An Evaluation of State-and-Transition Model Development for Ecological Sites in Northern Utah

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AN EVALUATION OF STATE-AND-TRANSITION MODEL

DEVELOPMENT FOR ECOLOGICAL SITES

IN NORTHERN UTAH

by

Jamin K. Johanson

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Range Science

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Ecological sites and state-transition models (STMs) have become the preferred means of summarizing plant community dynamics on distinctive types of rangeland. Ecological sites classify rangeland types based on soil-geomorphic and climatic conditions capable of producing a known plant community, while a STM depicts the vegetation dynamics of an ecological site. STMs are usually based on expert opinion rather than site-specific data; however, if they are to gain credibility, STMs must accurately describe the processes that drive plant community dynamics. This study examined three ways of developing process-based STMs using three levels of commonly collected field data. We began by taking field inventories of three ecological sites already mapped in northwestern Utah: Loamy Bottom, Mountain Gravelly Loam, and Upland Loam. The Loamy Bottom site was ideal for developing a data-rich, process-based STM because 1) the site concepts were well-defined, 2) the site was easy to recognize, 3)
potential states and transitions had already been hypothesized, and 4) the site was easily accessible. The Loamy Bottom study was designed to link plant community structural indicators to measurable indicators of ecological process. Principal components analysis and cluster analysis were used to classify 14 study plots into four distinct states. Simple linear regression showed relationships between perennial grass cover, perennial canopy gaps, and soil organic carbon. Analysis of variance (ANOVA) linked four general vegetation classes to soil stability measurements. The resulting STM describes the structure and function of four alternative states. The other two STMs, developed for the Mountain Gravelly Loam and Upland Loam ecological sites, used less-intensive data collection methods. Rangeland health assessments, used for the Upland Loam STM, are useful for refining initial ecological site and STM concepts, documenting states, hypothesizing transitions, and locating study locations for future research. Quantitative production and cover estimates, used for the Mountain Gravelly Loam STM, are useful for describing the structure of states, but structural indicators must be coupled with process measurements, as with the Loamy Bottom STM to understand the drivers of state change. A coordinated data collection effort is needed to produce STMs that accurately depict the plant community dynamics of ecological sites.
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Jamin K. Johanson
CONTENTS

ABSTRACT ........................................................................................................................ ii

ACKNOWLEDGMENTS ................................................................................................. iv

LIST OF TABLES ............................................................................................................ vii

LIST OF FIGURES ......................................................................................................... viii

CHAPTER

1. INTRODUCTION ................................................................................................. 1

   Background ...................................................................................... 1
   Literature Review ........................................................................... 10
   Research Approach and Questions ............................................. 18

2. A COMPREHENSIVE, PROCESS-BASED APPROACH TO STATE-AND-TRANSITION MODEL DEVELOPMENT ............... 21

   Introduction .................................................................................... 21
   Methods .......................................................................................... 23
   Results ............................................................................................ 30
   Discussion ...................................................................................... 57
   Conclusions ................................................................................... 60

3. TWO APPROACHES TO STATE-AND-TRANSITION MODEL DEVELOPMENT USING DIFFERENT LEVELS OF DATA COLLECTION .............................................................. 61

   Introduction .................................................................................... 61
   Methods .......................................................................................... 65
   Results ............................................................................................ 69
   Discussion ...................................................................................... 101
   Conclusions .................................................................................. 104

4. SYNTHESIS ............................................................................................... 106

REFERENCES ........................................................................................................... 110
<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>32</td>
</tr>
</tbody>
</table>

Pearson product-moment correlations between 22 averaged plot variables and the first three principal components (PCs) of the varimax factor rotated principal components analysis
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Distribution map of three soil components correlated to an ecological site within the northeastern Great Basin</td>
</tr>
<tr>
<td>2</td>
<td>A generalized state-and-transition model of community phases moving along community pathways within states</td>
</tr>
<tr>
<td>3</td>
<td>Map of the Loamy Bottom ecological site throughout northwestern Utah</td>
</tr>
<tr>
<td>4</td>
<td>Principal components analysis (PCA) and factor loadings associated with 22 variables representing 14 plots within the Loamy Bottom ecological site</td>
</tr>
<tr>
<td>5</td>
<td>Classifications of 14 plots into four groups based on average values for 22 measured variables</td>
</tr>
<tr>
<td>6</td>
<td>Bar chart of each of the 14 plots, labeled according to the groups obtained from hierarchical cluster analysis (Figure 5)</td>
</tr>
<tr>
<td>7</td>
<td>Simple linear regressions of perennial grass (PG) on soil organic carbon (OC) and of total perennial canopy gaps (GAP_tot) on OC</td>
</tr>
<tr>
<td>8</td>
<td>Simple linear regression of perennial grass on soil compressive strength</td>
</tr>
<tr>
<td>9</td>
<td>Differences in soil resistance measurements among cover types from analysis of variance (ANOVA) of the 560 microplots within the Loamy Bottom ecological site</td>
</tr>
<tr>
<td>10</td>
<td>State-and-transition model of the Loamy Bottom ecological site</td>
</tr>
<tr>
<td>11</td>
<td>Plant community phase 2.1</td>
</tr>
<tr>
<td>12</td>
<td>Plant community phase 2.2</td>
</tr>
<tr>
<td>13</td>
<td>Plant community phase 2.3</td>
</tr>
<tr>
<td>Figure</td>
<td>Plant community phase 3.1</td>
</tr>
<tr>
<td>--------</td>
<td>----------------------------</td>
</tr>
<tr>
<td>14</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Plant community phase 3.2</td>
</tr>
<tr>
<td>16</td>
<td>Plant community phase 4.1</td>
</tr>
<tr>
<td>17</td>
<td>Plant community phase 4.2</td>
</tr>
<tr>
<td>18</td>
<td>Plant community phase 5.1</td>
</tr>
<tr>
<td>19</td>
<td>Plant community phase 5.2</td>
</tr>
<tr>
<td>20</td>
<td>Plant community phase 5.3</td>
</tr>
<tr>
<td>21</td>
<td>Plant community phase 5.4</td>
</tr>
<tr>
<td>22</td>
<td>First draft state-and-transition model for the Upland Loam (mountain big sagebrush) ecological site</td>
</tr>
<tr>
<td>23</td>
<td>Upland Loam community phase 2.1</td>
</tr>
<tr>
<td>24</td>
<td>Upland Loam community phase 2.2</td>
</tr>
<tr>
<td>25</td>
<td>Upland Loam community phase 2.3</td>
</tr>
<tr>
<td>26</td>
<td>Upland Loam community phase 3.1</td>
</tr>
<tr>
<td>27</td>
<td>Upland Loam community phase 4.1</td>
</tr>
<tr>
<td>28</td>
<td>Upland Loam community phase 5.1</td>
</tr>
<tr>
<td>29</td>
<td>Upland Loam community phase 5.2</td>
</tr>
<tr>
<td>30</td>
<td>Upland Loam community phase 6.1</td>
</tr>
<tr>
<td>31</td>
<td>Upland Loam community phase 6.2</td>
</tr>
<tr>
<td>32</td>
<td>Bar graph showing total non-native invasive foliar cover for each of the eighteen mountain gravelly loam plots</td>
</tr>
<tr>
<td>33</td>
<td>Draft state-and-transition model for the Mountain Gravelly Loam (Gambel oak) ecological site</td>
</tr>
<tr>
<td>Figure</td>
<td>Mountain Gravelly Loam community phase 2.1</td>
</tr>
<tr>
<td>--------</td>
<td>------------------------------------------</td>
</tr>
<tr>
<td>34</td>
<td>.............................................</td>
</tr>
<tr>
<td>35</td>
<td>Mountain Gravelly Loam community phase 2.2</td>
</tr>
<tr>
<td>36</td>
<td>Mountain Gravelly Loam community phase 2.3</td>
</tr>
<tr>
<td>37</td>
<td>Mountain Gravelly Loam community phase 2.4</td>
</tr>
<tr>
<td>38</td>
<td>Mountain Gravelly Loam community phase 2.5</td>
</tr>
<tr>
<td>39</td>
<td>Mountain Gravelly Loam community phase 3.1</td>
</tr>
<tr>
<td>40</td>
<td>Mountain Gravelly Loam community phase 3.2</td>
</tr>
<tr>
<td>41</td>
<td>Mountain Gravelly Loam community phase 3.5</td>
</tr>
</tbody>
</table>
State-and-transition models (STMs) have become widely accepted communication tools that portray the plant community dynamics of rangeland ecosystems (Grice and McCleod 1994). Westoby et al. (1989) put forth the idea as an alternative to the quantitative climax model (Dyksterhuis 1949), or equilibrium model of plant succession, that would more accurately depict vegetation change in arid and semi-arid regions and provide the flexibility necessary for opportunistic management. Many others have since refined STM concepts and terminology (Laycock 1991; Friedel 1991; Bellamy and Brown 1994; Stringham et al. 2001; Bestelmeyer et al. 2003; Stringham et al. 2003; Briske et al. 2005; Briske et al. 2006), thus providing a robust theoretical foundation from which STM development efforts can proceed. Useful STMs must accurately portray the structure and function of rangeland ecosystems in a way that informs management of the underlying processes that work to maintain or degrade each state in the system (Bellamy and Brown 1994; Briske et al. 2008). The research contained herein represents our endeavor to develop process-based STMs for selected ecological sites found at the Camp Williams military training facility and throughout northern Utah using the current STM literature as a guide.

Background

Ecological Sites

Ecological sites are the basic land unit of the Natural Resources Conservation Service (NRCS) land classification system. An ecological site is defined as a distinctive
type of land that differs from other land in its ability to produce a particular kind and amount of vegetation and in its ability to respond similarly to management actions and natural disturbance (USDA-NRCS 2003). Unlike many other plant community classification systems, ecological sites are distinguished primarily by the soil-geomorphic and climatic conditions that provide the resources necessary to sustain a given plant community. Thus, ecological sites are not distinguished by the plant community alone, which can vary through time, but by the potential of the site to produce a particular kind and amount of vegetation that responds consistently to disturbance (Bestelmeyer et al. 2009). Consequently, the ecological site classification system provides an ideal framework for STM applications.

Ecological sites often iterate somewhat predictably across landscapes or regions according to patterns in soils, geology, landscape position, and climate (Monger and Bestelmeyer 2006). Once an ecological site is identified and the overall site concept is defined, the spatial variability of soil properties, climate, hydrology, landscape position, plant community composition, production, and other pertinent information is summarized in an ecological site description (ESD). The NRCS is currently in the process of developing ecological site-specific STMs to summarize the plant community dynamics of rangeland ecological sites using the best available information.

Ecological sites are identified on the ground and correlated to soil components by range specialists and soil scientists as part of the National Cooperative Soil Survey effort. An ecological site may be correlated to multiple soil components (Fig. 1), as long as
Figure 1. Distribution map of three soil components correlated to an ecological site within the northeastern Great Basin. The spatial variability in soils and climate is captured in the ecological site description.

each soil component is capable of supporting comparable kinds and amounts of vegetation that exhibit comparable successional dynamics. Ecological sites are mapped according to the distribution of their associated soil components.

State and Transition Models for Ecological Sites

STM s typically include a flow diagram consisting of boxes and arrows (Fig. 2), and a narrative consisting of photographs and descriptions of each box and arrow in the diagram. When developing STMs for ecological sites, a reference state is typically the first state to be described. The reference state represents the presumed plant community and community dynamics of the ecological site at the time of European settlement. The
reference state and all subsequent states may include multiple community phases that can transition from one to another along reversible successional lines known as community pathways. Community phases represent distinct structural expressions within a single state, and have been compared to the succession-retrogression patterns of traditional Clementsian succession on rangelands (Bestelmeyer et al. 2003; Vetter 2005).

As a stable state is exposed to environmental stressors that alter ecological processes, it may begin to lose resilience and approach a threshold of state change. Often as a state approaches a threshold, a characteristic at-risk community phase serves as a warning that ecological processes are changing (Briske et al. 2008). In other instances,
indications of altered processes may be subtle or occur over extended periods of time. In any case, if the ecological processes are altered such that a threshold is crossed, the plant community will transition from the original state to a new state with a suite of altered ecological processes that work to reinforce the function of the new state. As a result of the altered processes, the structure of the new state will differ from that of the previous state in species composition, ground cover characteristics, and/or production. State change will continue to occur on the site whenever ecological processes are altered, such that a suite of functionally distinct states can be capable of occupying any given ecological site. It should be noted that movement of community phases along community pathways within a state does not constitute the crossing of a threshold, nor does it suggest major changes in the function of ecological processes.

A process-based STM represents a summary of all known states, transitions, community phases and community pathways for a site, along with detailed descriptions of the processes driving each of these model components. By focusing STM narratives on processes, STMs can be used to diagnose the causes of state change instead of the symptoms, thus informing land managers how to focus resources in a way that will provide the greatest long-term effects.

The STM framework recognizes that most transitions between states are not typically reversible without significant, and usually very costly, management inputs (Friedel 1991). In some cases, information pertaining to a restoration pathway may provide a means of returning to a previous state; however, most restoration pathways are, by definition, very costly to implement. As a result, emphasis is placed on identifying
indicators of potential state change before a state transitions across a threshold. Increases in invasive species, amount or distribution of bare ground, and loss of structural/functional groups are common examples of indicators that can help identify communities at-risk of crossing a threshold. Restoration pathways, thresholds and at-risk communities are also included in STMs and described in detail when information is available (Fig. 2).

**Ecological Processes, Resilience and Feedbacks**

The ecological processes of a stable state are dominated by negative feedbacks that reinforce the resilience of that state. However, when an ecological site begins to approach a threshold, the energy flow, nutrient cycling, and/or water cycling processes of the original state become increasingly dominated by positive feedbacks that degrade the resilience of the state. That is, the altered ecological processes of the site begin to feedback in a way that promotes further alterations to the functioning of the system. If not remediated, these positive feedbacks will ultimately drive the site across a threshold and into an alternate state. This type of feedback switch (Fig. 2) may be triggered by a natural or management-induced event (such as fire or brush management), but is often coupled with other disturbances (such as poor grazing management and weed establishment) that lower the resilience of the state prior to the event that acts as the trigger (Briske et al. 2008).

For example, the processes of an at-risk sagebrush/perennial grass community with abundant fine fuel build-up and a seedbank dominated by annual grass seed may be triggered by a stand-replacing fire. The fire initiates a feedback switch from processes
that once reinforced sagebrush dominance to processes that now reinforce annual grass
dominance by making more light and nutrient resources available to germinating plants.
Still, this disturbance (fire) would not have triggered a transition to a new state if the
resilience of the sagebrush state had not been previously degraded by allowing annual
grass seed to replace perennial grass seed in the seedbank. Perhaps improper grazing
and/or drought, coupled with annual grass dispersal into the area, reduced the vigor and
abundance of perennial grasses, thereby reducing their energy capture, nutrient uptake,
and subsequent seed production. The available space, nutrients and water unused by the
perennial grasses may be increasingly usurped by annual grasses if the stress on perennial
grasses persists. Consequently, the at-risk community will steadily approach a threshold
until a fire event triggers the feedback switch. Finally, when the feedback switch is
initiated, the annual grasses establish with vigor and reinforce their own dominance by
changing the distribution and availability of light, nutrients and water (Norton et al. 2004;
Stavi et al. 2009). The specific processes, feedbacks and triggers, as well as the
timeframe affecting state transitions differ among ecological sites (Bestelmeyer et al.
2003; Stringham et al. 2003).

One of the most beneficial applications of the STM framework is prioritizing
management objectives based on the potential of ecological sites and the current states
occupying each site. In many cases at-risk communities are likely to receive priority over
communities that have already crossed a threshold since range improvements in at-risk
communities are generally less expensive and more likely to produce the desired
condition (Briske et al. 2008). Our ability to identify consistent indicators of at-risk
communities and functionally distinct states is dependent on 1) an accurate understanding of feedback mechanisms (how they provide evidence of altered ecological processes, since processes are often difficult to measure directly), and 2) our ability to link the evidence of altered processes to changes in plant community structure and/or dynamic soil/site properties that are easily observed and can serve as consistent indicators. Over short time periods, feedbacks between soils and vegetation can affect dynamic soil properties, like soil organic carbon (C), nitrogen availability, soil aggregate stability, soil structure and soil compaction, as well as bare ground and infiltration rates (Pyke et al. 2002; Peters and Havstad 2006; Petersen et al. 2009). For example, organic C inputs to soil from plant litter and root exudates, along with erosion resistance by plant roots, greatly contribute to soil development, which then feeds back to promote greater plant productivity via increased soil fertility, infiltration and water-holding capacity (Monger and Bestlemeyer 2006). Sustained alterations in the plant community structure will affect soil inputs, which feeds back to affect the plant-available resources and subsequent soil inputs. This is one example of how a feedback mechanism can provide measurable indicators of process change. If structural features such as indicator species or plant functional groups are correlated to measurable process indicators like soil organic C, then that information should be included in the ecological site’s STM. However, to ensure that STMs are practical for the intended users, process changes should be linked, to the extent possible, to structural indicators that are easily and consistently observed on the ground.
Feedback mechanisms have also influenced the development of our current ecological sites. Regional climate patterns and inherent soil properties, derived primarily from soil parent material and landscape position (McAuliffe 1994), affect plant communities either directly through physiological constraints, or indirectly through the soil microbial community and associated nutrient availabilities (Monger and Bestlemeyer 2006). These soil-initiated feedbacks place controls on the plant species capable of occupying the site, which feeds back in the form of organic matter inputs, soil development and ultimately, the development of a distinctive ecological site. However, the development of ecological sites typically occurs on a much longer timescale than the management timescale associated with state change.

**Rangeland Health for State-and-Transition Model Development**

Measuring ecological processes directly can be very difficult, expensive, and time-consuming. The rangeland health assessment tool is one way of detecting the state of ecological processes when rigorous data collection is not desired. Rangeland health assessment provides a snapshot of the condition of three attributes related to the proper functioning of an ecological site: soil and site stability, hydrologic function, and biotic integrity. A rating of the overall function of these three attributes is obtained by rating 17 qualitative indicators (e.g. rills, compaction layer, invasive species) against what is expected for each indicator on that ecological site (Pyke et al. 2002; Pellant et al. 2005). The expected condition of the 17 indicators is recorded in a reference worksheet in the ESD and is based on field observations of the ecological site in the reference state.
One of the primary uses of rangeland health is to provide early warning signs of potential problem areas by noting departures from the expected soil and site stability, hydrologic function, and biotic integrity based on reference conditions. Many of these 17 indicators of rangeland health can be included in STMs as indicators of at-risk community phases or of states that have already crossed a threshold.

Literature Review

The discussion about STM applications to range management was established by Westoby et al. in 1989. Subsequent publications (Svejcar and Brown 1991; Friedel 1991; Laycock et al. 1991; George et al. 1992; Bellamy and Brown 1994; Brown 1994) provided examples of practical STMs and outlined some additional advantages of STMs as a replacement for the quantitative climax model (Dyksterhuis 1949), which was used at the time to assess range condition based on succession-retrogression concepts (Sampson 1919). The primary argument in favor of STMs was their ability to account for new states and irreversible transitions that were well-documented on range sites in arid and semi-arid regions. By 1994, STMs were put into use for assessing range condition in northern Australia (Ash et al. 1994), although the concepts and terminology of STMs had not yet been formalized.

By the late 1990’s, the NRCS adopted the use of STMs to assess range condition for ecological sites in the United States, but acknowledged that the concepts and terminology of STMs still needed refinement (USDA-NRCS 1997). Since that time, a great deal of effort has been put forth to refine concepts and unify terminology of STM
theory (Stringham et al. 2001; Bestelmeyer et al. 2003; Stringham et al. 2003; Briske et al. 2005; Briske et al. 2006; Briske et al. 2008). A summary of the current STM ecological theory can be found in the background section of the introduction to this document.

In the decade since STMs were adopted by the NRCS, preliminary versions of STMs have been drafted for hundreds of ecological sites in the United States by NRCS personnel, researchers and other range management organizations. The overwhelming majority of these endeavors have relied on expert knowledge to apply range principles associated with general plant community types to STMs for specific ecological sites. However, since sites with similar plant community composition may have very distinct soil-geomorphic and climatic properties, the resulting STMs often include states and community phases that have not been documented to occur on the ecological sites that they are meant to describe (Davenport et al. 1998). Expert-based models generally lack ecological site-specific documentation of states and community phases as well as descriptions of processes due to a general lack of ecological site-specific information.

Davenport et al. (1998) modeled soil erosion for multiple ecological sites that are susceptible to invasion by Utah juniper (*Juniperus osteosperma*). Their results suggest that only ecological sites with specific inherent soil properties are in danger of significant soil loss associated with juniper encroachment. In order for a STM to include an eroded juniper state, it should be documented that such a state exists within the specific ecological site. Williams and Monaco (unpublished data) found that the degree of re-establishment of native species into subsequently undisturbed crested wheatgrass
(Agropyron cristatum) seedings was primarily related to the inherent soil properties of the site. Even though all of the seedings they studied were located in sagebrush ecosystems of the Great Basin, differences in soil texture and other abiotic factors affected the successional dynamics of the seedings. Examples such as these suggest that, although data from one ecological site may be useful for generating hypotheses about plant community dynamics on similar sites, the actual successional dynamics of each site ought to be validated by site-specific data.

In theory, the ecological site framework is ideal for STM applications because it groups functionally similar land units at a spatial scale relevant to management decisions. In practice however, ecological sites are very difficult to delineate based on objective indicators of ecological function (Creque et al. 1999; Herrick et al. 2006). Herrick et al. (2006) outlined the limitations of using ecological sites to classify functionally similar land units. One limitation is that most current ecological site delineations are based on the old range sites which were used by the NRCS primarily for livestock and wildlife considerations prior to being replaced by ecological sites (USDA-NRCS 1997). Range sites were not intended to group soil components that were expected to have the same ecological function and response to stressors, as are current ecological sites. As a result, many ecological site concepts do not yet emphasize the functional properties that drive the plant community dynamics of the site. Another limitation of the ecological site framework that is often overlooked is important within-site variability in ecological structure and function (Bestelmeyer et al. 2004; Monger and Bestelmeyer 2006). However, thoughtful STM narratives can help capture that information. Herrick et al.
suggest that perhaps the most challenging limitation to the ecological site framework is the infinite combination of soil-geomorphic, environmental and climatic properties. Ecological site classifications must therefore draw boundaries between groups based on factors that are assumed to be functionally important.

Because of the limitations of current ecological site delineations, efforts to produce data-driven STMs for ecological sites often reveal inconsistencies in ecological site concepts. That is to say that what appear to be two different states may actually be two different ecological sites (and vice-versa) due to poor ecological site delineation (Bestelmeyer et al. 2003, 2009). Consequently, long-term refinement of ecological site concepts and mapping will likely coincide with efforts to produce data-driven STMs (Bestelmeyer et al. 2009). Improved communication between NRCS soil survey personnel, agency field staff, researchers and landowners will be necessary in the effort to improve ecological site concepts and create reliable STMs (Bestelmeyer et al. 2003; Thacker et al. 2008). The systems and resources are not yet available for a cooperative ecological site and STM refinement effort to succeed, though recommendations for such an effort have been proposed (Herrick et al. 2006; Bestelmeyer et al. 2009). With very few exceptions, attempts to develop STMs in the literature do not address problems with ecological site concepts.

In order for STMs to be practical for use at the ecological site level, they must accurately describe the structure and function of one specific ecological site (Bestelmeyer 2003). Though expert knowledge is a necessary beginning in the process of developing STMs, multiple iterations of STM drafts based on increasingly reliable, site-specific data,
are needed to refine concepts and ultimately produce STMs that serve as reliable
management tools (Bellamy and Brown 1994; Bestelmeyer et al 2009). But even under
the best circumstances STMs will always be a work in progress. Even if reliable, site-
specific STMs are eventually developed, knowledge of local ecological site conditions
and changing environmental conditions (e.g. climate change) will always be necessary to
properly interpret and apply STM concepts for management decisions (Westoby et al.

There are few examples of site-specific, data-driven STMs in the literature.
Research efforts either separate states according to differences in plant community
structure (Allen-Diaz and Bartolome 1998), or they focus on a reduced number of states
and their associated processes at the watershed or hillside scale. Quetier et al. (2007)
identified plant traits as indicators of altered land use and nutrient cycling in subalpine
grasslands on a hillside in France. Thacker et al. (2008) compared the management and
disturbance history of four pastures in northern Utah to explain the dynamics of
snakeweed in an Upland Gravelly Loam (Wyoming big sagebrush) ecological site. They
observed that snakeweed could maintain dominance on the ecological site for five years
(or more) following a fire event, if the perennial deep-rooted bunchgrasses had been
absent from the community for several years prior to the burn. This study took advantage
of an opportunity to apply notable differences in adjacent pastures for the development of
a STM based on data from a specific ecological site. In doing so it not only added a
snakeweed phase to the site’s STM, but also provided five years of data for each of the
four pastures (community phases) studied.
Plant and Vayssieres (2000) combined expert knowledge, in the form of “if-then” statements, with a Geographic Information System (GIS) to simulate transitions under different management scenarios. Their suggested approach is applicable at the landscape scale given sufficient knowledge about the factors that are important to plant succession for a particular plant community. They modeled the increase of oak cover on a Sierra Nevada foothill oak woodland ecological site over a 41 year interval using an expert system merged with GIS technology.

Phelps and Bosch (2002) provide a good example of quantifying indicators of transitions for semi-arid grasslands in Australia. By collecting five years of monitoring data across gradients of degradation and grazing intensity, they were able to identify structural indicators of multiple transitions at the watershed scale. Petersen et al. (2009) presented the first attempt at STM development that directly measured the relationship between an ecological process (infiltration) and plant community structure (bare ground, juniper cover and sagebrush cover). They quantitatively estimated two thresholds associated with juniper encroachment based on differences in infiltration that could be correlated to structural differences in the plant community. This approach is conducive to understanding the relationship between plant community structure and function and is necessary to further our knowledge about indicators of ecological processes. But, when applied to STMs at the ecological site/landscape scale, this approach tends not to describe all states, nor can it describe the range of variability in structure and process that exists for an ecological site throughout the entire region where it occurs.
The literature suggests that STM development should be an iterative process (Bellamy and Brown 1994; Bestelmeyer et al. 2009) that adds information to STMs as it becomes available. Bestelmeyer et al. (2009) outlined eight steps that represent multiple stages in the STM development process at the ecological site level. The first step is the creation of initial ecological site and STM concepts. It should be acknowledged that the ecological site concepts tend to evolve as STM development efforts reveal important soil-geomorphic and climatic differences within ecological sites. Steps two through six outline site inventory needs, including: low-intensity inventory, site stratification, medium-intensity inventory, database development and data analysis. Step seven is the refinement and addition of concepts to the STM based on the results of the study. The final step deals with long-term monitoring and high-intensity characterization with rigorous scientific studies. Bestelmeyer et al. (2009) also provide an example of how these eight steps have been used to refine ecological site and STM concepts in the Chihuahuan desert. Their example, however, was only applied at the watershed scale and did not provide information about using the data to produce a site-specific STM.

Rangeland health has not been used in the literature to indicate functional differences between states for STM development. However, Briske et al. (2005) suggest that it may be the most cost-effective way to identify functional differences at broad spatial scales. Miller (2009) used the rangeland health protocol to investigate patterns in the processes of multiple ecological sites at 500 locations in the Grand Staircase-Escalante National Monument in Utah. His objective, however, was not to develop STMs, but to link rangeland health attribute ratings to differences in the historical use and
environmental constraints of different ecological sites. Since rangeland health provides a snapshot of the deviation of process indicators from reference conditions (Pellant et al. 2005), it could be useful in identifying indicators of at-risk community phases or functionally distinct states.

In summary, the current STM literature provides the information necessary to develop comprehensive, process-based STMs for ecological sites, but examples of such an endeavor are lacking. We expected infiltration to be a measurable ecological process that could be related to indicators of process change (Petersen et al. 2009). Soil nitrogen and organic carbon percent were also expected to provide quantitative indicators of soil-plant feedbacks associated with ecological processes, in lieu of direct process measurement (Norton et al. 2004; Monger and Bestelmeyer 2006). We recognized that some interpretations about process change would have to be inferred from structural and qualitative indicators derived from cover data, rangeland health, and current knowledge about ecological processes (Bestelmeyer 2003; Stringham et al 2003; Pellant et al. 2005; Briske et al. 2008). The type of models produced were expected to be descriptive in nature, rather than explanatory or predictive (Nyergis 1991). Even process relationships, if we encountered any, could not be interpreted as causal relationships, but rather as associations among classifications of states and community phases (Bellamy and Brown 1994). We expected that transition information could not be obtained in the short duration of this study (Friedel 1991; Phelps and Bosch 2002), and that transitions would have to be inferred from site history and indicators of altered processes. To our knowledge, this is
the first attempt to develop a process-based STM from an inventory of all accessible soil components of an ecological site.

Research Approach and Questions

ESDs and their associated STMs have numerous practical applications in rangeland ecology and management. Users of these products are steadily increasing in number and diversity. In order to maintain and improve their credibility, ESDs and STMs must accurately summarize the dynamics of rangeland systems in a way that is practical for management applications. Currently, the majority of STMs are not developed from data that is specific to one ecological site due to a general lack of site-specific datasets. Instead, STM concepts are applied to specific ecological sites based on their assumed similarity to a general community type, such as general sagebrush-steppe concepts being applied to dozens of distinct ecological sites. While this effort provides a good starting point for STM development by documenting the current knowledge in a semi-useable form (George et al. 1992), it assumes much about site-specific processes and cannot become the norm if STMs are to gain credibility as useful management tools.

From our observations, even STMs that have been developed from ecological site-specific data either do not attempt to enumerate all known states for a site, or they lack information about the key functional processes (water cycling, nutrient cycling, and energy flow) that drive state resilience and transitions. Based on these observations, we asked the following questions:
1) Is it possible to develop a comprehensive, process-based STM with data for every state and community phase presently accessible on an ecological site?

2) What type of data and resources are required to develop comprehensive, process-based STMs for specific ecological sites?

Since the literature lacks examples of STMs developed from comprehensive inventory data of an ecological site, we decided to develop three STMs based on three different levels of comprehensive inventory data. The first STM was developed using highly rigorous methods for an ecological site that was known to have well-defined site concepts and good accessibility. After the initial, low-intensity inventory, study plots were established to collect data that could relate structural differences to functional differences between states. The second STM was developed for a site with moderately well-defined site concepts but poor accessibility and limited STM concepts. Plant community structure data and rangeland health attribute ratings were collected at study plots for the second ecological site. The data for these two STMs were collected using standard vegetation and soil analysis methods to identify structural, and, to the degree possible, functional differences between states. The third STM was developed using rangeland health alone, with step-point transects to improve the consistency of indicator ratings related to cover (Miller 2009).

Each of the three STMs was developed using a space-for-time substitution, providing a snapshot of the condition of existing states at the time of the study. As such, it was assumed that the spatial variability in soils, landscape position, and climate, as defined in the ESD, would not significantly affect the plant community dynamics of the
study sites, and that the structure and function of each state was the result of differences in historical disturbances rather than differences inherent to the soils or climate. Study sites that did not represent the ecological site concept as described in the ESD were excluded from the sample frame. To strengthen our assumption that the ESDs accurately describe the spatial variability of soil components correlated to a site, each ESD was updated prior to STM development using the most current methods and information available to us through the NRCS.

Our expectation is that comprehensive, process-based STMs will help the growing population of STM users successfully interpret and manage the processes that drive plant community dynamics, thus expanding the credibility and use of STMs as tools for sustainable range management.
CHAPTER 2

A COMPREHENSIVE, PROCESS-BASED APPROACH TO
STATE-AND-TRANSITION MODEL
DEVELOPMENT

Introduction

The Loamy Bottom Ecological Site

Camp Williams is a military training installation that covers approximately 11,000 ha of mountainous terrain between Salt Lake county and Utah county in northern Utah. Dominant native vegetation types include Gambel oak (*Quercus gambelii*) woodlands, big sagebrush-steppe (*Artemisia tridentata*), basin wildrye (*Leymus cinereus*) bottoms, and pinyon-juniper (*Pinus monophylla, Juniperus osteosperma*) woodlands. A total of 12 rangeland ecological sites were identified at Camp Williams in a soil survey update published in 2005. We endeavored to develop a comprehensive, process-based STM using rigorous quantitative methods for one of the ecological sites at Camp Williams. The Loamy Bottom (basin wildrye) site was selected for the following reasons: 1) the site concepts were well-defined and a draft STM had already been developed by the NRCS, 2) the site is located in flat, productive bottom lands that are subject to a variety of land uses, and 3) the site has a manageable extent, covering roughly 7,000 ha throughout the northeastern Great Basin region, or, Major Land Resource Area (MLRA) D28A of the NRCS land classification system (Appendix A).
Figure 3. Map of the loamy bottom ecological site throughout northwestern Utah. The northeastern Great Basin is outlined in yellow. Red polygons are the soil components correlated to the loamy bottom site. The 14 research sites are represented by green dots.

The Loamy Bottom ecological site occurs on linear alluvial landforms in northwestern Utah, extending from Grouse Creek south to Ibapah, east to Orem, and north to Logan (Fig. 3). It developed in a continental climate receiving 25-35 cm of mostly cool-season precipitation annually. The site occurs in the watershed in areas that receive extra water and fine sediment from surrounding uplands. Consequently, the soils are deep, loamy Mollisols with high water-holding capacity and a seasonally-heightened water table from March to June. Buried surface horizons and very little rock characterize the soils, which classify as coarse-loamy to fine-silty mesic Cumulic Haploxerolls. The
soil moisture regime is xeric and the soil temperature regime is typically mesic. The historic climax plant community is dominated by basin wildrye, basin big sagebrush (*Artemisia tridentata* spp. *tridentata*), western wheatgrass (*Pascopyrum smithii*) and rubber rabbitbrush (*Ericameria nauseosa*). For more detailed information on the Loamy Bottom ecological site, refer to ESD R028AY006UT (Appendix B).

**Objectives**

The objectives of the Loamy Bottom study were to: 1) identify the states and community phases of all accessible soil map unit polygons correlated to the loamy bottom ecological site, 2) link measurable processes and process indicators to structural indicators of state differences, and 3) develop a STM with process-based descriptions of every state and community phase documented, and of hypothesized transitions, community pathways, restoration pathways and thresholds.

**Methods**

**Sample Frame Enumeration and Site Selection**

The sample frame was enumerated using Geographic Information System (GIS) technology and local expertise. A digital map of the Loamy Bottom ecological site was generated from soil survey spatial and tabular data by selecting all soil components correlated to the Loamy Bottom ecological site. Additional unmapped occurrences of the site were obtained from NRCS range conservationists familiar with the area and were validated by field visitation prior to inclusion in the sample frame. Each soil component
was examined for elevation, slope, surficial geology, current vegetation and accessibility prior to field visits using GIS technology. Any soil components that were not consistent with the soil-geomorphic properties of the site as contained in the ESD were noted as potentially misclassified and were more rigorously evaluated during field site validation. Expected vegetation based on aerial photographs and Southwest ReGAP classifications were also noted.

Site validation and enumeration of the sample frame was achieved in May, 2009 by visiting all accessible soil components and briefly describing the soil and vegetation characteristics with photographs and field notes. Most of the soil components correlated to the Loamy Bottom ecological site were conveniently located near roads, making field validation an efficient four-day exercise. Soil components that were inaccessible or whose primary use was cropland, housing, or irrigated pasture, were excluded from the sample frame. Some soil components were dropped from the sample frame because they were not within the range of variability described in the ESD, either because they did not appear to receive significant amounts of run-in water, were not in the proper landscape position, or they had significant amounts of rock fragments in the soil. Soil components retained in the sample frame were grouped according to similarities in vegetation structure, with each group representing a potentially different state or community phase.

The vast majority of soil map units correlated to this site had been converted to housing or cropland developments. About 50 polygons were excluded from the sample frame due to housing, irrigated pasture or cropland development, 25 were either outside the range of variability for the Loamy Bottom site or were too small for our sampling
methods, and eight were on inaccessible private property or military training areas. Of the remaining polygons in the sample frame, 14 were chosen to represent the hypothesized states and community phases of the Loamy Bottom ecological site.

**Field and Laboratory Methods**

Data were collected from early-June to late-July in 2009 and 2010. Each plot consisted of two subplots that were randomly located within a Loamy Bottom map unit polygon from the soil survey. GPS coordinates were recorded at the center of each subplot, and four 25 m transects extended 5 m to 30 m from the center point toward the northeast, northwest, southeast and southwest. A digital photograph was taken from the center point in the direction of each transect prior to any data collection. Special care was taken to walk on only the south side of transects and to record all measurements from the north side of transects.

Plant community structure was measured using three methods (Herrick et al. 2005). The line-point intercept method was used to determine percent canopy cover by species, sub-canopy cover by species, composition by species, plant height, percent basal cover, percent ground cover, and percent bare ground. For each transect, the gap-intercept method recorded gaps in the canopy of perennial species from 25-50 cm, 50-100 cm, 100-200 cm, and greater than 200 cm in length. Annual production by species was approximated using the double sampling method at 10 pre-determined points within each subplot.

Soil surface resistance to erosion was measured using three methods at five microplots along each transect, totaling 20 microplots per subplot, and 40 per plot. Soil
surface aggregate stability was rated using a soil stability kit (Herrick et al. 2001; Pellant et al. 2005) and one soil clod was collected at each of the microplots. Soil surface compressive strength was measured in each microplot using a pocket penetrometer (Cole-Parmer 99039-00), and soil surface shear strength was measured using a shear vane (Torsional Vane Shear Tester STCL-4). These two measurements were taken to examine any relationships between aggregate stability and physical soil resistance to compression and shear forces. The dominant cover type in each microplot was recorded as shrub, forb, grass, or bare ground.

Hydraulic conductivity was also measured at each microplot using a Decagon mini-disk infiltrometer according to Decagon’s instruction manual (Li et al. 2005). Hydraulic conductivity is a measure of how quickly water infiltrates when applied to a given soil type. Infiltrometer locations were prepared within each microplot by carefully removing litter so that the bottom of the infiltrometer made complete contact with a relatively undisturbed soil surface. Hydraulic conductivity readings were taken every 30 seconds for 2 minutes at the minimum negative pressure level of -1 cm (Li et al. 2005).

Rangeland health was assessed by meandering through both sub-plots within the soil map unit polygon (Pellant et al. 2005). The rangeland health reference worksheet contained in the Loamy Bottom ESD (Appendix B) provided the benchmark for reference conditions for each indicator.

Soil samples were collected 2-3 m from the 15 m mark of each transect at depths of 0-15 cm and 15-30 cm using a soil auger. The volume of each soil sample was measured by lining the empty hole with thin plastic and pouring fine silica sand from a
graduated cylinder until the sand was level with the soil surface. Soil samples from both depths were air-dried and passed through a 2 mm wire mesh sieve. The weight for rock fragments that did not pass through the sieve was recorded separately from the weight of the fine fraction. A subsample of the fine fraction was also weighed and set aside to obtain an oven-dry weight correction factor. Subsamples were oven-dried overnight at 105 °C, and oven-dry weights were recorded immediately upon removal from the oven. The ratio of weights before and after oven-drying was used to adjust the weight of the air-dried whole sample, as if the entire sample had been oven-dried. Rock volume was derived by diving rock weight by 2.65 (the density of silica). The volume of the fine fraction was then calculated by subtracting rock volume from total volume of the sample.

Bulk density values were obtained at both depths by dividing the total oven-dry weight by the volume of the fine fraction. All other soil methods were performed on well-mixed subsamples of the air-dried soil. The hydrometer method (Gee and Bauder 1986) was used to determine the texture of the fine fraction at both depths. Soil pH was obtained with a pH electrode and 1:2 soil to water slurry (Hendershot et al. 1993). Total N and C were assessed for the 0-15 cm samples according to the LECO CHN-2000 autoanalyzer instruction manual (LECO Corp., St. Joseph, MI). Total inorganic C was obtained using a modified pressure calcimeter method (Sherrod et al. 2002) for samples with any level of effervescence to hydrochloric acid. Soil organic C (OC) was derived from the difference between the total C and inorganic C.

In the fall of 2009 and 2010, soil pits were hand-dug to a depth of 1 m, about 5 m due north of the center of each subplot. The soil pedon was described according to
Schoeneberger et al. (1998). Horizonation, structure, roots, pores, ped and void surface features, and redoxomorphic features were described in the field. Approximately 500 ml of soil from each horizon was collected and returned to the lab for pH, texture, and color analysis.

**Data Analysis**

The vegetation data for each plot was best summarized as composition by foliar cover, which was calculated for common species and species groups by dividing the percent cover of the species or group by the total canopy cover of the plot. In order to capture information about the understory vegetation, top canopy and subcanopy presence were totaled for each species group. However, only one representative per group was counted at each point along the transects, thus avoiding composition values in excess of 100% by any group. A total of 14 vegetation variables, 10 soil variables, and five canopy gap variables were examined to describe the variability among the plots. Subsurface texture, subsurface pH and surface bulk density were not included in the analysis since each of these variables was highly correlated with its counterpart from the other sampling depth.

Principal components analysis (PCA) with a varimax factor rotation was used to reduce the dimensionality and improve the interpretability of the dataset (McCune and Grace 2002). All 29 variables were standardized to have a mean of zero and a standard deviation of one. The first two principal components extracted from the full dataset were utilized in the factor analysis. A total of 22 variables were retained in the dataset, each meeting the criteria of one factor loading greater than 0.5 and the other factor loading less
than 0.5. The subsequent PCA included the following 22 variables: percent sand, silt, clay, N, and OC from 0-15 cm soil depth; soil pH from 0-15 cm soil depth; soil surface aggregate stability, compressive strength, and shear strength; percent of gaps in perennial canopy between 25-50 cm, 50-100 cm, 100-200 cm, greater than 200 cm, and total percent of gaps in perennial canopy; and percent composition of basin wildrye, cheatgrass (*Bromus tectorum*), perennial grass, native grass (other than basin wildrye), non-native grass, perennial non-native grass, non-native invasive species, and shrubs. The 14 study plots were graphed in two dimensional space with the first two principal components as axes. Factor loadings were also graphed to show the Pierson product-moment correlation between the 22 variables and the two PCA axes. Significant pairwise correlations between the principal components and each of the 22 variables were identified using Pierson product-moment correlation coefficients at a significance level of $\alpha=0.05$. Hierarchical cluster analysis of the 22 variables helped separate the plots into ecologically meaningful groups using Ward’s classification method (McCune and Grace 2002). States were assigned according to the cluster analysis groups, and specific indicators of states were derived from the PCA and factor analysis. Structural differences within states were derived from a bar chart of species composition by foliar cover to identify potential community phases, and transitions and community pathways were obtained from the best available knowledge of each plot’s disturbance history. Soil OC and soil stability variables were linked to structural indicators using simple linear regression. All multivariate analyses were performed with JMP 9 software (JMP, Version 9. SAS Institute Inc., Cary, NC, 1989-2011).
Due to the large amount of variability in canopy cover and ground cover within each plot, the microplot data were also analyzed at the ecological site level to determine broader patterns in soil stability and hydraulic conductivity within the four general cover types (grass, forb, shrub, and bare ground). Microplot variables (soil surface aggregate stability, compressive strength, shear strength and hydraulic conductivity) from all 560 microplots were analyzed for significant differences among cover types at \( \alpha = 0.01 \) using analysis of variance (ANOVA). Prior to analysis, soil compressive strength was transformed using a square root transformation and soil compressive strength was transformed using an \( x^{0.6} \) transformation to meet the assumptions of normality within groups and achieve equal variance among groups. Soil aggregate stability did not require transformation to meet these assumptions. Differences in microplot variables among the four cover types can be indirectly linked to the grass, forb, shrub, and ground cover differences in the states and phases of the Loamy Bottom ecological site. The microplot data were analyzed using the R statistical computing environment (R Development Core Team 2004).

Results

To address our first objective, the plots were classified into groups representing potentially distinct states. The two PCA axes in Figure 4 explain 56.1% of the variability for 22 variables describing the 14 plots within the Loamy Bottom ecological site. The first principal component (PC) represents a gradient (x-axis) from high cover of non-native invasive species with large perennial canopy gaps to high cover of perennial grass,
particularly basin wildrye cover, with high soil stability and high soil N and OC. PC 2 represents a gradient (y-axis) from high cover of perennial non-native grass with high soil N, to low perennial non-native grass cover with medium-sized perennial canopy gaps, higher soil pH, and somewhat higher shrub cover. Plots with high amounts of invasive species cover and large perennial canopy gaps received lower scores for PC 1, while plots with high amounts of perennial grass cover, high soil stability and high soil N and OC received higher scores on PC 1. Of the plots with high scores on PC 1, those with higher

Figure 4. Principal components analysis (PCA) and factor loadings associated with 22 variables representing 14 plots within the Loamy Bottom ecological site. Panel (a) shows the relationship of each plot to principal components one and two, with the symbols corresponding to the cluster groupings obtained from hierarchical cluster analysis (Figure 5; circle = state 2, diamond = state 3, x = state 4 and triangle = state 5). Panel (b) shows the factor loadings (Pearson correlation coefficients, r) as vectors of all 22 variables. BRTE=cheatgrass cover, NNI=non-native invasive species cover, ONG=native grass cover (other than basin wildrye), LECI=basin wildrye cover, SS=soil shear strength, CS=soil compressive strength, AS=soil aggregate stability, PG=perennial grass cover, OC=soil organic carbon, N=soil nitrogen, PNNG=perennial non-native grass cover, and NNG=native grass cover.
perennial grass cover, soil stability and soil N and OC tended to score lower on PC 2, while those with medium sized canopy gaps, higher soil pH, and higher shrub cover tended to score higher on PC 2.

Pearson correlation coefficients between the variables and the first three PCs are shown in Table 1. PC 1 is significantly correlated to 13 of the 22 variables at α=0.05, and PC 2 is correlated to eight variables. PC 3, though not shown graphically for simplicity of interpretation, is included in the Table 1 because it is very highly correlated with shrub

**Table 1.** Pearson product-moment correlations between 22 averaged plot variables and the first three principal components (PCs) of the varimax factor rotated principal components analysis. Bold type indicates statistically significant relationships. *P < 0.05; **P < 0.01; ***P < 0.001.

<table>
<thead>
<tr>
<th>Variable</th>
<th>PC 1</th>
<th>PC2</th>
<th>PC3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand %</td>
<td>-0.52</td>
<td>-0.54*</td>
<td>-0.52</td>
</tr>
<tr>
<td>Silt %</td>
<td>0.56*</td>
<td>0.51</td>
<td>0.47</td>
</tr>
<tr>
<td>Clay %</td>
<td>0.30</td>
<td>0.54*</td>
<td>0.59*</td>
</tr>
<tr>
<td>Soil pH</td>
<td>0.28</td>
<td>0.61*</td>
<td>-0.17</td>
</tr>
<tr>
<td>Soil Nitrogen %</td>
<td>0.69**</td>
<td>-0.53*</td>
<td>-0.19</td>
</tr>
<tr>
<td>Soil organic Carbon %</td>
<td>0.70**</td>
<td>-0.49</td>
<td>-0.32</td>
</tr>
<tr>
<td>Soil aggregate stability</td>
<td>0.54*</td>
<td>-0.29</td>
<td>0.20</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>0.68**</td>
<td>-0.34</td>
<td>0.60*</td>
</tr>
<tr>
<td>Shear strength</td>
<td>0.62*</td>
<td>-0.19</td>
<td>0.54*</td>
</tr>
<tr>
<td>Canopy gaps 25-50 cm</td>
<td>0.53</td>
<td>0.58*</td>
<td>-0.07</td>
</tr>
<tr>
<td>Canopy gaps 50-100 cm</td>
<td>-0.03</td>
<td>0.65*</td>
<td>-0.02</td>
</tr>
<tr>
<td>Canopy gaps 100-200 cm</td>
<td>-0.55*</td>
<td>0.26</td>
<td>0.17</td>
</tr>
<tr>
<td>Canopy gaps &gt; 200 cm</td>
<td>-0.82***</td>
<td>-0.04</td>
<td>0.47</td>
</tr>
<tr>
<td>Total canopy gaps</td>
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<td>0.19</td>
<td>0.40</td>
</tr>
<tr>
<td>Basin wildrye cover %</td>
<td>0.59*</td>
<td>0.01</td>
<td>0.28</td>
</tr>
<tr>
<td>Shrub cover %</td>
<td>0.02</td>
<td>0.43</td>
<td>-0.73**</td>
</tr>
<tr>
<td>Cheatgrass cover %</td>
<td>-0.85***</td>
<td>-0.07</td>
<td>0.24</td>
</tr>
<tr>
<td>Non-native grass cover %</td>
<td>-0.51</td>
<td>-0.65*</td>
<td>0.11</td>
</tr>
<tr>
<td>Perennial grass cover %</td>
<td>0.88***</td>
<td>-0.36</td>
<td>0.06</td>
</tr>
<tr>
<td>Non-native invasive cover %</td>
<td>-0.93***</td>
<td>-0.07</td>
<td>0.27</td>
</tr>
<tr>
<td>Perennial non-native grass cover %</td>
<td>0.15</td>
<td>-0.69**</td>
<td>-0.05</td>
</tr>
<tr>
<td>Other native grass cover %</td>
<td>0.47</td>
<td>0.49</td>
<td>-0.39</td>
</tr>
</tbody>
</table>
cover and represents 13.8% of the variability in the dataset. Therefore, it should be noted that shrub cover is not well represented by PC 1 and PC 2 in Figure 4.

The hierarchical cluster analysis (Fig. 5) grouped plots into structurally and functionally distinct classes that likely represent states of the STM for the Loamy Bottom ecological site. Three splits separated the plots into four groups. The first split separated the five plots with negative scores on PC 1 from the nine plots with positive scores on PC

![Figure 5](image)

**Figure 5.** Classifications of 14 plots into four groups based on average values for 22 measured variables. Hierarchical cluster analysis was used to obtain the groupings and principal components analysis (PCA; Figure 4) was used to interpret the characteristics of each group. The numbers two through five at each terminal node represent the four classes, or potential states (number one is excluded since no plots were considered to represent reference condition, or state one).
1. The second split separated two plots that had moderately high scores on PC 1 and low scores on PC 2 from the group with positive scores on PC 1. The third split separated the five plots with the highest scores on PC 1 from two plots with scores just above zero for PC 1. Additional splits were not interpretable based on the PCA, thus four groups were chosen to represent the potential states and community phases of the Loamy Bottom ecological site. These groupings represent a subjective splitting cutoff based on PCA and cluster analysis. Therefore the foliar cover data were subsequently examined to verify that the groupings make reasonable ecological sense.

A bar chart of percent composition by foliar cover (Fig. 6) helps illustrate the major structural differences (in species composition) between the four groups, representing four potential states. Figure 6 also shows minor structural differences within each group, suggesting potential community phases within states. Groups 2 and 4 have the most perennial grass cover, but group 2 is characterized by native grass cover, while

![Figure 6](image-url)
group 4 is characterized by non-native perennial grass cover. Group 3 has less perennial grass cover than groups 2 and 4, and is characterized by high shrub cover and some non-native invasive species cover. Group 5 is characterized by high non-native invasive species cover with varying amounts of shrub cover. Groups 2 and 5 appear have multiple phases differentiated by shrub cover.

To address objective two, simple linear regression suggested a relationship between the process variable OC, and two structural variables, perennial grass cover and total gaps in perennial canopy (Fig. 7). Perennial grass cover as an indicator of soil OC had an adjusted $R^2 = 0.51$ and total perennial canopy gaps as an indicator of soil OC had an adjusted $R^2 = 0.54$, suggesting that soil OC pools will likely decrease as perennial grass cover decreases and gaps in perennial canopy increase.

Simple linear regression also revealed a potential relationship between soil compressive strength and perennial grass cover (Fig. 8) with an adjusted $R^2 = 0.55$. ANOVA detected significant differences between cover types throughout the Loamy

![Figure 7](image)

**Figure 7.** Simple linear regressions of perennial grass (PG) on soil organic carbon (OC) and of total perennial canopy gaps (GAP_tot) on OC. Adjusted $R^2 = 0.51$ and adjusted $R^2 = 0.54$ respectively.
Figure 8. Simple linear regression of perennial grass on soil compressive strength. $R^2 = 0.55$. Symbols correspond to the five groupings obtained from the hierarchical cluster analysis (Figure 5).

Bottom site for soil surface aggregate stability, compressive strength, and shear strength at the $\alpha=0.01$ level (Fig. 9). Aggregate stability values were equivalent for samples taken on bare ground and forb microplots. Aggregate stability values for grass cover were equivalent to that of shrub cover, and both grass and shrub aggregate stability values were significantly higher than those of bare ground and forb samples. Both compressive strength and shear strength were significantly higher for grass cover than forb cover and bare ground. Compressive strength and shear strength for shrub cover were significantly less than grass, forb or bare cover microplots.

Based on the microplot analysis, the soil surface of the Loamy Bottom ecological can be characterized as follows: grass cover is associated with a physically hard soil surface that is high in organic matter and resistant to water erosion; shrub cover is associated with a soft physical soil surface that is also high in organic matter and resistant
to water erosion; and forb cover and bare ground are associated with a moderate physical soil crust that is relatively low in organic matter and more prone to water erosion.

Therefore, states with higher bare ground and forb cover can be indirectly linked to decreased soil stability and increased water erosion on the Loamy Bottom ecological site.

**Figure 9.** Differences in soil resistance measurements among cover types from analysis of variance (ANOVA) of the 560 microplots within the Loamy Bottom ecological site. Different letters represent significant differences at the $\alpha=0.01$ level for each variable. AS = soil surface aggregate stability, CS = soil surface compressive strength, and SS = soil surface shear strength.
Soil pedon descriptions and rangeland health indicators provided context for interpreting the results of the statistical analyses. These data are descriptive in nature and could not be analyzed statistically. It was determined from soil pedon descriptions that every plot included in this study is representative of the soil characteristics described in the Loamy Bottom ESD. Thirteen of the 14 pedons were classified as deep Mollisols, some with argillic or calcic horizons and many with pachic or cumulic mollic epipedons. The one soil that was classified as an Entisol appeared to be rapidly agrading such that soil development did not meet mollic color requirements. However, the hydrology of the plot supported basin wildrye dominance and the plot was considered to fit within the natural range of variability of soil characteristics described in the ESD. No strong patterns surfaced that linked the soil pedon to state distinctions among the plots. Some weak platy structure was observed on one of the cheatgrass plots and two of the seeded range plots, but no consistent pattern could be identified.

The rangeland health indicators that were rated differently and consistently among the state classifications obtained from the cluster analysis were “Invasive / noxious plants” and “Functional / structural groups.” Other rangeland health indicators were not sensitive enough or consistent enough to decipher any pattern. Still, it is consistent with the multivariate analysis that these structural variables are useful indicators of functionally distinct states.

The Loamy Bottom State and Transition Model

The development of this STM for the Loamy Bottom ecological site addresses the third objective of this study and represents an effort to integrate the information obtained
from both the statistical data analysis and anecdotal information about past disturbances on each plot. The STM narratives are process-based and inform management of the structural indicators of changing ecological function, following the example of Briske et al. (2008). It builds on the ideas of the STM that existed in the NRCS database prior to this study, and follows the organization of that database. This STM may not represent every possibility on the Loamy Bottom ecological site, but it summarizes all documented states and community phases as concisely and accurately as possible.

**Ecological Dynamics of the Site**

This site was historically dominated by basin wildrye, western wheatgrass (*Pascopyrum smithii*), basin big sagebrush (*Artemisia tridentata var. tridentata*), and rubber rabbitbrush (*Ericameria nauseosa*). Fire return interval is presumed to be similar to surrounding sagebrush uplands, about 40-60 years. Native grasses would have dominated for 2-3 years following fire, with rabbitbrush and greasewood (*Sarcobatus vermiculatus*) increasing steadily in the community. Sagebrush would most commonly have re-established and begun to increase in the community within 10 years after the fire. Similar to fire, extended wet periods would have caused sagebrush to decrease in the community. Other shrubs that cannot tolerate extended wet periods in the rooting zone would also have been affected.

Today this site burns less frequently and may have altered hydrology due to diversions, wells, roads and other obstructions to runoff or subsurface flow. In addition, livestock grazing can put pressure on native grasses and forbs, sometimes causing them
to lose vigor or disappear from the community completely. Cheatgrass commonly establishes on this site and can become dominant when the ecological processes deteriorate due to improper grazing, drought, increased fire frequency, and/or a lowered water table. Other invasive plants that establish on this site include Russian thistle (*Salsola iberica*), jointed goatgrass (*Aegilops cylindrica*), squarrose knapweed (*Centaurea squarrosa*), various non-native thistles and several annual forbs. This site has potential for successful range seedings and is commonly converted to permanent cropland, irrigated pasture, or subdivisions. Figure 10 summarizes the plant community dynamics of this site in the form of a STM diagram.

**The Reference State - State 1**

The reference state contains plant communities presumed to occur prior to the introduction of non-native plants, livestock grazing, and other modern disturbances. Disturbance regimes resemble those described above in the ecological dynamics section.

**Phase 1.1 - Community Phase 1.1**

Phase 1.1 is 85-95% grasses, 5-20% forbs, and 0-5% shrubs. Basin wildrye, western wheatgrass, and native forbs re-grow vigorously shortly after a fire by taking advantage of the resulting nutrient pulse. This phase can also result from extended wet periods that negatively impact shrubs.

**Community Pathway 1.1a**

Community pathway 1.1a represents natural succession 3-10 years after fire and
Figure 10. State-and-transition model for the Loamy Bottom ecological site. For a detailed description and photograph of each state, plant community, transition, community pathway and restoration pathway, refer to the narrative section below.
without extended wet periods in the plant rooting zone as shrubs become established and begin to gather nutrients into islands of fertility (Schlesinger and Pilmanis 1998).

**Phase 1.2 - Community Phase 1.2**

Phase 1.2 has 35-55% grasses, 5-15% forbs and 20-30% shrubs. Rubber rabbitbrush and basin big sagebrush increase in dominance due to more than a decade without fire or extended wetting of the rooting zone.

**Community Pathway 1.2a**

Community pathway 1.2a represents natural succession without fire or extended wet periods. This pathway usually occurs gradually as sagebrush increases in dominance, outcompeting other species for resources. Nutrients are increasingly tied up in wood.

**Community Pathway 1.2b**

Community pathway 1.2b is the result of fire or a wet period severe enough to kill shrubs. Perennial grasses and forbs increase in vigor following fire and less so following extended wet periods.

**Phase 1.3 - Community Phase 1.3**

Phase 1.3 is 35-50% grasses, 5-15% forbs, and 40-50% shrubs. Basin big sagebrush becomes the dominant shrub, though rabbitbrush and greasewood may also be present. This phase occurs 25-60 years after fire or an extended wet period. Nutrients have a patchy distribution in the system associated with shrub islands of fertility.
Community Pathway 1.3a

Community pathway 1.3a occurs when fire or an extended wet period is severe enough to remove shrubs. Natural fire interval is presumed to be 40-60 years. Perennial grasses and forbs increase in vigor following fire and less so after extended wet periods.

Transition - T1a

Transition T1a represents the introduction of non-native plant species associated with European settlement. This transition is irreversible since eradication of non-native species would require costly management inputs; however, this transition results in minimal functional change.

Current Potential State - State 2

The current potential state functions comparably to the reference state, although non-native plant species are present in the community. Under proper management, the current potential state maintains the ecological processes and community phases that were present in the reference state.

Phase 2.1 - Community Phase 2.1

Phase 2.1 is 85-95% grasses, 5-20% forbs, and 0-5% shrubs (Fig. 11). Basin wildrye, western wheatgrass, and native forbs re-grow vigorously shortly after a fire by taking advantage of the resulting nutrient pulse. This phase can also result from extended wet periods that negatively impact shrubs. Non-native species are present, but not dominant.
Community Pathway 2.1a

Community pathway 2.1a represents natural succession 3-10 years after fire and without extended wet periods in the plant rooting zone as shrubs become established and begin to gather nutrients into islands of fertility (Schlesinger and Pilmanis 1998).

Phase 2.2 - Community Phase 2.2

Phase 2.2 has 35-55% grasses, 5-15% forbs and 20-30% shrubs (Fig. 12). Rubber rabbitbrush and basin big sagebrush increase in dominance due to more than a decade without fire or extended wetting of the rooting zone. Non-native species are present, but not dominant.

Community Pathway 2.2a

Community pathway 2.2a represents natural succession without fire or extended wet periods. This pathway usually occurs gradually as sagebrush increases in dominance,
outcompeting other species for resources. Nutrients are increasingly tied up in wood.

Community Pathway 2.2b

Community pathway 1.2b is the result of fire or wet period severe enough to kill shrubs. Perennial grasses and forbs increase in vigor following fire and less so following extended wet periods.

Phase 2.3 - Community Phase 2.3

Phase 2.3 is 35-50% grasses, 5-15% forbs, and 40-50% shrubs (Fig. 13). Basin big sagebrush becomes the dominant shrub, though rabbitbrush and greasewood may also be present. This phase occurs 25-60 years after fire or an extended wet period. Nutrients have a patchy distribution in the system associated with shrub islands of fertility. Non-native species are present, but are not dominant.
Community Pathway 2.3a

Community pathway 2.3a occurs when fire or an extended wet period are severe enough to remove shrubs. Natural fire interval is presumed to be 40-60 years. Perennial grasses and forbs increase in vigor following fire and less so following extended wet periods.

Transition – T2a

Transition T2a occurs when perennial grasses decrease due to prolonged improper grazing and/or drought. Shrubs increase in dominance and alter the distribution of nutrients and availability of light to the subcanopy. The threshold is crossed when perennial grasses are no longer able to recover even in the event of brush removal. An indicator of crossing a threshold is reduced perennial plant vigor, particularly in reproductive capability.
Transition - T2b

Transition T2b occurs when brush is removed and perennial grass seed is introduced in conditions that are not favorable for seed establishment, such as drought. The transition is triggered by brush removal that frees up resources on the site. However, due to poor conditions relating to seed germination and establishment of desired species, the seeding fails and resources become available for the increased germination and establishment of non-native invasive species.

Transition - T2c

Transition T2c occurs when brush is removed and perennial grass seed is introduced in conditions that are favorable for seedling establishment. Water and nutrients are available to seeded species and they establish well and reinforce their own dominance on the site by efficiently using available resources.

Non-sprouting Shrub State - State 3

The non-sprouting shrub state is characterized by increased shrub dominance in the community at the expense of native perennial bunchgrasses. The combination of lack of fire and reduced perennial grass dominance decreases the site's resistance to invasion by cheatgrass and other invasive species, which co-dominate the understory and the seed bank. Drought and/or improper grazing contribute to reductions in perennial grass. Drought may be due to a lowered water table or altered site hydrology from wells, diversions or other obstructions to runoff and subsurface flow. Even if drought or grazing pressure is remediated, sagebrush dominance and non-native species in the understory
and seed bank preclude the re-establishment of perennial grass dominance.

**Phase 3.1 - Community Phase 3.1**

Phase 3.1 is 20-40% grasses, 0-10% forbs, and 45-60% shrubs (Fig. 14). Improper grazing or drought cause the perennial grasses to lose vigor, while basin big sagebrush dominates the site. Utah juniper may be present and can shade out other species, decrease soil moisture, and tie up nutrients for extended periods of time.

**Community Pathway 3.1a**

Community pathway 3.1a represents further reductions in perennial grass vigor due to continued improper grazing, drought and/or fire.

*Figure 14. Plant community phase 3.1.*
Phase 3.2 - Community Phase 3.2

Phase 3.2 is 20-40% grasses, 0-10% forbs, and 45-60% shrubs (Fig. 15). Perennial grasses are still present in the understory, but cheatgrass is at least co-dominant. Utah juniper may be present and can shade out other species, decrease soil moisture, and tie up nutrients for a very long time. Basin big sagebrush often dominates. This community is at-risk of crossing a threshold that leads to cheatgrass dominance. Potential indicators of this at-risk community are: less than 5% foliar cover of basin wildrye, greater than 70% shrub foliar cover, greater cheatgrass cover than perennial grass cover, and/or extremely low perennial grass seed production.

Community Phase Pathway 3.2a

Community pathway 3.2a can only occur if the site hydrology is not altered. Chemical brush management, prolonged periods of proper grazing and lack of fire are

Figure 15. Plant community phase 3.2.
required to restore perennial grass vigor. Increased seed production and perennial grass cover are indicators of this pathway.

**Transition - T3a**

Transition T3a occurs when brush is removed and perennial grass seed is introduced in conditions that are favorable for seedling establishment. Water and nutrients are available to seeded species and they establish well and reinforce their own dominance on the site by efficiently using available resources.

**Transition - T3b**

Transition T3b occurs when brush is removed and perennial grass seed is introduced under conditions that are not favorable for seedling establishment. The transition is triggered by brush removal that frees up resources on the site. However, due to poor conditions relating to seed germination and establishment of desired species, the seeding fails and resources become available for the increased germination and establishment of non-native invasive species.

**Transition - T3c**

Transition T3c occurs when perennial grass cover and seed production are negligible and cheatgrass becomes more dominant than perennial grasses. Usually fire coupled with prolonged improper grazing and/or drought triggers the feedback switch. However, this transition can occur in the absence of fire if perennial grasses become less dominant than cheatgrass.
Seeded Range State - State 4

The seeded range state includes successful range seedings and old range seedings that have re-established native plant dominance.

Phase 4.1 - Community Phase 4.1

Phase 4.1 is a successful range seeding. It is 75-95% grass, 5-25% forbs, and 0-5% shrubs (Fig. 16). Introduced perennial grasses dominate. Some non-native invasive species may increase after seeding and some soil loss may occur when soil is disturbed.

Community Pathway 4.1

Community pathway 4.1 is a natural re-invasion of the range seeding by basin big sagebrush, basin wildrye, western wheatgrass and other native species. This pathway occurs gradually over decades with proper grazing, functioning site hydrology and lack of fire. Even under these conditions, however, this pathway may not always occur.

Figure 16. Plant community phase 4.1.
Phase 4.2 - Community Phase 4.2

Phase 4.2 is a range seeding that has been re-invaded by basin big sagebrush and native grasses and forbs. It is 35-55% grass, 5-15% forbs, and 30-50% shrubs (Fig. 17). Ecological function is presumed to be similar to the current potential state due to perennial grass dominance in the understory and sagebrush dominance in the overstory. Non-native perennial grasses and invasive species are present but not dominant.

Community Pathway 4.2

Community pathway 4.2 is brush management to increase grass production. This pathway may also result in increased rabbitbrush and non-native invasive species.

Figure 17. Plant community phase 4.2.
Transition - T4a

Transition T4a occurs when perennial grasses decrease due to prolonged improper grazing and/or drought. Shrubs increase in dominance and alter the distribution of nutrients and availability of light to the subcanopy. The threshold is crossed when perennial grasses are no longer able to recover even in the event of brush removal. An indicator of crossing a threshold are shrub dominance and reduced perennial grass vigor, particularly in reproductive capability.

Transition - T4b

Transition T4b occurs when a failed seeding results in cheatgrass dominance. This transition is most likely to occur when cheatgrass seed is abundant in the understory and can result from high cheatgrass seed production on site or on adjacent land.

Restoration Pathway - R4

Restoration pathway R4 occurs when long-term proper grazing efforts and favorable weather conditions allow for native plant establishment in an established seeding of perennial non-native grasses. Big sagebrush and perennial grasses drive ecosystem processes such that the distribution of water, nutrients and light is similar to that of the current potential state (State 2).

Invasive Annual Grass State - State 5

This state maintains itself by increasing fire frequency and efficiently utilizing available nitrogen resources in the soil. Diverse invasive forbs and annual grasses such as
Russian thistle, jointed goatgrass, squarrose knapweed, and various non-native thistles can be productive in this state, but cheatgrass is the dominant species. Basin wildrye may be present if the water table has not dropped significantly.

**Phase 5.1 - Community Phase 5.1**

Phase 5.1 has 45-75% grass, 5-25% forbs and 20-40% shrubs (Fig. 18). Big sagebrush dominates the overstory and cheatgrass dominates the understory. Various other invasive forbs and grasses may be very productive as well.

**Community Pathway 5.1a**

Community pathway 5.1a occurs when fire triggers a removal of shrubs and subsequent dominance of cheatgrass.

*Figure 18. Plant community phase 5.1.*
Phase 5.2 - Community Phase 5.2

Phase 5.2 has 65-85% annual grass, 5-25% forbs and 0-5% shrubs (Fig. 19). Cheatgrass dominates and various other invasive forbs and grasses may be very productive as well. There are no known pathways out of phase 5.1.

Community Phase Pathway 5.3a

Community pathway 5.3a occurs when a failed seeding is subject to cheatgrass establishment. Cheatgrass seed can come from the seed bank or adjacent land.

Phase 5.3 - Community Phase 5.3

Phase 5.3 represents a range seeding with poor establishment of seeded species. This phase usually lasts 1-5 years and is dominated by annual sunflower (*Helianthus annuus*) and other native and non-native forbs (Fig. 20). Soil stability is likely to be reduced in this phase and the risk of accelerated soil loss should be recognized.

Figure 19. Plant community phase 5.2.
Community Phase Pathway 5.3b

Community pathway 5.3b represents the recovery of a failed seeding due to conditions that are naturally favorable for perennial grass seedling establishment. This recovery occurs within 2-5 years after a seeding and is a matter of chance rather than management. Co-dominance of perennial species and non-native invasive species results.

Phase 5.4 - Community Phase 5.4

Phase 5.4 is the recovery of native species after a failed range seeding due to favorable conditions and a viable seed bank 2-5 years after the seeding attempt. This phase is characterized by rubber rabbitbrush co-dominance with native and non-native
perennial grasses (Fig. 21). Forb diversity is often reduced in this phase and invasive species are abundant, but not dominant.

**Community Phase Pathway 5.4**

Community pathway 5.4 results from multiple fires and/or improper livestock grazing that reduce the vigor of rubber rabbitbrush and perennial grasses. Cheatgrass becomes increasingly dominant.

**Discussion**

The research approach employed in this study suggests that process-based, data-driven STMs can be developed to represent the majority of states and community phases for at least some rangeland ecological sites. The STM development strategy proposed by
Bestelmeyer et al. (2009) provided a sound framework for ecological site inventory and study plot establishment on a regional scale. Our objectives built on the process-based approach proposed by Stringham et al. (2003) and Bestelmeyer et al. (2003). Although we used a process-based approach in a similar fashion to Phelps and Bosch (2002) and Petersen et al. (2009), our study was conducted at the regional scale rather than the watershed scale. By expanding the spatial scale of our study, we confidently summarized and documented the existing variability of the Loamy Bottom ecological site throughout the entire region where the site occurs, but at the expense of statistical power that can be attained at smaller scales. In particular, the experimental units at the regional scale are soil components correlated to an ecological site, while the experimental units at the watershed scale are patches within a soil component correlated to an ecological site. Therefore, not only was the spatial variability at the regional scale greater to begin with, but the number of potential sampling locations was greatly reduced when compared to process-based STM development efforts at the watershed scale.

The existing states and community phases found in the inventory were similar to those of the draft STM that was developed for the Loamy Bottom ecological site based on expert opinion. There were, however, a few key differences: 1) a new state, the invasive species state, was identified and described with four community phases, 2) the rubber rabbitbrush state, which was found to be associated with failed range seedings, was re-classified as a phase within the invasive species state, 3) the phases of the seeded range state were clarified, 4) a new restoration pathway from the seeded range state to the current potential state was recognized, and 5) all of the STM component descriptions
were expanded to include structural indicators of functional differences. These clarifications and additions represent a more accurate picture of the plant community dynamics that currently exist on the Loamy Bottom ecological site. By basing state designations on process-based indicators, we were able to develop STM narratives that describe, to the extent possible, the causes of state change instead of the symptoms alone.

The rangeland health assessment provided surprisingly consistent interpretations of departure from reference for the three attributes. The 17 indicators were very easy to interpret in the context of the larger dataset, particularly with species cover data and soil pedon descriptions. Research that generalizes the links between the indicators of rangeland health and ecological processes at the regional scale would greatly improve our ability to develop consistent indicators of process-driven state changes.

Soil bulk density was the most time and labor-intensive method used in this study and no patterns were detected for this variable on this site.

The infiltrometer data did not yield any patterns between plots or states at any stage of the analysis. This is likely due to the fact that less than 5 ml of water infiltrated between each reading, even at the lowest negative pressure setting. The recommended amount of infiltration between readings is 10-15 ml (Li et al. 2005), but the high organic matter under shrubs and perennial grasses exhibited somewhat hydrophobic properties such that water ponded on the soil surface for several minutes before infiltrating slowly. A weak negative correlation was found between aggregate stability and hydraulic conductivity to further illustrate the hydrophobic nature of soils with high levels of organic matter.
Conclusions

Though the methods used in this study may not be suitable for STM development on all ecological sites, they can likely be modified or replicated for ecological sites that have well-defined site concepts and a large amount of area that is currently used as rangeland. It is recommended that replicates of states be dispersed throughout the entire region (to the degree possible) in order to minimize the effects of regional bias. Identifying patterns in ecological processes that can be applied at the landscape or ecological site scale is difficult (Brown 1994). Ideally, these methods could be applied to ecological sites with abundant replications of each state, such that parametric statistical analyses could be used to quantify differences between states. The Loamy Bottom ecological site had only a few soil map unit polygons for each of the states, with the exception of the seeded range state. For this reason, it may be more practical to continue studying indicators of ecological processes at the watershed scale where experimental units are plots within soil polygons and not the soil polygons themselves.

Future efforts to develop process-based, data-driven STMs should be done in coordination with the NRCS and its partners, so that STM and ESD concepts can be communicated and new information added to the ecological site database (Bestelmeyer et al. 2003, 2009). Further refinements to the kinds and amounts of data required for this type of model will improve the accuracy and efficiency of their development. Data-driven, process-based STMs that accurately depict the plant community dynamics of ecological sites are desperately needed, since the credibility and utility of STMs depend on it.
CHAPTER 3
TWO APPROACHES TO STATE AND TRANSITION
MODEL DEVELOPMENT USING DIFFERENT
LEVELS OF DATA COLLECTION

Introduction

Ecological Sites and State-and-Transition Models

The type of data used to develop STMs should reflect the quality of existing ecological site and STM concepts. Ecological site concepts that are not consistent throughout the entire site extent cannot be expected to be described by a single STM (Bestelmeyer et al. 2009). Since current ecological sites were converted from livestock-oriented range sites that were based on varying methods for defining site potential (USDA-NRCS 1997), many ecological sites do not reflect functionally distinct groupings of map units. In order to delineate ecological sites into groups of functionally similar land units, a systematic update of ecological site concepts will be required (Herrick et al. 2006). However, the exact types of data that will be most useful to refine site concepts and delineate new site boundaries have not been identified. It is likely that a combination of remotely sensed data (Creque et al. 1999) and rapid field methods will be the most efficient approach to re-defining ecological site concepts (Bestelmeyer et al. 2009).

Bestelmeyer et al. (2009) suggest that two levels of data collection can help with the co-development of STMs and ecological site concepts. The first level, low-intensity traverses, consists of rapid assessment of a broad area that captures the variability in plant...
community structure, soil-geomorphic properties, and functional indicators for soil components correlated to an ecological site. Though soil pits are not a part of level one data, patterns in landscape position, soil surface features and vegetation are noted to help refine site concepts. We expected the rangeland health assessment tool to be an appropriate, standard method of rapid site assessment for level one data (Briske et al. 2005).

The second level of data collection, medium-intensity inventory, consists of quantitative data describing community structure and qualitative indicators describing ecological processes. Study plots are targeted to capture important differences in land-use history, soils, and landscape position. Simple pedon descriptions may be used in level two data collection to identify important soil patterns across the site extent (Bestelmeyer et al. 2009). We expected that the National Resources Inventory (NRI) protocol (Spaeth et al. 2003), currently used for monitoring of non-federal lands by the NRCS, could be a useful method for obtaining level two data. We also expected rangeland health to provide useful information for level two data without requiring much additional time.

To provide Camp Williams with additional STMs for their ecological sites, and to further our understanding of the STM development process, we endeavored to develop STMs for two of the largest ecological sites found on the installation. One STM was developed from rangeland health assessments (level one data) of map unit polygons correlated to the site, plus step-point intercept data to standardize cover-related indicator ratings. The other STM was developed from the quantitative methods included in the NRI protocol (level two data) by targeting specific differences in disturbance history based on
a very rapid inventory of map unit polygons correlated to the ecological site. Rangeland health indicators were assessed along with the quantitative methods.

Our objectives were to: 1) identify and describe states and community phases of two prominent ecological sites at Camp Williams using methods endorsed by federal agencies, 2) develop process-based STMs (to the degree possible) with the data collected, and 3) compare the amount of effort and usefulness of information for different levels of data collection, summarizing important factors to consider in future STM development.

**The Upland Loam (mountain big sagebrush) and Mountain Gravelly Loam (Gambel oak) Ecological Sites**

The Upland Loam (mountain big sagebrush) site occupies roughly 1,100 ha of the sagebrush foothills at Camp Williams (for detailed information about ecological site naming conventions in Utah, see Appendix A). The site is the most extensively mapped site in the northeastern Great Basin, or MLRA D28 (Appendix A), and is correlated to soils that cover more than 270,000 ha in northern Utah. The Upland Loam (mountain big sagebrush) site is a sagebrush-grassland that occurs primarily on loamy benches and foothills of the northeastern Great Basin. It developed in a continental climate receiving 33-48 cm of mostly cool-season precipitation annually. Soils are loamy Mollisols (dark brown in upper 50 cm), moderately deep to deep and typically have less than 15 percent rock fragments by volume. The soil moisture regime is xeric and the soil temperature regime is mesic. The reference state is dominated by bluebunch wheatgrass (*Pseudoroegnaria spicata*), mountain big sagebrush (*Artemisia tridentata ssp. vaseyena*), Indian ricegrass (*Acnatherum hymenoides*), and antelope bitterbrush (*Purshia tridentata*).
The landscape position and soil surface rock fragments are very good indicators of the Upland Loam site, however, Wyoming big sagebrush (*Artemisia tridentata* spp. *wyomingensis*) can easily be confused with mountain big sagebrush since the two species often hybridize. The Upland Loam (mountain big sagebrush) site is generally accessible along public roads and easy to identify quickly and accurately. However, the extremely large extent of the site was expected to be a limiting factor in enumerating the sample frame.

The Mountain Gravelly Loam (Gambel oak) site occupies roughly 1,500 ha of the traverse mountain range at Camp Williams. The site can be found throughout the Wasatch Mountains and is correlated to soils that cover more than 50,000 ha in northern Utah. The Mountain Gravelly Loam site is a patchy, Gambel oak woodland that occurs on mountain slopes, foothills and ridges of the northern Wasatch Mountains Region, or MLRA E47, (Appendix A). It developed in a continental climate receiving 40-55 cm of mostly cool-season precipitation annually. Soils are gravelly or cobbly Mollisols (thick, dark surface horizon) at least 50 cm in total depth. The soil moisture regime is xeric and the soil temperature regime is frigid. The reference state is dominated by Gambel oak (*Quercus gambelii*), with an understory composed of bluebunch wheatgrass, slender wheatgrass (*Elymus trachycaulis*), and a diversity of forb species.

Gambel oak is a fire-adapted species that forms thick, shrubby clones, usually less than 3 m in height on this ecological site (Abella 2008), and has large amounts of carbohydrate storage in its roots (McKell 1950). Gambel oak is well-documented to be extremely resilient to all traditional brush management techniques (Kufeld 1983) due to
its massive energy reserves. Even repeated defoliation events, which may reduce Gambel oak vigor, have generally been unsuccessful at eradicating Gambel oak at an affordable price (Van Epps 1974; Davis et al. 1975). These properties allow Gambel oak to control the energy flow, nutrient and water cycling on the Mountain Gravelly Loam ecological site.

Methods

A map of all soil components that had been correlated to the Upland Loam (mountain big sagebrush) ecological site was used to locate and describe each accessible soil map unit polygon throughout the entire site extent. When possible, rangeland health was assessed upon initial visitation to the soil map unit polygon. The ecological site was verified with several shallow soil pits and interpretations from the Upland Loam ESD. Privately-owned portions of the map unit polygons were described from the road and revisited later upon obtaining permission.

A photograph and GPS coordinates were recorded for each sampling location. Step-point transects were used to obtain canopy cover estimates in order to standardize ratings of rangeland health indicators related to cover and plant community composition (Miller 2009). Each indicator was rated according to the reference worksheet in the Upland Loam ESD (Appendix A). Soil map unit polygons that did not represent the range of variability described in the site description were noted and excluded from the sample frame. Common exclusions were due to cropland conversion, housing developments, and the presence of Wyoming big sagebrush rather than mountain big sagebrush. The
subspecies of big sagebrush was determined by morphological distinctions followed by a black light test of leaf material in water and leaf material in ethanol (Winward and Teasdale 1969). Twenty-four soil map units were described for the Upland Loam ecological site.

A map of the soil components correlated to the Mountain Gravelly Loam site suggested that accessibility would be a limiting factor in locating and describing all existing states and community phases for the site. Not only was the majority of the site located on private land, but there were also very few public roads immediately adjacent to the site. Furthermore, soil map unit polygons were very large, often covering entire mountains or hillsides consisting of multiple ecological sites. Accessing all soil map unit polygons for sample frame enumeration would have required communication with dozens of land owners and weeks of hiking. After an unsuccessful attempt to describe states and community phases from a distance with binoculars, it was determined that all soil map unit polygons could not be visited, given the time and resource constraints of the project. We therefore limited our sample frame to the Camp Williams soil survey.

All soil map unit polygons in the Camp Williams soil survey were visited and described with field notes and a photograph. Based on these field notes and our knowledge of Gambel oak ecology, we drafted a STM that included a Dalmatian toadflax (Linaria dalmatica) state, an invasive annual grass state, and an herbaceous, goat-browsed state, in addition to the reference and current potential states. Because the Gambel oak site is naturally patchy, only locations that had 50-75% of the total area occupied by Gambel oak clones (based on visual estimates) were included in the sample
frame. Eighteen locations were selected for study plots representing all hypothesized states, except the reference state. Three plots were established in areas invaded by Dalmatian toadflax, four in areas invaded by annual grasses, four in areas that were heavily browsed by goats in late summer each year for the past 9 years, and seven plots in areas that were presumed to represent phases of the current potential state, including seeded Gambel oak woodlands.

Data was collected from late-July to mid-August in 2009 and from early-June to mid-July in 2010. Each plot was randomly located within a Mountain Gravelly Loam map unit polygon from the Camp Williams soil survey, except for two plots from the Morgan County Soil Survey (UT609) that represented seeded Gambel oak woodland, a rare occurrence on this site that could not be found at Camp Williams. GPS coordinates were recorded at the center of each plot, and four 25 m transects extended 5 m to 30 m from the center point toward the northeast, northwest, southeast and southwest. A digital photograph was taken from the center point in the direction of each transect before any data was collected. Special care was taken to walk on only the south side of transects and to record all measurements from the north side of transects. This plot design was modeled after the NRI methods that are used for long-term monitoring by the NRCS (Spaeth et al. 2003).

Plant community structure was measured using four methods (Herrick et al. 2005). The line-point intercept method was used to determine percent canopy cover by species, sub-canopy cover by species, foliar cover by species, plant height, percent basal cover, percent ground cover, and percent bare ground. For each transect, the gap-intercept
method recorded gaps in the canopy of perennial species from 25-50 cm, 50-100 cm, 100-200 cm and greater than 200 cm in length. Annual production by species was approximated using the double sampling method at 10 pre-determined points within each plot. Belt transects, 1.5 m by 25 m, were used to record Gambel oak stem density on the two transects with the greatest Gambel oak cover.

Soil surface resistance to erosion was measured at five microplots along each transect, totaling 20 microplots per subplot, and 40 per plot. Soil surface aggregate stability (AS) was rated using a soil stability kit (Herrick et al. 2001; Pellant et al. 2005) and one soil clod was collected at each of the microplots. The dominant cover type in each microplot was recorded as tree, shrub, forb, grass, or bare ground. Soil surface compressive strength was measured in each microplot using a pocket penetrometer (Cole-Parmer 99039-00), and soil surface shear strength was measured using a shear vane (Torsional Vane Shear Tester STCL-4).

Rangeland health was assessed for each plot using the rangeland health reference worksheet contained in the Mountain Gravelly Loam (Gambel oak) ESD (Appendix B). Gambel oak vigor was documented on the rangeland health data form. Soil pits were described in the summer of 2010 for plots that were distant from any existing NRCS soil survey hole locations, or that were located on slopes or aspects that were not accounted for by NRCS soil survey holes. Each hole was dug to a depth of 1 m, or to the depth of a root-limiting layer, and described according to Hendershot et al. (1993).
Results

The Upland Loam (Mountain big sagebrush) State-and-Transition Model

Despite the large extent of the Upland Loam (mountain big sagebrush) ecological site, the vast majority of soil map unit polygons correlated to the site were excluded from the sample frame. Only four polygons in the Cache County soil survey (UT603) were suitable for data collection, with housing and dry farm developments precluding further data collection in that soil survey. The eastern Box Elder County soil survey (UT602) and the Tooele County soil survey (UT611) map units were dominated by Wyoming big sagebrush. Some soil map units in these two counties were not accessible due to private roads. The Camp Williams soil survey (UT605) provided the best access to soil map units that could be included in the sample frame. Five other soil surveys along the Wasatch Front correlated the Upland Loam ecological site only to soil map units that underlie developed urban and suburban areas.

As a result of land development and Wyoming big sagebrush dominance, only 24 soil map unit polygons were described. From these observations, a first draft STM was developed for the site, which included the reference state, the current potential state, a sagebrush dominance state, a compacted soil shrub state, an annual grass state, and a seeded range state. Each of nine community phases was described in at least two locations. State and community phase designations were primarily based on plant community structure, although soil compaction was one rangeland health indicator that separated four soil map unit polygons from the others. No other patterns in rangeland
health indicators could be elicited; therefore, the most meaningful summaries of our observations are the STM narratives describing the structure of states and community phases.

Ecological Dynamics

This site was historically dominated by bluebunch wheatgrass, Indian ricegrass, western wheatgrass, mountain big sagebrush, antelope bitterbrush and rubber rabbitbrush. Fire return interval is presumed to be about 40-60 years. Native grasses would have dominated for 2-3 years following fire, with rabbitbrush and bitterbrush increasing steadily in the community. Sagebrush would most commonly have re-established and begun to increase in the community within 10 years after the fire.

Today, this site burns less frequently and is susceptible to a multitude of non-native invasive species. Bulbous bluegrass (Poa bulbosa) and cheatgrass commonly establish on this site and can become dominant when the ecological processes deteriorate due to improper grazing, drought, increased fire frequency, and/or soil compaction. Other invasive plants that establish on this site include redstem filaree (Erodium cicutarium), Dalmatian toadflax, and tumble mustard (Sysimbrium altissimum). This site has potential for successful range seedings and is commonly converted to permanent cropland, dry land farming, or subdivisions. Figure 22 summarizes the plant community dynamics of this site in the form of a STM diagram.
Figure 22. First draft state-and-transition model for the Upland Loam (mountain big sagebrush) ecological site. For a detailed description and photograph of each state, plant community, transition, community pathway and restoration pathway, refer to the narrative section below.
The Reference State - State 1

The reference state contains plant communities presumed to occur prior to the introduction of non-native plants, livestock grazing, and other modern disturbances. Disturbance regimes resemble those described above in the ecological dynamics section.

Phase 1.1 - Community Phase 1.1

Phase 1.1 has 60-80% grasses, 10-20% forbs, and 0-20% shrubs. Western wheatgrass, native forbs and native bunchgrasses re-grow vigorously shortly after a fire by taking advantage of the resulting nutrient pulse.

Community Pathway 1.1a

Community pathway 1.1a represents natural succession 3-10 years after fire, under normal climatic conditions, as shrubs become established and begin to gather nutrients into islands of fertility (Schlesinger and Pilmanis 1998).

Phase 1.2 - Community Phase 1.2

Phase 1.2 has 35-55% grasses, 10-20% forbs and 20-40% shrubs. Rubber rabbitbrush, antelope bitterbrush and mountain big sagebrush increase in dominance due to more than a decade without fire.

Community Pathway 1.2a

Community pathway 1.2a represents natural succession without fire under normal climate conditions. This pathway usually occurs gradually as sagebrush increases in
dominance, outcompeting other species for resources. Nutrients are increasingly tied up in woody material.

**Community Pathway 1.2b**

Community pathway 1.2b is the result of fire severe enough to kill shrubs. Perennial grasses and forbs increase in vigor following fire.

**Phase 1.3 - Community Phase 1.3**

Phase 1.3 is 20-35% grasses, 5-15% forbs, and 45-65% shrubs. Basin big sagebrush becomes the dominant shrub, though rabbitbrush and bitterbrush are still present. This phase occurs 25-60 years after fire. Nutrients have a patchy distribution in the system associated with shrub islands of fertility.

**Community Pathway 1.3a**

Community pathway 1.3a occurs when fire is severe enough to remove shrubs. Natural fire interval is presumed to be 40-60 years. Perennial grasses and forbs increase in vigor following fire.

**Transition - T1**

Transition T1a represents the introduction of non-native plant species associated with European settlement. This transition is irreversible since eradication of non-native species would require costly management inputs; however, this transition results in minimal functional change.
**Current Potential State - State 2**

The current potential state functions comparably to the reference state, although non-native plant species are present in the plant community. Under proper management, the current potential state maintains the ecological processes and community phases that were present in the reference state. The current potential state cannot return to the reference state because of the high cost of non-native species eradication.

**Phase 2.1 - Community Phase 2.1**

Phase 2.1 has 60-80% grasses, 10-20% forbs, and 0-20% shrubs (Fig. 23). Western wheatgrass, native forbs and native bunchgrasses re-grow vigorously shortly after a fire by taking advantage of the resulting nutrient pulse. Non-natives not dominant.

*Figure 23. Upland loam community phase 2.1.*
Community Pathway 2.1a

Community pathway 2.1a represents natural succession 3-10 years after fire, under normal climatic conditions, as shrubs become established and begin to gather nutrients into islands of fertility (Schlesinger and Pilmanis 1998).

Phase 2.2 - Community Phase 2.2

Phase 2.2 has 35-55% grasses, 10-20% forbs and 20-40% shrubs (Fig. 24). Rubber rabbitbrush, antelope bitterbrush and mountain big sagebrush increase in dominance due to more than a decade without fire. Non-natives are not dominant.

Community Pathway 2.2a

Community pathway 2.2a represents natural succession without fire under normal climate conditions. This pathway usually occurs gradually as sagebrush increases in

Figure 24. Upland loam community phase 2.2.
dominance, outcompeting other species for resources. Nutrients are increasingly tied up in woody material.

Community Pathway 2.2b

Community pathway 2.2b is the result of fire severe enough to kill shrubs. Perennial grasses and forbs increase in vigor following fire.

Phase 2.3 - Community Phase 2.3

Phase 2.3 is 20-35% grasses, 5-15% forbs, and 45-65% shrubs (Fig. 25). Basin big sagebrush becomes the dominant shrub, though rabbitbrush and bitterbrush are still present. This phase occurs 25-60 years after fire. Nutrients have a patchy distribution in the system associated with shrub islands of fertility. Non-native species not dominant.

Figure 25. Upland loam community phase 2.3.
**Community Pathway 2.3a**

Community pathway 2.3a occurs when fire is severe enough to remove shrubs. Natural fire interval is presumed to be 40-60 years. Perennial grasses and forbs increase in vigor following fire.

**Transition - T2a**

Transition T2a occurs when brush is removed and perennial grass seed is introduced in conditions that are favorable for seedling establishment. Water and nutrients are available to seeded species and they establish well and reinforce their own dominance on the site by efficiently using available resources.

**Transition - T2b**

Transition T2b occurs when improper grazing and/or extended drought reduces the vigor of perennial grasses and increases shrub dominance. The threshold is defined as the point when perennial grasses are unable to reestablish dominance on the site in the event of a shrub-removing disturbance. This is due to a lack of established plants and a lack of viable seed in the seed bank. The exact amount of perennial grass required to avoid crossing a threshold is unknown, but less than 5% cover of native grasses and poor seed production likely indicate that a threshold has been crossed.

**Transition - T2c**

Transition T2c occurs when heavy vehicles drive on the soil repeatedly when soil conditions are wet enough to result in compaction. Indicators of soil compaction are loss
of perennial grasses, reduced annual production of grasses, and a compacted soil layer at depths from 10-30 cm below the soil surface.

Shrub and Invasive Grass State - State 3

The shrub and invasive grass state is characterized by increased shrub dominance in the community at the expense of native perennial bunchgrasses. The combination of lack of fire and reduced perennial grass dominance decreases the site's resistance to invasion by bulbous bluegrass and cheatgrass, which co-dominate the understory and the seed bank. Drought and/or improper grazing contribute to reductions in perennial grass. Even if drought or grazing pressure is remediated, sagebrush dominance and non-native species in the understory and seed bank preclude the re-establishment of perennial grass dominance.

Phase 3.1 - Community Phase 3.1

Phase 3.1 is 15-35% invasive grasses, 0-15% forbs, and 50-80% shrubs (Fig. 26). Improper grazing or drought causes the perennial grasses to lose vigor, while mountain big sagebrush or rabbitbrush dominates the site. Bulbous bluegrass and cheatgrass dominate the understory.

Transition - T3a

Transition T3a occurs when heavy vehicles drive on the soil repeatedly when soil conditions are wet enough to result in compaction. Annual production may be reduced as a result of this transition.
Transition - T3b

Transition T3b occurs when brush is removed by fire, chemical or mechanical means. If mechanical or chemical brush removal occurs, this transition will result in greatly reduced production, as nutrients are tied up in the woody material. Brush removal by fire, however, provides a flush of nutrients and immediately results in high production of bulbous bluegrass, cheatgrass, and annual forbs.

Transition - T3c

Transition T3c occurs when brush is removed and perennial grass seed is introduced in conditions that are favorable for seedling establishment. Water and nutrients are available to seeded species and they establish well and reinforce their own
dominance on the site by efficiently using available resources.

**Soil Compaction Shrub State - State 4**

The soil compaction shrub state has altered hydrology from that of other states. The site potential is reduced as water-holding capacity and penetration of the soil by plant roots are reduced.

**Phase 4.1 - Community Phase 4.1**

Phase 4.1 represents a compacted soil with shrub dominance and reduced production. It has 0-25% invasive grasses, 0-15% forbs, and 60-100% shrubs (Fig. 27). Non-native invasive grasses and forbs can occupy the understory.

**Figure 27.** Plant community phase 4.1.
Transition T4

Transition T4 occurs when shrub dominance is removed by fire or mechanical treatments. Perennial bunchgrasses are not expected to establish here, and invasive grasses are expected to dominate the site.

Invasive Grass State - State 5

The invasive grass state is characterized by bulbous bluegrass and cheatgrass dominance. There is no recognized path out of this state.

Phase 5.1 - Community Phase 5.1

Phase 5.1 has 65-90% grasses, 0-15% forbs, and 0-10% shrubs (Fig. 28). Bulbous bluegrass and cheatgrass dominate. Production is low, either temporarily due to mechanical treatment or permanently due to soil compaction.

Figure 28. Upland loam community phase 5.1
**Community Pathway 5.1a**

Community pathway 5.1a occurs when fire triggers a removal of shrubs and subsequent dominance of cheatgrass.

**Phase 5.2 - Community Phase 5.2**

Phase 5.2 has the same community composition as phase 5.1, but production is much higher due to lack of compaction and available nutrient resources (Fig. 29).

**Community Pathway 5.2a**

Community pathway 5.2a results in decreased production due to drought, compaction or mechanical disturbance of the soil surface.

*Figure 29. Upland loam community phase 5.2.*
Seeded Range State – State 6

This is a successful range seeding to non-native perennial plants, typically planted to increase forage production.

Phase 6.1 - Community Phase 6.1

Phase 6.1 is a successful range seeding dominated by perennial non-native bunchgrasses. Crested wheatgrass is commonly seeded on this site. It has 70-90% grasses, 0-10% forbs, and 0-20% shrubs (Fig. 30).

Community Pathway 6.1

Community pathway 6.1 represents natural succession and the co-dominance of native shrubs and perennial non-native grasses. Some native grasses may also be present.

Figure 30. Upland loam community phase 6.1.
Phase 6.2 - Community Phase 6.2

Phase 6.2 has 50-80% grass, 0-10% forbs and 20-50% shrubs (Fig. 31). Mountain big sagebrush or rubber rabbitbrush dominates the overstory and non-native perennial grasses dominate the understory.

Figure 31. Upland loam community phase 6.2.
The Mountain Gravelly Loam (Gambel oak) State-and-Transition Model

The quantitative data for the Mountain Gravelly Loam (Gambel oak) were examined using bar charts and cluster dendrograms to detect any patterns among the plots. The patchy nature of Gambel oak clones made the interpretation of oak cover data impossible at the plot scale. Total foliar cover provided the most useful representation of the plant community because it includes important differences in understory species that may not be well-represented by canopy foliar cover.

The only pattern that consistently emerged from the Mountain Gravelly Loam data was a separation of four plots that had significantly lower total non-native invasive foliar cover than the other 14 plots (Fig. 32). The four plots with minimal non-native invasive cover were in a 2-year-old burn, a 10-year-old burn, and two plots that had not burned for several decades (red bars in Fig. 32). There was no relationship between non-native invasive foliar cover and soil variables or Gambel oak stem density. Among the 14 plots with high non-native invasive cover, there was no obvious relationship between the type of non-native invasive cover, be it Dalmatian toadflax, invasive forb or annual grass cover, and disturbance history. However, all plots with Dalmatian toadflax or invasive forbs also had large components of invasive grasses, particularly cheatgrass.

The rangeland health assessments rated all plots with none-to-slight deviation from the expected soil/site stability and hydrologic function of the reference state. The four plots with minimal non-native invasive foliar cover were rated as non-to-slight for biotic integrity as well, while the other 14 plots were rated as slight-to-moderate or
Figure 32. Bar graph showing total non-native invasive foliar cover for each of the eighteen mountain gravelly loam plots. G=goats, A=annual understory, T=Dalmatian toadflax understory, B=recent burn, S=seeded, N=native understory, and J=Juniper encroachment.

moderate departure from the reference state for biotic integrity. Gambel oak was noted to be vigorous on all plots except the goat-browsed plots. The three goat plots on north-facing slopes had Gambel oak that was notably thinned but still healthy, while the goat plot on a south-facing slope had Gambel oak with an unhealthy appearance and many dead Gambel oak ramets.

Based on our interpretation of the data, the STM for the Mountain Gravelly Loam (Gambel oak) site at Camp Williams consists of a reference state (which we did not document), a current potential state, and an invaded understory state (Fig. 29). All states are dominated by Gambel oak in the overstory, but it is likely that the invaded understory state is associated with an increased fire frequency and/or annual heavy-goat browsing.
Ecological Dynamics

This site is characterized by Gambel oak dominance with perennial bunchgrasses and forbs in the interspaces. Historically, wildfires rejuvenated aging oak stands every 40-80 years on this site. Gambel oak resprouts vigorously after fire and oak stem density decreases steadily as time without wildfire increases. On higher elevation sites, mature oak can be invaded by juniper or Douglas fir. These resinous conifers increase the likelihood of wildfire which removes the invaders and resets the oak to vigorous resprouting and site dominance. Species that are most likely to invade this site when ecological processes deteriorate are cheatgrass, annual forbs, Dalmatian toadflax, and hounds tongue (*Cynoglossum officinale*). Gambel oak is presumed to increase under excessive grazing or repeated wildfires.

Reference State - State 1

The reference state is maintained by wildfire and Gambel oak resilience.

Presumed fire return interval is 40-80 years.

Phase 1.1 - Community Phase 1.1

Phase 1.1 is 10-20% grasses, 0-15% forbs and 80-90% shrubs. After a fire, Gambel oak sprouts vigorously and suppresses perennial grass and forb production.

Community Phase Pathway 1.1a

Community pathway 2.1a results from self-thinning of oak stems over time and represents natural succession following fire.
Figure 33. Draft state-and-transition model for the Mountain Gravelly Loam (Gambel oak) ecological site. For a detailed description and photograph of each state, plant community, transition, community pathway and restoration pathway, refer to the narrative section below.
Community Phase Pathway 1.1b

Community pathway 2.1b represents an aerial seeding and establishment of native and/or non-native perennial grasses and forbs following wildfire.

Phase 1.2 - Community Phase 1.2

Phase 1.2 is 20-40% grasses, 10-25% forbs, and 50-70% shrubs. Gambel oak stem density is less than phase 1.1, though oak production may be higher.

Community Phase Pathway 1.2a

Community pathway 1.2a is caused by wildfire.

Community Phase Pathway 1.2b

Community pathway 1.2b results from natural succession of the site and natural invasion of conifers into Gambel oak.

Phase 1.3 - Community Phase 1.3

Phase 1.3 is characterized by encroachment of conifer species, including Douglas fir, juniper and pinyon. Higher elevations of this ecological site are more susceptible to conifer encroachment. At lower elevations, this phase is characterized by decadent Gambel oak with patches of young sprouts. Gambel oak dies naturally around 80 years of age and promptly responds with vigorous young sprouts to replace the old foliage.
Community Phase Pathway 1.3a

Community pathway 1.3a occurs when wildfire eliminates encroaching conifers.

Transition - T1

Transition T1 represents the presence of non-native plant species and is irreversible once non-native species occupy the site. Most areas already have non-native species present, and represent State 2: the current potential state.

Current Potential - State 2

State 2 represents the potential of the site upon the arrival of non-native species associated with European settlement. Ecological function is not necessarily altered, but the presence of non-native species represents a threshold that cannot be reversed without significant management inputs.

Phase 2.1 - Community Phase 2.1

Phase 2.1 is 10-20% grasses, 0-15% forbs and 80-90% shrubs by air-dry weight (Fig. 34). After a fire, Gambel oak sprouts vigorously and suppresses perennial grass and forb production. Non-native species are present, but not dominant.

Community Phase Pathway 2.1a

Community pathway 2.1a results from self-thinning of oak stems over time and represents natural succession following fire.
Community Phase Pathway 2.1b

Community pathway 2.1b represents an aerial seeding and establishment of native and/or non-native perennial grasses and forbs following wildfire.

Phase 2.2 - Community Phase 2.2

Phase 2.2 is 20-40% grasses, 10-25% forbs, and 50-70% shrubs (Fig. 35). Gambel oak stem density is less than phase 1.1, though oak production may be higher. Non-native species are present, but not dominant.

Community Phase Pathway 2.2a

Community pathway 2.2a sets succession back due to wildfire.
Community Phase Pathway 2.2b

Community pathway 2.2b represents natural succession of the site and natural invasion by conifers into mature Gambel oak.

Phase 2.3 - Community Phase 2.3

Phase 2.3 is characterized by encroachment of conifer species, including Douglas fir, juniper and pinyon (Fig. 36). Higher elevations of this ecological site are more susceptible to conifer encroachment. At lower elevations, this phase is characterized by decadent Gambel oak with patches of young sprouts. Gambel oak dies naturally around 80 years of age and promptly responds with vigorous young sprouts to replace the old foliage. Native species are present, but not dominant.
Community Phase Pathway 2.3a

Community pathway 2.3a occurs when wildfire eliminates encroaching conifers and decadent Gambel oak. The presence of resinous conifers increases the likelihood of a stand-replacing fire in this phase.

Community Phase Pathway 2.3b

Community pathway 2.3b occurs when targeted thinning of oak via mechanical tools or intensive goat browsing or both results in decreased stem density of oak and increased herbaceous production.

Phase 2.4 - Community Phase 2.4

Phase 2.4 is an aerial seeding following fire (Fig. 37). Both native and non-native
perennial grasses and forbs are included in most seed mixes. Under proper grazing, native grass and forb species can outcompete introduced species and dominate the understory within 5-10 years.

Community Phase Pathway 2.4a

Community pathway 2.4a has been documented as a natural tendency of oak seedings to return to dominance by native perennial grasses and forbs within 5-10 years of seeding introduced species.

Figure 37. Mountain gravelly loam community phase 2.4.
Phase 2.5 - Community Phase 2.5

Phase 2.5 results from targeted thinning of Gambel oak with mechanical tools, intensive goat browsing, or a combination of the two (Fig. 38). This type of brush management is usually associated with fire breaks intended to reduce the fuel load. This is an at-risk community due to the increased likelihood of invasive plant establishment associated with high levels of disturbance.

Transition - T2a

Transition T2a most often results from high fire return intervals that favor invasive species dominance. Prolonged overgrazing can also degrade the resilience of the native perennial understory, resulting in an understory dominated by invasive species.

Figure 38. Mountain gravelly loam community phase 2.5.
Transition - T2b

Transition T2b occurs when repetitive Gambel oak thinning via mechanical tools and/or intensive goat browsing results in the understory dominance of invasive plants. Intensive goat browsing is particularly favorable to invasive plant establishment since goats devour entire perennial grass and forb plants, resulting in high mortality of bunchgrasses and summer and fall forbs. Spring forbs are not as susceptible to this type of goat browsing since they become dormant before most fire control efforts go into effect in July and August. Complete defoliation of native species year after year provides the light and nutrient resources necessary for invasive species establishment and eventual domination of the oak understory.

Invasive Understory State - State 3

The invasive understory state is still dominated by Gambel oak; however, the understory is dominated by fire-adapted invasive species rather than deep rooted perennial grasses. Relatively harsh sites (low elevations, south-facing slopes, or low water-holding capacity soils) are more prone to invasion and dominance of invasive annual grasses than sites with more plant available moisture (higher elevation, north-facing slopes, higher precipitation areas).

Phase 3.1 - Community Phase 3.1

Phase 3.1 is 10-20% grasses, 0-15% forbs and 80-90% shrubs (Fig. 39). After fire, Gambel oak and cheatgrass suppress other species. Diverse non-native annual
grasses and forbs dominate the understory, while Gambel oak continues to dominate the overstory.

**Community Phase Pathway 3.1a**

Community pathway 3.1a results from self-thinning of oak stems over time and represents natural succession following fire.

**Community Phase Pathway 3.1b**

Community pathway 3.1b represents an aerial seeding and establishment of native and/or non-native perennial grasses and forbs following wildfire.

**Phase 3.2 - Community Phase 3.2**

Phase 3.2 is 20-40% grasses, 10-25% forbs, and 50-70% shrubs (Fig. 40). Gambel oak stem density is less than phase 1.1, though oak production may be higher.
Diverse, non-native annual grasses and forbs dominate the understory and Gambel oak continues to dominate the overstory.

**Community Phase Pathway 3.2a**

Community pathway 3.2a sets succession back due to wildfire.

**Community Phase Pathway 3.2b**

Community pathway 3.2b represents natural succession of the site and natural invasion by conifers into mature Gambel oak. This pathway may not exist in State 3 due to a higher fire interval caused by the annual grass-dominated understory.
Phase 3.3 - Community Phase 3.3

Phase 3.3 is characterized by encroachment of conifer species, including Douglas fir, juniper and pinyon. Higher elevations of this ecological site are more susceptible to conifer encroachment. At lower elevations, this phase is characterized by decadent Gambel oak with patches of young sprouts. Gambel oak dies naturally around 80 years of age and promptly responds with vigorous young sprouts to replace the old foliage. Native species are present, but not dominant. This phase is not documented and may not exist if fire return intervals preclude conifer establishment.

Community Phase Pathway 3.3a

Community pathway 3.3a occurs when wildfire eliminates encroaching conifers and decadent Gambel oak. The presence of resinous conifers increases the likelihood of a stand-replacing fire in this phase.

Community Phase Pathway 3.3b

Community pathway 3.3b occurs when targeted thinning of oak via mechanical tools or intensive goat browsing or both results in decreased stem density of oak and increased herbaceous production.

Phase 3.4 - Community Phase 3.4

Phase 3.4 is an aerial seeding following fire. Both native and non-native perennial grasses and forbs are included in most seed mixes. Under proper grazing and favorable conditions following a fire, perennial grasses and forbs may be able to
outcompete introduced species and dominate the understory.

**Community Phase Pathway 3.4a**

Community pathway 3.4a represents a failed seeding due to either unfavorable conditions for seedling establishment or improper grazing of seeded species.

**Phase 3.5 - Community Phase 3.5**

Phase 3.5 is 20-50% grasses, 15-35% forbs, and 20-40% shrubs (Fig. 41). It results from targeted thinning of Gambel oak with mechanical tools, intensive goat browsing, or both for multiple years in a row. This type of brush management is usually associated with fire breaks intended to reduce the fuel load. On harsher sites, this phase may result in mortality of Gambel oak.

*Figure 41. Mountain gravelly loam community phase 3.5.*
Community Phase Pathway 3.5a

Community pathway 3.5a represents natural succession and filling in of Gambel oak when thinning agents are removed for several years.

Community Phase Pathway 3.5b

Community pathway 3.5b represents a seeding immediately following brush control. This pathway has not been documented.

Discussion

The rangeland health assessment tool provided a good descriptive inventory of the accessible states and community phases for the Upland Loam (mountain big sagebrush) ecological site. The method was efficient, requiring less than two hours per assessment, not including travel time. Beyond a descriptive inventory, however, rangeland health data were not consistent enough to group similar land units into states and community phases. With only step-point data to provide structurally-based state groupings, meaningful patterns in the 17 indicators and three attributes of rangeland health could not be identified within states. This could possibly be remedied with a greater number of “replicates” for each state and community phase, but in this first attempt the rangeland health assessment tool alone was ineffective at developing a reliable, process-based STM.

Given the fact that the Upland Loam site concepts contained in the ESD did not reflect what was observed on the ground for a large portion of the soil map unit polygons, specifically the frequent occurrence of Wyoming big sagebrush, level one data collection methods were probably the best use of time and resources for STM development on this
site. We were able to identify a specific problem with the Upland Loam ecological site concept without investing vast amounts of resources for the inventory. Based on our knowledge of sagebrush ecology, we suspect that Wyoming big sagebrush reflects soil and/or climate differences in Tooele and Box Elder counties.

To develop a STM that accurately describes the plant community dynamics of the Upland Loam ecological site, there must first be a revision of the ecological site concepts, which will include new correlations between soils and ecological sites, and will most likely result in the splitting of the Upland Loam (mountain big sagebrush) site into two or more sites.

Similar to findings by Miller (2009) the rangeland health assessments of the Mountain Gravelly Loam (Gambel oak) ecological site were more easily interpreted within the context of quantitative structural data. Quantitative data provide greater insight into the structural groupings of similar land units. After land units were grouped by structural characteristics it was easy to recognize the difference in attribute ratings for the four plots in the current potential state. The cost of improved interpretation through quantitative data collection was about 10 hours per plot. Such a significant time constraint suggests that quantitative data should only be collected when ecological site concepts are understood and specific questions about plant community dynamics are being asked.

The Mountain Gravelly Loam data suggest that fewer functionally distinct states exist for the site on Camp Williams than we initially thought. Because of the resilience of Gambel oak, the STM we developed for the Mountain Gravelly Loam site represented
only two states other than the reference state. All plots could be described as brushy thickets (Abella 2008) with Gambel oak stems of varying sizes and densities. However, oak stem size and density were not related to state designations, but rather they indicate phases within states related to time since disturbance.

At Camp Williams, Gambel oak is subject to more disturbance than that which generally occurs on the Mountain Gravelly Loam ecological site, particularly in the form of heavy annual goat browsing, high amounts of foot traffic, and high fire frequency. Still, Gambel oak was observed to be maintaining resilience on all plots except one goat-browsed plot on a south-facing slope (but further evidence is needed to determine aspect effects on Gambel oak resilience to goat browsing). Though this STM was developed only using map unit polygons from one soil survey, we expect that map unit polygons in other soil surveys are likely to experience less disturbance, and consequently have even more resilience of Gambel oak than on this ecological site.

The quantitative data collected for the Mountain Gravelly Loam ecological site was not very effective at linking ecological processes to structural differences among states. Still, it was useful for identifying states and community phases and describing structural differences. It also helped identify possible aspect, elevation, and soil effects on plant community dynamics of this site. As mentioned, goat browsing on a south-facing slope appeared to greatly reduce Gambel oak resilience. Juniper encroachment only occurred at the higher elevations of the site extent, suggesting that the likelihood of encountering a coniferous community phase could be dependent on elevation. The Dalmatian toadflax-infested plots were on or adjacent to extremely stony soils from
which the strongly rhizomatous forb appeared to have spread. Site-specific inventories
with both quantitative and qualitative data are a powerful means of documenting and
hypothesizing plant community dynamics that may become useful to inform management
through STMs.

Conclusions

Ecological site concepts must be well-defined in order to develop reliable STMs. Rapid assessment of states and community phases at the ecological site level provides an opportunity to refine ecological site concepts in coordination with STM development efforts. Quantitative data aids in the interpretation of rangeland health assessments by providing the plant community structure information necessary for grouping similar land units (Pyke et al. 2002).

The process of developing the Mountain Gravelly Loam (Gambel oak) STM revealed important factors that should be considered for future development of comprehensive STMs. First, the ecological site must be accessible for proper sample frame enumeration. Limiting factors to site accessibility are proximity to roads, number of land-owners, size of the soil map unit polygons, and rugged terrain. Each of these issues has the potential to greatly increase the cost of ecological site inventory for development of comprehensive STMs.

The second factor to consider is the quality of information contained in the current STM draft for an ecological site prior to renewed STM development efforts. Well-developed STMs provide the background information necessary for intensive data
collection, while poorly-developed STMs may not provide quality information and are therefore better candidates for extensive, descriptive inventories such as the rangeland health rapid assessment.

Broad-scale STM development efforts will be best achieved as part of a cooperative, iterative, refinement process as described by Bestelmeyer et al. (2009). Different levels of data can be used effectively in different stages of the STM development process, with comprehensive, process-based STMs as the ideal product. A cooperative effort between agencies, researchers and land managers could provide the resources to increase accessibility to private land, refine ESD concepts systematically through a common database, and document states and community phases prior to the development of comprehensive, process-based STMs.
CHAPTER 4
SYNTHESIS

In this study, we presented three levels of data collection with STM development applications. The first level consists of photographs, GPS coordinates, rangeland health assessment indicators, production and step-point cover estimates for each state. Level one data is low cost, fast and easy to collect. Level one data has applications in developing and refining ecological site and STM concepts, documenting existing states, hypothesizing drivers of state change via rangeland health indicators, and locating study locations for future research (Bestelmeyer et al. 2009). Many land managers and agency personnel already collect level one data, though not necessarily according to ecological sites or for the purpose of developing STMs. There is a need for a coordinated effort among land management agencies, land owners, and researchers to compile level one data in order to document and refine ecological site and STM concepts prior to collecting more expensive types of data (Bestelmeyer et al. 2003).

The second level of data collection builds on the first by replacing production and cover estimates with multiple transects consisting of line-point intercept, double-sampling for production, and canopy gap-intercept for each state. Level two data requires more time and training than level one, but yields more reliable and repeatable data conducive to statistical interpretations (Herrick. et al 2005). It also provides context for the interpretation of qualitative indicators like those used in range health assessments. Level two data is ideal for long-term monitoring to identify transitions and thresholds.
In addition, level two data is increasingly being collected by land management agencies (Spaeth et al. 2003).

Level three data seeks to identify the drivers of state change by quantifying ecological processes (Stringham et al. 2003) using space for time substitutions. Level three data is expensive, time-consuming, and requires extensive training to collect, but it will eventually become necessary for STMs to gain credibility among users. Level three data will most likely be collected by researchers seeking to understand the processes that ultimately drive ecological systems (Westoby et al. 1989). Other data that will continue to be collected by researchers, though not attempted in this study, are from controlled experiments at the watershed scale and opportunistic studies along fence line contrasts or degradation gradients. The three levels of data collection described in this document are comparable to the three-tiered approach to STM development suggested by Bestelmeyer et al. (2009), with the primary difference being our inability to monitor the level two and level three datasets over an extended period of time.

We posed the question whether comprehensive, process-based STMs could be developed in a practical way. Through our efforts developing the STM for the Loamy Bottom ecological site, we are of the opinion that process-based STMs can be successfully developed for an entire ecological site and applied to management throughout the site extent. Naturally, local knowledge should always be used to further adapt even the best STMs to the specific piece of land being considered for management (Westoby et al. 1989; Bestelmeyer et al. 2004). Further refinements of our STM development approach and, more particularly, application of these methods to ecological
sites with statistically valid replications of states, should reinforce the credibility of STMs for accurately depicting plant community dynamics on rangelands.

We also asked what type of data is required to produce credible STMs, that is, STMs that accurately describe the plant community dynamics of ecological sites in a way that informs management decisions (Bellamy and Brown 1994). The type of data that will ultimately be required to develop such STMs is exemplified by the Loamy Bottom (basin wildrye) site study. However, all three levels of data collected in this project play a role in the development of reliable STMs. The Loamy Bottom ecological site was a good candidate for comprehensive, process-based STM development because: 1) the ecological site concepts were well-defined, 2) the site was unique enough to be quickly and accurately identified, 3) potential states and transitions had been hypothesized, and in some cases documented, by experts that were familiar with the site, and 4) the majority of the soil map unit polygons were easily accessible. But most ecological sites do not meet these four criteria. Given the early stages of STM development as a whole, we suggest that all types of site-specific data can be useful for STM development, whether it be in the stage of conceptual refinement, quantitative inventory, or comprehensive, process-based STM development.

Given the enormity of the task of developing credible STMs for more than 10,000 ecological sites in the United States, we recommend that data collection efforts be focused according to the current stage of STM development for any given ecological site. The first step is to refine ecological site and STM concepts with level one data compiled and collected at the regional scale. Valuable resources can be wasted by collecting level
two or level three data on an ecological site that is poorly defined. Soil survey updates will help in the effort to refine ecological site and STM concepts, but soil survey areas are usually too small to capture all of the variability that exists on an ecological site throughout the region where it occurs. Therefore, we suggest that region-wide efforts are needed to coordinate data compilation and collection among agencies, land managers and researchers (Knapp and Fernandez-Gimenez 2009), taking advantage of existing datasets, local knowledge, and any other data resources throughout the STM development process.

The basis of this STM development effort is found in a few seminal papers that outline in great detail the limitations and opportunities of developing reliable STMs. We recommend that future broad-scale STM development efforts consult the strategies outlined in this paper and in the publications that directed our efforts (Bestelmeyer et al. 2003, 2009; Herrick et al. 2006; Monger and Bestelmeyer 2006; Briske et al. 2008).
REFERENCES


APPENDICES
Appendix A: Supporting Information
There are six possible modifiers to give to an ecological site when naming them. These modifiers name aspects which influence the kind and amount of plants present in the historical climax community. The factors to determine slope, surface fragments, soil depth, soil texture and dominant aspect stay the same throughout the state. In order to determine the ecological zone MLRA specific factors must be evaluated.

**Ecological Zone**
- Typical - desert, semidesert, upland, mountain, and high mountain.
- Run in sites – alkali flat, alkali bottom, wet meadows, etc.
- Refer to the Utah MLRAs documents

**Slope descriptions**
<table>
<thead>
<tr>
<th>Percent slope</th>
<th>Modifier</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-50</td>
<td>none</td>
<td></td>
</tr>
<tr>
<td>30-50</td>
<td>steep</td>
<td>Steep is rarely used.</td>
</tr>
<tr>
<td>50 or greater</td>
<td>very steep</td>
<td>Determination of slope class is also dependent on the plant community and soil.</td>
</tr>
</tbody>
</table>

**% coarse fragments**
<table>
<thead>
<tr>
<th>% of Fragments</th>
<th>Modifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>In top 24 inches</td>
<td></td>
</tr>
<tr>
<td>0-35</td>
<td>none</td>
</tr>
<tr>
<td>35-50</td>
<td>Gravely</td>
</tr>
<tr>
<td>50-65</td>
<td>Stony</td>
</tr>
</tbody>
</table>

This modifier is based on water holding capacity. If there are other features such as soil texture that are the dominant influence on water holding capacity, then this modifier is not used.

**Soil depth***
<table>
<thead>
<tr>
<th>Depth</th>
<th>Modifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-14 in.</td>
<td>Very Shallow</td>
</tr>
<tr>
<td>10-20 in.</td>
<td>Shallow</td>
</tr>
<tr>
<td>20 in or greater</td>
<td>None</td>
</tr>
</tbody>
</table>

**Soil texture***
<table>
<thead>
<tr>
<th>Texture</th>
<th>Modifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Many, refer to the soil descriptions</td>
<td>Chose the most encompassing texture of the associated soils that influences the plant community</td>
</tr>
</tbody>
</table>

**Dominant aspect**
This identifies the most visual and least dynamic species occurring on the site. The species named here are not necessarily the dominant species by production.

*These values come directly from the soil or soil map unit descriptions

The values presented in this table should serve as a guide. The unique combination of all the attributes at a site will influence how and when the modifiers are used.
MLRA 28A - Great Salt Lake Area

<table>
<thead>
<tr>
<th>Ecological Zone</th>
<th>Desert</th>
<th>Semidesert</th>
<th>Upland*</th>
<th>Mountain*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>0-8 inches</td>
<td>8-12 inches</td>
<td>12-16 inches</td>
<td>16-22 inches</td>
</tr>
<tr>
<td>Elevation</td>
<td>4,100-5,100</td>
<td>4,300-6,000</td>
<td>4,300-7,000</td>
<td>5,200-8,600</td>
</tr>
<tr>
<td>Soil Moisture Regime</td>
<td>Typic Ardic</td>
<td>Xeric Aridic</td>
<td>Typic Xeric</td>
<td>Typic Xeric</td>
</tr>
<tr>
<td>Soil Temp Regime</td>
<td>Mesic</td>
<td>Mesic</td>
<td>Mesic</td>
<td>Frigid</td>
</tr>
<tr>
<td>Freeze free Days</td>
<td>120-200</td>
<td>100-140</td>
<td>100-130</td>
<td>85-110</td>
</tr>
<tr>
<td>Notes</td>
<td>Salt desert shrub 250 -500 lbs/ac</td>
<td>Sagebrushes are typical. 500 – 800 lbs/ac</td>
<td>Pinyon and Utah juniper are present, Sagebrushes are typical 700 – 1,000 lbs.ac</td>
<td>Oak and Maple 2,000-2,300</td>
</tr>
</tbody>
</table>

*the aspect (north or south) can greatly influence site characteristics.
All values in this table are approximate and should be used as guidelines. Different combinations of temperature, precipitation and soil type can place an ecological site into different zones.
28A—Great Salt Lake Area

This area is in Utah (82 percent), Nevada (16 percent), and Idaho (2 percent). It makes up about 36,775 square miles (95,300 square kilometers). Salt Lake City, Logan, Ogden, Provo, Richfield, and Cedar City, Utah, and Malad and Preston, Idaho, occur in this MLRA. Interstate 80 crosses the northern end of the MLRA, and Interstate 15 parallels the eastern border. Interstate 84 crosses the northern tip, and Interstate 70 ends at Interstate 15 in the south end of the MLRA. Several national forests occur in this MLRA, including the Caribou, Dixie, Wasatch, Humboldt-Toiyabe, and Fish Lake National Forests. The Deseret Test Center and the Desert Range Experiment Station, including the Biosphere Reserve, occur in this area. The Hill and Wendover Air Force Ranges, the Tooele Military Depot, and the Dugway Proving Grounds also occur in this area. The Skull Valley Indian Reservation is in the area. The Bonneville Salt Flats Speedway, used by experimental cars for setting land speed records, also is in the area. The Golden Spike National Historic Site (joining point for the first transcontinental railroad) is in this MLRA.

Physiography

This area is the farthest eastern extent of the Great Basin Section of the Basin and Range Province of the Intermontane Plateaus. It is an area of nearly level basins between widely separated mountain ranges trending north to south. The basins are bordered by long, gently sloping alluvial fans. The mountains are uplifted fault blocks with steep side slopes. They are not well dissected because of low rainfall in the MLRA. A large salt desert playa is south and west of Great Salt Lake. Most of the valleys in this MLRA are closed basins containing sinks or playa lakes. Elevation ranges from 3,950 to 6,560 feet (1,205 to 2,000 meters) in the basins and from 6,560 to 11,150 feet (2,000 to 3,400 meters) in the mountains. The extent of the major Hydrologic Unit Areas (identified by four-digit numbers) that make up this MLRA is as follows: Great Salt Lake (1602), 58 percent; Escalante Desert-Sevier Lake (1603), 28 percent; Central Nevada Desert Basins (1606), 6 percent; Bear (1601), 5 percent; and Lower Colorado-Lake Mead (1501), 3 percent. The Jordan, Bear, and Weber Rivers, the main rivers in this area, all terminate in Great Salt Lake. The Sevier River is in the south half of the area. Numerous creeks drain the Wasatch Mountain front directly east of Salt Lake City, and many terminate in Great Salt Lake directly west of Salt Lake City.

Geology

Most of this area has alluvial valley fill and playa lakebed deposits at the surface. Great Salt Lake is all that remains of glacial Lake Bonneville, which covered this area during the most recent ice age. A level line on some mountain slopes indicates the former extent of this glacial lake. The uplifted mountains have exposed some Precambrian rocks at their margins. Most of the mountains in the interior of this area consist of tilted blocks of marine sediments from Cambrian to Mississippian age. There are no rocks representing the Mesozoic era in this area. Scattered outcrops of Tertiary continental sediments and volcanic rocks are throughout the area. These units are concentrated on the
east and west edges of the area. The Tertiary intrusives are the dominant rock types at the southern end of the MLRA.

**Climate**

The average annual precipitation is 5 to 12 inches (125 to 305 millimeters) in the valleys and is as much as 49 inches (1,245 millimeters) in the mountains. Most of the rainfall occurs as high-intensity, convective thunderstorms during the growing season. The driest period is from midsummer to early autumn. Precipitation in winter typically occurs as snow. The average annual temperature is 39 to 53 degrees F (4 to 12 degrees C). The frost-free period averages 165 days and ranges from 110 to 215 days, decreasing in length with elevation.

**Water**

Following are the estimated withdrawals of freshwater by use in this MLRA:

- Public supply—surface water, 5.5%; ground water, 8.5%
- Livestock—surface water, 1.2%; ground water, 0.8%
- Irrigation—surface water, 65.3%; ground water, 14.5%
- Other—surface water, 1.0%; ground water, 3.2%
The total withdrawals average 3,575 million gallons per day (13,530 million liters per day). About 27 percent is from ground water sources, and 73 percent is from surface water sources. Water is scarce. For the most part, streams are small and intermittent and depend on sources in the higher mountains. Reservoirs are used to store water in the mountains east of this area for irrigation in the flatter areas of this MLRA. As an example, the Sevier River, in the southern part of this area, is the most heavily used river in the United States. Almost 99 percent of its total flow is used before it reaches its terminus in the mostly dry Sevier Lake. The surface water from the mountains is of good quality, and its use generally is not limited. Irrigation return flows raise the levels of dissolved salts and suspended sediments, causing some contamination. Both surface water and ground water are used for irrigation. Use of deep wells is limited by a high cost. Shallow wells in the basin and valley fill aquifers provide almost all of the ground water used in this area. This shallow ground water generally contains less than 1,000 parts per million (milligrams per liter) total dissolved solids. Along the northeastern border of this area, near the Wasatch Front where the alluvial aquifers are recharged, ground water is much lower in dissolved salts (typically less than 250 parts per million) and is a primary source of drinking water for the populated areas all along the Wasatch Front. The ground water becomes almost saline near the playa lakes west of the recharge zone. A basin fill deposit near Sevier Lake contains high levels of arsenic.

Soils

The dominant soil orders in the MLRA are Aridisols, Entisols, and Mollisols. The soils in the area dominantly have a mesic or frigid soil temperature regime, an aridic or xeric soil moisture regime, and mixed mineralogy. They generally are well drained or somewhat excessively drained, loamy or loamy skeletal, and very deep. Calcixerolls formed in alluvium on alluvial fan remnants and lake terraces (Abela series) and in alluvium and lacustrine sediments on lake terraces (Collinston series). Moderately deep Haploxerolls (Middle series) formed in residuum on mountain slopes. Deep and very deep Haploxerolls (Ririe and Rexburg series) formed in loess and silty alluvium on fans, terraces, foothills, and basalt plains. Shallow Haploxerolls (Hymas series) to very deep Haploxerolls (Hondoho series) formed in colluvium and residuum derived from limestone on mountains and foothills. Torriorthents formed in alluvium on alluvial fans and beach plains (Clifdown series) and in alluvium mixed with lacustrine sediments on alluvial flats and fans, lake terraces, and lake plains (Timpie and Tooele series). Poorly drained Aquisalids (Saltair series) formed in alluvium and lacustrine sediments on lake plains and basin floors. Torripsamments (Yenrab series) formed in sandy eolian material on dunes. Haplocalcids formed in residuum on hills and mountains (shallow Amtoft series); in alluvium and colluvium on alluvial fans, terraces, and hills (Hiko Peak series); in mixed alluvium and lacustrine sediments on alluvial fans, terraces; and lake plains (Taylorsflat series); and in lacustrine sediments on lake terraces (Thiokol series). Natrargids (Skumpah series) formed in alluvium on alluvial fans and flats.
Biological Resources

This area supports desert shrub, Sagebrush Semidesert, and woodland vegetation. In areas where the average annual precipitation is less than about 200 millimeters, the soils support shadscale, winterfat, black sagebrush, and associated grasses, such as Indian ricegrass and squirreltail. Greasewood and Nuttall saltbush grow on soils having a high content of salts or sodium. In areas where the average annual precipitation is 200 to 300 millimeters, the soils support big sagebrush, shadscale, winterfat, and associated grasses, such as bluebunch wheatgrass, Indian ricegrass, and bluegrasses. In areas where the average annual precipitation is more than 300 millimeters, the soils support Utah juniper, singleleaf pinyon, big sagebrush, bluebunch wheatgrass, bluegrasses, and needleandthread. A large, nearly barren area west of Great Salt Lake has a very sparse cover of pickelweed, sapphire eriastrum, seepweed, and greasewood. Some of the major wildlife species in this area are mule deer, jackrabbit, cottontail, Cooper’s hawk, American kestrel, redtailed hawk, prairie falcon, rough-legged hawk, Swainson’s hawk, and chukar. Brine shrimp occur in Great Salt Lake and warm-water species of fish occur in other freshwater lakes in the valleys. Mountain streams in the Wasatch Mountains are inhabited by trout.

Land Use

Following are the various kinds of land use in this MLRA:

- Cropland—private, 6%; Federal, 44%
- Grassland—private, 21%; Federal, 44%
- Forest—private, 2%; Federal, 12%
- Urban development—private, 2%
- Water—private, 7%; Federal, 2%
- Other—private, 4%

About three-fifths of this area is Federally owned land, large tracts of which are used for training and testing purposes by the Armed Forces and the Nuclear Regulatory Commission. A large area west and southwest of Great Salt Lake is a salty playa. The rest of the area is in farms and ranches. Livestock production on rangeland is a principal agricultural enterprise in the west. The production of desert shrubs and grasses is very low. In most of the area, the extent of the livestock industry is determined largely by the amount of hay, pasture, and grain that can be produced under irrigation from limited water supplies. About 5 percent of the area is irrigated cropland or hayland used for alfalfa, small grain (wheat, barley, oats, and triticale), Austrian winter peas, corn for grain or silage, potatoes, vegetables (onions, pumpkins, sweet corn, peas, and squash), and fruits (apples, peaches, pears, apricots, and cherries). A small portion of the irrigated land is used for pasture. About 5 percent is used for production of dryland winter wheat and safflowers. The management concerns on rangeland include forage production and the efficient use of range vegetation. The rangeland in the area is increasingly impacted by invasive nonnative plants. The management concerns on dry-farmed cropland include productivity, wind erosion, water erosion, moisture management, and weed control. The
management concerns on irrigated cropland and hayland include productivity, the efficient use of limited water supplies, control of irrigation induced erosion, and nutrient and pest management. Soil tilth, compaction, and maintenance of the content of organic matter in the soils are additional concerns on irrigated and dry-farmed cropland. The management concerns on irrigated pasture include productivity, proper grazing use, efficient use of limited water supplies, nutrient management, and weed control. Conservation practices on rangeland generally include brush management, rangeland seeding, prescribed grazing, fencing, development of watering facilities, and erosion control. Conservation practices on dry-farmed cropland generally include terraces, sediment-control basins, summer fallow tillage, crop residue management, pest management, and nutrient management. Conservation practices on irrigated cropland and hayland include irrigation system improvement, irrigation water management, no-till hayland planting, forage harvest management, nutrient management, windbreaks, and pest management. Conservation practices on irrigated pasture generally include irrigation system improvement, irrigation water management, pasture planting, development of watering facilities, fencing, prescribed grazing, nutrient management, and pest management.
### MLRA 47XA - Wasatch Mountains - North

<table>
<thead>
<tr>
<th>Ecological Zone</th>
<th>Upland*</th>
<th>Mountain*</th>
<th>High Mountain</th>
<th>Subalpine</th>
<th>Alpine</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Precipitation (inches)</strong></td>
<td>12-16</td>
<td>16-22</td>
<td>22-40</td>
<td>&gt;35</td>
<td>&gt;35</td>
</tr>
<tr>
<td><strong>Elevation</strong></td>
<td>4,300-7,000</td>
<td>5,200-8,600</td>
<td>6,000-9,400</td>
<td>8,000-10,000</td>
<td>&gt;10,000</td>
</tr>
<tr>
<td><strong>Soil Moisture Regime</strong></td>
<td>Typic Xeric</td>
<td>Typic Xeric</td>
<td>Udic</td>
<td>Udic</td>
<td>Udic</td>
</tr>
<tr>
<td><strong>Soil Temp Regime</strong></td>
<td>Mesic or Frigid</td>
<td>Frigid</td>
<td>Cryic</td>
<td>Cryic</td>
<td>Cryic</td>
</tr>
<tr>
<td><strong>Freeze free Days</strong></td>
<td>100-130</td>
<td>85-110</td>
<td>50-100</td>
<td>20-35</td>
<td>5</td>
</tr>
<tr>
<td><strong>Notes</strong></td>
<td>P. and J. present. Pinyon is typically more dominant</td>
<td>Oak and Maple</td>
<td>Aspen and White Fir</td>
<td>Subalpine Fir, Engelmann Spruce</td>
<td>Above Timberline</td>
</tr>
</tbody>
</table>

*the aspect (north or south) can greatly influence site characteristics.

All values in this table are approximate and should be used as guidelines. Different combinations of temperature, precipitation and soil type can place an ecological site into different zones.
47XA—Wasatch Mountains North
Coalville, Heber City, Park City, Utah, and Evanston, Wyoming, are in this MLRA. Interstate 80 crosses this area. This MLRA includes numerous wilderness study areas. It has numerous national forests, including the Ashley, Caribou, Fishlake, Manti-LaSal, Uinta, and Wasatch-Cache National Forests.

Physiography
This area is in the Middle Rocky Mountains Province of the Rocky Mountain System. Parts of the western edge of this MLRA are in the Great Basin Section of the Basin and Range Province of the Intermontane Plateaus. The MLRA includes the Wasatch Mountains, which trend north and south. The steeply sloping, precipitous Wasatch Mountains have narrow crests and deep valleys. Active faulting and erosion are a dominant force in controlling the geomorphology of the area. Some of mountain areas that are above 7,500 feet (2,285 meters) and all of the areas above 10,000 feet (3,050 meters) have been subject to alpine or mountain glaciation. There are aretes, horns, cirques, all types of moraines, and outwash features. The Wasatch Mountains have an elevation of 4,900 to about 13,500 feet (1,495 to 4,115 meters). The extent of the major Hydrologic Unit Areas that make up E47 as a whole (including E47XA, E47XB, and E47XC) are as follows: Escalante Desert-Sevier Lake (1603), 25 percent; Great Salt Lake (1602), 18 percent; Lower Green (1406), 18 percent; Bear (1601), 13 percent; Great Divide-Upper Green (1404), 11 percent; Upper Colorado-Dirty Devil (1407), 9 percent; Lower Colorado-Lake Mead (1501), 4 percent; and White-Yampa (1405), 2 percent. The Weber and Provo Rivers run through this area.

Geology
The mountains in this area are primarily fault blocks that have been tilted up. Alluvial fans at the base of the mountains are recharge zones for the basin fill aquifer and are significant sources of sand and gravel for construction. An ancient shoreline of historic Lake Bonneville is evident on the footslopes along the western edge of the area. Rocks exposed in the mountains are mostly Mesozoic and Paleozoic sediments. Younger igneous rocks (ash and lava) are throughout the area.

Soils
The dominant soil orders in this MLRA are Aridisols, Entisols, Inceptisols, and Mollisols. The soils in the area dominantly have a frigid soil temperature regime on plateaus and the lower mountain slopes and a cryic soil temperature regime at the higher elevations. They have a mesic soil temperature regime at the lowest elevations, on south-facing slopes. The soil moisture regime is typically xeric. Mineralogy is typically mixed. The soils are very shallow to very deep, generally well drained, and loamy or loamy-skeletal. Haplocalcids formed in mixed residuum and alluvium on mesas, fan aprons, terraces, and plateaus (Langspring and Teagulf series) and in mixed alluvium and colluvium on fans, terraces, and toe slopes (Bruman series). Calcigypsids (Rogrube series) formed in mixed loess and residuum on plateaus. Torriorthents formed in residuum, in some areas mixed with colluvium, on hills, mesas, cuestas, plateaus, and
pediments (Atchee, Blazon, Delphill, Haterton, Huguston, and Moyerson series) and in alluvium on alluvial fans and valley floors (Sagers, Alldown, and Tebbs series). Dystrocryepts (Mirror Lake series) formed in till on moraines. Calciustepts (Rentsac series) formed in colluvium over residuum on mountains, hills, and plains. Haploxerolls (Agassiz series) and Argicryolls (Dranyon series) formed in residuum on mountains. Palexerolls (Borvant series) and Argixerolls (Ant Flat, Henefer, and Yeates Hollow series) formed in alluvium or colluvium on fan terraces, piedmonts, and hills. Palecryolls (Lucky Star series) formed in till, residuum, or colluvium on mountains and moraines.

Climate
The average annual precipitation in most of this area is 15 to 30 inches (380 to 760 millimeters). It can be as much as 73 inches (1,855 millimeters) at the higher elevations. Peak precipitation occurs in the winter months. The higher elevations receive significant amounts of snowfall each year. The average annual temperature is 30 to 58 degrees F (-1 to 15 degrees C). The frost-free period averages 140 days and ranges from 60 to 220 days, generally decreasing in length with elevation.
Water

Following are the estimated withdrawals of freshwater by use in E47 as a whole (including E47XA, E47XB, and E47XC):

- Public supply—surface water, 0.1%; ground water, 0.1%
- Livestock—surface water, 4.1%; ground water, 1.0%
- Irrigation—surface water, 69.7%; ground water, 17.4%
- Other—surface water, 3.7%; ground water, 4.0%

The total withdrawals average 380 million gallons per day (1,440 million liters per day). About 22 percent is from ground water sources, and 78 percent is from surface water sources. Streams, lakes, and ground water supply enough water for the grazing and forestry enterprises in most of the area. Reservoirs in the mountains of this area store water for downstream use. The mountain water is of excellent quality. Perennial streams from the Wasatch Mountains in this area provide irrigation and municipal and industrial water for most of the population in Utah. Ground water in this area is primarily in the unconsolidated deposits of sand and gravel filling the major river valleys in the interior of the area and similar deposits filling the basins on the western edge of the area. Water from these aquifers is very hard but typically contains less than 1,000 parts per million (milligrams per liter) total dissolved solids. Low levels of salts occur in the ground water closest to the recharge areas along the base of the mountains, while briny water occurs in the deeper parts of these deposits.

Biological Resources

This area supports conifer, aspen, grass, mountain shrub, and Sagebrush steppe vegetation. The composition of the vegetation varies with elevation. The zone above an elevation of about 13,000 feet (3,965 meters) supports alpine meadow. Coniferous forests of Engelmann spruce, white fir, subalpine fir, and Rocky Mountain Douglas-fir dominate the mid to high elevations. The most common understory plants in these forests are Oregongrape, myrtle pachystima, and heartleaf Arnica. Forests of quaking aspen commonly have an understory that includes blue wildrye, mountain brome, Fendler meadowrue, and aspen peavine. Bluebunch wheatgrass, bearded wheatgrass, blue wildrye, mountain brome, and numerous forbs grow in the understory in areas of Gambel oak, curl-leaf and birchleaf mountain mahogany, snowberry, and serviceberry. Big sagebrush and bluebunch wheatgrass are the dominant species in the sagebrush steppe plant communities that are common at the lowest elevations. Some of the major wildlife species in this area are moose, elk, mule deer, coyote, red fox, bobcat, beaver, porcupine, snowshoe hare, jackrabbit, turkey, sage grouse, chukar, sharp-tailed grouse, gray partridge, ruffed grouse, and blue grouse. The species of fish in the area include rainbow trout, brown trout, brook trout, cutthroat trout, catfish, and sucker.

Land Use

Following are various kinds of land use in E47 as a whole (including 47XA, 47XB, and 47XC):
Cropland—private, 2%
Grassland—private, 25%; Federal, 35%
Forest—private, 7%; Federal, 25%
Urban development—private, 1%
Water—private, 1%; Federal, 1%
Other—private, 1%; Federal, 2%

Less than one-third of this area is in farms and ranches. The rest of the area generally is Federally owned. Grassland and woodland are grazed in summer. Some dense forests are on moist sites. Recreation and mining are important land uses. A few valleys are irrigated. Forage for livestock is the main crop. The major soil resource concerns are wind erosion, water erosion, maintenance of the productivity of the soils, and maintenance of the quality of surface water. Maintaining a vegetative cover, maintaining the content of organic matter, and preventing excessive compaction are important. Mass movement of the soils also is a concern. Proper grazing use is a concern on grazing lands. In timbered areas, the primary concerns during timber harvesting are controlling erosion along roads and skid trails and minimizing the compaction caused by harvesting equipment. Conservation practices on rangeland generally include brush management, rangeland seeding, prescribed grazing, prescribed burning, fencing, and development of watering facilities. Conservation practices on dry-farmed cropland include terraces, sediment-control basins, summer fallow tillage, crop residue management, and pest management. Conservation practices on irrigated cropland and hayland include irrigation system improvement, irrigation water management, conservation tillage, crop rotation, crop residue management, forage harvest management, and nutrient management. Conservation practices on irrigated pasture include irrigation system improvement, irrigation water management, pasture planting, development of watering facilities, fencing, prescribed grazing, and nutrient management.
Appendix B: Ecological Site Descriptions
ECOLOGICAL SITE CHARACTERISTICS

Site Type: Rangeland

Site Name: Loamy Bottom (Basin Wildrye)

/ Artemisia tridentata ssp. tridentata - Ericameria nauseosa / Leymus cinereus - Pascopyrum smithii
( / basin big sagebrush - rubber rabbitbrush / basin wildrye - western wheatgrass)

Site ID: R028AA006UT

Major Land Resource Area: 028A-Great Salt Lake Area

Site concept: The loamy bottom (basin wildrye) ecological site is a run-in site found in the semidesert and upland precipitation zones of the northeastern Great Basin. It developed in a continental climate receiving 10-14 inches of mostly cool-season precipitation annually. The site occurs in the watershed in areas that receive extra water and fine sediment from surrounding uplands. Consequently, the soils are deep, loamy mollisols with high water-holding capacity and a seasonally-heightened water table from March to June. Buried surface horizons and very little rock characterize the soil profile. The soil moisture regime is xeric and the soil temperature regime is mesic. The historic climax plant community is dominated by basin wildrye (Leymus cinereus), basin big sagebrush (Artemisia tridentata ssp. tridentata), western wheatgrass (Pascopyrum smithii) and rubber rabbitbrush (Ericameria nauseosa).

Physiographic Features

This site receives extra water from surrounding uplands and is often associated with stream terraces, drainage ways, flood plains and alluvial fans. It is found on gently-sloping, low-lying areas at elevations between 4,500 and 6,200 feet. The water table is usually several feet below the soil surface, though raised water tables and brief flooding may occur from March to June. This site extends throughout both the semidesert and upland precipitation zones.

Landform: (1) Stream terrace
(2) Flood plain
(3) Alluvial fan
Elevation (feet): 4250 6200
Slope (percent): 0 4
Water Table Depth (inches): 72
Flooding:
  Frequency: None Rare
  Duration: Extremely brief Very brief
Ponding:
  Depth (inches):
  Frequency: None None
  Duration: None None
Runoff Class:
Aspect: No Influence on this site

Climatic Features

The climate of this site is characterized by warm, dry summers and cold, wet winters and springs. May is the wettest month and July and August are typically the driest. Much of the moisture required for plant growth enters this site as groundwater or runoff from surrounding uplands. Summer thunderstorms tend not to be a reliable source of moisture to support the vegetation of this site.

Minimum  Maximum
Frost-free period (days): 91 118
Freeze-free period (days): 127 150
Mean annual precipitation (inches): 10.0 14.0

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<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
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<td>0.49</td>
<td>0.61</td>
<td>0.59</td>
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<td>0.32</td>
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<td>38.7</td>
<td>46.1</td>
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<td>78.4</td>
<td>65.6</td>
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Climate Stations: (1) 42334803, Grantsville. Period of record 1956 - 2008
(2) 42349101, Grouse Creek. Period of record 1957 - 2007
(3) 42417401, Ibapah. Period of record 1948 - 2007
(4) 42672403, Payson. Period of record 1948 - 1999
Influencing Water Features

Wetland Description: System Subsystem Class

Representative Soil Features

The soils of this site formed in alluvium derived from sandstone, limestone or quartzite. These are deep, loamy soils with very little rock on the surface or throughout the profile. A mollic epipedon is typically present (though not always) and is 20 to 40 inches thick. Sometimes there is a buried surface layer at depths up to 60 inches. Available water holding capacity is high, ranging from 5.5 to 7.3 inches of water in the upper 40 inches of soil. These soils are well-drained with moderately slow to moderate permeability. Calcium carbonate is usually less than 15 percent, but can be as high as 30 percent. Soil pH typically ranges from 7.4 to 9.0. The soil moisture regime is xeric and the soil temperature regime is mesic.

Soil components correlated to this site are:

Soil Survey Area (UT) Soil Components (Map units in parentheses)

Box Elder County, Western Part (UT601) Birdow (8), Koosharem (44);

Camp Williams (UT605) Red Rock (8015);

Tooele Area (UT611) Birdow (6);

Utah County (UT621) Redola (RdA, ReC)

Parent Materials:
Kind: Alluvium
Origin: Limestone and sandstone, Quartzite

Surface Texture: (1) Loam
(2) Silt loam

Subsurface Texture Group: Loamy

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<th>Surface/Subsurface Fragments</th>
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<td>Surface Fragments &lt;=3&quot; (% Cover):</td>
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<td>8</td>
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<td>Subsurface Fragments &lt;=3&quot; (% Volume):</td>
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<td>10</td>
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Subsurface Fragments > 3” (% Volume): 0 2

Drainage Class: Well drained To Well drained
Permeability Class: Moderately slow To Moderate

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<tr>
<td>Depth (inches): 60</td>
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<td>Electrical Conductivity (mmhos/cm): 0 4</td>
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<td>Sodium Absorption Ratio: 0 5</td>
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<td>Calcium Carbonate Equivalent (percent): 0 30</td>
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<td>Soil Reaction (1:1 Water): 7.4 9.0</td>
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<tr>
<td>Soil Reaction (0.01M CaCl2):</td>
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<tr>
<td>Available Water Capacity (inches): 5.5 7.3</td>
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**Plant Communities**

Refer to STM in text.

**Ecological Site Interpretations**

**Animal Community:**
**Livestock:**
This site has good forage for cattle and horses, but may be less suited for sheep grazing. Basin wildrye is most palatable in the spring and may not be utilized at all during the winter months by livestock. (Dittberner)

**Wildlife:**
This site provides visual and thermal cover for wildlife species, particularly game birds, non-game birds, and small mammals. Mule deer, elk and pronghorn antelope may also bed beneath the Basin wildrye growth.

Reference State and Current Potential State: The abundant palatable forage and proximity to water make this state important for grazers and mixed feeders such as elk, deer, and antelope. The site also provides suitable thermal and escape cover for these animals. This plant community may provide brood rearing/foraging habitat for upland game birds. In good condition this site provides plentiful food, and cover for wildlife. Other wildlife using this site include cottontail rabbits; coyote; gold eagle; ravens and mule deer. This is a short list of the more common species found. Many other species are present as well as migratory birds are present at certain times of the year.

Seeded Range State: The seeded range site’s ability to provide wildlife habitat is dependent on the seed mix and mechanical treatments chosen by the manager. If the site is planted to a monoculture of a grass species, then wildlife use will be diminished. The above mentioned grazers will use the grasses species, but the use will be more seasonal
than if the area supported a diverse mix of species. And the lack of escape or thermal cover will also limit the amount of time the site is utilized for foraging or loafing. But if a diverse seed mix that is reflective of the reference state is established, wildlife use will be similar to the Reference State.

Annual Grass Invasion: This site has very limited wildlife habitat potential. Annual grasses such as cheatgrass green up for only a short time in the spring and then again in the late fall. This creates a long period of poor quality forage at the site. Also the thermal and escape cover is gone, thus creating a harsh environment that will receive very little use by the species expected in the reference state. In these disturbed states, wildlife that prefer less ground cover will dominate. Typically these are more generalist birds such as the lark sparrow, raven, and starlings. Other wildlife using this site includes cottontail rabbits; coyote; and mule deer. This is a short list of the more common species found. Many other species are present as well as migratory birds are present at certain times of the year.

Plant Preference by Animal Kind:

Hydrology Functions:
Soils are in hydrologic group B, with runoff curves ranging from 61 to 79 depending on hydrologic condition.

Recreational Uses:
This site has values for natural beauty. It attracts many kinds of wildlife for viewing and can have a diversity of flowering plants. Other recreation opportunities include hiking, picnicking, horseback riding and hunting. Roads are often built on or near this site, allowing easy access which may result in overuse and degradation of the site.

Wood Products:
None

Other Information:

Supporting Information

Associated Sites:

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Semidesert Loam (Basin Big Sagebrush)  R028AY221UT
Upland Gravelly Loam (Wyoming Big Sagebrush)  R028AY307UT

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<td>LOAMY BOTTOM 10-14 P.Z.</td>
<td>R028AY090NV</td>
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State Correlation:
This site has been correlated with the following states: NV

Inventory Data References:

Type Locality:
- State: UT
- County: Box Elder
- Township: 11 N
- Range: 13 W

Relationship to Other Established Classifications:


Western Intermountain Sagebrush Steppe (West 1983)
Natureserve Artemisia tridentata ssp. tridentata / Leymus cinereus Shrubland
CEGL001016

Other References:


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Reference Sheet

Author(s)/participant(s): Jack Alexander, Range Specialist, Synergy Resource Solutions, Inc. Julia Kluck, Soil Scientist, Synergy Resource Solutions, Inc. Shane Green, State Range Specialist, Utah NRCS
Contact for lead author: shane.green@ut.usda.gov

Date: 2/8/2010          MLRA: 028A          Ecological Site: Loamy Bottom (Great Basin Wildrye) R028AY006UT This must be verified based on soils and climate (see Ecological Site Description). Current plant community cannot be used to identify the ecological site.

Composition (indicators 10 and 12) based on: X Annual Production, Foliar Cover, Biomass

**Indicators.** For each indicator, describe the potential for the site. Where possible, (1) use numbers, (2) include expected range of values for above- and below-average years for each community and natural disturbance regimes within the reference state, when appropriate and (3) cite data. Continue descriptions on separate sheet.

1. **Number and extent of rills:** No rills present. Very minor rill development may occur in sparsely vegetated areas. If rills are present, they should be widely spaced and not connected. Rill development may increase following large storm events, but should begin to heal during the following growing season. Frost heaving will accelerate recovery. Rill development may increase when run inflow enters site from adjacent sites that produce large amounts of runoff (i.e. steeper sites, slickrock, rock outcrop). Site is essentially level and rills do not form.

2. **Presence of water flow patterns:** Few originating on this site. Flow patterns meander around rocks, litter, and perennial plant bases. They may be long (10-20’), but remain less than 1’ wide, and are widely spaced (5-15’ apart). They are stable with only minor evidence of deposition. This site is periodically inundated with runoff water due to its physiographic location.

3. **Number and height of erosional pedestals or terracettes:** Plants may have small pedestals (1-3”) where they are adjacent to water flow patterns, but without exposed roots. Terracettes should be few and stable. Terracettes should be small (1-3”) and show little sign of active erosion. Some plants may appear to have a pedestal but rather than be formed by erosion, the only place litter accumulates and soil collects is at plant bases forming the appearance of a pedestal.

4. **Bare ground from Ecological Site Description or other studies (rock, litter, standing dead, lichen, moss, plant canopy are not bare ground):** 10 – 20% bare ground (soil with no protection from raindrop impact). Herbaceous communities
are most likely to have lower values. As species composition by shrubs increases, bare ground is likely to increase. Poorly developed biological soil crust that is susceptible to raindrop splash erosion should be recorded as bare ground. Very few if any bare spaces of greater than 1 square foot.

5. **Number of gullies and erosion associated with gullies:** Gullies may be present, but are rare. They would usually be expected in the lowest part of the site where water flows concentrate and/or in locations where there are concentrated flows into the site from an adjacent site or watershed. Gullies may show signs of active erosion along steep side walls but the bottoms would be mostly stabilized with perennial vegetation. Additional erosion is to be expected where concentrated flow patterns enter the site from adjacent steep slopes or drainages.

6. **Extent of wind scoured, blowouts and/or depositional areas:** Very minor evidence of active wind-generated soil movement. Wind scoured (blowouts) and depositional areas are rarely present. If present they have muted features and are mostly stabilized with vegetation and/or biological crust. Gravel or desert pavement protects the site from wind scour.

7. **Amount of litter movement (describe size and distance expected to travel):** Most litter resides in place with some redistribution caused by water and wind movement. Very minor litter removal may occur in flow patterns and rills with deposition occurring at points of obstruction. The majority of litter accumulates at the base of plants. Some leaves, stems, and small twigs may accumulate in soil depressions adjacent to plants. Woody stems are not likely to move.

8. **Soil surface (top few mm) resistance to erosion (stability values are averages - most sites will show a range of values):** This site should have an erosion rating of 5 or 6 under plant canopies and a rating of 4 to 5 in the interspaces with an average rating of 5 using the soil stability kit test.

9. **Soil surface structure and SOM content (include type and strength of structure, and A-horizon color and thickness):** This description is based on the modal soil (Birdow SiL, soil survey area: 601, West Box Elder). This site has 3 correlated soils, resulting in variation of each of these attributes. Unless working on a location with the modal soil, it is critical to supplement this description with the soil-specific information from the published soil survey. Soil surface horizon is typically 20 to 41 inches deep. Structure is typically weak medium subangular blocky. Color is typically brown (10YR 5/3), very dark grayish brown (10YR 3/2) moist. Mollic epipedon is common.
10. **Effect on plant community composition (relative proportion of different functional groups) and spatial distribution on infiltration and runoff:** Vascular plants and any well-developed biological soil crusts (where present) will break raindrop impact and splash erosion. Spatial distribution of vascular plants and interspaces between well-developed biological soil crusts (where present) provide detention storage and surface roughness that slows runoff allowing time for infiltration. With the physiographic location of the site being in stream terraces, alluvial flats, drainage ways, and flood plains this site is one of the terminal accumulation sites for runoff water. As such, infiltration is naturally facilitated. Natural erosion would be expected in severe thunder storms or heavy spring runoff. When perennial grasses decrease, reducing ground cover and increasing bare ground, runoff is expected to increase and any associated infiltration reduced.

11. **Presence and thickness of compaction layer (usually none; describe soil profile features which may be mistaken for compaction on this site):** None. Naturally occurring soil horizons may be harder than the surface and should not be considered as compaction layers.

12. **Functional/Structural Groups (list in order of descending dominance by above-ground weight using symbols: $$\gg$$, $$\succ$$, $$\succeq$$ to indicate much greater than, greater than, and equal to) with dominants and sub-dominants and "others" on separate lines:**
   - Dominant: basin wildrye
   - Sub-dominant: western wheatgrass, basin big sagebrush
   - Other: shrubs $$\succ$$ forbs $$\succ$$ other grasses
   Additional: Functional/structural groups may appropriately contain non-native species if their ecological function is the same as the native species in the reference state (e.g. crested wheatgrass and Russian wildrye may substitute for mid stature cool season perennial native bunchgrasses.). Biological soil crust is variable in its expression on this site and is measured as a component of ground cover. Forbs can be expected to vary widely in their expression in the plant community based upon departures from average growing conditions.

13. **Amount of plant mortality and decadence (include which functional groups are expected to show mortality or decadence):** During years with average to above average precipitation, there should be very little recent mortality or decadence apparent in either the shrubs or grasses. Some mortality of bunchgrass and other shrubs may occur during very severe (long-term) droughts. There may be partial mortality of individual bunchgrasses and shrubs during less severe drought. Long-lived species dominate site. Open spaces from disturbance are quickly filled by new plants through seedlings and reproductive reproduction (tillering).
14. **Average percent litter cover (20-25 %) and depth (0.5-1 inches):** Litter cover includes litter under plants. Most litter will be fine litter. Depth should be 1-2 leaf thickness in the interspaces and up to 1/2” under canopies. Litter cover may increase to 25-30% following years with favorable growing conditions. Excess litter may accumulate in absence of disturbance. Vegetative production may be reduced if litter cover exceeds 40%.

15. **Expected annual production (this is TOTAL above-ground production, not just forage production):** 1500#/acre. Even the most stable communities exhibit a range of production values. Production will vary between communities and across the MRLA. Refer to the community descriptions in the ESD. Production will differ across the MLRA due to the naturally occurring variability in weather, soils, and aspect. The biological processes on this site are complex; therefore, representative values are presented in a land management context.

16. **Potential invasive (including noxious) species (native and non-native).** List Species which BOTH characterize degraded states and have the potential to become a dominant or co-dominant species on the ecological site if their future establishment and growth is not actively controlled by management interventions. Species that become dominant for only one to several years (e.g., short-term response to drought or wildfire) are not invasive plants. Note that unlike other indicator, we are describing what in NOT expected in the reference state for the ecological site: Halogeton, Russian thistle, cheatgrass

17. **Perennial plant reproductive capability:** All perennial plants should have the ability to reproduce sexually or asexually, except in drought years. Density of plants indicates that plants reproduce at level sufficient to fill available resource. Within capability of site there are no restrictions on seed or vegetative reproductive capacity.

Reference Sheet Approval:

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ECOLOGICAL SITE CHARACTERISTICS

Site Type: Rangeland

Site Name: Upland Loam (Mountain Big Sagebrush)

/ Artemisia tridentata ssp. vaseyana /  
( / mountain big sagebrush / )

Site ID: R028AY310UT

Major Land Resource Area: 028A-Great Salt Lake Area

Site concept: The upland loam (Mountain big sagebrush) site is a sagebrush grassland that occurs primarily on loamy benches and foothills of the eastern Great Basin. It developed in a continental climate receiving 13-19 inches of mostly cool-season precipitation annually. Soils are loamy mollisols (dark brown in upper 20 inches), moderately deep to deep and typically have less than 15 percent rock fragments throughout. The soil moisture regime is xeric and the soil temperature regime is mesic. This site produces 800 to 1400 pounds of vegetation annually. The historic climax plant community is dominated by bluebunch wheatgrass (Pseudoroegnaria spicata), mountain big sagebrush (Artemisia tridentata ssp. vaseyana), Indian ricegrass (Achnatherum hymenoides), and antelope bitterbrush (Purshia tridentata).

Physiographic Features

This site occurs on loamy lake terraces, alluvial fans and fan remnants at elevations of 4,200 to 6,500 feet. It is most commonly found on gentle slopes, but can occupy slopes of up to 30 percent. Runoff is variable depending on slope, basal cover and soil permeability. Much of this site has been developed for dry farming, CRP or residential housing.
Landform:  
(1) Alluvial fan  
(2) Lake terrace  
(3) Fan remnant

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevation (feet):</td>
<td>4200</td>
<td>6500</td>
</tr>
<tr>
<td>Slope (percent):</td>
<td>0</td>
<td>30</td>
</tr>
</tbody>
</table>

Water Table Depth (inches):

Flooding:
- Frequency: None  
- Duration: None

Ponding:
- Depth (inches):
  - Frequency: None  
  - Duration: None

Runoff Class: Low  
Aspect: No Influence on this site

Climatic Features

The climate of this site is characterized by cold, snowy winters and warm dry summers. The average annual precipitation is mostly 13 to 18 inches, but can be as high as 20 inches on south and west exposures. June is commonly the driest month in precipitation. May is typically the wettest month and July is typically the driest. The most reliable source of moisture for plant growth is the snow that accumulates over the winter and wets the soil throughout the spring and early summer. Summer thunderstorms tend not to be a reliable source of moisture to support the vegetation of this site.

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frost-free period (days):</td>
<td>109</td>
<td>133</td>
</tr>
<tr>
<td>Freeze-free period (days):</td>
<td>141</td>
<td>167</td>
</tr>
<tr>
<td>Mean annual precipitation (inches):</td>
<td>13.0</td>
<td>19.0</td>
</tr>
</tbody>
</table>

Monthly precipitation (inches) and temperature (°F):

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precip. Min.</td>
<td>0.82</td>
<td>0.77</td>
<td>1.03</td>
<td>1.01</td>
<td>0.95</td>
<td>0.33</td>
<td>0.23</td>
<td>0.3</td>
<td>0.38</td>
<td>0.73</td>
<td>0.77</td>
<td>0.86</td>
</tr>
<tr>
<td>Precip. Max.</td>
<td>2.05</td>
<td>1.99</td>
<td>2.27</td>
<td>2.4</td>
<td>2.46</td>
<td>1.54</td>
<td>1.17</td>
<td>1.29</td>
<td>1.62</td>
<td>1.98</td>
<td>1.89</td>
<td>1.92</td>
</tr>
<tr>
<td>Temp. Min.</td>
<td>14.3</td>
<td>18.2</td>
<td>25.7</td>
<td>32.2</td>
<td>39.6</td>
<td>46.9</td>
<td>54.1</td>
<td>52.6</td>
<td>43.6</td>
<td>33.4</td>
<td>24.2</td>
<td>16.0</td>
</tr>
<tr>
<td>Temp. Max.</td>
<td>36.6</td>
<td>41.8</td>
<td>51.0</td>
<td>60.6</td>
<td>70.9</td>
<td>81.3</td>
<td>90.2</td>
<td>88.3</td>
<td>78.5</td>
<td>65.4</td>
<td>49.1</td>
<td>37.9</td>
</tr>
</tbody>
</table>
Climate Stations:
(1) 42006103, Alpine. Period of record 1948 - 2007
(2) 42071603, Birdseye. Period of record 1948 - 1992
(3) 42179204, Cove Fort. Period of record 1948 - 1980
(4) 42272603, Farmington USU FLD STN. Period of record 1948 - 2007
(5) 42506504, Levan. Period of record 1895 - 2007
(6) 42727103, Richmond. Period of record 1928 - 2007
(7) 42768603, Santequin Chlorinator. Period of record 1948 - 2007
(9) 42882803, Trenton. Period of record 1948 - 2007

Influencing Water Features

Due to its landscape position, this site is not typically influenced by streams or wetlands.

Wetland Description: System Subsystem Class

Representative Soil Features

The soils of this site formed in alluvium derived from various types of parent materials. They are usually deep, though occasionally as shallow as 20 inches to lithic bedrock or duripan. Surface and subsurface textures are loams. Rock fragments usually make up less than 15 percent of the soil volume and may not be present on the soil surface. Permeability is slow to moderate and available water-holding capacity ranges from 5 to 7.2 inches of water in the upper 40 inches of soil. The soil moisture regime is xeric and the soil temperature regime is mesic or occasionally frigid.

Soil Survey Area: Soil Components (Map Units in parentheses);

Box Elder County, Eastern Part (UT602); Collinston (CwD, WmE); Dagor (DaB); Eccles (EcA, EcB, EcD); Forsgren (FgB, FgD, FgE); Gemson (GcD, GcE, GEE); Hansel (HaA, HaB, HaD); Kearns (KeB, KeC, KeD, KeE, KgD, PxD); Kidman (KIA, KIB, KmA, KmB, KmD, KmE); Mendon (MhB, MhD); Millville (MIA, MIB, MmB); Parleys (PbA, PdB, PeA, PeB, PeD, PeE, PLA, PmD, PmE, PnD, PyE, SuE); Pomat (PnD, PwD, PwE, PwG, PxE, PyE); Red Rock (RdA, ReA, ReB); Stingal (KgD, SvB, SvD); Timpanogos (TmA, TmB, TnA, ToB, ToC); Windmill (WnB, WnD, WnE);

Cache Valley Area (UT603); Avon (ArA, ArB, ArC, ArD, AsC, AsE); Battle Creek (BcA, BcD); Blackrock (BmB, BmC, BmD, MoG); Collinston (AsC, AsE, CIA, CmC, CmD, CmE2, MfB, MfE2, WIE2); Crowshaw 9CrB, CrC, CrD); Dagor (DaC, DaD);
Hendricks (HaD, HdB, HdC); Hillfield (HgE2, HhE2); Kidman (KdA, KdD, KfA, KfB, KfC); Lewiston (Ln); McMurtrie (McA, McB, McC, MdE2); Mendon (MeA, MeB, MeC, MfB, MfE2); Millville (MIA, MIB); Parleys (PaA, PaB, PaC); Parlo (PlA, PlB, PlC); Ricks (RhA, RhB, RhC); Timpanogos (HhE2, TmA, TmB, TmC, TmD2, TnA);

Davis-Weber Area (UT607); Ackmen (AbB, AbC, AbD, AbE2); Hillfield (HMG2, HnD2, HnE2, HTF2, HTG2); Kidman (FKG2, KaA, KaB, KaC, KaD, KaE2); Parleys (HTF2, HTG2, PaA, PaB, PaC, PaD, PaE2); Pleasant view (PvB, PvC, PvD, PvE, PvE2, Pwc, PwD); Timpanogos (HTF2, HTG2, TbA, TbB, TbC, TbD2, TbE2); Timpanogos Variant (TcD, TcE, TDD);

Fairfield-Nephi Area (UT608); Ashdown (AkA, AkB); Birdow (Bi); Calita (CaB, CaC, CaD); Dager (DaC); Deer Creek (DbD, DcD); Doyce (DbF, DfC, DgC, MrB); Dry Creek (DhD, DkD); Genola (GaC, GcB, GcC); Hansel (HaB, HbB); Hillfield (HeC); Juab (JaB, JbB, JbC, JcC, JdC); Justesen (JeD); Keigley (KaB); Modoc (McC); Moroni (McB); Musinia (McV, McV); Nephi (NaB); Parleys (PaA, PaB, PaC); Pleasant Vale (PnA, PoA, PoC, PpB); Timpanogos (TmA, TmB, TmC, TmD2); Timpanogos Variant (TcD, TcE, TDD);

Tooele Area (UT611) Doyce (15); Erda (19);
Salt Lake Area (UT612) Bluffdale (BlB, BnB, BmC, BnB); Dry Creek (DPD, DPE, DRD, HDF); Hans (HaB, HaC); Hillfield (HiC, HiA, HiB, HiC, HtF2); Kearns (KaB, KaC); Kidman (KdA, KdB, KdC, KfA, KfB); Parleys (PaA, PaB, PaC); Preston (KsF2, PrD, PrF, PsB); Red Rock (Re); Taylorville (HtF2, TaA, TaB, TaC, TbB, TbC, TcA, TcB, TcC2); Timpanogos (TtA, TtC, TuB); Trenton (Tv); Welby (WmA, WmB);

Millard County, Eastern Part (UT618); Bonolden (17, 18); Cessna (27); Church springs (29); Kidman (76, 86); Maple Hollow (34, 35); Probert (103);

Utah County (UT621) Dager (Da, Db); Dry Creek (DCF); Hillfield (HmE, HmF, HNG, HOF, HpF, WhD, WhE); Keigley (KeA, KeB, KgA); Kidman (KmA, KmB, KmC); Parleys (PaB, PaC, PbC, PcB); Pleasant vale (PnA, PoA, PoC, PpB); Timpanogos (TmB, TmC, TmD2); Welby (HpF, WbA, WbB, WbC, WeA, Web, WcC, WeD2, WhD, WhE);

Sanpete Valley Area (UT627); Arapien (ARD); Birdow (BnB, BnC, BoB); Calita (ARD, CaB, CaC); Doyce (BTC, DoB, DoC, MoC, PDC); Keigley (KcC); Moroni (McF, MGD); Snake Hollow (StB); Wales (WAC);

Sevier County (UT628); Arapien (ARE); Bock (TaB); Wales (OMC2); Watkins Ridge (CMD);
Iron-Washington Area (UT634) Doyce (372); Kanarra (395, 396); Lucero (318, 406, 407, 440, 447); Studhorse (486);

Beaver-Cove Fort Area (UT640); Clegg (CEF, CGF, CLF); Deer Creek (DKF2, DLE2,
Parent Materials:

Kind: (1) Loam
(2) Silt loam
(3) Fine sandy loam

Surface Texture: (1) Loam
(2) Silt loam
(3) Fine sandy loam

Subsurface Texture Group: Loamy

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Fragments &lt;=3&quot; (% Cover):</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>Surface Fragments &gt; 3&quot; (% Cover):</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Subsurface Fragments &lt;=3&quot; (% Volume):</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>Subsurface Fragments &gt; 3&quot; (% Volume):</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

Drainage Class: Moderately well drained To Well drained

Permeability Class: Slow To Moderate

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth (inches):</td>
<td>20</td>
<td>60</td>
</tr>
<tr>
<td>Electrical Conductivity (mmhos/cm):</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Sodium Absorption Ratio:</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Calcium Carbonate Equivalent (percent):</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>Soil Reaction (1:1 Water):</td>
<td>6.6</td>
<td>9.0</td>
</tr>
<tr>
<td>Soil Reaction (0.01M CaCl2):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Available Water Capacity (inches):</td>
<td>5.0</td>
<td>7.2</td>
</tr>
</tbody>
</table>

**Plant Communities**

Refer to STM in text.

**Ecological Dynamics of the Site**

As ecological condition deteriorates due to overgrazing, grasses and bitterbrush decrease, while mountain big sagebrush and rubber rabbitbrush increase.
When the potential natural plant community is burned mountain big sagebrush decreases while arrowleaf balsamroot and rabbitbrush increase.

Utah juniper, pinyon pine, cheatgrass and Russian thistle are most likely to invade this site.

**Reference State - State 1**

**Reference State - Community Phase 1.1**
The dominant aspect of this plant community is mountain big sagebrush and bluebunch wheatgrass. The composition by air-dry weight is approximately 60 percent perennial grasses, 10 percent forbs, and 30 percent shrubs.

**Reference State Plant Species Composition:**

<table>
<thead>
<tr>
<th>Group Name</th>
<th>Common Name</th>
<th>Symbol</th>
<th>Scientific Name</th>
<th>Low</th>
<th>High</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 -Primary Forb</td>
<td>arrowleaf balsamroot</td>
<td>BASA3</td>
<td><em>Balsamorhiza sagittata</em></td>
<td>36</td>
<td>60</td>
<td>36</td>
<td>60</td>
</tr>
</tbody>
</table>

**Grass/Grasslike**

<table>
<thead>
<tr>
<th>Group Name</th>
<th>Common Name</th>
<th>Symbol</th>
<th>Scientific Name</th>
<th>Low</th>
<th>High</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 -Primary Grasses</td>
<td>Indian ricegrass</td>
<td>ACHY</td>
<td><em>Achnatherum hymenoides</em></td>
<td>120</td>
<td>180</td>
<td>120</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>squirreltail</td>
<td>ELEL5</td>
<td><em>Elymus elymoides</em></td>
<td>36</td>
<td>60</td>
<td>36</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Sandberg bluegrass</td>
<td>PONE3</td>
<td><em>Poa nevadensis</em> (syn)</td>
<td>60</td>
<td>120</td>
<td>60</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>bluebunch wheatgrass</td>
<td>PSSP6</td>
<td><em>Pseudoroegneria spicata</em></td>
<td>180</td>
<td>300</td>
<td>180</td>
<td>300</td>
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</tbody>
</table>

**Shrub/Vine**

<table>
<thead>
<tr>
<th>Group Name</th>
<th>Common Name</th>
<th>Symbol</th>
<th>Scientific Name</th>
<th>Low</th>
<th>High</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 -Primary Shrubs</td>
<td>mountain big sagebrush</td>
<td>ARTRV</td>
<td><em>Artemisia tridentata ssp. vaseyana</em></td>
<td>120</td>
<td>180</td>
<td>120</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>antelope bitterbrush</td>
<td>PUTR2</td>
<td><em>Purshia tridentata</em></td>
<td>36</td>
<td>60</td>
<td>36</td>
<td>60</td>
</tr>
<tr>
<td>Group Name</td>
<td>Common Name</td>
<td>Symbol</td>
<td>Scientific Name</td>
<td>Annual Production in Pounds Per Acre</td>
<td>Foliar Cover Percent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------</td>
<td>------------------</td>
<td>-----------</td>
<td>---------------------------</td>
<td>-------------------------------------</td>
<td>----------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grass/Grasslike</td>
<td></td>
<td></td>
<td></td>
<td>Low: 36 High: 60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 - Secondary Grasses</td>
<td>blue grama</td>
<td>BOGR2</td>
<td><em>Bouteloua gracilis</em></td>
<td>12: 36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>thickspike wheatgrass</td>
<td>ELLA3</td>
<td><em>Elymus lanceolatus</em></td>
<td>12: 36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Idaho fescue</td>
<td>FEID</td>
<td><em>Festuca idahoensis</em></td>
<td>12: 36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>needle and thread</td>
<td>HECO26</td>
<td><em>Hesperostipa comata</em></td>
<td>12: 36</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>prairie Junegrass</td>
<td>KOMA</td>
<td><em>Koeleria macrantha</em></td>
<td>12: 36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>basin wildrye</td>
<td>LECI4</td>
<td><em>Leymus cinereus</em></td>
<td>12: 36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>western wheatgrass</td>
<td>PASM</td>
<td><em>Pascopyrum smithii</em></td>
<td>12: 36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forb</td>
<td></td>
<td></td>
<td></td>
<td>Low: 60 High: 120</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 - Secondary Forbs</td>
<td>common yarrow</td>
<td>ACMI2</td>
<td><em>Achillea millefolium</em></td>
<td>12: 36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>white sagebrush</td>
<td>ARLU</td>
<td><em>Artemisia ludoviciana</em></td>
<td>12: 36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>freckled milkvetch</td>
<td>ASLE8</td>
<td><em>Astragalus lentiginosus</em></td>
<td>12: 36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>tapertip hawksbeard</td>
<td>CRAC2</td>
<td><em>Crepis acuminata</em></td>
<td>12: 36</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>roundspike cryptantha</td>
<td>CRHU2</td>
<td><em>Cryptantha humilis</em></td>
<td>12: 36</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>shaggy fleabane</td>
<td>ERPU2</td>
<td><em>Erigeron pumilus</em></td>
<td>12: 36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>western stoneseed</td>
<td>LIRU4</td>
<td><em>Lithospermum ruderal</em></td>
<td>12: 36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>tailcup lupine</td>
<td>LUCAC3</td>
<td><em>Lupinus caudatus</em></td>
<td>12: 36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>tufted evening primrose</td>
<td>OECA10</td>
<td><em>Oenothera caespitosa</em></td>
<td>12: 36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>low beardtongue</td>
<td>PEHU</td>
<td><em>Penstemon humilis</em></td>
<td>12: 36</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>longleaf phlox</td>
<td>PHLO2</td>
<td><em>Phlox longifolia</em></td>
<td>12: 36</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>gooseberryleaf globemallow</td>
<td>SPGR2</td>
<td><em>Sphaerelcea grossularifolia</em></td>
<td>12: 36</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Pacific aster</td>
<td>SYCHC</td>
<td><em>Symphyotrichum chilense</em></td>
<td>12: 36</td>
<td></td>
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</table>
### Shrub/Vine

<table>
<thead>
<tr>
<th>Group Name</th>
<th>Common Name</th>
<th>Symbol</th>
<th>Scientific Name</th>
<th>Low</th>
<th>High</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 -Secondary Shubs</td>
<td>basin big sagebrush</td>
<td>ARTRT</td>
<td><em>Artemisia tridentata</em> ssp. <em>tridentata</em></td>
<td>12</td>
<td>36</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>fourwing saltbush</td>
<td>ATCA2</td>
<td><em>Atriplex canescens</em></td>
<td>12</td>
<td>36</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>yellow rabbitbrush</td>
<td>CHVI8</td>
<td><em>Chrysothamnus viscidiflorus</em></td>
<td>12</td>
<td>36</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nevada jointfir</td>
<td>EPNE</td>
<td><em>Ephedra nevadensis</em></td>
<td>12</td>
<td>36</td>
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<tr>
<td></td>
<td>slender buckwheat</td>
<td>ERMI4</td>
<td><em>Eriogonum microthecum</em></td>
<td>12</td>
<td>36</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>rubber rabbitbrush</td>
<td>ERNAN5</td>
<td><em>Ericameria nauseosa</em> ssp. <em>nauseosa</em> var. <em>nauseosa</em></td>
<td>12</td>
<td>36</td>
<td></td>
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<tr>
<td></td>
<td>granite prickly phlox</td>
<td>LIPU11</td>
<td><em>Linanthus pungens</em></td>
<td>12</td>
<td>36</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>plains pricklypear</td>
<td>OPPO</td>
<td><em>Opuntia polyacantha</em></td>
<td>12</td>
<td>36</td>
<td></td>
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<tr>
<td></td>
<td>mountain snowberry</td>
<td>SYOR2</td>
<td><em>Symphoricarpos oreophilus</em></td>
<td>12</td>
<td>36</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>spineless horsebrush</td>
<td>TECA2</td>
<td><em>Tetradymia canescens</em></td>
<td>12</td>
<td>36</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Annual Production by Plant Type:

<table>
<thead>
<tr>
<th>Plant Type</th>
<th>Annual Production (lbs/AC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass/Grasslike</td>
<td>Low 390  Value 705  High 840</td>
</tr>
<tr>
<td>Forb</td>
<td>Low 65  Value 118  High 140</td>
</tr>
<tr>
<td>Shrub/Vine</td>
<td>Low 195  Value 353  High 420</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td>Low 650  Value 1176  High 1400</td>
</tr>
</tbody>
</table>

### Structure and Cover:

#### Ground Cover

<table>
<thead>
<tr>
<th>Vegetative Cover</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass / Grasslike</td>
<td>15%</td>
<td>40%</td>
</tr>
<tr>
<td>Forb</td>
<td>3%</td>
<td>5%</td>
</tr>
<tr>
<td>Shrub/ Vine</td>
<td>10%</td>
<td>15%</td>
</tr>
<tr>
<td>Non-Vegetative Cover</td>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>----------------------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>Tree</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Non-Vascular Plants</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Biological Crust</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Litter</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Surface Fragments &gt; 0.25&quot; and &lt;= 3&quot;</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Surface Fragments &gt; 3&quot;</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Bedrock</td>
<td>0%</td>
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<tr>
<td>Water</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Bare Ground</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

**Ecological Site Interpretations**

**Animal Community:**
This site is suited for grazing by cattle and sheep during spring, summer, and fall.

Wildlife using this site include rabbit, coyote, sage grouse, pronghorn antelope, mule deer, and elk.

This is a short list of the more common species found. Many other species are present as well and migratory birds are present at times.

**Plant Preference by Animal Kind:**

**Hydrology Functions:**
The soils are in hydrologic group B with runoff curves ranging from 61 to 79 depending on hydrologic condition.

**Recreational Uses:**
Resources that have special aesthetic and landscape values are grassland aesthetics. Some recreation uses of this site are camping, hiking and hunting.

**Wood Products:**
None

**Other Products:**
Other Information:
Threatened and endangered species include plants and animals.

Supporting Information

Associated Sites:

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Site ID</th>
<th>Site Narrative</th>
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<tbody>
<tr>
<td>Loamy Bottom (Great Basin Wildrye)</td>
<td>R028AY006UT</td>
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<tr>
<td>Upland Stony Loam (Mountain Big Sagebrush)</td>
<td>R028AY334UT</td>
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<tr>
<td>Upland Stony Loam (Pinyon-Utah Juniper)</td>
<td>R028AY338UT</td>
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</table>

Similar Sites:

<table>
<thead>
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<th>Site ID</th>
<th>Site Narrative</th>
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</thead>
</table>

Inventory Data References:

Type Locality:
Relationship to Other Established Classifications:

Other References:
Type Location: Iron Mountain Fans; Hamlin Valley

Site Description Approval:

<table>
<thead>
<tr>
<th>Author</th>
<th>Date</th>
<th>Approval</th>
<th>Date</th>
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Site Description Revision Approval:

<table>
<thead>
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<th>Approval</th>
<th>Date</th>
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</thead>
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<tr>
<td>DJS</td>
<td>6/28/1993</td>
<td>Pat Shaver</td>
<td>8/30/1993</td>
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Reference Sheet

Author(s)/participant(s):Jack Alexander, Range Specialist, Synergy Resource Solutions, Inc. Julia Kluck, Soil Scientist, Synergy Resource Solutions, Inc. Shane
Green, State Range Specialist, Utah NRCS

Contact for lead author: Shane Green, Shane.Green@ut.usda.gov

Date: 2/9/2010    MLRA: 028A    Ecological Site: Upland Loam (Mountain Big Sagebrush) R028AY310UT

This must be verified based on soils and climate (see Ecological Site Description). Current plant community cannot be used to identify the ecological site.

Composition (indicators 10 and 12) based on: X Annual Production, Foliar Cover, Biomass

Indicators. For each indicator, describe the potential for the site. Where possible, (1) use numbers, (2) include expected range of values for above- and below-average years for each community and natural disturbance regimes within the reference state, when appropriate and (3) cite data. Continue descriptions on separate sheet.

1. Number and extent of rills: No rills present. Very minor rill development may occur in sparsely vegetated areas. If rills are present, they should be widely spaced and not connected. Rill development may increase following large storm events, but should begin to heal during the following growing season. Frost heaving will accelerate recovery. Rill development may increase when run inflow enters site from adjacent sites that produce large amounts of runoff (i.e. steeper sites, slickrock, rock outcrop). Site is essentially level and rills do not form.

2. Presence of water flow patterns: Water flow patterns will be short (2-5’) and meandering; interrupted by plants and exposed rocks. Some evidence of erosion or deposition associated with flow patterns. Where slopes exceed 5%, water flow patterns may be longer (5–10’).

3. Number and height of erosional pedestals or terracettes: Plants may have small pedestals (1-3”) where they are adjacent to water flow patterns, but without exposed roots. Terracettes should be few and stable. Terracettes should be small (1-3”) and show little sign of active erosion. Some plants may appear to have a pedestal but rather than be formed by erosion, the only place litter accumulates and soil collects is at plant bases forming the appearance of a pedestal. Well-developed biological crusts may appear pedestalled, but are actually a characteristic of the crust formation. Some plants may appear to have a pedestal but rather than be formed by erosion, the only place litter accumulates and soil collects is at plant
bases forming the appearance of a pedestal.

4. **Bare ground from Ecological Site Description or other studies (rock, litter, standing dead, lichen, moss, plant canopy are not bare ground):** 20-35% bare ground (soil with no protection from raindrop impact). Herbaceous communities are most likely to have lower values. As species composition by shrubs increases, bare ground is likely to increase. Poorly developed biological soil crust that is susceptible to raindrop splash erosion should be recorded as bare ground. Very few if any bare spaces of greater than 1 square foot.

5. **Number of gullies and erosion associated with gullies:** No gullies present.

6. **Extent of wind scoured, blowouts and/or depositional areas:** Very minor evidence of active wind-generated soil movement. Wind scoured (blowouts) and depositional areas are rarely present. If present they have muted features and are mostly stabilized with vegetation and/or biological crust. Gravel or desert pavement protects the site from wind scour.

7. **Amount of litter movement (describe size and distance expected to travel):** Most litter resides in place with some redistribution caused by water and wind movement. Very minor litter removal may occur in flow patterns and rills with deposition occurring at points of obstruction. The majority of litter accumulates at the base of plants. Some leaves, stems, and small twigs may accumulate in soil depressions adjacent to plants. Woody stems are not likely to move. On steep slopes (>30%), litter will move downhill to next obstruction.

8. **Soil surface (top few mm) resistance to erosion (stability values are averages - most sites will show a range of values):** This site should have an erosion rating of 5 or 6 under plant canopies and a rating of 4 to 5 in the interspaces with an average rating of 5 using the soil stability kit test.

9. **Soil surface structure and SOM content (include type and strength of structure, and A-horizon color and thickness):** There is no modal soil for this site. Due to the natural variability of soil attributes, it is critical to supplement this description with the soil-specific information from the published soil survey.

10. **Effect on plant community composition (relative proportion of different functional groups) and spatial distribution on infiltration and runoff:** Bunchgrasses important for increasing infiltration and reducing runoff. Litter plays a role in increasing infiltration and decreasing runoff. Plants provide microhabitat
for seedlings, catch litter and soil, and slow raindrops and runoff. Vascular plants and/or well-developed biological soil crusts (where present) will break raindrop impact and splash erosion. Spatial distribution of vascular plants and interspaces between well-developed biological soil crusts (where present) provide detention storage and surface roughness that slows runoff allowing time for infiltration. Interspaces between plants and any well-developed biological soil crusts (where present) may serve as water flow patterns during episodic runoff events, with natural erosion expected in severe storms. When perennial grasses decrease, reducing ground cover and increasing bare ground, runoff is expected to increase and any associated infiltration reduced.

11. **Presence and thickness of compaction layer (usually none; describe soil profile features which may be mistaken for compaction on this site):** None. Naturally occurring soil horizons may be harder than the surface because of an accumulation of calcium carbonate and should not be considered as compaction layers.

12. **Functional/Structural Groups (list in order of descending dominance by above-ground weight using symbols: \( \gg, >, = \) to indicate much greater than, greater than, and equal to) with dominants and sub-dominants and "others" on separate lines:** Dominant: bluebunch wheatgrass > Indian ricegrass, mountain big sagebrush; Sub-dominant: arrowleaf balsamroot, antelope bitterbrush, squirreltail; Other: other grasses, other shrubs, forbs

   Additional: Functional/structural groups may appropriately contain non-native species if their ecological function is the same as the native species in the reference state (e.g. crested wheatgrass and Russian wildrye may substitute for mid stature cool season perennial native bunchgrasses.). Biological soil crust is variable in its expression on this site and is measured as a component of ground cover. Forbs can be expected to vary widely in their expression in the plant community based upon departures from average growing conditions.

13. **Amount of plant mortality and decadence (include which functional groups are expected to show mortality or decadence):** During years with average to above average precipitation, there should be very little recent mortality or decadence apparent in either the shrubs or grasses. Some mortality of bunchgrass and other shrubs may occur during very severe (long-term) droughts. There may be partial mortality of individual bunchgrasses and shrubs during less severe drought. Long-lived species dominate site. Open spaces from disturbance are quickly filled by new plants through seedlings and reproductive reproduction (tillering).

14. **Average percent litter cover (10-20 %) and depth (0.5-0.75 inches):** Litter cover includes litter under plants. Most litter will be fine litter. Depth should be 1-2 leaf thickness in the interspaces and up to 1/2” under canopies. Litter cover may
increase to 20-30% following years with favorable growing conditions. Excess litter may accumulate in absence of disturbance. Vegetative production may be reduced if litter cover exceeds 40%.

15. **Expected annual production (this is TOTAL above-ground production, not just forage production):** 1175#/acre. Even the most stable communities exhibit a range of production values. Production will vary between communities and across the MRLA. Refer to the community descriptions in the ESD. Production will differ across the MLRA due to the naturally occurring variability in weather, soils, and aspect. The biological processes on this site are complex; therefore, representative values are presented in a land management context.

16. **Potential invasive (including noxious) species (native and non-native).** List Species which BOTH characterize degraded states and have the potential to become a dominant or co-dominant species on the ecological site if their future establishment and growth is not actively controlled by management interventions. Species that become dominant for only one to several years (e.g., short-term response to drought or wildfire) are not invasive plants. Note that unlike other indicator, we are describing what in NOT expected in the reference state for the ecological site: Utah juniper, pinyon pine, cheatgrass and Russian thistle

17. **Perennial plant reproductive capability:** All perennial plants should have the ability to reproduce sexually or asexually, except in drought years. Density of plants indicates that plants reproduce at level sufficient to fill available resource. Within capability of site there are no restrictions on seed or vegetative reproductive capacity.

Reference Sheet Approval:

<table>
<thead>
<tr>
<th>Approval</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shane A. Green</td>
<td>2/24/2010</td>
</tr>
</tbody>
</table>
ECOLOGICAL SITE CHARACTERISTICS

Site Type: Rangeland

Site Name: Mountain Gravelly Loam (Oak)

/ Quercus gambelii / - Elymus trachycaulus
( / Gambel oak / - slender wheatgrass)

Site ID: R047XA410UT

Major Land Resource Area: 047-Wasatch and Uinta Mountains

Site Concept: The mountain gravelly loam (Gambel oak) site is a patchy Gambel oak woodland that occurs on mountain slopes, foothills and ridges of the northern Wasatch mountains. It developed in a continental climate receiving 16-22 inches of mostly cool-season precipitation annually. Soils are gravelly or cobbly mollisols (thick, dark surface horizon) at least 20 inches in total depth. The soil moisture regime is xeric and the soil temperature regime is frigid. This site produces 1450 to 2,250 pounds of vegetation annually. The historic climax plant community is dominated by Gambel oak (Quercus gambelii), bluebunch wheatgrass (Pseudoroegneria spicata), slender wheatgrass (Elymus trachycaulus), and mountain snowberry (Symphoricarpos oreophilus).

Physiographic Features

This site occurs primarily on mountain slopes, foothills, swales and occasionally on alluvial fans and terminal moraines. It is found on all aspects at elevations ranging between 5,200 and 10,000 feet. Runoff varies from medium to very high depending on slope and ground cover. This site is considered a reliable watershed for lower lying areas.

Landform: (1) Mountain slope
(2) Hill
(3) Swale

<table>
<thead>
<tr>
<th>Minimum</th>
<th>Maximum</th>
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</thead>
<tbody>
<tr>
<td>Elevation (feet):</td>
<td>5200</td>
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<tr>
<td>Slope (percent):</td>
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<tr>
<td>Water Table Depth (inches):</td>
<td></td>
</tr>
<tr>
<td>Flooding:</td>
<td></td>
</tr>
<tr>
<td>Frequency:</td>
<td>None</td>
</tr>
<tr>
<td>Duration:</td>
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<td>Ponding:</td>
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<td>Depth (inches):</td>
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<td>Frequency:</td>
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<td>Duration:</td>
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</tr>
<tr>
<td>Runoff Class:</td>
<td>Medium</td>
</tr>
<tr>
<td>Aspect:</td>
<td>No Influence on this site</td>
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</tbody>
</table>

**Climatic Features**

The climate of this site is characterized by cold snowy winters and cool dry summers. The average precipitation ranges from 16 to 22 inches annually with 55% to 60% coming during the plant dormant period (October to March). Much of this precipitation comes as snow that acts as a reservoir for water until the growing season begins. This winter moisture is the most dependable supply of water for plant growth. Lower precipitation and higher evapo-transpiration rates during July, August, and September cause a reduction in plant growth for all species and dormancy in many of the grasses and forbs.

<table>
<thead>
<tr>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frost-free period (days):</td>
<td>113</td>
</tr>
<tr>
<td>Freeze-free period (days):</td>
<td>148</td>
</tr>
<tr>
<td>Mean annual precipitation (inches):</td>
<td>16.0</td>
</tr>
</tbody>
</table>

**Monthly precipitation (inches) and temperature (°F):**

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
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</thead>
<tbody>
<tr>
<td>Precip. Min.</td>
<td>0.99</td>
<td>0.99</td>
<td>1.21</td>
<td>0.98</td>
<td>0.98</td>
<td>0.37</td>
<td>0.31</td>
<td>0.41</td>
<td>0.4</td>
<td>0.81</td>
<td>1.02</td>
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<tr>
<td>Precip. Max.</td>
<td>2.77</td>
<td>2.49</td>
<td>2.71</td>
<td>2.55</td>
<td>2.66</td>
<td>1.65</td>
<td>1.19</td>
<td>1.43</td>
<td>1.94</td>
<td>2.31</td>
<td>2.52</td>
<td>2.6</td>
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<tr>
<td>Temp. Min.</td>
<td>14.8</td>
<td>18.4</td>
<td>25.6</td>
<td>32.9</td>
<td>39.9</td>
<td>46.9</td>
<td>54.2</td>
<td>52.8</td>
<td>44.1</td>
<td>34.5</td>
<td>25.4</td>
<td>17.3</td>
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<tr>
<td>Temp. Max.</td>
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<td>41.1</td>
<td>49.7</td>
<td>59.5</td>
<td>69.6</td>
<td>79.9</td>
<td>88.6</td>
<td>86.6</td>
<td>77.0</td>
<td>64.1</td>
<td>48.1</td>
<td>37.7</td>
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</table>
Climate Stations:

(1) 42205705, Deer Creek Dam. Period of record 1939 - 2007
(2) 42262503, Eureka. Period of record 1930 - 1984
(3) 42413505, Huntsville. Period of record 1976 - 2007
(4) 42811903, Spanish Fork Powerhouse. Period of record 1909 - 2007
(5) 42877103, Tooele. Period of record 1896 - 2007

Influencing Water Features

Due to its landscape position, this ecological site is not typically influenced by streams or wetlands.

Wetland Description: System  Subsystem  Class

Representative Soil Features

The soils on this site were formed in alluvium, colluvium, and residuum derived from various parent materials including sandstone, shale, quartzite and andesite. A thin organic layer of oak leaves and twigs is common on the soil surface and upper soil layers are dark brown in color. These soils formed on mountain slopes, are well-drained, and usually have gravel or cobbles on the soil surface. The subsoils are gravelly or cobbly loams with coarse fragments in the root zone averaging 30% to 60% by volume. They can be moderately deep or deep with bedrock at least 20 inches beneath the soil surface. Available water holding capacity ranges from 1.8 to 4.7 inches if water in the upper 40 inches of soil. The soil moisture regime is xeric and the soil temperature regime is frigid.

Soils Associated With This Site:
Soil Survey Area: Soil Components (Map Units in parentheses)

Fairfield-Nephi Area (UT608): Lizzant (LbE, LbF)
Morgan Area (UT609): Burgi (BuG); Heinhold (EVG, HpG); Horrocks (HvG); Lamondi (LaD, LaE)
Tooele Area (UT611): Smarts (SgG); Toncana (TaG)
Salt Lake Area (UT612): Gappmayer (GEG, GGG)
Summit Area (UT613): Dunford (107, 108, 124, 125)
Millard County (UT618): Lizzant (84); Searla (107)
Utah County (UT621): Dry Creek (DRG2); Gappmayer (GAG); McPhie (HFF, HFG2)
Heber Valley Area (UT622): Burgi (BWE, BWF, BXF, BYF); Gappmayer (GAD, GAF, GMF, GPF, GWF, HGF); McPhie (MCF, MHF, VMF)
Sevier County (UT628): Lizzant (LMG)
Surface Texture: (1) Very cobbly Loam
(2) Gravelly Loam
(3) Gravelly Fine sandy loam

Subsurface Texture Group: Loamy

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Maximum</th>
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</thead>
<tbody>
<tr>
<td>Surface Fragments &lt;=3&quot; (% Cover):</td>
<td>11</td>
<td>24</td>
</tr>
<tr>
<td>Surface Fragments &gt; 3&quot; (% Cover):</td>
<td>3</td>
<td>30</td>
</tr>
<tr>
<td>Subsurface Fragments &lt;=3&quot; (% Volume):</td>
<td>16</td>
<td>30</td>
</tr>
<tr>
<td>Subsurface Fragments &gt; 3&quot; (% Volume):</td>
<td>3</td>
<td>30</td>
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</table>

Drainage Class: Well drained To Well drained
Permeability Class: Moderately slow To Moderate

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Depth (inches):</td>
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<td>60</td>
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<tr>
<td>Calcium Carbonate Equivalent (percent):</td>
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<td>0</td>
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<tr>
<td>Soil Reaction (1:1 Water):</td>
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<td>7.8</td>
</tr>
<tr>
<td>Soil Reaction (0.01M CaCl2):</td>
<td></td>
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<tr>
<td>Available Water Capacity (inches):</td>
<td>1.8</td>
<td>4.7</td>
</tr>
</tbody>
</table>

Plant Communities

Refer to STM in text.

Ecological Site Interpretations

Animal Community:

Livestock:
This site provides a good balance of nutritious forage when oak, perennial grasses, and forbs are all present. Sheep, cattle, and horses do well grazing during the spring, summer, and fall. Goats often prefer Gambel oak and are capable of consuming over 50% oak in their diet. Tannic acid is present in all parts of oak plants and may become
fatal to livestock when oak is the only source of available forage.

Wildlife:
Gambel oak is a primary food and nesting resource for porcupines in the winter. Squirrels, deer, and upland birds consume acorns during the fall and winter. This site is good habitat for chukars, quail, turkeys, songbirds, squirrels, snowshoe hares, cottontails, bobcat, coyotes, mule deer, and elk. It is fair habitat for golden eagle, hawks, cougars, bear, and small mammals.

Plant Preference by Animal Kind:

Hydrology Functions:

Recreational Uses:
This site has aesthetic value and is excellent for hunting big game. A large number of forbs and shrubs are in bloom from early spring and throughout the summer and fall. Wildlife can often be viewed throughout the year. Shrubs offer screening for camping areas and picnicking. This site is often used for hunting upland game birds, coyotes, snowshoe hares, elk and mule deer. Motorized recreation is dependent on road access.

Wood Products:
Not all Gambel oak stands will grow large enough to be harvested for firewood, especially if the growing season is too short or the soil too shallow. Mature Gambel oak stands can be harvested for fence posts, stays and firewood. It is moderately weather-resistant and extremely hard. However, when moist it tends to rot more quickly than other post materials. As a fuel wood, Gambel oak is desirable because it gives off high amounts of heat and little smoke or soot. Though not used for lumber, Gambel oak has some value for small wooden crafts. A harvested stand resprouts immediately afterward and usually takes about 60 years to regenerate fully.

Other Products:

Other Information:

Supporting Information

Associated Sites:

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Site ID</th>
<th>Site Narrative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mountain Gravelly Loam</td>
<td>R047XA406UT</td>
<td>These two sites occur together in distinct patches. Gambel oak rarely propagates from seed in its northern ranges, and mountain big sagebrush cannot invade an oak stand due to</td>
</tr>
</tbody>
</table>
resource limitations. The result is a sharp mosaic of oak and sagebrush sites that changes very slowly if at all.

Mountain Loam (Mountain Big Sagebrush) R047XA430UT This site is often found near the mountain gravelly loam (Gambel oak) site in areas where the soil is deeper and less rocky. Gambel oak rarely propagates from seed in its northern ranges, and mountain big sagebrush cannot invade an oak stand. The result is a sharp mosaic of oak and sagebrush sites that changes very slowly if at all.

Similar Sites:

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<tr>
<td>Mountain Loam (Oak)</td>
<td>R047XA432UT</td>
<td>This site produces taller, more robust oak trees than the mountain gravelly loam (Gambel oak) site and produces less grass. It is found in deeper, less gravelly soils that retain more water. The two are often seen together where a gravelly slope meets a loamy bottom.</td>
</tr>
<tr>
<td>Mountain Shallow Loam (Oak)</td>
<td>R047XA448UT</td>
<td>This site has soils that are less than 20 inches deep, resulting in lower-statured oak and reduced annual production compared to the mountain gravelly loam (oak) site.</td>
</tr>
<tr>
<td>Mountain Stony Loam (Gambel oak)</td>
<td>R047XA463UT</td>
<td>This site has larger rock fragments in the soil and produces less forb, grass, and shrub biomass than the mountain gravelly loam (oak) site.</td>
</tr>
</tbody>
</table>

State Correlation:

This site has been correlated with the following states:

Inventory Data References:

Type Locality:

Relationship to Other Established Classifications:

Modal Soil: Ayoub CB-L, Organic Surface 15-40% – fine-loamy, mixed, frigid Typic Argixerolls

Other References:


Reference Sheet

Author(s)/participant(s): V. Keith Wadman, Shane A. Green

Contact for lead author: shane.green@ut.usda.gov

Date: 6/24/2004  MLRA: 047X  Ecological Site: Mountain Gravelly Loam (Oak) R047XA410UT  This must be verified based on soils and climate (see Ecological Site Description). Current plant community cannot be used to identify the ecological site.

Composition (indicators 10 and 12) based on:  Annual Production,  X Foliar Cover,  Biomass

Indicators. For each indicator, describe the potential for the site. Where possible, (1) use numbers, (2) include expected range of values for above- and below-average years for each community and natural disturbance regimes within the reference state, when appropriate and (3) cite data. Continue descriptions on separate sheet.

1.  Number and extent of rills: Minor rill development in exposed areas. Rills present should be short on flatter slopes but may become longer (4 to 8 feet) as slope steepens. They should be somewhat widely spaced (3 to 6 feet), and follow the surface micro-features. Old rills should be weathered and muted in appearance. Surface rock may reduce rill formation.

2.  Presence of water flow patterns: Flow patterns wind around surface rock and perennial plant bases and show minor evidence of erosion. They are somewhat short and stable and there is only minor evidence of deposition. Evidence of flow will increase somewhat with slope.
3. **Number and height of erosional pedestals or terracettes**: Plants may show minor pedestaling on their down slope side. Terracettes should be few and stable.

4. **Bare ground from Ecological Site Description or other studies (rock, litter, standing dead, lichen, moss, plant canopy are not bare ground)**: 20 – 30%. (Soil surface is typically covered by 35% to 65% rock).

5. **Number of gullies and erosion associated with gullies**: Few. Gullies should show only minor signs of active erosion and should be mostly stabilized with vegetation. Gullies may show slightly more indication of erosion as slope steepens.

6. **Extent of wind scoured, blowouts and/or depositional areas**: None. Wind caused blowouts and deposition are not present.

7. **Amount of litter movement (describe size and distance expected to travel)**: Some down slope redistribution caused by water. Some litter removal may occur in flow channels with deposition occurring at points of obstruction. Litter movement will increase with slope.

8. **Soil surface (top few mm) resistance to erosion (stability values are averages - most sites will show a range of values)**: 70 to 80% of this site should have an erosion rating of 5 or 6. 20 to 30% may have a rating of 3 to 4. The average should be a 5. Litter accumulation and cryptogamic crusts reduce erosion.

9. **Soil surface structure and SOM content (include type and strength of structure, and A-horizon color and thickness)**: Soil surface varies from 5 to 11 inches. Structure varies from medium granular to subangular blocky. Color varies from brown (7.5YR5/3) to very dark brown (10YR4/2). There is a mollic epipedon that extends from 10 to 20 inches deep.

10. **Effect on plant community composition (relative proportion of different functional groups) and spatial distribution on infiltration and runoff**: When perennial grasses decrease, reducing ground cover and increasing bare ground, runoff will increase and infiltration will be reduced.

11. **Presence and thickness of compaction layer (usually none; describe soil profile features which may be mistaken for compaction on this site)**: None. Some soils have an argillic horizon at about 6 to 20 inches that could be mistaken for a compaction layer.
12. **Functional/Structural Groups** (list in order of descending dominance by above-ground weight using symbols: >>, >, = to indicate much greater than, greater than, and equal to) with dominants and sub-dominants and "others" on separate lines:

   Dominant: Gambel oak, Slender wheatgrass, Bluebunch wheatgrass & Mountain big sagebrush.
   Sub-dominant: Letterman needlegrass, Bitterbrush, Mountain snowberry.
   Other:
   Additional: Assumed fire cycle of 40-60 years. Perennial bunchgrasses, large sprouting shrubs > sprouting shrubs, perennial forbs > invaders such as Cheatgrass, curlycup gumweed & Annual forbs. The perennial bunchgrass/ large sprouting shrub functioning group is expected on this site.

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13. **Amount of plant mortality and decadence** (include which functional groups are expected to show mortality or decadence): All age classes of perennial grasses should be present. Slight decadence in the principle shrubs could occur near the end of the fire cycle.

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14. **Average percent litter cover (20-25 %) and depth (0.75-1.25 inches):**

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15. **Expected annual production** (this is TOTAL above-ground production, not just forage production): 1900 - 2000 #/acre on an average year.

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16. **Potential invasive (including noxious) species** (native and non-native). List Species which BOTH characterize degraded states and have the potential to become a dominant or co-dominant species on the ecological site if their future establishment and growth is not actively controlled by management interventions. Species that become dominant for only one to several years (e.g., short-term response to drought or wildfire) are not invasive plants. Note that unlike other indicator, we are describing what in NOT expected in the reference state for the ecological site: Green rabbitbrush, curlycup gumweed, Kentucky bluegrass & Xeric perennial & Annual forbs.

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17. **Perennial plant reproductive capability**: All perennial plants should have the ability to reproduce in all years, except in extreme drought years. Gambel oak sprouts vigorously following fire and with repeated fire may completely dominate the site.