

Reducing Ecological Impacts  
of Shale Development:  
RECOMMENDED PRACTICES  
FOR THE APPALACHIANS

# LANDSCAPE-SCALE PLANNING



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Infrastructure development from shale oil and gas development — including well pads, roads, pipelines, staging areas and compressor stations — is transforming Appalachian landscapes. Each well pad and associated infrastructure directly impacts nearly nine acres of forest habitat on average. Increasing deforestation, fragmentation, amount of impervious cover, and potential for invasive species strongly influence the overall health of an ecosystem. Impacts on water quality and terrestrial/aquatic habitats range from localized effects to broad, landscape-level impacts. The combination of the Appalachian region's diverse, intact temperate forests and freshwater systems with the rapid development of shale resources makes landscape-scale planning central to reducing cumulative, surface impacts on Appalachian ecosystems and the services they provide.



## STATE OF THE RESEARCH

Substantial research reveals that the consequences of land conversion to non-natural cover, as occurs with shale development, are not limited to localized effects but can also profoundly influence terrestrial and aquatic ecosystems and ecosystem services on a larger, landscape scale.<sup>1-3</sup> The combined, cumulative impacts of shale development across the landscape and region can significantly affect a broad array of terrestrial and freshwater resources and habitat quality.<sup>1,4</sup>

One of the major impacts of shale infrastructure development is forest fragmentation, which results in habitat loss, reductions in core forest areas (interior forest habitat not influenced by edge), barriers to wildlife movement from roads and pipelines, and the spread of

invasive plant species.<sup>1-6</sup> Forest cover, size of forest patches, and the configuration of forest habitat in a landscape all affect the region's ability to sustain healthy ecosystems. Declining regional forest cover can result in loss of species, changes in community structure, and impacts to water quality.<sup>7</sup> The effects of fragmentation are cumulative and vary widely, depending upon the type and size of openings, the surrounding landscape, and the suite of species present. Changes to the reproductive success, habitat use and behavior of many species as a result of forest fragmentation is well-documented in scientific literature, particularly in birds.<sup>2,8,9</sup>

Land conversion from development can also alter hydrology and adversely affect stream health and aquatic life over large distances through changes in runoff



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*Landscape-scale planning is central to reducing the ecological impacts of shale development.*

patterns and increased impervious surface, deforestation, and erosion and sedimentation.<sup>10-12</sup> Altered distributions of some aquatic species, higher stream temperature and increased turbidity have all been linked to reductions in forest cover.<sup>13-16</sup>

Data on cumulative impacts and impacts to habitats and species from shale development are limited but growing. Additional research to determine threshold levels where habitat loss, fragmentation and degraded stream health become detrimental to species and ecosystem function in the Appalachian region are beginning to emerge and will prove helpful in developing effective conservation strategies.<sup>17</sup>

## EVIDENCE OF IMPACT Decreased Regional Forest Habitat

The extent and configuration of forest cover on a regional scale has a strong influence on the overall health of an ecosystem. Loss of regional forest cover can adversely impact stream health; reptile, amphibian, small/large mammal and bird species richness; and community structure.<sup>7,15,18-25</sup> Research suggests a watershed with 30 to 50 percent forest cover can support minimal habitat function, but still results in loss of important species and impacts to aquatic ecosystems.<sup>7</sup> Forest cover greater than 60 percent is more likely to support healthy habitats and wildlife long term.<sup>7</sup>

Beyond the amount of forest habitat in a region, connectivity between habitat areas is vital for species to be able to meet their breeding, feeding, shelter and migration needs.<sup>26,27</sup>

**Forest-interior birds**, such as black-throated blue warblers and blackburnian warblers, require relatively large core forest areas within regions of high forest cover. These species are almost always positively correlated with the percentage of regional forest cover, size of individual forest areas and proximity to other forest areas.<sup>18,19,24,25,27,28</sup>

**Amphibian and reptile** populations do best in areas with a low road density and high forest cover, wetland area and the presence of nearby wetlands. Many studies find these relationships over a wide range of landscapes, ranging from 330 feet to nearly 2 miles.<sup>11,16,20,22,23,29-33</sup>

Species that depend upon forested areas for dispersal corridors and over-wintering areas are particularly sensitive to development.<sup>22,23,34</sup>

## Increased Forest Fragmentation

One of the biggest impacts of shale development to wildlife and biodiversity in the Appalachian region is habitat fragmentation caused by [pipelines](#), [roads](#) and well pads.<sup>2,4,11,35</sup> Forest fragmentation involves the direct loss of forest habitat and the division of habitat into smaller pieces, resulting in less interior forest and more edge habitat. Research has shown measureable impacts from edge effects extending 330 feet into adjacent forest habitat.<sup>6,36,37</sup> Thus, the development of infrastructure causes not only a direct reduction of habitat, but also a reduction in habitat quality in the surrounding areas.

The subsequent effects of fragmentation on wildlife – changes in reproductive success, habitat use and behavior – are evident at both local and regional scales.<sup>11,35</sup> Generalist species (species that can thrive in a variety of environments), such as opossums, blue jays and white-tailed deer, can benefit from the effects of fragmentation. Conversely, fragmentation negatively impacts forest-interior species (species that rely on large, intact or “core” forest areas), such as the wood thrush, and habitat specialists (species that require a specific habitat or food source), such as timber rattlesnakes and Allegheny woodrats.<sup>9,35,38</sup> Evidence also suggests



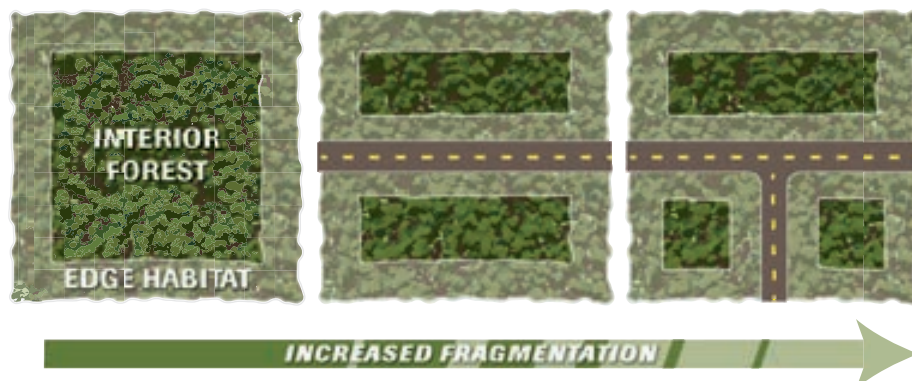
Forest-interior bird species, such as the black-throated blue warbler pictured above, are losing habitat as a result of forest fragmentation from well pads, roads, and pipelines.

relationships between fragmentation and extinction rates and thresholds of some species.<sup>39-41</sup>

## Loss of Interior Forest Habitat

As fragmentation increases, interior forest habitat is lost and edge habitat increases. Forest-interior species avoid edges for various reasons. Tree frogs, flying squirrels and certain woodland flowers are sensitive to forest fragmentation because of changes in canopy cover, humidity and natural light levels.<sup>1</sup> Northern long-eared bats, a species proposed as endangered by the U.S. Fish and Wildlife Service, depend upon contiguous forest areas for foraging and roosting areas.<sup>42</sup>

**Forest-interior birds** are negatively impacted by fragmentation, primarily because of habitat loss and the increase in predation and brood parasitism (laying eggs in another’s nest) found along forest edges.<sup>25,43-50</sup> A recent study in the Appalachian region found that forest-interior species declined with increasing well density, resulting in changes to avian communities.<sup>51</sup>



As forest fragmentation increases, interior forest habitat is lost and edge habitat grows. Edge effects can extend several hundred feet into adjacent forest habitat, altering light, temperature and moisture regimes. The effects of fragmentation can result in changes to plant and wildlife communities and is especially damaging to forest-interior species.



### Scales of Effect:

- Higher numbers of mammal, amphibian and reptile species are positively associated with the presence of forests and wetlands and negatively associated with roads up to 5 km away.<sup>4,52</sup>
- Interior-forest birds, like blackburnian warblers, are positively correlated with forest cover within 5 km.<sup>43</sup>
- Within a small watershed, a low proportion of forest cover, along with high road density, can adversely impact stream health and brook trout distribution.<sup>53</sup>



Shale energy well pads fragment a forested landscape in north central Pennsylvania. © USDA National Agriculture Imagery Program, 2013

### Barriers to Movement and Corridors for Invasion

Road and pipeline corridors can accelerate the spread of invasive plant species and can significantly decrease landscape permeability – the ability of species to move across a landscape – making it more difficult or impossible to reach necessary habitats and resources.<sup>41,54,55</sup> This can have cascading impacts on the distribution, survival and behavior of species within the region.

**Mammals** hampered by frequent road and pipeline crossings might exhibit increased stress levels and behavioral modifications that result in reductions or changes in habitat use.<sup>41,56-60</sup> Road avoidance behavior has been observed by a variety of mammals, including elk, Allegheny woodrat and black bears.<sup>41,60,61</sup>



Road avoidance behavior has been shown in some species of mammals, including black bears. © Kent Mason

Research suggests these changes are variable, depending upon species, sex, road type and traffic volume, but commonly increase in response to increasing traffic and road densities.<sup>41,52,60</sup>

**Amphibians and reptiles** need to be able to move through the landscape to locate breeding areas and places to overwinter/hibernate. The ability to move between terrestrial and aquatic habitats is crucial in sustaining populations of amphibians and some reptiles.<sup>22,23,41,62</sup>

Reduced landscape connectivity and permeability can isolate habitat and affect local extinction rates and thresholds, particularly if breeding areas are isolated beyond the reach of a species.<sup>16,23,32,63,64</sup>

**Aquatic species** move along a stream system to access areas for feeding, reproduction and refuge from environmental conditions (e.g., stream temperature) and predators.<sup>65,66</sup> Stream crossings can fragment stream systems, increase sedimentation and create barriers to passage, impacting survival, reproduction and behavior.<sup>65,67</sup>

**Invasive plant species** can spread into normally unreachable, highly forested habitats when fragmentation creates dispersal corridors.<sup>4,35,68,69</sup> Seeds can

be dispersed along these corridors by vehicles, equipment and people.<sup>70</sup>

The spread of **invasive species** is also influenced by surrounding landscape characteristics; a more fragmented landscape is more susceptible to the spread and establishment of invasive species.<sup>5,68</sup> Ecological impacts of invasive plants include alteration of community structure, displacement of native species, decrease in biodiversity and changes to ecosystem functions.<sup>5</sup>

### Watershed Impacts

More than 1,000 species rely on the unique riverine and wetland habitats in the Appalachian region. Impacts from development activities within the watershed can affect stream health over long distances because of the interconnected nature of streams to the surrounding landscape.<sup>10-12</sup> Impacts to streams can cascade broadly into other parts of the larger ecosystem, resulting in declines in aquatic and terrestrial species, water quality and the resilience of the stream ecosystem.<sup>71-73</sup> Riparian areas along streams can help reduce impacts to aquatic habitat and support aquatic ecosystem processes.<sup>74,75</sup>

Watershed condition, or health, is closely tied to land cover and land use. Studies



Brook trout are indicators of good watershed health and culturally significant to the Appalachian region. Much of the remaining brook trout habitat is in highly forested regions, where shale energy development is also taking place. © Eric Engebretson, U.S. Fish and Wildlife Service

have documented key thresholds, where watershed condition decreases in response to converting forest cover to impervious surfaces (e.g., roads and well pads).<sup>76</sup> A loss of sensitive aquatic species was documented where impervious surfaces accounted for more than 3 percent of the watershed area.<sup>72</sup> Between 10 and 25 percent impervious cover, streams might exhibit characteristics of fair water quality and biodiversity and, once watershed impervious cover exceeds 25 percent, streams might have unstable banks, fair to poor water quality and pollution-tolerant species.<sup>76</sup>

**Water quality** is degraded by development through altered hydrology; increased sedimentation; and changes in shorelines, stream channels and wetlands.<sup>10</sup> In particular, the crossing of

roads and pipelines over streams can have damaging impacts on the hydrological and biological functions of a stream ecosystem.<sup>65</sup>

**Aquatic species** can be adversely impacted by development through reduced habitat quality, loss of habitat and spawning areas, and barriers to movement.<sup>65,78,79</sup> On a landscape scale, even small reductions in forest cover are associated with higher stream temperature and fluctuations, suspended solids and turbidity.<sup>13-15</sup> The distribution of some fish species, such as brook trout, and declines in spawning are related to forest cover, road density, stream crossing density and wetlands.<sup>15,53,80,81</sup>

### Effects of water withdrawals

[Water withdrawals](#) for hydraulic fracturing are high in extraction volume, occur over a short period of time, and are typically concentrated near well sites to minimize transportation costs.<sup>82,83</sup> In the Appalachian region, surface water is the primary source of water for hydraulic fracturing fluids, and small streams and tributaries have been increasingly targeted to support hydraulic fracturing operations.<sup>84,85</sup> The concentrated timing and location of withdrawals in small stream settings increases the likelihood of cumulative impacts to downstream

hydrology, water availability and aquatic habitat.<sup>82,86-90</sup> The cumulative decrease in water availability might also result in increased contaminant concentrations and reduced downstream water quality.<sup>86,91-94</sup>

Individual withdrawals have the potential to impact the magnitude and timing of seasonal flow patterns, increase the frequency and duration of low flow conditions and decrease high flows in small stream settings.<sup>85,87,92</sup> These changes can reduce the availability and diversity of stream habitats, resulting in decreased growth and abundance of fish and macroinvertebrates, and in some cases, shifts in species composition and a loss of diversity.<sup>71,95-99</sup> Declines to species like crayfish, minnows and wetland plants negatively impact wading birds, birds of prey and mammals that rely on these aquatic food sources to survive.<sup>100-102</sup>

### Damages to Sensitive Habitats

The Appalachian region is host to a variety of habitats sensitive to development, including wetlands and vernal pools, headwater streams, floodplains, rocky outcrops, cave and karst systems, barrens, and old-growth forests. These habitats are particularly important in protecting rare, threatened and endangered species and maintaining biodiversity.<sup>71,103</sup> Approximately 130 globally rare species have populations in areas at high risk for shale development.<sup>1</sup>

### Wetland and vernal pool complexes

provide habitat for a diverse group of species, many of which are rare, and deliver essential ecosystem functions including water storage, groundwater replenishment, and sediment and nutrient retention.<sup>21,104,105</sup> Some wetland types, such as fens, bogs and seeps, are globally rare habitats and are highly sensitive to any encroachment.<sup>106</sup> Because most species associated with wetlands also rely on surrounding terrestrial habitat and the ability to move between wetlands, maintaining habitat connectivity is essential in sustaining regional populations.<sup>31,103,104,107</sup>



Barrens habitat in West Virginia. © Kent Mason



**Headwater streams** are a vital part of aquatic systems. They provide habitat for species unique to headwaters, refuge from predators and physical or chemical extremes in other areas of the stream (e.g., high temperatures or velocity), and critical spawning and rearing areas for some species.<sup>71,72</sup> Aside from providing important fish habitat, headwaters also significantly contribute to productivity downstream and support terrestrial food webs.<sup>71</sup> Consequently, the effects of headwater alteration can cascade into other parts of the ecosystem.<sup>71-73</sup>

**Floodplains** are another important part of aquatic ecosystems. They provide feeding and breeding habitat for a variety of species, maintain water quality, and recharge groundwater reserves. Development within floodplains can cause intensified flooding in other areas and degrade surrounding aquatic habitat.<sup>108,109</sup>

**Rocky outcrops** are habitat for some rare species in the Appalachian region, such as the Allegheny woodrat and timber rattlesnake. Maintaining forested habitat between rocky outcrop areas is important in sustaining these species by allowing movement between sites and maintaining gene flow.<sup>110</sup>

**Cave and karst** habitats support a diverse group of endangered plants, bats and rare insects. Beyond protecting species diversity, conserving these habitats also helps protect groundwater resources.<sup>42</sup>

**Barrens** are globally rare, fire-dependent shrubland habitats that support a high number of rare bird, reptile, mammal and plant species. Aside from habitat loss and fragmentation caused by development, infrastructure located in or near a barren habitat causes increased difficulties and dangers in maintaining essential fire management.<sup>111,112</sup>

**Old-growth forests** are rare habitats, existing in small pockets within the Appalachian region. These forests differ from other forest types in the Appalachian region in both structural complexity and biodiversity, providing a unique habitat for many species, such as pileated woodpeckers and northern flying squirrels.<sup>113</sup>



### CONSERVATION PRACTICES AND SCIENTIFIC SUPPORT

Scientific literature supports practices that encourage planning at a landscape scale to help avoid and minimize the impacts associated with habitat loss, forest fragmentation, watershed health, and damages to sensitive and aquatic habitats. The following practices are derived from management and guidance [documents](#) developed by state agencies, scientific/conservation organizations and industry groups.

### Account for Regional and Basin Scale Impacts

**Scientific literature** shows that the

cumulative impacts of development can influence the Appalachian region's terrestrial and aquatic habitats and wildlife.<sup>4</sup> Land use change, including changes in regional forest habitat and impervious land cover, at a landscape scale affect stream ecosystems and watershed health.<sup>7</sup> The configuration of habitats and connecting corridors in a landscape can have a profound effect on the reproductive success, habitat use and behavior of many species.<sup>114</sup>

Studies also document the need to prevent water withdrawals from impacting seasonal flow patterns.<sup>85,87,92,115-118</sup> Basin-specific studies for the Upper Ohio, Great Lakes, Susquehanna and Delaware basins document regional flow-related needs and provide recommendations to protect them.<sup>92-94,119</sup>

### Existing conservation practices

include consideration of infrastructure siting and development on a regional scale and maintaining connectivity between undisturbed, unfragmented habitats to facilitate wildlife movement. Comprehensive basin-scale water management should consider all uses and activities associated with water within a watershed to ensure water quality and protection of aquatic resources.

### Consolidate Infrastructure

**Scientific literature** suggests that one of the best ways to reduce the overall impact of shale energy infrastructure is to reduce its footprint, which can provide cost savings, reduce the needs of future reclamation, and minimize fragmentation and other environmental impacts.<sup>2,13,22,45</sup>

### Existing conservation practices

include planning at the landscape level and coordinating early with all stakeholders to promote shared infrastructure to minimize the overall footprint of infrastructure. This includes co-locating and consolidating infrastructure (e.g., using existing road and pipeline corridors) and using the maximum number of wells per pad, which also



Landscape-scale planning can help reduce forest fragmentation caused by well pads and associated infrastructure.  
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reduces truck traffic, and allows for centralized management of fluids.<sup>120</sup>

## Avoid Important and Sensitive Habitat Areas

**Scientific literature** suggests avoiding vast areas of forest, particularly those with large, intact core areas to help reduce fragmentation and preserve existing water quality in streams.<sup>2,7,13-15,32</sup> Beyond the size of individual forest patches, forest cover and configuration within the landscape are also indicators of habitat quality, including habitat connectivity between important wildlife habitats.<sup>19,23,39,107</sup> Protecting sensitive or unique habitats and important wildlife areas from the consequences of development (e.g., fragmentation, noise, artificial lighting) is essential for maintaining species diversity.<sup>2,7,110,111</sup> Development in wet areas or on areas prone to erosion can exacerbate the effects of sedimentation and erosion.<sup>121</sup>

**Existing conservation practices** include avoiding development in/on the following areas: steep slopes with greater than 10 to 15 percent grade, ridgelines, riparian areas, floodplains, lakeshores, wetlands, areas subject to severe erosion, contiguous forested areas, rare or unique habitats, and important wildlife areas.<sup>120</sup> Designing well sites and roads to fit within the landscape can help minimize excessive cut-and-fill construction practices.

## Inventory Landscape Components and Monitor

**Scientific literature** stresses the importance of identifying and assessing surrounding habitat and wildlife and developing an ecological baseline prior to development. Continued monitoring during and following development can be used to reduce risks, evaluate and improve practices, and help in reclamation.

**Existing conservation practices** recommend, prior to development, carrying out a complete inventory of wildlife concerns, operational constraints,

### Resources for Inventory and Monitoring:

<b>Landscape-Scale</b>	<b>Rare Species and Important Habitat</b>
→ U.S. Geological Survey landcover data	→ USDA Multiple Species Inventory and Monitoring Technical Guide
→ Pennsylvania Department of Environmental Protection GIS Mapping Tools	→ PARC Inventory and Monitoring: Recommended Techniques for Reptiles and Amphibians
→ Google Earth	→ NatureServe
<b>Water and Soils</b>	→ Pennsylvania Natural Heritage Program
→ County Conservation Districts	<b>Invasive Plants</b>
→ ALLARM Shale Gas Monitoring Toolkit	→ Inventory and Survey Methods for Nonindigenous Plant Species
→ Three Rivers Quest	
→ USDA Web Soil Survey	

### Considerations for Ecological Assessment Prior to Development:

- **Identify sensitive, unique habitat areas**, including wetlands and vernal pools (i.e. seasonally wet areas), barrens, floodplains, old growth forest patches and other areas identified in the County Natural Heritage Inventories. These areas tend to have a higher biodiversity conservation value and are therefore considered sensitive.
- **Carry out a complete inventory** of wildlife concerns, operational constraints, and biological and physical components to provide a complete baseline. This includes soil, geology, vegetation, surface and ground water quality, air quality, ambient light and noise levels, and wildlife.
- **Determine potential impacts** and practices to reduce them, such as establishing buffers to protect sensitive areas and practices that reduce soil compaction to improve reclamation. Consider the schedule of development. The seasonal timing of development activities can influence risks to wildlife, aquatic habitat and vegetation. Regular and continued monitoring can allow opportunities to evaluate and improve upon practices.
- **See more [resources](#)** related to pre-development considerations and issues.

and biological and physical components, including soils, geology, vegetation, ground and surface, water quality, air quality, ambient light and noise levels, wildlife, and other environmental and ecological considerations, to provide a complete baseline, identify possible impacts, and establish adequate buffers.

Other steps in the process include developing and implementing an adaptive management program that monitors, evaluates and improves practices.. Regular monitoring of infrastructure and treatment for invasive species are also important.

## TNC Recommended Conservation Practices

Based on scientific literature and existing practices, The Nature Conservancy recommends the following practices:



**Plan well pads and associated infrastructure at the landscape level** to reduce the risk of cumulative surface impacts on Appalachian ecosystems and the services they provide.

- Prior to development, conduct an inventory to identify ecologically important areas and document a baseline condition.
- Coordinate early with all stakeholders to identify suitable alternatives and assess risk through a cumulative environmental impacts analysis.
- Maintain regional forest cover. Research suggests maintaining at least 60 percent forest cover in a watershed to adequately support wildlife and ecosystem functions.
- Limit increasing total impervious cover, particularly beyond key thresholds, to maintain existing watershed condition. Key thresholds for watershed condition occur as impervious cover exceeds 3 percent (loss of biodiversity) and 10 percent (reduced biodiversity and water quality).
- Maintain connectivity between core habitats and migratory corridors and continue to recognize the role of public lands and special designation rivers in providing these functions.
- Manage water allocation at the basin scale, accounting for social and environmental needs and cumulative use.
- Consolidate and co-locate infrastructure (e.g., combine rights of way), using areas that have already been disturbed and where it does not increase risk to public health and safety.
- Implement reclamation and restoration strategies during all phases of development.



**Avoid placement of pads, roads, and pipelines in and near ecologically important habitats and areas subject to severe erosion.**

- In the Appalachians, these areas include large forest patches greater than 1,000 acres, cave entrances, rocky outcrops, scrub oak/pitch pine barrens, freshwater habitats, floodplains, wetland and vernal pool complexes, seeps, bogs, fens, and slopes greater than 10 percent. They also include the specific habitats of species with special designations.
- Infrastructure should not encroach on ecological buffers necessary to support watershed condition and key feeding, breeding and hibernation habitats.
- Consider the time of year construction and operations will take place, and take appropriate actions to minimize disturbances to wildlife, including practices that reduce impacts from soil erosion, noise and light.



**Regularly perform monitoring and maintenance activities** throughout the lifetime of the infrastructure to:

- Prevent the spread and establishment of invasive species.
- Identify areas where excessive erosion or infrastructure failure has taken place after storm events, such as roads, drainage systems and stream crossings.
- Inform adaptive management strategies.

**These recommendations are part of a suite of recommended practices intended to avoid and reduce impacts of shale development on Appalachian habitats and wildlife.** These practices might need to be adapted to incorporate new information, consider operational feasibility, and comply with more stringent regulatory requirements that might exist.



Visit [nature.org/shale-practices-refs](https://www.nature.org/shale-practices-refs) for a list of references used in this document