UPPER YELLOWSTONE RIVER WATERSHED LAND COVER ASSESSMENT

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Prepared for:

Governor's Upper Yellowstone River Task Force
5242 Highway 89 South
Livingston MT 59047

Prepared by:

Thomas L. Pick, Water Quality Specialist
Tom Potter, Geographic Information System Specialist
Natural Resources Conservation Service
Federal Building, Room 443
10 East Babcock Street
Bozeman, MT 59715-4704

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ABSTRACT

We used three basic indicators of watershed integrity: hydrologic function, water quality, and upland wildlife habitat to evaluate potential land cover changes within the upper Yellowstone River watershed. A satellite-based land cover classification was completed for 2,474,141 acres within the Yellowstone River basin (10070001–Yellowstone Headwaters and 10070002–Upper Yellowstone 4th code subbasins) using Landsat satellite imagery dated July 13, 1999, and July 12, 1985. Differences in spectral attributes between 1999 Enhanced Thematic Mapper (ETM+) and 1985 Thematic Mapper (TM) scenes, in addition to excessive cloud cover on the 1985 scenes prevented accurate comparison of land cover change over time. The land cover assessment was performed solely on the 1999 classification. Post-stratification accuracy was 72.2 percent. A Geographic Information System (GIS) analyzed the distribution and intersection of key resource theme attributes (soil, climate, ownership, topography, census, and important wildlife habitat) with the 1999 land cover classification. Results indicated that the very diverse landscape was largely composed of federally managed, coniferous forest, and shrub/grasslands. Urban or Developed and Agricultural Land–Irrigated land cover together accounted for less than 2 percent of the watershed area. Broadleaf Riparian represented the next to least in extent of the 15 cover classifications identified. Differences in land cover characteristics were measured between 5th code hydrologic units (HUCs). Low/Moderate Cover Grasslands, Agricultural Lands/Irrigated, Urban or Developed, and Broadleaf Riparian cover categories increased in relative composition in a downstream direction and in proximity to the river corridor. Low/Moderate Cover Grasslands surprisingly were the most prevalent land cover category within the 1/2 mile wide corridor bisected by the river. Evaluations of land cover related to hydrologic function, water quality characteristics, and upland wildlife habitat are also presented and discussed. Although land cover composition at the watershed scale appears to be relatively uninfluenced by human activity at present, we recommend periodic reassessment of land cover at the watershed and stream corridor scale in conjunction with monitoring common biotic indicators to track and evaluate the effect of land cover trends over time on stream and watershed function.

Key words:

- Yellowstone River,
- land cover,
- land cover change,
- watershed integrity,
- hydrology,
- water quality,
- wildlife habitat.

INTRODUCTION

History of the Task Force

Governor Marc Racicot created the Governor's Upper Yellowstone River Task Force (GUYRTF) through an Executive Order on November 5, 1997, in response to public concern over the health of the upper Yellowstone River in Montana following large flood events in 1996 and 1997. The Task Force's mission is: "….to develop a shared understanding of the issues and uses that impact the Upper Yellowstone River…for the purpose of encouraging a comprehensive approach to actions taken along the river to ensure that its integrity remains intact while balancing the needs of communities and landowners to protect property."

The USDA–Natural Resources Conservation Service (NRCS) helped the GUYRTF conduct a physical features inventory of the Yellowstone River channel within Park County, Montana during June 1998 to assess changes over the previous 11-year period. The Task Force–in association with local, state, and federal agencies–then initiated a Cumulative Effects Investigation to determine if and how river processes and functions were affected by human activities. Study topics included hydrology, riparian and wetland vegetation, fish and wildlife habitat, and socio-economics.

While most of the study topics necessarily focused on the channel and flood-prone areas, the GUYRTF was convinced that the "big picture" should not be ignored in the study process. The rationale for expansion of the scope of the studies is the recognition that cumulative change in landscape cover and how humans use or modify the landscape may profoundly impact watershed functions such as pollutant production, delivery and transport, hydrologic function, and aquatic and upland wildlife habitat values among other important watershed functions.

Change in land cover and land use often occurs at a temporal and spatial scale that is difficult to measure and interpret (Sisk 1998). Similarly, separating human-induced land cover change from that which naturally occurs at the watershed scale provides additional challenges (O'Keefe et al. 2003). In recognition of these unique study considerations, the GUYRTF appointed a work group to review the issue and to develop a study design.

BACKGROUND

Study Design

The interagency/interdisciplinary work group developed the assessment objectives and the study plan. The agreed upon objectives of the watershed assessment plan were to:

- Depict (spatial and quantitative) present (1999) land cover/use within the project area.
- Depict (spatial and quantitative) past (circa 1970's) land cover/use within the project area.
- Analyze temporal, spatial, and quantitative land use changes (1970's to 1999).
- Provide resource evaluations (as appropriate) related to land cover change and watershed function.
- Provide a land cover layer for incorporation with other components of the Cumulative Effects Investigation.

The assignment from the GUYRTF specifically requested that the assessment be restricted to quantitative interpretations rather than qualitative in terms of past or present land cover condition. The term land cover is used to represent the classifications performed in this study, unless otherwise noted. For the purpose of this study, the evaluation of land cover for potential management considerations was limited to three key indicators of watershed integrity in the upper Yellowstone River watershed:

- Hydrologic function
- Water quality
- Upland wildlife habitat

The underlying assumption that the work group made in this selection is that if these key indicators are maintained or exist in a sustainable state, then they are able to recover in response to periodic stresses brought about through flood, fire, or drought. This concept is known as dynamic equilibrium (a term borrowed from chemistry) where opposing processes or reactions occur at equal rates.

Categories selected for tentative inclusion in the classification key are based on National Resource Inventory (NRI) categories as follows:

- Cropland
    - Cropland (irrigated, non-irrigated)
    - Hayland (irrigated, non-irrigated)
    - Other cropland (summer fallow, cropland not planted)
- Pastureland (irrigated, non-irrigated)
- Rangeland
- Stocked Forest Land
- Non-stocked Forest Land (burned, harvested)
- Other Farmland (ranch headquarters, feedlots, CRP)
- Barren Land (bare exposed rock, gravel pits, river wash, permanent snow/ice)
- Urban and Built-up (large built-up > 10 acres, small built-up < 10 acres)
- Permanent Open Water (reservoirs, natural lakes, perennial streams)
- Transportation (roads -as available)

Noxious weed infestations were also identified by the GUYRTF as a desired land cover attribute. The GUYRTF was advised that this request would require a separate, dedicated effort to produce a noxious weed data layer. Park County does not currently have GIS-based weed mapping products that could serve the same purpose (Williams 2001).

Membership in the workgroup consisted of the following individuals:

Tom Pick–Water Quality Specialist, USDA–NRCS State Office, Bozeman, Montana
Ralph Bergantine–Hydrologist, USDA–NRCS State Office, Bozeman, Montana
Joe Carleton–Agronomist, USDA–NRCS State Office, Bozeman, Montana
Sandy Wyman–Range Specialist, USDA–NRCS State Office, Bozeman, Montana
Pete Husby–Biologist, USDA–NRCS State Office, Bozeman, Montana
Doug Harrison–State Resource Inventory Specialist, USDA–NRCS State Office, Bozeman, Montana
Liz Galli-Noble–Coordinator, Governor's Upper Yellowstone River Task Force
Dr. Duncan Patten–Chair, Technical Advisory Committee, Governor's Upper Yellowstone River Task Force
Dr. Richard Aspinall–Director, Geographic Information and Analysis Center (GIAC) at Montana State University-Bozeman

Study Considerations

Land Cover/Land Use—An evaluation of the interaction and potential influence of *land cover* and *land use* within the upper Yellowstone River watershed also requires some review as to the distinction between the two terms. Land cover is a dynamic attribute of the landscape with the amount and location of any one category of land cover constantly shifting in time between categories as a result of both natural processes and human action (Meyer 1995). Land cover is described by the ecological state and physical appearance of the land surface, for example grasslands, forest lands, or exposed rock. A significant characteristic of land cover is vegetation. Vegetation is a sensitive integrator of environmental factors and stressors (Reid 1993; Wickham et al. 2000). Vegetation affects a number of important watershed processes, including snow accumulation, soil moisture depletion, surface runoff, infiltration, and erosion (Knight et al. 1995).

Land use describes the purpose to which humans put land to use. Protected areas, forestry for timber products, irrigated agriculture, livestock grazing, or human settlement (Meyer and Turner 1994) are examples of land use. Necessarily, all categories of land use are attributable to human intent or action. Hydrologic and other attributes of land cover may be further influenced by the manner in which humans use land. Hydrologic response is an integrated indicator of watershed condition, and changes in land cover may affect the overall health and function of a watershed (Meyer 1995).

Watershed Concept—We based the design and scope of the upper Yellowstone River land cover assessment on the watershed concept. A watershed is the catchment area drained by a stream, and is delineated by topography (Langbein and Iseri 1983). Since surface water drains to one outlet in a watershed or sub-watershed, the nature of land cover and land use activities upstream can positively or negatively affect the water quality and hydrologic regime at that point (Berka et al. 1995). Three primary watershed properties govern potential hydrologic vulnerability in the form of rainfall runoff response and erosion: soils, land cover, and topography (Reid 1993). Variation in watershed-scale hydrologic response through time is primarily due to changes in the type and distribution of land cover (Miller et al. 2002). The amount of runoff expected from vegetated land cover types is influenced not only by the surface and soil physical properties, but also by the uptake capacity of the vegetation present. Climatic variation, flooding, vegetation succession, and fire, among other factors, govern land cover dynamics attributed to natural processes (Meyer 1995).

Scale—Size or areal scale also plays an important role in effectively interpreting relationships between land cover and watershed character. In general, the impact of land cover on hydrologic and water quality regimes decreases with the size of the watershed. Effects are most readily observed in smaller watersheds of up to several hundred square kilometers (Kiersch 2000). The exception to this generality is for persistent pollutants such as pesticides and metals, which remain in solution for long distances and periods of time (Wickham et al. 2000). Time or temporal scale is another important aspect of land cover characterization. The principal temporal aspect is the time it takes for change to occur (rate) and secondly, the time it takes for a change to have an impact (lag). Lag is dependent on rate and scale. Negative impacts often require more time for recovery than the time it takes for the impact to appear (Peters and Meybeck 2000).

Potential Impacts—The modern view of the dynamic processes regulating land cover recognizes nature as including both natural processes and human actions in the complex equations that influence the pace and direction of land cover change (Pickett and White 1985). Objective-based determinations of the cause and effect of land cover change is nearly impossible without first understanding the natural rate of change and the range of variation within natural systems (National Research Council 1992). It is also important to recognize that not all land cover change is undesirable, especially in light of the fact that change is inevitable. Realistically then, it is the pace and extent of land cover or land use change that is important in determining the magnitude and scale of possible impacts on ecological functions and/or desired management objectives.

Land cover and use changes are linked to increases in sediment, runoff, nutrients, pesticides, and other pollutants (Meyer 1995; Fitzpatrick et al. 1999; Heathwaite 1999; and Matheussen et al. 2000). Changes in land cover may alter the timing and volume of runoff (Lowry et al.1993; and Fitzpatrick et al. 1999) as well as the biodiversity of wildlife habitat (Hansen et al. 1998; and Maestas et al. 2001). Sediment can affect water quality through an increase in dissolved ions and suspended solids in water. Suspended sediment concentration is usually measured in milligrams per liter (mg/L). Excessive sediment can negatively affect aquatic life in many ways (McCabe and Sandretto 1985) that include interference with reproductive success and foraging and directly altering habitat. Turbid water heats more readily due to the absorption of energy and thereby reduces the oxygen holding capacity of water; adding to the cost of treatment for water supplies and reduction in the recreational value of water; and concentrations of pathogens such as enteric bacteria are often associated with elevated levels of sediment.

With increased development, roads, buildings, and other surfaces associated with urban land cover that are impervious to stormwater infiltration replace vegetated and natural areas in the watershed. This process serves to increase storm water runoff to streams, thereby increasing the frequency and severity of floods, and accelerating channel erosion (Booth and Jackson 1997). Bed composition, stream morphology, and base flows are also affected (Steuer and Hunt 2001; and Wang et al. 2001). Severe alterations in vegetation cover can produce up to 90 percent more runoff than in watersheds unaltered by human practices (Franklin 1992). All these attribute changes, individually and collectively, can have a negative effect on the aquatic community in terms of composition, richness, and diversity (Jones and Clark 1987). Watersheds with connected impervious surfaces (those areas that are impervious to infiltration and have direct connection to the downstream drainage system) greater than about 8 to 12 percent represent a threshold where minor increases in urbanization were associated with sharp declines in aquatic macroinvertebrate and fish communities at multiple scales from the watershed level to the reach level (Booth and Jackson 1997; Wang et al. 1997; and Stepenuck et al. 2002).

The magnitude of the impact of wildfire or logging on hydrology is known to be dependent on attributes of topography, geology, soil, climate, scope and severity of burn, and the rate of regeneration of cover (Anderson et al. 1976). In general, removal of forest cover results in an increase in the volume of water available for surface runoff due to an increase in snowpack and a decrease in interception, transpiration, and evaporation (Bosch and Hewlett 1982). The timing of the peak in surface runoff is usually advanced as well, resulting in a higher peak runoff (Troendle and King 1985). Removal of a significant amount of cover (regardless of the type or class of cover) generally has a stronger relationship to the amount of sediment production and the fluvial process rather than runoff volume per se (Reid 1993; Fitzpatrick et al. 1999). A review of the literature shows that the effects of fire on water yield and sedimentation rates often begin to decrease within three years or so in slight to moderately burned areas but may take as long as seven to 14 years following intense wildfires (Veenhuis 2001; Meyer 2001). Farnes et al. (2000) estimate that a return to prefire runoff conditions in Yellowstone National Park (YNP) as a result of the 1988 fires may require a century or more.

Specific land use patterns have been correlated with higher nitrate-nitrogen (NO^3-N) concentrations in surface and underground water resources (Hallberg 1989; Juergens-Gschwind 1989; Fletcher 1991). High density, coniferous forests typically export lower background nutrient loads than non-forested areas (Quinn and Stroud 2002). Excessive nutrients can result from nonpoint source human activities such as animal waste handling and disposal, application of nutrients (both animal waste and commercially manufactured products), septic tank leach field drainage, and the movement of soil particles (Hallberg 1989). Soil properties and effective management practices may affect the potential for nitrate leaching from agricultural systems (van Es et al. 2002). Municipal point source discharges associated with urban development and industrial users are also sources of nitrogen and phosphorus and are regulated under the National Pollutant Discharge Elimination System (NPDES) permits issued through the State of Montana.

Wildlife species tend to utilize specific areas with unique land cover attributes based on their preferences and requirements for food, water, and shelter. Hansen et al. (1998) observed that the strong gradients in climate, soil, and plant productivity (known as abiotic factors) found in the Greater Yellowstone area also have great influence on the spatial extent and abundance of native organisms. While diversity of habitat is relatively high as a result of these strong gradients, some preferred habitats may be very limited in extent by abiotic factors such that disturbance or change becomes a key factor in population dynamics. Natural and human induced disturbance to land cover can alter the extent, pattern, and distribution of required habitat types causing changes in how, when, and where individual species occur throughout the landscape (Maestas et al. 2001). Alteration of the unique land cover along the moisture gradient associated with streams, also known as riparian areas, can affect many functions such as shade, bank stabilization, sediment storage, contributions of organic litter and large woody debris to aquatic systems, nutrient retention and cycling, wildlife habitat, and general food-web support for a wide range of water and land-based organisms (NRC 2002). As many as 64 percent of neotropical migratory landbirds depend on riparian vegetation during the breeding season (BLM undated).

Remote Sensing

Remote sensing is the science and art of obtaining information about an object at a distance, rather than insitu. This is typically accomplished using aerial photographs, or a variety of satellite imagery. Interpretation of aerial photographs by a trained observer will nearly always give more accurate results with a higher degree of precision than an automated approach (Edwards 1990). This is due to the high resolution of aerial photographs, down to 0.5 meters in resolution (objects 0.5 meters in size can readily be seen and measured). Unfortunately, visual interpretation is time consuming, and change detection is difficult to replicate because different interpreters may produce different results.

A remote sensing approach was selected to detect and map land cover classification for several reasons, the most important being that remote sensing provides for a standardized method that can be repeated in the future to yield comparable results in measuring landscape scale change over time. Since the early 1970s, satellite imagery has been available for remote sensing analysis. The Landsat satellites have provided imagery ranging from 75 meters per pixel (picture element) resolution Multispectral Scanner (MSS), to 30 meters per pixel using the Thematic Mapper (TM) camera, to 15 to 30 meters per pixel from the Enhanced Thematic Mapper (ETM+) instrument. ETM+ imagery from the Landsat 7 satellite covers more bands and is better calibrated than MSS and TM images. This provides more accurate land cover monitoring and assessment. Digital imagery enables the application of an automated classification system to determine land cover and land use. Software programs can evaluate the values of individual pixels and group them into a designated number of classes. The use of digital imagery also allowed us to automatically link to a Geographic Information System (GIS). A GIS program allows the comparison and analysis of multiple layers of information at various scales. In the strictest sense, a GIS is a set of processes capable of assembling, storing, manipulating, and displaying geographically referenced information, i.e. data identified according to their locations. A GIS approach combines geospatial data (the shape and location of a place) with information describing the place (attribute data). Put simply, spatial data allows us to draw a map; attribute data makes the map meaningful.

STUDY AREA

Description

The study area encompasses the entire upper Yellowstone River watershed above the Park County line near Springdale, excluding the Shields River drainage. The area consists of about 2.47 million acres in Wyoming and Montana. About 1.4 million acres or 55 percent of the project area lies in Wyoming, of which about 49 percent is in Yellowstone National Park (YNP) (Harrison and Potter 2001). The watershed catchment area (Figure 1, page 33) is cradled by the Absaroka-Beartooth Mountains to the north and east, the Yellowstone Plateau to the south, the Gallatin Range to the west, and the Crazy Mountains to the north.

Environmental Influences

Climate

Climate in the study unit ranges from cold and moist in the mountainous areas to temperate and semiarid in the plains areas. Due to its interior location on the continent, the basin's weather is characterized by fluctuations and extremes (Missouri Basin Inter-Agency Committee 1969). Air masses from the Gulf of Mexico tend to dominate in spring and early summer, but Canadian-arctic air flow dominates in winter (Missouri Basin Inter-Agency Committee 1969).

Annual temperature extremes range from less than 30 degrees (Fahrenheit) below zero during the winter to greater than 100 degrees during the summer. Temperatures are generally coldest in January and warmest in July. The average frost-free period is less than 10 days at high elevations (Marston and Anderson 1991) and ranges to about 120 days at Livingston (Western Regional Climate Center 2003). Mean annual precipitation ranges from over 60 inches in the mountains near YNP to about 10 inches in the Gardiner, Montana area (Western Regional Climate Center digital data 2003). Forty to 45 percent of the average annual precipitation falls during April through June at the lower elevations. The seasonal effect decreases in the mountains (Figure 2, page 34). Mean annual snowfall ranges from more than 200 inches in YNP to about 26 inches at Gardiner, Montana, (Western Regional Climate Center 2003). About 28 percent of the average annual precipitation falls during April, May, and June compared to 42 percent during the winter months (November through March). The mountain ranges in the study area cause precipitation to vary strongly with elevation because in mountainous terrain, most of the variation in precipitation is explained by the orographic effect of the large-scale uplift features. At lower elevations, the seasonal effect on precipitation is more variable due to the random nature of convective thunderstorms. At Livingston, 41 percent of average annual precipitation falls during the April through June period (Western Regional Climate Center, digital data 2003).

Evapotranspiration (the combination of water lost as vapor from evaporation of open water, bare soil, and snow, and water transpired or used by living plants) varies with temperature and land cover, which, in turn, is strongly affected by elevation (Reider 1990). In the cold, high-elevation montane forests and alpine meadows, potential annual evapotranspiration is about 11.5 to 13.5 inches; much less than the 22 to 25 inches in the warmer, drier Yellowstone River Valley (Caprio et al. 1994). Evaporation and precipitation together distinguish the moist, mountain forest ecosystem from the lower-elevation regions where evaporation exceeds precipitation (Marston and Anderson 1991).

Hydrologic Regime

The Yellowstone River originates near Younts Peak along the Continental Divide in the Washakie Wilderness of the Shoshone National Forest before entering YNP and Yellowstone Lake. The Yellowstone River enters Montana about six miles above its confluence with the Gardner River, near Gardiner, Montana where it leaves YNP. The river then flows north through Yankee Jim Canyon and into the Paradise Valley prior to making a pivotal turn to the east at Livingston. The Yellowstone then undulates across the plains region in a general easterly direction until Miles City where it heads northeast. It joins the Missouri River about 15 miles after crossing the border into western North Dakota. The total length of the river is about 670 miles.

The hydrology of the Yellowstone River watershed is driven by mountain snowpack-dominated streamflow with a single annual snowmelt peak in late spring or early summer. Daily mean discharge and annual flows in the upper Yellowstone have low variability (Zelt et al. 1999) compared to rainfall-driven streams originating on the Great Plains. Mean annual flow is estimated to be about 4,100 cubic-feet per second for the Upper Yellowstone basin (including the Shields River contribution). USGS gauging station records indicate that mean annual runoff is about 12.8 inches for this area (Zelt et al. 1999). Based on long-term analysis of NRCS snow survey and precipitation gauge records in the basin, Bergantine (2002) estimated mean annual runoff ranges from 2 inches to over 18 inches as a function of elevation, annual precipitation, and vegetative cover (Table 1, page 31). Yellowstone Lake, covering 187,000 acres in the upper watershed, dominates all water-related features. With an estimated capacity of 12 million acre-feet and an average annual discharge of 1.1 million acre-feet (YNP 2003), the lake has a strong influence on the hydrology of the Yellowstone River basin as it serves as the principle catchment for the upper watershed. Further evidence of the variation in hydrologic response in the lower elevation watershed setting is evident when examining the influence of subwatershed contribution on average base flow. The watershed from the Corwin Springs USGS gauge to the Livingston gage represents a gain of about 928 square miles in area and produces an average of about nine inches of runoff. The incremental gain in surface area is about 35 percent, while the gain in average base flow is only about half as much, or 15 percent (Bergantine 2002).

Unconsolidated alluvial deposits along the river channel are an important source of groundwater. Water is often found in alluvial deposits topographically higher than the stream level only where surface water has been applied for irrigation (Lowry et al. 1993). Irrigation has been practiced along the upper Yellowstone since at least 1876 when a man named Gage dug one of the first ditches in the Yellowstone Valley (Brown 1969). USGS water use estimates for 1995 indicate surface water withdrawals for the entire Headwaters (10070001)and Upper Yellowstone (10070002) Hydrologic Units (HUs) total 521.83 million gallons per day (Mgal/day) (USGS 2002). This volume is equivalent to about 1600 acre-feet of water per day. This amount represents withdrawals for the Headwaters and Upper Yellowstone HUs including the Boulder River watershed. Of the total surface water withdrawn, 99.8 percent is for irrigation use. Figure 3 (page 35) depicts USGS water use estimates for ground and surface water withdrawals in the upper Yellowstone River basin.

Water Quality

B-1 is the water-use classification assigned by the State of Montana to waters in the upper Yellowstone River watershed outside the boundaries of Yellowstone National Park. In Yellowstone National Park, all waters within Montana are classified A-1. The B-1 classification means that the waters are to be maintained suitable for drinking, culinary and food processing purposes, after conventional treatment; bathing, swimming and recreation; growth and propagation of salmonid fishes and associated aquatic life, waterfowl and furbearers; and agricultural and industrial water supply beneficial uses (ARM 2003). The A-1 classification standards require the same beneficial use support categories, but are more stringent and generally allow no degradation of water quality (ARM 2003). Surface water quality standards, some water-use classification specific, have been adopted by the Board of Environmental Review and incorporated into the Administrative Rules of Montana (ARM) to establish maximum allowable changes in surface water quality and to establish a basis for limiting the discharge of pollutants which affect beneficial uses of surface waters (DEQ 2003).

The Yellowstone River mainstem in the upper basin has lower concentrations of dissolved solids than further down the river system. Suspended sediment is slightly more variable, but also increases in a downstream direction (Zelt et al. 1999). Concentrations of both suspended sediment and dissolved solids are generally lower in mountainous, forested areas and where older Precambrian rocks are exposed. Sources of suspended sediment are natural factors such as channel erosion and migration or anthropogenic sources associated with land use activities. The most common natural source of dissolved solids is dissolution of minerals in rocks and soil. Disturbances associated with human activities such as agriculture, mining, and development can increase dissolved solids by exposing more minerals for dissolution (Smith et al. 1993).

Water quality studies of the Yellowstone River conducted by the USGS during low-flow conditions in August 2000, were undertaken to evaluate the trophic condition of the river using chemical and biological indicators of nutrient enrichment (Peterson et al. 2001). The studies indicated that concentrations of nutrients (total nitrogen and total phosphorous) sampled at two Park County stations (Corwin Springs and near Livingston) were lower than all sites sampled further downstream. Concentrations of total nitrogen were below the ecoregion specific nutrient recommendation issued by the U.S. Environmental Protection Agency (USEPA 2002a), however total phosphorus concentrations exceeded the EPA recommendations as did turbidity, a measure of light penetration through water, and chlorophyll-a plankton, a measure of algal biomass. Algal productivity and standing crop, however, were greatest in the middle sections of the Yellowstone River near population centers such as Billings and Forsyth (Peterson et al. 2001). Turbidity and chlorophyll-a are considered potential indicators of excessive algal growth. Turbidity and phosphorus are usually related to suspended sediment concentrations.

Additional potential influences on the water quality of the upper Yellowstone River are superfund sites, point source and abandoned hard rock mine discharges, and Public Water Supply (PWS) systems. The Burlington Northern Complex in Livingston is listed on the EPA Comprehensive Environmental Response, Compensation and Liability System (CERCLIS) Superfund Site list (NRIS 2003). Volatile organic compounds, heavy metals, and petroleum by-products have contaminated the soil and groundwater at this site. Studies identified two contaminated ground-water plumes. One plume consisted of petroleum hydrocarbons. The other resulted from the release of Volatile Organic Compounds (VOCs). The plume extends northeast for more than a mile from the shop complex. VOCs contaminating the soil and ground water include tetrachloro-ethene (PCE), trichloroethene (TCE), dichloroethene and chlorobenzene. The ground water also has a diesel plume floating on top of the aquifer (EPA 2002b).

The Montana Department of Environmental Quality has issued 12 Montana Pollutant Discharge Elimination System (MPDES) permits within the project area (NRIS 2003). These permits are issued to regulate point source discharges of storm water runoff, treated municipal waste water, and facility discharges to state surface waters. The majority of the permits are for discharges to the Yellowstone River. Montana Bureau of Mines and Geology's (MBMG) abandoned hardrock mine database for the Headwaters subbasin (HU 10070001) lists five high-priority mine sites. Three sites are on the Montana Comprehensive Environmental Cleanup and Responsibility Act (CECRA) list: the Jardine Arsenic Tailings (Bear Creek), McLaren Mill Tailings (Soda Butte Creek), and the New World Mine. One hundred and twenty-two sites are carried on the abandoned and inactive mines database (NRIS online database 2003). Most of the sites are concentrated in the Jardine and Cooke City areas.

MBMG's abandoned hardrock mine database for the Upper Yellowstone HU (10070002 excluding the Boulder River drainage) lists one high-priority mine site near Emigrant. Nearly 180 sites in the study area are listed on the abandoned and inactive mines database (NRIS 2003). The sites are primarily associated with the Emigrant/Chico and Gallatin Mining Districts.

Forty-five Public Water Supply (PWS) systems are located within a one-half mile buffer of the Yellowstone River in Park County, Montana, serving about 8,000 users (NRIS 2003).

Septic tank density hazards are rated as low for most of the Park County portion of the project area. Less than one half of one percent is rated as high hazard, however, the trend in spatial distribution is along the valley floor. Within a half-mile buffer of the Yellowstone River, 96 percent of the area is rated as having a low hazard; 2.6 percent is rated moderate hazard; and 0.4 percent is rated a high hazard (NRIS 2003). Hazard classes are based on septic tank density using 2000 Census block data.

Physiography

The physical form and structure of the watershed has been strongly influenced by mountain building, volcanic and glacial events, and subsequent erosion. We calculated that 49 percent of the project area is over 8,000 feet above sea level (Figure 2, page 34). The volcanic Yellowstone Plateau shapes the headwaters on the southern border. USGS maps (Zelt et al. 1999) of the physiographic provinces described by Fenneman and Johnson (1946) indicate that about one-third of the study area is in the Northern Rocky Mountains Province and about two-thirds in the Middle Rocky Mountains Province.

The Northern Rocky Mountains Province consists primarily of the Gallatin Mountain Range. The Gallatin Range consists of high, rugged mountains rising to more than 9,000 feet above sea level with local relief in excess of 3,000 feet. Alpine glaciation has occurred to some degree in most of this region. Elevations range from about 4,300 feet to 11,000 feet above sea level.

The Middle Rocky Mountain Province landscape is characterized by mountain ranges and high plateaus. The Absaroka Range consists of thick, volcanic deposits broken up by rugged terrain dominated by deep, v-shaped valleys with steep, erosive mountain slopes and large extents of cliffs and talus (Despain 1990). Local change in relief can be up to 3,300 feet. Elevation on the nearly level and broad Yellowstone Plateau is about 8,200 feet above sea level. The Yellowstone River has cut a broad valley with a meandering channel through this landscape.

METHODS

Data Development

Two study areas were identified for the assessment (Figure 4, page 36):

1. Analysis and evaluation of the entire watershed area 4th code subbasins in Montana and Wyoming (8-digit HU 10070001–Yellowstone Headwaters, and 10070002–Upper Yellowstone, excluding the Boulder River drainage) at a scale of 1:100,000. The lowermost watershed limit is the Park County line near Springdale.

2. Analysis and evaluation of the Yellowstone River corridor in Park County, Montana at a scale of 1:24,000 (Figure 4, page 36). Physical boundaries of this delineation were described as the Yellowstone River corridor from Gardiner to Springdale to include the channel, flood plain, valley floor, and Pleistocene terraces confined between the mountain/foothill side slopes of the Absaroka-Beartooth and Gallatin Mountain Ranges.

Satellite imagery obtained by the orbiting Landsat 7 ETM$^+$ served as the 1999 land cover classification base. Figure 5 (page 37) depicts the instrument characteristics of the device. Several options were evaluated to provide historic land cover due to uncertainty in the resolution and variation of spectral qualities of available satellite imagery over the desired 30-year time span. Table 2 (page 31) illustrates the general sequence of steps in data acquisition and preparation planned for the respective scales and spatial distribution of study. The preferred means to provide an accurate land cover classification of the 1:24,000-scale river corridor was aerial photo interpretation, since the 1973 North American Landscape Characterization (NALC) imagery was deemed too coarse at this scale. 1970s era USGS orthophotoquads were purchased to serve as the image base for historic land cover mapping of the river corridor at the 1:24,000 scale.

Land-Cover Classification

We converted the original NRI-based land cover key to a Gap Analysis Program (GAP) type land cover legend modeled after the Montana Land Cover Atlas (Fisher et al. 1998). This helped to standardize land cover classes resulting in a more meaningful separation of land cover from land use. Fifteen dominant cover classes were derived. These classes were the result of post-classification review and field-based stratification rules. GIAC staff, under the direction of Dr. Richard Aspinall, provided NRCS with a 1999 Landsat 7 ETM$^+$ dataset using appropriate image processing protocols. Data was provided on CD-ROM and included a classified data set based on a land cover key with accompanying tabular files of accuracy assessment matrices and standard metadata files. A brief description of the steps used by GIAC to derive the 1999 land cover classification is provided in Appendix 1 (page 59).

A detailed description of the materials, methods, and products of the 1999 land cover/use characterization project are described in Harrison and Potter (2001) preliminary report, "*A Satellite-Based Land Cover Classification Map for the Upper Yellowstone River Watershed, Montana and Wyoming*". The 2001 report is attached as Appendix 2 (page 60) to this document. Calculations and comparisons of basic land cover composition were made for the entire upper watershed basin, subbasins (4th code HUCs), and tributary watersheds (5th code HUCs) using simple, Microsoft Excel functions.

Land Cover Change

We made several attempts to depict land cover change as a number of challenges emerged in assessing the historical land cover as the remote sensing project moved forward. The 1973 NALC imagery obtained for the 1:100,000 historical watershed analyses proved to be inadequate due to their 90-meter resolution and narrow spectral bandwidth. Attempts to improve resolution of the NALC imagery proved unsuccessful for comparison to the 1999 30- and 15-meter LANDSAT 7 scenes.

For this reason, the approach shifted to the use of 1985 LANDSAT 5 TM imagery. MSU (thanks to Dr. Andrew Hansen) provided two Landsat 5 TM scenes at no cost from June 12, 1985, for comparison with the June 13, 1999 LANDSAT 7 scenes.

A fuzzy membership classification method, as described by Brown (1998a, b) in Aspinall and Pearson (1995), was used by GIAC to produce a 1985 TM dataset and land cover change product (1985 to 1999). In this pixel-to-pixel comparison method, the 1999 land cover product was used to train the 1985 dataset and assign 1985 land cover classes within ArcView® GIS.

The scanned 1970's era USGS orthophotographs obtained for the 1:24,000 historical analyses were too dark and provided insufficient contrast to allow for accurate georeference methods or photo interpretation. We decided to use the 1985 Landsat TM imagery to provide the historical perspective at both the 1:100,000 and 1:24,000 scales realizing that this extrapolation would introduce some error into the 1:24,000 dataset.

GIS Setup for Watershed Integrity Analyses

Subsequent to delivery of the preliminary land cover report, compilation and evaluation of additional GIS-based data sets took place. These evaluations were used to display any obvious relationships between 1999 land cover characteristics and the selected indicators of watershed integrity: hydrologic function, water quality, and upland wildlife habitat. Table 3 (page 32) lists the data sets used to conduct these evaluations. The data sets provide stand-alone information to depict watershed attributes in addition to use in the watershed integrity evaluations. GIS evaluations utilized two basic methods: overlays and buffers.

Overlay analysis draws upon the power of GIS to determine the relationship between overlapping boundaries or attributes of natural resource features on the landscape. In this study, we looked for overlapping areas of influence and for obvious relationships between the land cover dataset and other GIS datasets available to identify relationships that could potentially affect watershed integrity and may warrant further investigation such as erosion potential, leaching index, human demographics, urbanization, and upland wildlife habitat. Figure 6 (page 37) illustrates a model for overlay analysis of natural resource themes within a GIS environment. Overlay analysis was conducted using ArcView 3.2a and Spatial Analyst software. Products were then exported as database files. Overlay data prepared in this manner are included in the Figures section of this report as maps and charts.

The buffer function available in GIS evaluated the spatial occurrence of the attributes of various data sets within a distance of one quarter-mile of the Yellowstone River channel. One to one-hundred thousand scale Topologically Integrated Geographic Encoding and Referencing (TIGER) system data from the U.S. Census Bureau provided the location of the river's left and right banks. The one quarter-mile buffer width provided a purely arbitrary measure of relative proximity to the channel that may indicate heightened sensitivity for impacts to the channel and warrant further study.

Hydrologic Function Indicators

GIS based watershed models have been increasingly utilized to evaluate hydrologic dynamics across time and space. A common limitation of currently available hydrologic models is related to the high degree of variability in snowmelt rate and pattern in mountainous, densely forested (conifer) watersheds like the upper Yellowstone with high snowpack accumulations (Bergantine 2002). For this reason, we did not attempt to model land cover scenarios in relation to timing and magnitude of surface runoff.

One aspect of land cover which is related to hydrologic function is sediment production. To depict the spatial variation in soil erosion potential throughout the watershed, GIS techniques were combined with applicable attributes of land cover and soil. The relative potential for sediment production throughout the watershed was evaluated using the 1999 land cover dataset combined (using overlap analysis) with key soil attributes from the Park County, Forest Service and YNP soil survey information. To perform the analysis, land cover for each of four precipitation zones was correlated to a bare ground factor representing percent bare ground for each of the land cover–precipitation zone combinations. These values are analogous to land use based runoff curve numbers (CN) utilized in standard hydrologic computations of runoff (USDA 1986). Results were expressed as fractions between 0.00 and 1.00. Table 4 (page 32) lists the land cover/bare ground factors developed for the analysis. The bare ground factor was then weighted by hydrologic group factor (HGF) using four classes, A through D, and average slope class (5 classes) to produce an erosion potential index value.

Hydrologic Group is a classification system that describes the infiltration potential of a soil after prolonged wetting. Descriptions of hydrologic groups are as follows:

- Group A–High infiltration rates. Soils are deep, well-drained to excessively drained sands and gravels. HGF = 1.0

- Group B–Moderate infiltration rates. Deep and moderately deep, moderately well- and well- drained soils with moderately coarse textures. HGF = 1.5

- Group C–Slow infiltration rates. Soils with layers impeding downward movement of water, or soils with moderately fine or fine textures. HGF = 2.0

- Group D–Very slow infiltration rates. Soils are clayey, have a high water table, or are shallow to an impervious layer. HGF = 2.5

Average slope class was derived from 30-meter Digital Elevation Models (DEMs). The formula used to calculate the erosion potential index follows:

EPI = Bare Ground Factor x Hydrologic Group Factor x Average Slope Class Factor

The resulting index values were distributed to a range of qualitative ratings indicating high, medium, and low sediment production potential from sheet and rill erosion. These values do not include gully erosion or refer to actual measured or modeled soil loss rates, but rather represent a relative measure of *sensitivity to disturbance*. Areas with a high rating indicate more sensitivity to land disturbing events or activities than those areas with a low rating. Knowledge of the location of these areas may be useful in planning activities that have the potential to disturb vegetation and lower ground cover or to otherwise understand factors relating to sediment production within a watershed. Other factors that are important determinants in sediment fate and transport to surface water are position on the landscape, proximity to waterways, and the complexity of local drainage patterns.

Water Quality Indicators

In classic land cover investigations, the spatial pattern of land cover is compared to modeled biological and/or water quality indicators, such as nutrient export loads, to quantify the condition of and relationship to changes in land cover or land use (Wickham et al. 2000). Typically, land cover indexes are calculated for comparison with a variety of indicators such as nutrient and sediment concentrations, pathogen counts, and macroinvertebrate metrics within a GIS environment. Given the lack of spatially distributed biologic and water quality indicators in the upper Yellowstone, this study focuses on development of current (1999) and past land cover indexes as a starting point.

The susceptibility to leaching or movement of nitrogen by water through the soil profile and below the crop management root zone is an important water quality interpretation based on soil attributes. A number of models have been developed to account for various soil, climate, and management factors that influence NO^3-N leaching (Williams and Kissel 1991; Pierce et al. 1991; van Es et al. 2002). Each model has its own strengths and weaknesses. For this study, we used a mathematical Leaching Index (LI) algorithm developed by Goss and Wauchope (1990) to model a relative LI using the following soil map unit attributes: the K_w factor which reflects soil permeability as modified by rock fragment composition, organic matter (OM) percentage, soil horizon depth (Hz) in meters, and hydrologic group factor. The calculated LI values for a limited number of soil map units were extracted from the Soil Survey Geographic (SSURGO) database as a relative rating of high (3), medium (2), or low

(1) risk to indicate the relative differences in leaching potential. Since the preliminary Park County SSURGO database used in this analysis is not complete as of this effort, no attempt was made to correlate leaching index with the 1999 land cover classification or other natural resource attributes. After the Park County soil survey is officially certified, this analysis should be performed to help land owners and resource managers prioritize areas where the implementation of voluntary best management practices could reduce the potential for nitrogen leaching.

We also compiled and evaluated other attributes of soil properties such as Important Farmland status and ownership to evaluate potential relationships of agricultural land use that could relate to agricultural water quality. The NRCS Park County soil survey identified Important Farmland status to indicate the presence of land favorably suited to agricultural production. Important Farmlands are divided into four categories: Prime Farmland, Unique Farmland, and Farmland of State and Local Importance. Prime Farmland is defined as land with a sufficient soil quality, growing season, and moisture supply to sustain high yields of crops under proper management and acceptable farming methods (Office of the Federal Register 1999). Prime Farmland generally must be irrigated in this region to meet the moisture criteria.

Farmland of Statewide Importance is identified by individual states and generally includes soils which are nearly prime farmland and that can economically produce high yields of crops when treated and managed according to acceptable farming methods. Prime and Farmland of Statewide Importance must meet specific national and statewide criteria. No Unique or Locally Important farmlands have been designated in Park County at the time of this report, although a process to develop criteria for Locally Important farmland has been initiated by the Park County Conservation District in conjunction with the NRCS.

Upland Wildlife Habitat Indicators

Digital big game habitat themes from Montana Fish, Wildlife and Parks (MFWP) (2002) were used as surrogate indicators for the spatial extent of important wildlife habitat. The wildlife habitat themes were overlayed with the 1999 land cover classification and the Park County, Montana, portion of the watershed's ownership data set produced new overlay tables. Themes used were general whitetail deer habitat, mule deer winter range habitat, and elk winter range habitat delineations. We then evaluated big game habitat themes with respect to 1999 land cover and ownership classifications. Differences in the methods and classifications employed in the development of Wyoming's habitat and ownership themes prevented direct comparison to Montana themes.

RESULTS

1999 Land Cover Classification

Land cover in the watershed is characterized by a diverse mix of 14 primary vegetation and ground cover classes. Final accuracy of the land cover product was determined to be about 72.2 percent following application of post-processing field stratification rules (Appendix 2, page 65). The primary source of error is confusion in the near-infrared reflectance classes 2020, 3200, 4300, and 6120. During the watershed integrity analysis phase of the project, an additional elevation-based stratification rule was applied to reduce confusion associated with glare off gravel bars and open water in the channel. Figure 7 (page 38) depicts the 1999 land cover composition for the drainage basin determined through the remote sensing process (see land cover map in Appendix 2, page 82).

The major (52 percent) land cover is conifer forest classes (4000, 4200, 4300, and 4400) followed in extent by Low/Moderate Cover Grassland (3150) and Sagebrush (3350)—14 and 12 percent, respectively. Low/Moderate Cover Grassland occurs most frequently below 6,000 feet in elevation in the Montana portion of the watershed. Urban or Developed Lands (1100) and Agricultural Land – Irrigated (2020), two classes that incorporate human use characteristics, cover less than two percent of the drainage basin area. Differences exist between the upper and lower 4th code HUs. Figures 8 and 9 (pages 39 and 40) depict the land cover composition of the two subbasins that constitute the Upper Yellowstone basin. The Yellowstone Headwaters HU (10070001) is over twice the size of the Upper Yellowstone HU (10070002). Both areas are characterized by a spatial dominance of High-Density Coniferous Forest (35.2 versus 37.3 percent) however; the lower subbasin has a substantial increase in the relative proportion of Low-Density Grasslands, Shrublands, and Agricultural lands. A decreased proportion of Open Water (5000) and land cover types related to high elevation topography [Snowfields (9100) and Alpine Meadows (8100)] is found in the lower subbasin. Figure 10 (page 41) depicts the difference in composition of cover classes between the 4th code HUs.

Very apparent trends in land cover characteristics are observed when the classifications are viewed at the 5th code HU (11-digit) level. The 5th code subbasins divide the watershed basin landscape into major tributary contribution areas. A map of the Yellowstone River subbasins is depicted in Figure 11 (page 42). Figure 12 (page 43) charts the relative composition of 5 th code subbasins moving from the upstream (1007000101) to downstream (1007000207) position. The prevalence of the Alpine Meadows (8100) and Snowfields (9100) cover classes predictably declines moving in a downstream direction, while the percent composition of Agricultural Lands (2020), Sagebrush (3350) and Broadleaf Riparian (6120) increases in the downstream direction. The composition of Standing Burnt Forest (4400) is fairly uniform throughout the upper subbasins, but declines after about Tom Miner Creek (1007000201). High Density Coniferous Forest (4200) cover declines steadily moving downstream, except for within the Mill Creek Watershed (1007000203) where it is by far the dominant cover class.

Land-cover was evaluated within a one quarter-mile buffer on each side of the Yellowstone River channel. The dominant cover type within the buffer zone is Low/Moderate Cover Grasslands (3150) (35 percent) followed by Agricultural Lands-Irrigated (18 percent). Sagebrush (3350) and Broadleaf Riparian (6120) classes comprise about equal parts (14 percent of the corridor). Urban or Developed Lands (1100) continue to comprise a minor portion (two percent) of the half-mile-wide corridor. Figure 13 (figure 44) depicts the composition of land cover within the corridor.

Land Cover Change

Verification of the 1985 land cover product indicated several deficiencies in the change model primarily due to differences in sensor attributes, the extent of cloud cover in the 1985 imagery, and qualities inherent to the pixel-to-pixel training method. The NRCS decided that the change product would not meet the objectives of the land cover assessment and as a result, no change analysis was reported. The NRCS presented the 1999 Land Cover Classification Report and Map to the GUYRTF in December of 2001 as a preliminary report pending compilation of the soil database and GIS coverage for the Park County Cooperative Soil Survey Area. Based on a mathematical evaluation of 1999 land cover types alone, the total percentage of cover classes associated with any form of disturbance represents slightly less than seven percent of the watershed area. The percentage associated directly with human disturbance is less than two percent. This mathematical approach may over- or understate changes between cover types due to human and natural influences and should thus be used with appropriate caveats.

Hydrologic Function

The Standing Burnt Forest class represents four percent of the total watershed area and about eight percent of the forest type area. Within the four most fire-affected 5th code subbasin watersheds (1007000106, 107, 104, and 103) this class represents 8.7, 6.5, 6.2, and 6.1 percent of subbasin land area respectively (Figure 12, page 40). These units are located in YNP and adjacent National Forests (107).

Urban land cover and use within the basin represents only a minimal fraction (0.10 percent) of the total watershed landscape (Figure 7, page 38). In the Upper Yellowstone HU where human population is more concentrated, the urban classification constitutes only 0.25 percent of the landscape (Figure 9, page 40). Within a quarter-mile buffer on each side of the channel, the urban classification comprises about 2 percent of the area's cover (Figure 13, page 44). When looking at the 5th code watershed in which Livingston is located (1007000205), the Urban/Developed land cover class represents only about 0.6 percent of the surface area (Figure 12, page 43).

Figure 14 (page 45) depicts the simulated potential erosion ratings. Importantly, the index values do not predict sediment yield, that is, the portion of eroded sediment delivered to surface waters. The rating classes indicate the relative potential to produce sediment due to rill and sheet erosion caused by water. The breakdown of the watershed area (2.474 million acres) as determined by the modeled erosion potential rating was: 19 percent–high; 18 percent–medium; and 59 percent–low.

Land Ownership

As depicted in Figure 15 (page 46), the federal government manages nearly five times more land than do private owners. A map of the upper Yellowstone River watershed land ownership is in Appendix 3 (page 83). Federal agencies account for 82 percent of ownership. Private ownership contributes around 17 percent with the balance in State Trust and MFWP managed lands. Of the federally managed lands, Yellowstone National Park contributes nearly 57percent with 1,116,245 acres in the upper basin.

As was expected, several land cover classes are highly associated with ownership pattern. Figures 16 and 17 (pages 47 and 48) depict the extent of land cover by ownership and the composition of land cover by ownership within the project area. Ninety-three percent of High Density (4200) and Low Density Forest Land (4000) is managed by the federal government. Several other classes are also primarily associated with Federal management. Privately owned lands are most closely linked with the Broadleaf Riparian (6120), Urban or Developed Lands (1100), and Agriculture Land–Irrigated (2020) classes.

Ownership also strongly correlates to topography and elevation (Figure 18, page 49). The federal government dominates (93 percent) control of lands in the watershed over 6,000 feet in elevation. Private ownership is highly associated with lower elevation and lower precipitation. The majority of lands below 6,000 feet are privately owned (84 percent).

Water Quality Indicators

The suitability of soil for agricultural-related land cover and land use can relate to water quality. Figure 19 (page 50) depicts the extent and spatial orientation of Important Farmland within the Montana portion of the project area. A total of 7,754 acres of Prime Farmland occur in the project area of which about 900 acres or about 12 percent occur within the one half-mile river corridor buffer between Gardiner and Springdale. There are about 12,000 acres of farmland of Statewide Importance in the project area, of which about 425 acres or 3.5 percent of the total lie within the buffer. Nearly all Important Farmland is privately owned with a minor amount occurring on State Trust Lands.

Figure 20 (page 51) illustrates the spatial orientation of the LI calculated with the limited soil dataset. It appears (no further analysis was run due to the preliminary nature of the dataset) that a high proportion of the soils within the channel corridor are classified in the ‘high category’. These lands are primarily in Agriculture–Irrigated land cover, but also fall within the human demographic density of 20 to 100 persons per square mile (Figure 21, page 52). This indicates that there should be some consideration for mitigating negative impacts during planning and future growth assessment work. Following completion of the soil survey database later in 2003, a complete LI product should be developed and utilized for such analyses.

Human Demographics

The 2000 Census estimates that in excess of 17,000 people live in the census blocks overlapping the watershed project area (U.S. Bureau of Census 2000). Figure 21 (page 52) depicts population density in the Montana portion of the project area. As expected, overall population densities (persons per square mile) are relatively low with the majority classified as having up to two persons per square mile (56 percent). Seventeen percent of the area is classified as uninhabited. The density of human population appears to increase as proximity to the Yellowstone River increases. The areas of highest human density (100 to 6,000 per square mile) appear to be concentrated in proximity to the river.

Upland Wildlife Habitat Indicators

Figures 22 and 23 (pages 53 and 54) depict the distribution and composition, respectively, of mule deer winter range with 1999 land cover and ownership classes. Low Moderate Cover Grasslands (39.5 percent) and Sagebrush (28.2 percent) provide the majority of vegetative cover on MFWP mapped mule deer winter range. Seventy-nine percent of mule deer winter range is privately owned.

Elk winter range habitat is composed of relatively equal parts High Density Coniferous Forest (28.3 percent), Low/Moderate Cover Grasslands (27.9 percent), and Sagebrush (22.1percent). Figures 24 and 25 (pages 55 and 56) depict the distribution and composition of MFWP mapped elk winter range within the 1999 Land Cover classes and ownership in the Montana portion of the watershed. Elk winter range habitat occurred about equally on private and USFS lands.

The distribution and proportion of whitetail deer habitat, land cover and ownership overlap is depicted in Figures 26 and 27 (pages 57 and 58). Low/Moderate Cover Grasslands (40.2 percent), Sagebrush (28.2 percent) and Agricultural Lands–Irrigated (11.3 percent) comprise the majority of cover types in the MFWP mapped whitetail deer habitat. Private ownership makes up the majority of whitetail deer habitat. Nearly all of the Agricultural Lands–Irrigated and Broadleaf Riparian classes in the project area overlap with whitetail deer habitat indicating this specie’s strong preference for these two cover classes.

DISCUSSION

Land Cover Classification

Land cover shows a distinct trend in a downstream direction due to abiotic (elevation, precipitation, and temperature) gradients. The bulk of the landscape is controlled and managed by the federal government. This ownership pattern has likely moderated permanent land cover change over the entire watershed area since settlement. Most of the lower elevation lands and the lands adjacent to the Yellowstone River in Montana are privately owned, agricultural lands with irrigation a common practice. These lands were very likely low/moderate cover grasslands or sagebrush land cover categories prior to settlement and conversion to irrigated agricultural lands (personal observation). However, low/moderate cover grasslands are still the dominant cover category adjacent to the river corridor by a factor of nearly two. Riparian areas in the Yellowstone drainage are to a great degree privately owned and are intimately associated with the water table along intermittent and perennial drainages.

Low elevation regions are primarily privately owned and used for agriculture. These areas also have the most favorable growing conditions, best soils, and occur along the Yellowstone River corridor. Higher elevation private lands are mainly associated with checkerboard (railroad land grants) lands and scattered mining claims. With the great majority of the lands immediately adjacent to the river corridor privately owned, locally significant change is possible and probable since the highest human population densities also occur in close proximity to the river corridor.

Potential hazards exist in some of these areas in the form of rapid permeability and high leaching indexes. Nutrients and pathogens from point and nonpoint sources can pollute groundwater following inadequate residence time or treatment. Awareness, adequate engineering and maintenance practices, or avoidance are the best means to counter this hazard. While the extent and pace of urban growth and rural development has obviously increased over the past 20 years, relatively minor portions of the total watershed or subwatershed area are currently urbanized or developed. Locally influenced limitations to hydrology, water quality, and upland wildlife habitat associated with urbanization and impervious cover could occur without careful planning and hazard mitigation.

Land Cover Change

A majority of the upper Yellowstone River landscape is in the public trust and is managed for intrinsic values through multiple use (national forest) and preservation (national park and wilderness areas) natural resource philosophies. As such, the upper Yellowstone River watershed has probably experienced relatively minimal, human-induced, basin-scale changes in land cover or use that could significantly upset the dynamic equilibrium of the mainstem’s hydrology, water quality, or wildlife habitat values. The headwaters of nearly all major tributaries are publicly owned and in the same sense somewhat protected from the potential for pervasive and permanent human-induced land cover change.

Based on the preliminary historical and land cover information, the NRCS estimated that it was highly unlikely that significant temporal and/or spatial change in land cover composition had occurred at the basin level to alter hydrologic function, water quality, or upland wildlife habitat. We then recommended that efforts to remotely sense land cover change at the basin-wide scale be reduced in priority. Aspinall and Pearson (2000), in an independent analysis of the change data set provided by GIAC, estimated that only about 8.3 percent of the land cover within the total project area had changed between 1985 and 1999. This figure approximates our estimate using the mathematical approach, although neither figure can be confirmed given the methods. In any case, the proportion of land cover change within the project is not considered to be significant in extent.

The NRCS and the TAC recommended continuing to evaluate land cover change at the corridor scale. The rationale was that this area compromised the more inhabited, non-federal, and developed portion of the landscape and was more likely to have undergone significant land use change since settlement, particularly over the past 50 to 60 years. With the 1985 land cover product unavailable for use in depicting land cover change at the 1:24,000 corridor scale, the NRCS prepared a recommended course of action for the GUYRTF to use in determining historic land cover and change at the river corridor level. The recommendation was to use historic aerial photo interpretation techniques in conjunction with GIS technology.

Hydrologic Function

As stated earlier, coniferous forest types and complexes dominate the upper Yellowstone River landscape within the project area, cumulatively accounting for some 1.27 million acres or nearly 52 percent of the watershed. It seems most plausible that change in ground cover characteristics resulting from forest activities such as logging, wildfire, or forest clearing could potentially have the most pervasive impact on infiltration, runoff, and cumulative hydrologic function of the watershed simply due to the major prevalence of forest cover. Our 1999 Land Cover Classification indicated a relatively small proportion (less than eight percent) of the forest landscape was altered by fire. The periodic fire-induced landscape shifts and resultant impacts are thought to be part of the dynamic equilibrium exhibited within the Greater Yellowstone landscape (Despain 1990), although human efforts to eliminate wildfire have likely modified the historic fire/vegetation regime (Farnes et al. 2000).

A study by Roy Ewing (1996) confirmed the effects of the 1988 wildfires on suspended sediment in the Yellowstone River. Suspended sediment loads showed a dramatic increase (60 percent) in snowmelt related loads compared to pre-fire conditions. The Yellowstone River sediment loads four years later had not returned to pre-fire conditions, although fire-related sediment on the Lamar River appeared to have diminished to near pre-fire levels over the same time period “possibly due to slower snowmelt rates influenced by the higher elevations in the Lamar River watershed”.

Independent hydrologic studies have indicated a slight (4 to 5.3 percent), long-term increase in Yellowstone River annual runoff at Corwin Springs as a result of the 1988 wildfires in Yellowstone National Park (Farnes et al. 2000). As stated earlier, individual tributaries draining subwatersheds that experienced significant cover change due to wildfire may have exhibited significant short-term change in hydrologic regime. However, such evaluation was not part of this study. Other land cover studies in the Intermountain Region have shown a steady trend in the expansion of forest cover types into former grasslands as a probable result of fire suppression (Klement 2001; Miller and Rose 1999), but the extent of this occurrence was not quantified through this study.

The results of our erosion potential simulation model probably over estimated erosion potential on some slopes, particularly very steep, rock outcrops. However, the results do appear to correlate reasonably well with a 1988 study of erosive lands in the upper Yellowstone River basin conducted by Henry Shovic et al. (1988). Their study attempted to determine source areas for sediment loads in the river. They found that the top five watersheds with the highest proportion of erosive lands to total drainage area were Soda Butte Creek, the Boundary Line area, the Upper Lamar River, Reese Creek, and the Gardiner River. The erosive lands in these areas were related to eroding glacial features and steep scarp slopes. Four of these five drainages were also the top four watersheds in terms of sediment production.

Knowledge of erosion potential could help decision makers and planners avoid land cover changes that could heighten erosion potential for a specific watershed or allow the more efficient focus of efforts within a larger watershed to eliminate sediment contributions. The purpose is to indicate the relative importance of maintaining effective cover on susceptible landscapes. Another commonly accepted model used to express erosive potential is the Universal Soil Loss Equation (USLE) (Wischmeier 1978). The USLE model was not used in this assessment effort since the required K factors were not fully populated in the preliminary Park County soils data base. An updated version of the USLE, the Revised Universal Soil Loss Equation II (RUSLE II) has been developed and updated (USDA 2002) to provide more precision in watershed level applications. When the Park County SSURGO data is completed and certified, it is recommended that RUSLE II be run within the project area to indicate more precisely the relative differences between subwatersheds with respect to erosion potential.

The potential for impacts to the Yellowstone River's hydrology from urbanization and associated impervious surfaces appears to be very localized due to the relatively low spatial extent of urban cover relative to the amount of non-urbanized cover. At the greatest extent in the 5th code HUs or subwatersheds, the Urban or Developed land category accounts for less than one percent of the land cover. As such, the impacts to the Yellowstone mainstream are likely diluted or overwhelmed rapidly by contributions from the relatively undeveloped, natural upstream watershed. Impact to tributaries may be more pervasive, given their smaller drainage area.

A number of Best Management Practices (BMPs) can be incorporated within urban and suburban landscape designs to reduce the impact of impervious surfaces. The most common BMPs are use of infiltration and settling basins to allow impervious surface runoff (roofs, parking lots, streets, etc.) to infiltrate and percolate through the soil profile. Obvious benefits are a great improvement in the time lag between runoff and entry to surface waters. Sediment and other particulate and suspended matter is allowed to settle out and be deteriorated by microorganisms in the soil. Groundwater recharge is benefited through infiltration and as a result, stream base flow is improved over the immediate flashy response to uncontrolled runoff.

Although irrigated lands only make up about one and one-half percent of the project area, irrigation as a land use may also affect hydrology in less obvious ways. USGS water-use data (Berkas et al. 2003) indicates that of the total irrigation water withdrawn in the Headwaters and Upper Yellowstone HUs, approximately 16 percent is consumed or used by plants and evaporation. Conveyance losses of about 60 percent reflect deep percolation and seepage from ditches and canals. Recent water resource investigations by John Olson, Montana Bureau of Mines and Geology, in the Paradise Valley indicate that roughly one-third of the irrigation water diverted moves through the coarse alluvium to recharge the shallow groundwater aquifer contributing to base flow (Olson 2003). Lowry noted that in Park County, Wyoming, the conversion of irrigated land to urban development poses potential problems in some areas because yields of water-supply wells will be adversely affected by reduced recharge (Lowry et al.1993)

Smaller tributaries, as noted earlier, are most impacted by conversion of native cover types to urban or agricultural land uses primarily as a function of their smaller drainage area and greater variability in seasonal flow regime. Irrigation may directly impact the hydrology of tributaries, particularly when a high proportion of the discharge is diverted and does not return as base flow to the tributary. Sixteen tributaries of the Yellowstone River within the project area are considered chronically or periodically dewatered (MFWP 2003). The majority of these tributaries occur within the Paradise Valley in association with Agriculture–Irrigated land cover. Big Creek, Sixmile Creek, Emigrant Creek, Eightmile Creek, and Mill Creek are classified under the chronic category. Changes in channel width and depth due to permitted irrigation withdrawals may also result in negative impacts to stream function and aquatic life (Reid 1993). Three of these tributaries have been recognized as providing significant spawning habitat for Yellowstone cutthroat trout (Byorth 1990). MFWP has contracted with water right holders on three tributary streams in the project area to secure the base flows needed to sustain Yellowstone cutthroat trout spawning success.

However, irrigation associated with agriculture has also led to an expansion in the extent of wetlands in the arid, lower elevations by distributing water in canals, over large areas parallel to waterways, and raising seasonal water tables (personal observation). Irrigation water BMPs that promote more efficient conveyance, application, and utilization of irrigation water by the target crop can mitigate water shortages during low flow periods and drought. Additional mechanisms used to stretch available water supplies include water leases, drought management plans, and water sharing arrangements.

Water Quality Indicators

The spatial orientation of Important Farmland (Figure 18, page 49) shows a strong influence by fluvial (river) and glacial processes with these lands being arrayed in a linear fashion along river features. The Important Farmlands designation identifies the lands ideally suited for agricultural production in the area. As such, they are also near rivers and are therefore doubly important to protecting water quality. Such lands generally have less potential to impact water quality and require fewer capital or labor inputs to overcome inherent limitations such as salinity or erosion hazard than do non-designated lands. Important Farmland is proportionately greater within the one half-mile wide corridor than outside of the corridor. In addition nearly all the Prime and farmland of Statewide Importance in the Paradise Valley are associated with the Yellowstone River valley floor, particularly in the area between the Mallards Rest Fishing Access Site (FAS) and the mouth of Suce Creek. We believe that this is likely related to the deposition of sediment associated with flooding and lateral channel migration/abandonment. Dalby and Robinson's (2003) channel classification through this area indicates a predominately 'braided' type. Other areas of Prime and Statewide Importance designated farmland in the project area are associated with tributaries draining relatively soft geological deposits along Trail Creek, Billman Creek, and Mission Creek.

Land cover classes most commonly associated with nutrient and pesticides issues are Urban/ Developed, and Agriculture–Irrigated classes. Given the relatively small extent of urban land cover and use within the watershed area, they are probably not a widespread source for ground and surface water contamination; although contamination problems with underground tanks and industrial sources have been noted within localized areas in the past (see Study Area, Environmental Influences, Water Quality, page 8). Agricultural lands within the project area are primarily used to produce tame hay (grass and alfalfa) and pasture crops that require minimal input of nutrients and pesticides compared to more intensive row crops found further down the Yellowstone River. As a result, the practice of less intensive agriculture in conjunction with the appropriate BMPs should result in lower potentials for nutrient and pesticide contamination.

The general correlation of water quality indicators and human demographics with the river corridor indicate a degree of sensitivity of lands within the corridor to changes in land cover and land use. Without nutrient and pesticide BMPs, agricultural and suburban users in areas of high and moderate LI hazard are at risk to contribute to ground or surface water pollution. A Comprehensive Nutrient Management Plan (CNMP), available through the Park Conservation District, NRCS, or qualified consultants provides a neutral budget approach to managing nutrients and preventing pollution from agricultural sources. Current nutrient levels in the upper Yellowstone do not appear to reflect excessive contributions of nutrients from point or non-point sources at this time. Within the limits of scale, functioning wetlands and forest buffer and riparian land cover types can help to protect water quality by offsetting the effects of urbanization or agriculture through filtering surface runoff, utilization of excessive nutrients, and infiltration to groundwater recharge.

Upland Wildlife Habitat Indicators

Agricultural development has historically been the initial product of land cover and use change following settlement. Whitetail deer are a good example of a wildlife specie's adaptation to disturbance provided by agriculture, although permanent land cover change can remove specific cover types needed by some native species during critical times of the year. One example evident in the basin is sagebrush (*Artemisia* spp). Some sagebrush species are heavily utilized by large ungulates like mule deer and antelope in the winter (Pollack 2000). The largest remaining contiguous block of the Sagebrush (3350) cover class at present is now located in YNP. Private ownership accounts for about 36 percent of the total watershed Sagebrush classification. Excluding YNP's Sagebrush acreage, private ownership accounts for nearly 65 percent of the balance, indicating that Sagebrush cover continues to be widely distributed on private lands throughout the watershed and in particular on the lower valley elevations.

Particularly important to both landowners and the public is the fact that about 67 percent of mule deer and elk winter ranges, which are a limiting factor in sustaining big game populations, are privately owned land used for agricultural production. Mule deer winter range occupies most of the grasslands and sagebrush land cover available in the Park County portion of the watershed, further indicating the importance of these cover types to wintering mule deer. These lands are also used for livestock grazing. Urban/Developed (1100) classes represent a small proportion of the total mule deer winter range although disturbance from development can occur outside the immediate developed footprint due to increased human density, noise, roads, and habitat fragmentation (Vogel 1989).

Exurban development–commonly thought of as ranchettes or subdivisions with larger than average lot size interspersed with agricultural land beyond the urban fringe–was not addressed within this study. This relatively recent type of land use may have impacts on wildlife habitat utilization and biodiversity in the western U.S. according to studies in Colorado (Knight et al. 1995; Maestas et al. 2001). The studies demonstrated that forest, grass, and shrublands used for livestock production had more species of native plants and less of exotic species than similar lands used for dispersed exurban development. The ranches had just as many species of songbirds and carnivores as protected wildlife refuges in terms of occurrence and density. Working ranchlands also had the healthiest grasslands and the least amount of bare ground compared to developed areas and protected wildlife refuges (Knight et al. 1995). Accordingly, the ranchlands also provided the best wildlife habitat. The study led to the conclusion that large ranches support a more desirable biodiversity than do urban areas or exurban developments (Maestas et al. 2001). The rationale for this conclusion was that working ranches provide unfragmented habitat zones in relatively good condition throughout the landscape. It was also noted that in their study area, ranchers generally did a better job of controlling invasive species and weeds as well (Knight et al. 1995).

Nearly all the Broadleaf Riparian (6120) acres identified within the watershed are located within the one-quarter mile buffer zone in the Montana portion of the watershed, indicating the unique affiliation of this resource to the Yellowstone River system in this semi-arid environment. Our findings seem to agree with Ohmart (1996) who concluded that riparian areas (including woody and herbaceous types) comprise only half to one percent of the land area of the 11 western states. Riparian areas in the western U.S., in proportion to their area within a watershed, are more biologically productive than uplands and as a result are considered crucial habitat for many organisms (NRC 2002).

While conflict between human use and modification of land cover has and will continue to occur, well-conceived and applied agricultural BMPs, state game management programs, and conservation ethics on the part of private landowners have, with few exceptions, enabled agriculture and wildlife to coexist and provide mutual benefits to landowners and the public in the upper Yellowstone watershed (personal observation).

MANAGEMENT CONSIDERATIONS

General

- There is usually a lag time between land cover change and measurable change in indicators of watershed condition or health. Activities to periodically monitor the status of land cover and land cover change in the basin should be continued.
- Multi-purpose indicators of the health or condition of the Upper Yellowstone River should be agreed upon, quantified, and monitored over time to serve as sustainability thresholds.
- Comparisons in trend will help to guide informed human actions to achieve desired outcomes.
- Initiation of an upper basin landscape plan that balances local, state, and federal objectives and mandates would be helpful to identify indicators and thresholds as well as potential management scenarios. This process is especially applicable to the majority of federally controlled coniferous forest that blankets the headwater drainages.
- Encourage the development of a citizen-led upper Yellowstone River Watershed Plan or equivalent document to provide a blueprint for the initiation and implementation of natural resource conservation practices on a voluntary basis on private lands in the watershed. The plan should include a strong educational and outreach component.

Hydrologic Function

- Areas identified as having potential limitations due to infiltration or higher hazard for runoff and erosion should be evaluated for site specific and cumulative impacts when changes in land cover or land uses naturally occur (catastrophic fire or flood) or are proposed, particularly within the river corridor.
- Efforts to minimize the concentration of impervious surfaces and in particular their connectivity to surface water should be encouraged
- The nature and extent of surface and groundwater interactions, especially in regard to tributaries and irrigation, should be further defined within the upper basin.
- Sponsor the conduct of a qualitative assessment of riparian sustainability to determine current values and future treatment needs.

Water Quality

- Evaluate soils and leaching potential and other soil suitability attributes to provide guidance and management considerations for ongoing growth and land use activities.
- Maintain effective riparian forest buffers and vegetative land cover adjacent to stream corridors and on connected uplands to promote stream function and sustainability.

Upland Wildlife Habitat

- Encourage programs and actions which sustain working agricultural lands as a means to protect open space and related wildlife habitat values. This recommendation also assumes adoption and utilization of appropriate agricultural BMPs to protect soil, water, air, plants, animal, and human resources.
- Maintain connectivity to riparian forest buffers and vegetative land cover adjacent to stream corridors as a means to sustain wildlife habitat integrity.
- Promote the adoption of coordinated and integrated efforts to map and control the introduction and spread of invasive species and noxious weeds.

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TABLES

Table 1. NRCS characterization of precipitation and runoff by elevation for the watershed area
Source: (Bergantine 2002).

Elevation Zone/ Dominant Land Cover	Annual Precipitation Range	Surface Runoff (percent of total precipitation : inches/year)
High Elevation > 8,000 ft. Forested	40” to 60”	45% to 50% : 18”+
Mid Elevation 6,000 to 8,000 ft. Grassland	20” to 40“	40% to 80% : 10” - 12”
Forested		20% to 45% : 12” - 18”
Low Elevation < 6,000 ft. Grassland	< 20”	10% to 25% : 2”-5”

Table 2. General sequence of data acquisition, processing and analysis for the land cover change study at the watershed and stream corridor scales.

	1970s	1999
1:000,000 SCALE	Adquire 90-meter NALC triplicate Granules (4).	Acquire 30 and 15-meter Landsat 7 ETM+ Scenes (2).
	Classify 1973 imagery to new land use categories producing clusters of similar signature.	Generalized classification to new land cover categories producing clusters of similar signature.
	Ground truth clusters to verify signature.	Ground truth clusters to verify signature.
	Create overlay files. Merge for GIS analysis.	Create overlay files. Merge for GIS analysis.
	Plot maps and tabular data.	Plot maps and tabular data.
	Verify Accuracy	
	Plot differences	
	Evaluation and Interpretation	

	1970s	1999
1:24,000 SCALE	Purchase, scan and georeference ortho-photoquads to UTM NAD83, Zone 12 projection.	Preparation included in 1:00,000 effort
	Photointerpret land use classifications. Field check mapping.	Plot maps and tabular data.
	Create overlay files.	Ground truth using preciously collected points as in 1:000,000 effort.
	Merge for GIS analysis.	
	Plot maps and tabular data.	
	Verify Accuracy	
	Plot differences	
	Evaluation and Interpretation	

Table 3. Data sets used in the watershed integrity analyses.

Dataset	Theme	Source
Draft SSURGO data set	Park County Cooperative Soil Survey	NRCS in development
Digital Elevation Models	30 m DEM topography	USGS: http://www.usgs.gov
Population data set	2000 Census for Park County, MT	U.S. Census Bureau
Big Game Habitat Distribution	Mule deer, white-tailed deer, and elk general and winter habitat distribution	Montana Fish Wildlife and Parks
Montana 5th-Code 11-Digit Watersheds	Hydrologic Units	USDA-NRCS http://nris.state.mt.us/nsdi/nris/e00/hd109.zip
Montana 4th-Code 8-Digit Basins	Hydrologic Units	USDA-NRCS http://nris.state.mt.us/nsdi/nris/e00/hd109.zip
Montana Roads from TIGER/Line Files	1:100000 Tiger Files	U.S. Census Bureau Geography Division http://nris.state.mt.us/nsdi/nris/road2000/road2000.html
Prism data set	Precipitation attributes	USDA-NRCS National Cartography & Geo-spatial Center, Fort Worth, TX in association with Oregon State University http://www.ocs.orst.edu/prism/prism_new.html
Soil on Federal Lands	Gallatin N.F., Shoshone N.F and YNP Soil Survey	USFS General; Technical Report RMRS-GTR-78-CD
Land Ownership and Managed Areas of Montana	1:100000 Scale Public Land Ownership Esements and Leases status	Montana Natural Heritage Program http://nris.state.mt.us/nsdi/nris/ab105/ownerse.html

Table 4. Percent bare ground factors associated with land cover classes and precipitation zones.

Land Cover Class ID	Land Cover Class Name	Precipitation Zone (inches/year)/Rating			
		< 10	10 to 14	15 to 19	> 19
		% Bare Ground			
1100	Urban or Developed Lands	0.30	0.30	0.25	0.25
2020	Agricultural Lands - Irrigated	0.25	0.20	0.15	na
3150	Low/Moderate Cover Grasslands	0.25	0.20	0.15	0.05
3200	Mixed Deciduous Shrubs	na	0.10	0.10	0.05
3350	Sagebrush (≥ 20% canopy)	0.40	0.40	0.20	0.15
4000	Low Density Confererous Forest	0.25	0.15	0.10	0.05
4200	High Density Confererous Forest	na		0.10	0.05
4300	Mixed Deciduous/Coniferous Forest	na	0.15	0.10	0.05
4400	Standing Burnt Forest- Regen	na	0.25	0.25	0.25
5000	Water (lakes and ponds)	na	na	na	na
6120	Broadleaf Riparian	0.10	0.05	0.05	na
7300	Rock/Rock Outcrop	0.10	0.10	0.10	0.10
7500	Riverwash Gravel pit/dist.	0.30	0.30	0.30	0.30
8100	Alpine Meadows	na	na	0.10	0.05
9100	Snowfields	na	na	na	0.25

bare ground rating factor = % bare ground divided by 100

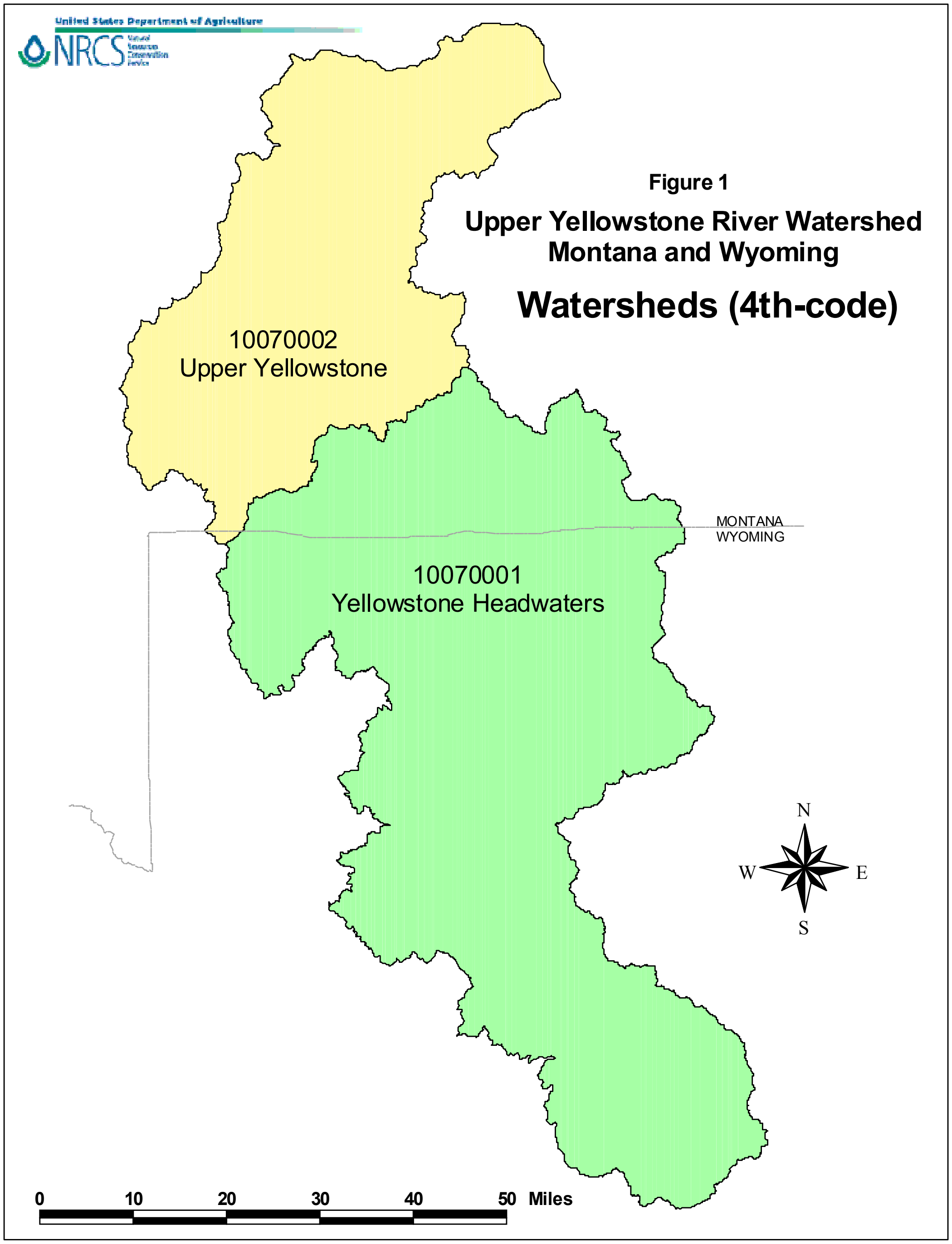


Figure 1

Upper Yellowstone River Watershed
Montana and Wyoming

Watersheds (4th-code)

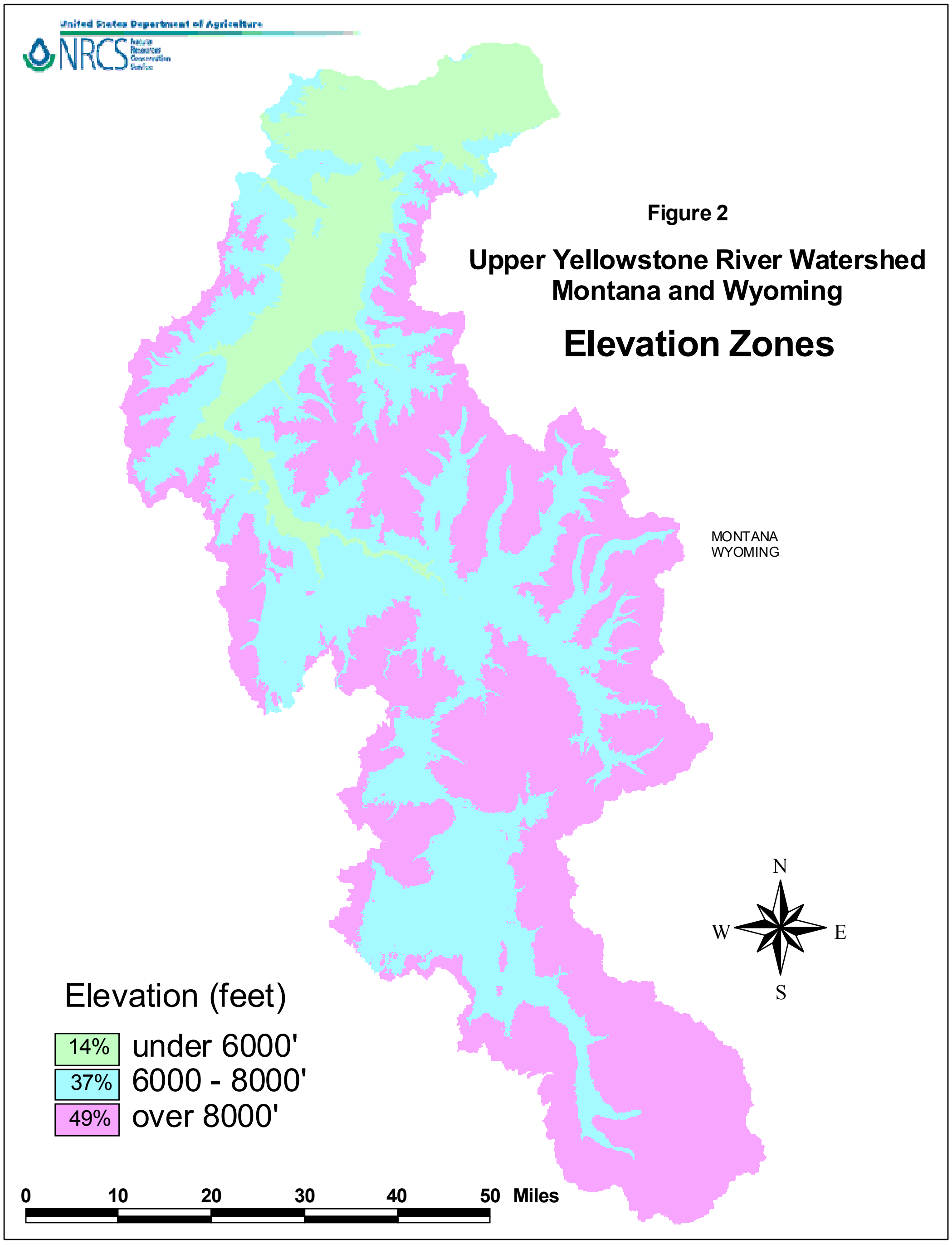


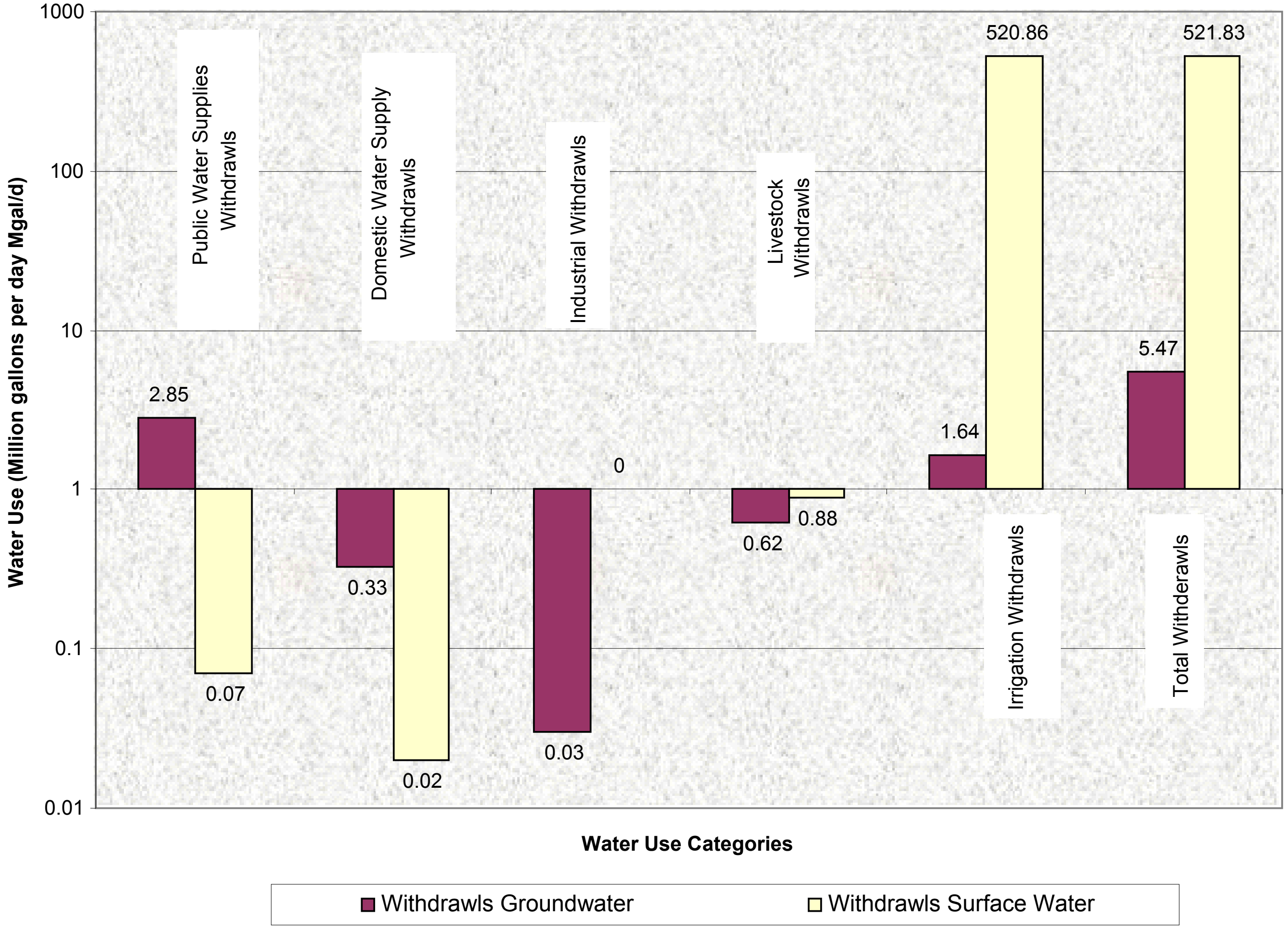
Figure 2

Upper Yellowstone River Watershed
Montana and Wyoming

Elevation Zones

Figure 3. USGS Water Use Estimates for Headwaters (10070001) and Upper Yellowstone River (10070002) HUs

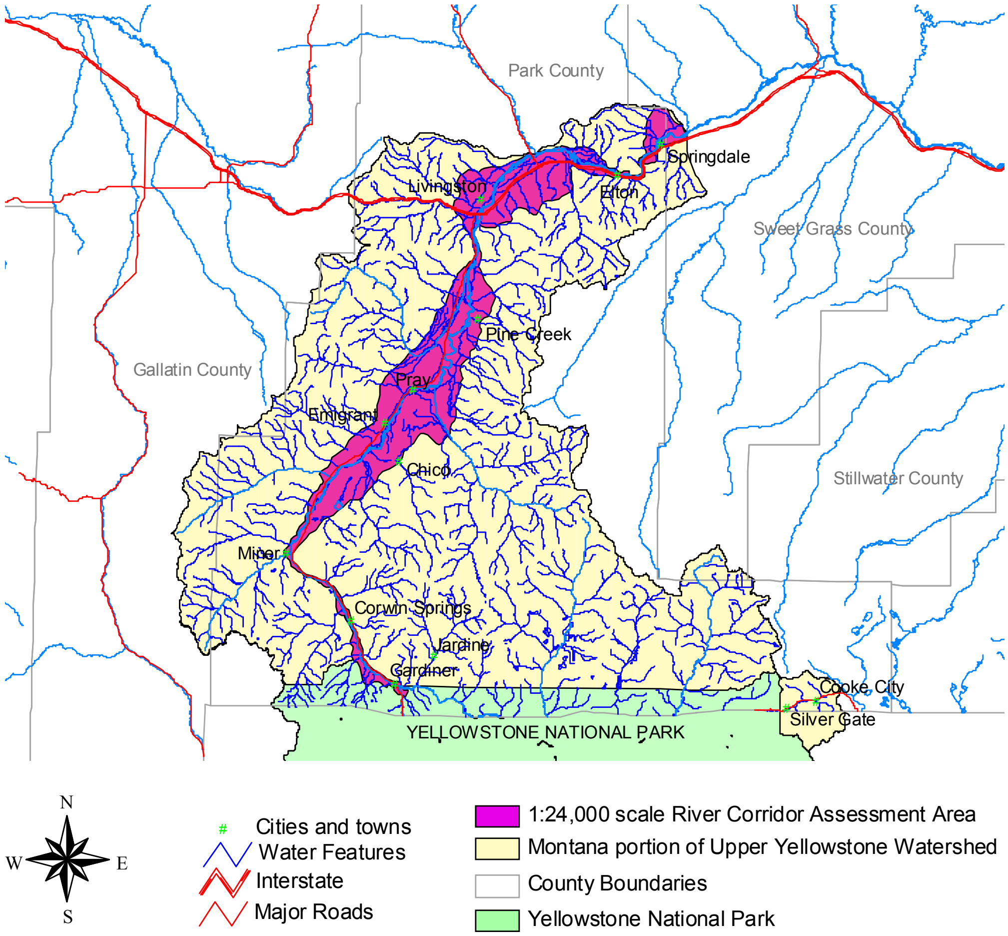
Note that scale on Y axis is logrithmic to depict smaller values



United States Department of Agriculture
NRCS Natural Resources Conservation Service

Figure 4

Upper Yellowstone River Watershed
Montana Portion
Study Areas



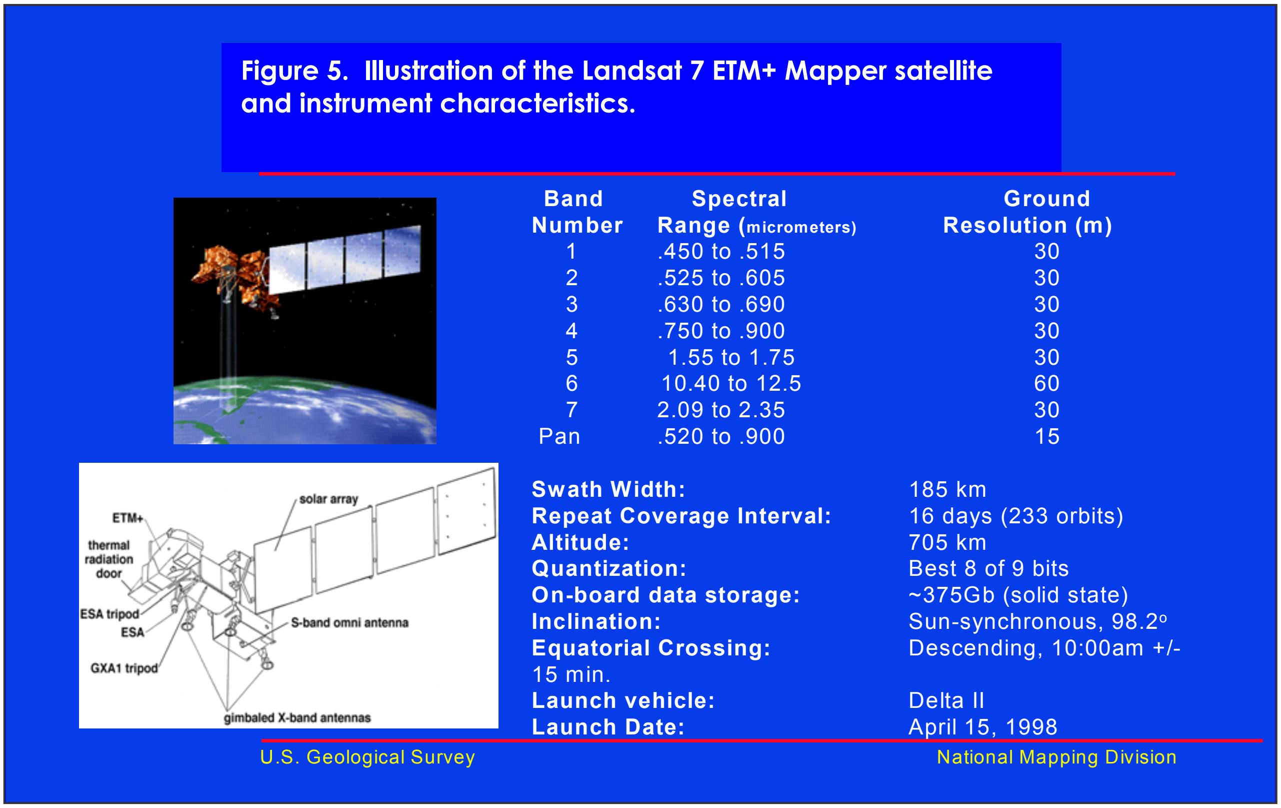


Figure 5. Illustration of the Landsat 7 ETM+ Mapper satellite and instrument characteristics.

Band Number	Spectral Range (micrometers)	Ground Resolution (m)
1	.450 to .515	30
2	.525 to .605	30
3	.630 to .690	30
4	.750 to .900	30
5	1.55 to 1.75	30
6	10.40 to 12.5	60
7	2.09 to 2.35	30
Pan	.520 to .900	15

Swath Width:	185 km
Repeat Coverage Interval:	16 days (233 orbits)
Altitude:	705 km
Quantization:	Best 8 of 9 bits
On-board data storage:	~375Gb (solid state)
Inclination:	Sun-synchronous, 98.2°
Equatorial Crossing:	Descending, 10:00am +/- 15 min.
Launch vehicle:	Delta II
Launch Date:	April 15, 1998

U.S. Geological Survey

National Mapping Division

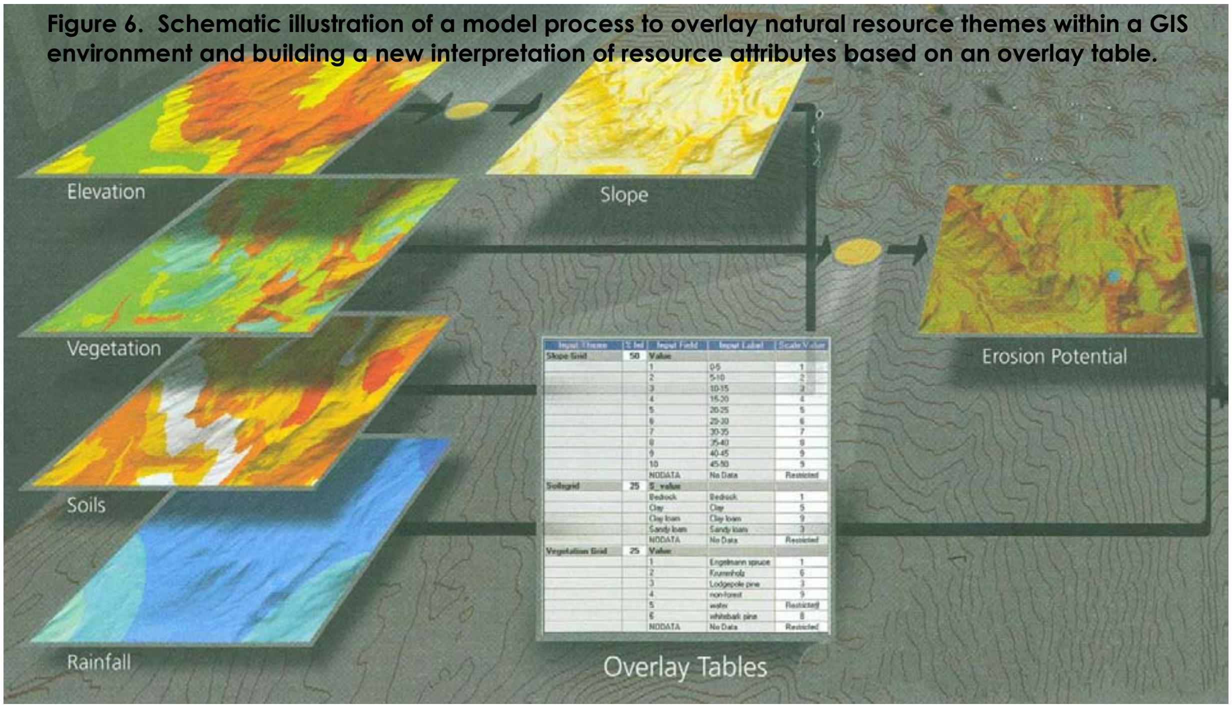


Figure 6. Schematic illustration of a model process to overlay natural resource themes within a GIS environment and building a new interpretation of resource attributes based on an overlay table.

Input Theme	% Inf	Input Field	Input Label	Scale Value
Slope Grid	50	Value		
		1	0-5	1
		2	5-10	2
		3	10-15	3
		4	15-20	4
		5	20-25	5
		6	25-30	6
		7	30-35	7
		8	35-40	8
		9	40-45	9
		10	45-50	9
		NODATA	No Data	Restricted
Soilsgrid	25	S_value		
		Bedrock	Bedrock	1
		Clay	Clay	5
		Clay loam	Clay loam	9
		Sandy loam	Sandy loam	3
		NODATA	No Data	Restricted
Vegetation Grid	25	Value		
		1	Engelmann spruce	1
		2	Krummholz	6
		3	Lodgepole pine	3
		4	non-forest	9
		5	water	Restricted
		6	whitebark pine	8
		NODATA	No Data	Restricted

Figure 7. Upper Yellowstone River Watershed, 1999 Land Cover Composition (Percentage of total area - 2,474,141 acres)

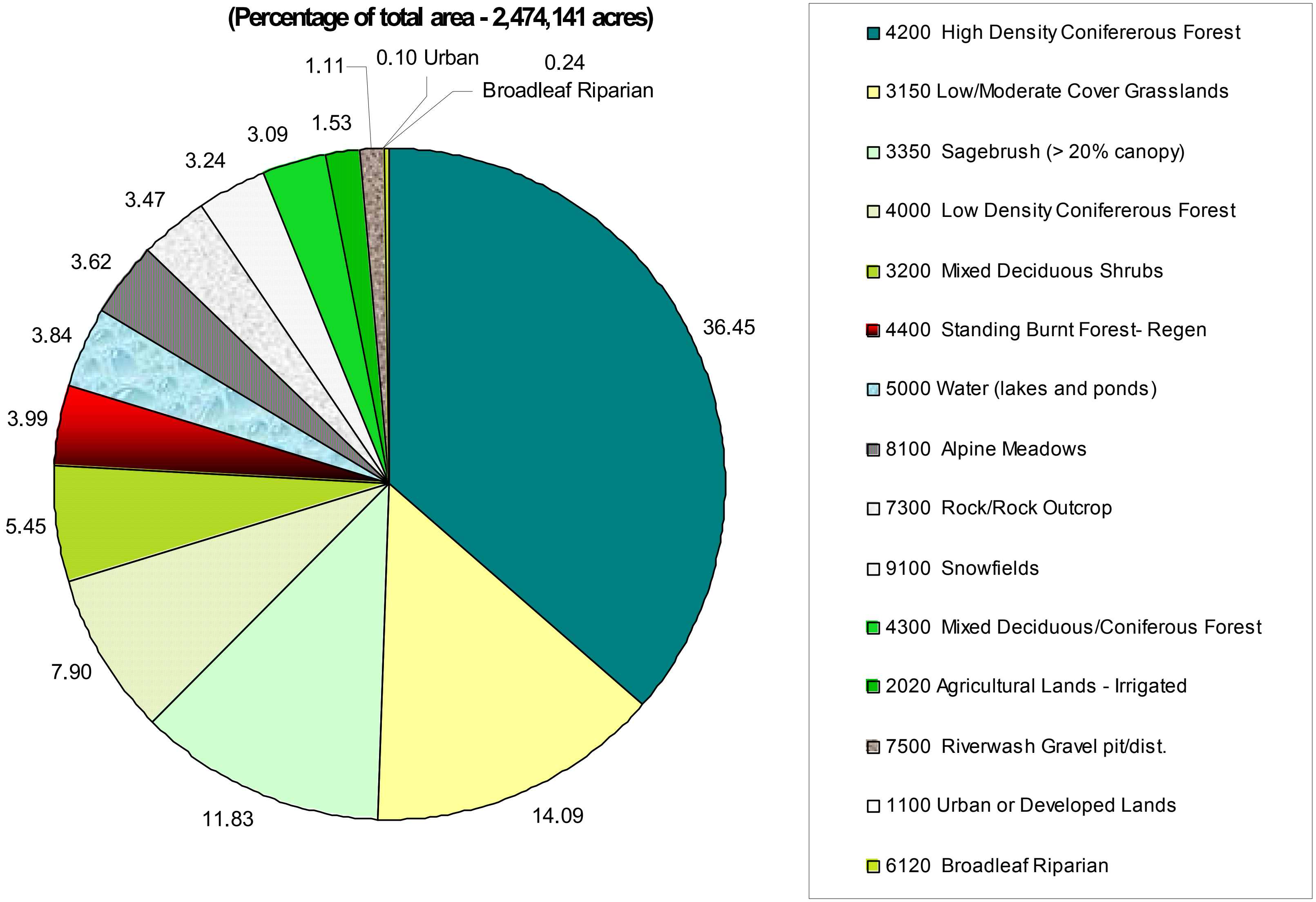


Figure 8. Upper Yellowstone River Watershed, Yellowstone Headwaters Subbasin (HUC 10070001)
1999 Land Cover Composition (Percent of total area - 1,657,127 acres)

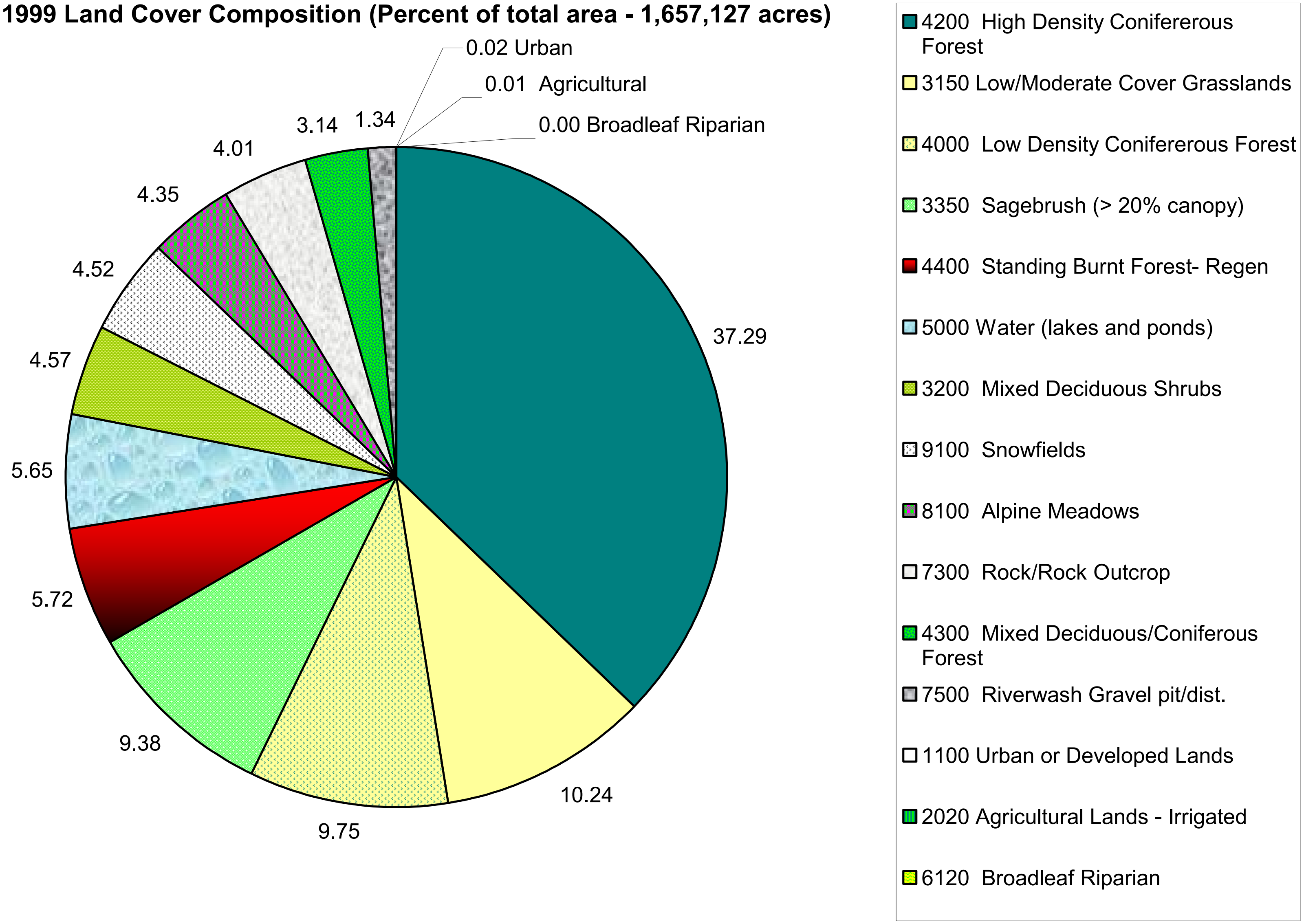
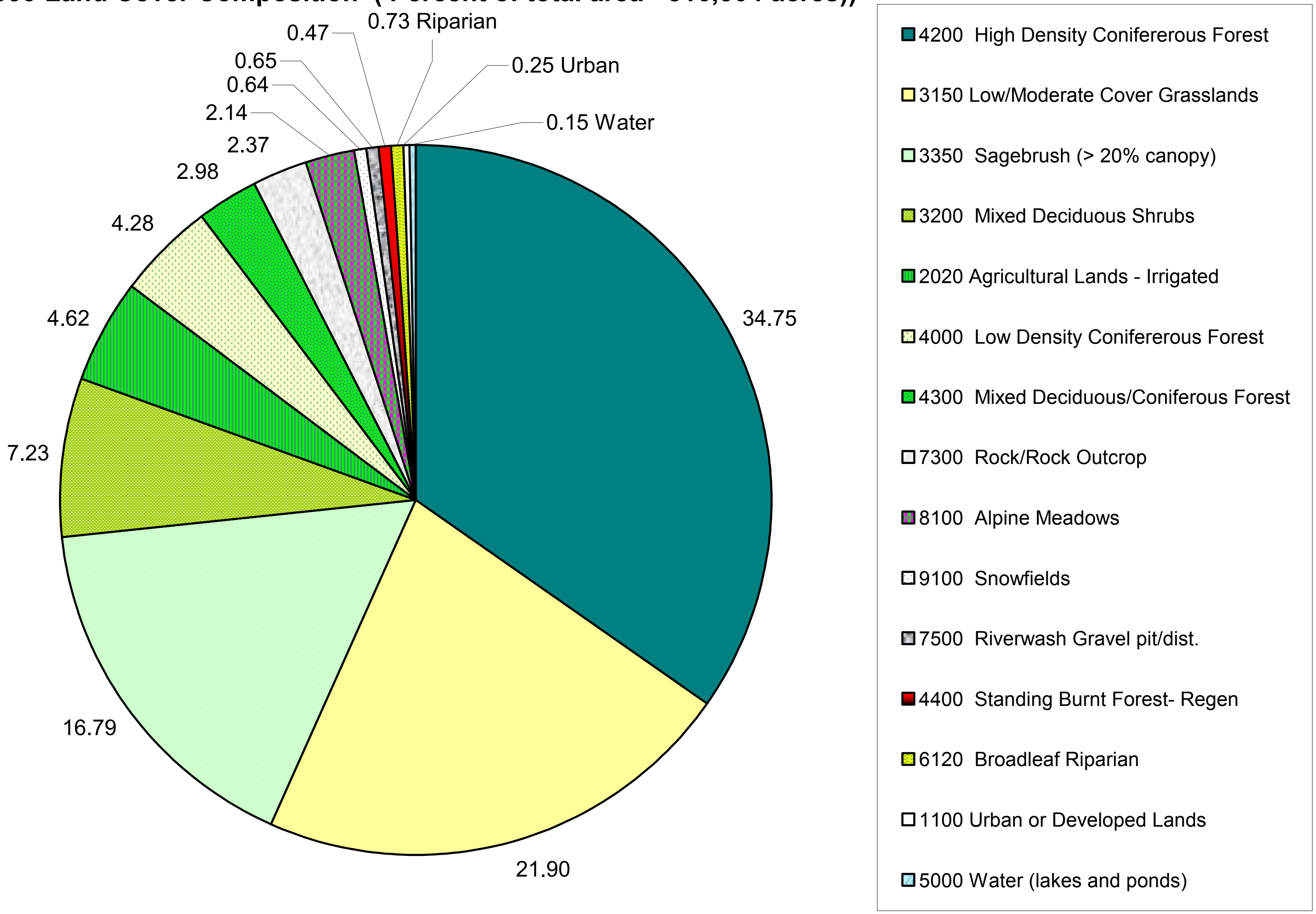


Figure 9. Upper Yellowstone River Watershed, Upper Yellowstone Subbasin (HUC10070002)
1999 Land Cover Composition (Percent of total area - 816,304 acres))



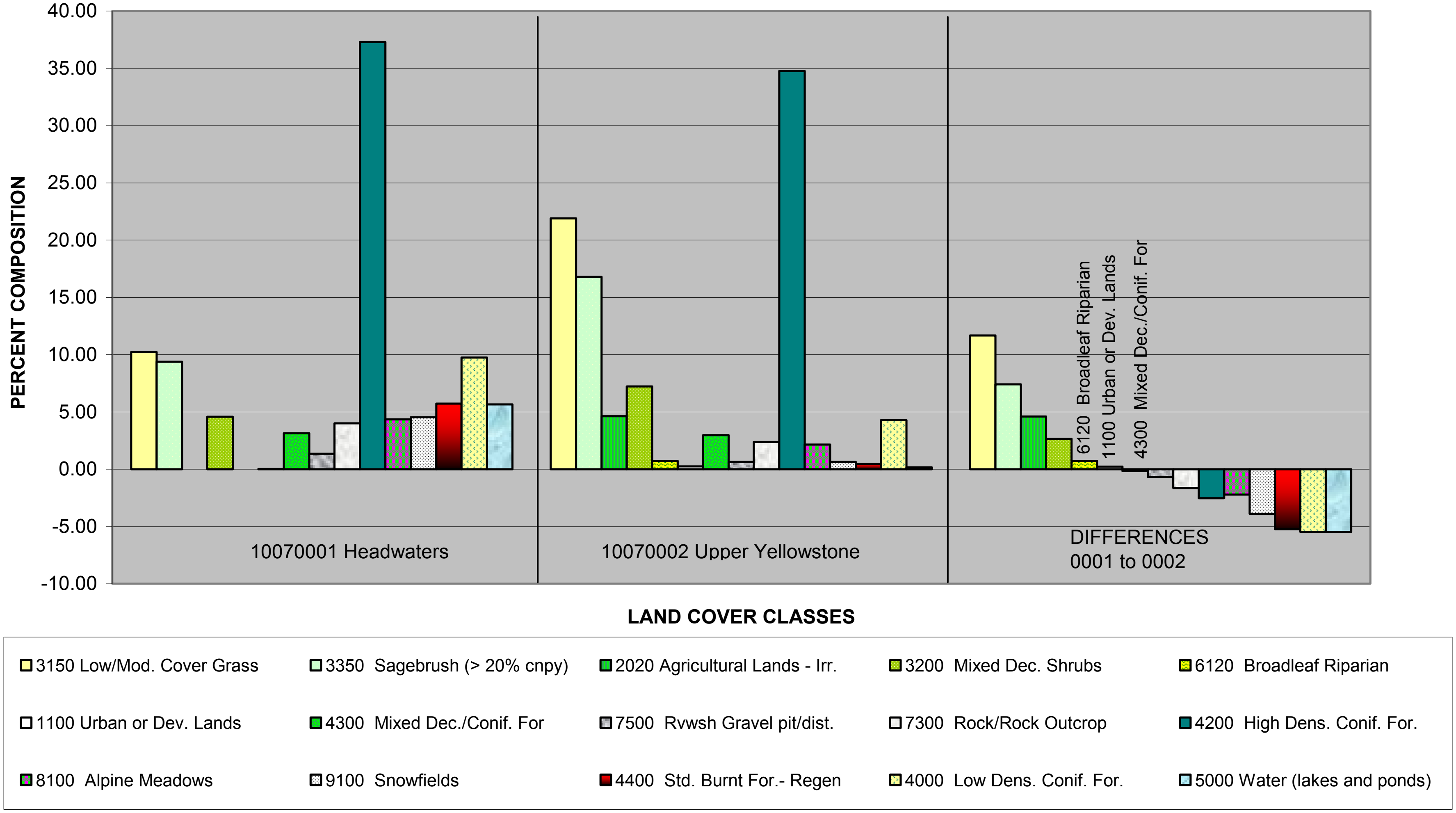


Figure 10. Upper Yellowstone River Watershed, Comparison in 1999 Land Cover Composition between 10070001 and 10070002

Figure 11

Upper Yellowstone River Watershed
Montana and Wyoming

Watersheds (5th-code)

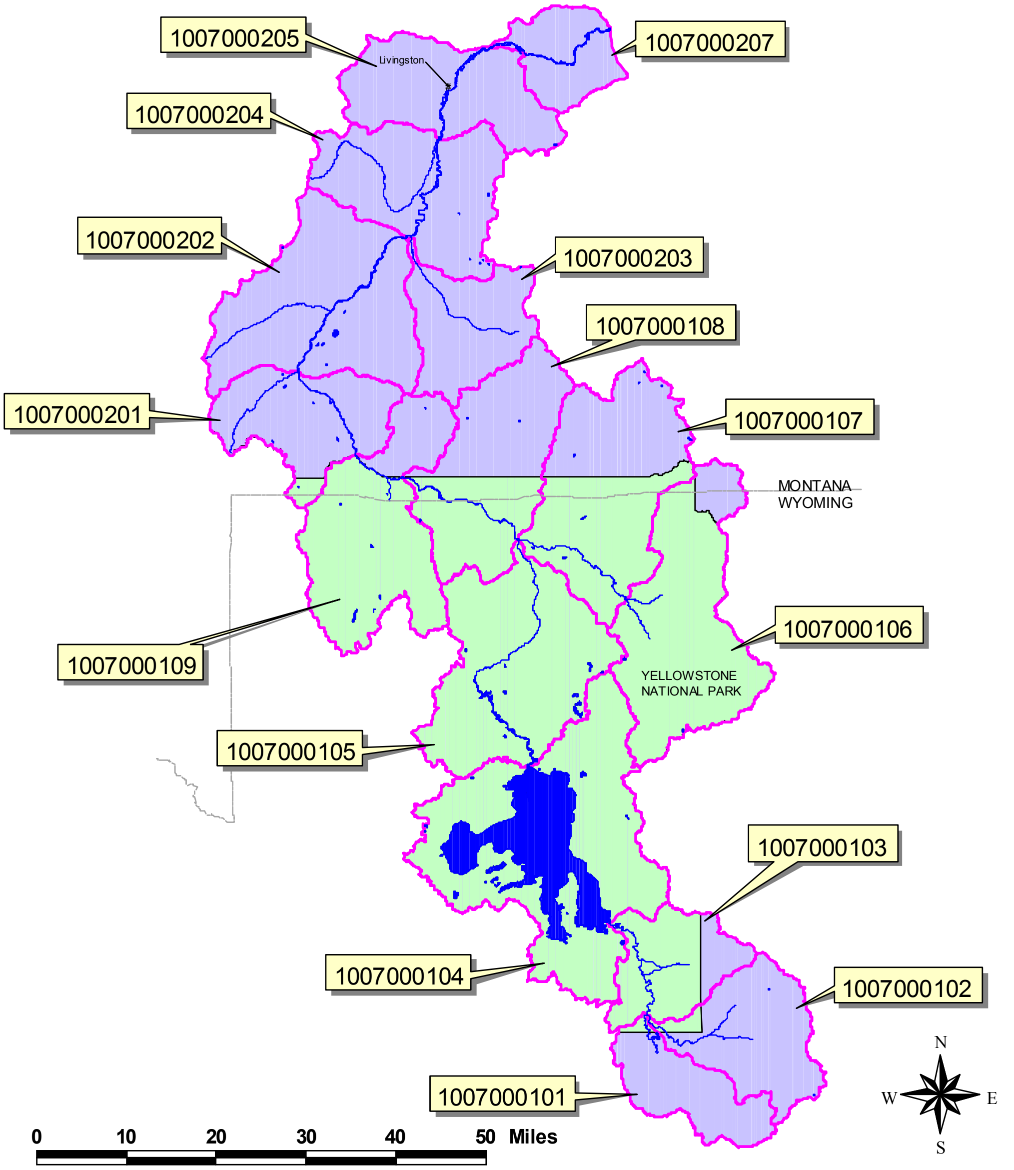


Figure 12. Upper Yellowstone River Watershed, 1999 Land Cover Composition by 5th Code HUC

Note: Subbasin HUCs not equal in area

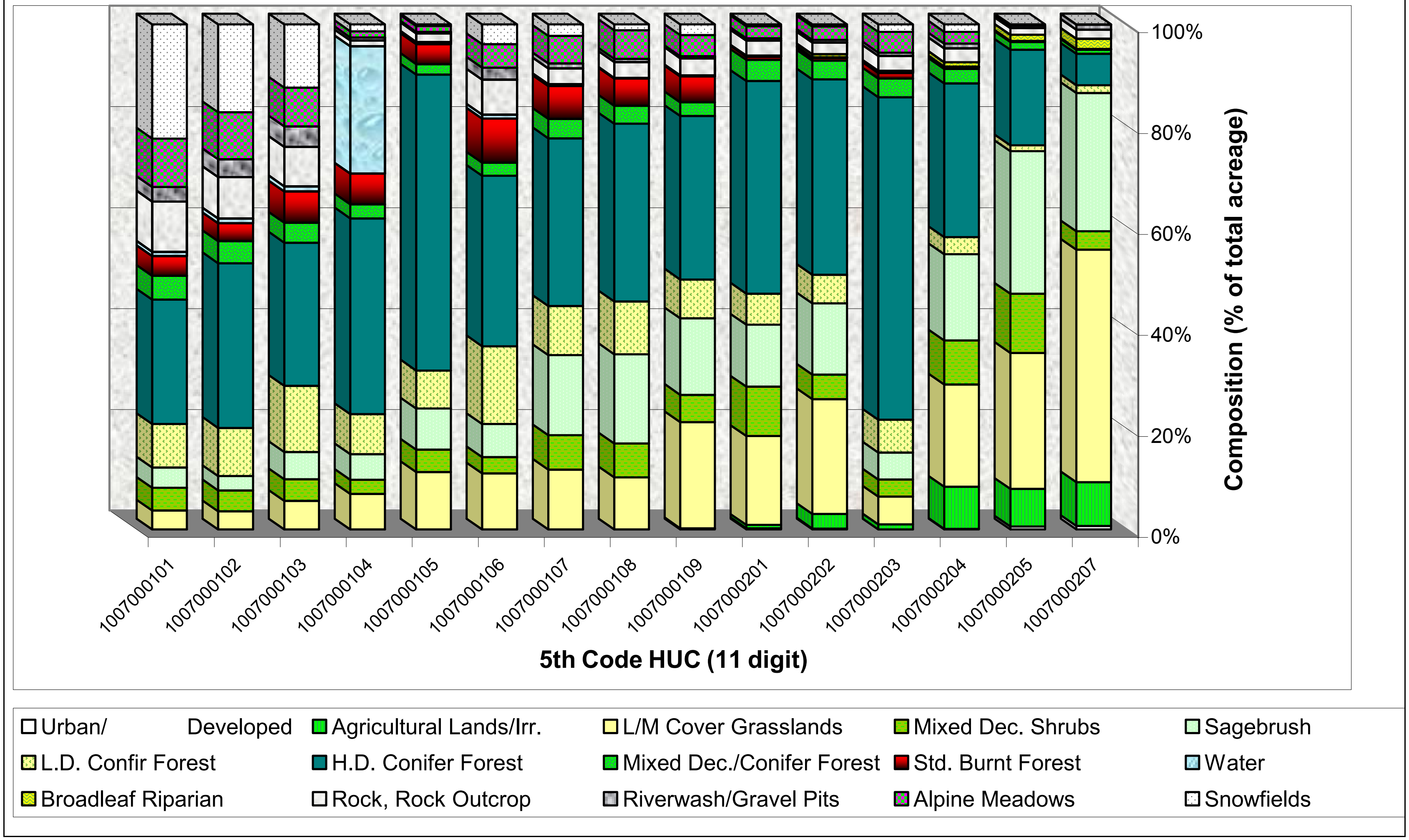
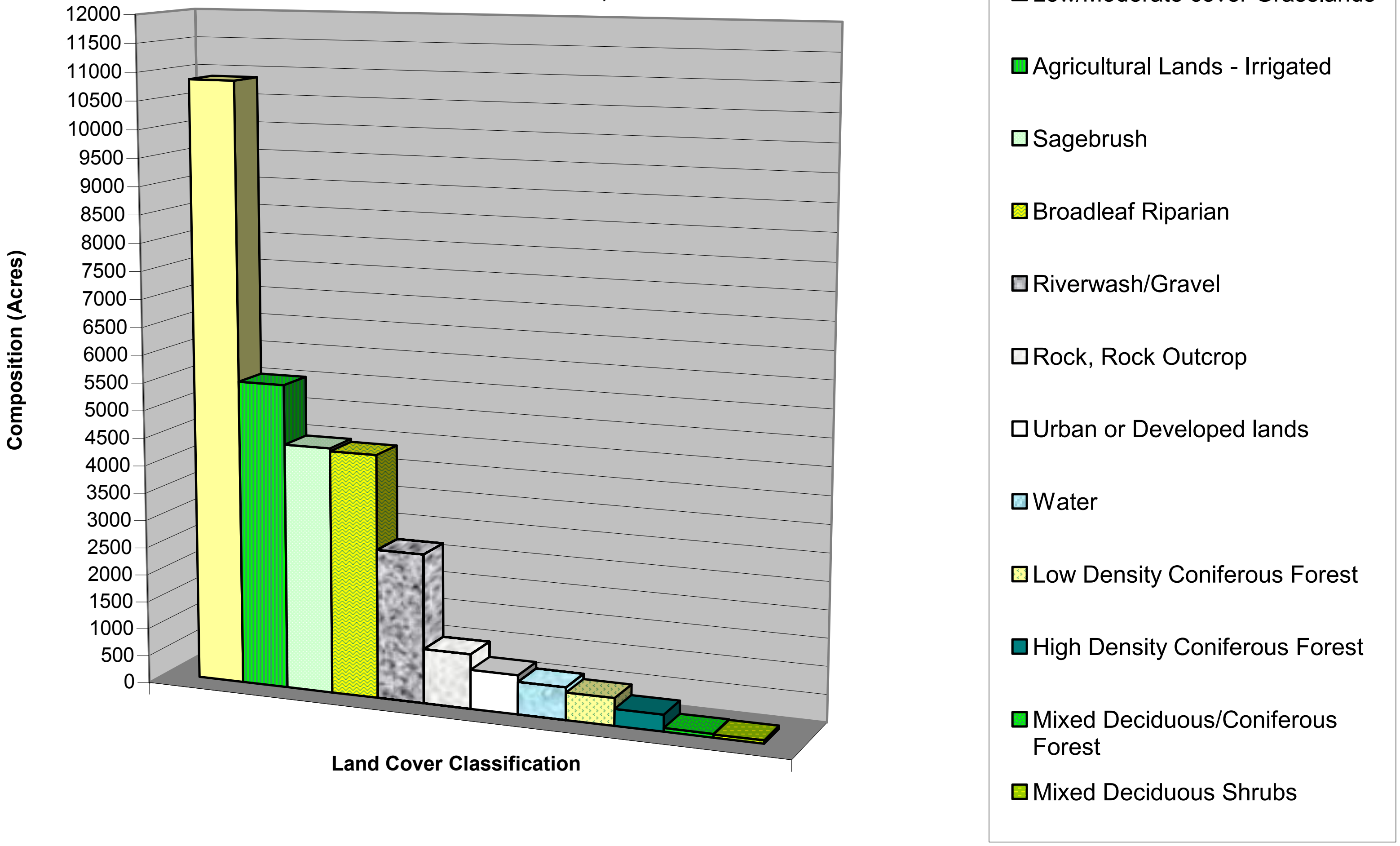


Figure 13. Upper Yellowstone River Watershed, 1999 Land Cover Composition within 1/4Mile of the Yellowstone River Channel - State line to Springdale

Total 31,121 acres



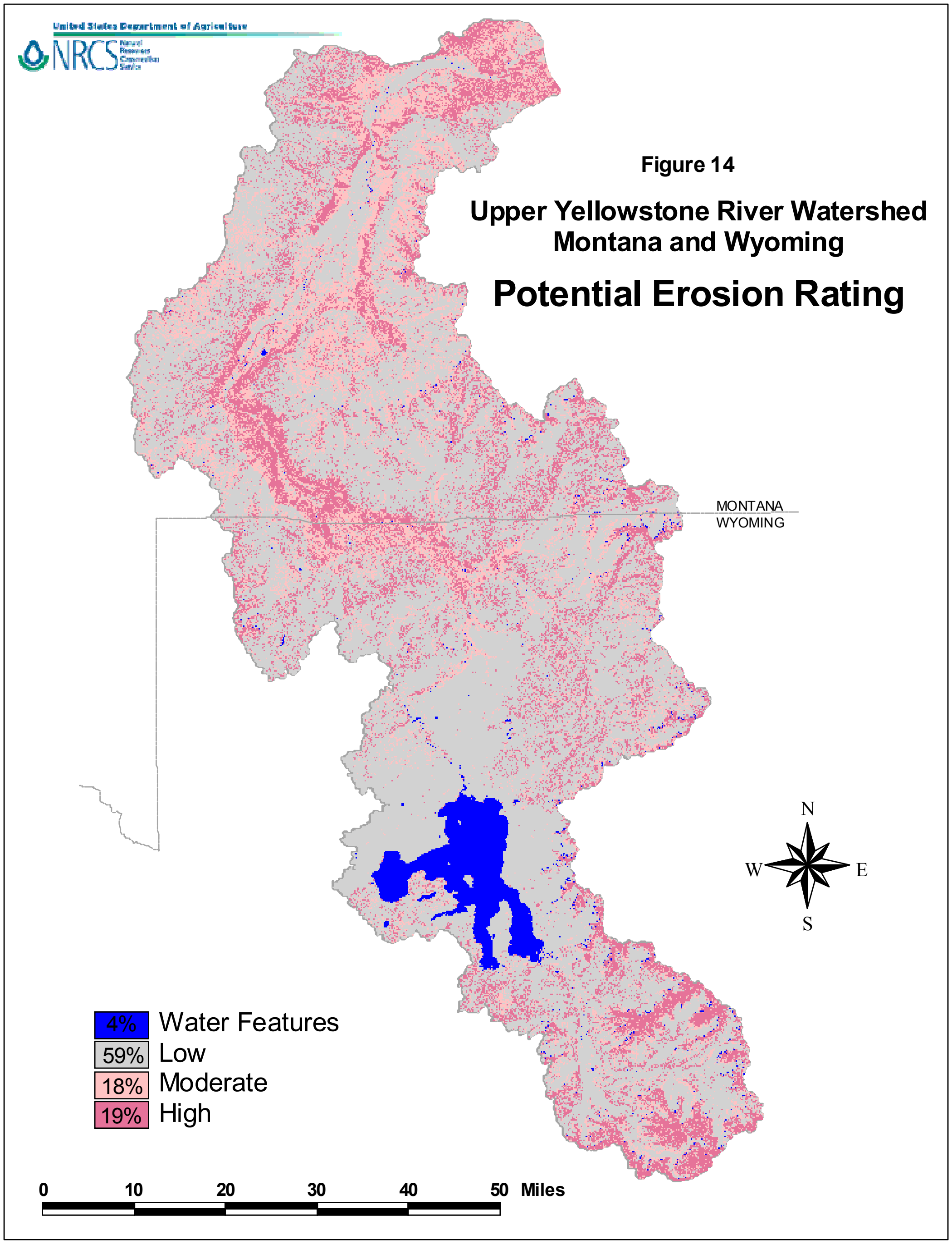


Figure 14

Upper Yellowstone River Watershed
Montana and Wyoming

Potential Erosion Rating

Figure 15. Upper Yellowstone River Watershed, Montana and Wyoming, Land Ownership Composition

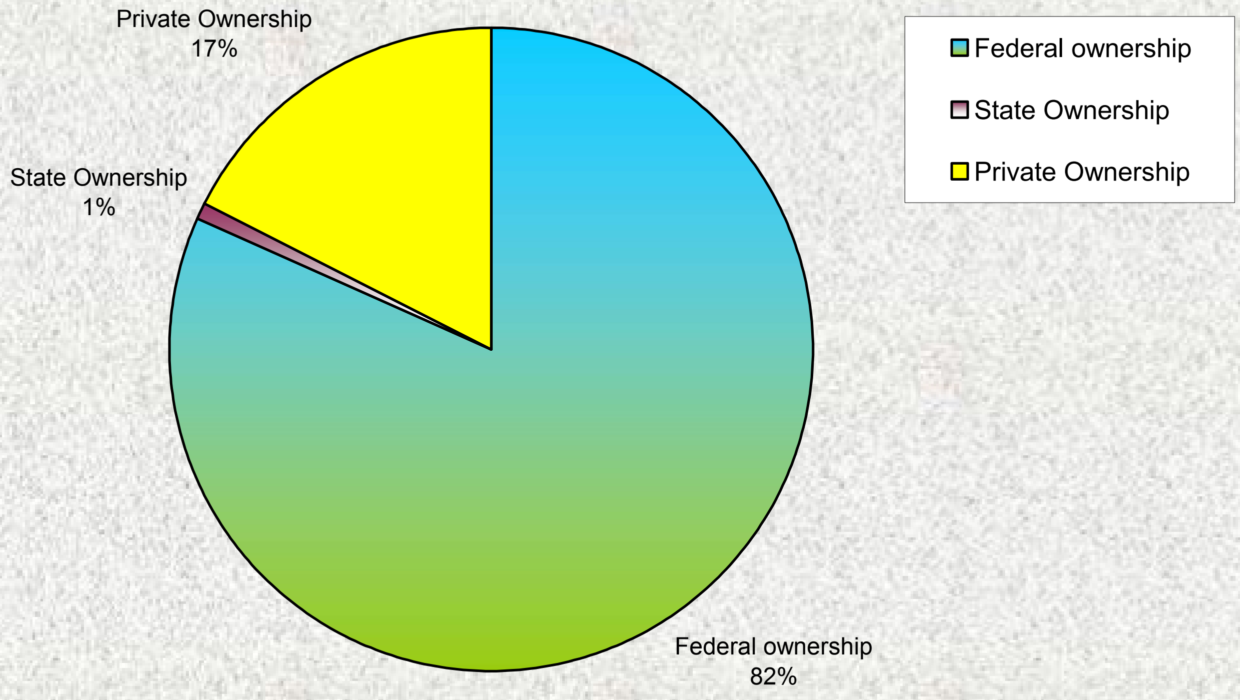
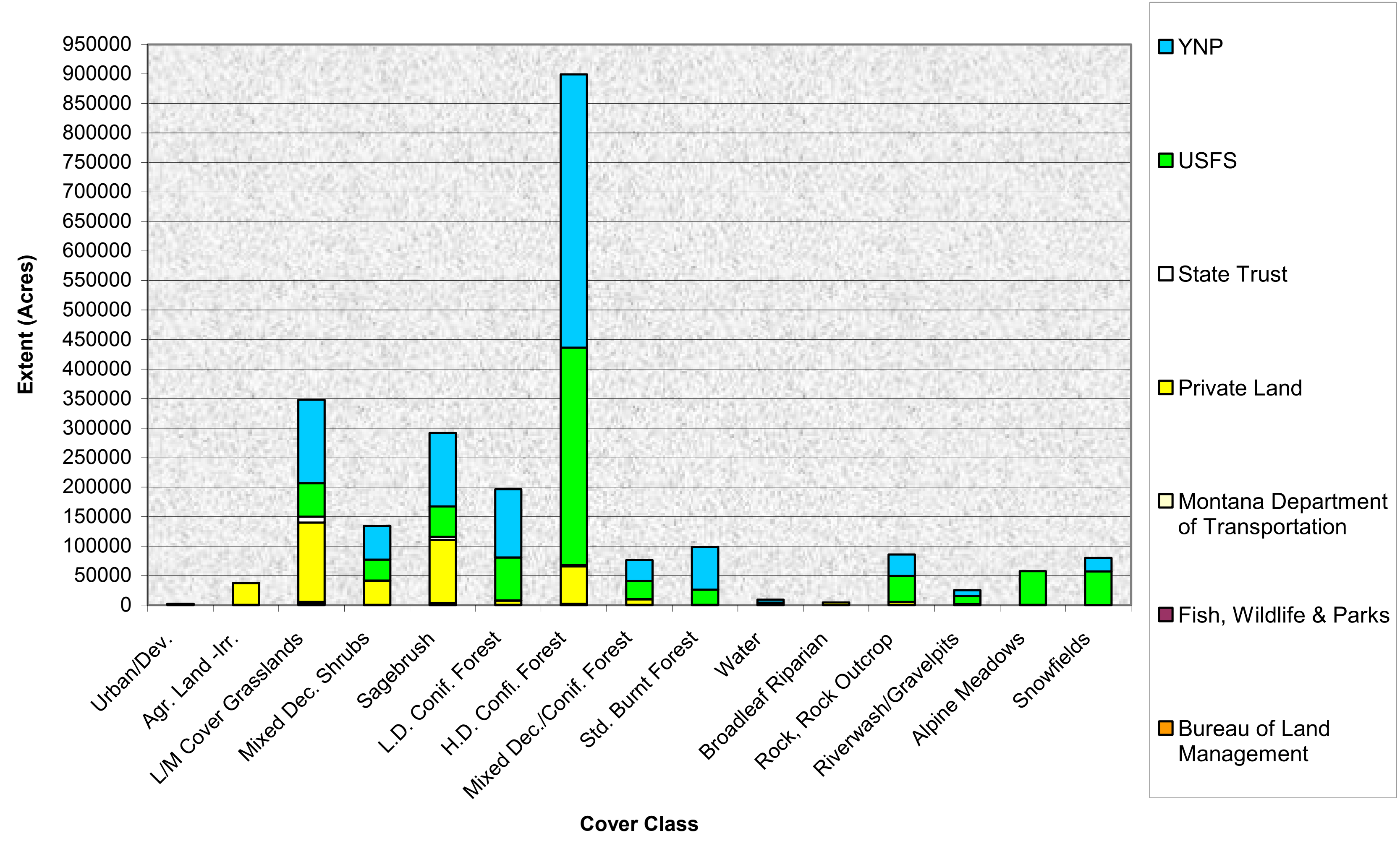


Figure 16. Upper Yellowstone River Watershed, Montana and Wyoming, 1999 Land Cover Extent by Ownership Classification



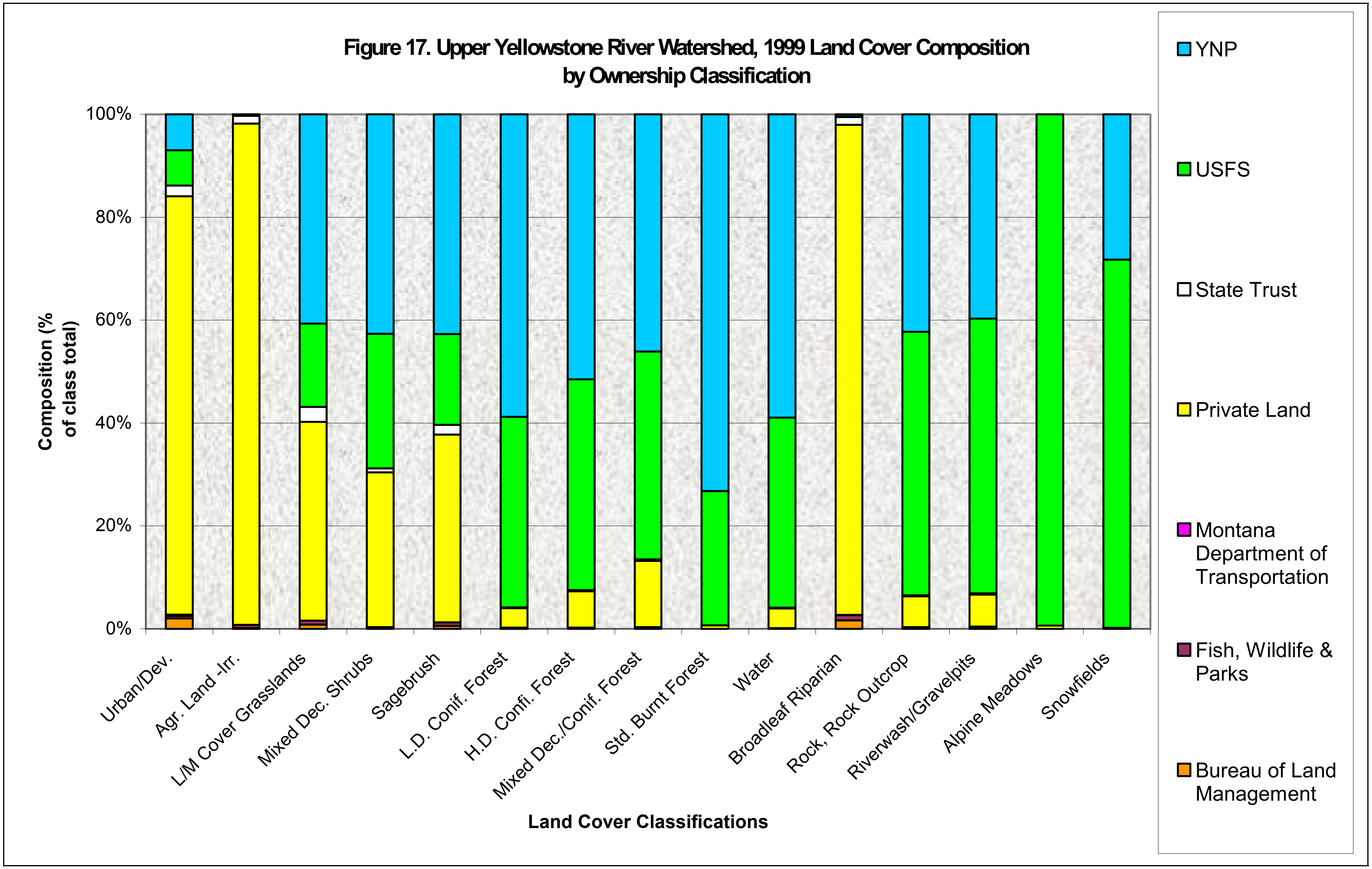


Figure 17. Upper Yellowstone River Watershed, 1999 Land Cover Composition by Ownership Classification

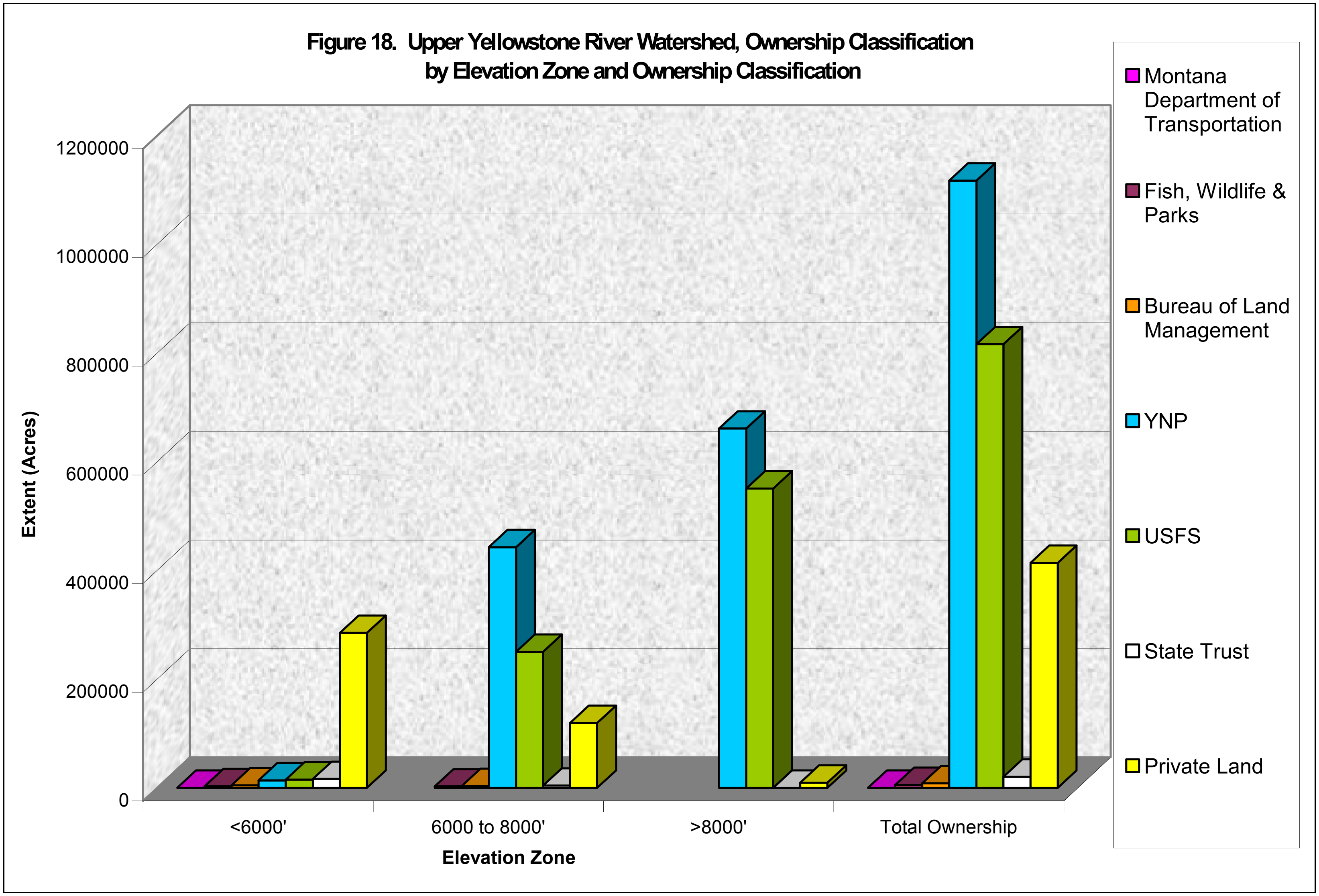


Figure 18. Upper Yellowstone River Watershed, Ownership Classification by Elevation Zone and Ownership Classification
Extent (Acres)
1200000
1000000
800000
600000
400000
200000
0
<6000'
6000 to 8000'
>8000'
Total Ownership
Elevation Zone
Montana Department of Transportation
Fish, Wildlife & Parks
Bureau of Land Management
YNP
USFS
State Trust
Private Land

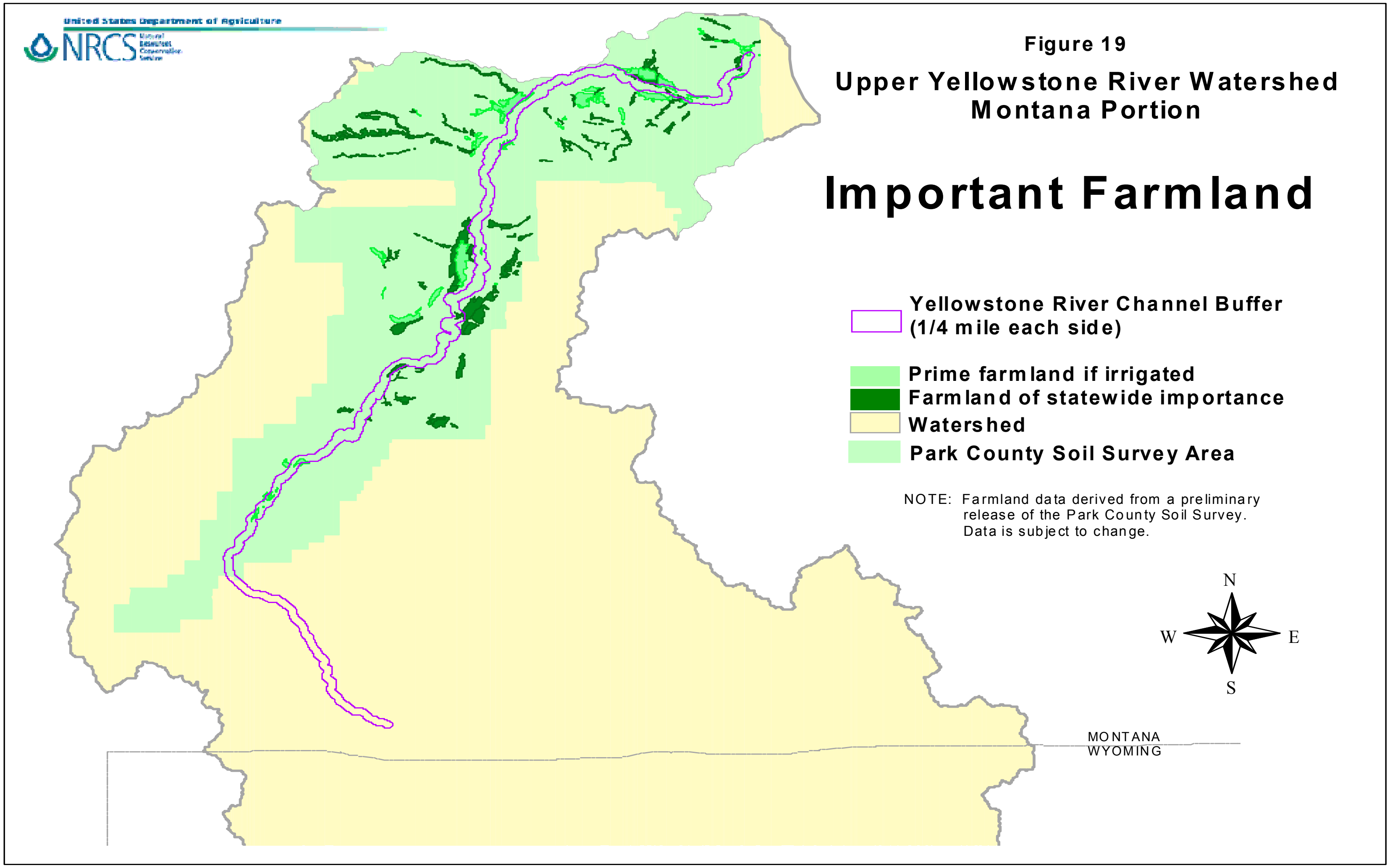


Figure 19

Upper Yellowstone River Watershed
Montana Portion

Important Farmland

NOTE: Farmland data derived from a preliminary release of the Park County Soil Survey. Data is subject to change.

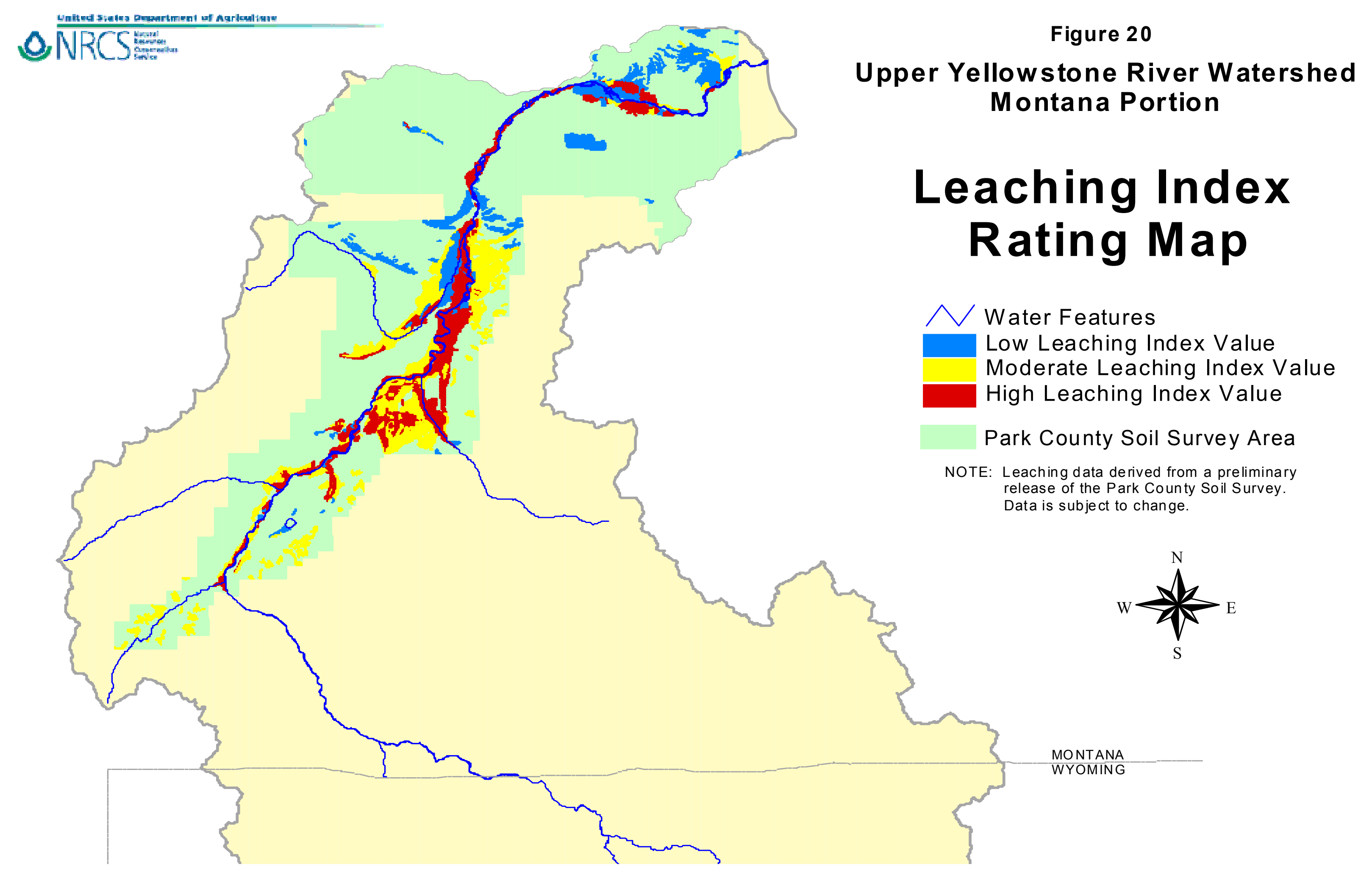


Figure 20

Upper Yellowstone River Watershed
Montana Portion

Leaching Index Rating Map

NOTE: Leaching data derived from a preliminary release of the Park County Soil Survey. Data is subject to change.

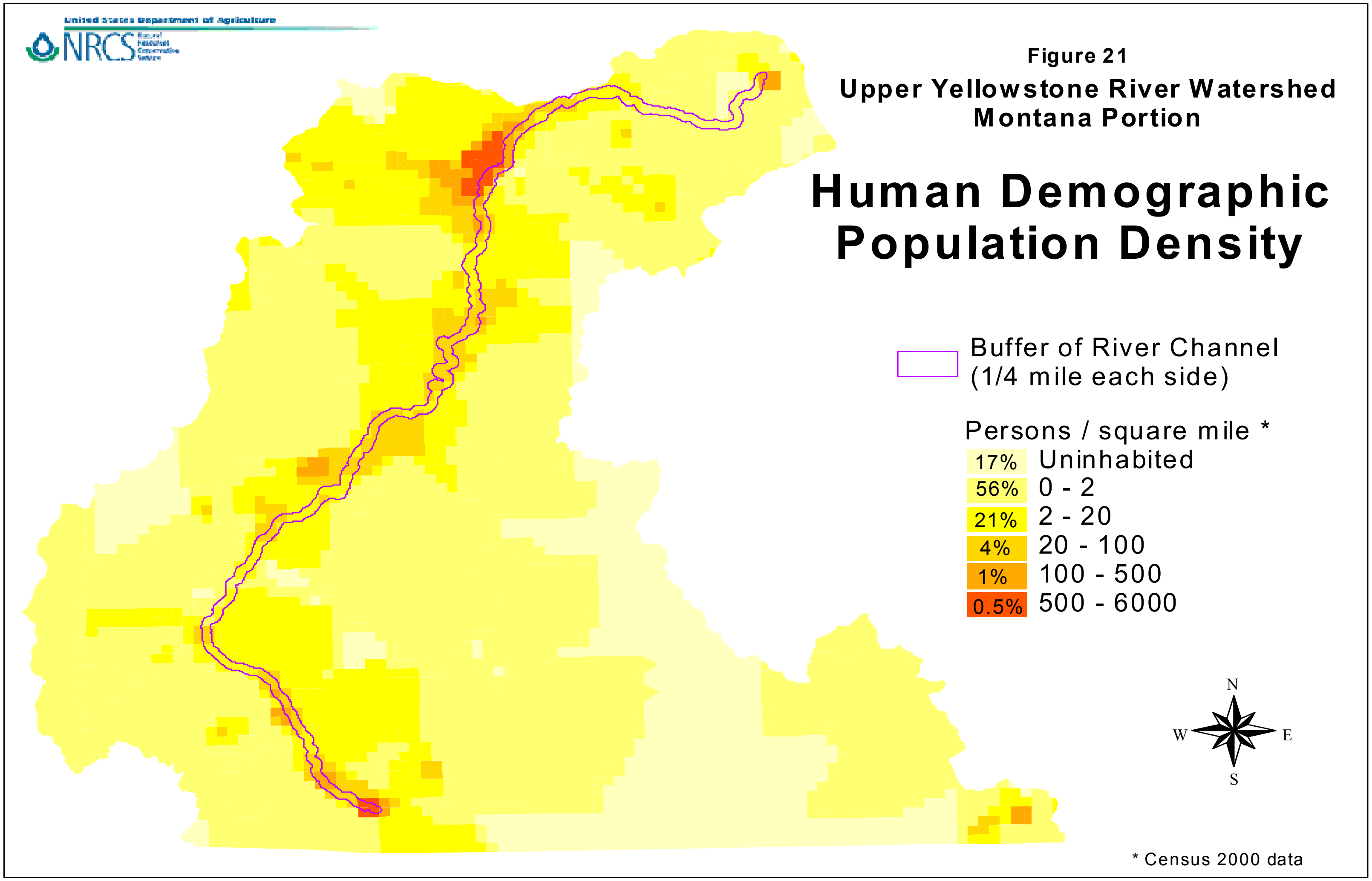


Figure 21
Upper Yellowstone River Watershed
Montana Portion

Human Demographic
Population Density

* Census 2000 data

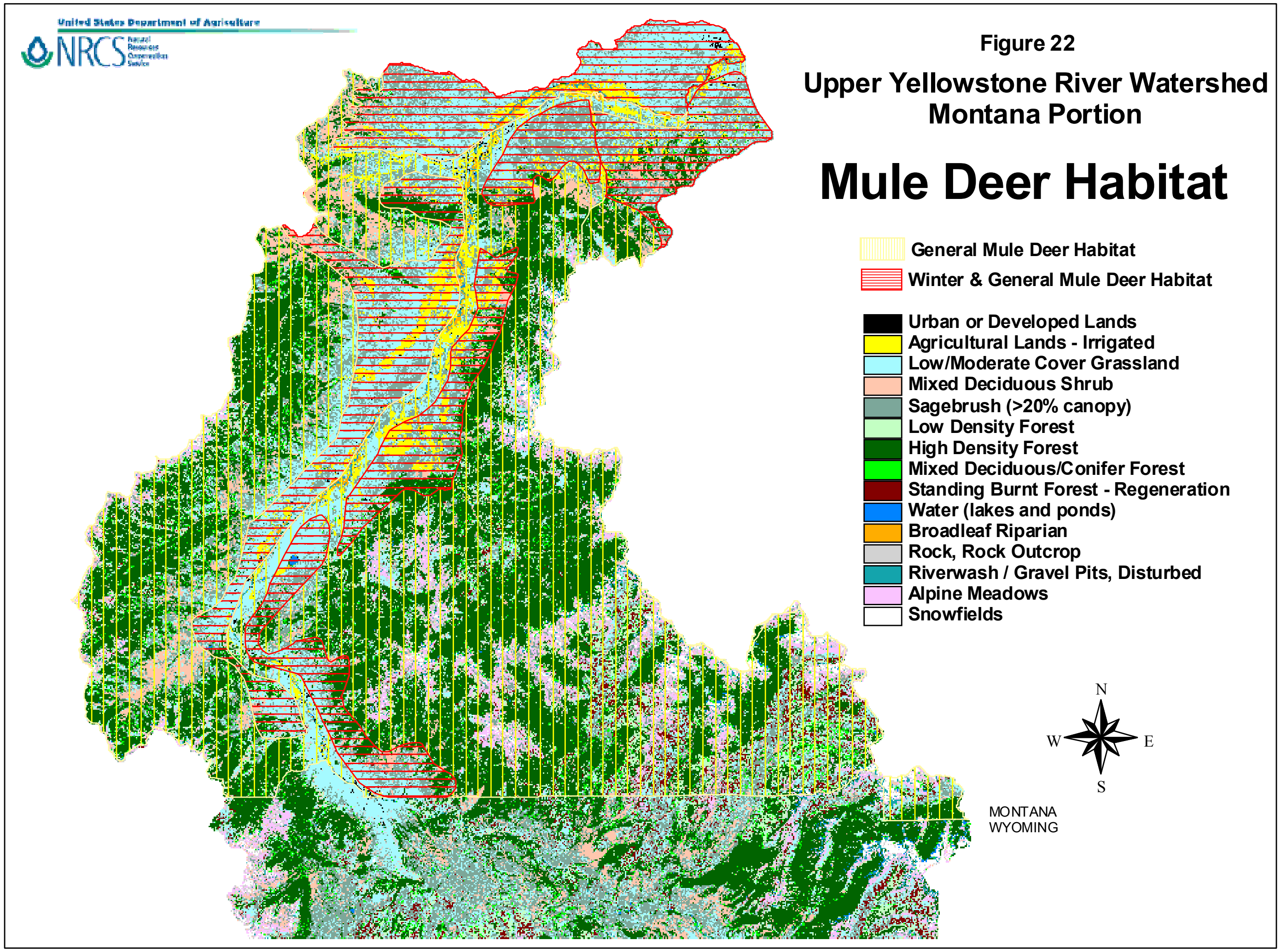


Figure 22

Upper Yellowstone River Watershed
Montana Portion

Mule Deer Habitat

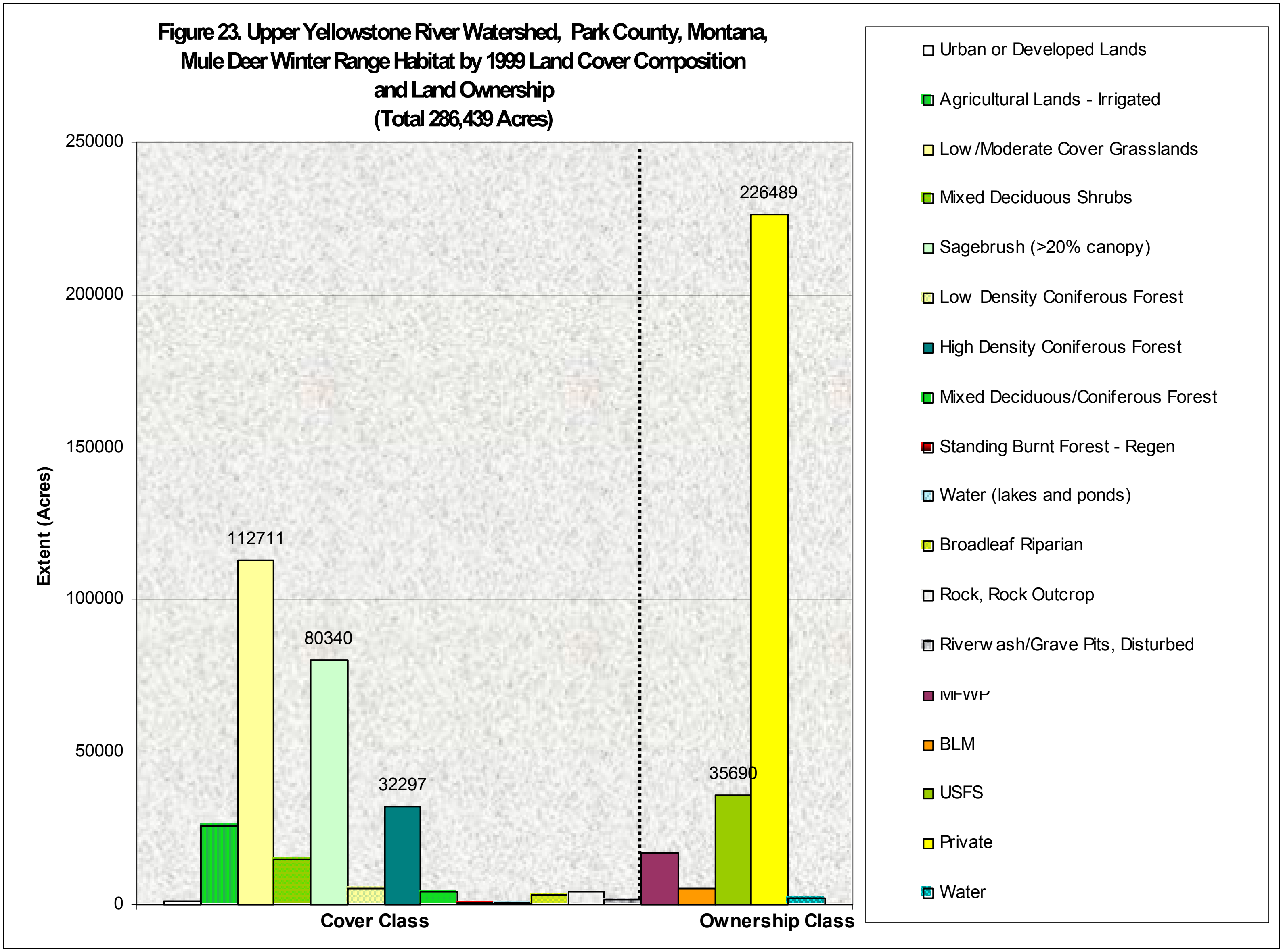


Figure 23. Upper Yellowstone River Watershed, Park County, Montana, Mule Deer Winter Range Habitat by 1999 Land Cover Composition and Land Ownership (Total 286,439 Acres)

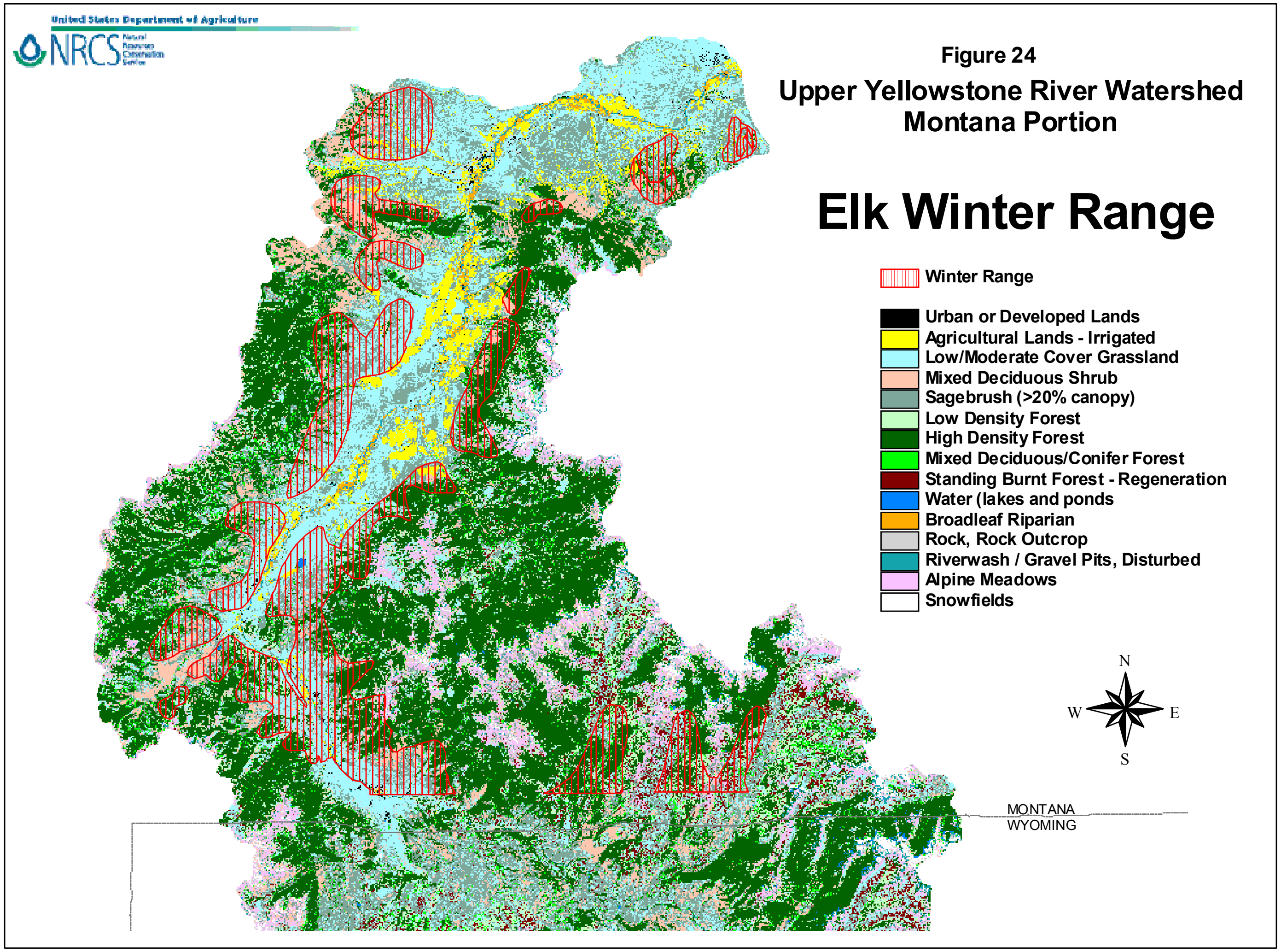
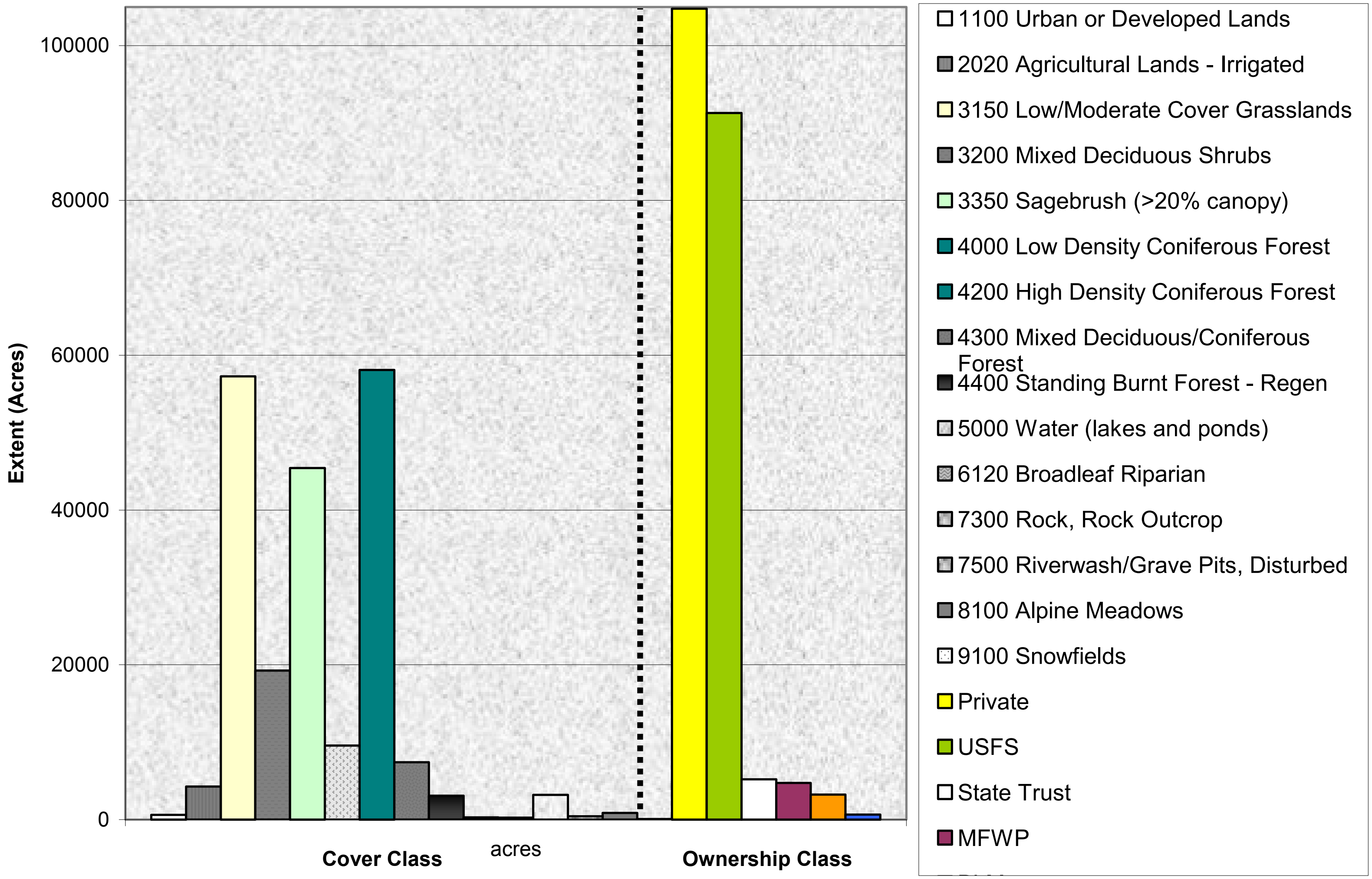


Figure 24

Upper Yellowstone River Watershed Montana Portion

Elk Winter Range

Figure 25. Upper Yellowstone River Watershed, Montana Portion
Elk Winter Range Habitat by 1999 Land Cover Composition and Land Ownership (Total Acres 210,096)



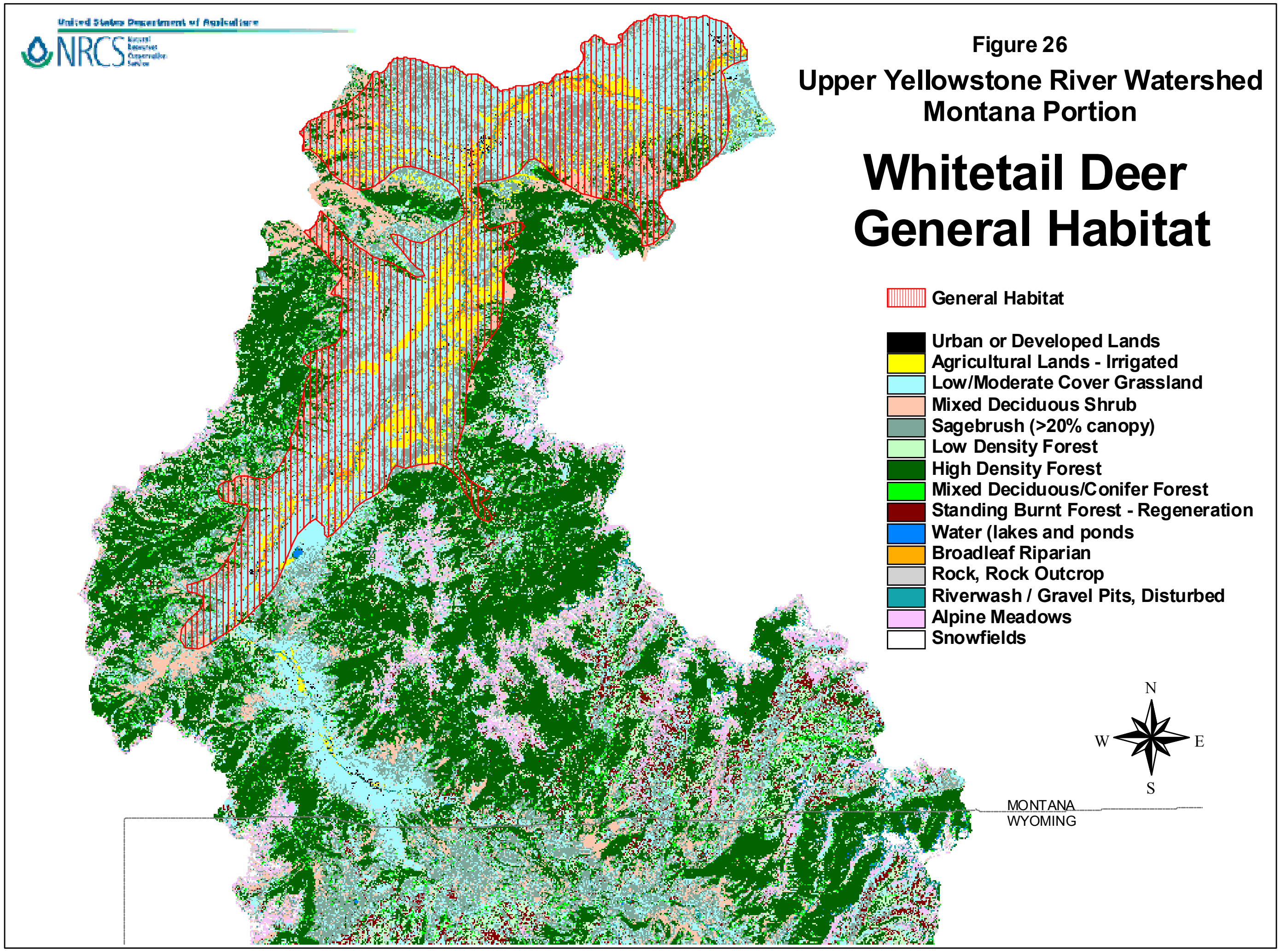


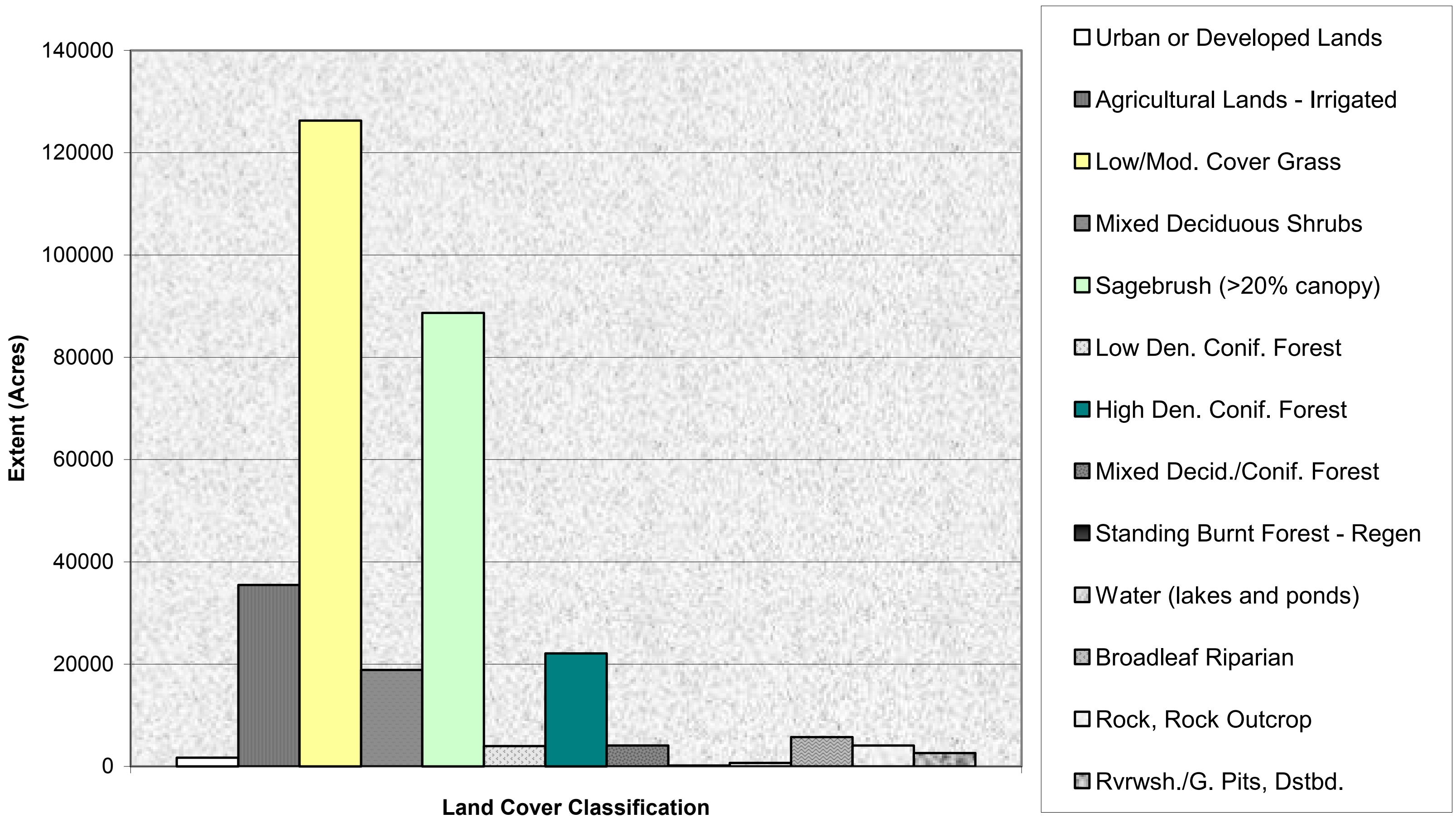
Figure 26

Upper Yellowstone River Watershed
Montana Portion

Whitetail Deer
General Habitat

Figure 27. Upper Yellowstone River Watershed, Montana Portion, Whitetail Deer General Habitat by 1999 Land Cover Composition

(Total 314,374 Acres)



APPENDICES

Appendix 1. Summary of procedures used to prepare the 1999 land cover classification as provided by the Geographic Information and Analysis Center (GIAC), Montana State University, Bozeman, Montana; Dr. Richard Aspinall, Director.

Land Cover Mapping

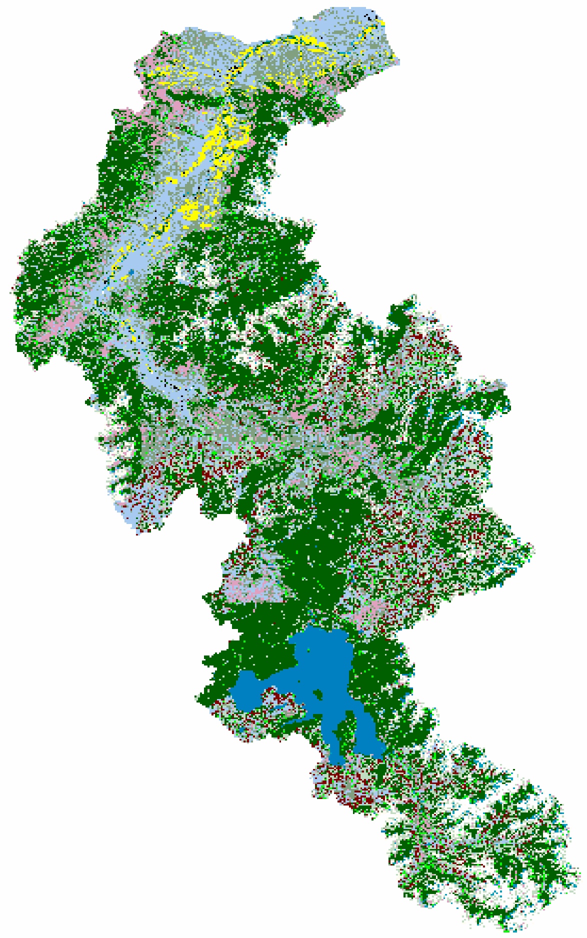
1. Georeference two 1999 LANDSAT 7 ETM+ scenes to UTM NAD83 Zone 12 projection.
2. Pan sharpen ETM+ imagery for 1999 to 15m pixel resolution. Uses a Principal Component method. This calculates principal components, re-maps the high resolution image into the data range of PC-1 and substitutes it for PC-1, then applies an inverse principal components transformation. The method is used in applications that require the original scene radiometry (color balance) of the input multispectral image to be maintained as closely as possible in the output file. As this method scales the high resolution data set to the same data range as Principal Component 1, before the inverse Principal Component calculation is applied, the band histograms of the current output file closely resemble those of the input multispectral image. This radiometric accuracy comes at the price of large computational overhead. The Principal Component method is consequently the slowest of the methods available and requires the most system resources. Another result of this methodology is that the output file tends to have the same data range as the input multispectral file.
3. Classify ETM+ into a maximum of 150 classes using Iterative Self-organizing Clustering. This is iterative in repeatedly performing an entire classification (outputting a thematic raster layer) and recalculating statistics. Self-organizing refers to the way in which the method locates clusters that are inherent in the data. It used the minimum spectral distance formula to form clusters. This begins with either arbitrary cluster means and each time the clustering repeats, the means of the clusters are shifted. The new cluster means are used for the next iteration. This is repeated until a maximum percentage of unchanged pixels have been reached between two iterations.
4. Organize key from field data collection.
5. Random sample of 2000 vegetation classes in YNP from Don Despain dataset−re-code types to match land cover key.
6. Examine spectral classes and label. YNP data are used to guide the labeling for classes that occur extensively inside the Park. Two classes identified for each spectral class (first, second). Irrigation and burned areas also identified as binary types superimposed on other land cover classes.
7. Use field data for validation.

Appendix 2.

A Satellite-Based Land Cover Map for the Upper Yellowstone River Watershed, Montana and Wyoming

By

W. Doug Harrison, Resources Inventory Specialist
Tom Potter, Geographic Information System Specialist



USDA Natural Resources Conservation Service
Bozeman, Montana

12/01

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A Satellite-Based Land Cover Classification Map for the Upper Yellowstone River Watershed, Montana and Wyoming

Introduction: A satellite-based land classification map describes, with reasonable accuracy, basic land cover types for about 2,474,141 acres in the Upper Yellowstone River watershed, Montana-Wyoming. The foundation data source consists of two Landsat satellite Enhanced Thematic Mapper (ETM+) scenes dated July 13, 1999. This cloud and haze-free imagery provided good spectral band representation with minimal defects.

In April, 2001 the USDA Natural Resources Conservation Service (NRCS) Montana GIS facility received an ETM+ classified data set from the Geographic Information and Analysis Center (GIAC), Montana State University, Bozeman, Montana. Data were provided on CD-ROM and included a classified data set based on a land cover key with accompanying tabular files of accompanying accuracy assessment matrices.

In order to standardized land cover types, the original land cover/use key used for field data gathering was converted to a GAP land cover legend modeled after the Montana Land Cover Atlas (1). [Note: Cover code numbers used for this project follow the same conventions and numbering protocol as those found in the referenced GAP report]. This helped standardized land cover classes resulting in a more meaningful separation of land cover from land use. A calculated accuracy assessment as determined by GIAC was 64.3%. Subsequent field visits were made in order to develop stratification decision rules to reduce land classification confusion and improve the overall accuracy of the map. A final post-stratification accuracy assessment of 72.2% was achieved. Documentation for the assessment may be found in the metadata file (upyell_lcc.met).

Project Area: The project area includes the upper reaches of the Yellowstone River beginning at the Park/Sweet Grass County line east of Livingston, Montana upstream including the headwaters of the Yellowstone River in Wyoming. The area includes the entire 4th code (8-digit) hydrologic unit #10070001 (Yellowstone Headwaters) and the portion of #1007002 (Upper Yellowstone) that describes the watershed upstream from the Park/Sweet Grass County line, excluding the Shields and Boulder river watersheds. (Figure 1). About 1,362,084 acres or 55% of the Upper Yellowstone watershed area lies within the state of Wyoming, of which about 1,203,600 acres or 49% of the project area lies within the boundary of Yellowstone National Park.

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(1) Fisher, F.B., J.C. Winne, M.M. Thornton, T.P., Z. Ma, M.M. Hart, and R.L. Redmond. 1998. Montana land cover atlas. Unpublished report. Montana Cooperative Wildlife Research Unit, The University of Montana, Missoula. Viii + 50pp.

Classification and Cover Classes: The 1999 land cover classes were derived by GIAC using appropriate image processing protocol. An unsupervised classification (post processing) process was used. A brief description of the steps used by Dr. Richard Aspinall and staff to derive the land cover classification is provided in Appendix A.

Fifteen dominant cover classes (Table 1) were derived. These classes are the result of post-classification review and field-based stratification rules. The full resolution of the data set was maintained at 0.056 acres per pixel for computation purposes. Table 3 lists total acreage and percent of area for the entire study area. The body of the report includes individual narratives that describe each cover class with a representative image.

Accuracy and Post Classification Stratification: An overall accuracy of 64.3% was achieved for the final unsupervised classification prior to the application of stratification rules. Upon review of the final classification, confusion existed relative to the distribution of some vegetative classes, most notably, those classes having high near infrared reflectance. The principal stratification tool used to reduce confusion was the 30-meter Digital Elevation Model (DEM) data.

Twenty-three 1:24,000 scale check plots were produced for field verification. Extensive field checks were made to determine how well the fifteen cover type clusters fit the landscape. Confusion and inconsistencies were documented from which a series of stratification rules were derived. Table 2 is a summary of the field-derived stratification rules in the order in which they were imposed. Confusion in the near infrared reflectance classes 2020, 3200, 4300, 4500 and 6120 required elevation-based stratification. For example, confusion between irrigated agriculture and upland deciduous shrubs required an elevation "cut-off" above which the irrigated agriculture class was unlikely to occur based on field observations. In some areas, such as the Tom Miner Basin, irrigated agriculture (hayland) was so intermixed with deciduous shrubs and aspen stands, that a clear separation was not possible.

Using the Map: The accompanying color wall map displays dominant land cover classes for the Upper Yellowstone River watershed. It is designed to show general land cover relationships for the entire project area with sufficient cultural feature data for reference, including roads and town sites. The scale of the map is about 1:211,000, or 1 inch equals about 3.33 miles. The projection is UTM, zone 12, datum NAD-83. The complete metadata may be found on the distribution CD-ROM.

Disclaimer: The Upper Yellowstone River watershed land cover classification map is to be used as a primary reference source and is not intended for site specific planning. Not all land cover types are shown and some may not be accurately represented. This is public information and may be interpreted by organizations, agencies, units of government or others based on needs; however they are responsible for the appropriate application.

Table 1. Upper Yellowstone River watershed classification legend based on the Montana GAP analysis legend

---

I Urban and Agricultural Land
1100 Urban or Developed Lands
2020 Agricultural Lands - Irrigated

II Grasslands
3150 Low / Moderate Cover Grasslands

III Shrublands
3200 Mixed Deciduous Shrub
3350 Sagebrush (>20% canopy)

IV Forest Lands
4000 Low Density Coniferous Forest
4200 High Density Coniferous Forest
4300 Mixed Deciduous / Coniferous Forest
4400 Standing Burnt Forest - Regeneration

V Water
5000 Water (lakes and ponds)

VI Riparian
6120 Broadleaf Riparian

VII Barren Lands
7300 Rock, Rock outcrop
7500 Riverwash / Gravel Pits, Disturbed

VIII Alpine
8100 Alpine Meadows

IX Perennial Snow and Ice
9100 Snowfields

Table 2. Stratification rules as applied to the Upper Yellowstone River watershed area

---

Applied universally

4300 (Mixed Deciduous / Coniferous Forest) to 4200 (High Density Coniferous Forest)
4214 (Rocky Mountain Juniper*) to 3150 (Low / Moderate Cover Grasslands)

*this class is not described; it may have been valid if it had been more narrowly defined in the cluster aggregation phase of classification.

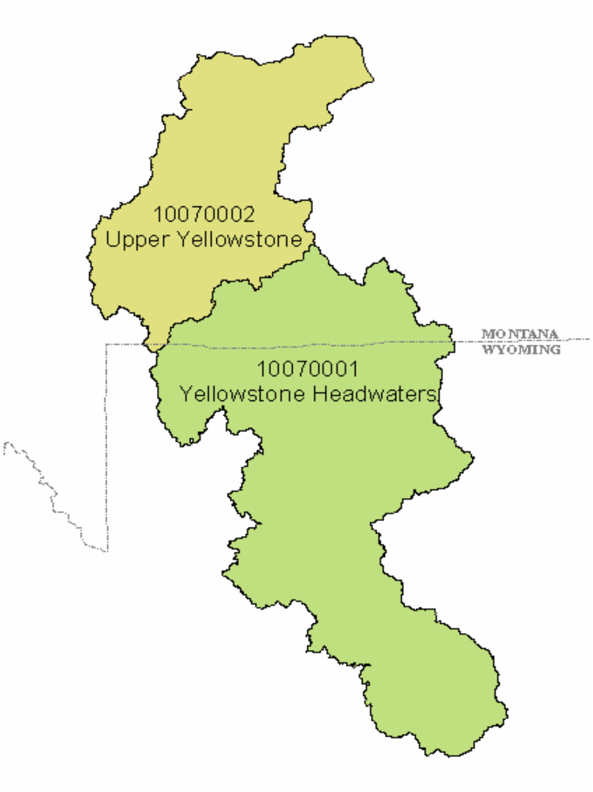
Applied based on elevation

6120 (Broadleaf Riparian) to 4300 (Mixed Deciduous / Coniferous Forest) > 5000'
1100 (Urban or Developed Land) to 7300 (Rock, Rock outcrop > 5800'
3150 (Low / Moderate Cover Grasslands) to 8100 (Alpine Meadows) > 9,200'
2020 (Agricultural Lands - Irrigated) + 4300 (Mixed Deciduous / Coniferous Forest) + 6400 (Mixed Riparian) to 3200 (Mixed Deciduous Shrub) > 5500'
4300 (Mixed Deciduous / Coniferous Forest) + 6400 (Mixed Riparian) to 2020 (Agricultural Lands - Irrigated) < 5500'
4400 (Standing Burnt Forest - Regeneration) to 3200 (Mixed Deciduous Shrub) < 6000'

Table 3. Upper Yellowstone River watershed land cover classification

Class #	Name	Pixel Count	Acres	%
1100	Urban or Developed Lands	43,642	2,426	0.10
2020	Agricultural Lands - Irrigated	680,547	37,832	1.53
3150	Low/Moderate Cover Grasslands	6,272,786	348,704	14.09
3200	Mixed Deciduous Shrubs	2,425,867	134,854	5.45
3350	Sagebrush (>20% canopy)	5,263,899	292,620	11.83
4000	Low Density Coniferous Forest	3,537,432	196,646	7.90
4200	High Density Coniferous Forest	16,287,696	905,433	36.65
4300	Mixed Deciduous/Coniferous Forest	1,374,070	76,385	3.09
4400	Standing Burnt Forest - Regen	1,775,639	98,708	3.99
5000	Water (lakes and ponds)	1,706,371	94,857	3.83
6120	Broadleaf Riparian	40,584	2,256	0.09
7300	Rock, Rock outcrop	1,545,439	85,911	3.47
7500	Riverwash/Gravel Pits, Disturbed	495,179	27,527	1.11
8100	Alpine Meadows	1,612,520	89,640	3.62
9100	Snowfields	1,444,966	80,326	3.25
0000	Unclassified Area	296	16	0.00
Totals		**44,506,933**	**2,474,141**	**100.00**

Figure 1. Upper Yellowstone River watershed by 4th code (8-digit) hydrologic units



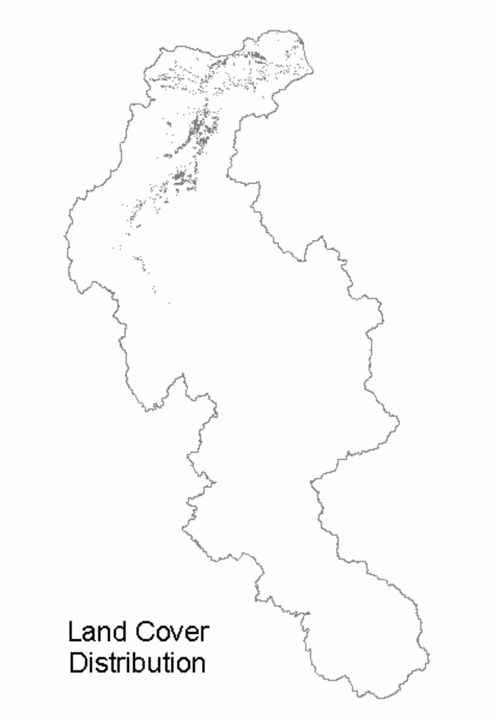
Cover Class Code	**10070001** Acres	%	**10070002** Acres	%
1100	364	0.02	2,062	0.25
2020	85	0.01	37,746	4.62
3150	169,825	10.24	178,816	21.90
3200	75,732	4.57	59,065	7.23
3350	155,484	9.38	137,084	16.79
4000	161,646	9.75	34,958	4.28
4200	617,936	37.27	287,335	35.19
4300	51,996	3.14	24,375	2.98
4400	94,876	5.72	3,802	0.47
5000	93,627	5.65	1,225	0.15
6120	--------	-----	2,256	0.28
7300	66,484	4.01	19,360	2.37
7500	22,185	1.34	5,324	0.65
8100	72,050	4.35	17,478	2.14
9100	74,837	4.51	5,418	0.66

1100 - Urban or Developed Lands

This cover type consists of high density residential and commercial development. This type includes the cities of Livingston and Gardiner and small rural town sites. Confusion may exist with areas of bare rock and pavement or shadows from steep hillsides or cliffs.

Total Area: 2,426 acres
Percent of Area: 0.10

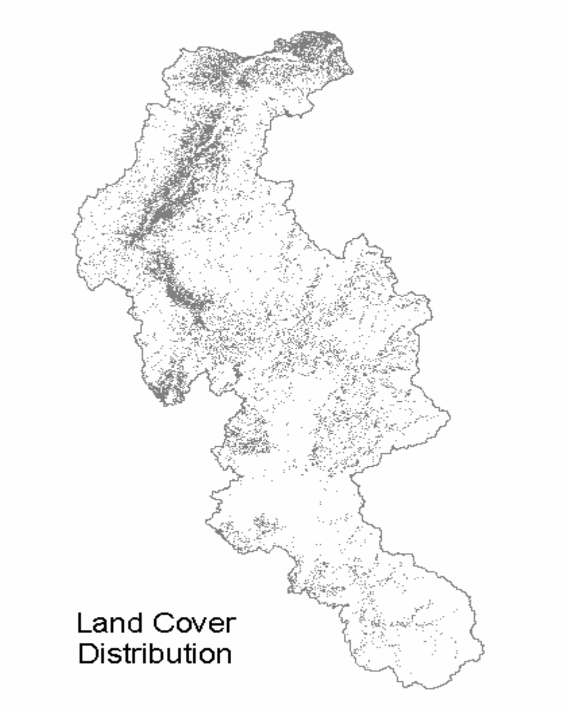
2020 - Agricultural Lands, Irrigated



This cover type consists of irrigated agricultural lands used primarily for crop or hay production. Principle crops include winter wheat, barley, grass hay and alfalfa hay. Areas of irrigated pasture are included. Some areas that were not actively irrigated at the time of imagery acquisition are included in cover type Low/Moderate Cover Grasslands (3150). Confusion may exist with areas of Mixed Deciduous Shrubs (3200) at higher elevations.

Total Area: 37,832 acres
Percent of Area: 1.5

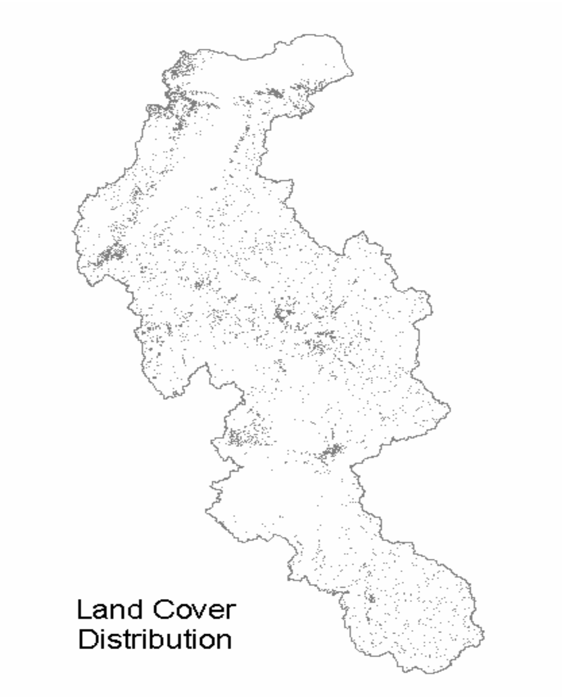
3150 - Low / Moderate Cover Grasslands



This cover type consists of low to moderate cover grasslands with total grass cover from 25 to 60% and shrub cover generally less than 15%. This type includes areas of native rangeland, non-irrigated pasture and miscellaneous disturbed sites, including idle cropland and burn areas. Representative species include bluebunch wheatgrass, needle and thread, western wheatgrass, crested wheatgrass, Idaho fescue and sandberg bluegrass. Some areas having less than 15% Rocky Mountain juniper, limber pine and Douglas fir cover are included.

Total Area: 348,704 acres
Percent of Area: 14.09

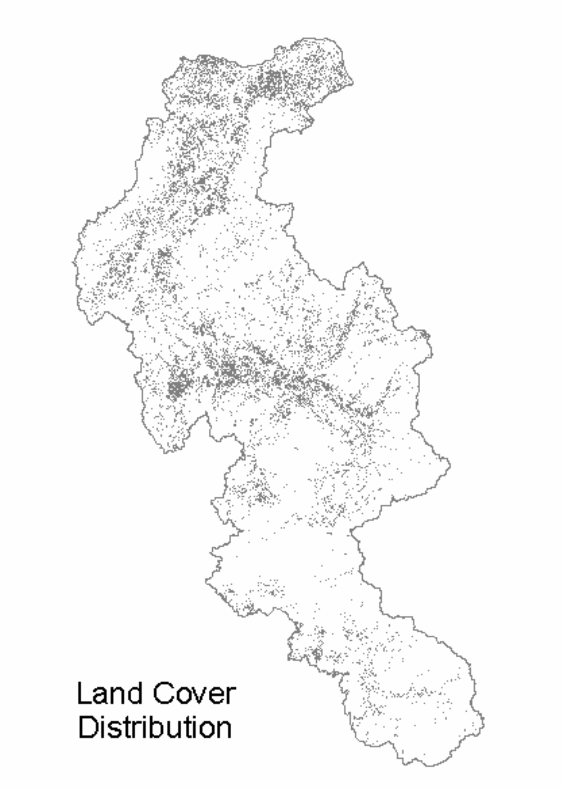
3200 - Mixed Deciduous Shrub



This cover type consists of mixed deciduous shrubs having canopy cover of about 30 to 90%. It occurs at elevations generally above 5500' in transitional zones from grassland to forestland. This type is associated with Mixed Deciduous / Coniferous Forest (4300). It may also be confused with small areas of non-irrigated hayland at higher elevations. Primary species include, but are not limited to, common snowberry, ninebark, Douglas hawthorn, western serviceberry and chokecherry.

Total Area: 134,854 acres
Percent of Area: 5.4

3350 - Sagebrush (> 20% canopy)



This cover type consists of shrubland dominated by sagebrush (Artemisia spp) having about 20 to 50% canopy. Dominant species include mountain big sagebrush, basin big sagebrush and silver sagebrush. It occurs on river terraces, alluvial fans, uplands and mountainsides. While evenly distributed over the project area, one of the largest concentrations is located in the northern areas of Yellowstone National Park on lands adjacent to the Yellowstone, Gardner and Lamar Rivers. These areas are associated with Low / Cover Grasslands (3150), when sagebrush canopy cover is less than about 15%.

Total Area: 292,620 acres
Percent of Area: 11.83

4000 - Low Density Coniferous Forest

This cover type consists of open forest land having canopy cover of about 20% to 40%. These areas are characterized by Douglas fir, Rocky Mountain juniper and limber pine with intermixed areas of grass and/or deciduous shrub cover. This type generally occupy drier sites (south and west aspects) on hillsides and mountain slopes. This cover type includes adjacent areas of Low / Moderate Cover Grasslands (3150) and/or Mixed Deciduous Shrubs (3200).

Total Area: 196,646 acres
Percent of Area: 7.95

4200 - High Density Coniferous Forest

This cover type consists of forest land having canopy cover from about 40% to over 90%. These areas generally occupy north and east aspects on mountainsides, all aspects above about 7500' and in cool mountain drainageways. Douglas fir and lodgepole pine represent the dominant forest species within this cover type. Areas of subalpine fir, Englemann spruce and whitebark pine are included.

Total Area: 905,433 acres
Percent of Area: 36.60

4300 - Mixed Deciduous and Coniferous Forest

This cover type consists of a mixture of deciduous and coniferous forest. Aspen is the dominant deciduous component and Douglas fir is the dominant coniferous component. This type occupies moist sites throughout the project area in drainage ways and depressions and on mountainsides having a north or east aspect. Tree canopy cover is about 30 to 80% Areas of Mixed Deciduous Shrub (4300) and High Density Forest (4200) are associated with this cover type.

Total Area: 76,385 acres
Percent of Area: 3.09

4400 - Standing Burnt Forest - Regeneration

This cover type consists of regenerating forest land primarily associated with recent forest fires. It is characterized by very dense stands of lodgepole pine saplings among standing and down snags and occurs nearly exclusively in and adjacent to Yellowstone National Park. Adjacent areas of Low / Moderate cover Grasslands (3150) and Mixed Deciduous Shrub (4300) are found in areas lacking regeneration of lodgepole pine.

Total Area: 98,708 acres
Percent of Area: 3.99

6120 - Broadleaf Riparian

This cover type consists of broadleaf deciduous trees, primarily plains cottonwood and willow (spp) along the lower portions of the Yellowstone River corridor including Mission Creek. This type represents the commonly used term "Cottonwood Galleries" on primary floodplains. It is associated with Agricultural Lands - Irrigated (2020).

Total Area: 2,256 acres
Percent of Area: 0.09

7300 - Rock, Rock Outcrop

This cover type consists of bare rock land and rock outcrop. While scattered areas of this type may occur throughout the project area, most areas are restricted to elevations greater than 9000' (alpine) and is associated with the Alpine Meadows (8100) and Snowfields (9100) cover types.

Total Area: 85,911 acres
Percent of Area: 3.47

7500 - Riverwash / Gravel Pits, Disturbed

This cover type consists of areas of bare river bed gravel exposed along the Yellowstone and Lamar rivers, open gravel pits and miscellaneous disturbed areas (mines) and alpine talus. Included are water areas associated with the Yellowstone River channel not included in Water (lakes and ponds) 5000, due to imaging and/or classification anomalies.

Total Area: 27,527 acres
Percent of Area: 1.11

8100 - Alpine Meadows

This cover type consists of open alpine areas above treeline on mountain tops at elevations above 9200'. Vegetation includes low growing forbs, sedges and cushion plants. This cover type is associated with Snowfields (9100) and Rock, Rock outcrop (7300).

Total Area: 89,640 acres
Percent of Area: 3.62

5000 - Water / Lakes, Ponds

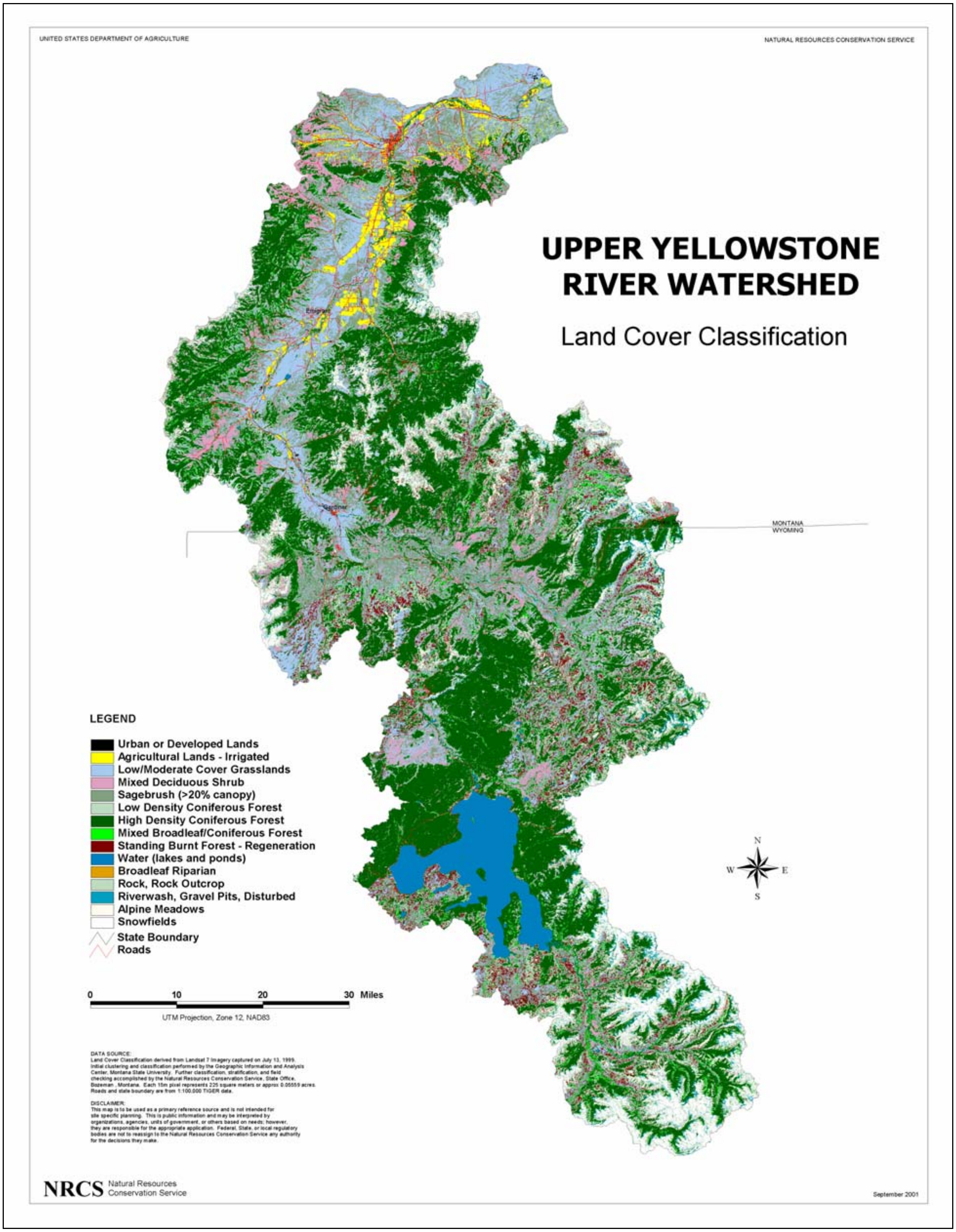
This cover type consists of open water bodies (lakes and ponds), the largest of which is Yellowstone Lake in Yellowstone National Park.

Total Area: 94,857 acres
Percent of Area: 3.83

9100 - Snowfields

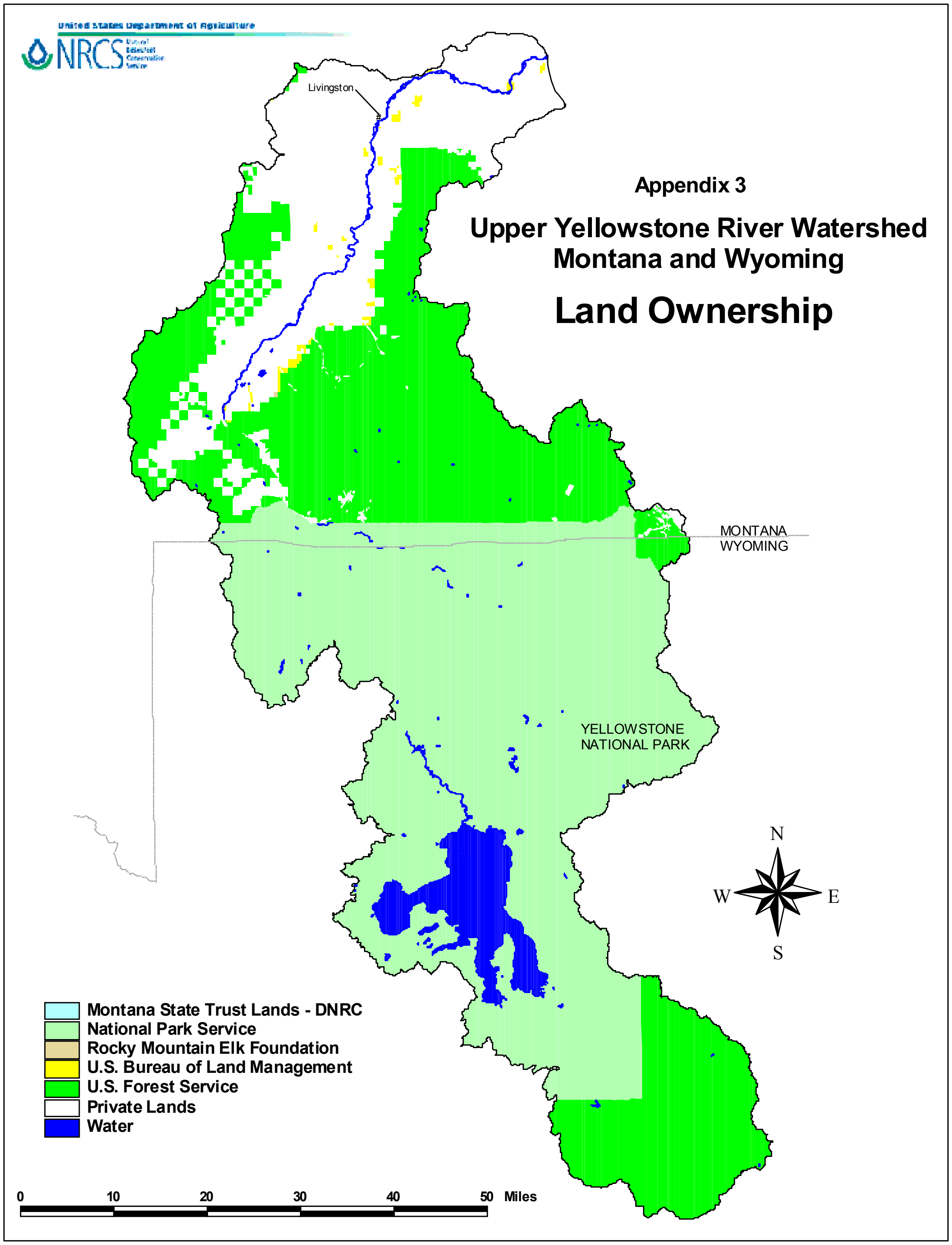
This cover type consists of areas of seasonal or permanent snow. This cover type is associated with Alpine Meadows (8100) at high elevations. This type may be confused with other highly reflective areas throughout the project area, such as rock outcrop.

Total Area: 80,326 acres
Percent of Area: 3.25



DATA SOURCE:
Land Cover Classification derived from Landsat 7 Imagery captured on July 13, 1999. Initial clustering and classification performed by the Geographic Information and Analysis Center, Montana State University. Further classification, stratification, and field checking accomplished by the Natural Resources Conservation Service, State Office, Bozeman, Montana. Each 15m pixel represents 225 square meters or approx 0.05559 acres. Roads and state boundary are from 1:100,000 TIGER data.

DISCLAIMER:
This map is to be used as a primary reference source and is not intended for site specific planning. This is public information and may be interpreted by organizations, agencies, units of government, or others based on needs; however, they are responsible for the appropriate application. Federal, State, or local regulatory bodies are not to reassign to the Natural Resources Conservation Service any authority for the decisions they make.



Appendix 3

Upper Yellowstone River Watershed
Montana and Wyoming

Land Ownership