

Supplemental Material

Analyzing the Effects of Land Cover Change on the Water Balance of Different Forested Ecosystems in the USA

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Pacific Northwest Cascades (Washington)

The high-disturbance (HD) watershed (Klickitat River) contains one of the longest undammed rivers in the Pacific Northwest that originates on Mt. Adams in the high elevations of the Yakima Nation Reservation and flows generally south to its confluence with the Columbia River in the Columbia River Gorge [1,2]. The river begins flowing through a broad canyon, then the canyon constricts into a tight, rock-walled gorge with rocky channel. This watershed consists of a basalt plateau several thousand meters thick that has gentle topographic relief but has been incised by deep (~200-500 m) steep-walled canyons carved by the watershed's stream/river network [1,3]. Soils in the watershed are Andisols, Alfisols, Aridisols, and Mollisols [1]. This forest is composed of 58% fir/spruce/mountain hemlock (*Abies* spp., *Picea* spp., and *Tsuga* spp., respectively), 27% Douglas-fir (*Pseudotsuga menziesii*), 12% lodgepole pine (*Pinus contorta*), and 3% ponderosa pine (*Pinus ponderosa*) [4]. Located within the boundaries of land belonging to the Yakima Nation Reservation, this watershed spans roughly 75% in the Eastern Cascades Slopes and Foothills and roughly 25% in the Cascades Level III ecoregions.

The low-disturbance (LD) watershed (American River) is in the Okanogan-Wenatchee National Forest, dividing the Norse Peak Wilderness to the north from the William O' Douglas Wilderness to the south. The LD watershed originates in high elevations of the eastern Cascade Range as a tributary of the Bumping River, which eventually connects with the Naches River and ultimately empties into the Yakima River. This watershed spans the same Level III ecoregion transition, but with roughly 25% in the Eastern Cascades Slopes and Foothills ecoregion and roughly 75% in the Cascades ecoregion. The Eastern Cascades and Foothills ecoregion is in the rainshadow of the Cascade Range and, therefore, experiences a continental climate regime with greater temperature extremes and a wider range of precipitation (500-3000 mm). The forest in this ecoregion is primarily ponderosa pine (*Pinus ponderosa*) forest with some lodgepole pine (*Pinus contorta*). The Cascades ecoregion experiences a moist,

temperate climate that supports an extensive and highly productive coniferous forest of primarily (70%) fir/spruce/mountain hemlock (*Abies* spp., *Picea* spp., and *Tsuga mertensiana*, respectively), and the remaining (30%) is represented by the Douglas-fir (*Pseudotsuga menziesii*) group type [4]. Andisols and Inceptisols are common in the LD watershed. Soil textures at high elevations in the LD watershed have textures of ashy sandy loam, gravelly ashy sandy loam, ashy loamy sand, gravelly ashy loamy sand or medial sandy loam, while soils on the lower elevation hills and terraces have less ash with textures of loams, silt loams, cobbly loams, stony loams, and stony silt loams [3,1].

Four-corners Region (Colorado)

Both Colorado watersheds primarily have tree cover at high elevations with a transition to grass/shrub in lower elevations of the watershed. The HD watershed (Mancos River) is in a semiarid climate transition zone where roughly 80% of the watershed is in the Colorado Plateaus Level III ecoregion and roughly 20% of the watershed is in the Southern Rockies Level III ecoregion. The HD watershed's tree cover is 71% pinyon-juniper woodland (*Pinus* spp., and *Juniperus* spp.), 9% oak (*Quercus* spp.), 8% aspen and birch (*Populus tremuloides* and *Betula* spp., respectively), 7% ponderosa pine (*Pinus ponderosa*), and 4% fir/spruce/mountain hemlock (*Abies* spp., *Picea* spp., and *Tsuga mertensiana*, respectively) [4]. All other forest type groups represent less than 1% of the watershed. Originating on the western flanks of the La Plata Mountains, four main tributaries (East Mancos, Middle Mancos, West Mancos and Chicken Creek) combine to form the Mancos River just upstream of the city of Mancos from where it flows to the southwest. At higher elevations, the upper watershed that includes the Mancos Valley and surrounding mountains, is noted to also contain a mixture of ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii*), aspen (*Populus tremuloides*), and Endelmann spruce (*Picea engelmannii*) forests [5]. Three reservoirs are in the watershed (Jackson Gulch Reservoir, Bauer Reservoir, and Weber Reservoir) that collect snowmelt and are used for redistribution to agricultural (irrigation) and municipal purposes (recreation and municipal water supply). Hydroelectric power generation began on Jackson Gulch Reservoir in 1995 but is only in operation during the irrigation (late spring – fall) season. Extensive irrigated cropland around the city of Mancos divides the upper and middle portions of the watershed. In the arid lower watershed, numerous small side canyons and ephemeral washes enter the river as it flows along eastern edge of Mesa Verde National Park and the Ute Mountain Ute Reservation through the Mancos Canyon. The middle and lower elevation region of this watershed begins in Mancos Canyon at the confluence of Weber Creek on the Ute Mountain Ute Indian Reservation and is characterized by pinyon-juniper woodlands (*Pinus* spp., and *Juniperus* spp.) [5]. The Mancos River then flows through relatively flat desert country of the Navajo Nation connecting with Navajo Wash before it eventually empties into the San Juan River in northwest New Mexico. However, the study site watershed is upstream from the streamgage near where the river meets State Highway 491, slightly northeast of the confluence with Navajo Wash. Sparsely covered grass/shrub (*Bouteloua gracilis*, *Atemesia tridentata*, *Cercocarpus montanus*), and desert scrub/saltbrush fans and flats are prevalent in the desert lowland portion of the watershed [5]. This watershed contains a variety of ashy loam, sandy loam, and cobbly loam, and sandy soil textures [7].

The LD watershed (Cochetopa Creek) is within the Gunnison National Forest. The waterway originates on San Luis Peak in the La Garita Mountains, flowing north as it runs through the Cochetopa caldera in the San Juan volcanic field through Cochetopa Canyon and opening into a vast open sagebrush and grass valley en route to connection with Tomichi Creek near Parlin, Colorado, and eventually empties into the Gunnison River. This study site watershed extends south from the streamgage that is just north of Homestead Gulch and upstream from the confluence with Tomichi Creek. This watershed is characterized by the Southern Rockies Level III ecoregion, which has a temperate semiarid steppe climate regime. A series of two high-elevation reservoirs are in the upper reach of the watershed southwest of Cochetopa Dome. Soils here are primarily stony, sandy, gravelly loam that are well to somewhat excessively drained, and contain considerable amounts of coarse fragments [8]. Vegetation of the Southern Rockies ecoregion is characterized by elevation with a range of high elevation alpine zones with low shrubs; dense subalpine forests of spruce-fir (*Picea* spp. and *Abies* spp.), ponderosa pine (*Pinus ponderosa*), lodgepole pine (*Pinus contorta*), aspen (*Populus*

tremuloides), juniper (*Juniperus* spp.), and oak (*Quercus* spp.); grassland (*Bouteloua gracilis*), and shrubland (*Artemisia tridentata*), while pinyon-juniper woodlands (*Pinus* spp., and *Juniperus* spp.) comprise lower elevations from about 1828–2438 m [9]. This LD watershed is composed of 61% fir/spruce/mountain hemlock (*Abies* spp., *Picea* spp., and *Tsuga mertensiana*, respectively), 26% Douglas-fir (*Pseudotsuga menziesii*), 10% aspen and birch (*Populus tremuloides* and *Betula* spp., respectively), and 3% lodgepole pine (*Pinus contorta*) [4].

Southern Appalachia (Alabama)

The HD watershed (Clear Creek) is immediately south of the LD watershed bordering the Bankhead National Forest, while the LD watershed (Sipsey Fork) is in the Sipsey Wilderness in Bankhead National Forest northwest of Lewis Smith Lake. Both watersheds are tributaries of the Black Warrior River. The Southwestern Appalachian Level III ecoregion is characterized by low mountains with steep slopes that sustain dense oak (*Quercus* spp.) and shortleaf pine (*Pinus echinata*) forests with some agricultural practices on lower slopes and valley floors. Soils tend to be shaley silt loams, sandy loam, clay loam, silty clay loam or silty clay textures that have developed in sandstone and shale [10,11]. Although historically more heavily used for corn and cotton production, the HD watershed today has a large portion covered with stands of second-growth timber [12]. According to Sayler et al. [13], the most common land cover change between 1973 and 2000 in the Alabama watersheds was tree cover conversions related to forestry/timber harvest including both cutting (tree cover to grass/shrub) and regeneration (grass/shrub to tree cover). Here, the HD watershed is composed of 65% an oak and hickory (*Quercus* spp. and *Carya* spp., respectively) group, 30% loblolly pine and shortleaf pine (*Pinus taeda* and *Pinus echinata*, respectively) group, 5% oak and pine group (*Quercus* spp. and *Pinus* spp., respectively) [4]. All other groups represent less than 1% of the watershed. The LD watershed is composed of 84% an oak and hickory (*Quercus* spp. and *Carya* spp., respectively) group, 13% loblolly pine and shortleaf pine (*Pinus taeda* and *Pinus echinata*, respectively) group, 3% oak and pine (*Quercus* spp. and *Pinus* spp., respectively) group [4]. All other groups represent less than 1% of the watershed.

Midwestern Northwoods (Wisconsin/Michigan)

This region is characterized by mixed broadleaf-coniferous forests that are commonly utilized for commercial timber production including species like jack pine (*Pinus banksiana*), balsam fir (*Abies balsamea*), black spruce (*Picea mariana*), and white spruce (*Picea glauca*), quaking aspen (*Populus tremuloides*), bigtooth aspen (*Populus grandidentata*), sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), yellow birch (*Betula alleghaniensis*), paper birch (*Betula papyrifera*), American basswood (*Tilia americana*), and oak (*Quercus* spp.) [14]. Wetlands and riparian land cover containing variety of sedges (*Carex* spp.) and sphagnum (*Sphagnum* spp.) [14] is much more abundant in this ecoregion than in the other forested sites in this study. At least 71% of land cover change between 1973 and 2000 is associated with tree cover conversions related to timber harvest (tree cover to grass/shrub) and regeneration (grass/shrub to tree cover) [15].

The St. Croix River in the HD watershed is a tributary of the Mississippi River that originates approximately 32 km south of Lake Superior in the northwestern corner of Wisconsin. This waterway flows southwest where it then connects with the Namekagon River, Kettle River, Snake River, Sunrise River, and Kinnickinnic River from the east. The St. Croix River then subsequently becomes much wider and carries significantly more volume until it empties into the Mississippi River southeast of St. Paul, Minnesota. Defined by streamgage location, this watershed's pourpoint is on the St. Croix River just below the confluence with the Namekagon River. Thus, we have expanded the watershed in this study to cover the upper portion of the St. Croix River and Namekagon River to account for streamflow contributions by both waterways. The Namekagon river is characterized as generally shallow with a rocky bottom until its confluence with the St. Croix River where the bottom substrate becomes predominantly sandy.

The expansive tree cover in this HD watershed is mostly deciduous and coniferous forest (31% aspen and birch group (*Populus tremuloides* and *Betula* spp., respectively), 24% white pine, red pine, and jack pine group (*Pinus strobus*, *Pinus resinosa*, and *Pinus banksiana* Lamb., respectively), 23% maple, beech, and birch group (*Acer* spp., *Fagus* spp., and *Betula* spp., respectively), 16% oak and hickory group (*Quercus* spp. and *Carya* spp., respectively), 4% spruce and fir (*Picea* spp. and *Abies* spp., respectively) group, and 3% elm, ash, and cottonwood group (*Ulmus* spp., *Fraxinus* spp., and *Populus deltoides*, respectively) [4]) with scattered wetlands and grazing land [16]. Wetlands range from small, closed depressions to expansive swamps, bogs, and fens that have very poorly drained soils that formed in acid peat or non-acid muck [16]. Much of the HD watershed, associated with St. Croix River drainage that underlies a substantial portion of the area covered with white pine, red pine, and jack pine, is covered in sand-textured soils with organic-rich loamy soils in low-lying wetland areas [17]. Although this study watershed is upstream from the St. Croix Falls Dam, approximately 170 dams are in place on over 70 rivers and streams within the watershed of the St. Croix River, as well as two hydroelectric dams on the Namekagon River (Trego Dam and Hayward Dam) in the HD watershed [17]. More than 800 lakes that are 25 acres (0.1 km²) or larger are in this watershed, which also excludes countless lakes that are smaller than that threshold [17]. The Namekagon River portion of the HD watershed is covered in loamy, moderately well drained soils over hard bedrock, and gently sloping, well drained, loamy soils on outwash plains [16].

The LD watershed (Ontonagon River) is a river system with four upstream branches (West, South, Middle, and East Branches) on the western Upper Peninsula of Michigan that connect to the main waterway flowing north and emptying into Lake Superior. The LD watershed lies within the Ottawa National Forest (26% aspen and birch group (*Populus tremuloides* and *Betula* spp., respectively), 3% white pine, red pine, and jack pine group (*Pinus strobus*, *Pinus resinosa*, and *Pinus banksiana* Lamb., respectively), 62% maple, beech, and birch group (*Acer* spp., *Fagus* spp., and *Betula* spp., respectively), 8% spruce and fir group (*Picea* spp. and *Abies* spp., respectively) [4]) and has minimal timber harvest today compared to the HD watershed. There are 17 registered dams in the Ontonagon River watershed, five of which are hydroelectric [18]. Bond Falls Dam and Bond Falls Control Dam store water and divert flow from the Middle Branch in the South Branch via a canal, which strongly affects seasonal flow patterns. The Cisco and Bergland Dams are used to ensure water supply for Victoria Dam's hydroelectric facility [19]. The LD watershed has impervious clay soils in the middle and downstream sections of the watershed [20].

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