and springs. Disturbed sites, including burned areas, are favorable for establishment. Can grow well in arid, alkaline to saline habitats. Found at elevations up to 11,000 ft, but does not spread as rapidly at high elevations. In Bernalillo, Sandoval, Santa Fe, Rio Arriba, Socorro, Cibola, and Valencia counties. Facultative species for Arid West and Western Mtns., Valleys, and Coast region; facultative wetland species for Great Plains region.

Similar Species: Other *Tamarix* species. *T. chinensis/ramosissima* are 5-merous, more common, and flowers from spring to fall. *T. parviflora* is 4-merous, not as widespread, and flowers in the spring only. *T. gallica* is not expected to be as widespread around NM.

General: Perennial shrub/tree, deciduous, usually glabrous throughout; to 8 (26.25 ft) m tall but often only 4-6 m (13.12-19.69 ft); branches slender and flexible; younger branches are reddish in color, older bark is brown.

Leaves: Scale-like, triangular-ovate, acute, 1.5-3.5 mm long.

Flowers and Fruits: Racemes 2-7 cm (0.79-2.76 in) long, 3-5 mm wide in flower (wider in fruit); flowers 5-merous, pinkish-white to pink; pedicels about 1 mm long; petals 1-2.3 mm long, persistent in fruit; sepal margins entire; filaments emerging from between the lobes of the nectary disc, which can vary in symmetry, shape, and filament insertion; pistils 2.5-4 mm long; capsule narrowly ovoid, 3-4 mm long, splits open to release numerous tiny seeds with apical tufts of hair for wind dispersal. Flowers April to November.

Photo by brando18

Photo by Rod

Photo by Ethan Wright-Magoon

Note: Use *Tamarix* and TAMAR2 if not confident on species ID.

Trees | Elm Family | Ulmaceae | Exotic

Ulmus pumila

Photo by CK2AZ

Photo by lejones417

Common Names: Siberian elm

Code: ULPU

Habitat: Very common throughout the state. Found along roads, fences, streams and riparian areas, and in sandy soil in disturbed areas. Elevation range 2,000 to 8,000 ft. In Bernalillo, Sandoval, Santa Fe, Rio Arriba, Socorro, Cibola, Valencia, and Torrance counties. Obligate upland species.

Similar Species: Looks like American elm, but there are currently no confirmed reports of American elm (or any other elm in NM) in the wild.

General: Small to large deciduous trees 8-30 m (49-98 ft) tall; with open crowns; gray to brown bark that deeply furrows with age.

Leaves: Leaf blades 2-6 cm long, 2-3 cm wide; the bases rounded to slightly asymmetric; the margins mostly singly serrate; dark green and hairless to rough on the top and hairless on the bottom.

Photo by James N. Stuart

Photo by Fiana Shapiro

Flowers and Fruits: Samaras orbicular and hairless. Flowers March to April, with flowers appearing before the leaves.

For Winter: Leaf buds very small, dark brown, 1.5-2 mm long; flower buds red-brown, 3-4 mm long, and mostly in small groups; bud scales are densely shaggy-white ciliate at the margin; young twigs slender, only initially hairy and soon becoming hairless.

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P123 Photo by CK2AZ, https://www.inaturalist.org/observations/182798779, Licensed by CC BY. Photo by Mark G, https://www.inaturalist.org/observations/127457212, Licensed by CC0. Photo by Craig Martin, https://www.inaturalist.org/observations/25709807, Licensed by CC0.

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A2 GRGWA USDA PLANTS Code Cheat Sheet

Form	Scientific Name	USDA PLANTS Code	Common Name	Nativity
Graminoid	*Achnatherum hymenoides*	ACHY	Indian ricegrass, sand ricegrass, Indian millet, sandgrass	Native
	Aristida purpurea	ARPU9	purple threeawn	Native
	Arundo donax	ARDO4	giant reed	Exotic
	Bromus inermis ssp. *inermis*	BRINI	smooth brome	Exotic
	Distichlis spicata	DISP	saltgrass, inland saltgrass	Native
	Elymus elymoides	ELEL5	squirreltail	Native
	Phragmites australis ssp. *americanus*	PHAUA6	American common reed	Native
	Phragmites australis ssp. *australis*	PHAUA7	European common reed	Exotic
	Phragmites australis ssp. *berlandieri*	PHAUB2	subtropical common reed	Native
	Saccharum ravennae	SARA3	ravennagrass, elephant grass	Exotic
	Sporobolus airoides	SPAI	alkali sacaton	Native
	Sporobolus cryptandrus	SPCR	sand dropseed	Native
	Typha latifolia	TYLA	broadleaf cattail	Native
Forbs	*Anemopsis californica*	ANCA10	yerba mansa, lizard tail, bear root	Native
	Bassia scoparia	BASC5	kochia, burningbush, summer cypress	Exotic
	Clematis ligusticifolia	CLLI2	western white clematis, hierba de chivo, yerba de chiva, old-man's-beard, virgin's-bower, traveler's joy, leatherflower	Native

Form	Scientific Name	USDA PLANTS Code	Common Name	Nativity
Forbs	*Convolvulus arvensis*	COAR4	field bindweed	Exotic
	Helianthus annuus	HEAN3	common sunflower	Native
	Lactuca serriola	LASE	prickly lettuce, wild lettuce, false lettuce	Exotic
	Lythrum salicaria	LYSA2	purple loosestrife	Exotic
	Medicago sativa	MESA	alfalfa	Exotic
	Salsola tragus	SATR12	prickly Russian thistle, Russian thistle, tumbleweed	Exotic
	Solanum elaeagnifolium	SOEL	silverleaf nightshade, trompillo, whiteweed, white horsenettle	Native
Shrubs	*Baccharis salicina*	BASA	seepwillow, willow baccharis, false willow, Great Plains false willow	Native
	Forestiera pubescens var. *pubescens*	FOPUP	New Mexico olive, stretchberry, desert olive	Native
	Lycium pallidum	LYPA	pale wolfberry, pale desert-thorn, rabbit thorn boxthorn, desert thorn	Native
	Lycium torreyi	LYTO	Torrey wolfberry, desert thorn, boxthorn	Native
	Salix exigua	SAEX	coyote willow, narrowleaf willow, sandbar willow	Native
Trees	*Ailanthus altissima*	AIAL	tree of heaven, ailanthus	Exotic
	Elaeagnus angustifolia	ELAN	Russian olive	Exotic
	Juniperus monosperma	JUMO	oneseed juniper, one-seed juniper	Native
	Populus deltoides ssp. *wislizeni*	PODEW	Rio Grande cottonwood	Native
	Salix gooddingii	SAGO	Goodding's willow	Native
	Tamarix chinensis	TACH2	salt-cedar, saltcedar, five-stamen tamarisk, tamarisk	Exotic
	Ulmus pumila	ULPU	Siberian elm	Exotic

A3 Encountering an Unknown Plant

Figure 1. Habitat photo of *Urtica gracilis* (slender stinging nettle, an exotic plant). *Photo by Jax Gaglianese-Woody*

While many plants can be readily identified in the field, it is also common to encounter unknown plants that require further investigation. Confidently identifying all plant species on a plot can be important to the monitoring process, especially if shifts in plant species composition are used to evaluate the effectiveness of treatments and restoration. This section covers the NMFWRI field crew protocol for documenting and identifying unknown plants. It includes steps to take in the field, recommendations on how to take photographs that can best support later identification in the office, important notes and observations, and additional resources.

Procedure:

1. **Observe and take notes.** Begin by carefully observing the plant and its surroundings and taking detailed notes about its growth form and habitat. Ensure the plant is truly "unknown." Plants can look different from their "textbook" descriptions depending on the time of year; if they are only vegetative and not reproductively active; and if they are experiencing stress from disturbances (e.g. grazing or flooding). Try to minimize disturbance of the site when collecting information about the plant and its habitat.

   Gather as much relevant information about the plant's context as possible. This could include habitat, location within the riparian ecosystem (i.e., within the floodplain, on a bank, a terrace, along the

Figure 2. Above left: *Urtica gracilis* habitat 2. Above right: leaf with finger for scale. *Photos by Jax Gaglianese-Woody*

transition between riparian and upland, sitting in water), moisture conditions, associated vegetation, and surrounding dominant woody and herbaceous species. Also take note of its abundance and growth habits: is it solitary, in clumps, or is it evenly distributed on the landscape?

Finally, it is important to be familiar with the noxious, rare, and protected plant species in the project area. If it is possible that the plant falls into one of these categories, be sure to follow the relevant agency-specific reporting and collection protocols. Also consider if the plant might be outside its expected community-type or range. This is particularly important when monitoring an area that might be transitioning into a different habitat type.

2. **Document and photograph.** Clear diagnostic photos are valuable pieces of information and can be more useful than a poorly collected specimen. When documenting and photographing an unknown plant it is essential to capture all of its key identifying features.

   Photograph the plant at multiple scales, beginning with a habitat shot to show the plant in its broader context. Then, take an image of the whole plant to capture its overall growth form. Close-up photos are also important: document the leaves (both top and underside) and the stems, including any visible hairs, buds, or cross-sections. If flowers or fruits are present, photograph them from multiple angles. For woody plants, include photos of the bark that capture its color and texture. Be sure to also document the base of the plant, looking for features like a rosette of leaves, rhizomes, or clumping growth.

Tips for photographing plants for identification:

- Include a scale for reference, such as a ruler, compass, hand, notebook, or pencil.
- Focus on key traits often referenced in dichotomous keys, including leaf arrangement, leaf margin, presence of stipules, inflorescence structure, and surface texture.
- When photographing the entire plant, place a notebook or hand behind it to avoid background clutter, which can make identification more difficult.
- Avoid casting shadows on important structures.
- A 10x hand lens can sometimes act as a macro-lens for close-up shots when held up to a phone camera.

Figure 3. Clockwise from top left, *Urtica gracilis* leaf shape, stem and surface, node, adaxial leaf surface, and abaxial leaf surface. *Photos by Jax Gaglianese-Woody*

- Be aware of the maximum physical (as opposed to digital) zoom ratio of the camera's lens. Do not zoom past this point as that decreases the quality of the photograph and is no different than zooming in on the image itself when reviewing it later.
- If possible, photograph multiple individuals to provide additional context for identification.

3. **Record all relevant information before leaving the field.** This includes date, site coordinates, approximate height, growth form, if the plant is only vegetative or if it contains reproductive structures, abundance, substrate, and any other distinguishing characteristics (e.g., do the vegetative structures have a milky sap when broken? If flowers are present, are they solitary or in heads? Any distinguishing odors?).

4. **Collect a specimen (if necessary and permitted).** Collecting is only appropriate when a confident identification cannot be made from photos and if collection is permitted. It can be difficult to identify to species particular families and growth forms such as graminoids, asters, and individuals without reproductive structures; sometimes these plants require additional examination in the office.

   Before collecting a plant specimen, always ensure you have the necessary permissions and refer to relevant policies and management regulations for the project area. Consider whether the plant is rare in the area or classified as a conserved species. Also, consider if photos would suffice, and assess the stability of the population in the area before removing a specimen.

Considerations for collecting:

1. Do NOT collect specimens if the plant is classified as threatened or endangered, if the population contains fewer than twenty individuals, or if collection is not permitted.
2. Collect outside of plots.
3. Only take the minimum amount of plant material necessary for identification.
4. For herbaceous plants, collect a representative individual and include roots, stems, leaves, and any reproductive structures.
5. For woody plants, collect a branch with leaves, buds, and reproductive structures.
6. If bark is needed, avoid causing damage to the plant when removing and consider if a photograph of the bark is sufficient for identification.
7. Immediately label each specimen. Labels should include the date, location (with coordinates and locality), project name, plot ID, a description of the habitat, the collector's name, and a temporary field ID such as "Unknown A, project name, plot ID."

Additional resources:

Collecting and pressing plant specimens - https://nmfwri.org/wp-content/uploads/2026/06/NMFWRI-Guidelines-and-Protocols-for-Monitoring-Upland-Forests-Field-Manual-Version-2.pdf

A4 Plant Identification Resources

The following list of online and print resources are recommended by the authors. Identifying plants can be intimidating and requires a high level of attention to detail. For true beginners, the book *Botany in a Day* by Thomas Elpel provides training on how to observe plants. There are specific details and patterns that, if they can be recognized, make plant identification feel much easier.

Another recommended resource for beginners is the New Mexico Wildflowers app, available for Android and IOS devices. Users can search for plants based on botanical characteristics such as flower color or leaf orientation. This app can be used offline and contains photos, range maps, and descriptions for the 3,262 plant species in the app. It also links to other websites, including those listed below, for a given species (this feature requires an internet connection). Versions for most other US states are also available.

Finally, iNaturalist is an invaluable tool for identifying and documenting plants. This website and app have an automated plant identification feature; however, the identification provided can be flawed, and its accuracy depends on the quality of the photo and the plant's taxa. For example, iNaturalist is unable to correctly identify many grasses due to the nuances required for identification. But iNaturalist can still help in such cases; it is also a social platform that many experts and hobbyists frequent, and these users can provide, confirm, or deny identifications.

Online Resources

Field Guide to Diseases and Insects of the Rocky Mountain Region, U.S. Department of Agriculture, Rocky Mountain Research Station, U.S. Forest Service

https://www.fs.usda.gov/r02/natural-resources/forest-health/insects-and-disease-rocky-mountain-region

This tool is meant for field identification of biotic and abiotic agents that damage native trees in the USDA Forest Service's Rocky Mountain Region. It focuses on tree diseases and insects that have significant economic, ecological, and/or aesthetic impacts.

A Field Guide to the Grasses of New Mexico

https://nmfwri.org/wp-content/uploads/2019/12/grasses-field-guide-nm.pdf

Third Edition, by Kelly W. Allred

iNaturalist

https://www.inaturalist.org/home

An online nonprofit social network and citizen science project. It offers a website and mobile applications and includes an automated species identification tool, though accuracy for certain taxa is unreliable.

Minnesota Wildflowers: a field guide to the flora of Minnesota

https://www.minnesotawildflowers.info/

This website includes many southwest plants that have ranges extending into the Midwest. By Katy Chayka and other contributors.

New Mexico Department of Agriculture Memorandum on additions to the New Mexico Noxious Weed List
https://nmdeptag.nmsu.edu/media/pdf/noxious-weed-memo-and-list-june-2020.pdf
https://pubs.nmsu.edu/_circulars/CR698/
The latest update to the NM Noxious Weed List, current to July 2, 2020.

New Mexico Rare Plants
https://nmrareplants.unm.edu/rarelist
This list includes information on rare plants listed under varying jurisdictions in the state. Maintained by the New Mexico Rare Plant Technical Council.

New Mexico Thistle Identification Guide
https://www.npsnm.org/wp-content/uploads/2016/02/NM_Thistles_screen_or_8.5x11_2162016.pdf
Thistles are notoriously difficult to identify. Some species native to the US are rare or endangered, and there are non-native species that are noxious weeds. Produced by Robert Sivinski for the Native Plant Society of New Mexico.

New Mexico Wildflowers
https://wildflowersearch.org/search?page=Apps
A smartphone app available on Google Play Store and Apple App Store. Users can search by plant name, as well as botanical features such as flower color, leaf orientation, and location. App versions are also available for most US states, most Canadian provinces and Northern Mexico.

Plants of the Gila Wilderness
https://www.gilaflora.com/
by Dr. Russ Kleinman, Associate Botanist, Dale A. Zimmerman Herbarium. Presented in Association with the Western New Mexico University Department of Natural Sciences & the Dale A. Zimmerman Herbarium

Plants of the Middle Rio Grande Bosque Field Guide
https://yerbamansaproject.org/field-guide/
A free field guide from the Yerba Mansa Project, based in Albuquerque, NM. This is an ongoing project created using the iNaturalist platform.

Plants of the World Online
https://powo.science.kew.org/
An online taxonomic database published by the Royal Botanic Gardens, Kew.

Plant Term Glossary
https://gobotany.nativeplanttrust.org/glossary/a/
A glossary of plant terms by the New England Native Plant Trust's Go Botany initiative. Some entries have images or illustrations.

Recognizing Plant Families of the West Field Guide
https://www.blm.gov/colorado/blm-library/blm-library/recognizing-plant-families-west
By Carol Dawson and Phil Krening for U.S. Department of the Interior, Bureau of Land Management, 2021. Print copies available from the BLM Printed Materials Distribution Services.

SEINet New Mexico-Arizona Chapter
https://swbiodiversity.org/seinet/index.php

A database portal containing digitized herbarium collections, including spatial data. It also contains "taxon pages, checklists, and other tools to help you understand the plants in your region of interest." The SEINet network also includes other regional databases.

Southwest Colorado Wildflowers
https://www.swcoloradowildflowers.com/#WEBSITECONTENTS
by Al Schneider

USDA PLANTS
https://www.plants.usda.gov/
The US Government database with standardized information on kingdom Plantae. "Includes names, plant symbols, checklists, distributional data, species abstracts, characteristics, images, crop information, automated tools, web links, and references."

Weeds of the West, 9th edition by Tom D. Whitson. 2006.
https://wyoextension.org/agpubs/pubs/wsws-1.pdf

Wildflowers of New Mexico
https://npsnm.org/wildflowersnm/
by George Miller

World Wide Flowering Plant Family Identification
https://www.colby.edu/info.tech/BI211/PlantFamilyID.html
An electronic form developed from Hansen and Rahn's (1969) punched card system for flowering plant family identification. By Ray Phillips for Taxonomy of Flowering Plants course.

Print Resources

Botany in a Day: The Patterns Method of Plant Identification by Thomas J. Elpel. 2004.
https://mountain-press.com/products/botany-day

Diseases of Trees and Shrubs by Wayne Sinclair and Howard H. Lyon. 2005.
https://www.cornellpress.cornell.edu/book/9780801443718/diseases-of-trees-and-shrubs/#bookTabs=1

A field guide to the Plants and Animals of the Middle Rio Grande Bosque
https://publiclands.org/products/a-field-guide-to-the-plants-and-animals-of-the-middle-rio-grande-bosque?srsltid=AfmBOoqODALq_tUndNe3LAOvSw_qni1CcsH_BDJ5mLUOkgczfwfr-fXb

Flora Neomexicana III: An Illustrated Identification Manual, 2nd Edition. By Kelly W. Allred, Eugene M. Jercinovic, & collaborators. Illustrated by Robert DeWitt Ivey.
https://floraneomexicana.org/flora-neomexicana-series/
Also available for free download as PDFs.

Flowering Plants of New Mexico by Robert DeWitt Ivey. 5th Edition published 2008.
https://www.lulu.com/shop/robert-dewitt-ivey/flowering-plants-of-new-mexico/paperback/product-1qn85y9v.html?page=1&pageSize=4

A Guide to Plants of the Northern Chihuahuan Desert by Carolyn Dodson. 2012.
https://www.unmpress.com/9780826350213/a-guide-to-plants-of-the-northern-chihuahuan-desert/

Identification of Trees and Shrubs in Winter using Buds and Twigs by Bernd Schulz. 2nd edition, 2025.
https://press.uchicago.edu/ucp/books/book/distributed/I/bo257334147.html

Meet the Natives: A Field Guide to Rocky Mountain Wildflowers, Trees and Shrubs by Walter M. Pesman. 2018

Mountain Wildflowers of the Southern Rockies by Carolyn Dodson and William W. Dunmire. 2007.
https://www.unmpress.com/9780826342447/mountain-wildflowers-of-the-southern-rockies/

Plant Identification Terminology: An Illustrated Glossary by James G. Harris. 2001.
https://upcolorado.com/university-press-of-colorado/plant-identification-terminology

Plant Names Explained: Botanical Terms and their Meaning by Julia Britton. 2005.

The Sunflower Family: A guide to the family Asteraceae in the contiguous United States by Richard Spellenberg and Naida Zucker, 2019.
https://shopbritpress.org/products/sunflowerfamily

Trees and Shrubs of New Mexico Revised and Expanded by Jack L. Carter. 2020.
Available from Gila Native Plant Society: https://gilanps.org/books/

Vascular Plants of New Mexico by Kenneth Heil and Steve L. O'Kane Jr. 2024.
https://press.uchicago.edu/ucp/books/book/distributed/V/bo237308748.html

Wildflowers of the Northern and Central Mountains of New Mexico by Larry J. Littlefield and Pearl M. Burns. 2015.
https://www.unmpress.com/9780826355478/wildflowers-of-the-northern-and-central-mountains-of-new-mexico/

Winter Botany: An Identification Guide to Native Trees and Shrubs by William Trelease. 3rd edition, 2011.
https://store.doverpublications.com/products/9780486218007?srsltid=AfmBOoq7Ue4Wdgc71F1EYS9GLfdMqhCxS8cbjAVUKZvCjh_QOQNJWwvT

B1 Creating a Basic Site Map

Riparian restoration projects tend to be relatively small in size. However, riparian ecosystems are often diverse and composed of a mosaic of several vegetation communities. Because of the complexity of riparian monitoring, a critical first step is the creation of a detailed site map. The map will indicate the basic cultural and natural features and indicate the structure and composition of the vegetation. It will also serve as the basis for stratifying the project area into similar vegetative units and provide the framework for planning the location of the sampling sites.

In mapping a project area, detailed aerial images of the area are a good place to start. Hydrologic features, structural elements, and distinct vegetation patches can be delineated in the office. Although low-level, high-resolution aerial photography is ideal, base maps can also be created using United States Geological Survey (USGS) quads or free computer tools such as Google Earth (*See Supplement B2 for instructions on creating site maps in Google Earth*).

We also suggest consulting this resource called Creating and Sharing Maps with Online Tools, for more support in creating maps: https://storymaps.arcgis.com/stories/a001f65811e64865aa39cf7fc07c8e01

A hard-copy base map and a Global Positioning System (GPS) unit should be used during field reconnaissance and the collection of baseline data. During this initial phase of field work, detailed observations are important in order to accurately characterize current conditions. Observations may be geographically referenced using the GPS unit or simply drawn on the map. Spending time observing site dynamics can go a long way to developing a successful restoration monitoring project. When conducting the site analysis, it's important to involve as many members of the partner team as possible and to map all relevant landmarks and obstacles, such as fence lines and jetty jacks.

Water features that should be noted include:

- Main stream channel, side channels, and ditches
- Dry washes and gullies
- Surface water at the site and whether it is standing or flowing

If standing surface water is present, it may also be helpful to measure and record the depth, length, and width of this area to detect changes and/or accurately map the site. Consulting river gauge data will help to define the relationship between the standing water and high flow periods. This information coupled with multiple site visits will help to determine the length of time that the site is usually inundated each year. The average period of inundation is an important parameter in selecting appropriate plant species for revegetation. Long periods of soil saturation limit the growth and survival of woody riparian species, which generally require highly aerated soils. A restoration site with a long period of inundation may be more successfully treated as a wet meadow and planted with appropriate herbaceous species. Keep in mind that, in areas where beaver are present, inundation may be a dynamic process which is difficult to predict from one year to the next.

As with any inventory, it is important to walk the entire project area and sketch out areas of different species composition and/or density of vegetation, noting any obvious differences in soil moisture or texture. Although access may be difficult where dense stands of saltcedar or Russian olive are present, it's essential to explore as much of the area as possible, identifying and sketching major vegetation communities across the site. If identified, important microhabitats such as wetlands can be avoided by heavy equipment or herbicide application.

Other important observations include:

- Identification of plant species, collecting samples of any species that are abundant for later identification
- Presence of exotic species
- Hydrologic clues from plants. For example, cattails, willows, or herbaceous species such as meadow fescue that require wet soil; xeric species such as four-wing saltbush and prickly pear; and species such as four-wing saltbush, saltgrass, and switchgrass that may indicate saline or moderately saline soil.[1–3]

Works Cited

1. Howard, J. L. Atriplex canescens, fourwing saltbush. *Fire Effects Information System,[Online]. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer)*. https://research.fs.usda.gov/feis/species-reviews/atrcan (2003).
2. Uchytil, R. J. Panicum virgatum, switchgrass. *Fire Effects Information System,[Online]. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer)*. Available:*https://research.fs.usda.gov/feis/species-reviews/panvir* (1993).
3. Hauser, A. S. Distichlis spicata, saltgrass. *Fire Effects Information System,[Online]. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer)*. https://research.fs.usda.gov/feis/species-reviews/dispi (2006).

B2 Making a Simple Map in Google Earth

Google Earth Pro is a user-friendly platform that, while limited in functionality when compared to a program like ArcGIS Pro or QGIS, offers most of the mapping tools needed to plan and coordinate monitoring. Its strength is in the simplicity of its user interface and in the ease with which it allows for the sharing of large complex spatial datasets.

This brief introduction will cover the basics necessary for managing a monitoring project in Google Earth Pro, including:

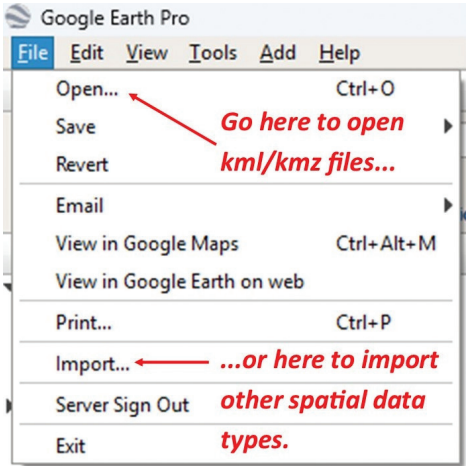
- Navigating the program
- Importing files in various formats
- Drawing features such as polygons, lines, and points
- Organizing features in a map
- Georeferencing images
- Changing the appearance of layers and designing a finished map
- Exporting a map to various formats
- Opening an exported map on a hand-held device

This is not an exhaustive tutorial for the program. At the end there are additional resources for further reading.

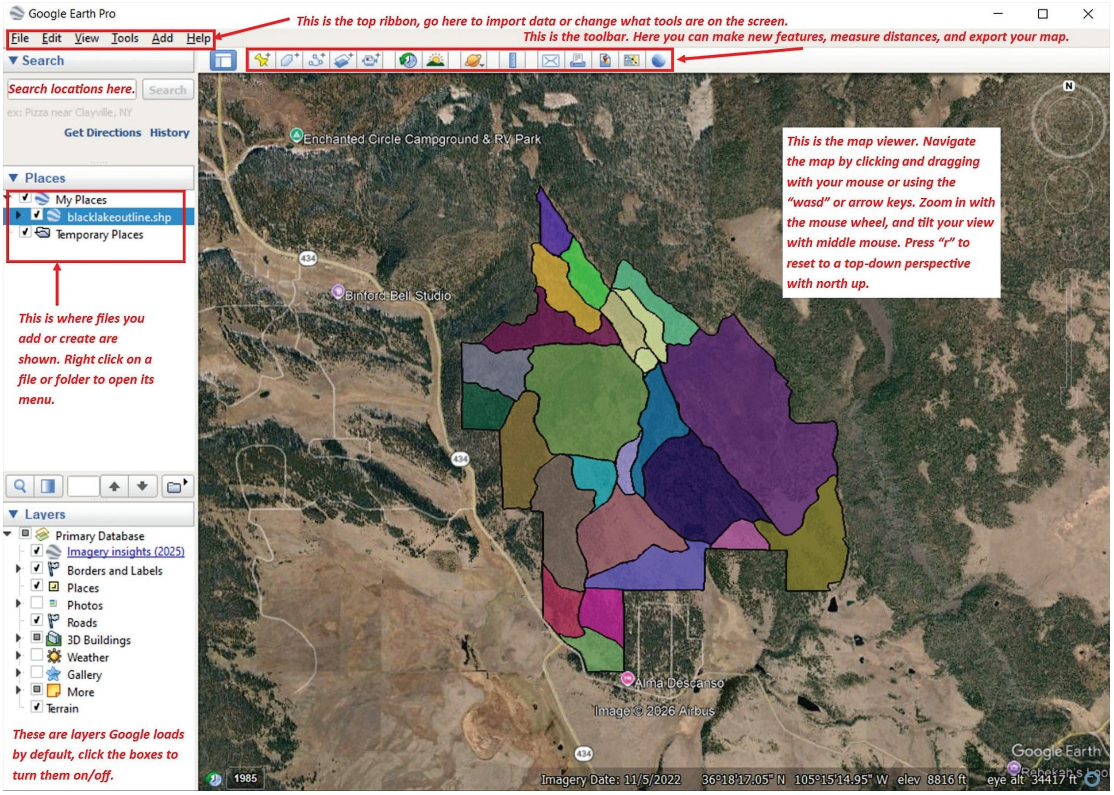
Importing Files

To begin, define the project area. Earth Pro supports importing polygons, lines, and points as well as drawing them in the program.

- **To import a file**, open Earth Pro and **go to "File" in the top ribbon** then click on "Open" or "Import" and select the file to view.
    - **"Open"** is meant for files in Google's own "Keyhole Markup Language" (.kml file endings, .kmz for zipped files).
    - **"Import"** is for files in other formats of spatial data such as Esri shapefiles (.shp) or GPS exchange files (.gpx).



- Either option works for most kinds of geospatial data files. The only difference is in how they handle shapefiles with many features (at least thousands). **When importing very large shapefiles, use the "Import" option.**
- It may be necessary to **select the file type being imported from the drop-down menu** on the right of the file-selection window that opens. Alternatively, scroll all the way to the bottom of the menu and choose "All files"—this will show file types even if they can't be opened.



When importing a non-kml file Earth Pro will ask whether it should apply a style template to the features. This pop-up can be ignored, but it is generally a good idea to say yes as the next menu gives the option for choosing a column from the imported features' data table to act as names. This choice is only available when first importing data. The appearance of features can be changed here too, although all these options will still be available later.

When a file opens, the map view automatically zooms to the imported features' location. Take a second to make sure that the features are in their expected places.

Drawing Polygons, Lines, and Points.

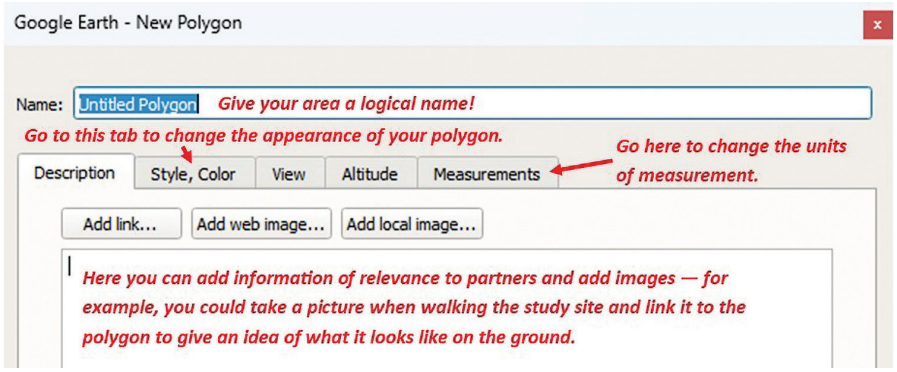
It might be necessary to start a map from scratch in Earth Pro. To begin, navigate the map viewer to the location of the project.

- **Addresses, locations,** or **coordinates** can be searched in the box to the top-left of the map viewer.

- **To move the map, click-and-drag in the map viewer** or use the W-A-S-D key cluster or arrow keys.
- **Zoom by scrolling the middle mouse button** and adjust the viewing angle by pressing and holding this button.

- The bird's eye view can distort the map perspective, to avoid this, **reset the view to be top-down and north-up with the "r" key** before marking up an area.

In the toolbar above the map view are a few options: add placemark, add polygon, or add path. These do what they say on the box; a placemark is a point and a path is a line. A polygon is most suitable for a project boundary.



Click on "add polygon." A pop-up window opens that gives the option to change several things about the feature being drawn including its name, description, appearance, and measurement units. All these options will still be available after the feature is complete, but **do not close this window** until the polygon is finished as this will exit editing mode. If the window is closed accidentally, or further edits are necessary later on, it can be re-opened by right-clicking on the feature and selecting "Properties."

- To draw the polygon, **left-click on the map to add vertices.**
- **Select a vertex to delete it or drag it** to a different place.
- Once the polygon is complete, **click "Ok"** on the "New Polygon" window.
- Points and lines can be added in the same way.

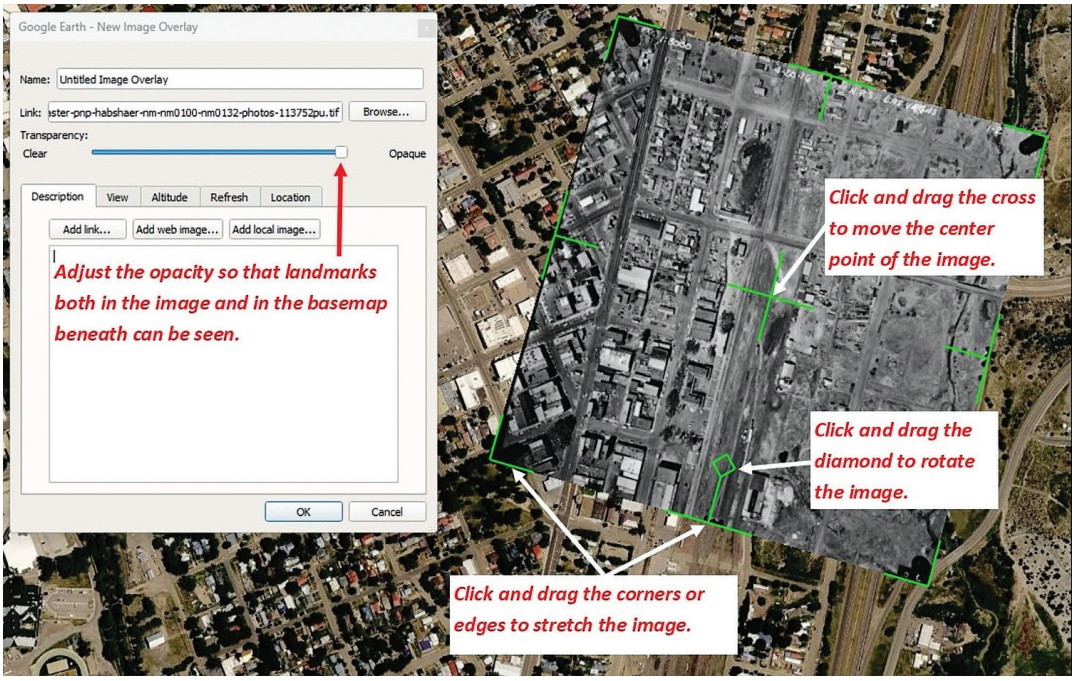
As features are added to the map, they will appear under the "Places" pane to the left of the map viewer. Here they can be moved between folders or organizing into new folders. Create a new folder by right-clicking on either the "My Places" or "Temporary Places" root folders.

Georeferencing Images

Sometimes, information relevant to a project is not in a specialized spatial data file format but instead in an image (.jpeg, .png, .tiff); for example, project boundaries sketched on a physical map or treatment information found in historical aerial photos. If dealing with this sort of information is a large part of

the anticipated workflow it might be best to dive into learning QGIS as it allows for much more accurate georeferencing, but basic tasks can be done in Earth Pro.

- To start, move the map to view the area of interest, then **go to the toolbar and select "Add Image Overlay."** This opens a window much like the one for drawing a polygon, where the layer can be named and a file selected to be imported (e.g., a scan of a physical map from walking the project area).
- Choose an image and Earth Pro will lay it directly on the map. Be aware that it is not possible to crop an image once it has been imported, so make any necessary edits like removing image borders first. This can be done in most image viewers.



- Adjust the opacity so that both the geographic landmarks in the image and those on the basemap beneath it are visible.
- **Use the green cross at the center of the image to position it, the green diamond to rotate it, and pull on the edges and corners to stretch the image.** A good practice is to choose four landmarks that are highly visible in the image, one in each corner, and then manipulate the image until these landmarks overlay the same landmarks on the basemap.
- **Choose reference landmarks that are unlikely to change** such as crossroads or major buildings in case the image and the basemap are from different times. Be aware that it will likely be impossible to make the image and the basemap match exactly, as Earth Pro does not allow for the image "warping" necessary to fit most images exactly to a projected map. The smaller the area, the less this discrepancy will matter.
- Features from the image can be digitized by creating new polygons as previously described.

Editing the Appearance of Features

The appearance of a feature can be changed either when first creating it or by right-clicking on it in the "Places" pane and selecting "Properties" if it is already on the map. In the edit window that opens, **navigate to the "Style, Color" tab.** Here various elements can be adjusted, including the fill, outline, and opacity of polygons; the label, icon color, and scale of placemarks; and the color and size of paths. It is also possible to change the icon for placemarks but this option is directly to the right of the name field in the editing window, rather than under the "Style, Color" tab.

Several features can be edited at once if they are in the same folder. Right-click on the folder and go to its properties. Under "Style, Color" **select "Share Style" to edit all features in the folder simultaneously.** This also gives the option of randomizing the fill colors for all features in the folder, which can be useful for distinguishing separate areas adjacent to each other.

Below the "Places" pane is the "Layer" pane that controls which of Google's own pre-loaded layers are displayed on the map. For example, select the box next to "Roads" to show/hide Google's road lines or expand the drop-down next to "More" and click the box next to "Parks/Recreation Areas" to show outlines of green spaces.

Exporting and Sharing a Map

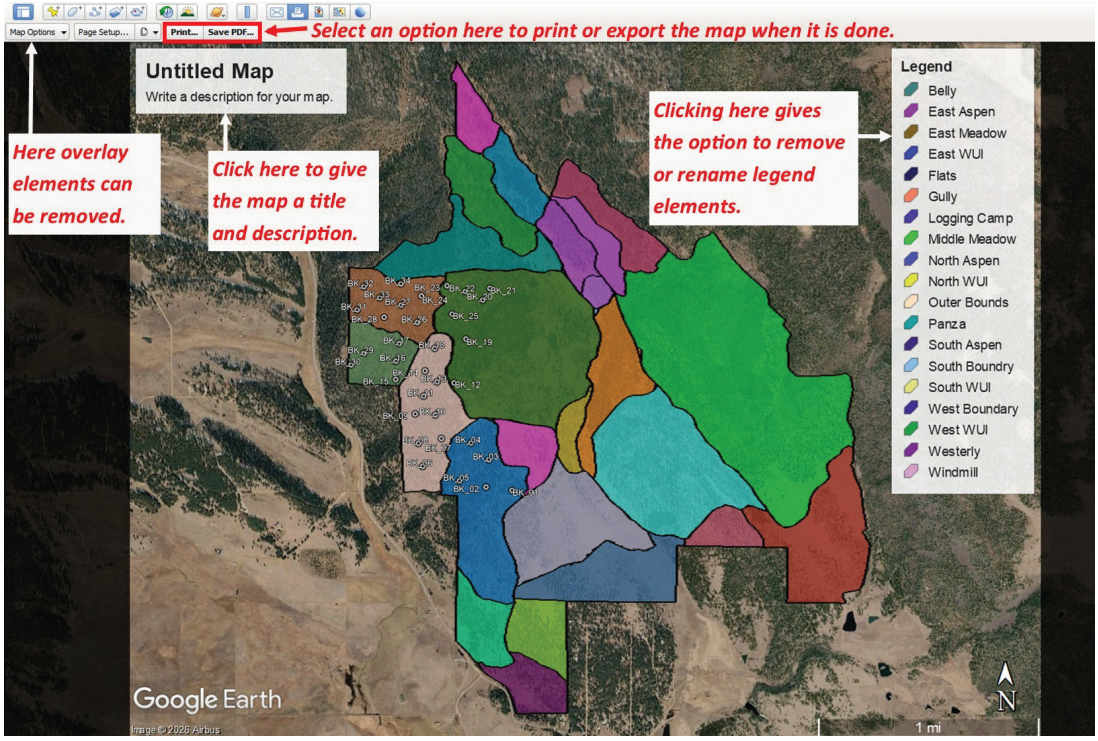
On the right of the toolbar are several options: **Email, Print,** or **Save Image.** Selecting "Email" gives a few more options to send either a screenshot, the current view, or the selected placemark/folder.

- **Sending a screenshot** is the simplest way to share a map but be aware that this will send a simple image of exactly what is in the map viewer when this option is chosen and selecting either "Print" or "Save Image" gives more customization options.
- **Emailing the "Current View"** simply sends a link that opens the current map view in Google Earth for the recipient, but they will not see any of the features on the map.
- Finally, **choosing "Selected Placemark/Folder"** will send the currently selected features to the recipient as a .kml/.kmz file which they can then open in their own map viewer of choice.

This last option is the same as right-clicking on the feature/folder in the "Places" pane and selecting "email" from the context menu. Also in the right-click menu is an option to "Save As" which will download the feature as a kml/kmz which can then be shared by email later or opened in a different mapping program.

The **"Print"** and **"Save Image"** options are slightly different. Choose one of these options to share a polished image but not the underlying data of the map. A paper map can be useful in the field or for sharing with partners that want to simply see the map rather than interact with it.

- **To print the map directly** or save it as a pdf choose **"Print."**
- **To save it as a .jpg or .png** choose **"Save Image."**
- Selecting either of these options will open **a "layout" view** that adds a title, legend, compass, and scale bar to the map view.



- Under the tool bar there is a new drop-down menu with **"Map Options"** where these overlays can be turned on or off. Click on the title to change the name of the map or select the legend to remove features or name them differently.

Once the appearance of the map is finalized, print it or save it to the desired format.

Google My Maps

It is also possible to **access features from Earth Pro directly in a handheld device**, or have them **in a map embedded in a website.** These options are available through Google My Maps.

- First, **choose the features** to share and **download them** from Earth Pro.
- Next, go to **Google My Maps** (mymaps.google.com) and **create a new map**. Give the map a title, and import the files from Earth Pro.
- **Create a layer** for each type of feature being imported. For example, put points into one layer and polygons into another. The appearance of all features in a layer can be changed with the paint roller icon, or that of individual features can be adjusted by clicking on the paint bucket next to their names.

Now, share the map with the button below the title. Choose who can access it and share it on Google Drive. If the goal is to have the map on a website it will need to be publicly accessible. To the right of the map title is a drop-down menu that gives the option to embed it in a site.

The map can also now be accessed from a phone with Google Maps, providing the same account is used for both Google Maps and My Maps. In the app go to "You," scroll all the way down to the bottom and select "Maps." Choose the map shared from My Maps and the features will be displayed in the app.

Further Google Earth Resources

Google Earth Pro User Guide: https://earth.google.com/intl/ar/userguide/v4/index.htm

Google Earth Pro (and Web) tutorials: https://www.google.com/earth/outreach/learn/

Google Earth (Web, mainly) blog with information on the latest program developments: https://blog.google/products-and-platforms/products/earth/

Google Earth (again, mainly web) YouTube channel with lots of information on how to use Earth Engine and cool examples of projects: https://www.youtube.com/@googleearth/videos

Storymap on Google Earth *and* other mapping resources: https://storymaps.arcgis.com/stories/a001f65811e64865aa39cf7fc07c8e01

Other GIS Programs

ArcGIS; the industry standard and subscription required: https://www.esri.com/en-us/home

QGIS; similar capabilities as ArcGIS and free: https://qgis.org/

For other more specialized options, check out this ranked list of GIS programs: https://gisgeography.com/best-gis-software/

B3 Spatial Data Resources

Supplemental data may be helpful in planning riparian restoration and monitoring activities. Publicly available digital datasets may inform project planning or monitoring by providing ecological or social context. For example, the US Web Soil Survey provides mapped soil information that can inform which plant species are likely to succeed in revegetation efforts, or the monitoring units might be created based on soil type.

Figure 1. Spatial resources, like the NMRipMap, can be helpful in planning riparian restoration and monitoring activities.Credit: Screenshot from https://nhnm.unm.edu/riparian/NMRipMap

Here we provide some data resources that we think are useful and relevant. The resource list in Table 1 is not exhaustive but rather focuses on local datasets that are up-to-date and currently accessible. Some datasets are longstanding, such as weather observations, while others represent the latest innovations in characterizing riparian ecosystems.

The quantity and quality of spatial data is rapidly rising as smartphones, drones, sensors, and satellites offer unprecedented access to location-based information collection and analysis within Geographic Information Systems (GIS). Many spatial datasets are hosted in ArcGIS Online (AGOL) where they can be viewed and manipulated but the data are not available for download. Those spatial datasets that can be downloaded at the time of this publication and utilized for additional analyses are noted in Table 1.

Remote sensing is the science of gathering information from a distance (using sensors on satellites, aircraft, or drones) to detect and measure reflected and emitted energy. Utilizing specific wavelengths of light to capture different phenomena, sensor snapshots are mathematically processed to describe vegetation, water, or soil properties. Remote sensing data products may include direct measurements of physical properties collected by sensors such as temperature or reflectance, but more often, remote sensing provides calculated indices. These ecologically meaningful metrics may be developed using a fully automated process or may be merged with a human interpretation component and, in some cases, there may be observations and modeled datasets for the same variables. For example, temperature and rainfall are measured and reported for individual weather stations. Models extend those observations across the landscape to produce gridded products that summarize weather for any location and time period. These datasets help extend and expand the information available about a particular piece of ground but, like all models, they should be understood in the context of their assumptions, appropriate scale, and intended use. We have provided a brief summary of these features below for the data products linked in Table 1. Digital data outputs should be collaboratively evaluated by project partners (including local knowledge holders and subject matter experts) to ensure that local conditions are accurately characterized prior to any decision-making or policy-setting. Resources are listed and linked in Table 1 with additional details describing the datasets provided following the table, presented in alphabetical order.

Data Resources

Feature	Description	Data Source	Available at	Download Available
Vegetation	Riparian plant communities	NM RipMap	https://nhnm.unm.edu/riparian/NMRipMap	yes
Riparian connectivity	Riparian connectivity	NM Natural Heritage Riparian Conservation Opportunity Areas	https://nhnm.unm.edu/rcoas	yes
Aquatic connectivity	Low-head dam inventory	US Army Corps of Engineers	https://nid.sec.usace.army.mil/lhdi	no
Surface water	Drainage map	USGS NHD	https://apps.nationalmap.gov/downloader/	yes
	Streamflow and discharge	USGS	https://waterdata.usgs.gov/state/New%20Mexico/	
	Water quality	NMED SWQB	https://www.env.nm.gov/surface-water-quality/water-quality-monitoring/	
Groundwater	Depth to groundwater map	Healy Collaborative Network	https://weaver.newmexicowaterdata.org/collabnet	yes
Wildlife habitat	Beaver habitat	Beaver Restoration Assessment Tool	https://data.riverscapes.net/p/d74c8d3d-ca3a-4fd7-922c-41bc1e8d3875/	yes
	Potential habitat for Southwestern willow flycatcher	USGS	https://usgs.maps.arcgis.com/apps/webappviewer/index.html?id=b362c94bd7714969805ab7dd29336ce0	no
Evaporative demand	Evapotrans-piration	OpenEt	https://etdata.org/	yes

Feature	Description	Data Source	Available at	Download Available
Weather	Weather station observations	WRCC	https://wrcc.dri.edu (requires free registration)	yes
		NIFC RAWS	https://data-nifc.opendata.arcgis.com/datasets/nifc::public-view-interagency-remote-automatic-weather-stations-raws/about	yes
		ZiaMet	https://weather.nmsu.edu/ziamet/	
		CoCoRaHS	https://www.cocorahs.org/	
		NSF NEON	https://data.neonscience.org/	
	Gridded climate data	PRISM	https://prism.oregonstate.edu/ (requires free registration)	yes
Soils	NRCS site allows user to download soil surveys as shapefiles. User can also generate custom reports.	NRCS	https://sdmdataaccess.nrcs.usda.gov/	
	NRCS site allows user to create soil surveys for a defined area.	NRCS	https://websoilsurvey.sc.egov.usda.gov/app/	

Table 1. Data resources

Beaver Habitat Suitability

The New Mexico statewide BRAT (Beaver Restoration Assessment Tool) modeling project provides the most comprehensive analysis to date of where beaver activity can support riverscape restoration, conservation, or coexistence management across the state. Over 23,000 km of perennial streams were evaluated to estimate beaver dam capacity, human-beaver conflict risk, and priority reaches for restoration and conservation. By knowing which stream reaches are best for beavers to build dams and where they are most likely to cause problems, land managers can set realistic expectations and achieve better restoration outcomes.

Healy Collaborative Groundwater Monitoring Network

A public network of hundreds of groundwater wells with collaborative data collection and regular depth to water measurements across New Mexico. The network is designed to track groundwater trends and support decision-making, mostly in rural and under-monitored regions of the state.

Low-head Dam Inventory

The National Low-Head Dam Inventory includes information on more than 10,000 low head dams, which can create barriers for aquatic organisms and sediment. Users can find artificial in-stream structure locations and suggest missing dams for addition.

National Hydrography Dataset

The National Hydrography Dataset (NHD) is a national-scale map of surface water features produced at 1:24,000 scale by the U.S. Geological Survey (USGS). Used as the authoritative map of streams, rivers, canals, lakes and ponds for decades, the dataset is currently getting a 3D makeover to improve spatial accuracy and better support hydrologic and hydraulic modeling. Although officially retired and no longer maintained, NHD data remain available in a geodatabase or shapefile format.

New Mexico Environment Department Surface Water Quality Bureau (NMED SWQB) Water Quality

The Surface Water Quality Bureau at the NM Environment Department monitors water quality in surface water bodies across the state on a 10-year rotation. Summary reports are available by watershed or waterbody and raw water quality data (flow, temperature, pH, dissolved oxygen, turbidity, and specific conductance) can be downloaded by location.

New Mexico Riparian Conservation Opportunity Areas (RCOAs)

The Riparian Conservation Opportunity Areas (RCOAs) spatial toolkit was built upon NMRipMap to support conservation and restoration planning for New Mexico's riparian and wetland resources. The portfolio applies prioritization of habitat value and conservation within a GIS framework that includes vegetation composition, landscape features, and ownership. RCOAs are discrete sites in river corridors (> 12 acres) that provide operational targets for local and basin-wide conservation and restoration planning to improve overall riparian health and habitat connectivity throughout the state.

New Mexico Riparian Habitat Map (NMRipMap)

A fine-scale, comprehensive map of riparian and wetland vegetation along all perennial rivers and streams in New Mexico. By including intermittent stretches that connect the perennial reaches, the map reflects continuous riparian corridors. The full floodplain extent is mapped along all perennial streams regardless of current land use. Natural riparian areas and wetlands are mapped as well as agricultural and urban areas located in the historic floodplain. The map was produced through a process that combined aerial imagery, LiDAR, environmental data, field data, GIS analysis, and photo interpretation. NMRipMap is designed for use at a 1:6,000 spatial scale so higher-resolution mapping is recommended for project-level detail.

OpenET

OpenET uses remote sensing to estimate evapotranspiration (ET) for improved water management across the western United States. Nearly real-time, the satellite-based model data are reflected on the website within a few days. The tool accurately estimates water use at the agricultural field scale currently, but the model performance has not been fully evaluated in riparian ecosystems. Riparian ET estimates are expected to improve as additional research and instruments come online. Within the raster view of the public data portal, users can draw a custom boundary and download historic and cumulative ET data for an area of interest.

Soil Survey Geographic Database

Soil Survey Geographic Database (SSURGO) provides extensive information on soil of a given area such as water holding capacity, suitability, texture, and many other characteristics.

Southwestern Willow Flycatcher Habitat Suitability

The model predicts the probabilities for suitable habitat for the endangered Southwestern Willow Flycatcher and can be used to guide restoration efforts.

Streamflow

The USGS installed the first stream gage in the country on the Rio Grande River near Embudo in 1889. Thousands of gages have since been added and technology has improved, but the principles remain the same. All USGS gages report gage (or stage) height, which is the height of the water above the reference point. Stage height from a nearby gage can help to determine flood frequency and the accessibility of the floodplain, but gage height is not necessarily water depth. Some gaging stations also include estimates of discharge, or streamflow. Reported in units of volume per unit time, discharge is calculated using a rating curve constructed from many concurrent measurements of gage height and streamflow. The volume-height relationship requires a consistent cross-sectional area, so some gages are constructed with weirs that constrain the stream dimensions. Discharge may not be estimated correctly for flow events that fall outside the values used to construct the rating curve, but technology is extending the accuracy and scope of discharge estimation.

References

Muldavin, E., E. Milford, J. Triepke, C. Gonzalez, A. Urbanovsky, G. McCartha, A. Kennedy, Y. Chauvin, J. Smith, J. Leonard, L. Elliot, P. Hanberry, D. Diamond, and A.E. Clark. 2023. New Mexico Riparian Habitat Map (NMRipMap): Version 2.0 Plus. New Mexico Natural Heritage, Museum of Southwestern Biology, University of New Mexico; USDA Forest Service, Southwest Region; Missouri Resource Assessment Partnership (MoRAP), University of Missouri, and USDA Forest Service, Geospatial Technology and Applications Center (GTAC), Salt Lake City, UT. Accessible at https://nhnm.unm.edu/riparian/NMRipMap.

Hatten, J.R., 2016, A satellite model of Southwestern Willow Flycatcher (Empidonax traillii extimus) breeding habitat and a simulation of potential effects of tamarisk leaf beetles (Diorhabda spp.), Southwestern United States: U.S. Geological Survey Open-File Report 2016–1120, 88 p., http://dx.doi.org/10.3133/ofr20161120.

C1 Field Safety

Always follow your general field procedures for safety. The section below provides a summary of specific hazards and mitigations to keep in mind while doing field work.

Figure 1. Water crossings, steep drop-offs in the road, and signage stashed in trees are all hazards of traveling by vehicle. *Photos by Kathryn Mahan*

Traveling by Vehicle

HAZARDS:

- Getting lost or getting the wrong directions.
- Remoteness.
- Poor access/degraded or impassable roads.
- Mechanical problems.

MITIGATIONS:

- Prioritize good communication prior to going into the field.
- Have an emergency action plan (EAP) worked out ahead of time, be sure everyone knows it, and keep it with you.
- Bring appropriate maps; ask questions about the route and terrain before heading out into the field.
- Create trigger points for turnarounds/knowing when not to pursue the project.
- Ensure drivers have defensive driving training.
- Follow standard 4WD protocols (FWRI staff have a detailed driving protocol to follow).
- Swap drivers regularly and/or as difficulty of travel demands.
- Use the buddy system and take two vehicles equipped with chains, tow straps, and chainsaws into very remote areas. Make sure you know if your organization requires chainsaw certifications and follow all related safety protocols.
- Communicate from the field if possible: use a radio, personal locator beacon (PLB), cell phone, etc. Keep everyone up to date if plans get changed.

Figure 2. Rocky terrain, steep slopes, downed logs and slash, and body posture when taking transects are all potential hazards of working in the forest. *Top left photo by Jax Gaglianese-Woody, all others by Kathryn Mahan*

Traversing and Working in the Field

HAZARDS:

- Very steep terrain and/or cliffs on plot or encountered traveling between plots.
- Traveling through dense understory/areas with lots of downed trees.
- Getting poked by limbs of trees trying to measure DBH.
- Bending over for long periods of time for certain protocols.
- Watching a GPS, map, or datasheet instead of watching the ground you're walking on, etc.

MITIGATIONS:

- Move slowly and cautiously.
- Maintain situational awareness.
- Use topographic maps.
- Wear sturdy boots and proper PPE (eye protection, long sleeves, gloves).
- Wading boots or waders may be necessary in wet areas.
- When working around wetlands, be careful about stepping on unsupported mats of vegetation, soft mud, or quicksand.

- A hiking pole or stick can be helpful for probing the ground surface ahead, checking water depth, and to maintain balance while walking in water. Take breaks when travel is difficult.
- Maintain awareness of other field crew members to ensure you stay together. When traversing terrain with loose rocks or debris, maintain adequate spacing between crew members.
- Take turns switching up physically taxing tasks.
- Ensure crew members have first aid training and bring appropriate equipment, i.e. radios, first aid kit.

Weather

HAZARDS:

- Lightning, monsoon, flooding, hail, etc.
- High winds.
- Temperature extremes.
- Hypothermia, hyperthermia, etc.

MITIGATIONS:

- Maintain good communication.

Figure 3. Approaching mid-afternoon monsoon rains. *Photo by Jax Gaglianese-Woody*

- Know the local area and weather patterns.
- Bring rain gear and other PPE suitable for wide variations in weather. Consider bringing a change of clothes and socks.
- Plan ahead; don't park in areas prone to flooding and depart from areas where roads/terrain may become impassable.
- Follow a lightning protocol (e.g. 30/30 rule, know the lightning position).

Lightning Protocol:

Pay attention to the sky, especially if you hear thunder/see lightning. If thunder follows 30 seconds or less after a lightning strike the thunderstorm poses danger. Five seconds is equivalent to 1 mile, 30 seconds being equivalent to 6 miles.

- The safest places to shelter during a thunderstorm are inside vehicles or fully enclosed buildings. If sheltering in a vehicle, keep the windows up. Plan your day accordingly based on weather patterns to ensure the vehicle is in close proximity to your monitoring plots.
- If unable to seek shelter in a vehicle or building, practice the following safety tips:
  - Avoid exposed ridges, hilltops, and open fields.
  - Avoid tall, isolated trees or other objects. Look for a uniform stand of trees to shelter in.
  - Avoid bodies of water, metal objects or fences, and shallow caves.

Figure 4. Above left: Unhappy tech in a disposable poncho. Above right: Ground covered in hail after a hailstorm. *Photos by Jax Gaglianese-Woody*

- Spread out your group to reduce the risk of current traveling person to person.
- Assume lightning position: crouch down low to the ground with your feet together.
- Avoid lying flat on the ground, you want to minimize the amount of contact your body has with the ground. If a foam pad or backpack without metal wiring is available, you can sit on top of that for greater comfort.
- Always seek shelter whenever possible. Following the safety tips listed above can help minimize the risk of being struck, but you are not safe outdoors during a thunderstorm.

Wildlife

Figure 5. Snake sheltered under vegetation. *Photo by Kathryn Mahan*

HAZARDS:

- Encounters with venomous snakes, spiders, etc.
- Rabid or aggressive animals.
- Hantavirus infection.
- Food motivated animals e.g., bears, javelinas.

MITIGATIONS:

- Maintain situational awareness.
- Be familiar with local area.
- Secure your food.
- Specific to snakes: sweep under and around trees before measuring; use snake chaps or wear tall boots.
- Avoid caves, small enclosures, and old structures where mice and other small rodents might live (Hantavirus).

Figure 6. Plants like stinging nettles (*Urtica*), thistles (*Cirsium*), cactus species, Russian olive, and poison hemlock all present hazards. *Top left photo by Kathryn Mahan, all others by Jax Gaglianese-Woody*

Vegetation

HAZARDS:

- Spiny & sharp plants (e.g. Russian thistle, Russian olive, cactus, *Cirsium* species, etc.).
- Poisonous wild edibles.
- Skin irritation caused by plants (e.g. poison ivy, stinging nettles, poison hemlock).

MITIGATIONS:

- Wear protective clothing.
- Wear eye protection.
- Have first aid kits & first aid training.
- Wear sturdy boots with heavy soles.
- Don't put plants in your mouth or on your skin unless you're 100% positive about your identification.

Figure 7. Use caution when working with sharp and spring-loaded equipment. *Left photo by Kathryn Mahan, right by Jax Gaglianese-Woody*

Sharp and Spring-loaded Equipment

HAZARDS:

- Machetes, Spencer (spring-loaded metal-reel) diameter tapes with nails, metal clipboards, papers, etc.

MITIGATIONS:

- Always wear eye protection.
- Wear other personal protective equipment when appropriate (e.g. gloves) and use caution.
- Be familiar with your equipment.
- Use two people to rewind a Spencer tape.

Figure 8. Stump holes and other hazards are present in burned areas. *Photos by Kathryn Mahan*

Burned Areas

HAZARDS:

- Very difficult travel in burned areas.
- Risk of windthrow and/or falling dead trees and branches.

- Ash is slippery, especially if wet.
- Stump holes (sunken areas) may exist or appear.
- Post-fire flooding.

MITIGATIONS:

- Create a safety zone where you can retreat to in the event of high winds.
- Use proper PPE such as hard hats.
- Establish a wind cutoff and carry a kestrel to measure windspeed. NMFWRI's wind cutoff protocol instructs field crews working in burned areas to wear hard hats when winds are over 15 mph. When there are sustained winds over 40 mph, crews do not work.
- Maintain good communication and regular check-ins.
- Check the weather.
- Proceed with caution.

Overnight Stays

HAZARDS:

- Heavy backpacks, carrying lots of equipment, loading & unloading that equipment.
- Front-country communications options may not work (e.g. no cell service).
- Improper campsite selection could result in exposure to high winds, lightning, flooding.
- Increased chance for encounters with wildlife (importance of proper food storage).
- Importance of group and personal hygiene especially when getting water, preparing food, and using the restroom.
- Team members face more challenges trying to stay warm and dry.
- Distance to medical help makes prevention much more critical.
- General hazards in kitchen and campsite (knives for food preparation, fire for cooking, guy lines, etc.).
- Operating in the dark.
- Emotional stresses intensify.

MITIGATIONS:

- Ensure everyone in the group follows standards for hygiene, etc.
- Wear the proper PPE to avoid burns, cuts, sunburns, etc.
- Properly treat all drinking water (by boiling, Aqua Mira/chlorine treatment, iodine, etc).
- Pay attention to campsite selection and weather forecasts.

Figure 9. Difficult terrain, campfires, heavy backpacks, and livestock are common hazards when camping for fieldwork. *Bottom left photo by Jax Gaglianese-Woody, all others by Kathryn Mahan*

- Keep all equipment in good condition and bring extra warm/dry clothes.
- Keep camp clean and secure food properly to reduce the draw for wildlife (in a locked car or trailer at night and when away from camp during the day).
- Ensure personal and collective gear is safely packed away and that your camps can withstand extreme weather conditions such as wind or rain (put away all equipment in tents or vehicles, zip up tents and rain flies, and thoroughly stake down tents when leaving camp).
- Prepare equipment beforehand to ensure nothing is left behind.
- When moving lots of heavy equipment, use proper posture and lift with a partner.
- Bring extra/backup batteries for field equipment and keep equipment in bags when there is risk of exposure to moisture. Sleep with batteries in your sleeping bag to keep them warm.
- Be courteous and communicate with team members. Be prepared to practice psychological first aid. (Learn more here: https://www.responderalliance.com/resource-hub).

C2 Planning Your Day

Begin each day with a plan for each crew:

1. What time they're heading out and returning.
2. How often they'll check in and with whom.
   - We often use a radio check-in every two hours, on the hour, with the other crew in the area.
3. What plots they're covering and in what order.
   - Consider access, topography, skill, and speed of the crew.
4. What safety hazards they're watching for and what they'll do in case of emergency.
5. Be sure everyone goes through their checklists and has everything they need (equipment, food, raingear, first aid, etc.).

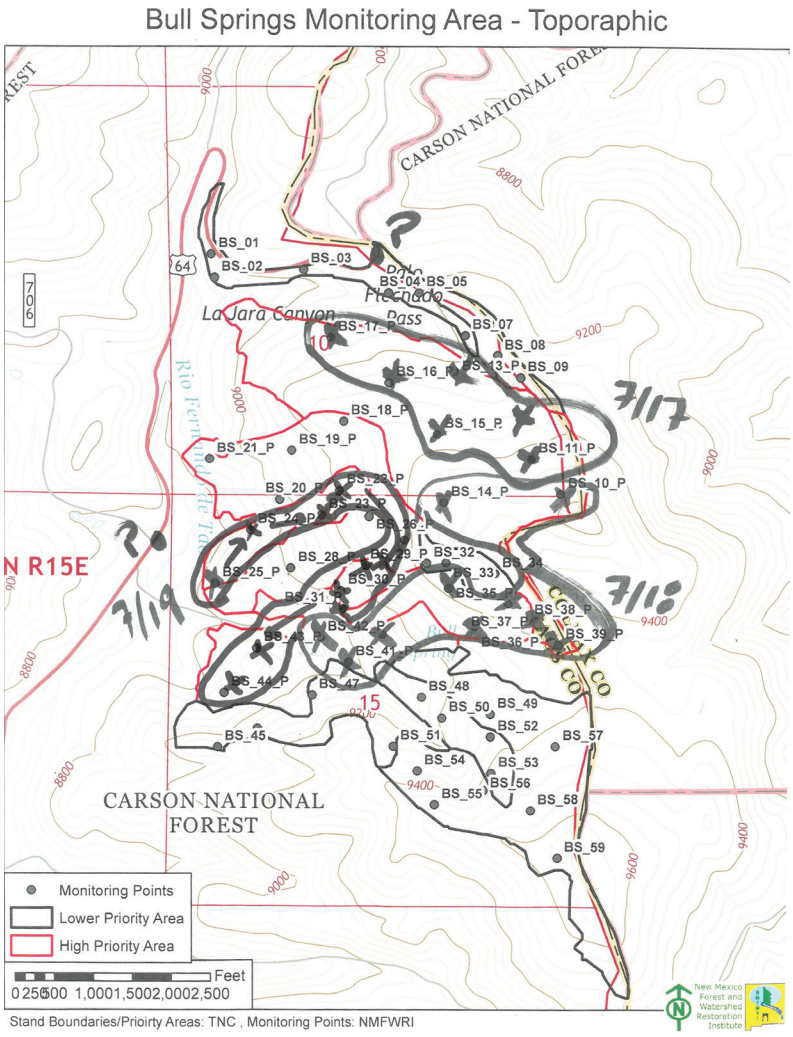


Figure 1. Keeping a marked-up paper map of monitoring areas can be nice way to keep crew members informed on monitoring plans and locations. *Map by NMFWRI Monitoring Crew*

At the end of each day:

1. Finalize QC and make sure all data was completed.
2. Take notes on the day and the project. For instance, did you learn anything about access to plots, or encounter any partners while working? Include in your notes anything that would benefit a future crew in working more safely and efficiently.

3. Record the route each crew took and what plots they finished that day on one master map. Be sure that map stays with the datasheets or project information. Having a master record of the sequence in which things happened allows for the data entry team to solve any mystery that may arise if a detail isn't recorded in the field.

DATA MANAGEMENT AND QUALITY CONTROL

D1 Data Management Best Practices

One of the most important concepts to consider when approaching data management is that there is no right answer; there are best practices, but these are generalized constraints. The most useful approach for you may not be the same for another organization, or even another department within your organization. Data comes in many different forms and functions, and decision making surrounding these data is context-dependent.

Planning

Key Questions

- What kind of data are you collecting? Consider file formats and software needed to access the data.
- What is the quality of the data?
- What technologies are currently being used in the process?
- Are you limited to specific technologies?
- How do you want to use the data? Do you want to preserve it? Share it? Analyze it?
- Who is responsible for the data and management process?

Common Challenges

1. Technology constraints or user inexperience
2. Poor/missing/incomplete data
3. Lack of personnel
4. Not knowing all the options

Organization

Key Questions

- Is there already a management system in place?
- How is the data currently stored? / Where will you store the data?
- How do you plan on documenting current data and changes made to data?
- How is the data structured?

Common Challenges

1. Turnover can create gaps in knowledge and process
2. Existing structure is confusing and messy
3. No current documentation
4. Lack of/improper security around storage

Implementation

Key Questions

- How many sources do the data come from?
- Does data need to be cleaned up or normalized?
- How will historic data be treated?
- Will new data be integrated with historic data?
- Do you want to automate parts of this process?
- How will data be accessed?

Common Challenges

1. Technological overhead
2. Working with data sources
3. Automations
4. Cleaning data

Technologies and Resources

Databases

Industry Standards

- Microsoft SQL Server (requires licensing on databases >10GB)
- PostgreSQL
- SQLite
- Microsoft Access

Cloudbased

- Amazon Web Services

- Microsoft Azure
- Oracle

Programming Languages

- Python – general purpose
- R – statistical programming
- Visual Basic – automation within Office 365 products
- Bash – automate Windows processes such as moving and renaming files *Miscellaneous*
- Github – useful for documenting and versioning code
- EML – Ecological Markup Language; framework for documenting metadata
- SharePoint – Microsoft file storage server
- DMP Tool – website for designing and writing Data Management Plans

Create A Data Management Plan

The following information is sourced from DMPTool.org. Visit https://dmptool.org/ to be guided through a template to create a data management plan.

Data Collection

- What type, format and volume of data?
- Do your chosen formats and software enable sharing and longterm access to the data?
- Are there any existing data that you can reuse?

Give a brief description of the data, including any existing data or third-party sources that will be used, in each case noting its content, type and coverage. Outline and justify your choice of format and consider the implications of data format and data volumes in terms of storage, backup and access.

Documentation and Metadata

- What information is needed for the data to be to be read and interpreted in the future?
- How will you capture/create this documentation and metadata?
- What metadata standards will you use and why?

Describe the types of documentation that will accompany the data to help secondary users to understand and reuse it. This should at least include basic details that will help people to find the data, including who created or contributed to the data, its title, date of creation and under what conditions it can be accessed.

Documentation may also include details on the methodology used, analytical and procedural information, definitions of variables, vocabularies, units of measurement, any assumptions made, and the format and file type of the data. Consider how you will capture this information and where it will be recorded. Wherever possible you should identify and use existing community standards.

Ethics and Legal Compliance

- Have you gained consent for data preservation and sharing?
- How will you protect the identity of participants if required? e.g. via anonymization
- How will sensitive data be handled to ensure it is stored and transferred securely?

Ethical issues affect how you store data, who can see/use it and how long it is kept. Managing ethical concerns may include: anonymization of data; referral to departmental or institutional ethics committees; and formal consent agreements. You should show that you are aware of any issues and have planned accordingly. If you are carrying out research involving human participants, you must also ensure that consent is requested to allow data to be shared and reused.

Storage and Backup

- Do you have sufficient storage or will you need to include charges for additional services?
- How will the data be backed up?
- Who will be responsible for backup and recovery?
- How will the data be recovered in the event of an incident?

State how often the data will be backed up and to which locations. How many copies are being made? Storing data on laptops, computer hard drives or external storage devices alone is very risky. The use of robust, managed storage provided by university IT teams is preferable. Similarly, it is normally better to use automatic backup services provided by IT Services than rely on manual processes. If you choose to use a thirdparty service, you should ensure that this does not conflict with any funder, institutional, departmental or group policies, for example in terms of the legal jurisdiction in which data are held or the protection of sensitive data.

Selection and Preservation

- What data must be retained/destroyed for contractual, legal, or regulatory purposes?
- How will you decide what other data to keep?
- What are the foreseeable research uses for the data?
- How long will the data be retained and preserved?

Consider how the data may be reused e.g. to validate your research findings, conduct new studies, or for teaching. Decide which data to keep and for how long. This could be based on any obligations to retain certain data, the potential reuse value, what is economically viable to keep, and any additional effort required

to prepare the data for data sharing and preservation. Remember to consider any additional effort required to prepare the data for sharing and preservation, such as changing file formats.

Data Sharing

- How will potential users find out about your data?
- With whom will you share the data, and under what conditions?
- Will you share data via a repository, handle requests directly or use another mechanism?
- When will you make the data available?
- Will you pursue getting a persistent identifier for your data?

Consider where, how, and to whom data with acknowledged longterm value should be made available. The methods used to share data will be dependent on a number of factors such as the type, size, complexity and sensitivity of data. If possible, mention earlier examples to show a track record of effective data sharing. Consider how people might acknowledge the reuse of your data.

Responsibilities and Resources

- Who is responsible for implementing the DMP and ensuring it is reviewed and revised?
- Who will be responsible for each data management activity?
- How will responsibilities be split across partner sites in collaborative research projects?
- Will data ownership and responsibilities for research data management be part of any consortium agreement or contract agreed between partners?

Outline the roles and responsibilities for all activities, e.g. data capture, metadata production, data quality, storage and backup, data archiving and data sharing. Consider who will be responsible for ensuring relevant policies will be respected. Individuals should be named where possible.

D2 File Naming Convention Worksheet

This worksheet was designed by the California Institute of Technology and is reproduced here.

1. What group of files will this naming convention cover?

You can use different conventions for different file sets.
Example: This convention will apply to all of my microscopy files, from raw image through processed image.

2. What information (metadata) is important about these files and makes each file distinct?

Ideally, pick three pieces of metadata; use no more than five. This metadata should be enough for you to visually scan the file names and easily understand what's in each one.
Example: For my images, I want to know date, sample ID, and image number for that sample on that date.

1:

2:

3:

4:

5:

3. Do you need to abbreviate any of the metadata or encode it?

If any of the metadata from step 2 is described by lots of text, decide what shortened information to keep. If any of the metadata from step 2 has regular categories, standardize the categories and/or replace them with 2- or 3-letter codes; be sure to document these codes.
Example: Sample ID will use a code made up of: a 2-letter project abbreviation (project 1 = P1, project 2 = P2); a 3-letter species abbreviation (mouse = "MUS", fruit fly = "DRS"); and 3-digit sample ID (assigned in my notebook).

4. What is the order for the metadata in the file name?

Think about how you want to sort and search for your files to decide what metadata should appear at the beginning of the file name. If date is important, use ISO 8601-formatted dates (YYYYMMDD or YYYY-MM-DD) at the beginning of the file names so dates sort chronologically.
Example 1: My sample ID is most important so I will list it first, followed by date, then image number.

1:

2:

3:

4:

5:

5. What characters will you use to separate each piece of metadata in the file name?

Many computer systems cannot handle spaces in file names. To make file names both computer- and human-readable, use dashes (-), underscores (_), and/or capitalize the first letter of each word in the file names.
Example: I will use underscores to separate metadata and dashes between parts of my sample ID.

6. Will you need to track different versions of each file?

You can track versions of a file by appending version information to end of the file name. Consider using a version number (e.g. "v01") or the version date (use ISO 8601 format: YYYYMMDD or YYYY-MM-DD).
Example: As each image goes through my analysis workflow, I will append the version type to the end of the file name (e.g. "_raw", "_processed", and "_composite").

7. Write down your naming convention pattern.

Make sure the convention only uses alphanumeric characters, dashes, and underscores. Ideally, file names will be 32 characters or less.
Example: My file naming convention is "SA-MPL-EID_YYYYMMDD_###_status.tif" Examples are "P1MUS023_20200229_051_raw.tif" and "P2-DRS-285_20191031_062_composite.tif".

8. Document this convention in a README.txt (or save this worksheet) and keep it with your files.

D3 Sample QC Checklists

Reports and management decisions are only as good as the data they are based on. Good data starts with careful data collection, but there are many ways small errors can enter into the record between the observer and the final file. If these make it to the analysis stage and are scaled from plot-level observations to inferences about an entire project, they can lead to misinformed decisions. Having a plan in place to catch errors—we are all human, they will happen—reduces this risk. One basic but powerful tool is a quality control checklist.

The example presented here is intended to be used when entering field data into a digital spreadsheet, but QC checkpoints can be set up at various stages of a project. A technician repeating the observations called out by another crew member when filling out a datasheet is another example of a simple but effective technique to prevent a common source of errors (although technically this would be considered quality assurance). QC can also be performed before and after data analysis. Wherever it occurs, the goal is the same: to create a slower and more methodical approach to data collection and management so that confident decisions can be made using high quality data.

Example QC Checklist

The exact contents of a checklist will depend on the particular sampling protocol used and the format chosen to organize data; different steps of data management require a focus on different elements too. These are some examples of things to check to make sure that field data was entered into a digital spreadsheet correctly. Consider having two people conduct QC and independently sign off on each item. Further resources at the end give more tips and tricks, including how to make Excel do much of this work for you.

General Considerations

- ☐ Make sure that all plots have the correct sampling date. Spreadsheets are sometimes too smart for their own good and will auto-fill dates in sequence, so ensure that plots that were visited during the same day have the same date.
- ☐ Spot-check that date formats are correctly entered (dd/mm vs. mm/dd).
- ☐ Make sure that all species codes are spelled correctly and correspond to the correct species.
  - ○ Sort species entries by name. There will likely be large blocks of data with the same codes; check the outliers to make sure they are not misspellings of more common species.
  - ○ Use the USDA PLANTS website to confirm that codes correspond to the species intended.
- ☐ Do all plots have a breakpoint diameter defined? For example, ensure the definitions for "sapling" and a "tree" are clear for the project.

- ☐ Ensure that the densiometer measurement method is recorded (dots or squares) as well as what was counted (open or closed canopy area).
  - ○ Sanity-check measurements against other recorded data: is the canopy open but the plot had many live trees?
    - Plot photographs can be used to help verify canopy conditions.
- ☐ Make sure all null values and zeros are correct.
  - ○ A zero and a null value data field are not the same thing. A zero should never be in a datasheet if it was not recorded in the field. Some data fields do not apply under certain conditions, for example, live crown height is not recorded for a dead tree. These types of fields should contain a null value (digital entry) or have a line through them (paper entry).
- ☐ Check plot sizes. Plots in a project will be the same size, so outliers should be easy to spot. In NMFWRI protocols the outer plot is 0.1 acre and the inner plot is 0.01 acre.
- ☐ Perform a random spot check; pull a few paper datasheets at random (more for a larger project, less for a smaller) and pick a section or a few lines of data and check it against the spreadsheet.
  - ○ If several errors are found, consider a more thorough line-by-line check.

Trees

- ☐ Sort tree data by diameter and check that there are no trees smaller than the defined breakpoint that should have been labeled as saplings.
- ☐ Tree Status checks:
  - ○ Sort tree data by status and make sure no dead trees have a live crown height recorded, and that all live ones do.
  - ○ While still sorted by status, check the fields for the number of live and dead stems and make sure they are filled.
    - Check that live trees have at least one live stem and that dead trees only have dead stems.
  - ○ Ensure that all trees recorded as sick have damage codes and severities filled out or comments explaining their condition.
- ☐ Sort by DBH and check for red flags.
  - ○ Make sure that diameters correspond with reasonable heights and that they generally increase together. A Rio Grande cottonwood (*Populus deltoides* ssp. *wislizeni*) with a 2 in diameter is unlikely to be 37 ft tall, for example.
    - The opposite can happen, however, if the tree is damaged. If the height seems small for the diameter, check for a damage code and severity to explain the situation, such as a dead or broken top or lean.
  - ○ Sort by species and then by diameter. Make sure that diameters are in reasonable ranges for the species and verify outliers with the original datasheets. A narrowleaf willow (*Salix exigua*) with a diameter of 41 inches would be a concern.
- ☐ Sort by height and check for red flags.

- Sort by species and then by height and make sure there are no extreme outliers or heights that do not make sense for the species recorded.

Aerial and Ground Cover

- ☐ Create a column that sums all categories of ground cover if you have not done so already and verify that it totals 100% for every plot.
- ☐ Ensure that species codes correspond with logical entries for aerial cover. For example, a shrub species should be counted as a shrub, not a forb or graminoid.
- ☐ Check with plot photos that aerial estimates seem reasonable. Exact verification would be impossible, but if one plot in a project is much denser than other photos can show if this was truly the case or whether it is a data entry error.

Brown's Lines

- ☐ Double-check Brown's transect lengths. In our protocols, these are:
  - 1-hr and 10-hr length: 6ft.
  - 100-hr length: 35ft.
  - 1000-hr length: 60ft.
- ☐ Sort course woody debris by diameter and make sure none are less than three inches.
- ☐ Check plot photos to verify any that seem abnormally large.

Seedlings and Saplings

- ☐ Check the counts of seedlings and saplings seem reasonable and align with what can be seen in plot photos.
- ☐ Check that all species codes make sense and correspond with the intended species in the USDA PLANTS database.

Photographs

- ☐ Check that content of photos matches descriptions and file names.
  - If photo 26.34_1_N shows a whiteboard with "E" there is an issue. It could be the photo is mislabeled, or the whiteboard was incorrect when the photo was taken, in which case it should be noted.

Further Resources:

- Broad factors to consider when managing a database: https://data.org/guides/how-to-improve-data-quality-through-validation-and-quality-checks/
- Excel QA and QC tips tailored for ecological data: https://datacarpentry.github.io/spreadsheet-ecology-lesson/04-quality-control.html

Works Cited for Supplements D1, D2, D3

Briney, K. A. (2020, June 2). File Naming Convention Worksheet. California Institute of Technology. https://doi.org/10.7907/894q-zr22

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E1 Additional Monitoring Methods and Protocols

Besides our monitoring approach outlined in Chapters 3 and 5, there are many other monitoring methods available which vary widely in terms of the time and expertise required to implement.

Notes to consider when researching other monitoring methods: Some management agencies and programs have guidelines for the level of change that is considered significant. There may be trigger points, such as an intervention if noxious weed cover crosses a particular cover threshold. The selected monitoring protocols should consider the necessary measurement precision and spatial scale, to assess any relevant management or policy thresholds. In the interest of reducing crew time in the field, it can be tempting to use methods that estimate ecological conditions by categories in place of measurements. One example is the use of Daubenmire cover classes to characterize understory cover. Although this method is popular and relatively accurate, it does not provide a quantitative measure that can be tested statistically. Small-scale changes may take place without shifting to the next category. Also, categorical assignments can prevent comparisons across jurisdictions. In contrast, a quantitative cover estimate can be compared across boundaries, even if cover was estimated using a Line-Point Intercept (LPI) by one partner, a belt transect by another, and a quadrat by the third.

Monitoring Manuals for Grassland, Shrubland, and Savanna Ecosystems

- This two-volume set provides clear, concise instructions, datasheets, and examples for collecting ecological data. The first volume describes the standard methods for the Bureau of Land Management (BLM; Assessment, Inventory and Monitoring) and the Natural Resource Conservation Service (NRCS; National Resource Inventory) monitoring programs. The methods have been collaboratively developed over several decades and can be applied across a range of ecosystems. Volume II covers additional methods, including riparian monitoring, plant production, and soil compaction.

  Link: https://www.blm.gov/noc/blm-library/technical-reference/monitoring-manual-grassland-shrubland-and-savanna-ecosystems

Bosque Ecosystem Monitoring Program (BEMP) - Research Protocols

- BEMP was founded in 1996 to monitor the state of the Bosque ecosystem of the middle Rio Grande. The organization provides the protocols they have utilized to monitor ecological indicators at 33 field sites, including groundwater quality, litterfall and woody debris, arthropod diversity, and cottonwood tree monitoring. BEMP protocols are designed for K-12 students to collect consistent ecological data.

  Link: https://bemp.org/research-guides-protocols/

National Water-Quality Assessment Program (NAWQA)

- This is a methodology for characterizing stream habitat, developed by USGS/ Department of Interior. The methodology characterizes stream habitat, basins, segments, and reaches. At the basin level, data such as drainage boundaries, drainage area, runoff, climate, gradient, flow characteristics, and more are recorded. At the segment level, data such as sinuosity, gradient, water-management features, stream order, and more are recorded. At the reach level, metrics include discharge, canopy closure, bank height, bank stability index, and others recorded. Specific habitat metrics collected at the reach level include depth, velocity, dominant bed substrate, embeddedness, bank erosion, siltation, channel cross sections, pebble counts, sediment laboratory analyses, point-quarter vegetation, and vegetation plots. NAWQA data is also accessible, which could help provide context on habitat relative to a regional baseline for certain projects.

  Links: https://www.usgs.gov/mission-areas/water-resources/science/national-water-quality-assessment-nawqa

  https://pubs.usgs.gov/wri/wri984052/pdf/wri98-4052.pdf

The New Mexico Environment Department (NMED)

- Surface Water Quality Bureau (SWQB) Wetlands Program in collaboration with Natural Heritage New Mexico (NHNM) at the University of New Mexico has initiated the development and use of a rapid assessment framework to evaluate the ecological status of wetlands and riparian areas throughout New Mexico. This provides a cost-effective and consistent evidence-based tool for assessing wetland ecological condition and an associated database system to track outcomes. It uses a select set of observable and relatively easy-to-measure spatial analyses and field indicators (landscape, size, biotic and abiotic metrics) to express the relative condition of a particular wetland site and incorporates an adaptation of the Hink and Ohmart structure classification system. NMRAM metrics are relative in that they have been developed in the context of a "reference set" of wetlands that vary along an anthropogenic disturbance gradient. The underlying premise is that wetland condition among similar wetlands will vary along this disturbance gradient, from high quality and functionality with low disturbance to the most degraded with high disturbance. The ecological condition of a particular site is evaluated and rated as excellent, good, fair, or poor based on a preponderance of evidence.

  Link: https://www.env.nm.gov/surface-water-quality/wetlands-rapid-assessment-methods/

Physical Habitat SOP

- These are the standard protocols used by the New Mexico Environment Department Surface Water Quality Bureau and include basic physical habitat attributes and geomorphology. For example, reach-wide pebble count, thalweg profile, large woody debris tally, cross section survey, slope, percent canopy cover, and streamflow.

  Link: https://www.env.nm.gov/wp-content/uploads/sites/18/2023/06/5.0-Physical-Habitat-SOP-20230609-Final.pdf

AIM National Aquatic Monitoring Framework: Field Protocol for Lentic Riparian and Wetland Systems

- The Bureau of Land Management's Assessment, Inventory, and Monitoring (AIM) monitoring framework provides an outline of their data collection process. Data collected include plant species inventory, soil profile descriptions, and surface water characteristics.

Bureau of Land Management. 2024. AIM National Aquatic Monitoring Framework: Field Protocol for Lentic Riparian and Wetland Systems. Tech Reference 1735-3. U.S. Department of the Interior, Bureau of Land Management, National Operations Center, Denver, CO.

Link: https://www.blm.gov/sites/default/files/docs/2024-04/FieldProtocolForLenticRiparianandWetlandSystems.pdf

The National Riparian Core Protocol

- This protocol provides methods for sampling riparian vegetation and physical channel characteristics along wadeable streams. Collected metrics include plant species composition, vertical vegetation structure, and geomorphic features.

  Merritt, David M.; Manning, Mary E.; Hough-Snee, Nate, eds. 2017. The National Riparian Core Protocol: A riparian vegetation monitoring protocol for wadeable streams of the conterminous United States. Gen. Tech. Rep. RMRS-GTR-367. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 37 p.

  Link: https://www.fs.usda.gov/rm/pubs_series/rmrs/gtr/rmrs_gtr367.pdf

Forest Soil Disturbance Monitoring Protocol Volume I: Rapid Assessment

- This USFS protocol creates a visual method for assessing the impact of forest management activities on soil quality using a transect-based sampling system. Collected metrics include soil compaction, rutting, and displacement.

  Page-Dumroese, Deborah S.; Abbott, Ann M.; Rice, Thomas M. 2009. Forest Soil Disturbance Monitoring Protocol: Volume I: Rapid assessment. Gen. Tech. Rep. WO-GTR-82a. Washington, DC: U.S. Department of Agriculture, Forest Service. 31 p.

  Link: https://research.fs.usda.gov/treesearch/34427

Riparian Fuels Treatments in the Western USA: Challenges and Considerations

- This document is not a monitoring protocol, but contains an overview of other protocols that may be helpful: This is GTR-352 published in 2016 based on research by Rocky Mountain Research Station, which includes (1) a literature review of fire effects on riparian and aquatic characteristics and functions, provided as background for considering the need and potential impacts of fuel treatments; (2) a review of the potential effects of prescribed fire and mechanical treatments on riparian and aquatic resources and biota; (3) results of an online survey of resource managers, summarizing information about proposed and completed fuel reduction projects in riparian areas and wetlands in the interior west; (4) suggestions for pre- and post-project-level monitoring for riparian fuels projects; and (5) a presentation of case studies, describing riparian fuel treatments with different objectives and methods. Research on the effects of fuel treatments on riparian and aquatic resources is limited, and monitoring of projects is highly encouraged, especially in watersheds supporting species of concern. The Chapter 5 Monitoring section includes a table of protocols and references for different protocols depending on the metrics of interest and a basic overview of monitoring plan design.

  Link: https://doi.org/10.2737/RMRS-GTR-352

PROTOCOLS

E2 Surface Water Quality

Figure 1. Technician monitoring water quality. *Photo by Jax Gaglianese-Woody*

What is water quality?

Water quality refers to the physical and chemical characteristics of a water body. Whether these characteristics are acceptable or not depends entirely on what use the water is being put towards. Whether the water is being evaluated for the sake of aquatic organisms, agricultural irrigation, or human recreation will determine not only what metrics are relevant but also the acceptable ranges of those metrics. For instance, "good" water means something different to a plant than it does to a human digestive system.

Why monitor water quality?

Water quality parameters reflect conditions in the water body and the contributing watershed, so they can be helpful in assessing project impacts and separating those impacts from factors beyond the project that may affect riparian project outcomes. Once a baseline has been established, changes in water quality can also provide an early detection system for ecosystem changes. Water quality monitoring data can support project design, regulatory compliance, decision-making, and adaptive management.

Since riparian ecosystems are closely linked to the health of their neighboring water body, water quality monitoring can help to design and evaluate riparian restoration activities. Changes to riparian vegetation, such as removing non-native plants or reseeding native species, can affect bank stability and the delivery

of sediment and nutrients to the water. One of the most common water quality impacts from riparian restoration is an increase in water temperature resulting from reduced tree cover and shading. By establishing the magnitude and duration of these impacts, water quality monitoring can help project managers adjust their restoration practices to reduce negative impacts on important species and ecosystems.

Commonly Measured Water Quality Parameters

The three most basic water quality parameters are temperature, dissolved oxygen (DO), and pH. These parameters are relatively simple to measure and provide useful information about the health of a water body. Other commonly measured water quality parameters include alkalinity, conductivity/salinity, turbidity, and total dissolved solids (TDS). The parameters are interrelated, so composites of these parameters provide a clearer picture of trends than changes within a single parameter.

Temperature: Temperature is a significant driver of an aquatic ecosystem's biological and chemical state, acting as a key limiting factor for the survival of aquatic organisms. Water temperature is influenced by a variety of factors including shading, weather patterns, snowmelt, and major disturbance events such as fire. Because water temperature is closely linked to most other water quality parameters, changes in temperature often affect chemical and biological aspects of the ecosystem. For example, as temperature increases, DO concentrations decrease. Temperature is a crucial component of any water quality monitoring plan, but it comes with certain key considerations because of its natural variability. Measurements should ideally be horizontally and vertically distributed across the waterbody, or else be taken in well-mixed areas which represent an average temperature, and, if sampling is repeated, all visits should occur at the same time of day so that the data is comparable.

Dissolved Oxygen (DO): Most aquatic organisms require oxygen to live. Just as terrestrial organisms respire—or consume oxygen—for basic physiological processes, so do aquatic flora and fauna. Most oxygen in water comes from the mixing of atmospheric oxygen or the photosynthesis of aquatic plants and algae. This oxygen is then available to aquatic life for respiration and normal biological functions. Similar to temperature, DO levels follow predictable daily and seasonal cycles. For instance, DO concentrations steadily decrease at night when photosynthesis ceases but respiration continues. Additionally, as temperature, salinity, altitude, and nutrient runoff increase, DO decreases. Like temperature, oxygen is challenging to monitor because its natural cycles can obscure actual changes in the system, so it is recommended to collect data that is as spatially and temporally distributed as possible. If it is only feasible to take single samples during each monitoring visit, these would ideally occur early in the morning when DO is at a minimum.

pH (acidity): pH is a measure of the concentration of free hydrogen ions (H+) relative to free hydroxyl ions (OH-) in water. pH is reported on a logarithmic scale from 0 to 14, where the difference between each interval is by a factor of ten (a solution with pH 6 is 10 times more acidic than a solution with pH 7, and a solution with pH 5 is 100 times more acidic than one with pH 7). A pH of 7 is considered neutral, meaning the solution (water) is in a stable state, and the concentration of positive hydrogen ions (H+) is equal to that of negative hydroxyl ions (OH-). A pH less than 7 indicates a more acidic solution containing more H+, and a pH greater than 7 indicates a more basic solution containing more OH-. The pH of water is usually between 6 and 9 and depends on numerous factors, including temperature and the presence of dissolved substances from soil, run-off, and bedrock. pH influences critical biochemical reactions by dictating nutrient availability, and most aquatic life relies on a relatively stable pH.

Alkalinity: Alkalinity is a measure of the ability of a body of water to maintain a stable pH level. It is not a measure of acidity, although, as a general rule, more alkaline water also tends to be more basic. It can be estimated by continually recording the pH of a water sample while adding increments of acid. After a certain point, the ability for compounds in the water, such as bicarbonates, to neutralize the acid is exhausted, and its pH begins to increase linearly. This inflection point can be used to determine the water's alkalinity. Monitoring alkalinity is important because most organisms are not adapted to rapidly changing pH levels. High alkalinity can be a buffer that mitigates the effects of shocks such as acid rain or wastewater contamination; in effect, it increases the resilience of an aquatic ecosystem. Alkalinity is generally determined by geology; rocks such as limestone contribute calcium carbonate or other ions that can bind with free hydrogen molecules to raise the pH and alkalinity of water.

Conductivity/salinity: When salts dissolve in water, they separate into ions that can conduct electrical currents. Conductivity is measured by a probe that records the drop in voltage as electricity is transmitted from one electrode to another through water. Once a baseline has been established, a significant change in conductivity can indicate pollution entering the aquatic resource. If conductivity increases, the contamination may be from agricultural runoff or a sewage leak adding chloride, phosphate, or nitrate ions; if it decreases, it may indicate the addition of organic compounds like oil. Conductivity measurements are converted to approximate concentrations of total dissolved solids (TDS) and salinity using conversion factors.

Turbidity: Turbidity measures the clarity of water and is related to the amount of solid material—organic (e.g., algae) and inorganic (e.g., soil particles)—suspended in the water body (but it is not the same as TDS). High levels of turbidity can have many effects on an ecosystem or watershed: decreased light penetration leads to less photosynthesis and ecological productivity, sedimentation causes habitat degradation, and the particles that cloud water also act as carriers for metals and bacteria that can be harmful to humans and aquatic organisms. Turbidity can be caused by erosion, algae, microorganisms, or ash. Elevated turbidity may indicate the disruption of sediment by human and/or natural factors. Human factors can include erosion caused by forestry, agriculture, construction, farming, or increased water usage; disturbance from recreation or dredging; and both urban and agricultural runoff (such as fertilizers leading to eutrophication). Natural factors influencing turbidity include runoff from precipitation/weather events, snowmelt, wildfires, or more localized disruption such as feeding by muskrat or carp.

Total Dissolved Solids (TDS): The TDS level measures the content of anything dissolved in water that is not an H2O molecule. These substances can include salts, metals, and minerals which end up in water from both human activity and through natural occurrences. Water with a higher mineral content is considered hard water while water with lesser mineral content is considered soft water. Minerals and salts containing calcium, magnesium, and potassium may be delivered to water bodies through the natural weathering of rocks. Other contributors to TDS have anthropogenic origins, such as pesticides and herbicides from agricultural and urban runoff, chlorine from water treatment, bacteria from wastewater discharge (industrial or municipal), and salt used to de-ice roads.

Sondes and Data Loggers

What are sondes/data loggers?

Because of the natural fluctuations inherent in all water quality parameters, it is ideal to collect data continuously so that long-term patterns can be established. Sondes and data loggers collect ongoing

Water Quality Parameters

Parameter	What is Measured	Measurement Methods
Temperature	The kinetic energy of water molecules, which is usually expressed in °C or °F	Thermometer
Dissolved Oxygen (DO)	Either the absolute concentration of DO *or* the percent saturation of DO relative to the maximum amount the water can hold, which depends on temperature, barometric pressure, and salinity	Colorimetric DO Test Kits DO meter Winkler titration (lab analysis)
pH	The concentration of free positive ions (H+) relative to negative hydroxyl ions (OH-)	Indicator strips/Litmus paper pH meter
Alkalinity	The amount of acid that can be added to water until pH changes	Colorimetric titration kits pH meter titration
Conductivity	the water's ability to transmit an electrical current	Conductivity meter*
Total Dissolved Solids (TDS)	the volume of dissolved solids	TDS meter* Gravimetric method (lab analysis)
Turbidity	the extent to which solids within a water column scatter light	Turbidimeter Secchi disk

Table 1. Water quality parameters and measurement methods. *Because conductivity is related to the concentration of dissolved solids, conductivity can also be an indirect measure of TDS. Conductivity meters and TDS meters both measure conductivity; however, a TDS meter then converts the raw conductivity measurement into an estimated concentration of dissolved solids (usually reported in parts per million, or ppm).

measurements, as frequently as desired, making them ideal for monitoring changes in water quality over time while complementing other ongoing monitoring.

Sondes are multi-parameter water-quality instruments equipped with multiple probes (sensors), a robust power-supply, an internal computer and data storage, and sometimes remote communication and data retrieval features. Depending on the model and sensor capabilities, these instruments simultaneously measure pH, temperature, dissolved oxygen, conductivity, turbidity, nutrients, and chlorophyll (algal content). They can be submerged for long periods of time, recording parameters of interest at user-specified time intervals, or they can be used for single-event water quality checks.

Data loggers generally measure one or two parameters. They are often used to measure water temperature, submersion (presence or absence of water), and dissolved oxygen (DO), and are intended for long-term deployment. Compared to sondes, they are cheaper, more compact, and can be easier to calibrate and deploy. They are best suited for monitoring multiple sites simultaneously.

Figure 2. Example of dataloggers: HOBO water temperature logger (middle), HOBO water level logger (bottom), and waterproof data shuttle and logger coupler for data retrieval (top). *Photo by Cody McLean, Taos BLM Fisheries Biologist, used with permission.*

Before purchasing a sonde/ data logger

Continuous water quality monitoring instruments are a long-term investment with a wide range of prices, parameters, and practices for deployment and maintenance. Consider the following when selecting a unit:

- parameters-of-interest (e.g., pH, dissolved oxygen, turbidity, conductivity, algal growth)
- site characteristics (e.g., stream, river, pond, lake, weather, time of year, etc.)
- measurement intervals (e.g., 15 minutes, hourly, daily, weekly)
- maintenance and storage capabilities
- data handling and management
- deployment methods and site accessibility
- standard procedures
- total cost of initial purchase, regular calibration (including solvents and buffers), routine maintenance, proper storage, and necessary software

Figure 3. Technician monitoring water quality with a YSI EXO3 sonde. *Photo by Jax Gaglianese-Woody*

Figure 4. Above left: Examples of multi-parameter water quality sondes and Above right: corresponding handheld displays: YSI Professional Plus sonde and YSI EXO3 sonde.
Photos by Cody McLean, Taos BLM Fisheries Biologist, used with permission.

Note: It is crucial to thoroughly understand selected water quality monitoring instruments, including their calibration, operation, data transfer/storage methods, maintenance, and proper storage when not in use. Below are additional resources to help you learn about water quality and select the most suitable sondes and/or data loggers.

Additional Resources

- https://www.usgs.gov/water-science-school
- https://www.epa.gov/awma
- NMED Surface Water Quality Bureau - https://www.env.nm.gov/surface-water-quality/
- EBook: A Citizens' Guide to Understanding and Monitoring Lakes and Streams by Joy P. Michaud: https://apps.ecology.wa.gov/publications/documents/94149.pdf
- Book: Streamkeeper's Field Guide by Tom Murdoch and Martha Cheo with Kate O'Laughlin
- USGS National Field Manual for the Collection of Water-Quality Data - https://www.usgs.gov/mission-areas/water-resources/science/national-field-manual-collection-water-quality-data-nfm

PROTOCOLS

E3 Groundwater Monitoring and Installing Shallow Groundwater Wells

Groundwater Monitoring

Depth to Groundwater

Understanding the depth to groundwater, fluctuations in groundwater levels, and the depth to saturation can greatly improve riparian restoration success because hydrology is a primary factor driving species composition in riparian areas. Where floodplain terraces are disconnected from the river channel and flooding is limited, the depth to groundwater will be a critical parameter driving the potential for restoration and appropriate revegetation.

Instructions for installing shallow groundwater monitoring wells in sandy, alluvial soils are provided below. Installation in cobble or bedrock may require specialized expertise and/or equipment. A soils map and on-site topography will help identify these locations. Site size and variability along with funding constraints should dictate the number of wells installed. As a rule of thumb, ground water levels within eight feet of the surface indicate good riparian restoration potential in the arid Southwest. The NRCS publication "A Guide for Planning Riparian Treatments in New Mexico" provides more specific revegetation guidance.

Installing Shallow Groundwater Wells

(Modified from Thibault J. (University of New Mexico. Dept. of Biology). Instructions for installing shallow groundwater wells. [Unpublished]; 2008.)

Bosque PVC Ground Water Monitoring Wells JRT August 08 (rev)

I. Introduction

Shallow ground water (GW) wells are used in riparian ecosystems to monitor water table (WT) elevations and to provide representative water chemistry samples from the saturated zone. Networks of wells can be used to determine shallow subsurface flow paths and spatial and temporal biogeochemical characteristics of GW.

The wells are composed of two-inch internal diameter PVC pipe with a solid upper casing and an intake that intersects the WT. The intake is the screened segment of the well through which GW flows. In the shallow, mostly unconfined aquifers typical of many lowland river sites, the water level in the well is a good indicator of the depth to the water table (DWT).

Piezometers differ from monitoring wells in that they are constructed with a very short intake and are designed to measure hydraulic head from pressure head and elevation head. The water level in a piezometer generally does not give the direct position of the WT. Nested piezometers set at various depths are used to measure GW gradients and to construct flow nets. However, they are less suited for biogeochemical sampling

than monitoring wells because the short intake restricts yield and represents a limited region of the saturated zone.

If possible, the well intake should be of sufficient length to encompass the range of expected WT elevations (Fig. 1). This may not be possible during flooding and high flows or during very dry periods with low flows.

The optimal time to install wells is during baseflow when low WT elevations facilitate hole boring. Baseflow conditions depend of course on weather conditions and vary in time and space. Low flows may occur during:

1. April, when irrigation begins but prior to peak snowmelt runoff.
2. Late June, post snowmelt peak and prior to summer monsoon season.
3, Late September/early October, post monsoon season but before the end of irrigation season.

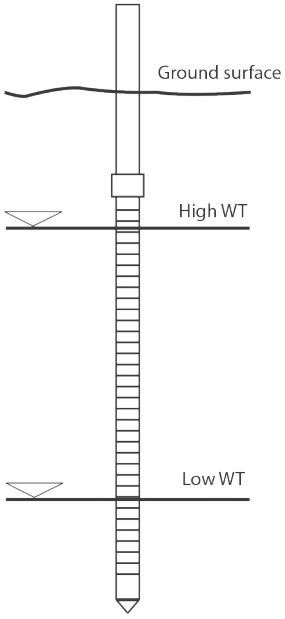


Figure 1. Intake screen should capture range in WT elevations if possible.

II. Supplies, Tools and Equipment

Supplies

- PVC pipe - 2" ID Sch 40, screened (0.01" or 10-slo) for intake and solid for casing. Amount depends on DWT, flooding vs. non-flooding site, etc. Pipes come in various lengths, are sold by the foot, and come with male and female threaded ends. Solid pipe ends might also be sold unthreaded, some with built-in coupling. Unthreaded solid pipes w/coupled joints are less likely to break.
- 2" PVC well caps - slip type. 1/well. Locking types available.
- PVC primer and cement for some joint connections, e.g. slip points w/cut screen pipe.
- Bentonite - to seal annular space near surface, sold in 50# bags as Hole- or Kwik-Plug. Go with 3/8" chips vs. pellets or powder. Enough for several wells.
- Silica sand - size 10-20, for the well filter pack. Plan on ~ 1 bag/well.

Tools/Equipment

- Soil auger w/3" (or 4") bucket and extensions, 2 adjustable wrenches and a strap wrench
- San Angelo rod w/spade end for breaking up roots, hard soils
- Steel rods for packing sand - 1-2, 1 long enough to reach near depth of well if possible
- Fence post driver that fits over PVC pipe
- Sledgehammers - 1 large (10-12 lb. head), one small (for packing rods, etc.)
- Sledgehammer blocks - ~15" L 4"x4" blocks w/partially bored hole that fits over the 2" PVC pipe. Note: fence post driver preferred over sledgehammer driving.

- Stepladder - to stand on, if necessary, when starting the well driving
- Pipecutter - for ≥ 2" pipe
- 10m graduated ½" PVC pole for measuring depths in bore hole
- Water level indicator (beeper)
- Tape measure (w/metric highly preferable)
- Well bailer
- Duct tape, hacksaw, large screwdriver, WD-40, pipewrench, shovel
- Spray paint - cans of gray and brown spray paint to camouflage wells as needed
- Compass (or GPS unit), 100m tape, flagging, loppers, and bow saw for siting wells
- Sediment sampling materials - Whirli-bags, dumping bin, trowel
- 5-gallon bucket - for supplies and to stand on, if necessary, e.g. starting the well driving

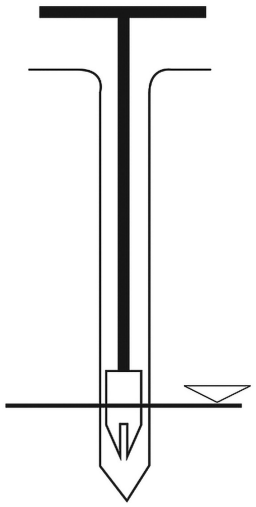


Figure 2. Work the seds with the auger to advance the hole.

Misc

Head protection (hard hats/goggles, if using sledgehammer method), work gloves, site keys and permits, field book, pencil, calculator, black sharpie, rag or two, drinking water, bug spray

III. Well Installation

A. Bore Hole

- Auger down to WT, collecting sediment samples for texture analysis if desired. The seds should be sloppy-wet at the WT. If just damp you may have only reached the capillary fringe – keep digging.
- At the WT, the hole will collapse and boring deeper will be limited. Use the auger/ rod to try to work (loosen) the seds at the WT and advance the hole as best you can (Fig. 2). This will facilitate driving in the well. Estimate DWT using the PVC rod or beeper.

B. Assemble the Well

- Determine the intake length based on the DWT. Try to extend the well ~ 100cm below the WT (more if WT is not near baseflow). The intake should end up ~ 25cm below ground. So, cut the screened PVC to the DWT plus 75cm (Fig. 3). It's best to use the pipecutter to ensure that connections are tight.

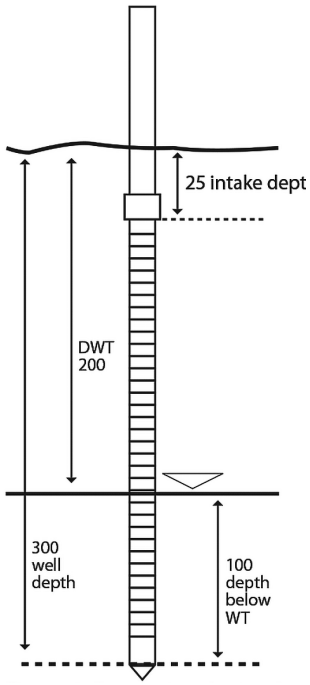


Figure 3. Determine the intake length. Ex: If DWT = 200 cm, cut 275 cm of screen length.

- Attach a drive point and a length of solid PVC for the casing to the intake screen. Use male/female or slip-type points and slip couplings as necessary. Use PVC primer and cement if necessary. The solid PVC should be long enough to cover the 25cm below ground depth and to fit the fence post driver (150cm is a good length).
- Now that the well is assembled, measure the effective screen length (Fig. 4), correcting for sections covered by couplings, etc. For example, a slip-type drive point inserted into a cut piece of screened PVC pipe will eliminate ~3.3cm of intake.

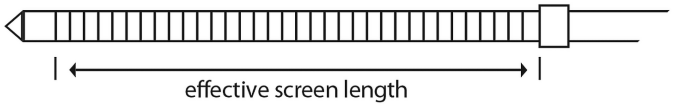


Figure 4. Measure effective screen length.

- Measure the well from the bottom, marking the casing at convenient intervals (e.g. 10cm, Fig 5). Also measure/mark a distance from the upper end of the intake to a point on the solid casing that will end up above ground, e.g. 150cm above the intake.

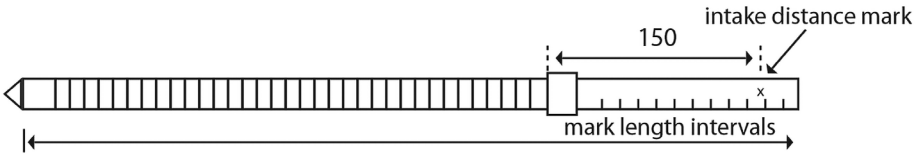


Figure 5. Mark length intervals and the intake measurement point on the casing before driving the well into the ground.

C. Insert the Well

- Drive the assembled well into the bored hole, working it in by hand as deep as possible.
- Cover the top of the well casing with a couple of strips of duct tape
- Drive the well to the desired depth using the fence post driver. Less recommended is to place a wood block atop the casing and strike it with the sledgehammer (the block will need to be held in place by a crewmember – wear your hard hat, goggles and gloves). The sledgehammer can also be used to advance the fence post driver if it becomes too difficult to advance by hand – use a 2x4 scrap atop the post driver. With either method, don't use too much force or you risk shattering the well, particularly the intake. This is the main reason that it's best to install wells at baseflow, since the hole can be cored deeper and pounding the well is minimized. Driving the well may require standing on a stepladder.
- When the well is at the desired depth, determine the grade level where the casing and ground intersect and notch lightly with a saw. Now record the depth to intake: measure the distance from the intake distance mark you measured previously to the grade notch and subtract this from the intake distance mark value. This is the depth to intake. Ideally, intake depth should be shallow, e.g. 25-50cm. If for some reason your intake mark is below grade (and you can still see it), add the distance to the grade notch.

D. Pack the Well

- Partially fill the annular space around the well with the filter pack (silica sand). The filter pack enhances well yield and helps filter out fine materials that can accumulate in the well and clog the intake. Pour some sand, pack, and repeat as necessary (see next step).
- Tamp the sand with steel rods (Fig. 6) to eliminate gaps and make a tight packing. Wiggle the well to help move sand down the borehole. Fill and pack to ~ 10cm above the intake depth (measure w/rod or beeper). The well should be packed tight, difficult to spin by hand.
- Adjust the casing height to the desired length by cutting or extending with a coupler, e.g. ≤ 20cm in non-flooding sites, above potential flood level in flooding sites. A pipecutter makes a more level cut than a hacksaw and eliminates PVC shavings. Cut two notches in the casing ~ ½" apart with a hacksaw (Fig. 7). This area serves as the tape position when beeping the well. Make a final case height measurement from the sawed notch at grade level to the top of the well (between beep tape notches).
- Next, fill and pack with some of the extracted bosque sediments to within ~ 10cm of the ground surface, then add a thin layer (~2-3cm thick) of bentonite around the casing (Fig. 8). Pour a couple of bailers' worth of water into the bentonite and allow to soak in. Fill the remainder of the hole with more of the extracted sediments and pack tightly around the base of the well with a short blunt object, e.g. the end of a hammer or wrench. Don't use the long rod, which could trash your bentonite layer

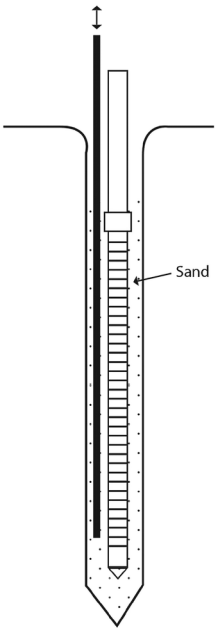


Figure 6. Tamp the filter pack.

Figure 7. Cut two notches at the top of the casing to locater beeper tape.

E. Well Specs

- Label the well on the inside and outside of the casing.
- Beep the well. Calculate and record the well specs in your field book. It is helpful to sketch the well and fill in some of these data, similar to Fig. 9.
- Effective screen length (measured before you installed well): _____
- Intake depth (determined before you packed the well): _____
- Casing height (CH): _____
- Total well length (TWL, measure from marked intervals on casing): _____
- Well depth (TWL - CH): _____

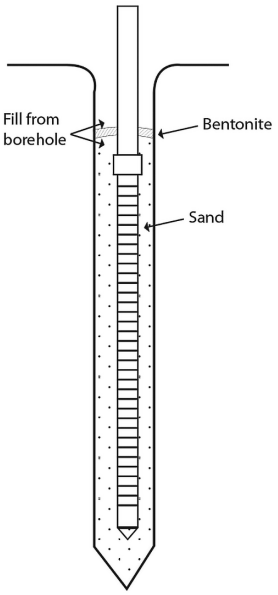


Figure 8. The annular space should include the sand filter pack and a bentonite seal sandwiched by native seds.

- Beep: _____
- DWT (beep - CH): _____
- Depth below WT (TWL – beep): _____
- Other info that might be useful to hydrogeology types:
    - Auger/borehole diam.: 10cm (4")
    - Intake diam.: 5cm (2")
    - Casing diam.: 5cm (2")
    - Screen slot size: 0.25mm (0.01")
    - Filter pack: 10-20 mesh silica sand
    - Surface seal: 3/8" bentonite chips

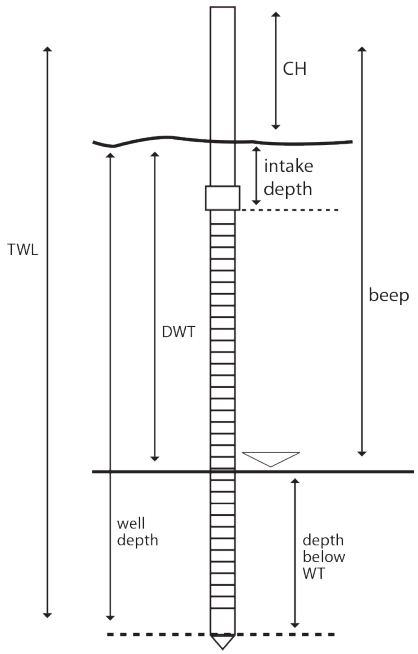


Figure 9. Well specs

F. Work the Well

- Wells should be worked extensively after they are installed to clear fine materials and leach solvents if used (PVC cement).
- Elevate and drop the bailer several times to flush fines, etc. out of the well and filter pack annular space. Also, bail the well several times. The well water should become noticeably clearer. Cap the well LOOSELY or use a locking cap if available.
- Wells should be worked regularly, especially prior to GW sampling.
- Make the well inconspicuous if it is in area susceptible to vandalism. Dry off the well casing and apply a coating of gray spray paint, then a few splotches of brown spray paint, or use camouflage spray paints, if available. Re-label the well over the paint with a black Sharpie, if necessary. Try to hide the well with branches, leaves, bark pieces, etc.

E4 NMFWRI CSE-Based Riparian Monitoring Protocol

This section briefly outlines the monitoring methods currently in use on GRGWA projects. These methods can provide an example for how to document monitoring protocols selected for a project.

Please note that these protocols are applied to all new and existing projects, but when re-measuring older projects, if other protocols were initially used (e.g. NMRAM, or different rules for establishing placement of photopoints) those protocols will also be re-measured for allow for comparison across time. Those legacy protocols are not documented here but documentation can be provided upon request.

NMFWRI Riparian CSE-Based Plot Sample Protocols Used on GRGWA Projects

Based on the 2011 Guidelines and Protocols for Monitoring Riparian Forest Restoration Projects (Bonfantine, et al.) and the Common Stand Exam-based protocols used by NMFWRI for CFRP projects

Crews, Navigation, & Plot Setup

Plots are most efficiently accomplished with a 3-person crew but can also be taken with 2 people. More detailed plots, presented here as options, are most efficient with a 4- to 5-person crew. All crews need basic knowledge of monitoring methods and rationale, equipment, plant species and common tree pests and diseases.

Plots are established using a random point location with project-specific boundaries e.g. stand boundaries, treatment areas, vegetation types, etc. In our office, maps and plot locations are generated with ArcGIS utilities and are loaded onto a Tablet/Geode pair and Garmin GPS units. The sampling density scheme for GRGWA projects is as follows:

Projects under 21 acres – 2 plots
21-50 – 1 plot per 10 acres
For projects 51+ acres:
51-70 ac – 5 plots
71-90 ac – 6 plots
91-110 ac – 7 plots
111-200 ac – 8-9 plots
201-400 ac – 10 plots
400+ ac – discuss alternate sampling methods (e.g. LiDAR)

The plot minimum spacing is 300 ft on most projects, or 200 or 100 ft on projects where a 300 ft spacing will not allow the prescribed number of plots to fit within boundaries. Plots must be a minimum of 50 ft from project boundary. Plots will be moved in a random direction towards the interior of the project if the plot lands within 50ft of the boundary when using the "Create Random Points" function in ArcGIS Pro. Note that within this framework, flexibility exists to add plots as needed to capture site diversity.

Unit maps, driving maps and driving directions are created and sent with the field crew. Once in the project area, navigation to a plot is typically accomplished through paper maps and the Garmin GPS units. Paper

maps can be easily marked with Sharpies to indicate sequence of plot collection, dates, and teams at work; this information can be stored with the datasheets and may help answer questions that arise later. NMFWRI uses Garmin GPS units because they are user-friendly and can run on AA batteries, which are easily replaced in the field. Then, the tablet and Geode are used to more accurately determine plot location and collect updated plot location coordinates which can later be post-processed for greater location accuracy with a handheld GPS unit. Plots must be moved one chain (66 ft) at a random azimuth from their original, intended location if they are within 75 feet of a road.

A marker (typically a 1-foot piece of ½ inch rebar with a mushroom cap) is installed at plot center if the landowner/manager gives permission. Markers should be low to the ground and well flagged so that they are obvious to managers and treatment contractors. Where plots are being re-visited, a good metal detector may be of use to locate the center stake (marker). Copies of the previous plot photos can also be useful.

Plots are set up using 8 pin flags in addition to the center stake. Crew members walk cardinal azimuths (N, E, S, W) from plot center and place pin flags at 11.78ft (11' 9") and 37.24ft (37' 3") to give visual aids for the two plots (1/10th ac and 1/100th ac) whose purposes are described below.

Photographs, Witness Trees, & Other Plot Data

Eight photographs are taken per plot. If more than the two standard Brown's transect is collected, additional photographs are taken in the same format. Typically, a white board with marker is used to tag each photo. The first photo taken at each plot is of the white board on the ground at plot center ("PC"). This ensures the data technicians are able to read the plot name and number and correctly identify the photos that follow. It is helpful if the camera used can record GPS coordinates.

Additional photos include:

- "C," taken from 75 feet along the North azimuth looking at a crew member holding the white board at plot center
- Brown's transect photo, "B_*degrees*" taken from the 75-foot mark of each fuels azimuth looking towards a crew member holding the white board at plot center
- "N," "E," "S," and "W" photos taken from plot center facing a crew member holding the white board at 37.24' at each of the four cardinal azimuth flags. Additional photographs may be taken, but it is recommended that these be taken after the mandatory eight plot photos. Note them on the data sheets, so that there is no confusion for the data technicians.

All plot photos except "PC" need to be documented in the Photopoint Log. The Photopoint Log provides places to document landmarks and other information about each photograph to make re-takes simpler. A witness tree or trees should be near plot center to assist with finding plot center and ideally should be expected to survive any future thinning, fire, or other disturbance. For example, mature cottonwood trees near plot center are easy to find and not likely to be thinned. Any healthy, native tree will work. The tree should be flagged, noted in the overstory data, and described on the Plot Description datasheet.

Photo order, hill slope, dominant aspect, coordinates, elevation, date, and time are recorded for each plot. Comment fields are available on all datasheets and we encourage all observations, including species, land use impacts, fire history, challenges in taking plot, etc. to be documented here.

Overstory

All trees and snags are measured within the fixed area, circular, 1/10th acre (37.24 ft radius) sample plot. We typically define a tree as ≥ 4.5 ft. tall and > 5 in DBH or DRC, although other cutoffs may be used depending on objectives. Species, condition, DBH or DRC, number of stems, total height, and live crown base height are recorded for each tree located within the plot. Most trees are measured at DBH with exception of *Quercus* spp., *Juniperus* spp. or *Pinus edulis* species with more than two stems at DBH. Be aware that other trees/large shrubs with multiple stems, such as saltcedar, Russian olive, mountain mahogany or chokecherry, cannot be processed if they are measured at DRC since their conversion formulas are unavailable. Depending upon the project, other information may be collected including damage and severity, scorch height, snag decay class, crown ratio, and crown class. Trees are recorded starting from the north azimuth line and moving clockwise, like spokes of a wheel from plot center. In dense stands, we find it helpful to flag the first tree measured to keep the crew oriented. If appropriate, this first tree may also serve as the witness tree. Do not forget to flag and record the witness tree.

Tree regeneration is measured on the nested 1/100th acre circular plot (11.78 ft. radius) and species, condition, and height class (>0-0.5 ft; >0.5-1.5ft; >1.5-2.5ft; >2.5-3.5ft.; >3.5-4.5ft) are recorded for each seedling or sprout. Saplings (>4.5ft but <1.0in DBH/DRC) are also recorded in this way. Shrubs are measured on the same nested subplot and species, condition and height/diameter class are recorded for each stem just as with tree species; we typically record cacti in this category as well. Other cutoffs may be used for height and diameter classes depending upon objectives.

Trees and shrubs are typically recorded using their USDA PLANTS code, which is commonly a four-letter code defined by the first two letters of the genus and first two letters of the species name (e.g. PIPO, ABCO, PIFL, PIED, JUDE, JUSC, QUGA, etc). Note that upon entry into a database, it is common for these codes to be followed by various numbers in order to differentiate between other species whose names would create the same code. These symbols can be found on the USDA PLANTS website, https://www.plants.usda.gov/.

Canopy cover (density) is an average of four measurements from a spherical densiometer. These four measurements are taken facing out at the four small-plot pin flags along the perimeter of the nested subplot. In this way, each reading is spaced 90 degrees apart. Each of the four measurement is recorded separately on the datasheet. The crew should be consistent across the project in counting squares or dots and recording the area as covered or open; methods selected should be clearly documented.

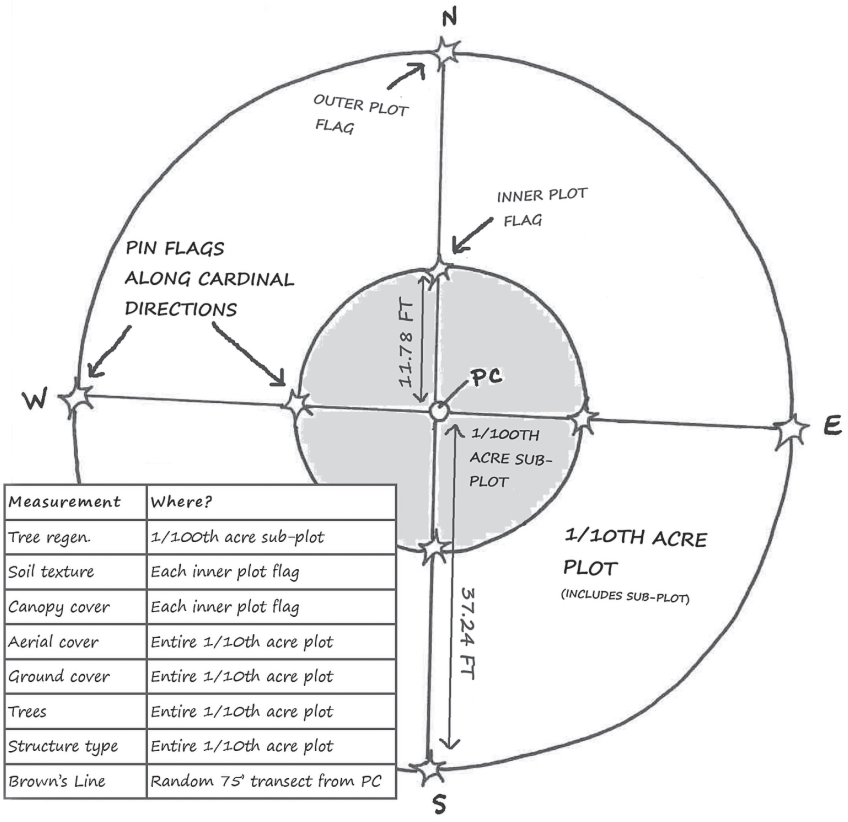
Vegetative Community Structure type is a classification system developed by Hink and Ohmart to describe patterns of vegetation specifically along the Middle Rio Grande. The "original" Hink and Ohmart scheme uses vegetation height and presence of understory vegetation to assign a structure type between 1 and 6. In addition, the New Mexico Environment Department developed a "modified" Hink and Ohmart system that assigns a value of 1, 2, 5, 6S, 6W, 6H or 7. We recommend the field crews take copies of the keys for both original and modified schemes and apply them to the entire 1/10th acre plot.

Soils

Soil texture is collected in four locations. At each of the four 1/100th acre cardinal direction flags, collect 3 subsamples of soil using a shovel or soil corer to a depth of 6 inches. Standing over the flag as if taking canopy

cover, i.e. facing away from plot center in the cardinal direction of the flag, collect soil subsamples 2 feet to the left, right, and toward plot center as shown in *Supplement E4.6*.

Combine each set of three subsamples into one sample by mixing thoroughly in a bag or tub. Remove any large organic debris such as plants or wood chips. Follow the soil texture flow chart (*Supplement E4.11*) to determine soil texture for each combined sample at each measurement point. Record this on the datasheet for a total of four soil textures per plot. Return soil to all holes when sampling is complete.



Measurement	Where?
Tree regen.	1/100th acre sub-plot
Soil texture	Each inner plot flag
Canopy cover	Each inner plot flag
Aerial cover	Entire 1/10th acre plot
Ground cover	Entire 1/10th acre plot
Trees	Entire 1/10th acre plot
Structure type	Entire 1/10th acre plot
Brown's Line	Random 75' transect from PC

Figure 1. Plot layout, and measurements taken throughout plot. *Diagram by Jax Gaglianese-Woody.*

Fuels (Brown's)

Dead woody biomass and forest floor depth are measured using two planar Brown's transects.

These are at random azimuths. To select a random azimuth, one crew member spins a compass and another decides when to stop. Typically, in our protocol, a fiberglass tape is run from the plot center stake out 75 feet and fuels are measured from 15 to 75 feet to account for the expected foot traffic disturbance around plot center. Parameters measured include 1, 10, 100, and 1,000 hour fuels ("time- lag fuels"). See diagram below for standard lengths of various transects.

For full protocol details, see Brown 1974[1] and subsequent guidelines or the NMFWRI training manual. Quick reminders: Note that in our protocol, a piece of coarse woody debris (CWD) must be >3" in diameter and at least 3 feet long to count as a 1000-hour fuel; if it is >3" in diameter, but under 3 feet long, we count it as a 100-hour fuel. Decay class (1 to 5) and sometimes length is collected for each 1000-hour fuel. The comment field on the datasheets is often used to record species and how the log came to be on the ground (when discernable). The sampling plane goes up to 6 ft above the transect. Rooted vegetation does not count unless it has a lean over 45 degrees. Litter and duff depth measurements are taken at 45 feet and 75 feet on each transect.

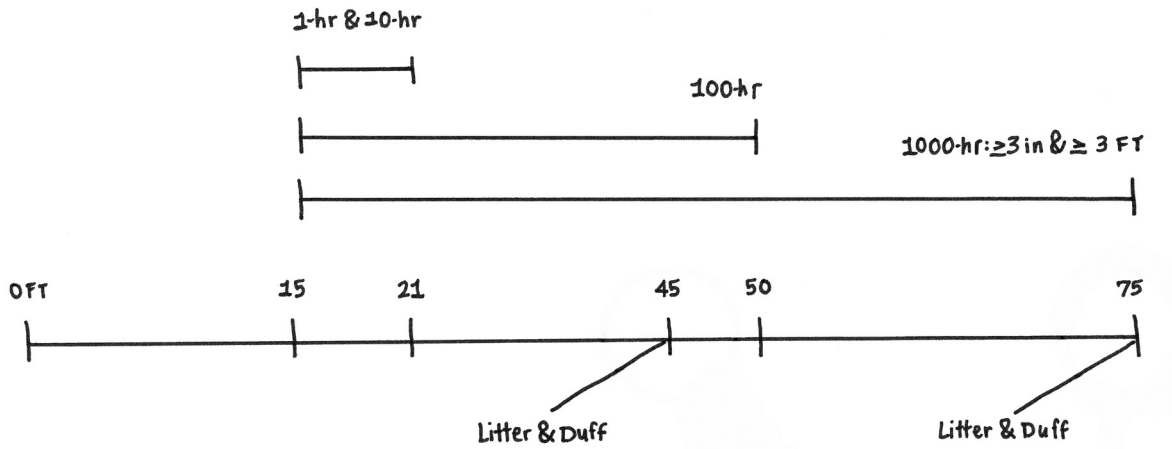


Figure 2. Fuels Transect. *Diagram by Meredith Prentice*

Understory Cover

Vegetation and ground cover are estimated across the entire 1/10th acre plot. Vegetation measurements include aerial percent cover of seedling/saplings, shrubs (including cacti), graminoids, and forbs, and may not necessarily total 100%. Aerial percent should be further stratified by individual species greater than 1% cover. USDA PLANTS codes are preferred. The status of each group of vegetation (live, dead, sick) as well as the nativity (Native, Exotic, or Unknown) should be recorded. Any unknown plants should be described in comments, photographed (after plot photos!) and samples collected in a field press for subsequent identification. Include sticky notes (or better yet, a filled-out herbarium voucher) with each pressed sample describing the collection location and conditions, including which plot it was collected near.

Ground cover measurements include percent cover of plant basal area (including cacti), boles, litter, bare soil, rock, gravel, and water/wet soil and must total 100%.

Data Processing and Reporting

At this time, NMFWRI uses FFI software, as well as Excel spreadsheets, and a custom Microsoft Access database (NERDS) to enter and analyze data. FFI is able to export to FVS and FuelCalc. FFI software and User Guides are available for download here: https://www.frames.gov/partner-sites/ffi/software-and-manuals/

In order to process individual piñons, junipers, and oaks with more than 2 stems or whose branch structure made access difficult and were therefore measured at root collar (DRC) instead of breast height (DBH), NMFWRI uses the equations developed by Chojnacky and Roger (1999).[2]

All results are typically reported to two significant digits, with exceptions for those metrics known to be measured with more or less precision.

Sample reports can be found on our website: https://nmfwri.org/projects/

Works Cited

1. Brown, J. K. Handbook for inventorying downed woody material. *Gen. Tech. Rep. INT-16. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 24 p.* 016, (1974).
2. Chojnacky, D. C., & Rogers, P. (1999). Converting tree diameter measured at root collar to diameter at breast height. *Western Journal of Applied Forestry, 14*(1), 14–16. https://www.usu.edu/beetle/documents2/1999Chojnacky%20Rogers_Converting%20Tree%20Diam.pdf.

E4.1 Photopoint and Photo Management Best Practices

Taking Photopoints

Photopoints are powerful visual tools for documenting changes over time. When taken consistently and accurately, they provide clear and accessible information. They are particularly valuable in outward-facing documents—such as reports, publications, and educational materials—but can also serve an important role internally as a tool for data verification.

However, the value of photos depends on their quality. Variables such as the photographer, the camera used, and features of the landscape can change between visits, making reproducibility challenging. It is therefore critical for all field technicians to know how to take good photos and follow consistent guidelines.

Figure 1. Monitoring technician attempting to shade out the sun while taking a plot photopoint.
Photo by Jax Gaglianese-Woody

Best Practices for Taking Photos:

- Develop a photopoint log to collect document information about the photos (e.g. coordinates, photo ID, foreground and background landmarks, azimuth, and so forth).
- Monument photopoint locations when possible so that they can be retaken from the same location.
- Create a list of the photos you need to take before starting so that nothing is missed.
- Consider the time of day or year. Taking photos directly into the sun can result in poor quality images.
- If installing any photopoint or plot markers (e.g. flagging witness trees), make sure to do so *before* collecting photos.
- Ensure GPS tracking is enabled on your camera (if available).
- Confirm the camera's date and time is correct before taking photos.
- Hold the camera level horizontally. Do not zoom in or out.

Figure 2. Two photopoints showing an area before treatment (top) and 10 years after treatment (bottom). These photos are of the same area and are nicely lined up for comparison. *Photos by NMFWRI Monitoring Crew.*

- If any people are present in photos, ensure they are wearing proper clothing and PPE and appear professional.
- Double-check photos using the camera's playback function after taking a photo or before leaving the plot, and retake photos that:
    - Are blurry, too dark or washed out
    - Are obstructed in any way (e.g. fingers over the lens)
    - Include vehicles in the background (if the vehicle can be moved)
    - Include visible backpacks/gear or crew members who were not intended to be part of the image
    - Include transect tapes that are "wiggly"–straighten them up or remove them
- If retaking photos from already established photopoints:

- Bring copies of previous photos to the field for reference.
- Try to use the same kind of camera, or at least the same aspect ratio/frame as was used for previous images.
- Ensure the new and old photos match as perfectly as possible to show the changes in the area since the last visit. Prioritize perfect matching of the images over perfect matching of the previously recorded azimuth.

Photo Management

Photographs are valuable tools for contextualizing numerical data and communicating the progression of a project site over multiple visits. To use them most effectively, however, it is crucial to have a consistent and easy-to-follow record-keeping practice. Without such a convention, it can be easy to lose the information needed for future repeat photos. We recommend establishing a standardized photopoint logging protocol to help both with matching photograph locations on subsequent visits and keeping files identifiable in the office.

NMFWRI tracks project photopoints in the field using a "Project Photopoint Log." *See Supplement E4.11 for a copy of NMFWRI Project Photopoint log*.

NMFWRI technicians record the following metadata in a log before leaving the field:

- Project ID/ Photopoint number (e.g. 19.01_1_N)
- Data & time
- Photo number (found within the camera)
- Latitude (dd.ddd)
- Longitude (ddd.ddd)
- Direction or azimuth photographer was facing (cardinal direction or degrees)
- Foreground landmark: description, distance, bearing, flagging color if applicable
- Background landmark: description, distance, bearing
- Whiteboard distance
- Camera used and photograph ID number in the camera
- Field crew initials
- Comments (e.g. which portion of the project is shown)

NMFWRI also follows a standardized naming convention for photo files. Like the paper datasheet, this helps manage photographs both in the office and in the field during future site visits. NMFWRI adheres to the following naming conventions:

- Plot photopoints (not of plot center):

    - YEAR_ProjectID_PlotID_CardinalDirection
    - Ex: 2025_25.01_2_N
- Plot photopoint (of plot center, PC):
    - YEAR_ProjectID_PlotID_PC
    - Ex: 2025_15.07_2_PC
- Brown's line photopoints:
    - YEAR_ProjectNum_PlotID_BR+Azimuth
    - 2025_25.11_1_BR145
- Photopoints that are not one of our 8 plot photos:
    - YEAR_ProjectNum_PlotID_Azimuth
    - Ex: 2025_15.02_3_323

These naming conventions are documented and accessible to all monitoring technicians, ensuring consistency across years and crews.

Project/ Photopoint ID	Date & Time	Photo Number	Lat (dd.ddd)	Long (ddd.ddd)	Direction Facing	Foreground Landmark: Description Distance, Bearing, Flagging color	Background Landmark: Description, Distance, Bearing	Whiteboard Distance	Camera Used	Field Crew	Comments/ Veg polygons
16.13_1_N	1/18/2022 11:10am	100-0399	35.11110154	-107.8694233	N/ 0 deg	4-wing saltbush @14' @356deg. Flagged pink.	Salt cedar @570' @0/360deg	11.7'	Olympus red CAM003	CB, RM, AM	Bare ground, field of 4-wing saltbush
16.13_1_E	1/18/2022 11:10am	100-0400	35.11110154	-107.8694233	E/ 90 deg	Bare ground PC @21' @180deg	Fence @563' @90deg	11.7'	Olympus red CAM003	CB, RM, AM	Bare ground, 4-wing saltbush, field and fence

Figure 3. Example of a filled out photopoint log.

E4.2 Canopy Cover by Densiometer

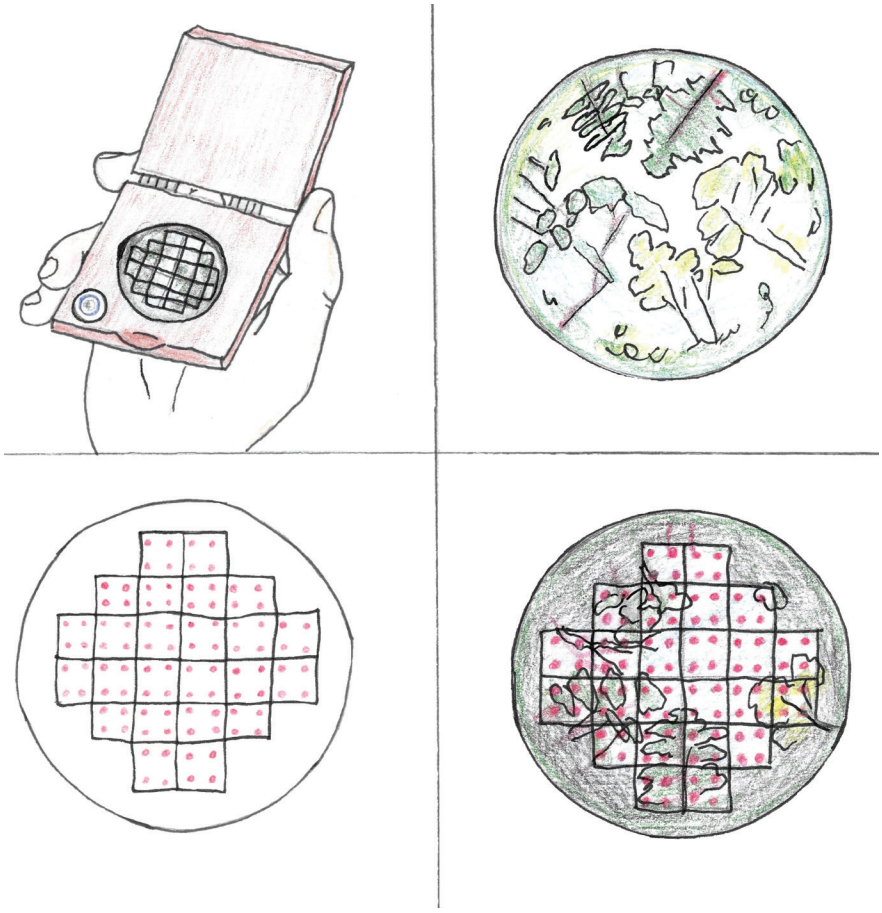


Figure 1. Using a densiometer to estimate canopy cover. *Diagram by Zoe Ahrens*

Spherical densiometers are tools developed for estimating overstory canopy density in forests. They are available with concave and convex mirrors; NMFWRI crews use the concave models. In addition to the methods described below, there are a number of other ways to use spherical densiometers, such as the Strickler modification, that crews may encounter in other monitoring protocols or jobs.

Four canopy cover estimates are taken at each plot. In NMFWRI's protocol, these four estimates are collected while standing at each inner plot flag (North, East, South, West), facing out towards the corresponding outer plot flag.

To begin,

1. Stand at the first point facing North from the reference point. In the NMFWRI riparian protocol, the first point is at the North inner plot flag facing the North outer plot flag.

2. With the densiometer open, hold it about waist high, level, and just far enough away so only sky/canopy is visible in the densiometer mirror. Typically, the user's elbows should be bent at a 90° angle and pressed against the side of their body.
3. To ensure the densiometer is level, keep the bubble centered in the black circle in the lower right corner.
4. Proceed using either the Square or Dot Method outlined below. NMFWRI monitoring crews are trained to use the Square Method on project plots.

Square Method:

- There are 24 engraved squares in the densiometer mirror.
- Count the number of squares which are NOT occupied by canopy. Half squares can be combined within a single measurement, but each measurement should be reported in a whole number of squares.
- Subtract the number of open squares from 24 to get the number of covered squares.
- Record this number and move on to the next measurement. If the first measurement was taken at the North inner plot flag facing North, the next three measurements are at the East, South, and West inner plot flags. Each of these measurements are recorded independently before calculating plot canopy cover.
- In the analysis, the four measurements will be added together and multiplied by 1.04 to calculate percent canopy cover.

Square Method Example A:

1. First, estimate number of open squares at each inner flag (N, E, S, W)

   North Inner Flag facing North: 6 squares were open.

   24 - 6 = *18* = canopy

   East Inner Flag facing East: 18 squares were open.

   24 - 18 = *6* = canopy

   South Inner Flag facing South: 0 squares were open.

   24 - 0 = *24* = canopy

   West Inner Flag facing West: 11 squares were open.

   24 - 11 = *13* = canopy

2. Next, add up canopy numbers

   18 + 6 + 24 + 13 = 61

3. Next, multiply by 1.04 to correct for only having a total of 96 squares (24 x 4 = 96).

   61 x 1.04 = 63.44 ≈ **63**

Result: the average canopy cover is 63% on the plot.

Dot Method:

- There are 24 engraved squares in the densiometer mirror. Imagine each square has 4 smaller squares with a dot at the center of each small square, totaling to 96 dots.
- Count the number of dots which are NOT occupied by canopy.
- Subtract the number of open dots from 96 to get the number of covered dots.
- Record this number and move on to the next three measurements.
- In the analysis, the four measurements will be averaged, and the average will be multiplied by 1.04 to obtain percent canopy cover.

Dot Method Example A:

1. North Inner Flag facing North: 44 open dots

   96 - 44 = *52 = canopy*

   East Inner Flag facing East: 32 open dots

   96 - 32 = 64 = canopy

   South Inner Flag facing South: 70 open dots

   96 - 70 = 26 = canopy

   West Inner Flag facing West: 51 open dots

   96 - 51 = 45 = canopy

2. Next, add up canopy numbers

   52 + 64 + 26 + 45 = 187

3. Next, divide sum by 4 to calculate average.

   187 / 4 = 46.75

4. Finally, multiply by 1.04 to correct for only having 96 dots.

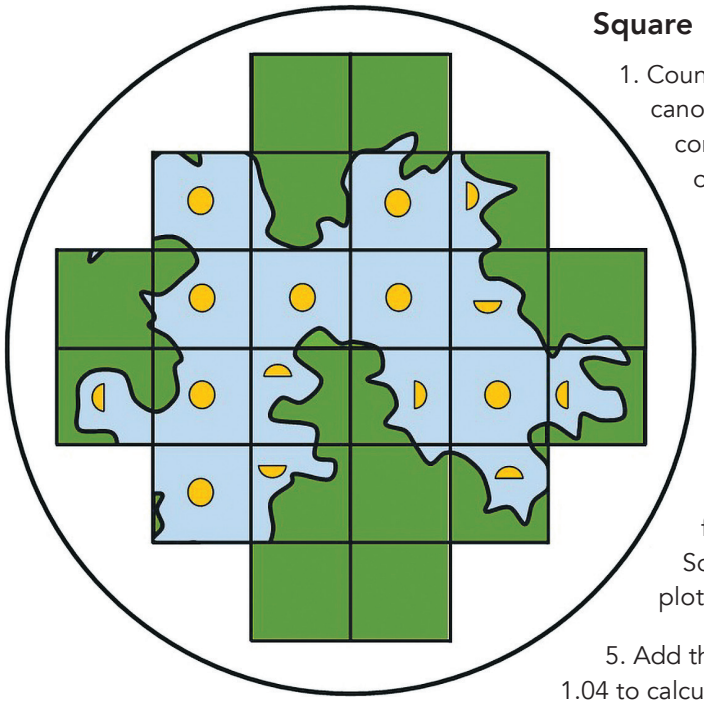
   46.75 x 1.04 = 48.62 ≈ **49**

So, the average canopy cover is 49% on the plot.

Special Cases:

Cliff/Ground providing cover in measurement on steep slopes:

- Include this as "cover" but leave a note estimating the percent coverage that was ground/rock rather than canopy.



Square Method Example B

1. Count how many squares are not covered by the canopy. If a square is half canopy and half sky, combine these partial squares to make whole ones.

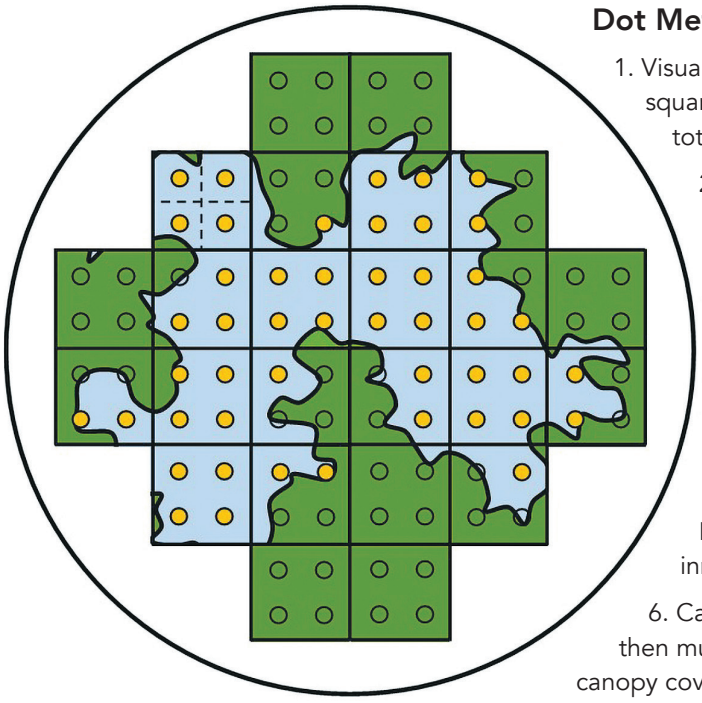
2. In this example, there are 12 squares not covered by the canopy.

3. Subtract the 12 uncovered squares from the total of 24 squares, leaving 12 squares covered by the canopy.

4. Repeat this process three more times. Assuming the first measurement was taken facing North, repeat this process facing East, South, and West at the corresponding inner plot flags.

5. Add the 4 measurements and multiply the sum by 1.04 to calculate percent canopy cover.

Figure 2. In this example, squares with yellow circles represent full open canopy, and squares with half yellow circles represent half open/half closed canopy. *Note that this example does not correspond to Square Method Example A (on page 202).* *Diagram by Jax Gaglianese-Woody*



Dot Method Example B

1. Visualize 4 smaller squares inside each of the 24 squares and a dot at the center of each square, totaling to be 96 evenly spaced dots.

2. Count how many of those dots are not covered by the canopy.

3. In this example, 47 dots are uncovered.

4. Subtract the 47 uncovered dots from the total of 96 to find that 49 dots are covered by the canopy.

5. Repeat this process 3 more times. Assuming the first measurement was taken facing North, repeat this process facing East, South, and West at the corresponding inner plot flags.

6. Calculate the mean of the 4 measurements, then multiply the mean by 1.04 to get percent canopy cover.

Figure 3. In this example, the yellow dots represent open canopy, and empty dots represent closed canopy. *Note that this example does not correspond to Dot Method Example A (on previous page).* *Diagram by Jax Gaglianese-Woody*

Burned/dead canopy:

- Squares with dead branches without leaves can make for difficult canopy estimations, as it is not always clear how many dots would actually be covered by thin branches. In these cases, estimate the amount of sky visible in each square (I.e. 50% sky and 50% coverage would be half a square or 2 dots of coverage).

Calibration/Troubleshooting:

- Crew members using the densiometer can come up with a wide variation in readings. To become consistent, it's important to agree upon a method (dots vs squares) and to spend time practicing with all crew members taking the same readings from the same point and comparing readings. Always record the method and use the same method across the entire project. It helps to calibrate the crew so similar judgements are made about counting dots and squares, especially with small, irregular openings. Have the same crew member measure all four directions within one plot.
- When working in forests with deciduous trees, such as riparian areas, ensure canopy readings are taken during the same season each time, as leaf-off will impact readings.
- Sunglasses are recommended when using the instrument in open canopy on sunny days.

E4.3 Estimating Aerial Cover

Aerial cover refers to the percentage of the ground obscured by vegetation (leaves, branches, etc.) from a viewpoint above the plot. In our protocol, aerial cover is estimated in the entire 1/10th acre plot and encompasses estimations of the cover of seedling/saplings ("tree regen"), shrubs, graminoids, and forbs. Aerial cover may not necessarily total 100%. When vegetation overlaps, cover values greater than 100% are possible. When vegetation is sparse, aerial cover may be much less than 100%. Depending upon objectives, aerial cover estimates may be further stratified by individual species (usually with at least greater than 1% cover) and/or by growth habit.

List by Species	Status L = Live D = Dead S = Sick	Nativity N = Native E = Exotic Unk = Unknown	Aerial Cover (%) (Entire 1/10th acre plot) Estimate Aerial Cover % for Species by Lifeform				
			Tree	Shrub	Forb/herb	Gramanoid	Cactus
AIAL (Tree of heaven)	L	E	3%				
PODEW (RG cottonwood)	L	N	6%				
ANCA10 (yerba mansa)	L	N			2%		
LASE (prickly lettuce)	D	E			10%		
PHAU7 (common reed)	L	E				40%	

Figure 1. Example of the Aerial Cover datasheet used by NMFWRI. *Diagram by NMFWRI Monitoring Crew.*

Terms:

- **Aerial cover** - Percent of ground covered by each category of vegetation when viewed from a top-down/overhead perspective.
- **Tree** - A woody perennial plant, commonly with one main stem, that branches high above the ground, and a mature height taller than that of shrubs. (see note below on distinguishing trees and shrubs).
- **Shrub** - A woody plant smaller than a tree at maturity; has several main stems arising at or near the ground (which plants are considered "shrubs" or "trees" may depend upon monitoring objectives but should be consistent; growth form information can also be found in USDA PLANTS).
- **Forb/herb** - An herb, a flowering plant, other than grass.
- **Graminoids** - Grasses or grass-like plants.
- **Cacti** – Succulent, usually spiny perennials in the Cactaceae family

Steps:

1. Be sure all four flags of your inner circle/small plot are in place.
2. Visualize the circle you are estimating; walk around it and look up and down.
3. Imagine you are looking down from above at your inner circle.
4. Estimate the percentage of your circle covered by each item in the table. Break the circle down into quadrants and sum up the cover in each quadrant if needed. Consult with others if you are unsure.
5. To stay consistent, have the same person do the estimation for all plots in a project.

E4.4 Estimating Ground Cover

In the NMFWRI riparian protocol, ground cover is measured on the entire 1/10th acre plot. Ground cover measurements include percent cover of plant basal area (including cacti), bole, litter, bare soil, rock, and gravel, and water/wet soil. This estimate must total 100%.

GROUND COVER (%) (Entire 1/10th acre plot) (must total 100%)							
Plant basal	Bole	Litter	Bare soil	Rock (>2.5in)	Gravel (<2.5in)	Water, Wet Soil	Total (%)
70	2	7	18	1	2	0	100

Figure 1. Example of the Ground Cover datasheet used by NMFWRI. *Diagram by NMFWRI Monitoring Crew.*

Terms:

- **Plant basal** - Area of the ground occupied by the base of the plant stem. Plant basal includes mosses, cactus, lichen, and cryptobiotic crust.
- **Bole** - Main trunk of tree or woody plant.
- **Litter** - Small dead plant material such as leaves, bark, and needles. For ground cover estimations, this also includes down woody debris (DWD) such as sticks and logs, and other non-living organic materials including ash.
- **Bare soil** - Exposed mineral soil.
- **Rock** - Material greater than or equal to 2.5 inches in diameter.
- **Gravel** - Material under 2.5 inches in diameter but larger than a grain of sand.
- **Water, Wet Soil** - includes standing water, moving water, and water-saturated soil.

Steps:

1. For this estimation, imagine everything in your plot at less than an inch above the ground to estimate how the surface is covered.
2. Estimate the percentage of your circle covered by each item in the table. Sometimes it is easiest to divide the circle into quarters between the inner flags and plot center. Remember that if something fills up an entire quarter, it covers 25% of the plot. It also may help to remember that 1% of the 1/10th acre plot is 43.56 square feet, about the size of a king-size bed.
3. To stay consistent, have the same person do the estimation for all plots in a project.
4. To begin, estimate plant basal area. This is basically the area where the plant stem intercepts the ground surface. So, for instance, if graminoids and forbs are estimated at a total of 83% in the aerial cover table, the basal area would mostly likely be less than the 83% aerial cover. This number does not include any part of the plant except what is right on the soil surface. The stems of cacti are included in basal area.

5. Next, do your bole estimation. A bole is the part of a woody stem (the main trunk) that goes into the ground. It doesn't include branches or twigs, and it doesn't include any pieces of wood that are not stuck into the ground. Cut stumps do count, however.

6. Your litter estimation will capture all needles, sticks, logs, loose pieces of dead grass, etc., that may be on your plot. Only include material that is in direct contact with the ground. For example, some logs may be partially in contact with the ground and partially suspended in the air.

7. Bare soil means an area is totally bare. Don't forget that gravel or pine needles are not bare soil.

8. Rock is a piece of solid mineral material ≥ 2.5 inches in diameter, while gravel is under 2.5 inches.

9. Use a calculator to check your total. Make sure your ground cover totals 100%.

E4.5 Plot Layout

Figure 1. It can be helpful to have a crew member with a compass sight the person measuring and placing inner and outer plot flags at each cardinal direction. *Photo by Jax Gaglianese-Woody*

This protocol presents instructions on laying out a plot for the NMFWRI CSE-Based Riparian Monitoring Protocol. Additional considerations for where to establish plots can be found in Chapter 3.1 and the previous protocol overview.

1. Use GPS to locate plot center (PC) (*see Supplement F4 for more guidance on using GPS/GNSS*). If this is a revisit to a monumented plot, use previous plot photos and comments to assist in re-locating the plot center location. A metal detector may also be used.

2. At PC, find or establish a monument. If the plot will be permanent, drive a piece of rebar or another plot center marker or stake into ground at a height of 4-6" and add a mushroom cap. Otherwise, use a chaining pin or similar marker that can support a tape but can be removed at the end of data collection. If using permanent monuments, ensure the center marker is obvious to managers and treatment contractors.

3. For a 1/10th acre circular plot, run tapes from the PC marker out in each cardinal direction (N, E, S, W) to 37.24 ft. Have another crew member direct from PC with a compass to double-check that each line matches the correct azimuth. (*See Supplement F1.1 Help With Tools for more guidance on using a compass.*) Place pin flags at each location.

4. To establish the 1/100th acre circular nested subplot, place pin flags at 11.78 ft along the same tapes.
5. If the plot is a revisit, confirm locations of both sets of pin flags against previous plot photos.
6. Run a tape at the specified azimuth(s) for the Brown's line(s). Again, have another crew member direct with a compass, and use photos of the previous Brown's line (if applicable) to get the tape as close as possible to the previous tape layout. For a permanently monumented plot, find or drive another piece of rebar into the ground at the end of the Brown's line (75') and add a mushroom cap. If you have to offset the Brown's line rebar, be sure to make a note in the comments (i.e., Brown's line rebar placed at 76.5 ft due to rocks at 75 ft). *For more on Brown's lines, see Supplement E4.8.*
7. Record the plot-level information, such as plot center coordinates (*See Supplement F4 for more guidance on using GPS/GNSS*), declination, plot slope and aspect, recorders, observers, project and plot name, time, and comments. *See Supplements F1 and F2 for more guidance*.
8. Identify and flag the witness tree (where applicable).

Measurement	Where
Tallying tree regeneration, shrubs, and cacti	1/100th acre inner plot
Soil texture	Each inner-plot flag (3 locations per flag)
Canopy cover	Each inner-plot flag (facing out)
Aerial cover	Entire 1/10th acre plot
Ground cover	Entire 1/10th acre plot
Trees	Entire 1/10th acre plot
Hink and Ohmart structure type (Modified & Original)	Entire 1/10th acre plot
Fuels transect/Brown's line	Random 75 ft transect from plot center

Table 1. Measurements taken and their locations on plot.

E4.6 Soil by Texture

Soil texture class is related to weathering and parent material. Clay soil stores water differently than sandy soil. This can be a factor in appropriate species selection because some plant species are tolerant of a wide range of soil textures and others are more specific. Soil texture also influences aeration, which, in turn, influences microbial activity, nutrient availability, and plant root growth (Walters et al. 1992). Simple measurements of soil texture can be performed in the field and provide another piece of the revegetation puzzle.

Soil texture by feel is a method used to determine the proportion of sand, silt, and clay present in a sample. *The attached flow chart in Supplement E4.11 guides the user through the steps in determining texture and is further described here.*

A soil sample is collected often by combining multiple subsamples for one area into a bag or bucket and thoroughly mixed. Large debris such as plants, wood chips, or rocks are removed. A golf-ball sized portion of the soil is taken, and water is slowly added until the soil feels similar to putty.

The ball is then pressed using a thumb and forefinger to create a ribbon until it breaks. The length of the ribbon is recorded. Next, excess water is added to assess the smoothness or grittiness of the soil.

For further instructions and photos, see this resource from the University of Kentucky: https://uknowledge.uky.edu/cgi/viewcontent.cgi?article=1139&context=anr_reports

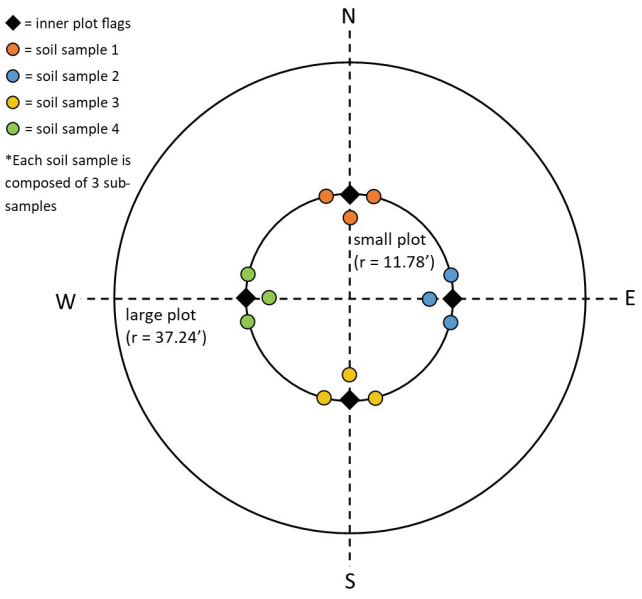
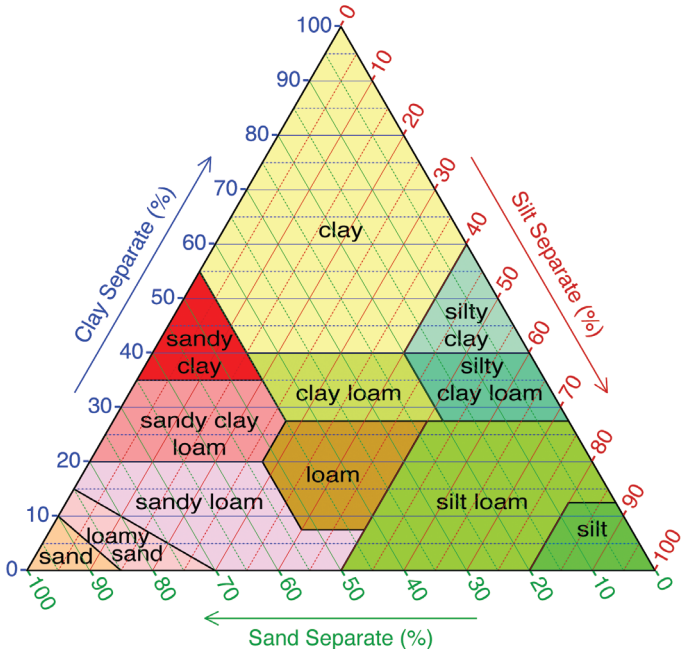


Figure 1. Above: Soil texture is analyzed at each inner-plot flag, and each soil sample is composed of three sub-samples. Note that plot layout is not to scale. **Figure 2.** Below: Soil texture triangle showing the names for different types of soil. The type of soil is determined by the ratio of clay, silt and sand (Source: https://commons.wikimedia.org/wiki/File:SoilTexture_USDA.svg, Authors: cmglee, Mikenorton, United States Department of Agriculture. Licensed by CC BY-SA 4.0 https://creativecommons.org/licenses/by-sa/4.0/deed.en)



E4.7 Vegetation Cover Classification

Hink and Ohmart Structure Types

The following are examples of the modified Hink and Ohmart Vegetation Vertical Structure Type Definitions categories with text from Muldavin (2021).[1] All photos credit NMFWRI. *For copies of both the Modified and Original Structural Class Worksheets, see Supplement E4.11 Data Collection Forms.* The modified classifications are presented below.

Vegetation Vertical Structure Type Definitions for NMRAM

Multiple-Story Communities (Woodlands/Forests)

Type 1 - High Structure Forest with a well-developed understory. Canopy from trees (woody species >6 m tall) covers >25% of this community and a woody understory layer of tall shrubs or short trees (1.5-6 m tall) covers >25%. There is substantial foliage in all height layers.

Type 2 - Low Structure Forest with little or no understory. Canopy from trees (woody species >6 m tall) covers >25% of this community and a minimal woody understory layer (1.5-6 m) covers <25%. Most of the foliage is over 7 m above the ground.

Single-Story Communities (Shrublands, Herbaceous and Bare Ground)

Type 5 - Tall Shrubland. A young tree and shrub (woody species 1.5-6 m tall) layer covers >25% of the community polygon. The stand is dominated by tall shrubs and young trees but may also include herbaceous vegetation underneath the woody vegetation.

Unit	Threshold		
Meters	1.5m	6m	7m
Feet	4.9ft	19.7ft	23ft

Type 6S - Short Shrubland. Short stature shrubs or very young trees (<1.5 m tall) cover >25% of this community. The stand is dominated by short woody vegetation but may include herbaceous vegetation among the woody vegetation.

Type 6W - Herbaceous Wetland. Herbaceous wetland vegetation covers >10% of this community. The stand is dominated by obligate wetland herbaceous species. Woody species are absent or cover <25% of the community.

Type 6H - Herbaceous Vegetation. Herbaceous vegetation covers >10% of the area of the community polygon. The stand is dominated by herbaceous vegetation of any type except obligate wetland species. Woody species are absent or cover <25% of the community.

Type 7 - Sparse Vegetation, Bare Ground. Total vegetation cover in this community is <10%. The bare ground may be caused by a natural disturbance (e.g., cobble bars) or humans (e.g., roads).

Estimating Vegetation Cover using Remote Sensing

This write-up from NMFWRI's GIS team briefly outlines a process for estimating vegetation cover using LIDAR. This write-up refers to a Trimble software called eCognition only because this was the software available to use when this method was developed. Using up-to-date LiDAR data, a Digital Terrain Model (DTM) is created by filtering only the point clouds classified as ground and then only those ground point clouds are converted to a raster DTM. Next, LiDAR first returns are filtered and selected to represent surface features. Only those first returns are converted to a raster Digital Surface Model (DSM). Birds and other noise that are not surface features are removed before creating the raster DSM. In order to get true heights above

ground the Digital Surface Model was subtracted from the Digital Terrain Model creating a Normalize Digital Surface Model (nDSM). The values of the nDSM are heights above ground in meters.

eCognition software is an object-based image classification system that allows for a semi-automated analysis of high-resolution images. This approach divides the image into meaningful homogenous regions, known as image objects. These image objects are groups of pixels that are adjacent to each other and are spectrally similar. Once image objects are created, they provide a great deal of information from which an image classification can be developed.

Having height information with LiDAR greatly increases the accuracy of the classification. Though the use of traditional remote sensing is an effective means of mapping and monitoring land cover, the mapping of small shrubs and trees based only on spectral information is challenged by the fact that shrubs and trees often spectrally resemble grassland and thus cannot be safely distinguished and classified. With the aid of LiDAR-derived information, such as elevation, the classification of spectrally similar objects can be improved.[1]

Image segmentation within eCognition is based on elevation surface models. The 4-Band National Agriculture Imagery Program (NAIP) imagery is then used to calculate image brightness values and Normalized Difference Vegetation Index (NDVI) values are calculated, and both are used as inputs to identify vegetated and non-vegetated areas. The image is classified to identify vegetation vertical structure types representative of the modified Hink and Ohmart system. LiDAR profiles are used to identify understory vegetation to determine if forested areas are Hink and Ohmart classes Type 1 or Type 2. A digital surface model for all heights above ground is used to classify single-story communities (Types 5, 6S, 6H, and 7). This classification incorporates height classes as well as NDVI to identify active vegetation. Once the vegetation is classified by height the resulting classification is exported from eCognition as a Raster image and acreages are calculated.

Works Cited

1. Muldavin EH, Addicott E, Hunter JT, Lewis D, Faber-Langendoen D. (2021) Australian vegetation classification and the International Vegetation Classification framework: an overview with case studies. *Australian Journal of Botany* 69, 339–356. https://doi.org/10.1071/BT20076

2. Hellesen, T. & Matikainen, L. An Object-Based Approach for Mapping Shrub and Tree Cover on Grassland Habitats by Use of LiDAR and CIR Orthoimages. *Remote Sensing 5*, 558–583 (2013).

E4.8 NMFWRI Brown's Line

Fuels, or down woody debris (DWD), are a key component of forested riparian ecosystems. Quantifying the amount of DWD and its stage of decay can help managers evaluate potential fire behavior, forest structural diversity, wildlife habitat quality, carbon storage, nutrient cycling, and other ecological processes. A common measurement method is the fuels transect, also called the Brown's transect.

The Brown's transect was presented by James K Brown in GTR INT-16 in 1974. Below, we present the particular adaptation of this protocol that NMFWRI follows. Be aware that other programs may use different approaches (e.g. different transect lengths, azimuths, or duff/litter sample locations). For further reading, we recommend resources such as:

Handbook for Inventorying Downed Woody Material: Brown (1974), https://www.fs.usda.gov/rm/pubs_int/int_gtr016.pdf

FIREMON Fuel Loading Protocol, https://www.fs.usda.gov/rm/pubs_series/rmrs/gtr/rmrs_gtr164/rmrs_gtr164_06_fuel_load.pdf

Sampling protocol, estimation, and analysis procedures for the down woody materials indicator of the FIA program, https://research.fs.usda.gov/treesearch/13164

The Basics

The components sampled to estimate fuel loading include dead and down woody debris (DWD) and litter and duff depths. Pieces of DWD are tallied in the standard fire size classes:

- 1-hour (0 to 0.24 in.)
- 10-hour (0.25 to <1.0 in.)
- 100-hour (1.0 to <3.0 in.)

Pieces 3 inches or greater in diameter and over 3 feet in length are recorded as 1000-hour fuels and additional diameter and decay class information is collected for those pieces. See Table 1 for a summary of fuel size classes. Duff and litter depth are measured at two points along each 60-foot transect. Biomass of DWD, duff, litter, and vegetation can be calculated using computer software, or by hand using the calculation sheet in Chapter 4.3 Data Analysis Calculations.

Terms:

The following definitions need to be understood so that data gathered is consistent between field crews.

Litter is the loose layer of freshly fallen plant material on the forest floor, including leaves, needles, small twigs (<0.25 inch), cones, bark fragments, dead moss and lichens, herbaceous stems, and small pieces of decayed wood. It is minimally decomposed and readily identifiable.

Because it is exposed to the air, litter acts as flash fuel that can ignite quickly and carry surface fire. It does not include material still attached to logs, rotten wood contained within a log, or animal manure.

Duff is the layer beneath litter, composed of dark, decomposed organic matter with no recognizable plant parts, derived from the decomposition of plant and animal litter (pine straw, leaves, twigs, etc.) and deposited on either an organic or a mineral surface. When moss is present, the duff begins just below the green moss layer and extends down to the mineral soil.

In the Southwest, duff depth rarely exceeds a few inches. It is much denser than litter—often weighing more than six times as much for the same volume—which can help distinguish the two layers.

Fuelbed is the accumulated mass of dead woody material on the forest floor surface. It begins at the top of the duff layer and includes litter, fine woody debris (FWD), coarse woody debris (CWD), and dead woody shrubs, but excludes dead hanging branches on standing trees (FIA General Technical Report NC-256). Fuelbed depth is not measured in this protocol but can be a useful term to understand.

Woody refers to a plant with stems, branches or twigs that persist from year to year. These structural components support leaves, needles, cones, and similar parts, and are the elements tallied along the Brown's transect.

Dead material has no live foliage or is completely severed from the plant where it grew. Sampling in the dormant season should only be done by crews with the expertise to distinguish dormant vegetation from dead trees and shrubs. *See more tips on identifying dead vs. live trees in Supplement E4.94 Tree Health & Damage Codes*. Importantly, material can be classified as "dead" even if green foliage remains attached if it has been severed from the parent plant—for example, fresh slash or newly broken branches.

Down Woody Debris (DWD) is the general term for dead woody material, which is then subdivided into the fine and coarse size categories. This includes dead trees (snags) with the main stem on the ground or supported by branches. A tree is considered down if it is leaning more than 45 degrees from vertical, is not self-supporting, and/or is in contact with the ground.

Fine Woody Debris (FWD) includes down, dead branches, twigs, and small woody boles that are less than 3 inches in diameter at the transect intersection. FWD are within 6 feet of the forest floor and are not attached to their original plant, are suspended by other material, or are attached to plants that are themselves dead and down. FWD may be connected to larger downed material, but only pieces that intersect the sampling transect are counted. Piece angle is not important for determining whether material is down.

FWD does not include any pieces over 3 inches in diameter at the transect intersection, dead branches still attached to live or standing dead trees or shrubs, dead foliage, needles, cone scales, bark fragments, or other non-woody litter, or small chunks of highly decomposed wood (i.e. cubical rot).

Coarse Woody Debris (CWD) includes down, dead tree and shrub boles, large limbs, and other woody pieces that are detached from their original source and lying on the ground. It also includes dead trees leaning more than 45 degrees from vertical (whether root-supported, severed, or uprooted) and round wood such as fence posts and cabin logs.

CWD does *not* include any pieces less than 3 inches in diameter at the transect intersection, dead trees leaning 0–45 degrees from vertical, dead shrubs that remain self-supported by roots, any trees showing signs of life,

rooted stumps, and dead foliage, bark, or other non-woody material not integral to a bole or limb (note that bark attached to a portion of a piece *is* considered an integral part).

Diameter of Dead Woody Classes

Dead Woody Class			Piece Diameter (in.)
DWD	FWD	1-hr	0 to 0.24
		10-hr	0.25 to 0.99
		100-hr	1.0 to 2.99
	CWD	1000-hr and greater	3.0 and greater

Table 1. Characterization of down woody debris (DWD) as fine woody debris (FWD) and coarse woody debris (CWD).

Locating and Establishing Line Transects

The location of the transects depends on the protocol. In our standard protocol we use two transects that extend out from plot center at random azimuth which are remeasured at those same azimuths during subsequent visits.

Another common arrangement is three transects originating from plot center at azimuths of 0, 135, and 270 degrees. Using three transects can help reduce sampling bias on sloped terrain, where coarse woody debris (CWD) may be aligned in a particular direction, by increasing the likelihood of capturing logs positioned parallel, perpendicular, and across the slope.

NMFWRI's default is to sample over a 60-foot distance with an additional 15 feet of buffer from plot center to minimize the impact of disturbance from plot set-up. In other words, the tape will go from plot center out to 75 feet, and sampling will occur from 15-75 feet. In some very dense riparian areas, the transect length may have to be shortened to 35 feet. Note the slope of the fuels transects—these will be needed for the analysis. Always record the transect azimuths, and monument both ends if possible, so you can repeat measurements in the future.

Laying Out the Measuring Tape

A measuring tape laid close to the soil surface defines the sampling plane. The sampling plane extends from the top of the forest floor to a height of six feet. When laying out the tape, crew members need to step so that they minimize trampling and compacting fuels.

The process of laying out the tape is typically more difficult than it sounds because the tape needs to be straight (Figure 1). If the tape zigzags, the selection of pieces is biased, and remeasurement of transect lines and tally pieces for future change detection cannot be done properly. Take your time when laying out the tape.

Note: If photos of previous fuel transects are available, use these to align the measuring tape so that the photos match exactly (even if the azimuth appears to be slightly different from what was recorded).

Tips for getting the straightest tape:

Two crew members need compasses. One crew member can stand at plot center holding the zero end of the tape and the other can advance along the azimuth with the tape reel.

Before leaving plot center, the crew member with the tape should sight a bearing (*see more in Supplement F Using a Compass*) to follow. The crew member remaining at plot center will also sight a bearing. The crew member with the tape will move away from plot center, following both their own bearing and the directions of the other crew member until they reach the 75-foot mark on the tape. At this point, they should be able to sight with their compass back to plot center and be exactly 180 degrees off their original mark. The crew member at plot center should hold the zero end of the tape over the plot center while the other crew member pulls the tape tight. They should work together to lower the tape as close to the ground as possible without disturbing the debris being measured. In most cases, the tape will rest on some DWD and low vegetation but remain below the crowns of shrubs and seedlings.

After the tape is positioned, secure it in place so it does not move until all sampling is complete. Most tapes have a loop at the zero end that can be secured at plot center with rebar or a chaining pin. A chaining pin can be inserted through the tape handle to secure the opposite end. On roll-up tapes, the winding crank can usually be flipped so the knob faces the reel which locks the reel and prevents the tape from unwinding.

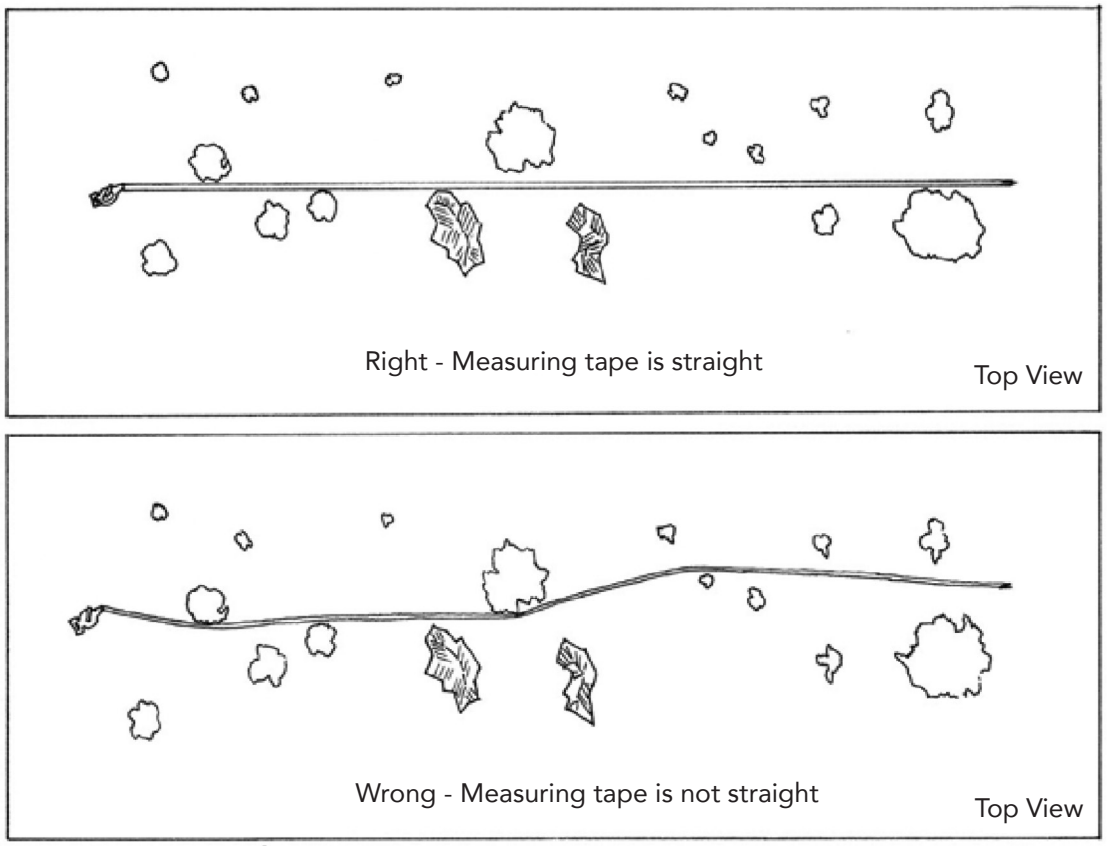


Figure 1. The measuring tape, which represents the lower portion of the sampling plane, should be as straight as possible. If the tape is not straight it needs to be offset left or right until it can be established without kinks or bends. *Image by FIREMON*

We recommend adding a piece of rebar to the 75-foot mark for reliable resurvey of the fuels transect. If mastication is planned, the rebar can be pounded close to ground level and marked with a plastic cap. NMFWRI also collects a photopoint *(see Supplement E4.1 Photopoint and Photo Management Best Practices)* from the 75-ft mark looking along the transects toward plot center to help in re-establishing the transects.

Sampling Time!

DWD is sampled along specific transect segments based on piece size (Figure 3). One- and 10-hour fuels are tallied from 15-21 ft, 100-hour fuels from 15-50 ft, and 1000-hour fuels from 15–75 ft. FWD uses shorter distances because they are more abundant so can be adequately sampled over shorter lengths. The first 15 feet of the tape are excluded from sampling due to expected disturbance near plot center.

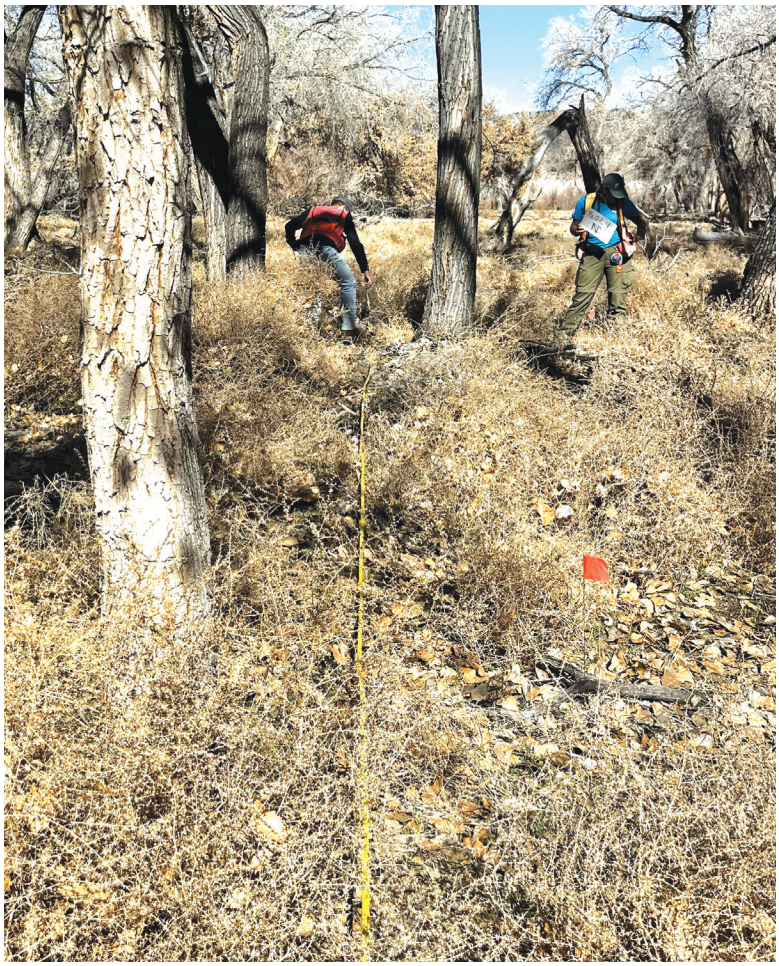


Figure 2. Monitoring tech straightening tape on Brown's Line.
Photo by Jax Gaglianese-Woody

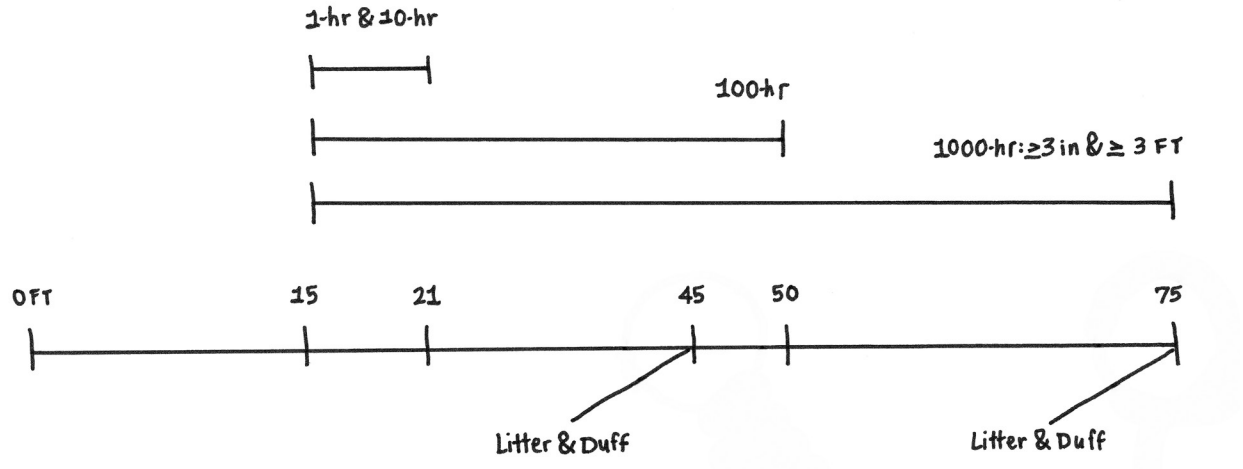


Figure 3. Dead fuels, duff/litter, and vegetation data are recorded at specific locations on or along each sampling plane. The 1-hour and 10-hour fuels are sampled from the 15-foot to the 21-foot marks along the plane, the 100-hr fuels are sampled from the 15-foot to the 50-foot marks, and pieces 3 inches and larger are sampled between the 15-foot and 75-foot marks along the plane. Duff/litter measurements are made at the 45-foot and 75-foot marks.
Diagram by Meredith Prentice

Sampling FWD Using a Fuels Gauge

FWD is tallied in three size classes: 1-hour, 10-hour, and 100-hour. A go/no-go gauge (Figure 4) has slots that match the three fuel-size thresholds, allowing for rapid classification of pieces.

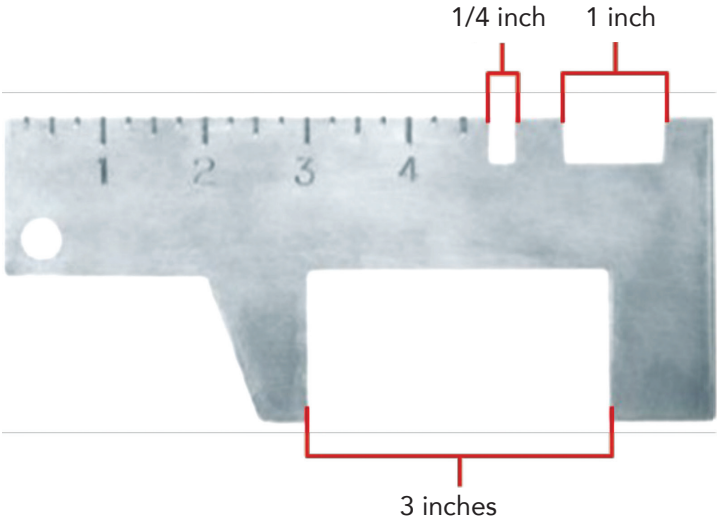


Figure 4. A go/no-go gauge can help samplers tally 1-hr, 10-hr and 100-hr fuels quickly and accurately. *Image by FIREMON*

Count 1-, 10-, and 100-hour fuels that intersect the transect between the 15- and 21-ft marks (Figure 5); from 21 to 50 ft, tally only 100-hour fuels. Remember the sampling plane extends 6 feet above the ground along the transect tape. Classify each piece by its diameter at the point of intersection to one edge of the tape, using the go/no-go gauge. Check carefully for hidden pieces to ensure accurate counts—pieces can overlap or be hidden by vegetation.

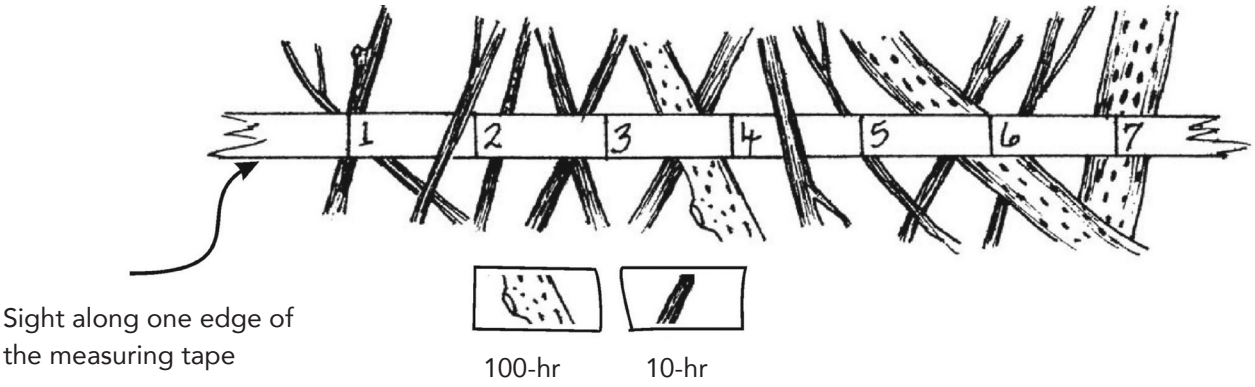


Figure 5. Tally pieces that intercept the sampling plane both above and below the measuring tape. Focus on one edge of the tape to make counting easier. Be sure to note any lower fuels that are hidden by pieces above. In this illustration there are 11 10-hour and three 100-hour fuels. *Image by FIREMON*

Sampling CWD using a diameter tape

Tally pieces that intersect the transect and meet the CWD criteria, from 15 to 75 feet along the transect, up to 6 feet above the ground. Record the diameter and decay class for each piece (see more on decay class in Table 2); under some protocols additional measurements are taken, including char, log length, large-end diameter, species, intersection point, or estimated volume loss to decay.

Wrap a diameter tape around the bole to measure the diameter where the piece's central axis intersects with the transect, perpendicular to the axis, to the nearest 0.1 inch. If a piece crosses the transect more than once, record each intersection separately (see Figure 6). For irregular shapes (e.g. logs with missing chunks of wood or splintered ends), take two measurements and average them to get the diameter. Do not sample a piece of CWD if the central axis of the piece is in or below the duff layer where it crosses the transect (Figure 7).

Angle rule: CWD that intersects the sampling plane at more than 45° above horizontal is considered down only if it is part of a broken dead bole with at least one end touching the ground (not supported by branches or other vegetation). CWD at 45° or less above horizontal is considered down regardless of whether it is broken, uprooted, or otherwise supported (Figures 8 and 9).

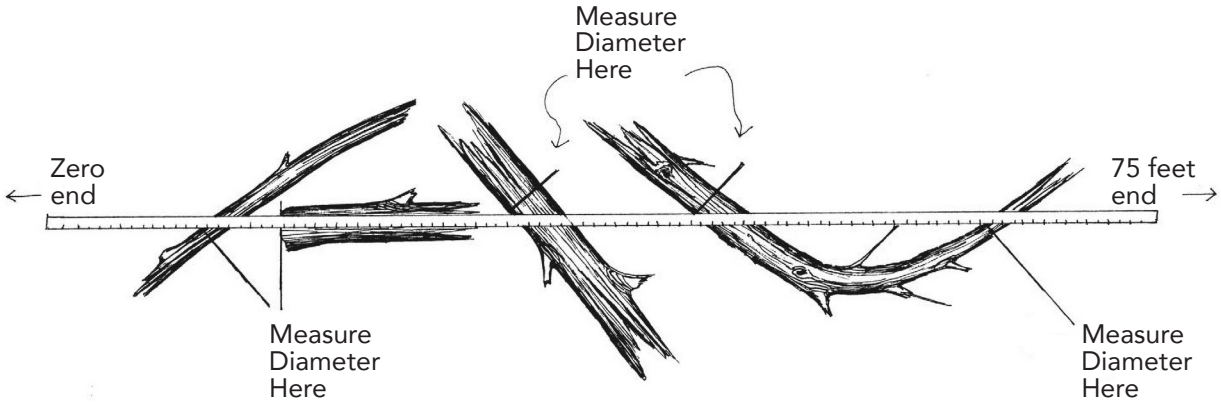


Figure 6. Measure the diameter of CWD crossing through the sampling plane perpendicular to the central axis of the piece. If a curved piece passes through the plane more than once, measure its diameter at each intersection. *Image by FIREMON*

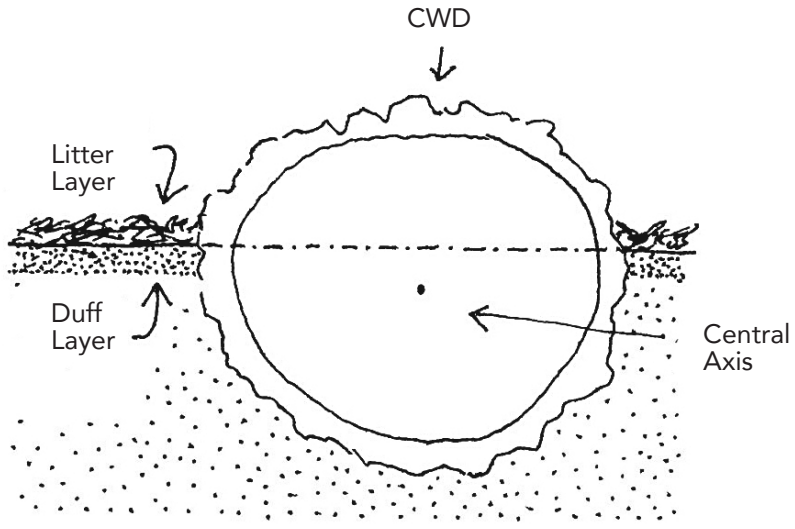


Figure 7. Do not sample CWD when the central axis of the piece lies in or below the duff layer. *Image by FIREMON*

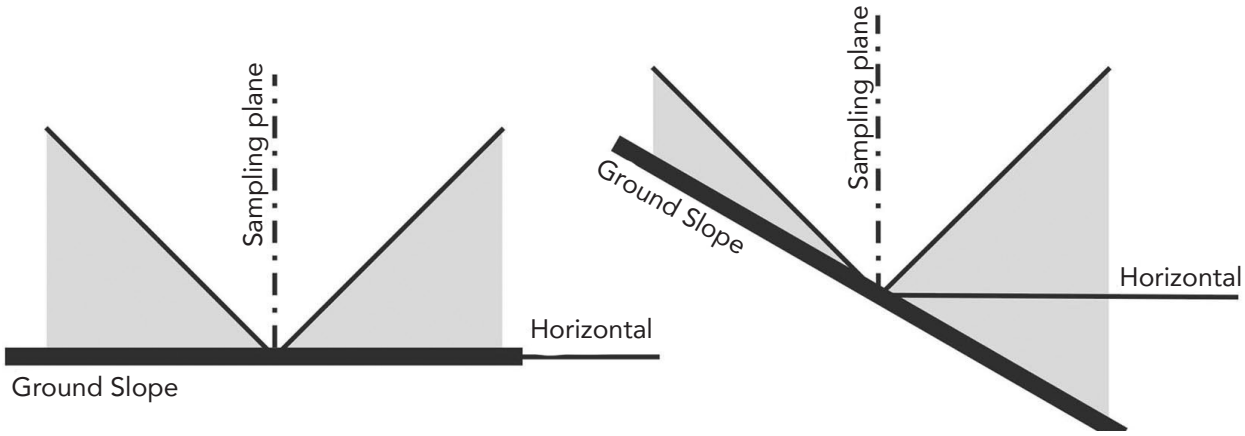


Figure 8. CWD pieces crossing through the sampling plane at an angle less than 45 degrees from horizontal (represented by the shaded areas in the figure) are always considered to be "down." Some CWD leaning greater than 45 degrees may be considered "down." See the text for details. *Image by FIREMON*

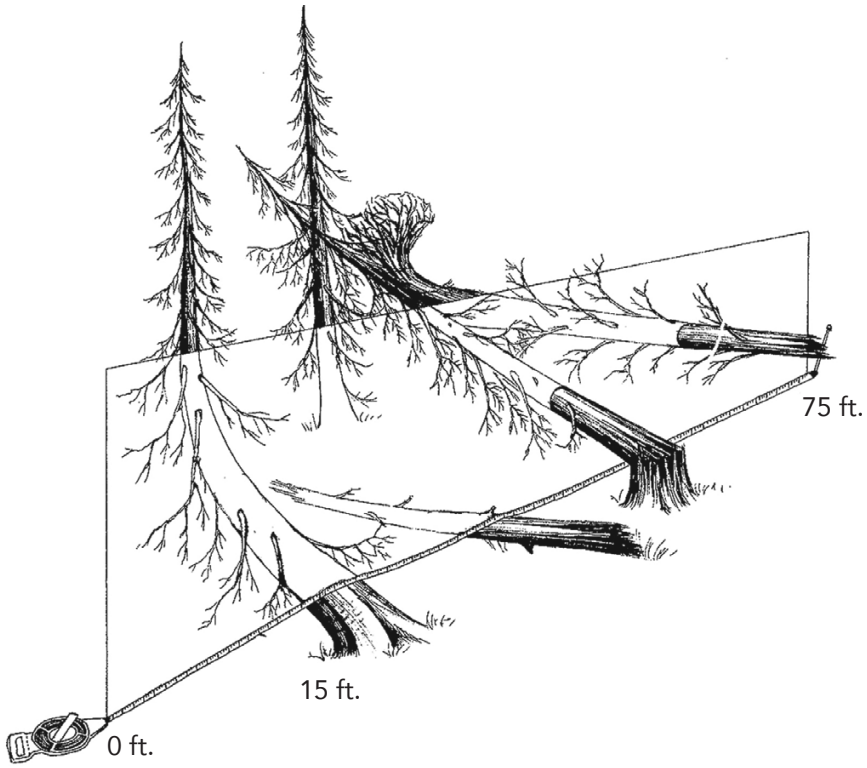


Figure 9. All of the pieces crossing through the sampling plane in this illustration would be considered "down." *Image by FIREMON*

Decay Classes

Decay class can vary along a single piece of CWD, and the condition at the diameter measurement point may not represent the entire log. However, recording decay class at the measurement point provides a consistent and representative sample along the transect.

Note that Decay class 5 logs can blend into duff and litter, but must still resemble a log to be tallied.

Decay Class Types

Decay Class	Description
1	All bark is intact. All but the smallest twigs are attached. Old needles are probably still present. Solid, freshly fallen, intact logs, hard when kicked.
2	Some bark is missing, as are many of the smaller branches. No old leaves still on branches. Hard when kicked.
3	Most of the bark is missing. Most of the branches less than 1 inch in diameter are also missing. Still hard when kicked, still supports its own weight.
4	Looks like a class 3 log but the sapwood is rotten. Sounds hollow when kicked and you can probably remove wood from the outside with your boot. Pronounced sagging if suspended for even moderate distances.
5	Entire log is in contact with the ground. Easy to kick apart but most of the piece is above the general level of the adjacent ground. If the central axis of the piece lies in or below the duff layer then it should not be included in the CWD sampling as these pieces act more like duff than wood when burned.

Table 2. Use these descriptions to determine the decay class where the log crosses the sampling plane.

Duff and Litter Depth Measurements

Depth of the duff and litter layers—and the overall fuelbed—is used in fire models to estimate fire behavior, effects, spread, smoke, and to calculate fuel loads. Measure duff and litter depth at the 45- and 75-ft points on each transect.

Sampling Duff and Litter

The duff and litter layers occur below the transect so cannot be measured using the planar intercept method. Instead, two or more points are collected along each transect by exposing an undisturbed profile of duff and litter.

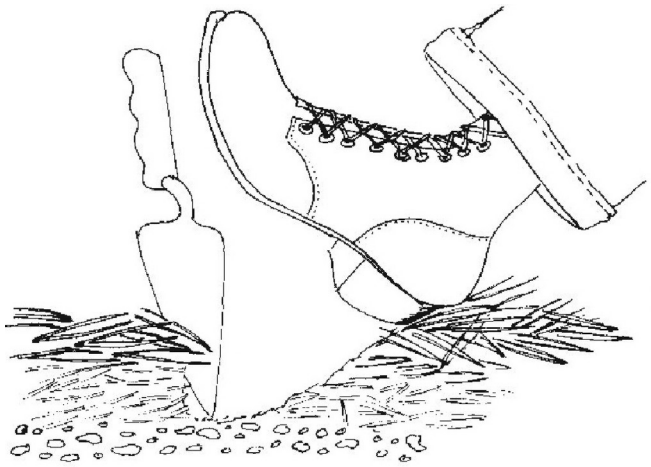


Figure 10. Use your boot to carefully pull the litter and duff layers away, until you are down to mineral soil. *Image by FIREMON*

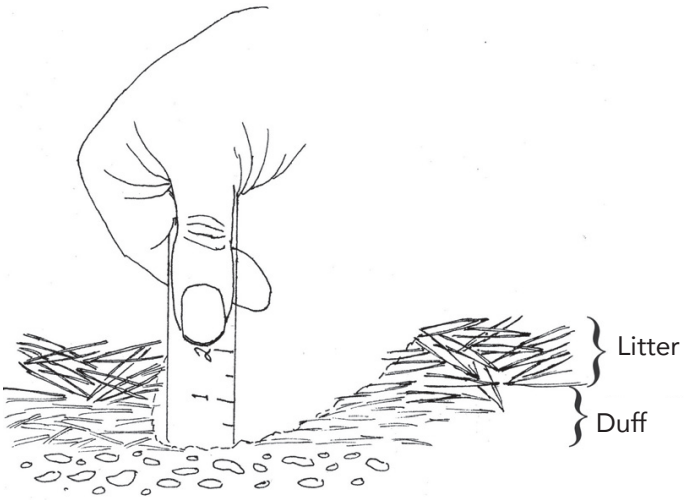


Figure 11. Use a clear plastic ruler to measure duff and litter depth. Here, both measurements are about 1 in. *Image by FIREMON*

Take measurements within 3 feet of the 45-ft and 75-ft marks. At each location, choose a point that best represents the litter/duff conditions within a 3-foot radius. Walk carefully to avoid trampling the area.

Expose the profile carefully by digging with a trowel or boot heel down to mineral soil (Figure 10). Be careful not to compact or otherwise disturb the profile. Measure litter and duff depths separately to the nearest 0.1 inch using a ruler (Figure 11). Measurements are most accurate on the most vertical, undisturbed face of the profile. When measuring deep duff layers, take extra care to make sure the duff bottom is correctly identified.

Wrapping Up

Before picking up the transects, make notes about any observed conditions that might affect fuel loading. For example, evidence of flood, fire, browsing, or treatments that could be impacting the fuel loading, or any notes that will help future crews exactly recreate the transect.

Works Cited

Lutes, D. C., Keane, R. E., Caratti, J. F., Key, C. H., Benson, N. C., Sutherland, S., & Gangi, L. J. (2006). *FIREMON: Fire effects monitoring and inventory system.* Gen. Tech. Rep. RMRS-GTR-164. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 1 CD., 164. https://doi.org/10.2737/RMRS-GTR-164

E4.91 Trees Part 1: What to Record

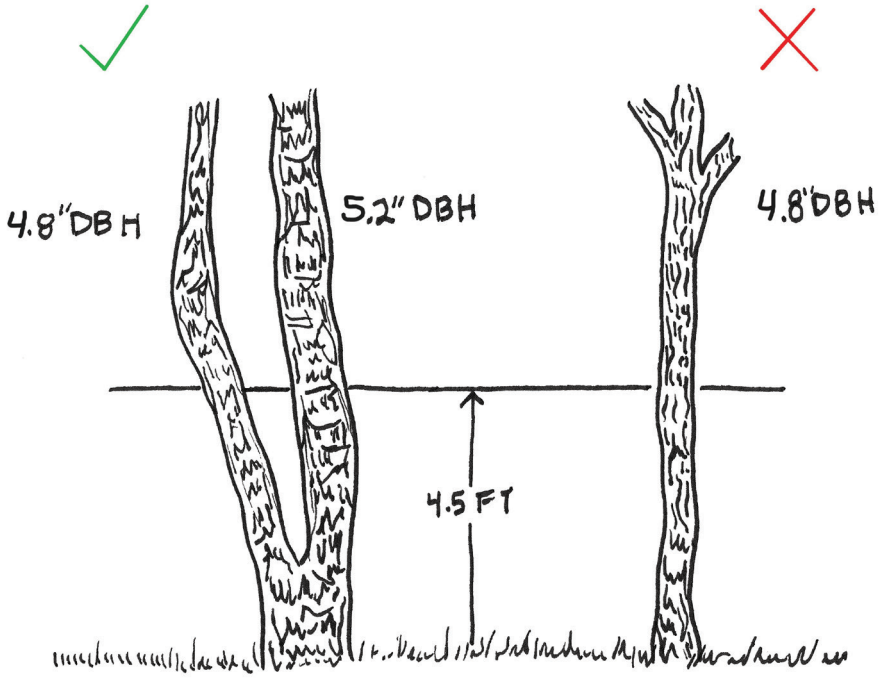


Figure 1. Record both stems of the tree on the left, as the main stem is over 5" DBH. Do not record the tree on the right as the diameter is below 5" DBH and it is not connected to any stems over 5". *Diagram by Raymundo Melendez and Meredith Prentice*

NMFWRI records detailed information for every stem of every tree and snag within the 1/10th acre circular, fixed-area sample plot (37.24 ft. radius).

By Diameter:

Trees and snags are recorded in the 1/10th acre plot if they have one stem greater than or equal to the established breakpoint diameter for the protocol. In the following examples, we will use a 5" breakpoint diameter to separate saplings from trees. If there is more than one stem per tree or snag you will collect multiple diameters if they meet certain criteria (see Figure 1, above).

First determine what stem has the largest diameter. This is generally considered your main stem. If its diameter is 5" or greater, it is considered a tree and all of its stems, even those below 5" in diameter, are recorded. A stem generally grows in an upright position and contributes to the main structural support of a tree crown. *See Supplement E4.92 Trees Part 2 for more details on dealing with multiple stems.*

By Distance from Plot Center (PC):

All trees should be determined to be in or out of the plot based on their horizontal distance from plot center (PC), not the slope distance. In a sloping plot, have a crew member help you hold the transect tape horizontally while measuring tree distance from PC. For example, if the tree of interest is uphill from plot

center you will have to raise the tape above DBH at plot center so that the tape is level when measuring if the tree is in. *See Supplement E4.93 Tree Heights for more guidance on determining slope distance vs horizontal distance.*

Trees and snags are determined to be in or out of the plot by the location of any part of the bole (not the midpoint) at DBH height (4.5 feet). See Figure 2. A tree or snag rooted in the plot that leans out of the plot at DBH should not be recorded and vice versa.

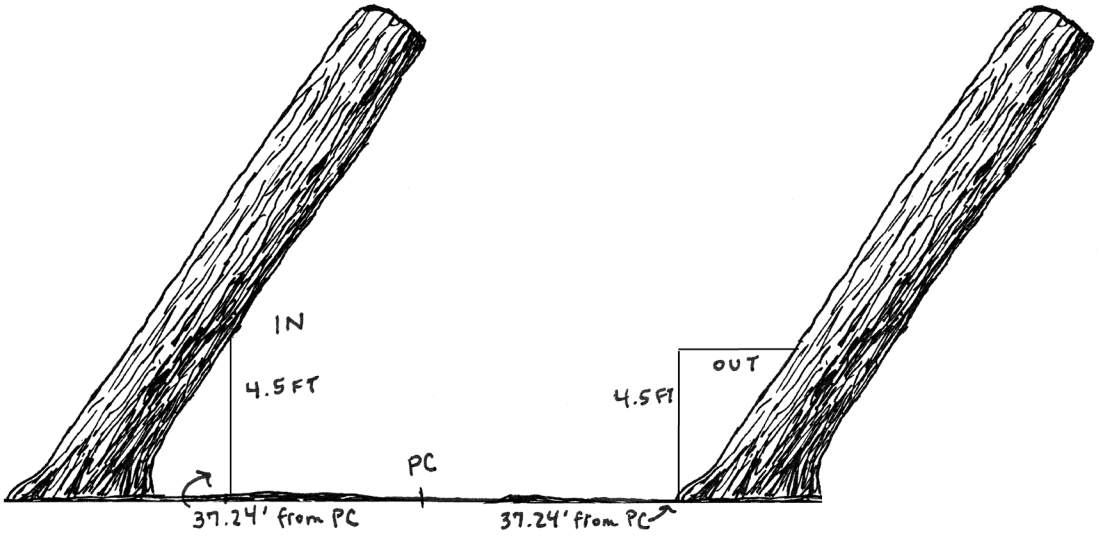


Figure 2. The tree on the left is rooted out of the plot, but leans into the plot at DBH height, and therefore should be recorded. The tree on the right is rooted in the plot, but leans out of the plot at DBH, and therefore should not be recorded. *Diagram by Zoe Ahrens*

By Angle:

Snags leaning at an angle greater than 45 degrees from vertical should not be recorded in the tree data and instead will be captured in fuel measurements (Figure 3). Live or sick trees should be recorded regardless of angle (along with appropriate damage code/severity).

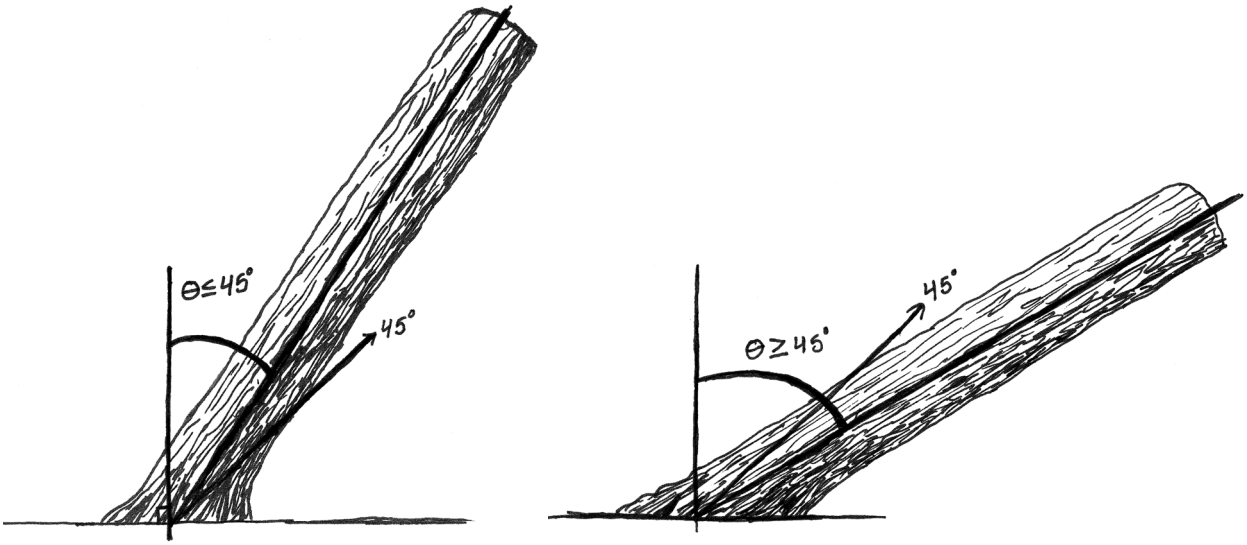


Figure 3. The snag on the left is leaning at an angle less than 45 degrees, and therefore should be recorded as a tree (with a lean noted as a damage code). The snag on the right is leaning at an angle greater than 45 degrees, and therefore should not be recorded as a tree, but instead be recorded in the fuel transect if applicable. *Diagram by Zoe Ahrens.*

E4.92 Trees Part 2: Tree Diameters

Figure 1. Above left: Measure 4.5 feet on yourself to quickly know where to take DBH on any tree you approach. *Photo by Kathryn Mahan.* Above right: Diameter of 45.7 inches. *Photo by Carolina May*

The following section outlines the NMFWRI monitoring protocol for measuring tree diameters. It also covers how to handle multiple stems.

Rules for Measuring Diameter at Breast Height (DBH)

Diameter at breast height is a standard measurement in forestry. This measurement is the diameter of a tree at 4.5 feet above the ground. It is important to measure all trees at the same height, to the extent possible, to keep forest inventory data consistent. Diameter tapes (aka logger's tapes or D-tapes) are adjusted by the value of π to provide the diameter of the tree.

The Basics:

To measure DBH, first determine where the 4.5 ft height sits on yourself. You will use this spot to determine where to take DBH on a tree. Remembering this position saves lots of time when you are taking DBH on numerous trees. If trees were previously tagged, measure DBH just above the nail to maintain consistency between measurements.

DBH is always taken on the uphill/ upslope side of the tree being measured. Position the tape so it forms a 90° angle with the bole. On a straight tree, this means the tape will be horizontal to

the ground. On a leaning tree, adjust the tape angle to match the tree's lean while maintaining a perpendicular measurement plane (see Figure 3). Tapes can easily get twisted around the bole and the DBH can get inflated by a branch or burl. For larger DBH trees, get someone to help you wrap the tape around the tree to ensure it is straight, level, and taut. To read the tape, look at the number where the zero crosses. Round to the nearest 0.1 in, as the diameter tape is in tenths. For example, the tape on the right in Figure 1, above, reads 45.7 in. For the purpose of determining breakpoint diameter, do not round. With a breakpoint diameter of 1 in a tree that is 0.99 in in diameter is not recorded, as it does not cross the determined threshold.

Reminders & Special Situations

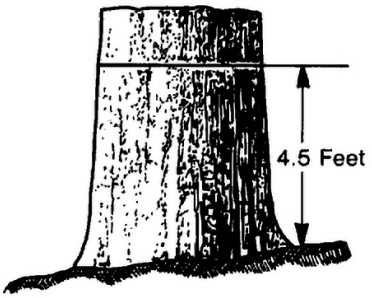


Figure 2. Measure from the uphill side.

Sketches from Forest Service Washington
FSH 2409.12 – Timber Cruising Handbook

1. Always measure from the uphill side. See Figure 2, below.
2. Always measure height to DBH vertically, not diagonally with the lean of the tree. If a tree leans so severely that it does not reach 4.5 feet vertically, it will not be measured as a tree in our protocol.
3. Once DBH height is established, measure diameter perpendicularly to the lean of the tree. See Figure 3, below.

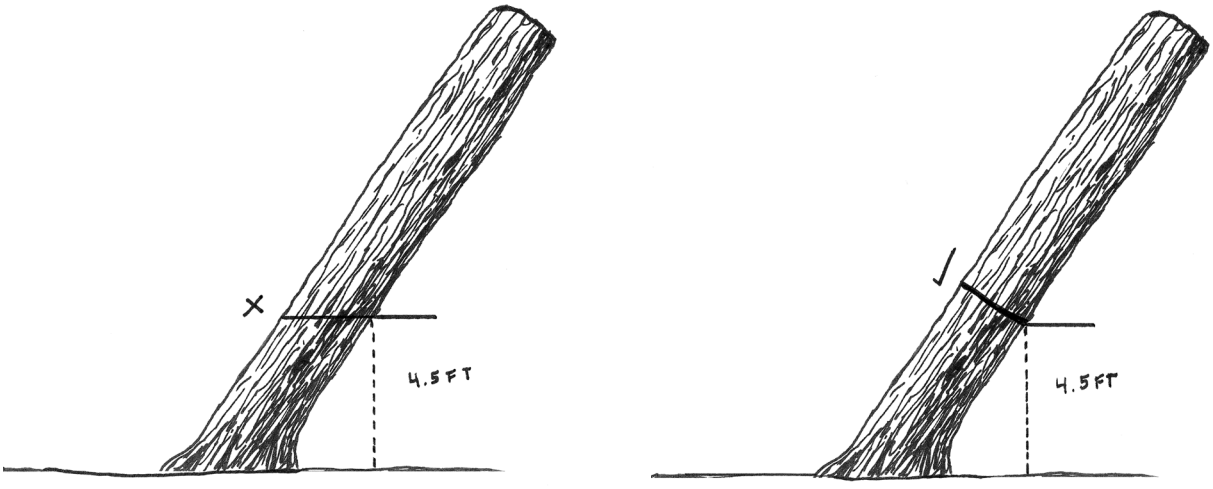


Figure 3. The tree on the left is not measured perpendicular to the lean of the tree, and therefore is measured incorrectly, overestimating the diameter. The tree on the right depicts the correct orientation of the DBH tape on a leaning tree.
Diagram by Zoe Ahrens

4. If the tree is forked below 4.5 feet but is determined to have common rootstock and a unified crown, record as a single tree with two stems. If unsure, apply the ankle-height rule. If there is light between the two stems at ankle height, record as two trees. If there is no light at the ankle, record as one tree with two stems and two DBH's with the same tag number.

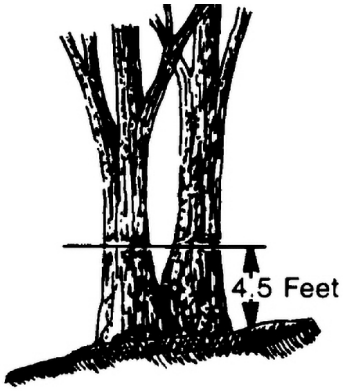


Figure 4. Fork occurs below 4.5 feet.

5. If a tree is forked above 4.5 feet, but the stems are together at DBH, measure it as one tree with one stem, and record one DBH. Record in the comments that the tree is forked and at what height, and what percentage of the total length of the bole is forked. See Figure 5.

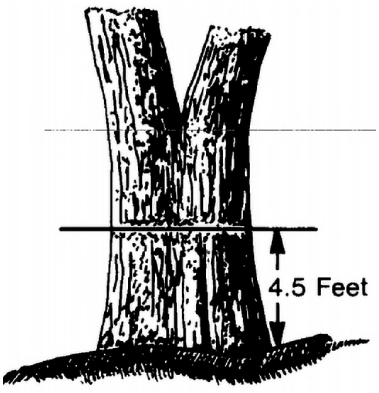


Figure 5. Fork occurs above 4.5 feet.

6. Abnormalities: For abnormalities, measure at the first place above 4.5 feet where the tree appears normal. Be sure you note where you measured DBH in the comments field on the datasheets. See Figure 6.

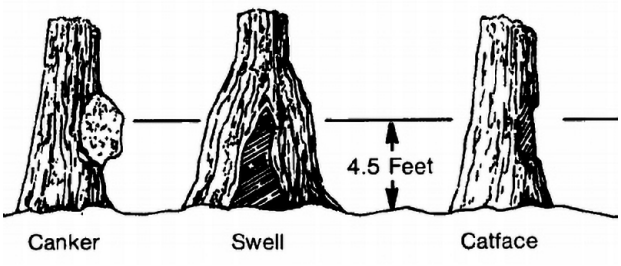


Figure 6. Abnormalities at 4.5 feet.

7. For trees growing on objects, measure at 4.5 feet from the root crown, not the forest floor. See Figure 7.

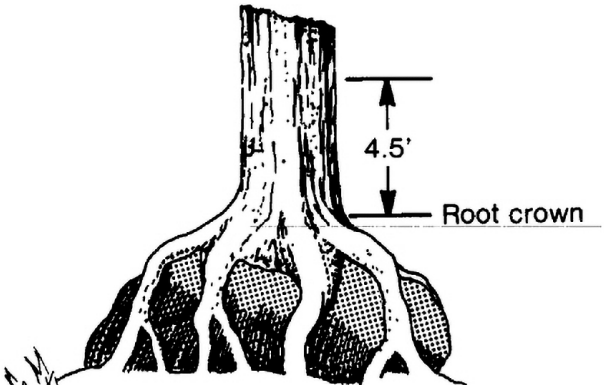


Figure 7. Measuring DBH on trees growing on objects.

8. See Figure 8 for rules concerning measuring DBH on broken trees. If DBH is at A, measure normally. If DBH is at B, measure just above on broken portion where the tree appears normal, e.g. at C. Make note of the tree abnormality in the comments, but as the bole is vertical at the original DBH height, the 45-degree lean cutoff for dead trees is not a concern here.

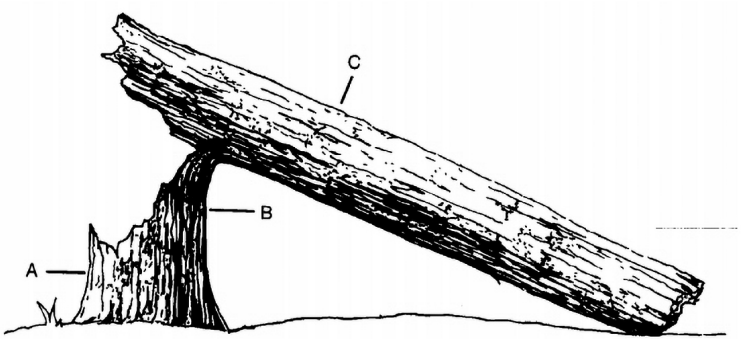


Figure 8. Measuring DBH on broken trees.

9. Unable to measure above: If it is not possible to measure at or above breast height because of the vertical extent of the irregularity, or because the top of the tree is missing entirely, then adjust the DBH measurement to better reflect the diameter of a regular bole: if 50% or more of the circumference of the bole is intact, reconstruct the diameter at DBH. If less of the bole is intact, record the measurement of the remaining bole and explain in the comments.

In Summary:

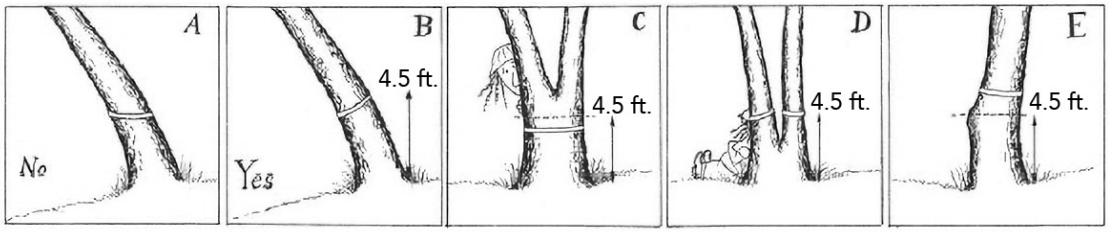


Figure 9. DBH measurements. A) Diameter tape is not perpendicular to the tree stem. B) Correct way to measure tree diameter is with tape perpendicular to tree stem. C) If the tree splits above breast height measure tree diameter below any swell caused by the separation. D) If the tree splits below breast height measure as two trees. E) Measure the most representative diameter above or below any deformity.

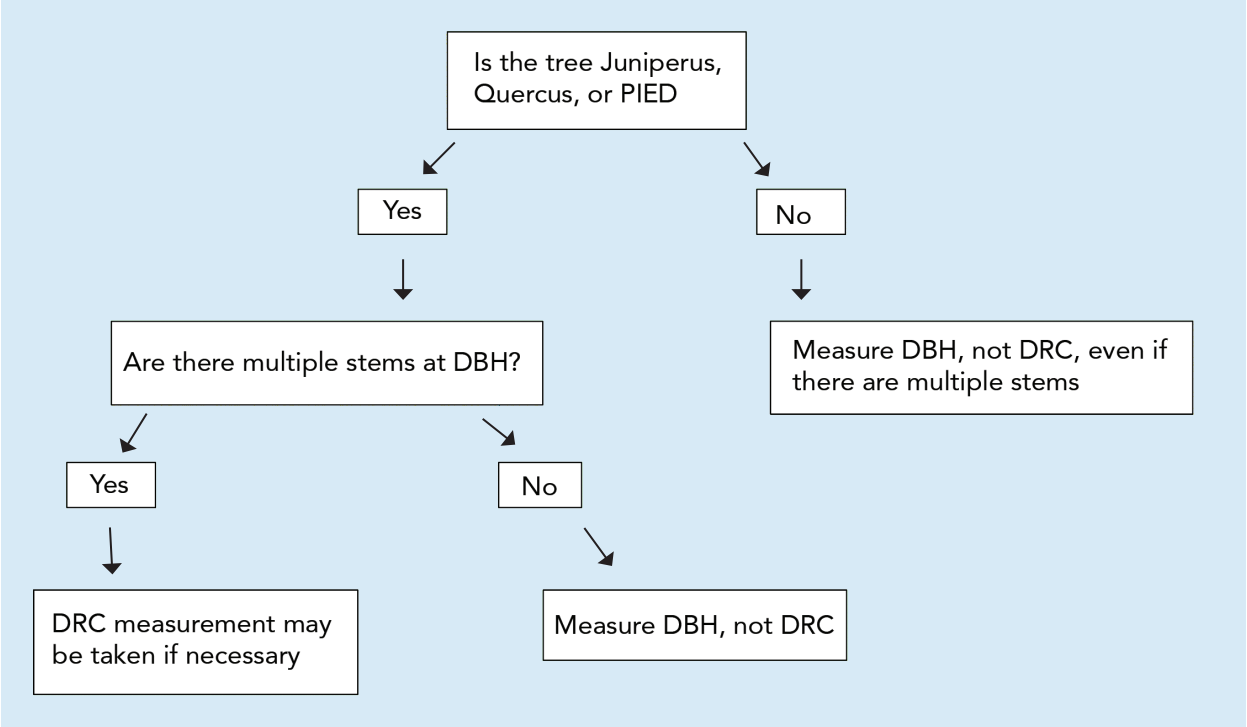
Rules for When and How to Measure at DRC

When to take DRC Measurements:

Measuring diameter at root collar (DRC) may be used for multi-stemmed trees in some situations. Measuring DBH generally provides a better estimate of tree size than measuring DRC. Use DRC only in scenarios where taking DBH measurements of individual stems for all trees on a plot would be very prohibitive. Using the Chojnacky and Rogers conversions, DRC should only be taken on junipers, oaks, and piñon pine.

See the below flowchart for when DRC can be measured:

Flow Chart for DRC



Flowchart 1. Flow Chart for determining whether it is more appropriate to measure DRC or DBH on a tree.

How to take DRC Measurements:

1. Remove loose material on the ground, but DO NOT remove mineral soil. Watch for snakes when reaching under trees.
2. Measure at ground line when reasonable.
3. Measure DRC just above any swells present.
4. Must be measured in a location that is a good representation of the volume in the stems.
5. If excessive diameter exists at the base, measure the stems occurring above the base individually.

6. If a tree has unified crown and common rootstock, but has several separate stem clumps with soil in between, take multiple DRC measurements for the same tree tag number. Do not include any soil or open spaces at ground level between stems in a single measurement.

7. If using tree tags, tag at the height DRC is taken. If re-measuring tagged trees, take DRC just above nail.

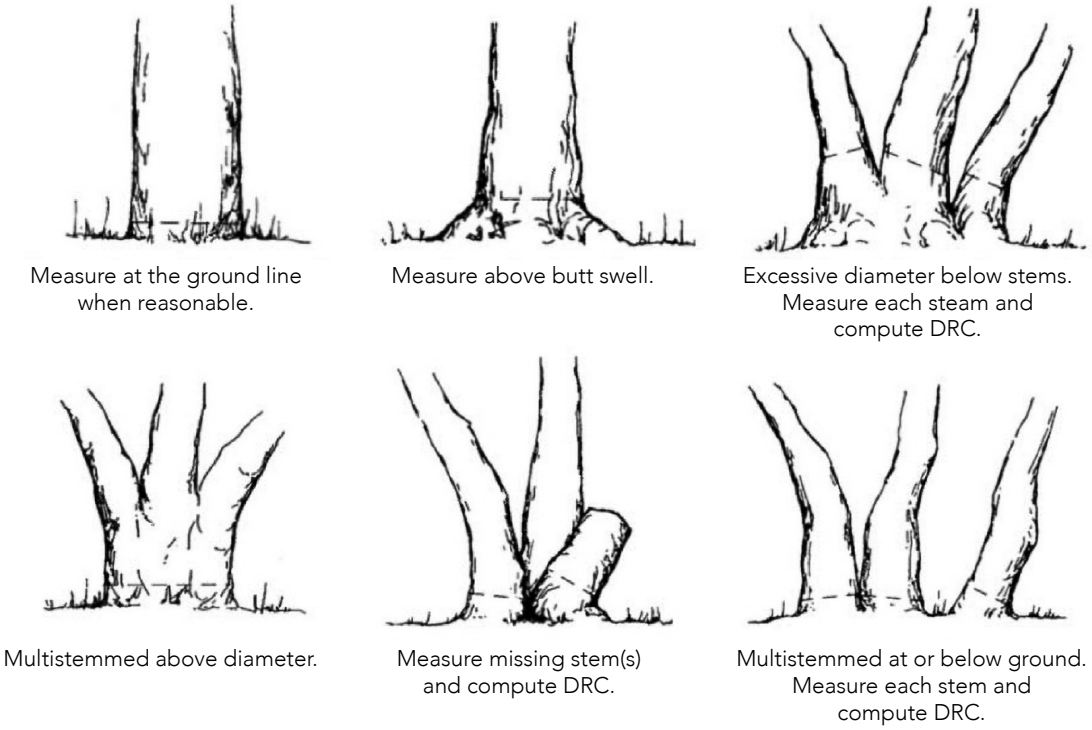


Figure 10. Guidelines for taking DRC. *Figure by Bonfantine et. al (2011).*

DRC/DBH Conversion Protocols:

DRC values must be converted to equivalent diameter DBH values for analysis. Figure 11 from Chojnacky & Rogers (1999) shows established DRC to DBH conversion equations. These conversions are done after field data collection, and both the original DRC value and converted DBH value are reported.

Measuring Multi-Stem Trees

What defines a single multi-stem tree vs. multiple trees?

Terms:

Unified crown: Stems come together to form a contiguous crown, often teardrop or vase shaped, without large gaps (See Figure 12B).

Parameters and equation to convert drc to dbh for piñon pine, Utah juniper, and Gambel oak

Measurement	Parameter estimates							No. of	Fit statistics	
units	β_0	β_1	β_2	β_3	β_4	β_5	β_6	trees	R^2	*CV* (%)
English	–2.6843	1.0222	0.7433	0.7469	–0.0399	1.2244	–0.0689	224	0.98	13
Metric	–6.8180	1.0222	1.8879	1.8971	–0.0399	3.1100	–0.0689	224	0.98	13

[1] Conversion equation:

$$dbh = \beta_0 + \beta_1\, drc + \beta_2\, stm + \beta_3\, Pied + \beta_4 drc_P + \beta_5\, Quga + \beta_6 drc_Q$$

where

dbh = diameter at 1.3m above groundline of all live and dead stems 2.5 cm and larger (cm or in.)

drc = diameter at root collar above groundline of all live and dead stems 2.5 cm and larger (cm or in.)

$$diameter = \sqrt{\sum_{i=1}^{n} d_i^2}$$

n = number of live and dead stems at dbh or drc with diameter 2.5 cm or larger

d_i = stem diameter (cm or in.)

stm = 1 for trees with one stem (n = 1) at drc, 0 otherwise

Pied = 1 for pinyon pine species, 0 otherwise

drc_P = drc for pinyon pine species, 0 otherwise

Quga = 1 for Gambel oak species, 0 otherwise

drc_Q = drc for Gambel oak species, 0 otherwise

Figure 11. DRC to DBH conversion formulas from Chojnacky and Rogers, 1999.

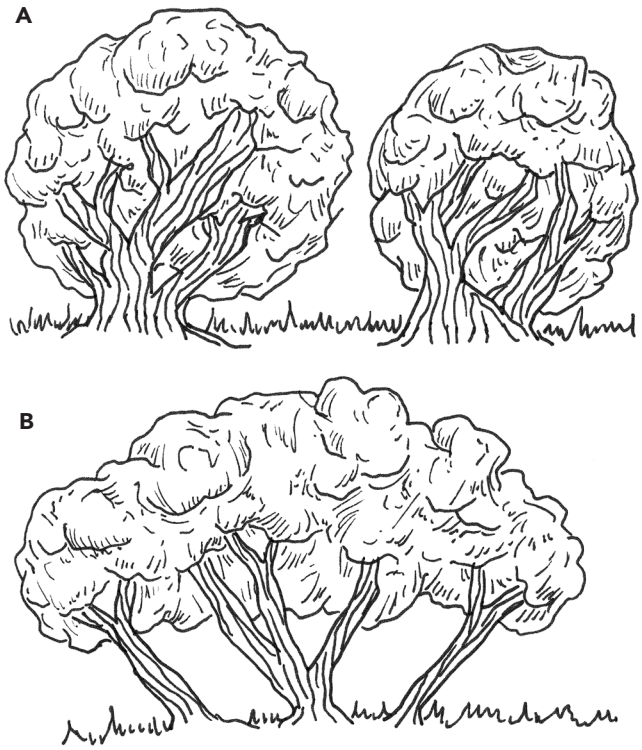
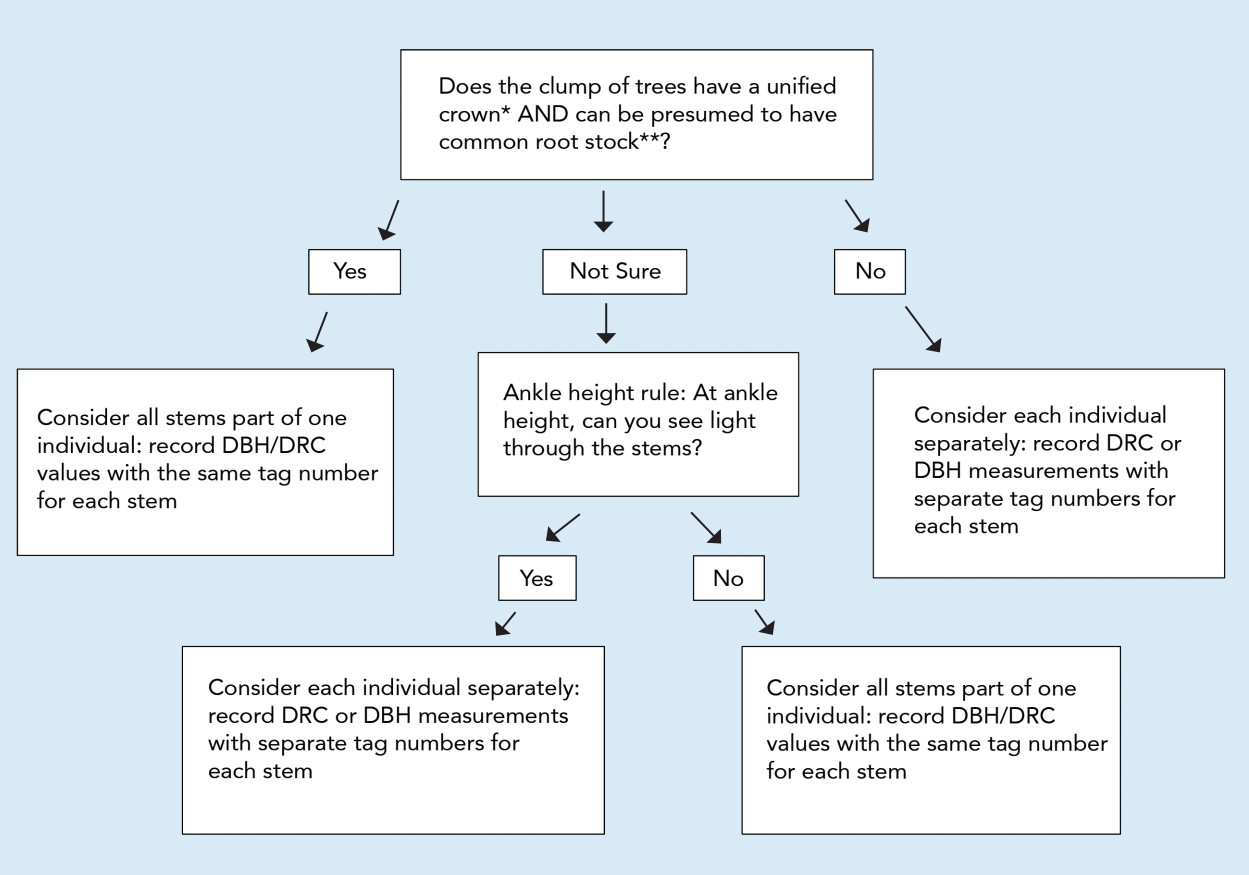


Figure 12A Shows two trees with distinct crowns, which should be recorded as separate trees. **Figure 12B** Shows a single tree with a unified crown and assumed common rootstock, which should be recorded as a single tree with multiple stems.
Diagram by Raymundo Melendez and Meredith Prentice

Common rootstock: A rootstock is part of a plant, often an underground part, from which new aboveground growth can be produced. Stems which are of the same species and originate from the same place in the ground can be considered to have common rootstock. See Figure 12B.

Flow Chart for Defining Multi-Stem Trees



Flowchart 2. Flow Chart for Defining Multi-Stem Trees.

Flow Chart for Defining Multi-Stem Trees

What is a stem vs a branch?

A stem generally grows in an upright position and contributes to the main structural support of a tree crown.

Special Cases:

NMFWRI monitoring teams use a few additional rules in particular cases, such as when it is challenging to determine what is a stem versus a branch, or if counting every stem for a particular species on plot would be prohibitively time intensive.

When working with bushy tree species with multiple curved limbs and no clear main upright stems, (e.g. some oneseed juniper, see Figure 12) consider applying a rule such as this: when determining

whether something is a stem or a branch, stems captured need to be at least 1/3 the diameter of the main stem AND must branch out from the main stem at an angle of 45 degrees or less. Note that this rule MAY NOT be used broadly to exclude smaller stems, only in cases where it is unclear whether something is a stem or a branch.

Stump sprouts originate between ground level and 4.5 ft on the boles of trees that have died or been cut. Stump sprouts are handled the same as trees with multiple stems. For multi-stemmed woodland species, treat all new sprouts as part of the same new tree. *(Use the 99000 code, see Supplement E4.94 Trees Part 4: Tree Health & Damage Codes).*

In cases of extremely high density multi-stemmed species, it may be possible to use a stem-level diameter cutoff instead of a tree-level for efficiency. In such cases, this protocol should be implemented consistently for a given species across an entire project. The counts of live and dead stems recorded should reflect all stems present (including those below breakpoint DBH) that are part of the individual. In no case should part of an individual tree or shrub be recorded as tree and another part of the same individual as sapling or seedling; if any part of the individual qualifies as a tree, the rest of the stems will be counted with that tree. Leave detailed explanations in the comments.

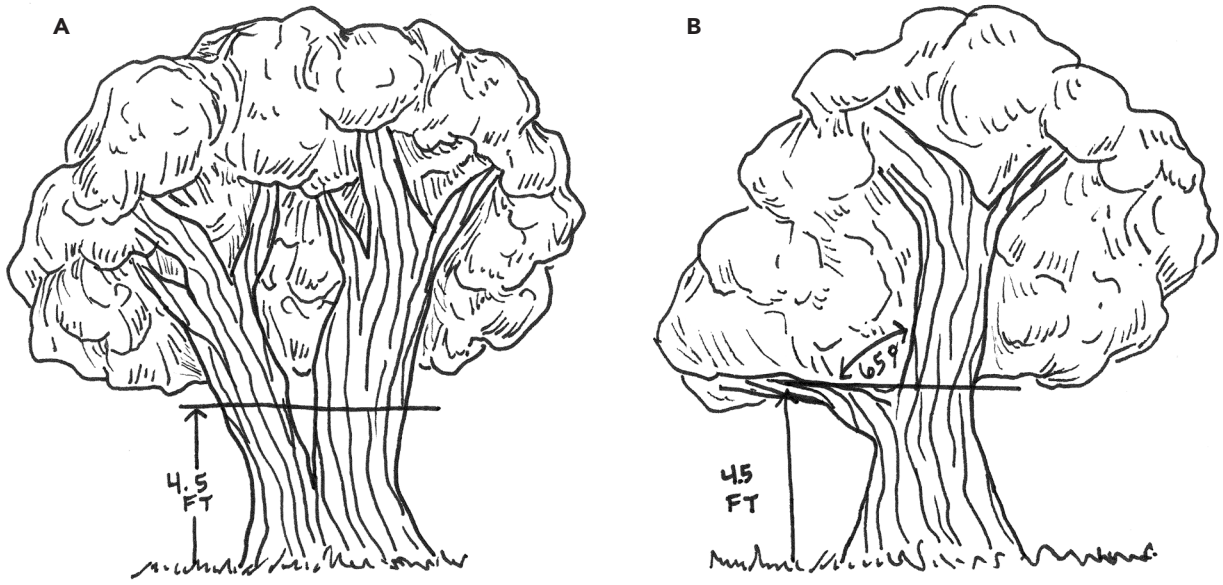


Figure 13A Shows a tree with two stems at DBH. **Figure 13B** Shows a single stem tree with a branch.
Diagram by Raymundo Melendez and Meredith Prentice

Other Recommendations for Measuring Trees with Multiple Stems

- Record each stem of a multi-stem tree as a separate line of data with an individual diameter, height, live crown base height, and condition status (live, dead, or sick). Multi-stem trees should start with the same tag number followed by a decimal and its respective consecutive number. Certain databases may not allow you to record tag numbers with decimals. In these cases indicate the specific tag numbers in the comment form. We recommend this method over the square-of-squares method for multi-stem trees.

1/10th acre plot (37' 3" radius)									
Tree #	Stem #	Species	Tree cond.	DBH	Total Tree Ht	LiCrBHt	Damage	Severity	Comments
1	1	ELAN	L	6.8 in	18 ft	4 ft			tag 1.1
1	2	ELAN	L	5.1 in	16 ft	2.5 ft			tag 1.2
1	3	ELAN	D	1.2 in	8.5 ft	----			tag 1.3
2	1	PODEW	L	21.2"	68 ft	36 ft	23001	231	
3	1	SAGO	L	7.4 "	26 ft	11 ft			

Figure 14. Sample record of multi-stemmed trees. *Diagram by Kathryn Mahan*

- Maintain the same clockwise progression within the multi-stemmed tree that is maintained in the plot as a whole while recording stems.
- Onion-shaped junipers are common and getting past the outer branches of a large specimen to measure the stems at the root collar can be a challenge. The crew member doing this must wear proper eye protection and work gloves and should watch out for rattlesnakes.
- Multi-stemmed tamarisk are more often defined using the ankle-height rule, as common root stock and unified crown can be hard to determine.

Works Cited

Forest Service Washington FSH 2409.12 – Timber Cruising Handbook

Bonfantine, K., J. Zebrowski, and Egan, A. (2011). *Guidelines and protocols for monitoring riparian forest restoration projects*. New Mexico Forest and Watershed Restoration Institute. https://nmfwri.org/wp-content/uploads/2020/07/Riparian_forest_monitoring_guidelines-1.pdf

E4.93 Trees Part 3: Tree Heights

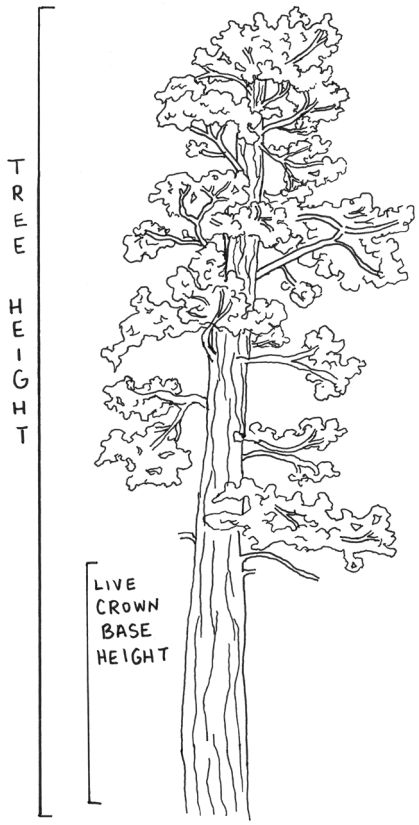


Figure 1. Note that branch bends lower to ground a few feet out than it does where it connects to the tree. Use the distance from the ground to the lowest live foliage for your Live Crown Base Height measurement. *Diagrams by Meredith Prentice*

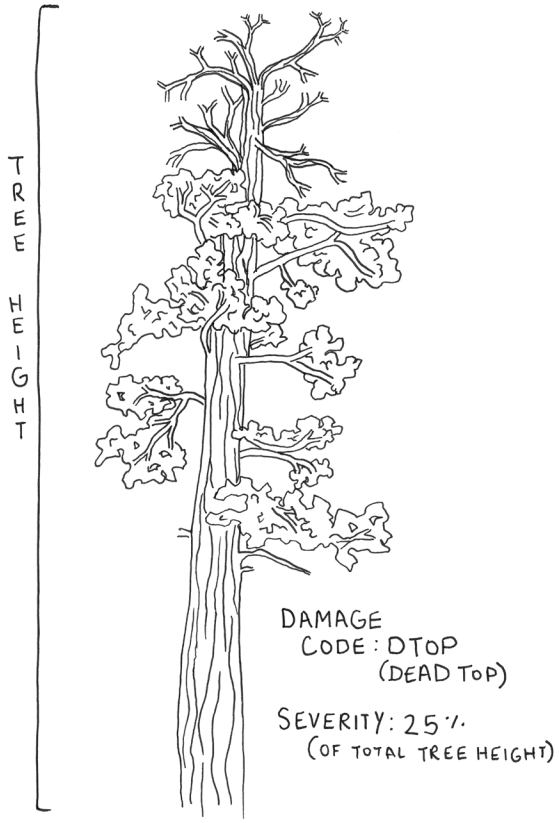


Figure 2. The treetop is dead. However, for our Tree Height, we measure from the ground to the highest part of the tree. Remember to add a damage code and severity indicating the dead top.

The following sections explain the NMFWRI Monitoring protocol for measuring tree height.

Rules for Measuring Tree Heights

Rules for Measurements

- *Tree Height:* Record height from ground to highest part of the tree. For multi-stem trees with a Diameter at Breast Height (DBH) for each stem, record individual heights for each stem.
- *Live Crown Base Height (LiCrBHt):* Record the height from the ground to the start of continuous live foliage. For multi-stem trees with a DBH for each stem, record individual LiCrBHt for each stem.
- *Leaners:* Measure from ground to highest point, even though the tree would measure taller if it were standing up straight.

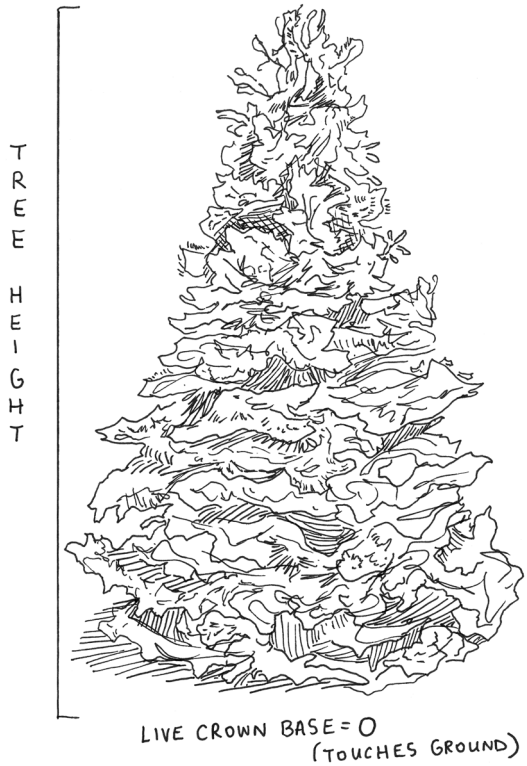


Figure 3. The Live Crown Base Height is 0, because the foliage touches the ground.
Diagrams by Meredith Prentice

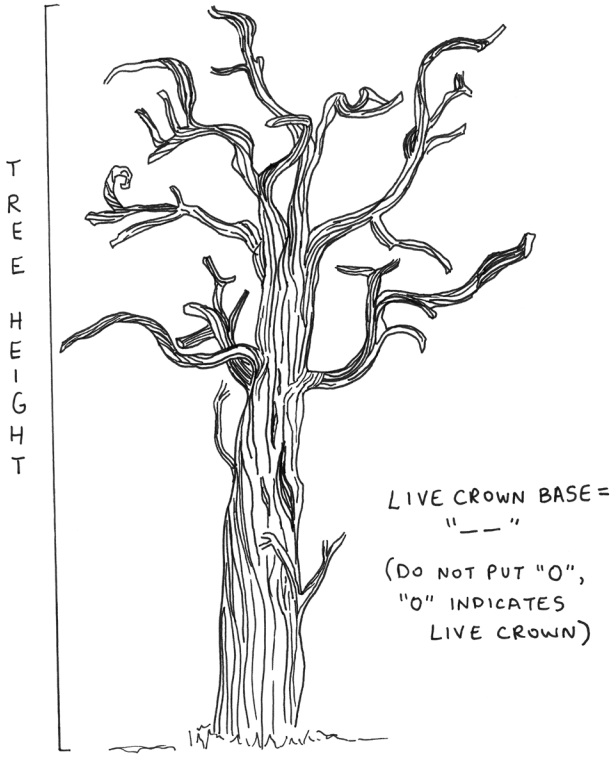


Figure 4. The tree is dead (a snag). For tree height, measure from the ground to the highest part of the tree. The tree's condition will be a "D" for dead. The Live Crown Base Height should be entered as a null value for electronic data entry or recorded as "---" on the datasheet. Do NOT enter or record a "0" because a value of "0" indicates the crown is present and touching the ground. For absent live crown, always leave the field blank or use dashes.

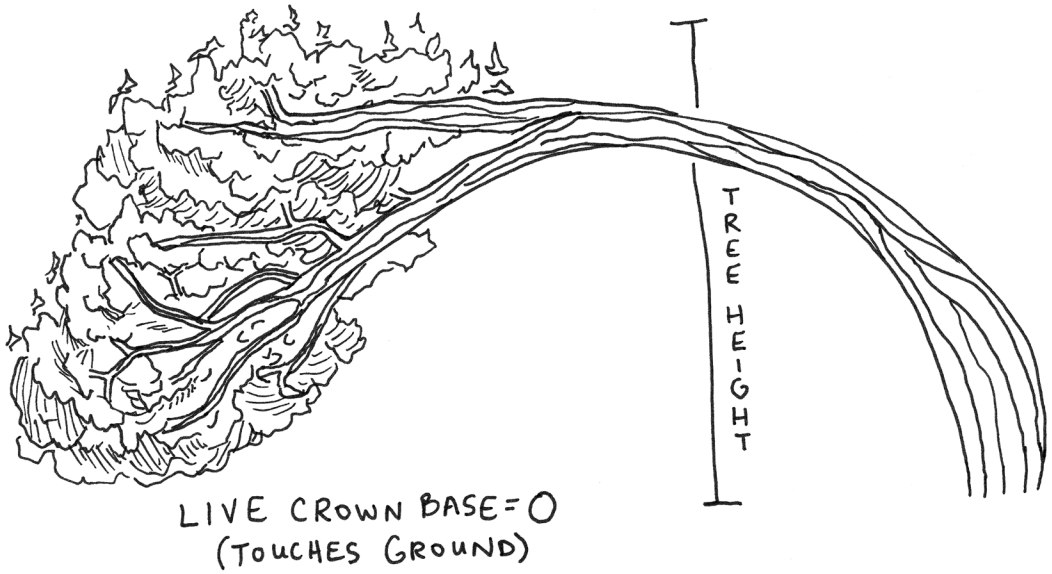


Figure 5. The tree is bent over. For tree height, measure from the ground to the highest part of the tree. Since the crown touches the ground, record a live crown base height of 0. Also record a damage code and severity to indicate a lean.

Measuring Tree Heights Using a Hypsometer

A hypsometer (or rangefinder) is a tool that uses a laser to calculate height/distance of an object. In the case of this protocol, hypsometers are used to measure the height and live crown base height of trees. Laser hypsometers can make taking tree heights fast work, as they typically handle slope distance adjustment calculations for you and do not require you to stand a chain away from your target. Make sure the hypsometer your crew is using is accurate; many models operate outside the recommended +/- 0.5ft precision standard for height. One model NMFWRI crews use is a TruPulse 360R.

Instructions:

1. Power on the hypsometer and ensure it has been recently calibrated.
2. Ensure the hypsometer is in the correct mode and units. Tree height measurements will be taken with a "3-point height routine", which uses a horizonal distance, a base angle, and a top angle to calculate heights.
3. Stand at least 30 ft away from the tree you are measuring, until you are able to clearly see the top. Taller trees will need to be measured from a further distance.
4. Look through the eyepiece and aim the crosshairs at the bole of the tree you are measuring while holding the hypsometer horizontal; if you are not on the same contour as the tree, this may mean that you are aiming significantly above (or below) where your eye-level would fall if you were standing next to the tree. Press the button to activate the laser. You should see a distance value appear. If this number is unreasonably high or low, the bole may not have been hit by the laser.

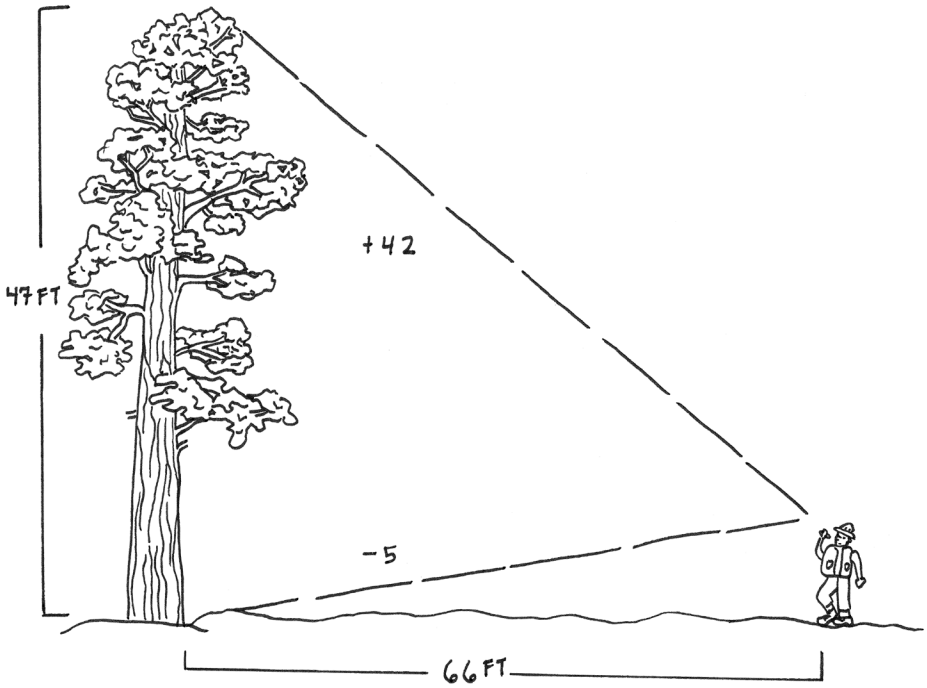


Figure 6. Technician uses hypsometer to shoot 1) the distance to the bole of the tree, 2) the angle to the base of the tree, and 3) the angle to the top of the tree.
Diagram by Raymundo Melendez and Meredith Prentice

5. Direct the crosshairs to the base of the tree. Activate the laser. An angle reading will appear.
6. Direct the crosshairs to the very top of the tree. Activate the laser. An angle reading will appear, followed by a height measurement for the tree.

Hypsometer Tips and Troubleshooting

- The hypsometer is not usable in rain or heavy fog and can be challenging to use in windy conditions.
- Do not point the hypsometer into direct sunlight.
- Similarly to a compass, hypsometers are sensitive to magnetic materials and magnetic fields. Keep pin flags, nails, computers, spare batteries, etc. away from the hypsometer while in use.
- If height measurements seem incorrect, check:
  - Is the hypsometer in the correct mode for a 3-point height routine?
  - Is the measurement starting with horizontal distance?
  - Is the laser able to hit the bole of the tree, or is it hitting other vegetation in the way?
  - Is the user standing too close to see the true top of the tree?
  - Is the hypsometer low on battery?
  - Is the hypsometer properly calibrated? Calibration is key to keeping these sensitive instruments functioning as they should. See user manual for information on calibrating.

Measuring Tree Heights Using a 1:66 Clinometer

A clinometer is an instrument commonly used in forestry to measure slope and tree height. The instructions that follow are based on a Suunto clinometer.

Instructions:

1. Confirm your clinometer has a 1:66 scale. For 1:66 scale clinometers, percent slope is on the left side and the 1:66 scale used to measure tree heights is on the right. If uncertain about which side of the scale to read, you can tilt your head back while looking through the clinometer and reference the unit labels at the bottom of the scale.
2. Determine the tree you want to measure and move 66 ft away. You can either measure with a DBH tape (nail stuck in tree), or pace off a chain.
3. From 66 ft away, sight through the glass eyepiece of the clinometer with both eyes open to the very top of the tree. Remember to point the sighting dot at the tree; the dot represents your line of sight. Record this number and its sign (+ or -).

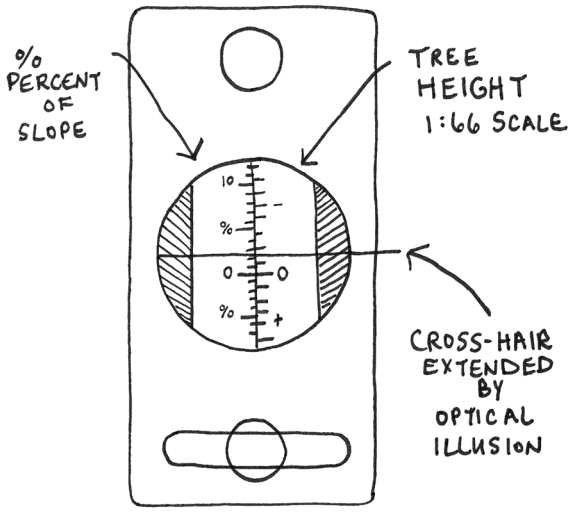


Figure 7. Use the scale on the left if you are measuring percent slope, and the scale on the right if you are measuring tree height. *Diagram by Raymundo Melendez and Meredith Prentice*

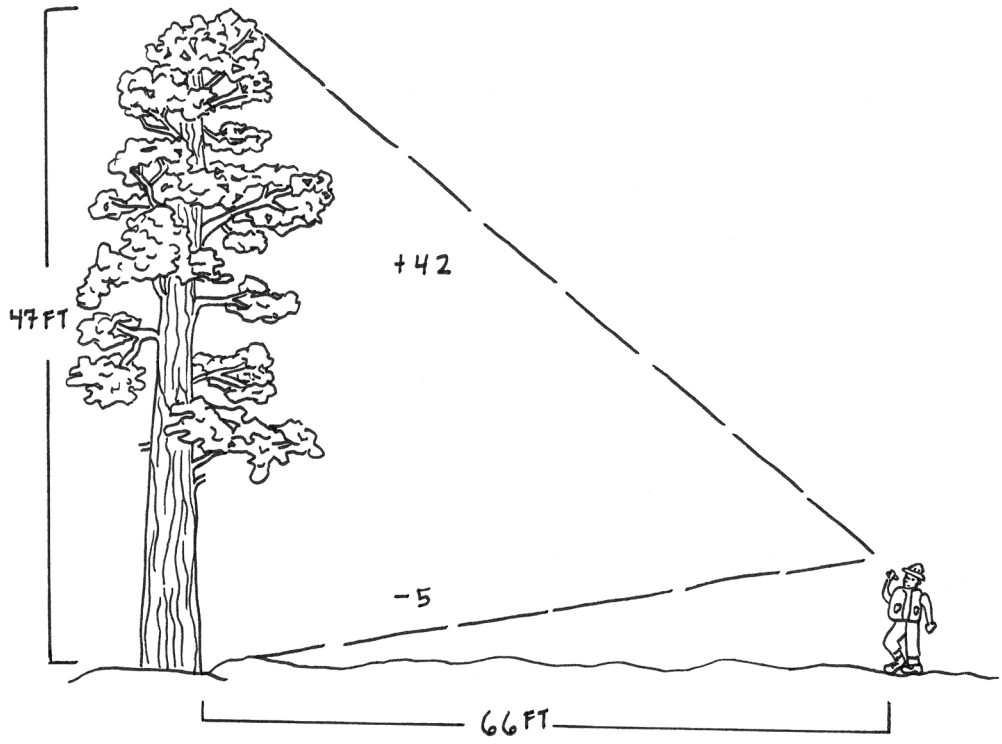


Figure 8. Example of using a clinometer to calculate tree height.
Diagram by Raymundo Melendez and Meredith Prentice

4. From exactly the same location, and while trying not to move your head, tilt the clinometer downward until the sighting dot is lined up with the base of the tree. Sight through the clinometer with both eyes open to the base. Record this number and its sign (+ or -).

5. You will now use the equation "top" - "bottom" to get tree heights. For example, "top" - "bottom" = 42 - (-5) = 42 + 5 = 47 ft tall.

Chains

1 chain = 66 feet
80 chains = 1 mile
You can determine how many paces (one pace = two steps) your chain is by laying out a tape and counting the paces required to reach 66 ft. When determining your chain pace number, always take multiple (at least three) and average them.

How does the terrain change your pace?

- Shorter in tall vegetation than in short vegetation.
- Shorter walking uphill than walking downhill.
- Shorter walking on sloping ground than on flat ground.
- Shorter walking on soft ground than on hard ground.
- Level vs uphill vs downhill?

- In general, when slope is >5%, your "level" pacing is no longer accurate.

Common sources of error when using the clinometer:

- The distance between you and the tree was not perfectly measured and/or paced. This is a common challenge in very dense or very steep areas. Remember that slope distance is not always the same as horizontal distance. See below for more information on Slope Correction when using a clinometer.
- The tree is taller than 66 ft, which means using a 1:66 scale is less accurate.
  - Ideally the trees you measure should be less than 66 ft, or you should consider alternate scales. For example, you could use the percent (left) side of the clinometer if you were standing 100 ft away, since this is a 1:100 scale.
- Arithmetic errors, such as mixing up signs.
- You cannot see the top and bottom of the tree and are estimating. This is a common challenge in very dense areas.
  - Try moving to another area.
  - Do not move between sighting the top of the tree and the base.

Slope Corrections

When using clinometers, it is sometimes necessary to correct the difference between slope distance and horizontal distance. Slope distance is always longer than horizontal distance. When possible, always try to walk the contour so that you are not going uphill or downhill from the tree you are measuring. Another option for slope correction would be to calculate the slope distance needed to reach one chain (66 ft) in horizontal distance.

Conversion Chart for Slope Percent to Degree

Grade	Angle	Grade	Angle	Grade	Angle	Grade	Angle	Grade	Angle
2%	1.15	22%	12.41	42%	22.78	62%	31.80	82%	39.35
4%	2.29	24%	13.50	44%	23.75	64%	32.62	84%	40.03
6%	3.43	26%	14.57	46%	24.70	66%	33.42	86%	40.70
8%	4.57	28%	15.64	48%	25.64	68%	34.22	88%	41.35
10%	5.71	30%	16.70	50%	26.57	70%	34.99	90%	41.99
12%	6.84	32%	17.74	52%	27.47	72%	35.75	92%	42.61
14%	7.97	34%	18.78	54%	28.37	74%	36.50	94%	43.23
16%	9.09	36%	19.80	56%	29.25	76%	37.23	96%	43.83
18%	10.20	38%	20.81	58%	30.11	78%	37.95	98%	44.42
20%	11.31	40%	21.80	60%	30.96	80%	38.66	100%	45.00

Table 1. Slope conversion table for percent grade and degrees.

Use this formula to calculate slope distance:

Slope distance = horizontal distance/cos α (slope in degrees)

To convert your measured percent slope (grade) to degrees α, reference the conversion table provided on the back of your clinometer. Do not use percent slope in this equation. Horizontal distance will always equal 66 ft.

Example: A crew comes across a tree that can only be accurately and safely measured from uphill. First, slope percent is taken at 40%. Using a conversion table, this converts to 21.8 degrees. Using the formula below, a slope distance of 71.3 ft is calculated.

Slope distance = horizontal distance/cos α (slope in degrees)
Slope distance = 66 ft/ cos(21.8)
Slope distance = 71.3

Using a tape, the crew pulls out to 71.3 ft uphill (in the direction the slope was taken) from the bole of tree across the ground. Standing here, the technician is at a distance of 66 horizontal feet. To measure multiple trees occurring across the same slope, the technician could count and remember the number of paces required to reach 71.3 ft uphill and use this as a chain pacing for this plot.

Important Takeaways:

On this 40% slope, taping out 66 ft parallel to the slope does not result in a run (horizontal distance) of 66 ft. Measuring tree heights from a slope distance of 66 ft would result in an error of nearly 10 percent. Always calculate slope correction before using a clinometer to measure tree heights on a slope. Alternatively, pacing along the contour and maintaining the same elevation as the tree, or using a hypsometer, removes the need for this calculation.

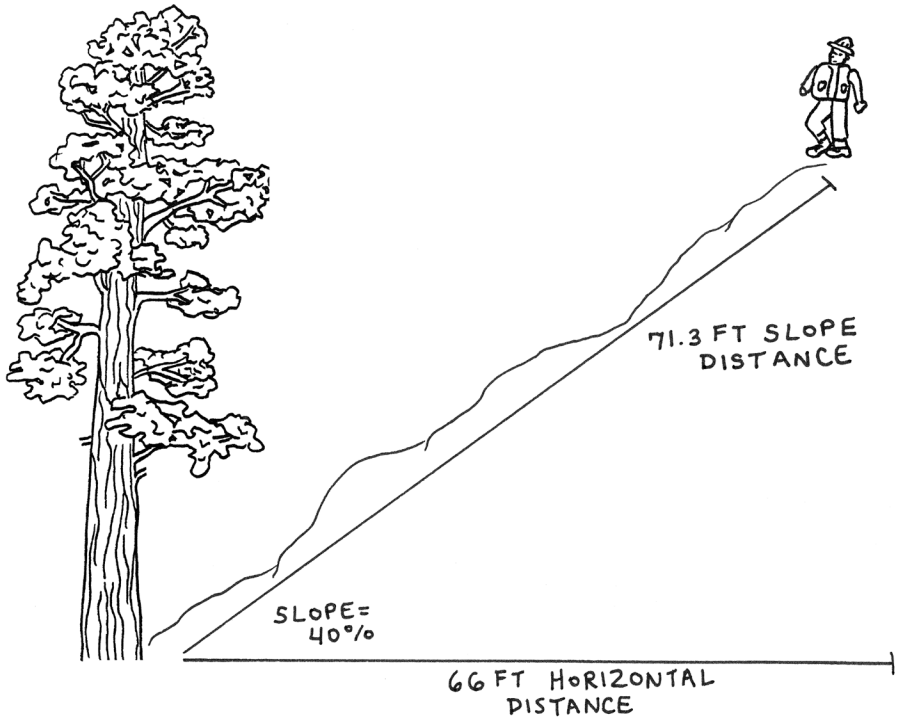


Figure 9. Example of the difference between slope distance and horizontal distance. *Diagram by Raymundo Melendez, Meredith Prentice, and Carolina May*

E4.94 Trees Part 4: Tree Health & Damage Codes

Status:

Status denotes whether the trees, shrubs, saplings, or seedlings are live, dead, or sick.

Dead (D):

Tree has no green foliage or sign of living tissue. Branches and twigs snap with no flexibility and do not have a green or wet cambium when cut. For trees where the main stem is dead with resprouts from roots, record the status as dead and record "sprouts at base" in the comments.

Sick (S) vs Live (L):

In general, sick trees (as defined by FIREMON) have extensive biotic or abiotic damages that will ultimately cause death within 5-10 years. Designation of sick status is ultimately subjective as it may vary by management objectives, site conditions, and crew expertise with specific damage agents. Note that damage codes and severity should be recorded on any tree with damage agents present, even if the tree is not marked as sick. It is critical that any tree designated as sick must also have supporting documentation such as damage codes, severity, and any relevant comments recorded. For our purposes, we find it more useful to analyze and report by damage agent/severity across growing stock (live + sick trees considered together) vs dead trees, because of the subjectivity of defining sick trees.

Damage Code Systems

Damage codes are used to record signs of illness, injury, and abnormalities in overstory trees.

NOTE: All damage codes should also be recorded with a severity measure (minor/severe or % damage).

Multiple code systems are available to record damage. We will cover and provide references for two of the most common systems. The table below includes common damages and how they are represented by each system. Where damage equivalencies exist between the two systems, codes are displayed side by side. In cases where no equivalencies exist, "---" will be displayed.

Letter-based system

The letter-based system, used by the National Park Service, uses 4-letter abbreviations to represent various damage codes. This system is easy to use for those new to monitoring but has a much smaller set of possibilities than the numeric system and is less commonly used. More comprehensive information on the letter-based system can be found here: https://www.nps.gov/orgs/1965/upload/fire-effects-monitoring-handbook.pdf

Number-based system

The number-based system, used by the United States Forest Service (USFS) and others, uses a 5-number system to indicate damage. The format is Category/Agent. The Damage Category is a

2-digit code (see table below), and the Damage Agent is a 3-digit code. (Note that some programs may combine the Damage Category/Agent code with Tree Part (letter code)/Severity(numeric) to create a single alphanumeric code, such as 10000BO1, where the severity is rating scale associated with specific degrees of damage. Our datasheets encourage separate entry of the Damage Category/Agent and the Severity, and we recommend using the severity assessment suggested in the table below. FFI includes a suggestion of the following minimum numeric Damage Category/Agent codes, shown in the table below, but it is possible to type in and use any of the Damage Category/Agent codes found in the expanded list. More comprehensive information on the number-based system can be found here:

https://www.fs.usda.gov/nrm/documents/fsveg/cse_user_guides/userguide_fsveg_apdx_k_damages.docx

The table below includes common damages encountered in the field. The letter- and number-based systems have been grouped together to compare equivalencies. Severity codes listed for damages are based on the USFS number system.

Damage Codes

The following damage code table reflects the types of damage commonly encountered in riparian ecosystems.

USFS Damage Category	NPS Damage Code	Damage Description	Severity	Notes
10000	**INSE**	General Insects	**101 - Minor:** bottlebrush or shortened leaders, 0-2 forks on stem, OR <20% of branches affected, OR <50% of bole with visible larval galleries OR **102 - Severe:** 3 or more forks on bole, OR 20% or more branches affected, OR terminal leader dead, OR 50% or more of bole with visible larval galleries	Beetles, moths, sawflies, ants, wasps.
12239	**---**	Tamarisk Leaf Beetle	1 = Light defoliation (1-25%), no topkill 2 = Light defoliation (1-25%), topkill ≤10% 3 = Light defoliation (1-25%), topkill >10% 4 = Moderate defoliation (26-75%), no topkill 5 = Moderate defoliation (26-75%), topkill ≤10% 6 = Moderate defoliation (26-75%), topkill >10% 7 = Heavy defoliation (76-100%), no topkill 8 = Heavy defoliation (76-100%), topkill ≤10% 9 = Heavy defoliation (76-100%), topkill >10%	Assign a category to quantify the damage

USFS Damage Category	NPS Damage Code	Damage Description	Severity	Notes
17000	**GALL**	Gallmarker Insects	**171 - Minor** OR **172 - Severe**	Abnormal growths on stems, roots, or leaves. Formed by pathogen/ parasitic infection.
19000	---	General Disease	**191 - Minor** OR **192 - Severe**	Blister rust, etc.
21000	**ROTT**	Root/Butt Disease	**211** – Tree within 30 feet of tree with deteriorating crown, tree with diagnostic symptoms or signs, or tree killed by root disease **212** - Pathogen (sign) or diagnostic symptom detected – no crown deterioration **213** – Crown deterioration detected – no diagnostic symptom or signs **214** – Both crown deterioration and diagnostic signs symptoms detected **215** – Bleeding present on bole **216** – Bleeding present on bole and adjacent mortality present **217** – Laboratory confirmed Sudden Oak Death	The presence of fungi other than shelf-like fruiting bodies/ conks. Indicate specific fruiting body or it's general morphology in the comments.
22000	**CONK**	Stem Decay/ Canker	220: 0-4% rotten 221: 5-15% rotten 222: 16-25% rotten 223: 26-35% rotten 224: 36-45% rotten 225: 46-55% rotten 226: 56-65% rotten 227: 66-75% rotten 228: 76-85% rotten 229: 86-100% rotten	The presence of shelf-like fruiting bodies/ conks. If not shelf-like fungus, use ROTT. Specify presence of conk in the comments.

USFS Damage Category	NPS Damage Code	Damage Description	Severity	Notes
23001	**MISL**	Mistletoe	231 - Hawksworth tree DMR rating = 1; light infection 232 - Hawksworth tree DMR rating = 2; light infection 233 - Hawksworth tree DMR rating = 3; medium infection 234 - Hawksworth tree DMR rating = 4; medium infection 235 - Hawksworth tree DMR rating = 5; heavy infection 236 - Hawksworth tree DMR rating = 6; heavy infection 237 – Vine damage: less than 50% of crown involved 238 – Vine damage: 50% or more of crown involved	Parasitic plant that forms a dense cluster of shoots. Can sprout from bole or branches. Affects PIPO, PIFL, PIED, PSME, PIEN, PIPU, JUxx, as well as PODEW and other hardwoods. Learn more about Hawksworth ratings here: https://research.fs.usda.gov/treesearch/65144
25000	**---** **OR** **BROM**	Foliage Diseases	**251 - Minor:** <20% of foliage affected or <20% of crown in brooms OR **252 - Severe:** >20% of foliage affected or >20% of crown in brooms	Needle cast, needle blight, witches' broom. Make a note of the specific damage in the comments.
30000	**FIRE**	Fire	**301 - Minor:** <20% of crown affected OR **302 - Severe:** >20% of crown affected	
40000	**MAMM**	Animal Damage, Source Unknown	**401 - Minor** OR **402 - Severe**	Bear claw marks, porcupine or beaver chewings, deer/elk rubbings. Make a note in the comments about specific damage.

USFS Damage Category	NPS Damage Code	Damage Description	Severity	Notes
41010	**BIRD**	Wood-pecker	**411 - Minor:** <20% of crown affected, bole damage is <50% circumference OR **412 - Severe:** >20% of crown affected, bole damage is >50% circumference, upper 1/3 of crown is killed	Holes are larger, more chiseled than beetle holes. 41010 code indicates Woodpecker, NPS letter code not as specific.
50000	**---** **OR** **OZON/ FRST**	Abiotic Damage	**501 - Minor:** <20% of crown affected, bole damage is <50% circumference OR **502 - Severe:** >20% of crown affected, bole damage is >50% circumference, upper 1/3 of crown is killed	Air pollutants, chemical damage, drought, frost. Make a note of the specific damage in the comments.
50008	**LIGT**	Lightning Scar	**501 - Minor:** <20% of crown affected, bole damage is <50% circumference OR **502 - Severe:** >20% of crown affected, bole damage is >50% circumference, upper 1/3 of crown is killed	
70000	**UMAN**	Human Activities	**701 - Minor** OR **702 - Severe**	Markings, girdling, cuttings, etc. Make note of the specific damage in the comments.

USFS Damage Category	NPS Damage Code	Damage Description	Severity	Notes
90000	**---**	Unknown	900: 0 – 9% affected 901: 10 – 19% affected 902: 20 – 29% affected 903: 30 – 39% affected 904: 40 – 49% affected 905: 50 – 59% affected 906: 60 – 69% affected 907: 70 – 79% affected 908: 80 – 89% affected 909: 90 – 100% affected	Used when damage cannot be identified.
90001	**BROK**	Broken Top	% of original height that is missing; for example, if a tree was originally 100 feet high, but 15 feet of the top is broken or missing; enter "15" in the severity code	Live, sick, and dead trees can all have broken tops.
90002	**DTOP**	Dead Top	% of total tree height that is dead	Only live and sick trees can have a dead top.
99004	**FORK/ TWIN**	Forked Top	% of total tree height above fork	Uncharacteristic, forked top, (not applicable for PODEW, SAEX, and other common riparian species spp., etc). NPS letter codes use FORK for forking above DBH, TWIN is used for forking below DBH.
99006	**CROK**	Crook or Sweep	% of total tree height, which contains the crook or sweep	Use when uncharacteristic for tree species.

USFS Damage Category	NPS Damage Code	Damage Description	Severity	Notes
99016	**SPAR**	Foliage Loss	**1 = Minor** OR **2 = Severe**	Unusually sparse foliage.
99026	**WOND**	Open Wound	% of bole or trunk affected using the height and width of the wound; for example, if a tree is 100 feet tall and the wound covers 15 feet of the bole, enter a value of "15"	
99036	**FIRE**	Fire Scar	% of bole covered by fire scar	
99037	**LEAN**	Leaning Tree	% lean from vertical	Should be greater than 15% and less than 45%. Trees with a lean greater than 45% are captured in the fuel measurements.
99000	**---** **OR** **ABGR/** **BURL/** **EPIC/** **HOLW/** **ROOT/** **SRPT**	Physical Effects	900: 0 – 9% affected 901: 10 – 19% affected 902: 20 – 29% affected 903: 30 – 39% affected 904: 40 – 49% affected 905: 50 – 59% affected 906: 60 – 69% affected 907: 70 – 79% affected 908: 80 – 89% affected 909: 90 – 100% affected	Large, exposed roots, hollowed out, bole, abnormal growth pattern, burl, epicormic sprouts from bole/limbs, sprouts at base, etc. Make a note in the comments of specific damage.
---	**X**	Not Assessed		

E4.10 NMFWRI Equipment Checklist

Essentials

- ☐ Extra Datasheets (enough for each plot/photopoint)
- ☐ NMRAM data sheets (1 per site)
- ☐ Photopoint log data sheets (1 per site)
- ☐ Plot data sheets (1 per plot)
- ☐ Copy of photos & data from last visit (paper or downloaded on tablet)
- ☐ Reference materials (Hink & Ohmart, Soil Texture Flowchart, etc.)
- ☐ Color maps of sites w/ shapefiles & points
- ☐ Driving directions
- ☐ Emergency Action Plan (1 per vehicle)
- ☐ High-precision GNSS receiver (e.g. Trimble or Geode)
- ☐ Garmin GPS unit w/ points & project shapefiles loaded (if possible)
- ☐ Extra AA batteries for Garmin
- ☐ Tablet for use with Geode w/ points loaded & charger (1 per crew)
- ☐ Clipboard
- ☐ Pencil/pen (2+ per person)
- ☐ Pin flags (10+ per crew)
- ☐ Sharpie (black & silver, depending on maps)
- ☐ Camera (charged) w/ memory card & extra battery
- ☐ Rangefinder/hypsometer with charged battery
- ☐ Whiteboard (9"x12")
- ☐ Whiteboard marker (1-2 per person)
- ☐ 2 compasses

- ☐ Spare camera (personal/phone/etc.)
- ☐ 2 candy cane stakes (chaining pins)
- ☐ Flagging tape
- ☐ 2 100-ft tapes
- ☐ Rebar stakes
- ☐ Rebar caps
- ☐ Hammer
- ☐ Densiometer
- ☐ Clinometer
- ☐ Diameter tape w/ nail
- ☐ Copies of IDs/licenses
- ☐ Fuels (go/no-go) gauge/ruler
- ☐ First aid kit
- ☐ Calipers
- ☐ Spare Garmin GPS
- ☐ Water (drinking and for soil samples)
- ☐ Lunch & snacks
- ☐ Boots & clothing suited to dense vegetation & thorns
- ☐ Plant ID books
- ☐ Raincoat/jacket & pack cover (or trash bag)
- ☐ Hat/sunscreen
- ☐ Soil corer or shovel
- ☐ Container for soil samples (bag or small bucket)
- ☐ Emergency communications device (satellite phone, PLB, cell phone, etc.)

E4.11 NMFWRI Data Collection Forms

Riparian CSE Datasheets (pg. 254-257)

Soil Texture by Feel Flow Chart (pg. 258)

Modified Hink and Ohmart Categories (pg. 259-262)

Original Hink and Ohmart Categories (pg. 263)

Project Photopoint Log (pg. 264)

Landowner & Contractor Survey (pg. 265-269)

CSE-Based Riparian Plot Description

Observer:

Recorder:

Latitude (dd.dddddd): _____

Longitude (ddd.ddddd): _____

Elevation (ft): _____

Administrative Unit: _____

Project Unit: _____

Macroplot: _____

Date (DD/MM/YYYY): _____

Time: _____

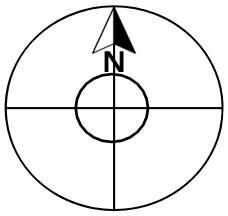
Plot Size	Micro	Macro
Size (Acres)	1/100	1/10
Radius (Feet, Decimal Feet)	11.78	37.24
Radius (Feet, Inches)	11' 9"	37' 3"

Hill Slope (from PC where steepest): _____%

Aspect (click one): N ○ E ○ S ○ W ○

Aspect azimuth: _____°

Mag Declination: _____°



Describe Witness Tree(s):
USE LIVE NATIVE TREES ONLY

Photo Azimuths: (1) of whiteboard at PC. (1) from 75 feet N looking south to PC (4) from PC in all four cardinal directions; (1) from end of each Brown's transects looking toward PC.

Order Taken: _____

Tree Canopy Cover (densiometer)
(Use the Square Method; Record Covered Squares)

N_____, E_____, S_____, W_____

Hink & Ohmart Dominant Structural Class

Original:

Modified:

Comments:

Soil Texture (4 locations)

North:

East:

South:

West:

Comments/Description of Plot:
(Include description of plot location relative to roads, buildings, water, and/or other notable landmarks. Common species around the plot. Important access notes.)

Draw location of tree on plot
Color of Flagging Used: _____

SMALL PLOT INCLUDES ALL SEEDLINGS OR SAPLINGS <5 INCHES DBH/DRC.

Species	Condition (Live, Dead, Sick)	Small Plot (1/100th Acre only) - Tree Regen, Shrubs & Cacti					Species	Condition (Live, Dead, Sick)	Small Plot (1/100th Acre only) - Tree Regen, Shrubs & Cacti				
		Height classes —Seedlings (feet)							Diameter classes —Saplings (inches)				
		> 0 - 0.5'	> 0.5 - 1.5'	> 1.5' - 2.5'	>2.5' - 3.5'	>3.5' - 4.5'			> 0 - 1"	>1 - 2"	>2 - 3"	>3 - 4"	>4 - 5"

New Mexico Forest and Watershed Restoration Institute

Plot Description Version: 6/23/2026, km sf

Precisions:		
Slope:		±5 percent
Vegetation Cover	:	±1 class estimation or ±10%

Aerial & Ground Cover

List by Species	Status L = Live D = Dead S = Sick	Nativity N = Native E = Exotic Unk = Unknown	Aerial Cover (%) (Entire 1/10th acre plot)				
			Estimate Aerial Cover % for Species by Lifeform				
			Tree	Shrub	Forb/herb	Gramanoid	Cactus
TOTALS			0	0	0	0	0

GROUND COVER (%) (Entire 1/10th acre plot) (must total 100%)							
Plant basal	Bole	Litter	Bare soil	Rock (>2.5in)	Gravel (<2.5in)	Water, Wet Soil	Total (%)
							0

Comments on Species Composition and/or Ground Cover:

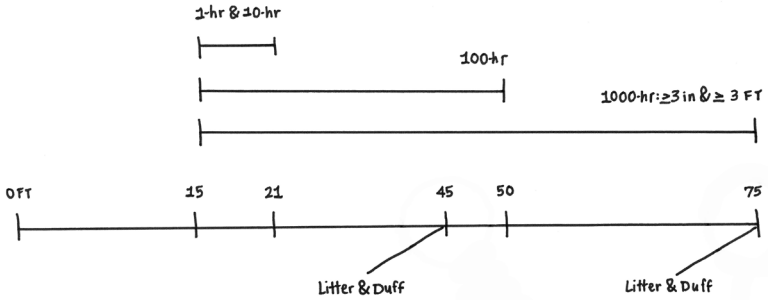
Fine Woody Debris—Coarse Woody Debris

Observer:	_____
Recorder:	_____

Administrative Unit:	_____
Project Unit:	_____
Macroplot:	_____
Date (DD/MM/YYYY):	_____
Time:	_____

1-hour Transect Length - 6'	10-hour Transect Length - 6'
100-hour Transect Length - 35'	1000-hour Transect Length - 60'

CLASS		DIAMETER (in)
FWD	1-hr 10-hr 100-hr	0 to 0.25 to 1.0 to 3.0
CWD	1000-hr and greater	3.0 and greater



	Transect	Azimuth	Slope	1 - Hr Count	10 - Hr Count	100 - Hr Count	Comment
FINE WOODY DEBRIS	1						
	2						

	Transect	Azimuth	Log No.	Log Diameter	Decay Class	Comment
COARSE WOODY DEBRIS (1000-hour Fuels)						

	Transect 1	45'	75'	Transect 2	45'	75'
LITTER & DUFF	Litter Depth (in)			Litter Depth (in)		
	Duff Depth (in)			Duff Depth (in)		
	Comments?			Comments?		

Precisions: Diameter: ±0.5 in ; decay class ±1 class ; Slope ±5 percent

Decay Class Description

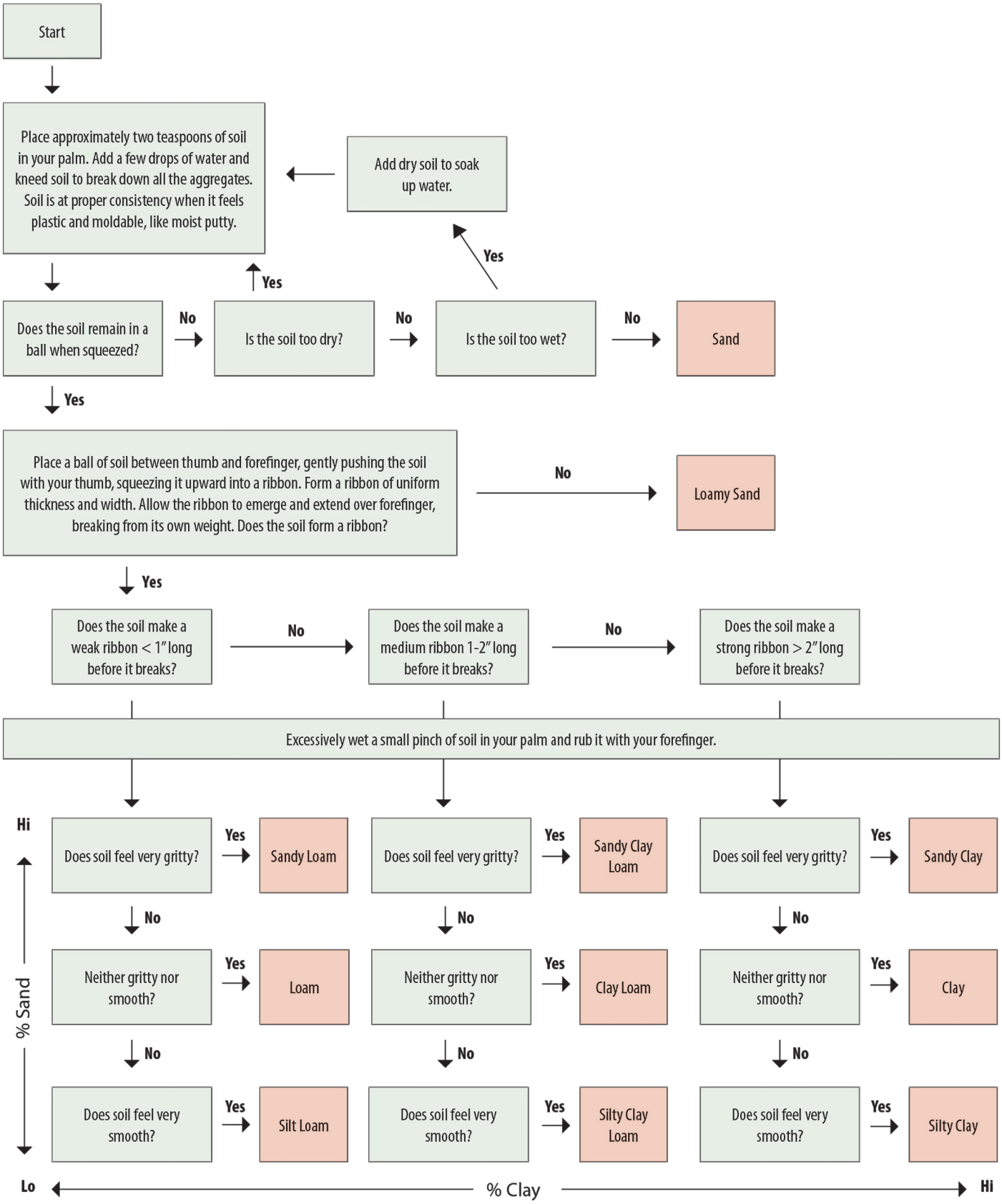
1. All bark is intact. All but the smallest twigs are present. Old needles probably still present. Hard when kicked
2. Some bark is missing, as are many of the smaller branches. No old needles still on branches. Hard when kicked
3. Most of the bark is missing and most of the branches less than 1 in. in diameter also missing. Still hard when kicked
4. Looks like a class 3 log but the sapwood is rotten. Sounds hollow when kicked and you can probably remove wood from the outside with your boot. Pronounced sagging if suspended for even moderate distances
5. Entire log is in contact with the ground. Easy to kick apart but most of the piece is above the general level of the adjacent ground. If the central axis of the piece lies in or below the duff layer then it should not be included in the CWD sampling as these pieces act more like duff than wood when burned.

Overstory Trees

Observer/Recorder: _____ **Project/Site/Plot:**_____ **Date:** _____

1/10th acre plot (37' 3" radius)									
Tree #	Stem #	Species	Tree cond. (L,D,S)	DBH (in)	Total Tree Ht (ft)	LiCrBHt (ft)	Damage	Severity	Comments

Soil Texture by Feel Flow Chart



SOIL TEXTURE BY FEEL (THIEN 1979)

MATERIALS NEEDED

• water • squirt bottle • texture by feel instruction sheet • distilled water

Modified Hink and Ohmart Categories

The following are examples of the modified Hink and Ohmart Vegetation Vertical Structure Type Definitions categories with text from (Muldavin E. , 2021). All photos credit NMFWRI.

Unit	Threshold		
Meters	1.5m	6m	7m
Feet	4.9ft	19.7ft	23ft

Multiple-Story Communities (Woodlands/Forests)

Type 1 - High Structure Forest with a well-developed understory. Trees (>6 m) with a canopy covering >25% of the area of the community polygon and woody understory layer of tall shrubs or short trees (1.5-6 m) covering >25% of the area of the community (polygon). Substantial foliage is in all height layers.

Type 2 - Low Structure Forest with little or no understory. Trees (>6 m) with canopy covering >25% of the area of the community polygon and minimal woody understory layer (1.5-6 m) covering <25% of the area of the community (polygon). Majority of foliage is over 7 m above the ground.

Single-story Communities (Shrublands, Herbaceous and Bare Ground)

Type 5 - Tall Shrubland. Young tree and shrub layer (1.5-6 m) covering >25% of the area of the community polygon. Stands dominated by tall shrubs and young trees, may include herbaceous vegetation underneath the woody vegetation.

Type 6S - Short Shrubland. Short stature shrubs or very young trees (>1.5 m) covering >25% of the area of the community (polygon). Stands dominated by short woody vegetation, may include herbaceous vegetation among the woody vegetation.

Type 6W - Herbaceous Wetland. Herbaceous wetland vegetation covering >10% of the area of the community polygon. Stands dominated by obligate wetland herbaceous species. Woody species absent, or <25% cover.

Type 6H - Herbaceous Vegetation. Herbaceous vegetation covering >10% of the area of the community polygon. Stands dominated by herbaceous vegetation of any type except obligate wetland species. Woody species absent or <25% cover.

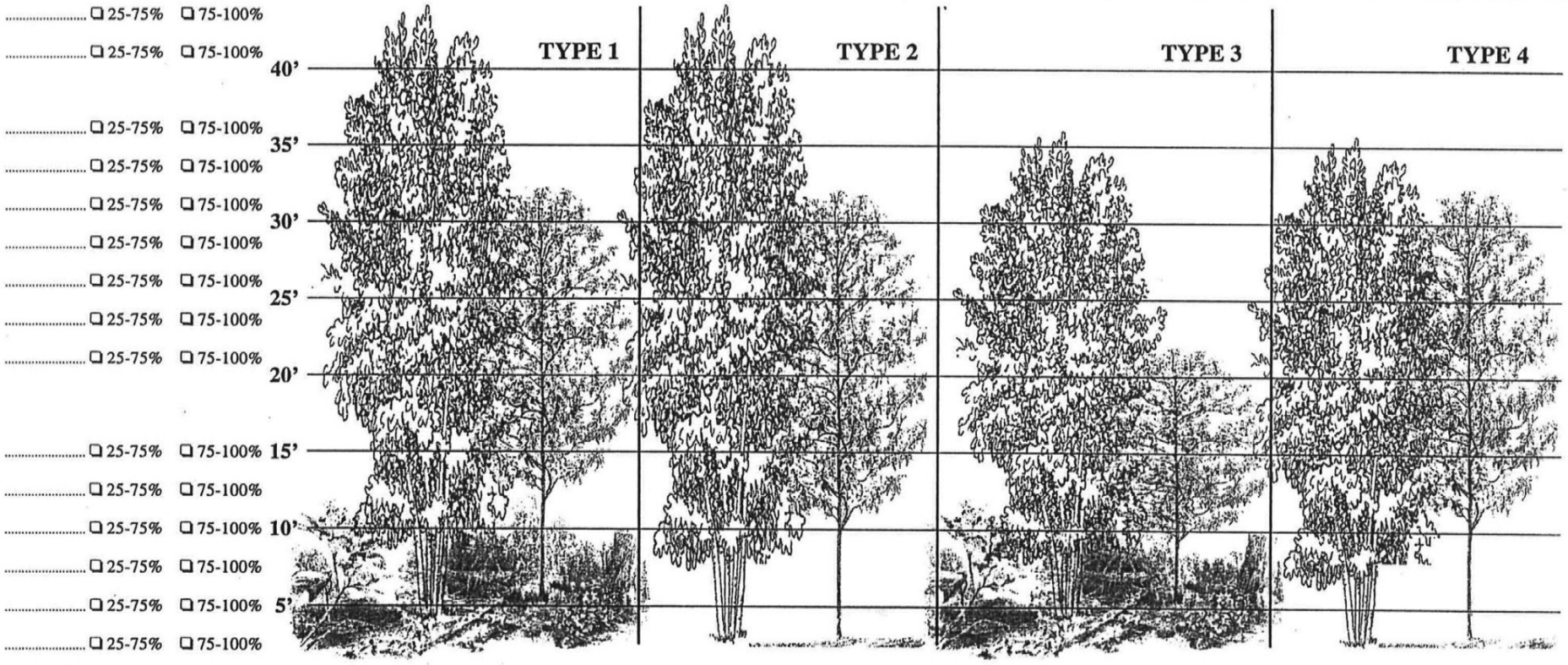
Type 7 - Sparse Vegetation, Bare Ground. Bare ground, may include sparse woody or herbaceous vegetation, but total vegetation cover <10%. May be natural disturbance in origin (e.g., cobble bars) or anthropogenic (e.g., roads).

Original Hink and Ohmart

Date _____ Recorder _____ UTM • E _____ Polygon ID _____

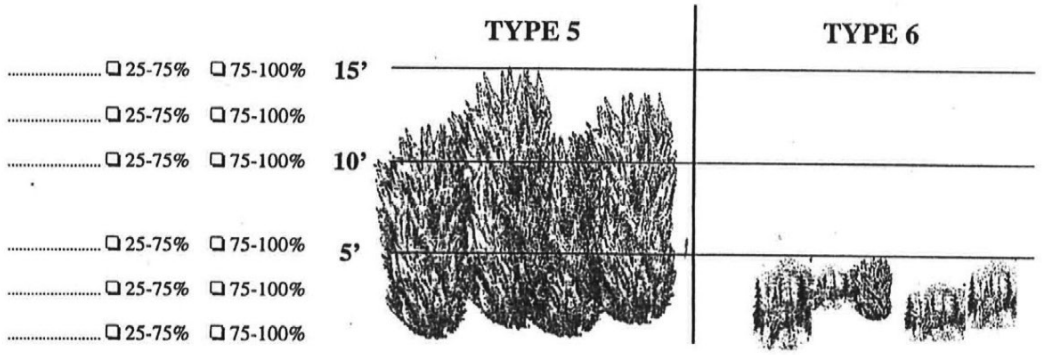
N _____ Waypoint _____

H&O Classification:



SPECIES:

A	= False Indigobush	LC	= New Mexico Locust
ATX	= Fourwing Saltbush	LY	= Wolfberry
B	= Baccharis (seep willow)	MB	= Mulberry
BD	= Broom Dalea	NMO	= New Mexico Olive
C	= Cottonwood	RO	= Russian Olive
CAT	= Cattail	SB	= Silver Buffaloberry
CR	= Creosote	SBM	= Screwbean Mesquite
CT	= Catalpa	SC	= Salt Cedar
CW	= Coyote Willow	SE	= Siberian Elm
HL	= Honey Locust	SS	= Sand Sage
HMS	= Honey Mesquite	TH	= Tree of Heaven
J	= Juniper	TS	= Threeleaf Sumac
		TW	= Tree Willow



(credit to SWCA 2006/ SWCA Environmental Consultants. Hink and Ohmart structural class datasheet. [place unknown]: [publisher unknown]; 2006.)

Project Photopoint Log

Project ID	Date	Time	Photo ID	Lat	Long	Direction facing	Foreground landmark	Background landmark	Whiteboard distance	Camera used	Field crew initials	Comments
(e.g. 19.01)	(MM/DD/YYYY)		(format: 19.01_1_N)	(dd.ddd)	(ddd.ddd)	(N,S,E,W or degrees)	(description, distance, bearing, flagging color)	description, distance, bearing)	(usually 11.78" if standalone PP;37.24" if part of plot)	(e.g., Red Olympus, CAM_004)		

Landowner and Contractor Survey

*The goal of this survey is to capture information related to the most recent activity. Can be applied to initial and re-treatments.

Project	
Date of visit	
Visit lead	
Landowner/manager	
Community	
Contractor	
Current treatment dates (starting and finish)	

I. Landowner Section

1) Property type:

- ☐ Private
- ○ Tribal
- ○ Municipal
- ○ Other (please explain):

2) Primary/current land use:

- ☐ Grazing
- ☐ Agriculture
- ☐ Residential
- ☐ Other (please explain):

3) Historical land use:

- ☐ Grazing
- ☐ Agriculture
- ☐ Residential
- ☐ Other (please explain):

4) Observed grazing intensity:

- ☐ Low
- ◯ Moderate
- ◯ High

5) Animals grazed:

- ☐ Cows
- ☐ Goats
- ☐ Sheep
- ☐ Alpaca
- ☐ Horses
- ☐ Mules/Donkeys
- ☐ Other (please explain)

6) Who will provide ongoing maintenance for the site?

- ☐ Landowner
- ☐ SWCD
- ☐ Contractor
- ☐ Other (please explain)

7) Major disturbance history in the last 15 years:

- ☐ Flood
- ☐ Fire
- ☐ Restoration
- ☐ Other (please explain):

8) Flowing surface water on the land:

- ☐ Yes
- ☐ No
- ☐ Ephemeral
- ☐ Year-round

9) Technical limitations to work?

- ☐ Equipment limitations
- ☐ Terrain
- ☐ Special considerations (please explain):

10) Access concerns?

- ☐ Permits
- ☐ Locked gates
- ☐ Other (please explain):

II. Treatment/Contractor Section

11) Desired condition:

12) Is this an initial treatment?

- ☐ Yes
- ○ No

***If this is a retreatment, complete questions 13 to 27. If this is an initial treatment, continue to question 19.**

13) What retreatment is this?

- ○ First
- ○ Second
- ○ Third
- ○ Fourth

14) Please describe re-sprout presence/absence before the retreatment occurred:

15) How many years has it been since the last treatment? _____

16) Targeted species during last treatment?

17) Target species observed onsite after treatment?

- ☐ Yes
- ◯ No

18) Target species intentionally left?

- ☐ Yes
- ☐ No
- ☐ Reason:

19) Mechanical treatment?

- ☐ Yes
- ☐ No
- ☐ If yes, please explain:

i) Treatment type & equipment used:

ii) Slash treatment: ☐ Mastication ☐ Removal

ii) Average mastication depth (inches): _____

iv) Average percent masticated: _____

v) Treatment comments:

20) Chemical treatment?

- ☐ Yes
- ☐ No
- ☐ If yes, please explain:

i) Application type:_____

ii) Application rate:_____

iii) Herbicide and concentration:_____

iv) Adherence to label recommendations? ☐ Yes ☐ No

v) Application comments:

21) Planted/seeded?

- ☐ Yes
- ☐ No
- ☐ If yes, seeding mix/plants planted: _____

22) Acres treated: _____

23) Contractor award amount $: _____

24) Non-targeted & native species considerations/information/comments:

25) Vegetation response comments:

26) Treatment comments:

27) Overall project comments:

F1.1 Using A Compass and Setting Declination

Getting set up

For each project, we recommend adjusting the declination of every crew member's compass to the declination appropriate for the project location. *Note that many of the photos use a Silva Ranger compass, but other models have similar features.*

Compass Declination

Declination is the difference between magnetic north and true north. Declination changes over time and differs depending on location, so it is important to know the current declination of your monitoring site. We correct for this difference when working from a map or when re-taking plots over time so that, for instance, the "north" photo of the plot remains in the same location.

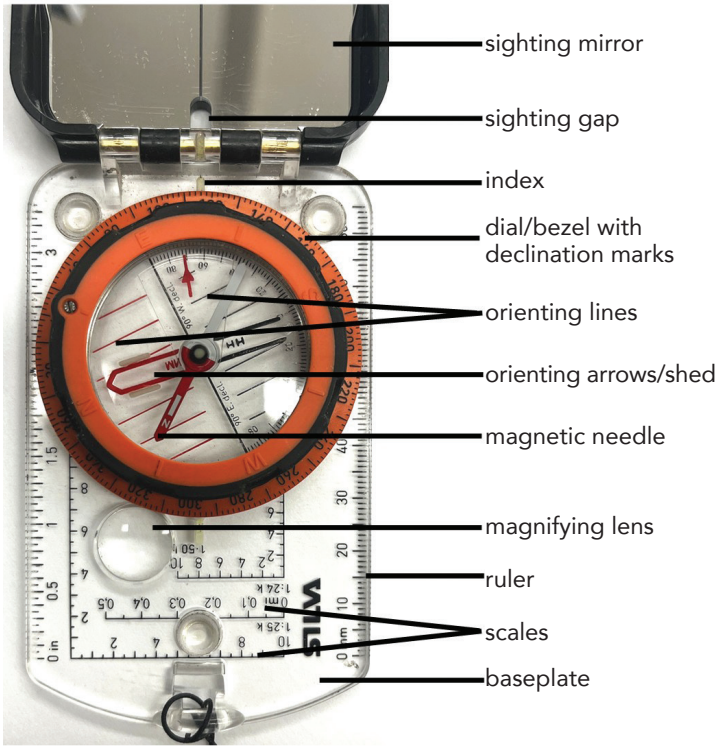


Figure 1. *Photo diagram by Jax Gaglianese-Woody*

Looking Up Declination

The following link leads to a declination calculator that estimates declination based on a latitude, longitude, and date: https://www.ngdc.noaa.gov/geomag/calculators/magcalc.shtml.

Correcting for Declination – Method 1

One way to correct for declination is to set the compass wheel.

1. Locate the small metal key included along the compass lanyard. If the compass does not have a metal key, anything small enough (and non-magnetic) to adjust the screw on the compass wheel would suffice.
2. Insert the metal key into the adjustment screw on the wheel on the front or back of the compass to set the declination.

3. Turn the screw until the declination indicator matches the declination for the area of work (make sure to adjust in the correct direction—if estimated declination is a positive value, correct to the east, and if the estimate declination is a negative value, correct to the west).

4. Make sure everyone on the crew sets their compasses to the same declination and test this by sighting a line.

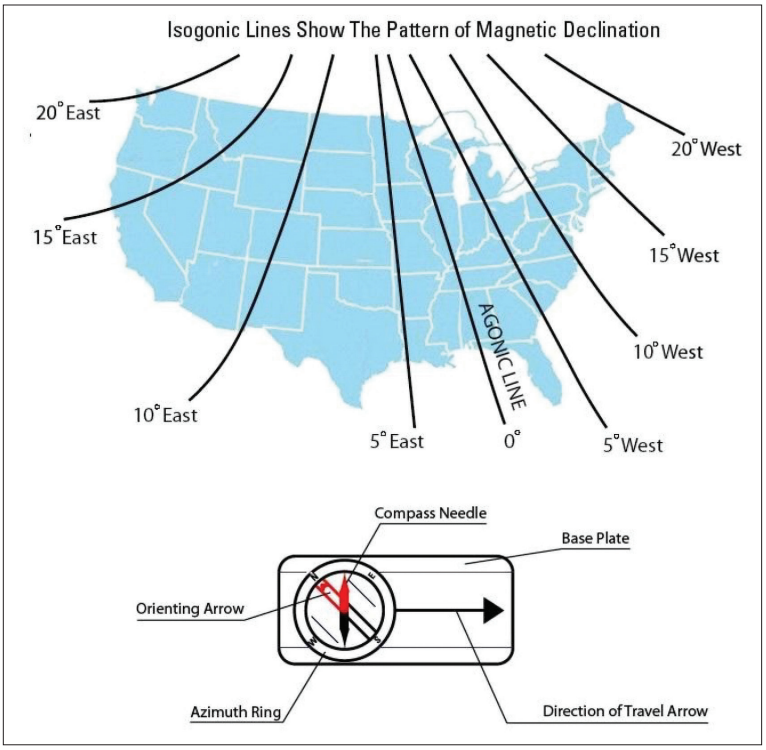


Figure 2. *Diagram by USGS Educational Resources*

Correcting for Declination – Method 2

If the compass does not have adjustable declination, it is possible to correct for declination with addition and subtraction. One method is to use the formulas:

True reading
- east declination
= magnetic reading

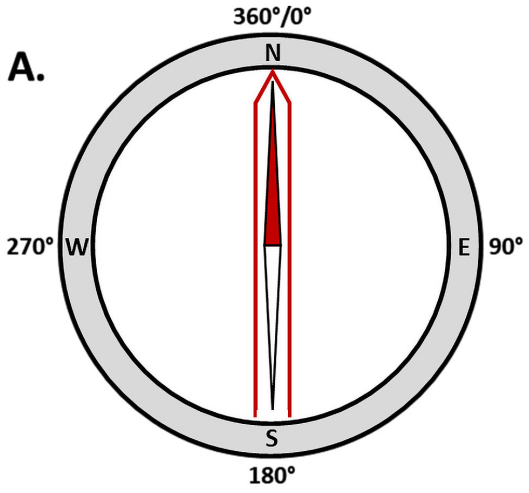
True reading
+ west declination
= magnetic reading

So, for example, if declination is 10 degrees East (+10°), the following formula can be used to walk a line northward:

True reading
- east declination
= magnetic reading

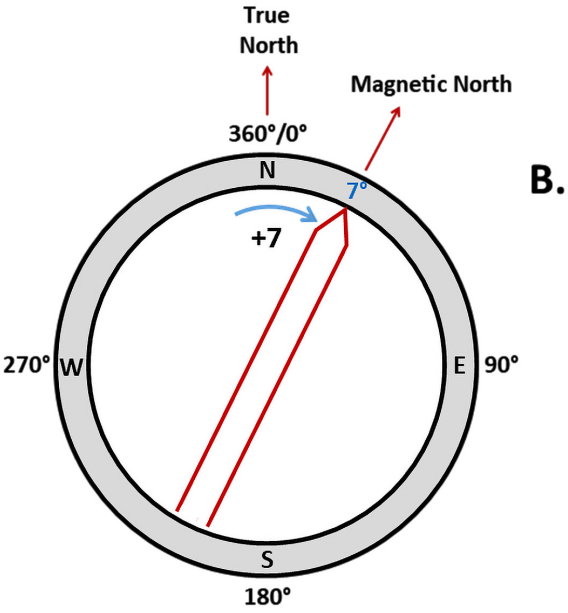
Figure 3. *Photo by Carolina May*

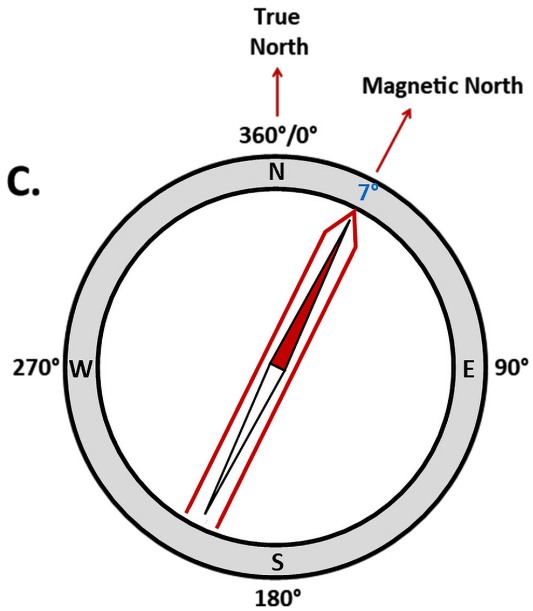
360 - 10 = 350, so the compass would need to be set to 350 degrees to get a true north line.



When the magnetic needle and orienting arrow (or shed) are aligned with "North," the compass is oriented to Magnetic North, not True Geographic North. The compass needle aligns with the local magnetic field, *and the angle between True North and Local Magnetic North is called magnetic declination.* The compass must be adjusted to account for that difference.

The local magnetic field varies by place and time, and a declination estimator can be used to determine how much adjustment is needed. Suppose the estimated declination is 7° East (or + 7°). The shed on the compass should be rotated 7° to the east (see "Method 1" in Supplement Compass Declination)





Once the shed is adjusted for the local magnetic declination, aligning the magnetic needle inside the shed will more accurately orient the compass to True North.

Figure 4. Explanation of magnetic declination on a compass. *Diagram by Jax Gaglianese-Woody*

F1.2 Azimuths with A Compass

Azimuth is the horizontal angle between the direction of an object and north (360 degrees), measured in degrees. A compass can be used to orient an individual to a specified direction, to determine a direction of interest, or to identify the azimuth of a particular object relative to a given location (e.g., the azimuth of a witness tree from plot center).

Finding an Azimuth

1. Turn the compass dial to line up your desired azimuth with the indicator at the top of the compass.
2. While holding the compass level, turn your body until the red magnetic needle is inside the red orienting arrow ("Red Fred in the shed.").
3. The direction that you are now facing is your desired azimuth.

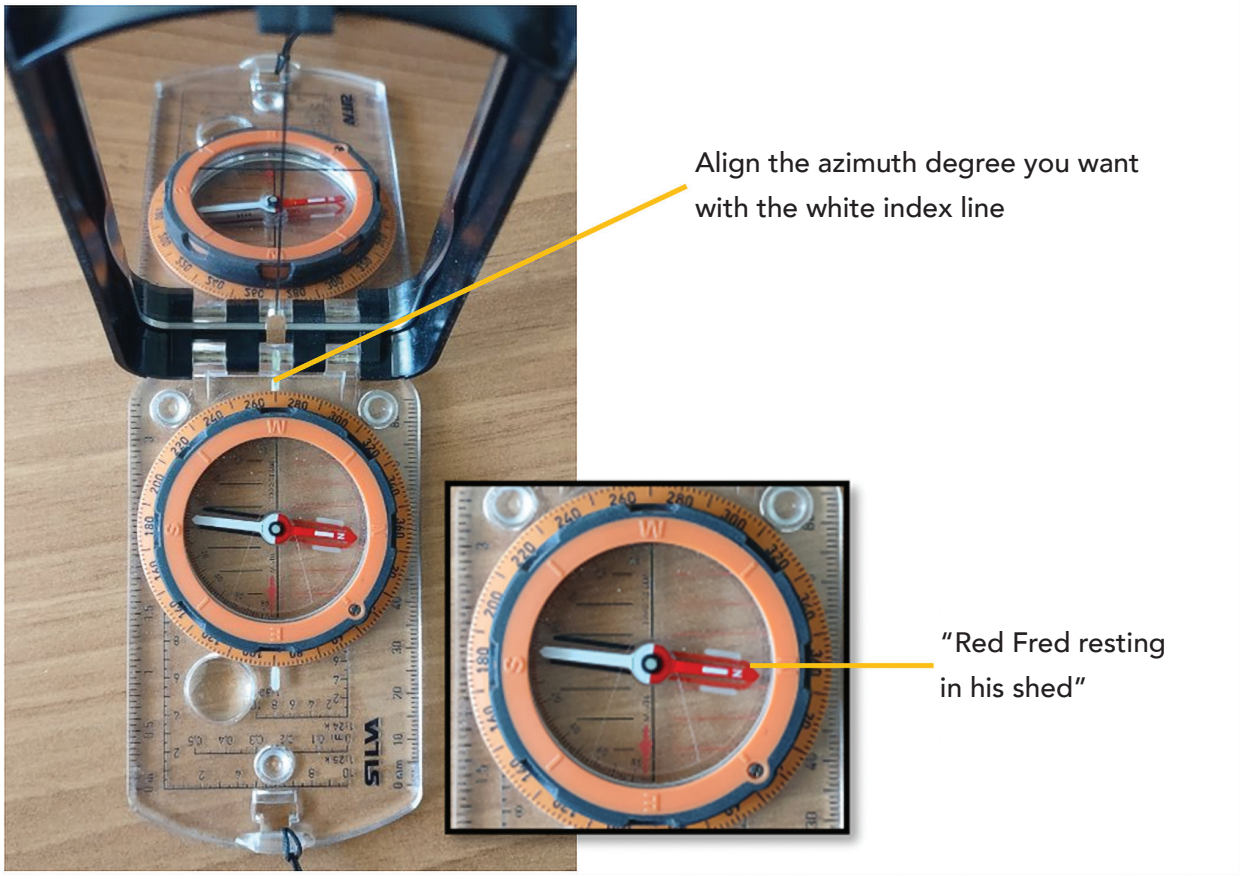


Figure 1. Finding an azimuth. *Photo by Jax Gaglianese-Woody*

Figure 2. *Photo by Carolina May*

Walking a line

1. To walk a straight line, such as to the West, turn the dial on the top of your compass so the "W" is lined up with the center mark (index).

2. Next, rotate yourself and your compass so that the red magnetic needle lines up with the red orienting arrow on the compass face. (See bottom right photo). Be sure to avoid metal near the compass (e.g., phones, GPS devices, smartwatches, laptops, metal equipment, etc.).

3. Hold the compass level. Keep the red magnetic needle and the red orienting arrow aligned and look through the sights at either the top of the cover or at the base. While looking through the sights, choose

Figure 3. Field tech sighting with a compass. *Photo by NMFWRI Field Crew*

Figure 4. Technician sights with a compass. *Photos by Kathryn Mahan.*

a distinct landmark or object that is in your sighting direction. In the top left photo on the next page, we can see a tree through the sights. If your compass has a mirror on the top cover, this can be used to keep the arrows on the compass face in view while sighting.

4. Walk toward this object. If there is no suitable landmark to use as reference, you can instead walk in the appropriate direction while keeping the red magnetic needle and red orienting arro aligned at all times.

5. Walk out the appropriate distance (bring your tape along) and stop.

6. Turn around and use the sights on the compass to look back at where you came from. This time, the WHITE magnetic needle should line up with the red orienting arrow (you are looking backwards, or in the opposite direction you walked). Step right or left as needed until the alignment is perfect.

7. To double-check yourself, have someone stand where you started and sight to you with their own compass. If your declination was set the same, you should both agree on the right position.

Taking an Azimuth of an Object

1. Aim your compass sight at the desired object (e.g., a tree).
2. While holding the compass level, turn your compass dial until the red needle is inside the red orienting arrow.
3. The number lining up with the indicator is the azimuth of the object in your sight.

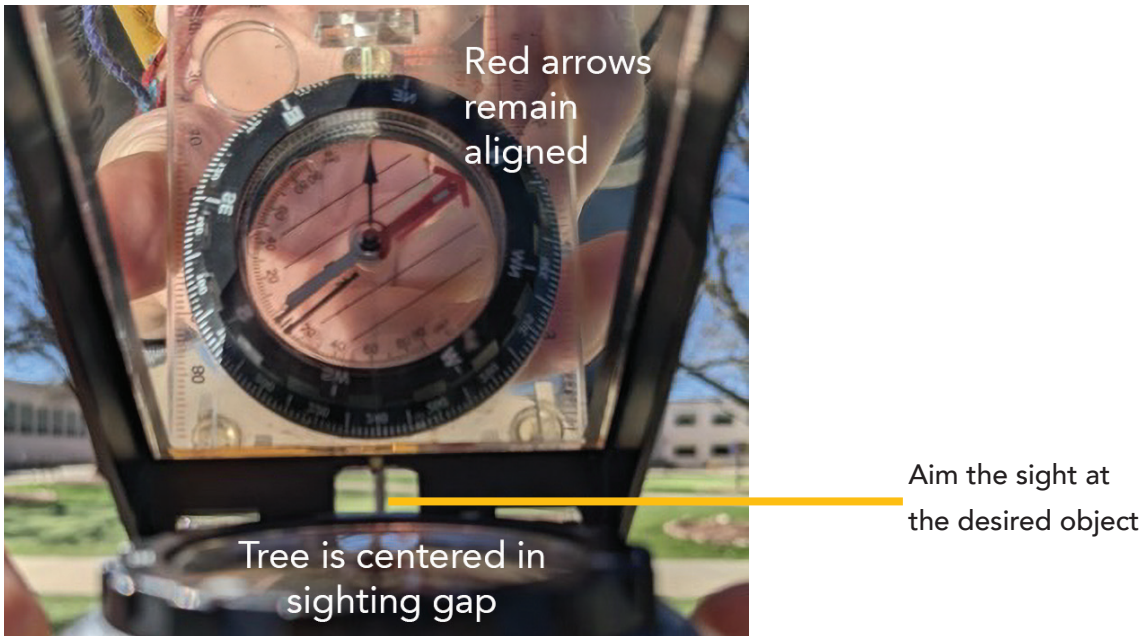


Figure 5. *Photo by Carolina May*

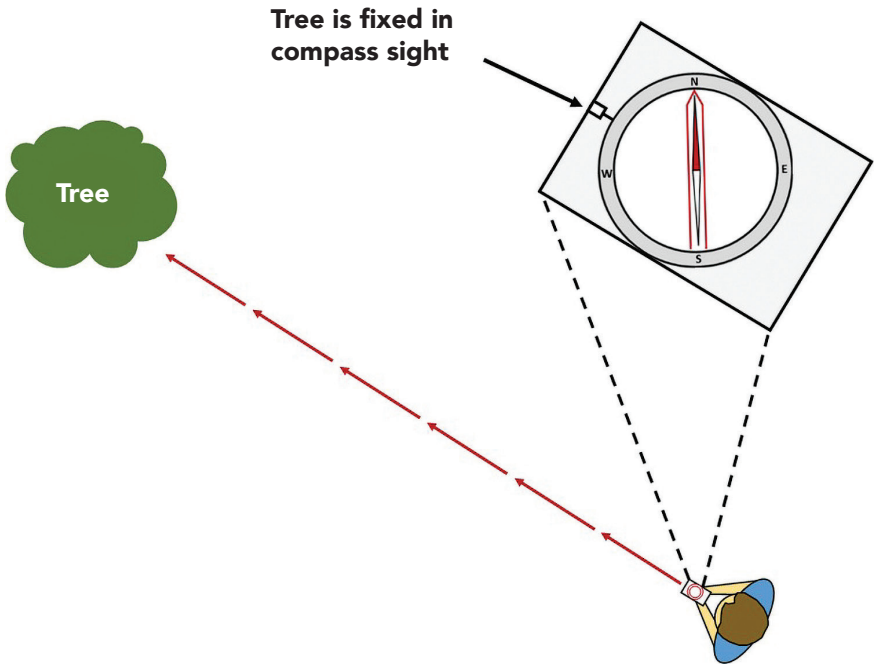


Figure 6. *Diagram by Jax Gaglianese-Woody*

Common errors and troubleshooting

1. It is recommended to always use your dominant eye when sighting. Be sure you know this for yourself, or sight with both eyes open.
2. Hold the compass level while sighting with it.
3. If you are holding something metal such as pin flags or a metal tape, these will attract the compass needle, and your line will be off.
4. If you are consistently off, double-check your declination setting. These tic marks are difficult to read, so it is easy to make a mistake initially. In very dense stands, have someone stand at plot center (PC) and guide you around trees and brush.
6. Try to keep the compass protected from extreme temperatures or rapid changes in elevation to reduce the chance of getting bubbles in the liquid inside. These bubbles, if they are large enough, can make the compass difficult to use.
7. If compass liquid is gone, large bubbles are present, or if the magnetic needle is spinning loosely, the compass is unusable.

F1.3 Aspect with a Compass

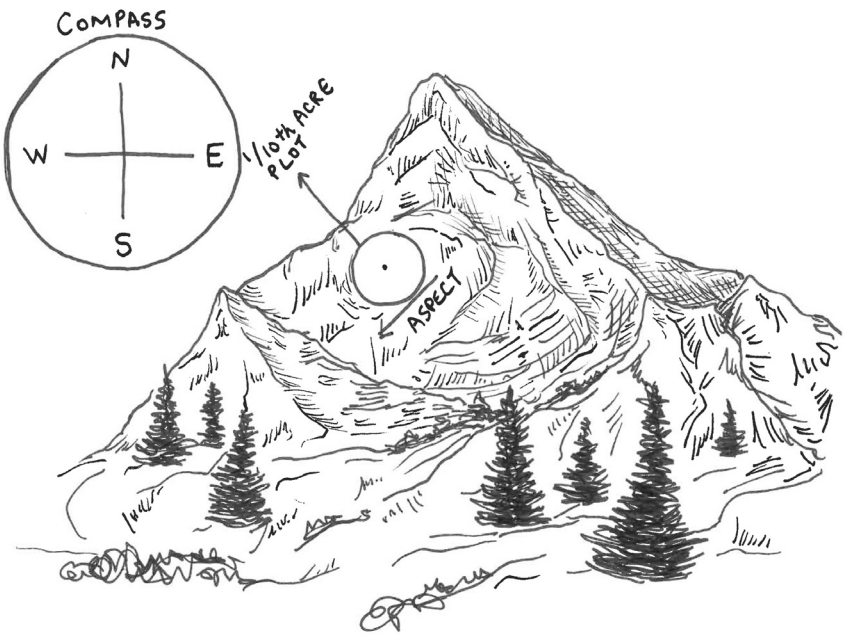


Figure 1. Aspect is the direction of a plot's slope. *Illustration by NMFWRI Monitoring Crew*

Aspect is the general orientation or direction of a slope. For each plot, aspect is recorded with a specific azimuth (degrees) and a cardinal direction (N, E, S, W).

1. Stand at plot center and hold the compass facing up with the sights facing away from you.
2. Hold the compass flat and parallel to the ground.
3. Turn your body so that you aim the sights of the compass in the direction the slope is facing. You can conceptualize this by positioning yourself as if you were downhill skiing the fastest route off your plot, or by visualizing which direction water would flow from plot center.
4. Without moving yourself or the compass base, turn the dial to align the red orienting arrow with the red magnetic needle.
5. Read the number that now aligns with the sights.
6. Record this number exactly as you see it (aspect azimuth) and as whatever cardinal direction it is closest to (aspect). For example: 230 degrees, West.

F2 Slope With a Clinometer

Choosing a Clinometer

Clinometers are tools that can be used for measuring slopes, angles, or heights of objects, including trees. They are available with many different units of measurement, such as secant, percent, degree, topographic, 15- and 20-meter, and more. Each clinometer comes with two units. We recommend using a percent and topographic clinometer, also known as "PM5/1:66," because these allow you to measure both plot slopes and tree heights. The following instructions are based on Suunto clinometers.

Measuring slope with a partner:

1. Find a partner and establish where your eye level falls on them.
2. Stand at least 37.24 ft apart on the steepest part of the plot. The slope measurement does not need to pass through plot center but it can.

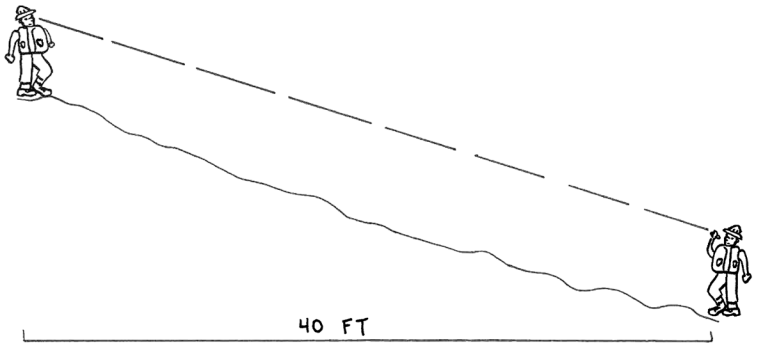


Figure 1. The technician on the right measures slope uphill by angling the clinometer to eye level on their partner. *Diagram by Raymundo Melendez and Carolina May*

3. Hold the clinometer to your eye. It is best to look with both eyes open, one eye looking through the lens at the wheel and the other looking at the object or landscape, so that the image of the wheel is superimposed over your view of your surroundings. Initially closing one eye or the other may help trick the brain into overlaying these images, but for some people this might not occur and it may be necessary to alternate which eye is open.
4. With your vision from both eyes overlayed or alternating your eyes to see both your surroundings and the clinometer lens, place the horizontal sighting line from the clinometer on the object you are measuring.

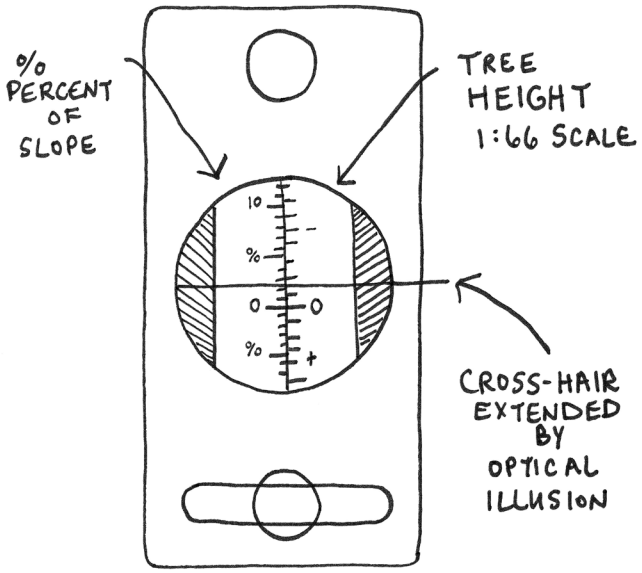


Figure 2. Use the scale on the left for percent slope measurements.
Diagram by Raymundo Melendez and Meredith Prentice

Figure 3. Taking slope with a clinometer.
Photo by Kathryn Mahan

5. Holding your head steady, tilt the clinometer until the sighting line aligns with the point you established as eye level on your partner.

6. Read the number closest to the sighting line on the correct side of the wheel—remember that two scales appear through the clinometer lens. If you forget which side to read, look at the wheel on the side of the clinometer to see the units, or look through the lens and tip the wheel until you can see symbols. On a PM5/1:66 clinometer, the scale on the left indicates percent slope (rise/run x 100), while the scale on the right measures height in feet if you are on the same contour and 66 feet (one chain) away from your target.

F3 Reading Tape Measures

Many kinds of tape measures may be used in monitoring. Before taking measurements, make sure you understand which tape you are using, how its measurements should be read and recorded, and where the measurement scale starts.

CAUTION! Tapes built with a hook/ring on the end are designed to be read only if the hook/ring is attached to something and the tape is pulled taught. The end of the tape is NOT zero. Zero is at the end of the hook/ring.

Figure 1. Example of a decimal feet tape. *All photos in this chapter were taken by the NMFWRI Monitoring Crew.*

Figure 2. Example of a decimal feet tape with tenths marked differently.

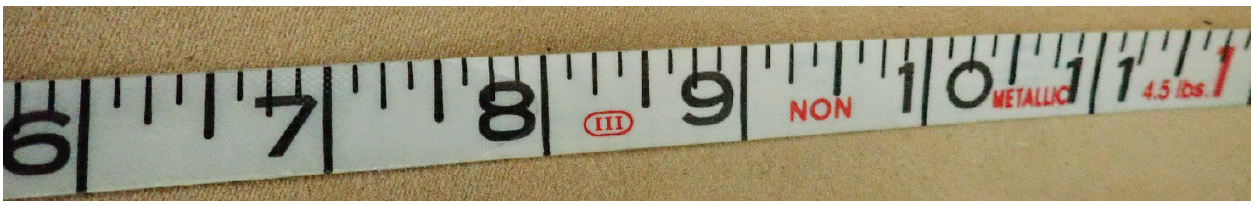


Figure 3. Example of a tape marked in feet and inches.

Types of Tapes

1. **Fiberglass/Reel Tapes**
   Sometimes these tapes have one side, and sometimes two. Read the tape to know what units it uses (see pictures above). For instance:

   Figure 1 is in decimal feet (feet and tenths-of-feet). This tape only counts to 10, with the tenth being the feet mark.

   Figure 2 is the same, but the tenths are marked with a decimal point.

   Figure 3, however, is marked in feet and inches. Notice how it has twelve divisions. Note: it's common to find fiberglass tapes with both a metric and U.S. Customary side. Typically, the sides are two different colors.

Figure 4. Decimal feet side of logger's tape.

Figure 5. Adjusted for diameter side of logger's tape.

2. **Diameter/Logger's Tapes**
   Spencer tapes (aka D-tapes, diameter tapes, or logger's tapes) are commonly two-sided. For example:

   Side 1 (figure 4) - decimal feet, designed to be read from the end of the loop. This side can be used like a reel tape; it is useful for measuring lengths of logs, finding the appropriate distance from a tree when taking height by clinometer, or laying out your plot.

   Side 2 (figure 5) - in inches and tenths of inches, adjusted for the value of pi. This side is meant to be read when measuring the diameter of a tree or 1000-hour fuel. It is read where the number and the zero-mark line up.

3. **Flat tape/ruler**
   Sometimes rulers are also used, especially if your fuels gauge doesn't have a ruler to measure the depth of litter or duff, or if you are checking plant ID by measuring the lengths of parts of a plant. Be sure to check the units.

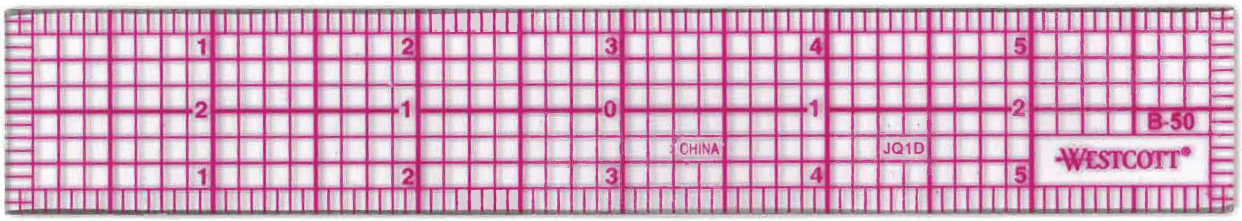


Figure 6. Example of a flat ruler that might be used to measure plant morphology or the width of woody debris.

Abbreviating Measurements

Remember, there are standard abbreviations for inches and feet. Always indicate the units being recorded on a datasheet and be careful not to confuse inches and tenths of feet.

Acceptable ways to record			
Inches	2.1 inches	2.1 in	2.1"
Feet	6 feet	6 ft	6'

Measuring by Tenths of a Foot

1. Place the tape measure on a flat surface where it can be clearly read.
2. Reading from left to right, notice that the tape measure reads from ".1" to ".9" or "1" to "9", then there is a "FT" mark. Each one of the nine vertical dashes between the foot marks represent 1/10th of a foot (or 0.10 feet).
3. Remember that if the tape begins with a permanent hook, it is designed to be read from a stake or chaining pin, so the measurement begins at the far end of the hook (see Figure 7).

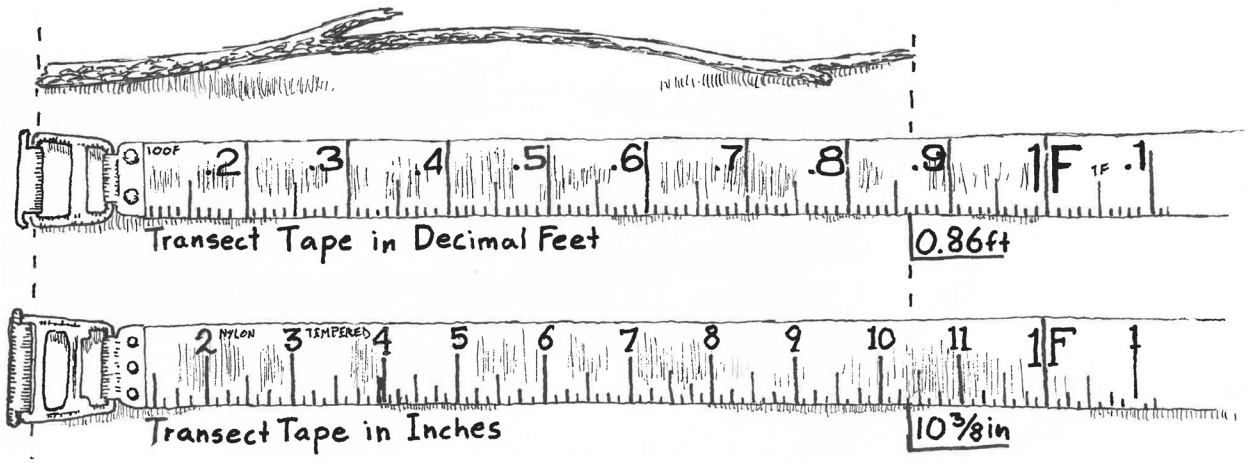


Figure 7. Note the units (inches vs. decimal feet) and where measurements begin on each tape. Measurements begin at the hook/loop on a transect tape. *Diagram by Vincent Vispo*

F4 Using GNSS/GPS

The Global Positioning System (GPS) is a satellite-based navigation system and one of several Global Navigation Satellite Systems (GNSS). Receivers, such as handheld Garmins, smartphones, and tablets typically use GPS as well as one or more other GNSS constellations (e.g., GLONASS, Galileo) to provide accurate location information. The accuracy of a recorded location depends on many factors, including the receiver, the satellite systems it uses, terrain, vegetation, and atmospheric conditions. Modern smartphones often provide sufficiently accurate GNSS positioning for many applications, but high-precision GNSS receivers may be appropriate when precise plot relocation is critical or work is conducted in challenging terrain. Canyons, steep valleys, dense forest canopies, and tall buildings can block or reflect satellite signals, reducing positional accuracy.

The following guidelines are for Garmin GPSMAP handheld receivers, which NMFWRI and many partners commonly use. Please note that specific instructions will vary by device.

Calibrating GPS Units

Most GPS units need to be recalibrated occasionally. On Garmin units, navigate to the compass, select 'Menu', and then select 'Calibrate Compass'. Follow instructions on screen.

Navigating to a Pre-Loaded Point

On Garmin units, select 'Find' and then 'Waypoints'. Scroll until the waypoint of interest is located.

Navigating to GPS Coordinates

On Garmin units, select 'Find' and then 'Coordinates'. Type in GPS coordinates in decimal degrees.

Recording a Waypoint

On Garmin units, select 'Mark'. Use up and down arrows to input point name and notes. Use a standardized point naming system to avoid confusion (i.e. Plot Name). Select Done, Save, or OK to store the waypoint.

GPS Tips & Troubleshooting

- Ensure all necessary GPS points are loaded onto all GPS devices before heading into the field.
- In deep canyons, GPS access to satellites may be obscured. GPS units need a clear view of the sky to be used with accuracy.
- Satellite locations will vary throughout the day, and therefore GPS accuracy will vary.
- Low battery warnings are frequent on Garmin GPS units, but often battery life will continue long after low battery warnings. Always bring plenty of spare batteries along.

G Additional Resources for Planning, Monitoring and Management

MONITORING & PLANNING

Geomorphology/Stream Measurements:

- NMED SWQB SOP 5.0 Physical Habitat Measurements (2025)
  https://www.env.nm.gov/wp-content/uploads/sites/18/2023/06/5.0-Physical-Habitat-SOP-20230609-Final.pdf
- USFS Stream Channel Reference Sites: An Illustrated Guide to Field Technique (Harrelson et al., 1994)
  https://www.nae.usace.army.mil/portals/74/docs/regulatory/StreamRiverContinuity/Stream_Channel_Reference_Sites_(2004).pdf
- USDA Forest Service, National Stream & Aquatic Ecology Center
  https://www.fs.usda.gov/biology/nsaec/products-videoswebinars.html
- NMED NMRAM Abiotic Metrics Intro, Floodplain Recon (video)
  https://nhnm.unm.edu/sites/default/files/2025-05/IVa_Abio_Intro_and_Overview.mp4

Protocols & Methods:

- New Mexico Rapid Assessment Method (NMRAM)
  https://nhnm.unm.edu/NMRAM
- Soil Texture by Feel
  https://www.cpow.net/2014/wp-content/uploads/2016/05/soil-texture-9_color-flow-chart.pdf
- Ocular Cover Estimates
  https://landscapetoolbox.org/field-methods/ocular-cover-estimate-plot-based/

Data Management Plan Tool:

https://dmptool.org/

Restoration:

- Information on Salt Cedar and Riparian Restoration
  https://www.riversedgewest.org/
- Information on plant selection and planting techniques from the New Mexico NRCS office.

  https://www.nrcs.usda.gov/plantmaterials/nmpmctn9432.pdf

  https://www.nrcs.usda.gov/plantmaterials/nmpmcsy03852.pdf

Plant ranges and wetland status:

- Detailed information on plants including photos, species codes, range maps, and wetland indicator status.
  https://www.plants.usda.gov/

National Wetland Plant List:

- Contains lists of wetland plants in the U.S. The lists are searchable by wetland region and by species. Includes photos of many species.
  https://nwpl.sec.usace.army.mil/

Resources for finding formulas, software, and texts

- R Studio:
  This site provides information on downloading and installing R and R Studio.
  https://rstudio-education.github.io/hopr/starting.html
- EPSCoR:
  Provides lessons and workshops on "data carpentry," focusing on data organization, cleaning, analysis, and visualization using various software and tools.
  https://datacarpentry.org/lessons/#ecology
- Stream Mechanics:
  Provides informational resources with a collection of guiding tools, such as spreadsheet tools, assessment manuals, webinars, and references to other informative resources.
  https://dep.wv.gov/WWE/getinvolved/sos/Pages/Scores.aspx
- FIREMON:
  The GTR-164-CD provides information on sampling approaches and design.
  https://www.fs.usda.gov/rm/pubs_series/rmrs/gtr/rmrs_gtr164.pdf

Publications:

  - A Simple Guide to Common Forest Measurements (University of Tennessee, Institute of Agriculture) discusses common forest metrics, such as DBH, TPA, tree height, and basal area.
    https://utia.tennessee.edu/publications/wp-content/uploads/sites/269/2023/10/W1117.pdf
  - How Much Timber Do I Have: A Landowner's Guide to Evaluating Basal Area and Volume (University of Arkansas, US Department of Agriculture, and County Government Cooperating) discusses common forest metrics, such as DBH, TPA, tree height, and basal area.
    https://www.uaex.uada.edu/publications/pdf/FSA5036.pdf

Photo by Abigail Han

Photo by Alex Makowicki

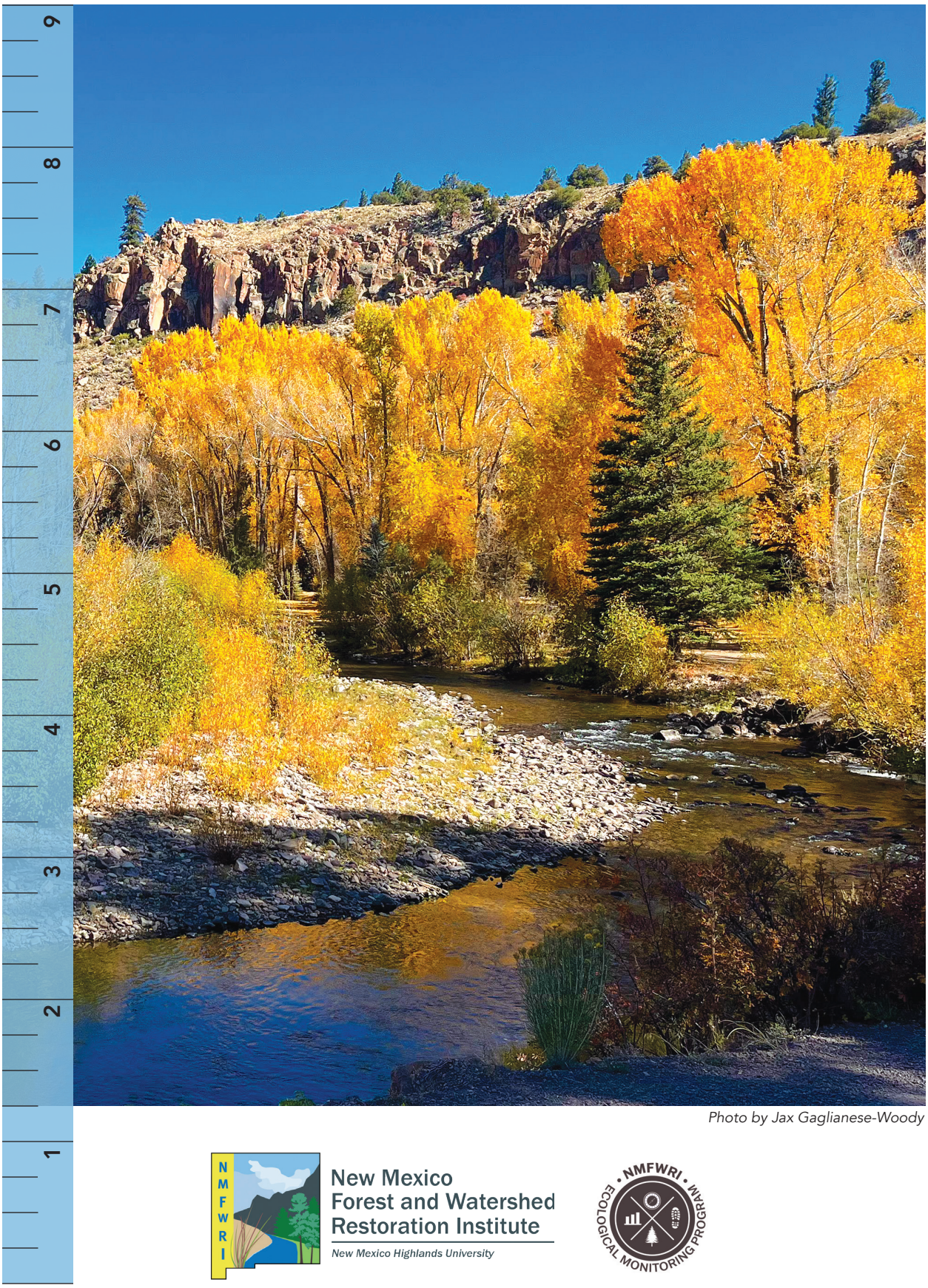


Photo by Jax Gaglianese-Woody

New Mexico
Forest and Watershed
Restoration Institute
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Riparian Monitoring in New Mexico: A Practitioner's Handbook