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An overview of natural gas well pad surface disturbances and techniques used to increase reclamation success within the Vermillion Basin, Wyoming

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**LIST OF ACRONYMS**

| | |
|---|---|
| BLM | Bureau of Land Management |
| BMP | Best Management Practices |
| EA | Environmental Assessment |
| EPA | Environmental Protection Agency |
| NEPA | National Environmental Protection Act |
| NRCS | Natural Resources Conservation Service |
| SOM | Soil Organic Matter |
| VOC | Volatile Organic Chemical |

**ABSTRACT**

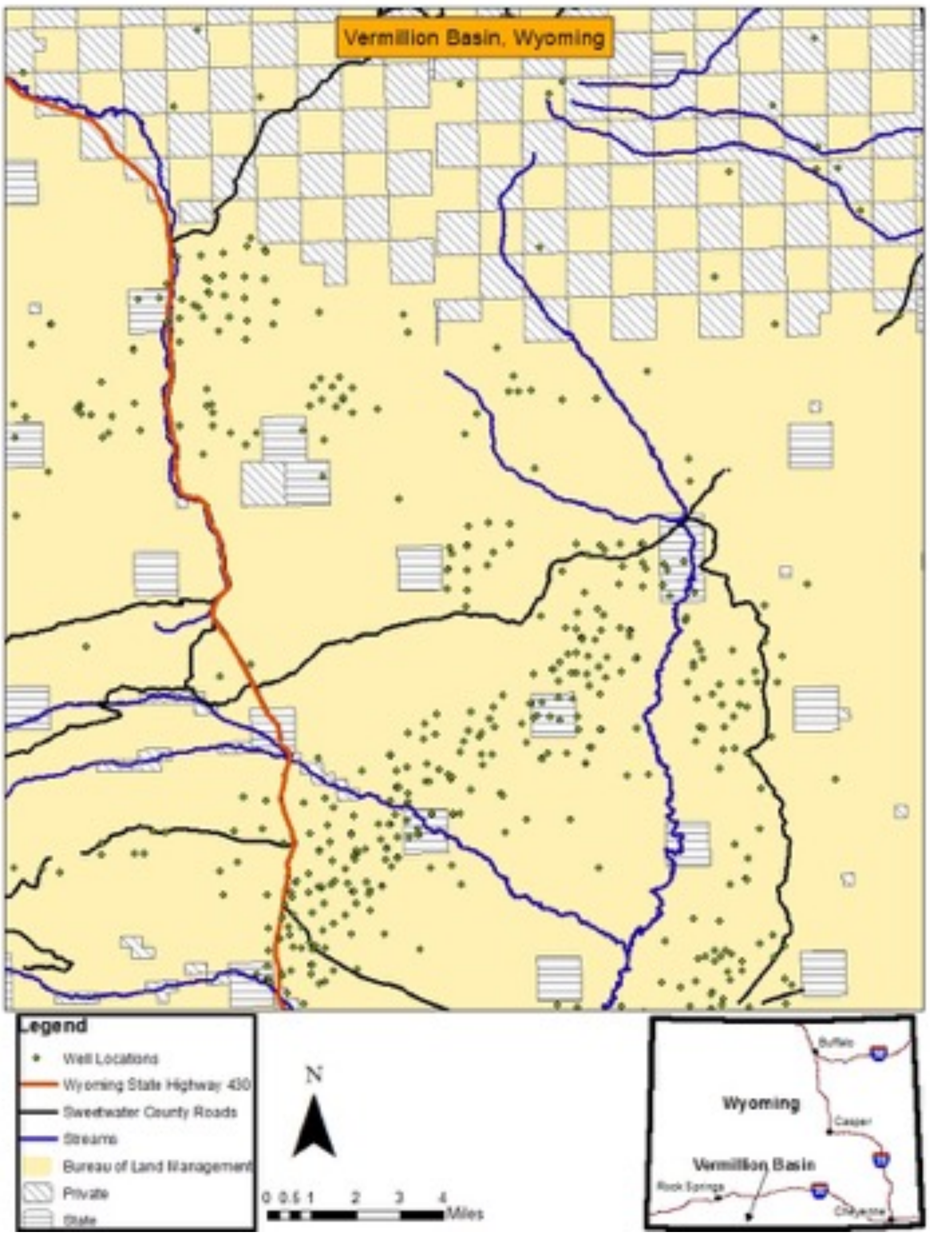
The Vermillion Basin, located in southwest Wyoming is an inhospitable, high altitude desert with unique biota and environmental conditions. The area has a long history of usages by humans including recreation, livestock grazing and mineral development. The natural gas industry has had a strong presence in the area since the 1940s, resulting in thousands of acres being disturbed for construction of well pads, access roads and pipelines, and this industry significantly contributes to the local and state economy. The disturbances have severely effected local wildlife, vegetation, water flow, nutrient cycles and other factors necessary for the environment to properly function. To minimize these effects, when a gas well on federal land is no longer productive the site must be reclaimed. This is done by plugging the well, removing all production facilities and recontouring the surface to approximate pre-disturbance conditions. Past reclamation efforts have been marginally successful, due to many factors including poor topsoil care and invasions by noxious weeds. To help achieve successful and timely reclamation, many science based techniques can be used including proper pre-disturbance control measures, controlling invasive weeds, using properly controlled grazing, topsoil care (especially avoidance of unnecessary compaction) and nutrient amendments, use of reseed mixes containing drought and erosion resistant native species, use of controlled burns and careful monitoring of the site for erosion or other reclamation hampering factors. The harsh conditions in the Vermillion Basin make reclamation difficult but when the techniques outlined in this paper are utilized, successful reclamation timelines can be accelerated. This can help the Vermillion Basin repair its ecological cycles and functions and allow all other natural resources in the area to be sustained.

## INTRODUCTION

### Site location and Description

The Vermillion Basin, located in southwest Wyoming near the Colorado and Utah borders, is an inhospitable, high altitude desert with sparse vegetation, alkaline soils and abundant natural resources. The ecoregion is a shrub-steppe, broad basin dominated by arid grasslands and shrublands. The area is very arid and barren as it receives approximately 6 to 9 inches of precipitation annually and average daily temperatures range from 10°F to 30°F during winter and from 50°F to 85°F during summer (Vermillion Basin EA 2000). The majority of the Vermillion Basin is managed federally by the Bureau of Land Management (BLM) under a multiple-use doctrine, and common usages by people include recreation such as cultural resource viewing and hiking, livestock grazing and natural gas production. A large amount of surface disturbance has occurred in the area, due to many factors as a result of the area being managed for multiple-use, and this disturbance and its associated effects create many roadblocks to achieving natural resource sustainability. The natural gas industry especially has caused much of this surface disturbance due to construction and installation of the many well pads, access roads, pipelines and other associated infrastructure needed for the industry to operate. Oil and gas operators must file a reclamation bond that is returned once the well is plugged, the site is recontoured and has achieved acceptable reclamation with a native, self sustaining stand of vegetation and stable soils. The bond money is held in reserve by the BLM in case the operator becomes defunct and plugging and abandonment procedures become the responsibility of the BLM. Figure 1 is an overview map showing the distribution of well pads in the Vermillion Basin and Figure 2 illustrates a typical operating natural gas well pad and associated production equipment found in the area.

**Figure 1. Overview map of the Vermillion Basin showing its location in Wyoming.**




## The Need For Proper Reclamation

The natural gas industry has been drilling and producing natural gas in the Vermillion Basin since the 1940's. (Vermillion Basin EA 2000). The network of roads and pipelines as well as the amount of natural gas well pads and associated infrastructure that have been built in the

**Figure 2-A typical natural gas well pad showing the wellhead (foreground) and production tanks (background). Note the area has been completely cleared of vegetation and the soils have been compacted to support necessary production equipment.**

area over the last 80 years has severely fragmented the habitat (see figure 3). Records are incomplete and inconclusive, but hundreds of gas well pads and infrastructure such as roads and pipelines have been built totaling approximately 50,000 acres of disturbance (Vermillion Basin EA 2000) out of approximately 300,000 total acres in the Vermillion Basin.

In 1969, the United States passed the National Environmental Policy Act (NEPA) which substantially changed how the federal government manages public lands. NEPA mandates that any action with the potential to disturb federally managed lands must be throughly analyzed

**Figure 3-Aerial View of the Vermillion Basin-well pads can easily be seen along with access roads.**

to identify potential impacts to other resources, and the public must be given a reasonable chance to provide comments on the proposed action. The act requires any substantive public comments to be considered in the decision process before a proposed action is approved or denied.

After NEPA was established, other resource management regulations followed. According to revised Onshore Order #1 (2007), when an oil or gas well on federally managed land is plugged and the site is to be abandoned (often 30+ years after the well was drilled), "the disturbed area must be returned to productive use and reclaimed to a satisfactorily revegetated, safe, and stable condition." This is done by removing all facilities and tilling or breaking up the compacted soils and re-contouring the site back to approximate pre-disturbance conditions. The site must then be reseeded with a native seed mix and returned to as close to its natural state as possible, including noxious weed control and achieving soil stabilization before the operator is relieved of liability for maintenance of the reclaimed site and their reclamation bond is returned. This forces the re-disturbed surface to begin the revegetation process again with native grasses, forbs and shrubs.

Past reclamation efforts in the Vermilion Basin have been marginally successful due to many factors including noxious weed invasions, absence of wildfire, improper livestock grazing, poor care of stockpiled topsoil and other reasons. This has caused some reclaimed well pads in the area to take over 20 years for native vegetation such as Wyoming big-sagebrush (*Artemisia tridentata*) and shadscale (*Atriplex confertifolia*) to mature and any trace of the original disturbance be erased, which is the ultimate goal of reclamation. Due to the various ecosystem and habitat types that the BLM manages, there are no set reclamation standards, though some regulations exist such as requiring weed free seed mixes be composed of native species.

Some reclamation regulations exist, but are largely subjective and arbitrary, such as requiring recontouring to “approximate pre-disturbance conditions” or that the site must be “stable” (BLM 2007). Federal oil and gas inspectors follow similarly subjective federal regulations to determine when a site has successfully been reclaimed, is ready for the operator to be relieved of maintenance liability and when their reclamation bond is to be returned. The aim of this paper is to analyze techniques, methods and best management practices (BMPs) to maximize reclamation success of oil and gas related surface disturbances in the Vermillion Basin, while investing less time and resources than in the past to do so. This would also help sustain the area’s multiple-use values as well as the ecological functions of the area, which is a subject of great interest to BLM resource specialists and land managers.

**Vegetative Resources**

The Wyoming Basin ecological region encompasses the Vermillion Basin (EPA website 2013). This basin is a broad, intermontane geographic area intermixed with hills and low mountains and dominated by arid grasslands and shrublands (EPA website 2013). The area is surrounded by similar shrub-steppe habitats to the north, east and west as well as conifer forested mountains to the south and southwest. Pinyon-juniper woodlands are found further south in Colorado, though peripheral slopes around the edges of the Vermillion Basin can contain small pockets of pinyon-juniper habitats on north facing slopes. These wooded habitats become more common as the slopes start giving way to the adjacent mountains to the south and southwest, allowing the soils to hold water and snow longer allowing better habitat for trees and larger shrubs. Common plants native to where most of the well pads are in the Vermillion Basin include Wyoming big sagebrush, shadscale, Sandberg bluegrass (*Poa secunda*), thick-spike wheatgrass (*Elymus lanceolatus*), indian ricegrass (*Oryzopsis hymenoides*) and spiney hopsage (*Grayia spinosa*).

**Soil Resources**

According to the Natural Resources Conservation Service (NRCS website 2015), the dominant soil order found within the Vermillion Basin is entisols. These generally are sandy and very shallow soils that are largely unaltered from their parent material, which in the Vermillion Basin can be unconsolidated sediment, siltstone, sandstone, mudstone, limestone, or shale (Vermillion Basin EA 2000). The dominant suborder of these soils is orthent, which largely lack horizon (layers) development due to slopes or parent materials lacking weatherable minerals (NRCS website 2015).

Being that the Vermillion Basin is very dry I believe the pulse-reserve paradigm described by Ward (2009) is magnified as compared to areas that average more annual precipitation. Ward (2009) describes the pulse-reserve paradigm for arid lands as the association between rainfall (which triggers plant growth pulses) and reserves of carbon and energy in the soil, and how these environmental factors influence each other. I believe the pulse-reserve paradigm is magnified in the Vermillion Basin because on the relatively rare occasion that the area receives rain, vegetation scrambles to utilize as much as it can and store what else it can as a reserve, unlike the vegetation in areas that typically receive more annual rainfall. What moisture remains on the surface quickly evaporates or is utilized by fauna as the local soils do not allow it to easily be infiltrated into the aquifer. Arid soils generally contain less soil organic matter (SOM), and especially humus, which is the material that allow soils to retain water (Soil Stories Video 2015) than more mesic soils. This is possibly due to the arid soil's generally low nutrient level and low plant productivity, which recycles fewer nutrients back into the soils when plants die and decompose.

Most upland soils in the Vermillion Basin are associated with, and derived from, the Green River Formation (Wilkins Peak member) and Wasatch Formation (Niland Tongue) (Vermillion Basin EA 2000) and are subject to erosion and can be very difficult to stabilize during reclamation. For successful reclamation, restoring drainages rerouted during well pad construction to their natural corridors as well as the establishment of strong rooted vegetation is important to keep erosion to a minimum and soil stabilization high.

Soil erosion in the area normally results from wind and water movement, but may be aggravated by herd animals or lack of stabilizing vegetative roots. Soil compaction has been extensively studied, shedding light on how its effects such as decreased water permeability and greater erosional potential reduce plant rooting ability, therefore reducing the soil's ability to collect soil nutrients and other resources (Frouz & Kuráž 2013). Highly compacted soils also may encourage invasive weed infestations (Sinclair et al. 2009) and prevent subterraneous animals such as prairie dogs and ground dwelling insects from using the area, reducing soil aeration (Vermillion Basin EA 2000) and other issues. These disturbances may cumulatively cause negative effects to various ecological functions and interactions in the Vermillion Basin. These degraded soil functions in turn may affect associated water and nutrient cycles, as well as plant's ability to photosynthesize. These processes are among the simplest building blocks of ecosystems and we're only beginning to understand how soil functions contribute to properly functioning ecosystems. We're also only starting to understand how human technology, pollution and development are altering these soil nutrient cycles and what the cumulative environmental effects of those anthropogenic changes are. To restore and maintain these vital ecosystems functions, proper care and stockpiling of the soil during initial well pad construction and during reclamation of well pads and roads is especially critical.

**Recreational Resources**

Recreation is a large part of the multiple-use doctrine that dictates how the BLM manages the Vermillion Basin. In addition to the gas field roads, numerous unimproved roads exist and are popular with off-road drivers. Hunting, wildlife viewing, hiking and cultural resource viewing are also popular recreational activities conducted in the solitude that is found there. Gas well pads and associated construction and maintenance create adverse visual and noise impacts to humans and wildlife (Vermillion Basin EA 2000). The "eye-sores" that well pads create can be eliminated with successful reclamation and noise resources are normally only adversely impacted during the construction, drilling and recontouring phases of the wells. Routine maintenance of the site can also cause noise pollution and effect the solitude experience of the surrounding area, and can be even more troublesome for wildlife during high stress times such as during parturition or extreme winter weather.

**Livestock Grazing**

The Vermillion Basin has experienced cattle and sheep grazing since the late 1800s. Several livestock owners utilize the grazing resources in this area. The numbers of livestock vary depending on the time of year and animal unit months (AUM) also vary based on precipitation, grazing intensity, etc., but averages around 20-50 acres per AUM (Vermillion Basin EA 2000). Sheep and cattle are the most common domestic livestock that use the area, but some goat and horse grazing occurs.

There are multiple livestock water troughs, guzzlers and grazing exclosures scattered throughout the area. Exclosures are fenced areas of varying size that prevent livestock from grazing inside the fenced area. Studying the vegetation inside these exclosures and comparing it to the adjacent grazed areas outside the exclosure help to monitor long-term vegetation health and trends, and allow managers to properly regulate grazing intensity to reach management goals. This data also has been useful in determining natural canopy cover levels, species diversity and soil compaction levels, which can be used to help determine what pre-disturbance conditions were before an oil or gas well pad was built.

**Water Resources**

The watershed of the Vermillion Basin is is comprised of many creeks, but all eventually drain into Vermillion Creek, which is a direct tributary of the Green/Colorado river system. The lower stretch of Vermillion Creek (outside of the Vermillion Basin) is a perennial stream, though the drainage channels in the Vermillion Basin are predominately erosive in nature with little if any riparian vegetation. This suggests that the overland flows in the area are largely ephemeral in nature, flowing mainly in response to snow melt and storm events with limited groundwater interactions. Reclamation in the area is largely dependent upon rain and snow for moisture, though some limited artificial irrigation on reclamation has been used. Results are inconclusive, but personal observations suggest irrigation has had limited success.

The Wyoming Water Development Commission's Groundwater Study Chapter 5 (WWDC 2010) indicates that the area is near the southern extent of multiple aquifer systems that include the Wasatch Fort Union, Green River Basin Lower Tertiary, Mesa Verde and Laney Aquifers. Depths to water and water quality are variable. Groundwater recharge from this area to the Green/Colorado River System is estimated to be no greater than zero to one half inches (WWDC 2010). The general direction of flow follows surface contours from east to southwest towards the Green River. Drilling rigs in the area often draw drilling water from local water source wells, which given the number of wells in the area, may have drawn down the aquifer below the area, possibly altering the ecology and water cycles on the surface.

**Wildlife Resources**

Many biologists and land managers believe mule deer (*Odocoileus hemionus*) and sage-grouse (*Centrocercus urophasianus*) are the most important and sensitive herbivores in the Vermillion Basin. I disagree, as I see them as no more important than the native rabbits or other animals but they are a hot button topic with land managers and politics in the area, as the critical winter habitat these species depend upon is often in the same areas that are ideal for natural gas wells and other associated infrastructure such as compressor stations. This is partially why proper and prompt reclamation of abandoned well pads is so important in the Vermillion Basin. The more suitable habitat that is available for these sensitive species the better their survival rates are in already inhospitable habitat.

In springtime, sage-grouse often gather in open areas called "leks" to strut and breed. Well pads and access roads create ideal leks due to the cleared vegetation, causing additional mortality due to vehicle collisions. Proper reclamation of abandoned natural gas well pads and infrastructure, including their access roads would return a lot of general sage-grouse habitat to the area, though the birds would have to become more reliant on naturally open areas to lek on. This may temporarily inconvenience sage-grouse during the first few lekking seasons, but overall may help ensure these high profile species continue to exist. See Figure 4.

Large herds of elk *(Cervus canadensis*), mule deer and pronghorn (*Antilocapra americana*) used to (and still do) roam the Vermillion Basin and can cause significant erosion damage to creek beds and critical winter habitats. These effects are largely natural, as for millennia large herd animals such as elk and the no longer present bison (*Bison bison*) trampled the area causing churning of the top soils, spread nutrients by wallowing and digestive processes and other important ecological functions (Roman 2015). Today, the amount of roads and fences as well as other natural gas infrastructure has altered migration patterns of the remaining large wild ungulate herds in the area (McCarthy 2014), concentrating or diverting the effects of erosion and soil compaction that herd animals naturally caused. Proper reclamation of surface disturbances no longer in use would help minimize or even completely reverse these effects to wildlife among other resources, helping to reinstate natural ecological functions and restore the ecosystem.

**Figure 4-A sage-grouse hen killed by a vehicle near a natural gas compressor station. While habitat loss is thought to be the biggest cause of mortality for disturbance sensitive species, the increased vehicle traffic in their habitat is also a factor.**

**Socioeconomic Implications**

Reclaiming well pads, access roads and other infrastructure such as pipelines once no longer needed requires heavy soil moving equipment, drill seeders and other equipment. There are businesses locally that specialize in nothing but reclamation work and weed spraying, adding to the importance that all phases of well life have to the local economy. According to Andersen and Coupal (2009) a multitude of factors could influence reclamation costs. They determined an overall reclamation cost of a well (including equipment removal, well plugging, site recontouring, reseeding, monitoring of progress, etc.) averaged $10.81 per foot of well depth. Well depths vary in the Vermillion Basin from roughly 8,000 to 10,000 feet deep, so this would translate to approximately $86,500 to $108,100 per well in reclamation costs. Multi-well pads are becoming more common in the area and this both reduces the amount of disturbance needed (a single well pad and access road per well v.s. a single well pad and access road for multiple wells), so these figures are somewhat arbitrary but do give a rough estimate of the magnitude of the money and economic impact involved with reclamation in the area.

**Cumulative Ecosystem Implications**

The Vermillion Basin, its topography, weather patterns and natural resources can be viewed in terms of macroecology, as the mineral resources recovered there are used throughout the world and the effects of recovering those resources are felt worldwide too. Air quality has been becoming more of an issue there recently due to the volatile organic chemical (VOC) emissions given off by facilities and equipment used to extract crude natural gas, and is largely thought to be a major contributor to global climate change (Brantley et al. 2015). Additionally, the many roads and pipelines add to the cumulative loss of vegetation and wildlife habitat.

Once pipelines are installed and roads are built, replacement of potential vegetation occurs (Perry et al. 2008) along the right-of-ways with various annual grasses and some species of invasive and often poor forage value vegetation, negatively effecting wildlife and livestock grazing values. No studies specific to soil erosion and water channels being altered due to the amount of pipelines and roads in the local area were found, but I believe these negative effects are likely to have happened. Reliable techniques to counter this are among the sustainability approaches I am interested in and part of why the BLM requires reseeding of reclaimed disturbances with native vegetation such as indian ricegrass and thick-spike wheatgrass which is adept at soil stabilization and is of good forage value. This helps to minimize cumulative resource impacts and sustain overall ecosystem health.

Ecosystem health is a subjective topic that is especially contentious in areas with controversial activities such as livestock grazing and natural gas exploration, both of which are prevalent in the Vermillion Basin. Ecosystem health is critically dependent upon the ability of the system to retain nutrients and water after a disturbance occurs and prolonged ecosystem health can be reduced if system nutrient capital isn't adequately protected (Perry et al. 2008). Adaptive management, or incorporating management objectives, results and constant adaptation of management implications until success is achieved (Herrick et al. 2012) is an especially useful tool the BLM uses in managing rangelands and other areas with unnatural disturbances. The tilling and reseeding of reclaimed disturbances such as natural gas well pads until acceptable revegetation is achieved is an example of adaptive management and is an approach I support to sustain nutrient cycles, biodiversity and ecosystem health in the Vermillion Basin.

The biodiversity and ecology of the area cumulatively results in a classic example of intricate trophic interactions, or food webs as described by Estes et al. (2011). This includes the vegetation that is removed by building well pads and access roads, which results in animals being displaced due to the loss of habitat. Many animals remain in nearby, unaltered habitat as they are local residents however many other species such as mule deer and mountain lions (*Puma concolor*) largely migrate here from the surrounding mountains during winter, further complicating the area's trophic interactions and increasing the importance of proper reclamation of surface disturbance once natural gas infrastructure is no longer needed.

The first trophic level, or basal level, consists of green plants, then herbivores and pathogens and finally the top trophic levels consist of predators and parasites (Perry et al. 2008). An elementary example of these levels and their interactions in the Vermillion Basin would be grasses such as indian ricegrass, then common herbivores such as pronghorn and finally large predators such as mountain lions and possibly gray wolves (*Canis lupes*). Biodiversity and the trophic levels of an area are important in maintaining ecosystem functions, and reduction or loss of these components (especially large predators) can substantially change the area's ecosystem processes and functions, as top predators are critical for controlling ecosystem food webs (Binkley et al. 2006).

All the plant and animal species present in the Vermillion Basin have natural processes that influence the natural flow of water, nitrogen and phosphorus cycles through the air and soils as well as other critical ecosystem processes. The undisturbed portions of the Vermillion Basin is "old-growth" sagebrush-steppe, according to the descriptions provided by Veldman et al. (2015), who also determined that frequent fires and herbivory are essential elements for healthy old-growth grasslands. The cumulative impacts to an ecosystem are dependent upon the various nutrient cycles, properly functioning soils and the functions animals evolved associated with environmental processes as well as water and atmospheric influences. It is widely accepted that ecosystems will fail to properly function without all of these critical components. This is why proper management, including use of BMPs to ensure successful reclamation of well pads and other natural gas infrastructure is so important in sustaining ecosystem health while maintaining other resources in the area such as recreation and livestock grazing for all interest groups to use and enjoy.

## REDUCING THE EFFECTS OF NATURAL GAS INFRASTRUCTURE DISTURBANCES

Among the most important tools an operator can use to ensure successful reclamation once the disturbance is reclaimed is to choose proper sites to begin with and keep disturbances at a minimum. Traditional construction techniques for well pads involve large amounts of cut and fill, displacing existing vegetation and shifting large amounts of soil (Mitchem et al. 2009), creating ideal conditions for noxious weed invasions. The use of oak planks to support drilling equipment is becoming more common as it can save vegetation from needing to be removed and also may reduce soil compaction, though their use requires a naturally flat area. Mitchell et al. (2009) found that use of oak mats did protect vegetative resources and minimize weed establishment, however their use also blocked any sunlight from reaching the vegetation for the duration of the drilling process, which can be several months depending on circumstances. Sunlight is critical for vegetation to perform its life functions such as photosynthesis and various nutrient transporting functions. For this reason, oak mat use is considered better during the winter months, when many plants are dormant and unable to utilize sunlight anyhow.

This causes a complication though, as winter is the time when wildlife are most susceptible to hardships and malnutrition, and are especially so during the strenuous winters the Vermillion Basin experiences. To survive these winters, wildlife require as little outside disturbances and stress as possible. Well drilling rigs and their use cause severe noise pollution as well as increased daily vehicle and human traffic. Because of these reasons, the BLM largely discourages the use of oak mats in the Vermillion Basin regardless of their potential to increase reclamation success once the well pad is to be reclaimed, though other techniques have been shown to be successful and less strenuous to wildlife and vegetation.

**Reseeding the Site**

Once an abandoned site has been tilled and recontoured, it must be reseeded with a certified weed free, native species seed mix. A seed mix consisting of species specific to the site is used when that information is available, but many well pads in the area were drilled 50+ years ago and vegetation inventory was not conducted when the well was approved. Monitoring adjacent undisturbed lands can provide suggestions to which species to include in the seed mix, but the BLM generally requires grasses, forbs and shrubs such as Indian Ricegrass, scarlet globemallow (*Sphaeralcea coccinea*) and Wyoming big sagebrush to be in the seed mix. These species help stabilize soils, compete well against invasives and are generally drought resistant (BLM 2000).

Timing of reseed application is a factor managers must consider. BLM inspectors have generally concluded that in the Vermillion Basin, reseeding in the fall within weeks before the first frost generally produces better revegetation success than reseeding at other times of the year. As a result we normally recommend this time period to operators conducting reseeding efforts. I could find no specific studies confirming this from a scientific standpoint, but the findings of Monsen and Stevens (2004) reflect what BLM reclamation inspectors have suspected.

Additional reseeding considerations include application method, such as drill seeding or broadcasting. The method used is dependent upon environmental factors such as humidity, soil type, species and time of year in which they're applied. More research is needed before definitive conclusions are drawn, but drill seeding is generally desirable during late fall, possibly to avoid frozen ground from damaging seeds and reducing viability. If the site is to be broadcast seeded, BLM inspectors have generally found that doubling the volume or weight per acre of seed mix one would use for drill seeding produces better results. Like with reseed timing, no applicable studies could be found to verify optimal application methods, but the above is what BLM inspectors often regard as optimal and consequently is what we suggest to operators.

**Invasive Weeds**

One of the biggest roadblocks to successful reclamation in the Vermillion Basin is the establishment of noxious and invasive weeds and uncontrolled livestock grazing on reclaimed lands. Despite weed free seed mixes used for reseeding, invasive weeds normally populate a reclaimed site before desirable plants do. Unlike agricultural weeds, invasive plants successfully establish and spread to new habitats once introduced to a new area with little, if any help from humans (Radosevich et al. 2007). They often spread to new habitats, displace native species and may threaten the biodiversity and the ecosystem function of the area they have invaded. Noxious and invasive weeds common to the Vermillion Basin that cause severe ecological and economic impacts to reclamation efforts include black henbane (*Hyoscyamus niger*), halogeton (*Halogeton glomeratus*) and cheatgrass (*Bromus tectorum*). See figures 5-7 for illustrations.

Invasive weeds alter the habitat in ways that are not yet well understood. What has been recognized though, is that where invasive species are present or biophysical conditions are severely altered such as areas tilled for farmland or development, ecosystems may never return to an old-growth state (Stromberg and Griffin 1996; Veldman et al. 2015). The invasion of cheatgrass has also has been linked to substantially increased wildfire occurrence (Balch et al. 2013).

Many noxious and invasive weeds are of poor nutritional value for wildlife and livestock and can exhibit what is known as the “Novel Weapon” hypothesis. Krueger-Mangold et al. (2009) describe this as mechanisms or processes which are not naturally present in an invasive’s new environment and can disrupt inherent, coevolved interactions with the coexisting native vegetation, which has not evolved mechanisms to cope with or counteract the invasive’s “weapon”. As an example, halogeton emits a “poison” from it’s roots into the soil that largely prevents other plants from growing near it (USDA 2016a). Native plants have evolved no

**Figure 5-Black henbane growing alongside a natural gas well pad access road in the Vermillion Basin. This plant is toxic to nearly all herbivores. It is not even recommended to be mechanically managed without gloves, as rashes and skin irritation can occur.**


countermeasure to the poison which may be why halogeton easily invades and overtakes the area. Other issues invasive plants cause in the Vermillion Basin include black henbane (and to a lesser extent halogeton) being toxic to herbivores and cheatgrass significantly reducing forage availability as it is of poor nutritional value, especially when in its climax stage (James et al. 1991). These factors make noxious and invasive weeds a serious roadblock to reclamation success in the Vermillion Basin and are expensive for natural gas operators to manage for.

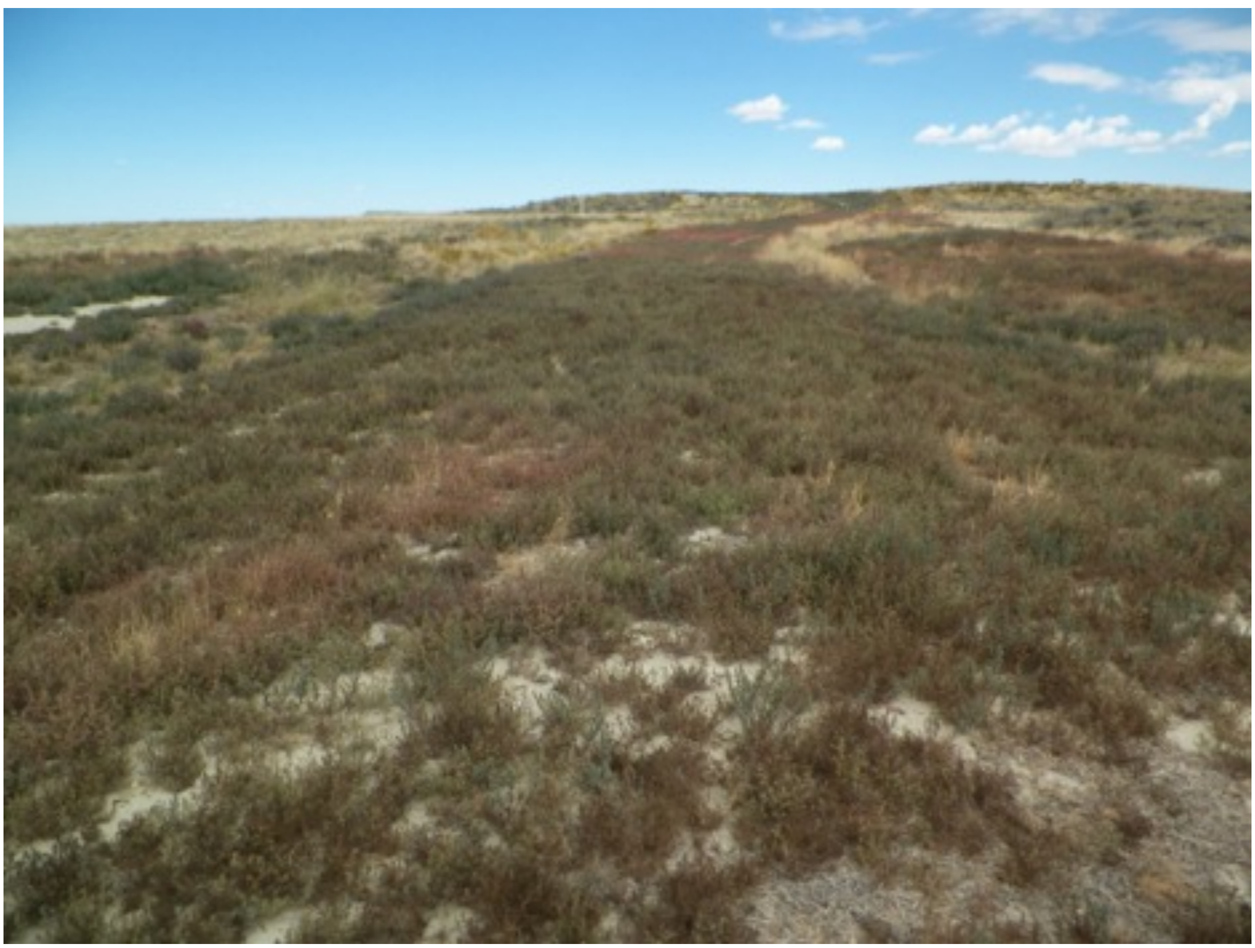
**Figure 6-Halogeton, likely the most common invasive plant in the Vermillion Basin and a major nuisance to natural gas well pad reclamation efforts.**


Options do exist for managing these invasive weeds though. Chemical herbicides can be applied, though factors such as plant physiology, timing, application rates, moisture levels and other factors can vary the success these chemicals have on weed invasions. Use of chemicals is also controversial due to its effects to non-target plants and the residual nature of some chemicals negatively effects soils and watersheds (James et al. 1991). Other management options exist such as biological control, including use of targeted grazing. These techniques use insects or livestock to graze on and control specific weeds. Research is ongoing, but I am aware of no insect which has been utilized to control halogeton, however some limited personal observations of sheep grazing suggests that they potentially could be used to control halogeton, especially early in the growing season, as halogeton can prove to be poisonous to sheep if grazing intensity is too high

**Figure 7-Cheatgrass is becoming increasingly established in the Vermillion Basin, causing economic issues with livestock grazing, reclamation efforts and is a major fire hazard during late summer and autumn when the grass is senesced and dry.**

or conducted during the later part of the growing season (James et al. 1991). Use of prescribed fire can also help manage invasive weed infestations, but no studies specific to halogeton control were found to verify this either. The success of these methods are also subject to varying habitat conditions and possible unintentional secondary effects. Due to this, these methods are being studied and limited use of them have occurred in the Vermillion Basin, though BLM land managers are considering more future use.

**Figure 8-A reclaimed access road experiencing poor revegetation due to invasive weeds. Halogeton can be seen in the foreground, but cheatgrass is also present. This site was also not tilled and recountoured properly, as hard packed soils can be seen and little topography was restored, as compared to undisturbed adjacent areas.**



**Livestock Grazing**

In addition to possibly controlling invasive weeds, closely managed livestock grazing may increase reclamation success in the Vermillion Basin by influencing SOM condition, fire suppression and erosion control. Though controversial due to unnatural disturbances, notorious riparian damage and differences in their preferred browse, properly managed livestock can be used to partially mimic the ecological processes that the no longer present wild bison herds provided for the habitat. Yeo (2005) conducted a study to determine the effects of cattle grazing on rangelands and found that with improperly managed cattle grazing, bare ground cover occurred more frequently than in adjacent areas within grazing exclosures. Other studies such as Espeland (2014) and Schuman et al. (1990) have shown that when properly managed, livestock grazing can help improve reclamation success.

Driessen et al. (2011) determined an unconventional, but effective reclamation method utilizing ranchers and their livestock in the reclamation process: a controlled livestock impact technique. They found that by confining livestock to recontoured and reseeded sites the animals could improve the seedbed and soils through fertilization and churning of the soils from hoof action. They found that post-cattle treatment sites contained more mineralizable carbon and more nitrogen than sites not subject to the livestock treatment, which indicates a positive impact from the livestock on SOM characteristics. Soil compaction is a factor that must be carefully considered when using livestock as a management tool, as when improperly used livestock can highly compact soils and prevent any vegetation from from growing.

Use of properly controlled and managed livestock grazing, specifically high stocking rates for short time periods on reclaimed lands immediately after reseeding, can increase reclamation success (Norton et al. 2009). Despite recent improved range management techniques, livestock grazing still may limit native plant communities in sagebrush-steppe ecosystems (Yeo 2005) when particular conditions exist. The health of dry land ecosystems can be improved with livestock exclusion in the absence of other disturbances (Yeo 2005) such as invasive weeds and soil disturbances such as tilling or compactness.

Stripped and stockpiled topsoil can result in reduced SOM levels. Studies have found that when reapplied for reclamation purposes, stockpiled topsoils that had been stripped for coal mines contained between 35%-69% less SOM than in their undisturbed states (Anderson et al. 2008; Driessen et al. 2011; Mummey et al. 2002; Norton et al. 2009) and that time since reclamation does not have a consistent effect on the difference in SOM content between reclaimed and undisturbed soils (Norton et al. 2009). Additionally, studies have found that by using properly controlled livestock, various nutrients and organic materials of varying composition can be added to the seedbed from digestive waste, unconsumed feed, etc. which improves seed-soil contact and ultimately, reclamation success (Driessen et al. 2011; Norton et al. 2009; Schuman et al. 1990).

While many of these studies were conducted in more fertile soils than what is generally present in the Vermillion Basin, their results do point toward the potential to use livestock to aid reclamation in the less fertile, alkaline soils of the Vermillion Basin. Livestock would recreate, to at least some degree, ecological functions such as grazing, stampeding, etc. that disappeared with the loss of bison and the reduction of elk herds and that native vegetation evolved with. There are inherit ecological response differences between cattle and bison though, and land managers must take these differences into consideration. Hidinger and Steuter (1999) found that bison preferred a perennial grass diet and more open landscapes as opposed to cattle who included more forbs in their diet and prefer riparian areas during the growing season. When stocked at similar rates, the amount of grass when the dormant season begins is higher with buffalo than with cattle (Hidinger and Steuter 1999) suggesting that while both can be used to restore sagebrush-steppe ecosystems, they should be managed differently and carefully.

**Figure 9-Livestock inside the fenced area of an active reclamation site. Note the quality of revegetation occurring and few weeds, though late successional shrubs have not grown in yet. Use of livestock is carefully managed to avoid unnecessary soil compaction and over grazing of the successful revegetation that has occurred thus far at the site. Use of livestock on public lands is controversial and must be monitored carefully.**

**Soil Rehabilitation**

Topsoil health is very important in successful reclamation and revegetation processes. Soils that are highly compacted are often unable to grow vegetation, especially desirable vegeta-ion and also impede subterraneous animals such as various insects and prairie dogs from utilizing the area. These animal burrows help aerate soils and enhance nutrient flow through the topsoil (Vermillion Basin EA 2000). Physical soil properties such as bulk density and rock fragments are more difficult to alter by tilling than other properties such as pH (Sinclair et al. 2009). Disturbed sites that have been recontoured often have higher soil bulk densities, lower water storage potential and slower hydraulic conductivity, which often limit root growth and result in lower revegetation success (Sinclair et al. 2009). Figure 10 below shows a recently tilled and recontoured well pad that is not yet revegetated.

This means that reclamation seed mixes should include early successional species that are known to be drought resistant and tolerant of alkaline soils. Native grasses such as Sandberg bluegrass and Indian ricegrass are good candidates for reclamation seed mixes in this area and the BLM has had good success with them. They are known to discourage invasive species, are resistant to or benefitted by properly managed grazing, can stabilize soils and set the stage for late succession vegetation communities such as sagebrush-steppe communities (Jones 2005). Commercial mulches, straw and other soil amendments can also be used to increase nutrient levels and promote mycorrhizae in the topsoil, which may have been degraded from being stockpiled for many years. Incorporation of hardy and root stabilizing native grass seeds as well as artificial nutrient enhancements into reclamation plans could be useful to set the stage for successful reclamation.

As unique and varied as the soil structure is in the Vermillion Basin, site specific reclamation plans have proven to be invaluable. Site specific reclamation plans utilize science based methods and technology that are customized to each individual site being reclaimed (House et al. 2009). Developing these plans allows managers to utilize unique characteristics of the site such as soil type, wind and water erosion potential, moisture content, dominant vegetation, etc. Given that the science of reclamation is still developing, an umbrella or generalized reclamation plan

**Figure 10-A well pad that was recently tilled up and recontoured, approximating the original contour of the land pre-disturbance. This site is ready for reseeding when conditions are right, which in the Vermillion Basin, usually means autumn, right before the first frost. Mulch or other soil amendments would help set the stage for successful reclamation. This site will be in rehabilitation until the soils have stabilized, native vegetation has reestablished itself and the site becomes part of the natural habitat again.**

that does not take into account site specific factors could limit reclamation success (House et al. 2009) and should be avoided, especially in areas such as the Vermillion Basin where various soil types and other variable environmental factors exist.

**Figure 11-An abandoned well pad that has been poorly retilled and is still hard packed. The tire tracks were from vehicles used to reseed the site. This site needs retilled and soils broken up to allow subterraneous animals to return and perform their ecological processes. Close monitoring of the site over the next few years will help keep invasive weeds minimized and allow reclamation to be more successful.**

**Use of Wildfire for Ecosystem Restoration**

Wildfire is the most widespread and common natural disturbance to forests and rangelands (Perry et al. 2008). Wildfire in the Vermillion Basin has largely been inhibited in the last century, as it has in most all other areas of the world to protect buildings, human settlements and in the case of the Vermillion Basin, the oil and gas infrastructure. Wildfire used to rage unchecked throughout the area, influencing the evolution and structure of soils and vegetation with the hotter, drier conditions that fire creates (Bowman et al. 2009). Habitats depend upon periodic fires to function properly and rejuvenate grasses. Fire can have either positive or negative effects to an ecosystem depending on the specific habitat factors and environmental conditions.

Use of controlled burns on improperly reclaimed or invasive weed covered sites is being considered by the BLM as an alternative to rejuvenate soil productivity and ultimately, increase reclamation success (See figure 12) in the Vermillion Basin. Nutrients such as nitrogen and phosphorus are often limited in dry land ecosystems (Drenovsky and Richards 2004), and additional nutrients such as sodium is abundant in the Vermillion Basin due to the high alkaline soils (Vermillion Basin EA 2000). Shrub-steppe grassland fires often move quickly and relatively cool compared to forest fire so seeds in the soils frequently survive (Buckhouse 1985). Additionally, Biggs (1997) found that nitrogen and phosphorus levels could be significantly increased with the managed use of wildfire as a management option in shrub-steppe ecosystems though (Wright and Bailey 1982; Mcpherson 1995) found that sodium is generally not volatilized during fire and thus remains on site. Since the soils in the Vermillion Basin contain a lot of natural alkaline and are very dry, the BLM requires reclamation seed mixes to include sodium tolerant and drought resistant naive species. Since those seeds would likely remain viable after a controlled burn and the soil's limited nutrients could be rejuvenated, use of controlled fire has great potential to increase reclamation success on reclaimed well pads in the area.

With increased fire occurrence, wind erosion of the soils often also increases; affecting site recovery, ecosystem processes, air quality and other important ecosystem components (USDA 2016b). Additionally, wind erosion is more likely to occur in flat areas rather than water erosion (USDA 2016b) and since the Vermillion Basin is relatively flat this caution should be noted by land managers.

**Figure 12-An improperly reclaimed well pad access road covered in invasive weeds and bare areas needing additional treatment. This would be a potential site for an experimental controlled burn to determine its effect on reclamation success.**

Controlled burns in the active well fields would also require substantial safety equipment and workers in order to prevent a fire from unintentionally spreading beyond its intended boundaries, and perhaps threatening pipelines or other crude natural gas holding facilities in addition to human safety. The cheatgrass invasion that has been occurring in the area in recent years could also complicate fire safety, especially if the burns were conducted in the fall when many grasses, especially cheatgrass, are dead and dry, which increases the fire hazard (Balch et al. 2013). Due to these reasons, extreme care would be needed but when properly conducted, controlled burns could increase reclamation success. These are just some of the considerations that managers would have to take into consideration if controlled use of fire was to be utilized as a reclamation tool in the Vermilion Basin. I would support the experimental use of controlled burns on poorly reclaimed sites in the area, as like livestock grazing, carefully controlled burns potentially hold the ability to create stable alternative states in the absence of its natural occurrence.

**The Importance of Monitoring**

Many ecosystem components and processes such as nutrient cycles and vegetative health of reclaimed sites are not closely examined but are crucial for proper ecosystem function (Stahl et al. 2009). By monitoring various locations undergoing active reclamation in the Vermillion Basin, and especially monitoring seemingly trivial components such as insect colonization and erosion levels in addition to conventionally monitored factors such as moisture level, knowledge and insight can be gained of site specific reclamation performance. Future reclamation plans can then be modified or enhanced based on that information gained through monitoring.

Figure 13 shows a poorly recontoured abandoned well pad which has experienced severe soil erosion. Proper monitoring could have identified problems early in the reclamation process and repairs could have been made before erosion reached unnecessary and damaging levels. Additionally, monitoring for illegal activity such as off-road driving and unauthorized livestock grazing can prevent harming topsoils through unnecessary compaction and other reclamation harming activities. Monitoring for these circumstances or situations would help achieve reclamation success.

**Figure 13-A reclaimed well pad which was poorly recontoured and is experiencing severe runoff erosion. Note the lack of vegetation, which is contributing to unstabilized soils. This site will likely need properly recontoured and reseeded to achieve stabilization.**

An important aspect that many natural gas operators overlook in the reclamation process is the time it takes for proper revegetation growth, even in ideal moisture and soil conditions. Climax vegetation can take from years to centuries to achieve climax levels (Jones 2005) depending on phenology and habitat conditions. Wyoming big sagebrush, possibly the most dominant shrub in the Vermillion Basin,  is slow to mature but the process can be sped up by use of scientifically proven BMPs regarding soils and monitoring (Schlaepfer et al. 2014). Under the correct conditions long-lived shrubs and forbs can grow rapidly in spring and survive drought through vegetative dormancy (Kitchen 1992), increasing reclamation success in times of drought, which Wyoming has been experiencing the last several years.

While the Vermillion Basin is not a forest, I believe the conclusions that Swanson et al. (2010) came to could be pertinent as improper reclamation often reduces biodiversity richness during reclamation's early stages of vegetative succession. Since well pad and access road construction typically involves complete clearing of vegetation (clearcutting if you will) and soil compaction from heavy equipment this effect may be more severe as compared to areas that are not completely cleared and graded. Swanson et al. (2010) also stress that when maintaining or even increasing biodiversity is a management objective (such as during reclamation), the importance of healthy early vegetative successional stages is underrated. Additionally, according to Gundlach et al. (2009), proper monitoring and management can significantly decrease the time required for a disturbed site to reach successful revegetation levels. To maximize reclamation potential, I believe monitoring for erosion, invasive weeds and revegetation success during early reclamation stages is especially critical and needs to be integrated into management plans. Prompt responses to issues identified through monitoring and utilizing BMPs and other preventative damage control practices such as restricting off-road driving and unwarranted livestock grazing can help set the stage for prompt and successful reclamation, allowing the operator's reclamation bond to be returned and relieved of maintenance liability of the site.

## SUMMARY OF RECOMMENDATIONS

- **Develop and utilize a science based adaptive management plan, which may include site-specific efforts such as soil amendments complimenting the site's specific soil characteristics as well as implementing an overall reclamation plan that adapts to varying environmental conditions such as drought or invasive weed presence.**

- **Choose proper well pad sites during pre-construction surveys to minimize environmental effects and maximize reclamation potential. Examples of this would be to avoid sites requiring large amounts of cut and fill or in drainage areas prone to heavy runoff.**

- **Manage noxious and invasive weeds to keep their effects minimal. Chemical and biological (including targeted grazing) control or use of prescribed burns can be considered, dependent upon weed species and site specific environmental factors.**

- **Use carefully managed livestock grazing, or avoid it completely if conditions are not optimal for their use. For example, utilizing high stocking rates for short time periods immediately after reseeding has been shown to improve reclamation success, but prolonged grazing periods may result in highly compacted soils and increased erosion, negatively affecting reclamation success.**

- **Properly care for stockpiled topsoil, avoid compaction and add nutrient amendments if necessary. Avoid compacting or contaminating stockpiled topsoil that is intended for use during reclamation of the site. Nutrient enhancing soil amendments such as mulch can add organic matter to the soil, prepping it for better vegetation regrowth potential.**

- **Reseed reclamation with good, soil-stabilizing and drought resistant native species. Timing of reseed applications is also important. Unverified observations by BLM inspectors suggest that seeding in late fall, right before the first frost has been shown to be optimal in the Vermillion Basin.**

- **Use carefully managed prescribed fire to recharge soils with organic matter and increase limited nutrients, especially phosphorus and nitrogen. In particular conditions, fire can also reduce invasive weed potential and their associated effects.**

- **Monitor the site closely, especially for erosion, invasive weeds and illegal off-road driving. Immediately addressing issues found, whether it be managing invasive weeds or reseeding the site before the problem becomes worse will ultimately help reclamation success.**

## CONCLUSION

Biodiversity often positively effects individual species niches as well as macroecosystem functions (Pasari et al. 2013). I believe that the Vermillion Basin in conjunction with all of its natural components work together to regulate nutrient and hydraulic cycles, maintain microclimates and defend against exotic species invasions (Altieri 1999). I believe the invasion of cheatgrass, halogeton and black henbane in the Vermillion Basin over the last several years is evidence that these ecosystem functions are not working properly. Pasari et al. (2013) concluded that distinctness among communities and larger scale species richness only had positive environmental effects when multiple functions were working together. This reinforces my theory

**Figure 14-a well pad that is experiencing proper and successful revegetation. Note the bunch grasses and lack of invasive weeds. Also note the fence, used to keep livestock contained when utilized and out when their function has been obtained. This site still needs more time for complete reclamation, but is progressing well.**

that all species, regardless of how insignificant they initially seem can be equally important for an ecosystem to continue to function the way it evolved to.

**Figure 15-A fully and successfully reclaimed well pad in the Vermillion Basin. Notice the vegetation is mature and the edges of the disturbance are largely indistinguishable from the surrounding natural areas. Also note the external dry hole marker used to identify the exact location of the plugged well bore. This practice is no longer used, as the well bore marker is now buried when well pads are reclaimed. This site is ready for reclamation bond release and all maintenance liability by the operator is relieved.**


The natural gas industry has had profound positive social and economical effects in the Vermillion Basin and elsewhere, but also has negatively affected the biotic and abiotic interactions that influence the biodiversity and ecosystem functions that the area's natural environment depends on (Perry et al. 2008). Utilizing effective BMPs could increase reclamation success of the Vermillion Basin's natural gas industry's disturbances and also reverse degraded ecosystem functions such as the nutrient cycles that the large amount of disturbance in the area has caused. These cycles are dependent upon healthy soils and water drainages which evolved alongside biotic factors such as various dry land grasses and drought tolerant animals, as well as the area's food web dynamics. All of these factors combined have evolved into the Vermillion Basin, an unforgiving environment of immense beauty and natural resources which have been negatively affected by human intervention, and especially the natural gas industry. I hope my support and encouragement to utilize proven BMPs and continue research concerning reclamation techniques provides information for land managers to avoid sustainability roadblocks and make more informed decisions to sustain the remaining natural resources as well as the beauty and recreational value of the Vermillion Basin.

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