COLORADO EMAP

Ecological Monitoring and Assessment Report

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EMAP

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Acronyms and Abbreviations

CDNR	Colorado Division of Natural Resources
CDOW	Colorado Division of Wildlife
CDPHE	Colorado Department of Public Health and Environment
CL	Chloride
CWN	Colorado Watershed Network
DE	Discrimination Efficiency
EDAS	Ecological Data Application System
EMAP	Ecological Monitoring and Assessment Program
GDP	Gross Domestic Product
GNIS	Geographic Names Information System
IBI	Index of Biotic Integrity
MMI	Multimetric Index
N	Nitrogen
NAWQA	National Water Quality Assessment Program
NCDC	National Climatic Data Center
NTU	Nephelometric Turbidity Units
O/E	Observed Taxa/Expected Taxa
ORD	Office of Research and Development (USEPA)
OTU	Operational Taxanomic Unit
P	Phosphorous
REMAP	Regional Ecological Monitoring and Assessment Program
RIVPACS	River Invertebrate Prediction and Classification System
RT_Final	USEPA *a priori* site designation
RT_Mod	Colorado *a priori* site designation
SO4	Sulfate
STAR	Science to Achieve Results Program
STORET	Storage and Retrieval database (USEPA)
SWSI	Surface Water Supply Index (Colorado Div. of Water Resources/USDA)
ueq/L	Microequivalents per Liter
ug/L	Micrograms per Litre
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
USU	Utah State University
WEMAP	Western Ecological Monitoring and Assessment Program
WRCC	Western Regional Climate Center

I. Study area

Colorado

The study area for this chapter is the state of Colorado, which covers 104,432 square miles and is home to approximately 4,722,460 people (U.S. Census Bureau 2005). The state serves as the headwaters of four major rivers including the Platte, Arkansas, Colorado, and Rio Grande. Within its boundaries are six Level III Ecoregions (Omernik 1987), which for the purpose of this study have been merged to create three bioregions: Plains (Western High Plains, Southwestern Tablelands Ecoregions), Mountains (Southern Rockies Ecoregion), and Xeric (Wyoming Basin, Colorado Plateau, and Arizona/ New Mexico Plateau Ecoregions).

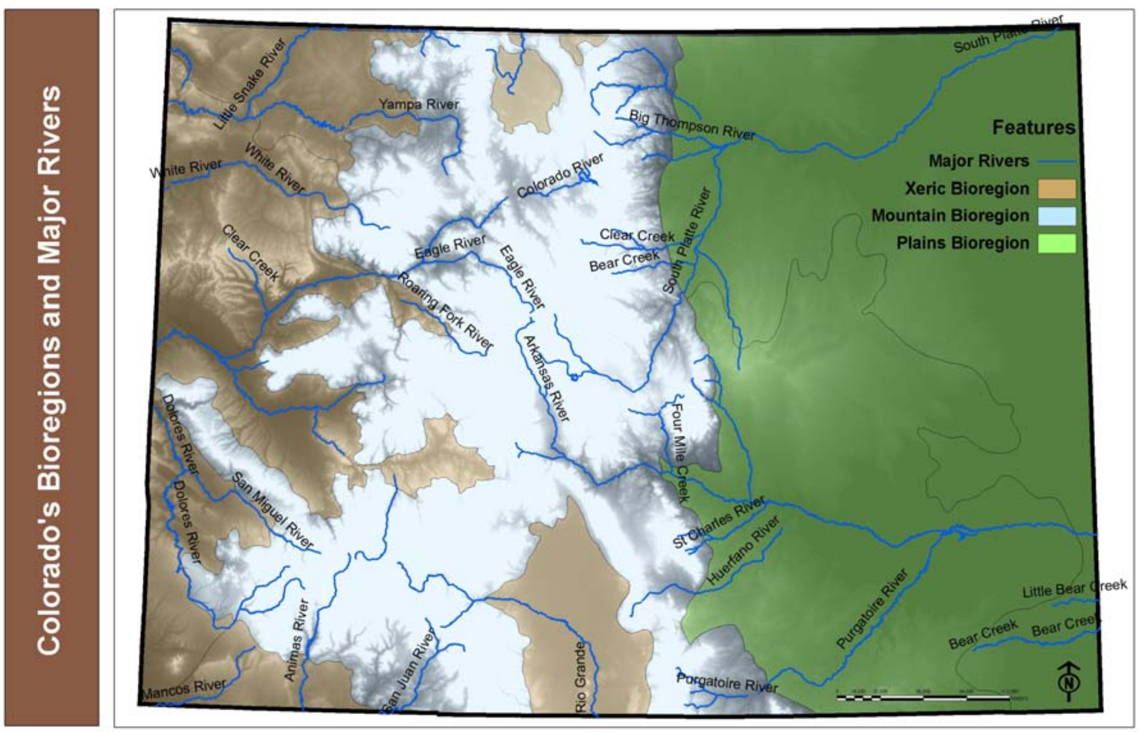


Figure 1—Colorado Bioregions and Major Rivers

Bioregions

The Plains Bioregion in eastern Colorado is the largest bioregion in the state, covering 43,776 square miles (42%). The elevations of the Plains is the lowest in the state and includes the lowest point, 3,350 feet above sea level (WRCC), where the Arkansas River crosses the border into Kansas. The Plains bioregion is characterized by prairie grasslands, tablelands, and croplands, which are broken by occasional hills, bluffs, and small canyons. With a growing season of 140-160 days, numerous crops such as wheat, corn, alfalfa, spring grains, and sugar beets can be easily grown. Although the majority of the Plains bioregion is agricultural land, eighty-six percent of the state's population resides in this region. Eighty-three percent is concentrated along the Front Range of the Rocky Mountains in highly developed residential and commercial tracts.

Table 1—Colorado Land Area

Region	Area (mi^2)
Colorado	104,092.71
Plains	43,776.05
Mountains	37,424.48
Xeric	22,892.18

Although the Plains bioregion accounts for the largest land area in the state, the Mountains bioregion accounts for a nearly equal portion at 37,424 square miles (36%). The mountains bioregion has its boundaries at the eastern and western edges of the Rocky Mountains, which are oriented vertically across the state, just west of center. The mountains exhibit features such as alpine cirques and tarns, glaciers/glacial moraines, broad U-shaped valleys/parks, and glacial outwash plains at lower elevations. This bioregion boasts the state's highest elevations, with fifty-four mountains exceeding 14,000 feet above sea level, greatly contributing to a state elevation average of 6,800 feet, the highest in the nation. Landcover in the Mountains bioregion consists primarily of pinyon-juniper, spruce fir, ponderosa pine, aspen, lodgepole pine, and Douglas fir forests, with localized areas of open parks and alpine tundra above treeline (10,500-12,000 ft). The majority of the state's 35,300 square miles of forest (CDNR, 2002) fall within this bioregion.

The Xeric Bioregion covers the remaining 22,892 square miles of the state along the western border. It is characterized by high mesas, buttes, and canyonlands that are typical of the Colorado Plateau, the dominant feature of the bioregion. The elevation ranges from approximately 4,300 to 12,100 feet above sea level. Landcover in the bioregion is quite variable and includes large portions of forests, grasslands, irrigated croplands, rangelands, and shrublands. Fruit production is also possible in the valleys of west-central Colorado as warm, moist air from the Pacific Ocean provides the specific climate that is suitable for these types of crops. The Xeric also contains the San Luis Valley, which, with the addition of the state's first agricultural ditch in 1852, became a productive area of irrigated cropland (Colorado Data Book 2005).

Geology

Formation of Colorado's present geological features began in the Paleozoic Era as advancing and retreating seas resulted in deep sedimentary layers of marine deposits over existing Precambrian rocks, producing the abundant coal fields found today. The Colorado Orogeny (1.7 bya) formed the region's first mountains, the Uncompahgria and Frontrangia ranges, whose near complete erosion resulted in extensive sediment deposition on floodplains and deltas. Colorado's second major mountain building event, the Laramide Orogeny (72 mya), was a polyphase orogeny that created the current mountain ranges of Colorado as the Late Cretaceous sea receded from the Western Interior. (Tweto 1980)

Regional heterogeneous geologic composition varied the extent of heating as the uplift progressed. The resulting structural sags formed North, Middle, and South Park while periods of volcanic activity in the southwest portion of the state produced what is known as the San Juan range (Tweto 1980). In the eastern portion of the state, basins subsided concurrently with the uplift of the adjoining mountains. Veins of gold, silver, copper, lead, zinc, and other ores had emerged as rising mineral-laden fluids cooled and produced what is known as the "Mineral" or "Mining belt" of Colorado. This highly mineralized area runs northeast to southwest and is generally located between Boulder County and the San Juan Mountains (Miller 2003, Elias 2002). As the Pacific plate's rate of subduction decreased, its incline increased, resulting in activity closer to the fault line and west of the mountains in Colorado. Consequently, the thin sandstone surface layer of western Colorado rose nearly horizontally and became the top of the Colorado Plateau. Following the Plateau's development was the formation of one of the last major geologic features of Colorado, the San Luis Valley. Tensile stress widened the Rio Grande Rift where subsequent block-faulting resulted in a series of grabens forming the lowland area some 26 million years ago.

Stream gradients increased significantly due to mountain uplift and basin subsidence, leading to increased erosional forces on the newly created ranges. The power of these forces is particularly apparent in the western portion of the state where the soft shale sides of the sandstone-capped plateaus were eroded to create a dramatic topographic relief consisting of high mesas and buttes separated by steep ravines and gorges. Vast amounts of the resulting erosional sediment created numerous formations, including the Green River oil shale deposits in Lake Unita and the Colorado Piedmont on the eastern Plains (Chronic 1980). The Colorado Piedmont's deposits reach depths of 2,500 feet, covering the High Plains Upper Cretaceous sandstone and underlying Cretaceous Pierre Shale (Tweto 1980). The Miocene-Pliocene uplift followed the period of mountain formation in Colorado raising the state by over 5,000 feet to its present elevation. Following this uplift, glaciation and other erosional forces sculpted the landscape producing the topography seen today.

Climate

The climate in Colorado is classified as a continental highland climate, characterized by highly variable local temperatures, abundant sunlight, and a moderate wind environment. The state's relatively high elevation contributes to a thin atmosphere with increased solar penetration, while low humidity results in increased rates of evapotranspiration. Local climates are shaped largely by their elevation, their orientation to topographic features, and wind movement. The mountains are typically cool year-round, while the plains can have very warm summer days with initially high temperatures abated by afternoon thunderstorms.

The general air movement in Colorado is west to east, supplying the state with moisture-rich air from the Pacific Ocean. Most of the precipitation from this source is delivered to the mountains as the air is forced up and over the mountains by orographic lift, leaving little moisture to carry over to the eastern plains. High-elevation ranges normally collect around 400 inches of snowfall per year, but can receive in excess of 500 inches annually (National Climatic Data Center 2006). The accumulated mountain snowpack generally melts during the spring and summer months, becoming the primary source of Colorado's water supply.

While the mountains typically receive the greatest amounts of precipitation during the winter months, nearly 80 percent of annual moisture on the plains falls within the growing season from April to September (WRCC). The source of precipitation-bearing storms on the plains is generally warm, humid air from the Gulf of Mexico that is forced aloft due to contact with cold polar air. The warm, moist air cools as it rises, resulting in precipitation and sometimes severe weather conditions. In contrast, areas near the Front Range of the Rocky Mountains are typically dry and cool with winter temperatures that can occasionally increase rapidly by 25 to 35 ^{o}F due to warm westerly downslope winds known locally as Chinook winds. Annual climate statistics can be seen in the table below.

Table 2—Colorado Annual Climate Summaries

Station	Bioregion	Period of Record	Elevation* (ft)	Temperature** Max (F)	Min(F)	Precipitation** (in)
Berthoud Pass	Mountains	1971-2000	11325	40.1	18.6	38.45
Alamosa	Xeric	1948-2005	7543	59.2	23.6	7.09
Grand Junction	Xeric	1900-2005	4593	65.3	40.2	8.7
Lamar	Plains	1918-2005	3625	69.8	37.8	15.2

**Source:* USGS GNIS database

***Source:* Western Regional Climate Center

Human Presence

History

Human presence in Colorado may date to 15,000 B.C. although conclusive evidence dates Big Game Hunters in this location by at least 9,200 B.C. From approximately 600 A.D. to 1300 A.D., Cliff Dwellers inhabited the Mesa Verde region of southwestern Colorado, becoming the first permanent residents of Colorado. Around 1500, Ute Indians settled in the Southern Rockies making them the oldest continuous residents of Colorado. For the next 300 years, explorers such as Coronado, La Salle, Pike, and Long crossed portions of Colorado in search of gold, transportation routes, and information regarding the new territory. The fur-trapping era began around 1825 and shortly after in 1851, the oldest non-Indian settlement in Colorado was founded at Conejos in the San Luis Valley. This was the site of the first recorded irrigation structure, the "San Luis People's Ditch," which opened in April of 1852. In 1858 and 1859, placer gold deposit discoveries led to rushes of great numbers of miners to the Front Range and central portions of Colorado's mountains, resulting in the establishment of numerous mining camps throughout Colorado.

The 1860's and 1870's led to Colorado's first oil well near Florence (Plains), the construction of railroads connecting Denver to Kansas and Wyoming, the beginning of hard-rock mining, discovery of extensive silver deposits, and Colorado's entry into the Union in 1876. The passage of the Sherman Act in 1890 and its subsequent repeal in 1893 marked the beginning and end of the nation-leading silver boom in Colorado. In 1891 the White River National Forest preserve near Meeker was established, starting a trend for federal land management and ownership in Colorado. This area inspired the Wilderness concept and grew to 2.3 million acres (USFS 2006); encompassing much of the land on which Colorado's ski industry would prosper a half-century later.

By 1900, the state's population had exceeded 500,000 and shortly after, due to private and government-sponsored projects, Colorado would rank highest among the states in irrigated acres, with 2,790,000 acres receiving diverted water. By 1917, Colorado reached maximum mineral production totaling more than $80 million annually, due in large part to gold, coal, and molybdenum extraction. The period between the two world wars saw numerous highway and railroad expansion projects, the state's highest agricultural production, and the population surpass 1 million residents. After 1945, the tourism and skiing industries began to expand rapidly, as did the U.S. military's presence in Colorado. An increasing population meant increasing storage and diversion of water, resulting in added pressure on water resources around the state (**Table-3**). Since the 1970's, the metro areas of the Front Range have expanded rapidly and residential and commercial developments continue to grow. As domestic and commercial demand increases with the rising population, water rights and water quality protection will be issues of escalating concern and consequence.

Table 3—Diversions and Irrigated Land

Irrigated Acres by Basin 2004		
Basin	Estimated irrigated acres	Average diversions (acre feet)
South Platte	1,003,500	2,545,500
Rio Grande	632,700	1,619,000
Colorado	237,700	1,986,900
Arkansas	538,100	1,769,900
Gunnison	263,500	1,736,100
Dolores/San Miguel	255,000	902,200
Yampa/White/Green	118,400	652,000
North Platte	115,700	396,900
TOTAL	3,164,600	11,605,000
Source: SWSI and Colorado's Decision Support Systems and Basin		

Population

Colorado's population totaled 4,722,460 in 2005, an increase of 9 percent from 2000 (Colorado Data Book 2005). The current state growth rate of 1.8 percent per year is nearly double the national average (Colorado Data Book 2005), and promises to place ever-growing

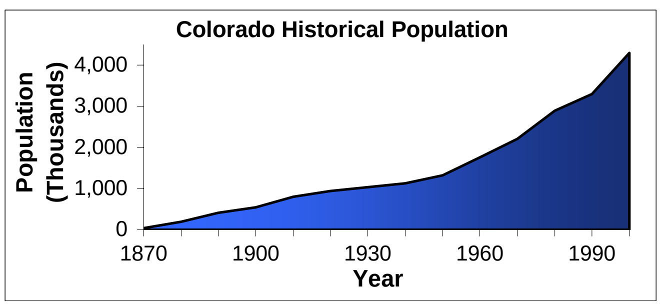


Figure 2—Colorado Historical Population

pressure on the state's water resources and environment. Due to aesthetic surroundings and ample economic and recreational opportunities, Colorado's population growth seems certain to continue in the foreseeable future. While the Front Range continues to rapidly expand, the largest percentage increases will be in the northeastern, Western Slope and Central Mountain areas (**Table-4**).

Table 4—Colorado Population

Region	2000 Estimate	2005 Estimate	2010 Projection	2025 Projection	2035 Projection
COLORADO	4,338,789	4,722,460*	5,209,892	6,787,307	7,798,107
Front Range	3,538,755	3,866,821	4,250,200	5,425,645	6,195,569
• *Denver/Boulder Region*	2,418,292	2,627,314	2,850,055	3,543,553	3,954,344
• *Greeley*	183,560	228,729	264,853	419,741	551,288
• *Ft. Collins*	253,141	271,990	296,519	403,147	473,223
• *Colorado Springs*	541,718	587,689	672,582	849,468	973,313
• *Pueblo*	142,054	151,099	166,191	209,736	243,401
Western Slope	468,368	513,062	585,313	854,379	1,026,411
Eastern Plains	159,071	162,272	175,088	227,735	257,920
Central Mountains	126,179	131,784	147,571	217,820	250,965
San Luis Valley	46,416	48,521	51,720	61,728	67,242

Source: Colorado Data Book August 2006

For more detailed population information, please see State Demography website – www.dola.state.co.us/demog/index.htm

*Colorado Population in 2005--4665177(U.S. Census Bureau Estimate)

Economics

Historically, Colorado has been a productive area for mineral extraction. As national energy demands grow, coal, natural gas, potential oil-shale reserves and alternative energy sources, as well as other mineral reserves, ensure that Colorado's mining and energy industry will continue to thrive. Agriculture's contribution to the state GDP has declined, but it still remains an integral part of the economy, controlling a large portion of private lands. Livestock has overtaken crops as the largest revenue-producing commodity in Colorado agriculture and value-added (organic, free-range) foods show promise as a revenue producing commodity.

Colorado's present economy is grounded in high-tech and skilled sectors that are driven by a highly-educated workforce. The services (i.e., health, financial), governmental, defense and aerospace, telecommunications, bioscience, nanotechnology, and software sectors all possess stable, competitive positions and have positive economic growth outlooks within Colorado (**Table-5**). Numerous socio-economic opportunities encourage residence in Colorado, thus driving a robust real-estate and construction market. Tourism has also been an increasing contributor to the revenue of the state, bringing in $7.1 billion in 2003 (Longwoods International 2003).

Table 5—2005 Colorado GDP and Employment

GDP Millions of Dollars*	Sector	Employment** (Annual Average) Persons	Percent
56,807	Services	860,665	39.3%
44,203	Finance, Insurance, and Real Estate	153,677	7.0%
25,673	Government	345,972	15.8%
18,729	Information	77,438	3.5%
13,975	Manufacturing	150,586	6.9%
13,669	Construction	160,102	7.3%
13,404	Retail Trade	246,048	11.2%
11,489	Wholesale Trade	93,781	4.3%
8,591	Mining	17,007	0.8%
5,650	Transportation and warehousing	61,103	2.8%
2,525	Utilities	7,949	0.4%
1,823	Agriculture, forestry, fishing, and hunting	14,963	0.7%
216,537	**Total**	**2,189,291**	**100.0%**

*Source: U.S. Bureau of Economic Analysis
**Source: Colorado Data Book August 2006

Impacts to Streams

Alterations of the environment by humans and natural processes can lead to degradation of the chemical and physical quality of streams. These changes negatively impact aquatic life can inhibit a stream’s ability to fulfill its designated use(s). In Colorado, human activity has the largest impact on stream quality through point and non-point source discharges, agriculture and silviculture, urban and road runoff, as well as mining and resource extraction. However, natural biogeochemical, climatological, and hydrological processes also contribute to water quality degradation within the state. See **Table–18** in the **Appendix.**

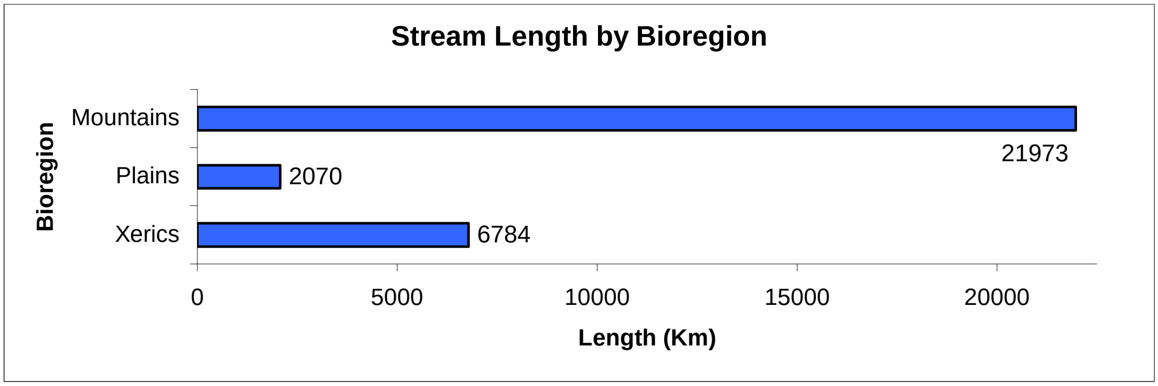
Human degradation of streams affects nearly all physical and chemical characteristics of streams, directly or indirectly. Chemical quality of streams is affected by mining activity, which contributes heavy metals that are toxic to aquatic life. Naturally occurring elements are exposed in mine tailings, and the chemicals used to extract ores leach into streams causing unsafe metals concentrations and low pH conditions. Pesticides, herbicides, nutrients, and pathogens found in agricultural runoff affect metabolic rates within streams as well as aquatic life health. Chemical quality is also affected by municipal wastewater facilities and rural septic systems that contribute ammonia, organic matter, and bacteria to streams. Dam releases change stream chemistry by influencing dissolved oxygen levels, turbidity, temperature, and chemical composition.

Physical characteristics of streams are also heavily influenced by human activity. Flow management, channelization, diversions, and impoundments alter natural hydrographs, bed composition, as well as floodplain inundation extent and duration. Logging activities increase sediment loads in streams by reducing soil stability in the watershed and also increase the volume of runoff. Construction and development of riparian areas also affect bank stability, canopy density, and channel morphology. A list of non-point source human impacts to streams can be seen in the **Appendix (Table 19)**.

Natural processes and climatological events also contribute to the stream degradation. High levels of precipitation from blizzards or thunderstorms wash chemicals, nutrients, and sediment into streams through overland and subsurface runoff. Humic substances from terrestrial sources are also delivered to streams by runoff, affecting the treatability of the water for drinking. Erosional processes can expose naturally occurring geologic element such as Selenium, which is a constituent of local shale. Wildfires cause high sedimentation rates due to vegetative reduction and can potentially increase instream pH. Natural processes such as atmospheric deposition can lead to human driven elements, such as mercury from coal combustion, being found in unsafe levels in the state's surface waters.

II. Colorado EMAP Study

Extent of Resource



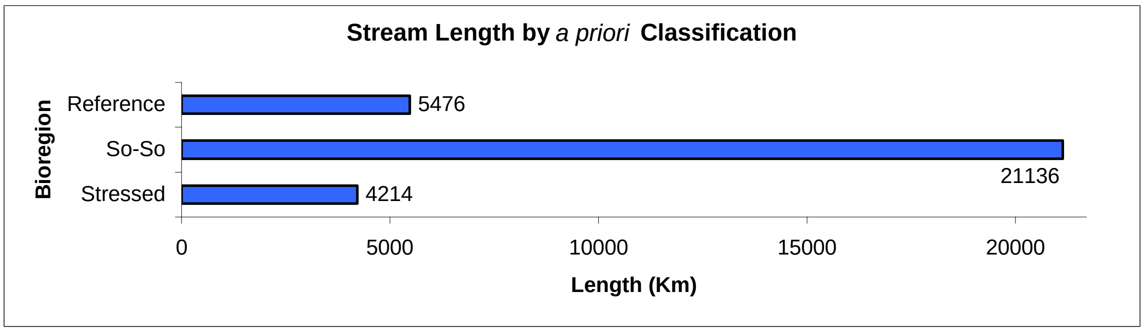


Figure 3—Colorado Stream Length Assessed for EMAP Study (July 2000—August 2004)

Data Sources

Colorado's EDAS database (Ecological Data Application System) contains extensive macroinvertebrate and water chemistry data from CDPHE's (Colorado Department of Public Health and the Environment) monitoring program. However, due to spatial and temporal gaps within data, additional macroinvertebrate and chemistry datasets were compiled to achieve a robust dataset upon which to base the development of the Macroinvertebrate Multimetric Index (MMI) and O/E predictive model for this study. Chemistry data from the national STORET (Storage and Retrieval database, USEPA) database was used to supplement data for sites where macroinvertebrate data was collected, but corresponding chemistry data was unavailable. To eliminate spatial gaps in surveyed sites, additional macroinvertebrate and chemistry data was drawn from high quality datasets where similar sampling methods were employed. These datasets included chemical, biological, and physical habitat data from the USEPA's WEMAP (Western Ecological Monitoring and Assessment Program) and Southern Rockies REMAP (Regional Ecological Monitoring and Assessment Program), USU-STAR (Utah State University, Science to Achieve Results Program), and NAWQA—USGS (National Water Quality Assessment Program—United

States Geological Survey). This merger of data allowed the inclusion of 717 sites statewide from which the Macroinvertebrate MMI and O/E model would be developed.

To compare macroinvertebrate data from datasets of varying taxonomic resolution, an operational taxonomic unit (OTU) system was utilized. This system assigns a standardized numeric code to each taxonomic level associated with specific macroinvertebrates. By examining these designations, the highest taxonomic level that is exhibited by all sites can then be selected, allowing direct comparison of all sites from all datasets compiled for this study. In order to be compatible with CDPHE data, non-CDPHE samples were also sub-sampled to a 300-organism count. While some taxonomic resolution was sacrificed, mainly within the CDPHE data, the use of the combined dataset led to a more accurate and powerful tool for index and model development.

The data utilized in the Fish Index of Biotic Integrity (IBI) development was collected at 91 sites throughout Colorado during the WEMAP project. Periphyton MMI development data was also from the WEMAP project and used information from 69 reference sites in Colorado, Utah, and Wyoming.

Reference Site Determination

In this study, an *a priori* approach (See **Table 20** in the **Appendix**) was used in site classification and establishment of reference condition. These sites represent natural (reference) and impacted (stressed) conditions in each bioregion and were designated based on physical and chemical conditions. *A priori* sites are the foundation for the development and calibration of the Fish IBI, the Macroinvertebrate and Periphyton MMIs, and the Macroinvertebrate multivariate predictive model (O/E model). Metrics to be included in the IBI and MMIs were chosen based on the level of discrimination efficiency they exhibit between reference and stressed sites. In the O/E model, reference sites were used to determine the number of expected taxa at each site, which is then used as part of a ratio to generate a unit-less score associated with taxa loss. Reference sites were then used to generate thresholds for scores from the Macroinvertebrate and Periphyton MMIs, the Macroinvertebrate O/E model, as well as the fish IBIs (see **Threshold Determination**).

A priori reference site designation for the Macroinvertebrate MMI and O/E model was conducted by their respective developers, Tetra Tech, Inc. and Chuck Hawkins of Utah State University. These researchers used standards in Colorado's Basic Water Quality Standards; screening criteria from USEPA's Office of Research and Development (ORD); water quality standards and EMAP selection criteria from Wyoming and Montana; as well as best professional judgment to establish a set of selection criteria for designating *a priori* classification. The subsequent criteria utilized varying levels of parameter stringency for each bioregion to allow for comparisons between sites in adjacent bioregions where natural conditions can be dramatically different. The criteria were then applied to water chemistry, land cover/land use, and physical habitat data from the Plains, Mountains, and Xeric bioregions to produce the final *a priori* classifications for the macroinvertebrate tools.

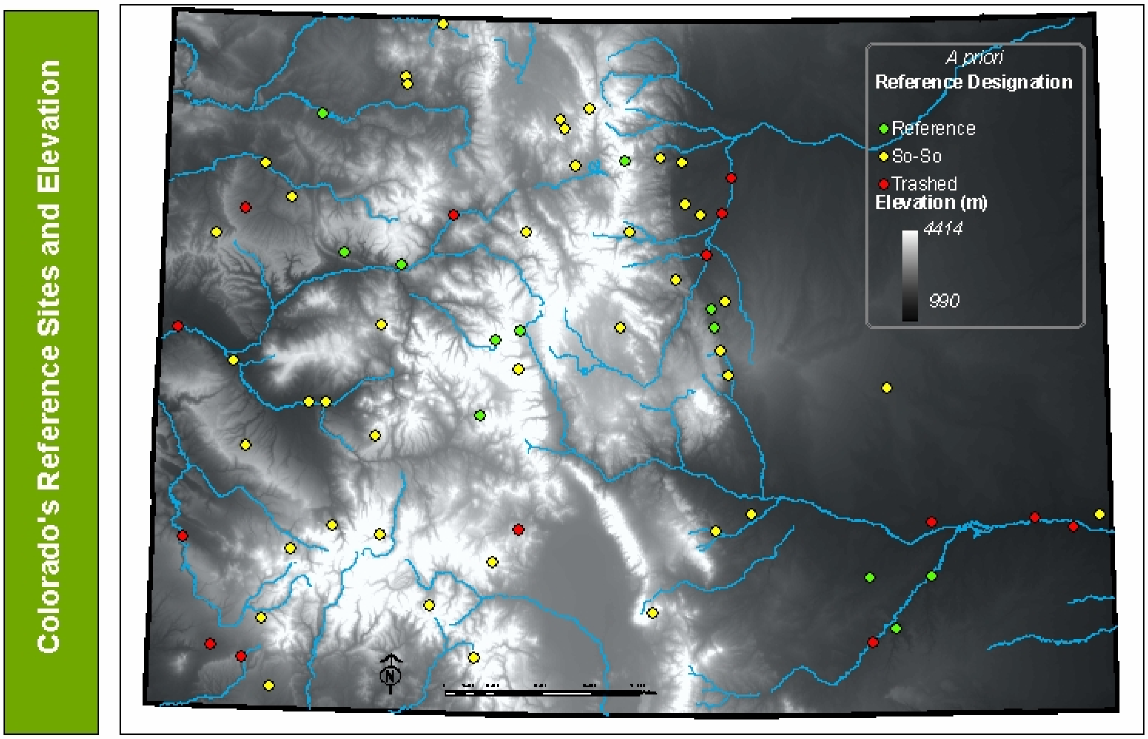


Figure 4—Colorado EMAP Reference Sites

The EMAP and STAR site designation process was based on an inclusion by exclusion selection design. This process was aimed not at distinguishing reference sites, but rather excluded sites exhibiting characteristics associated with stress. Alternatively, CDPHE sites that passed four parameter criteria thresholds without a failure were designated Reference, while sites that failed four or more parameters were designated as Stressed. CDPHE sites from the reference list were then reviewed by CDPHE staff with detailed knowledge of the candidate reference sites to determine whether characteristics of a site that were not apparent in the data should exclude a site from reference designation.

Colorado's Fish IBI was developed by researchers from the CDOW (Colorado Division of Wildlife), CDPHE, CWN (Colorado Watershed Network), and the USEPA and followed a separate reference site designation process. These agency scientists used chemical and physical screening criterion, developed by John Stoddard and Alan Herlihy at the EPA's ORD (Stoddard et al. 2005), as a guideline for reference site designation. Reference sites were selected if they met the ORD criteria and were then individually examined by those who possessed specific knowledge of the sites. Characteristics not apparent within the dataset were accounted for by refining site designations using best professional judgment during three workgroup meetingsin July 2005 and April and May of 2006.

Colorado's Periphyton MMI utilized *a priori* designations from the EPA's ORD (RT_Final) for index calibration while its test set relied on designations developed in Colorado for the Fish IBI (RT_Mod). Variation between these two designation lists was low for sites within Colorado and allowed sites outside of the state that had ORD designations to be used.

External site inclusion strengthened the index by bolstering the number of reference sites used in the development of the Periphyton MMI.

Bioassessment Tool Development

Periphyton MMI Development

Colorado's periphyton index was developed by scientists from USGS, USEPA, and CDPHE in January 2007. Index development utilized over 250 diatom metrics from five categories, as well as data from sites in Utah, Wyoming, and Colorado. External validation of bioregionally specific periphyton indexes was accomplished by utilizing separate sets of calibration and test data. Plains data from Colorado and Wyoming as well as Xeric data from Colorado and Utah were randomly split in two, creating two calibration data sets for index development and two test sets for index validation. In the mountains bioregion, data from Utah and Wyoming were used as the calibration set, while data from Colorado was used as the test set.

Metric selection was based on each metric's ability to discriminate between reference and stressed conditions. This response to stress was discerned by plotting metric values against corresponding *a priori* sites designations. Metrics that passed the responsiveness screening were then sequentially evaluated based on range, signal to noise ratio, and independence from other metrics. The remaining metrics were then compared to other metrics in their same category (i.e., morphology, composition) and selected for inclusion within the index based on their scores in each previous screening test. The resulting indexes incorporated the most responsive metrics from as many categories as possible. The final metrics for each index can be seen below.

Table 6—Periphyton MMI Metrics

Bioregion	Metric	Category
Plains	Cymbella (old taxonomic classification) Richness	Richness
	Cymbella (new taxonomic classification) Percent Taxa	Composition
	Van Dam (et al. 1994) Trophic Class 5&6 Number of Individuals	Tolerance
	Van Dam (et al. 1994) Oxygen Class 1 Percent Taxa	Tolerance
Xeric	Navicula (old taxonomic classification) Richness	Richness
	Cymbella/(Cymbella+Navicula)(new taxonomic classification) Percent Taxa	Composition
	Bahls (2004) Mod. & Highly Motile Number of Individuals	Morphology
	Van Dam (et al. 1994) Trophic Class 5&6 Richness	Tolerance
Mountains	Navicula (new taxonomic classification) Richness	Richness
	Achnanthes (old taxonomic classification) Percent of Individuals	Composition
	Bahls (2004) Mod. & Highly Motile Number of Individuals	Morphology
	Van Dam (et al. 1994) Trophic Class 1&2 Percent Taxa	Tolerance

Macroinvertebrate MMI

Multimetric indexes (MMI or IBI) allow multiple biological measurements, or metrics, to be combined into a single, unitless index value. Metrics are attributes of the biological assemblage, which can be quantified as a response to human and natural alteration or stress of the environment. MMIs are calibrated using reference conditions and are created to exhibit a site's correlation to these conditions based on multiple categories (metrics). By incorporating metrics such as richness, composition, functional feeding group, and pollutant tolerance for benthic macroinvertebrate communities, MMIs can accurately indicate macroinvertebrate community health and aide in stream condition determination statewide. Tetra Tech, Inc. developed Colorado's Macroinvertebrate MMI as part of a 319 grant project.

Candidate metrics were drawn from five categories: richness, composition, pollution tolerance, functional feeding group (trophic), and habit (locomotion). Selection was based on discrimination efficiency (DE), low variability, ecological meaningfulness, contribution of representative and unique information, and sufficient range of values.

In this case, discrimination efficiency is the capacity of biological indicators to detect stressed conditions. Box plots of inter-quartile ranges of reference and stressed sites display the indicator's ability to discriminate between reference and stressed conditions. If the boxes do not overlap, the DE is said to be 75% or greater. The metrics with higher DE values were preferred, and those less than 25% were excluded from the index. The Coefficient of Variability (CV=Standard Deviation/ Mean) was calculated for each reference site and, although no numeric threshold was set, lower CV values were preferred. Metrics selected were also indicative of expected responses of assemblages to change. The largest number of non-redundant metrics was used to encompass as many indicators of stress as possible.

Table 7—Macroinvertebrate MMI Metrics

Bioregion	Metric	Category
Plains	Percent Chironomidae, which are *Criptopus* and *Chironomus*	Composition
	Percent Diptera	Composition
	Percent Oligochaete	Composition
	EPT Taxa	Richness
	Hilsenhoff Biotic Index	Tolerance
	Percent Sprawlers	Habit
Xeric	Percent Coleoptera	Composition
	Percent Ephemeroptera	Composition
	Hilsenhoff Biotic Index	Tolerance
	Percent dominant taxon	Tolerance
	Percent EPT which are Hydropsychidae	Tolerance
	Percent Sprawlers	Habit
	Percent Filterers	Trophic
Mountains	Percent Chironomidae which are Cricotopus and Chironomus	Composition
	Diptera Taxa	Composition
	EPT Taxa	Richness
	Percent Tolerant Individuals	Tolerance
	Percent Trichoptera which are Hydropsychidae	Tolerance

O/E Development

RIVPACS (River Invertebrate Prediction and Classification System) (Moss et al. 1987, Wright 1995) assessments determine biological condition or quality by estimating the taxonomic completeness of a standard sample. Taxonomic completeness is a fundamental aspect of biological integrity and is defined here as the proportion of the taxa that occur over those that are expected in a single sample. The O/E model describes which taxon are predicted to naturally occur at a site (E, expected) versus which taxon were actually collected by sampling the site (O, observed), where E is the sum of the probabilities of capture for each taxa. Individual probabilities of capture are derived from regionally classified reference sites, which are grouped by taxonomic similarity.

The O/E model output is a number from 1 (O=E) to 0 (O<E), where a departure from 1 indicates the presence, as well as the degree, of biological impairment. Developmental steps of O/E models are:

1. Select reference sites representing natural environmental gradients
2. Classify sites based on taxonomic similarity (predictor variables) by pair-wise similarities (dendrogram)
3. Calculate (Tally) each taxonomic occurrence frequency for each reference site class
4. Develop a discriminate model based on taxonomic distribution variables to predict probabilities of new sites' reference class designation
5. Estimate taxonomic probability of capture as the frequency of occurrence among classes weighted by site classification probability
6. Estimate E as the sum of the probabilities of capture
7. Assess model performance by comparing the O with # and calculating the precision of O/E estimates

Ninety-seven reference (least-disturbed) sites were used for the development of the O/E model for Colorado. These sites contained 173 OTU's, eighty of which occurred in five or more samples and were used to biologically classify sites for the model. Sites were well-distributed geographically throughout the state with the exception of a cluster along the western base of the Southern Rocky Mountains. These sites were selected as adequate representation of natural conditions due to low chemical contamination, low flow alteration, and natural riparian and habitat conditions. Sites were then classified based on their taxonomic similarities.

Sites were divided into as many classes as were feasible in order to maximize similarity, with the requirement that each class contain no fewer than five sites. Classification of sites allowed for the estimation of frequencies of taxon occurrence in each site class and the development of a discriminate function model from taxonomic predictor variables that allowed the prediction of reference site classification probability for new sites. John Van Sickle's (USEPA) all subsets software was utilized to evaluate 32,767 discriminate models in order to determine which metric combination maximized precision and minimized bias for each predictor variable.

Table 8—O/E Model Predictor Variables

Predictor Variables
Longitude (Decimal Degrees)
Mean annual air temperature (^oC x 10)
log watershed area (km^2)

Performance measures were based on internal validation and included the mean, standard deviation, and root mean square error of O/E. Predictor variables that could be influenced by humans were eliminated, and only map-derived variables were utilized to illustrate the influence of local factors on spatial and temporal distribution of the biota. The final three predictor variables were: longitude (decimal degrees), mean annual air temperature (^oC x 10), and log watershed area (km^2). A strong relationship between temperature and biotic classes implies that thermal variation across Colorado is the single most important factor affecting the distribution of stream taxa. (Tetra Tech, Inc. 2005)

O/E score calculations are based on a probability of capture threshold of >0.5. Ideally, the greatest number of taxa are used to develop a model, but this threshold is used as it minimizes predictive error based on the presence of rare taxa. It should be noted that utilizing this capture threshold decreases taxonomic resolution and may mask specific species' sensitivity to stress.

Fish IBI Development

Representatives of CDPHE, USEPA, CDOW, and CWN held a series of workshops in the fall 2005 and spring of 2006 to create a Fish IBI for Colorado. A list of 761 metrics were compiled from species counts collected at each Colorado site sampled during the WEMAP study. An inter-quartile box plot was created for each metric to discern DE between Least- and Most-Disturbed sites. Those metrics that exhibited a DE of greater than seventy-five percent (boxes did not overlap) between reference and stressed sites were retained for further evaluation. A Pearson's correlation was conducted on the remaining metrics and redundant metrics were removed. In order to garner a comprehensive index, the metrics were then categorized based on reproductive and feeding habits, habitat preference, stress tolerance, and taxonomic classification to ensure inclusion of each facet of the biological community that was potentially responsive of disturbance.

This process resulted in the creation of an IBI for both the Xeric and the Plains bioregions. An index for the Mountains bioregion failed to be developed as metrics were unable to discriminate between reference and stressed sites. The final metrics for each index can be seen below.

Table 9—Fish IBI Metrics

Bioregion	Metric
Plains Bioregion	Number of nonnative individuals Percent of species that are native herbivores Percent of hider individuals Percent of native species that are long-lived and tolerant to sediment Percent of native individuals that prefer warm-water habitats Number of individuals that are benthic and tolerant to sediment
Xeric Bioregion	Number of individuals of intermediate tolerance to nutrients and prefer cool water habitat Percent of hider individuals Percent of long-lived species with intermediate tolerance to sediment Percent of species that are lithophilic

Stressors

Examination of ecological stressors is critical when assessing the biotic health of surface water due to their direct impacts on the biota living in the stream. Water quality and physical habitat characteristics (**Table-10**) were analyzed and recorded as part of this project in order to determine which stressors were most influential as they pertained to macroinvertebrate, periphyton, and fish health in Colorado. By studying multiple stressor parameters and comparing their extent to the condition of stream biota, relative risks (see **Relative Risk**) to biotic health can be calculated for each stressor parameter. Understanding which parameters are influencing stream health allows management and regulatory practices to be developed or altered in order to minimize future impacts and mitigate degraded conditions due to specific stressors of streams.

Table 10—Stressor parameters of Colorado EMAP study

Type	Stressor	Data Code
Chemical	Total Phosphorus (ug/L)	PTL
	Total Nitrogen (ug/L)	NTL
	Chloride (ueq/L)	CL
	Sulfate (ueq/L)	SO4
	Closed Headspace pH	PHSTVL
Physical Habitat	Mean Bank Canopy Density (%)	XCDENBK
	Riparian Disturbance--Sum of All Types (Proximity Weighted Presence)	W1_HALL
	Turbidity (NTU)	TURB
	Log10[Relative Bed Stability]	LRBS_BW5
	Substrate Fines—Silt/Clay/Muck (%)	PCT_FN

Water chemistry and physical habitat are of great importance in bioassessment studies because they determine habitat quality and influence biological processes in streams. Phosphorous and nitrogen are influential nutrients in a stream that effect primary production rates and overall stream metabolism. Agricultural runoff, waste-water treatment facility effluent, and allochthonous organic matter are primary point and non-point sources of N and P.

Riparian disturbance is a qualitative measure that indicates levels of human and non-human impact on the land area directly adjacent to the stream. Canopy density is important due to its effect on in-stream temperature, sunlight penetrance, as well as its contribution of litterfall (organic matter) into streams. Relative bed stability describes the substrate of the stream and its mobility, which is determined by substrate composition and flow characteristics at a site. This parameter, along with percent fines, details benthic micro-habitat in a stream as well as sediment availability for microbial colonization as part of hyporheic metabolism.

Threshold Determination

In order to classify streams based on level of disturbance, thresholds were set for each biologic indicator and ecological stressor. Biological Indicator thresholds were established using two sets of percentiles, both using land cover weights calculated in Statistica 7.0. The 25th and 5th percentiles of reference site scores were used for the Fish IBI thresholds, while the 25th percentile of reference site scores and the mean of the remaining scores were used for the Macroinvertebrate MMI and O/E model as well as the Periphyton MMI. Land cover was based off of a GIS layer of Land Cover Data that was developed for the Colorado Gap Analysis Project. A one kilometer radius buffer was drawn around each site and percentage of each land cover type was calculated and classified as natural or

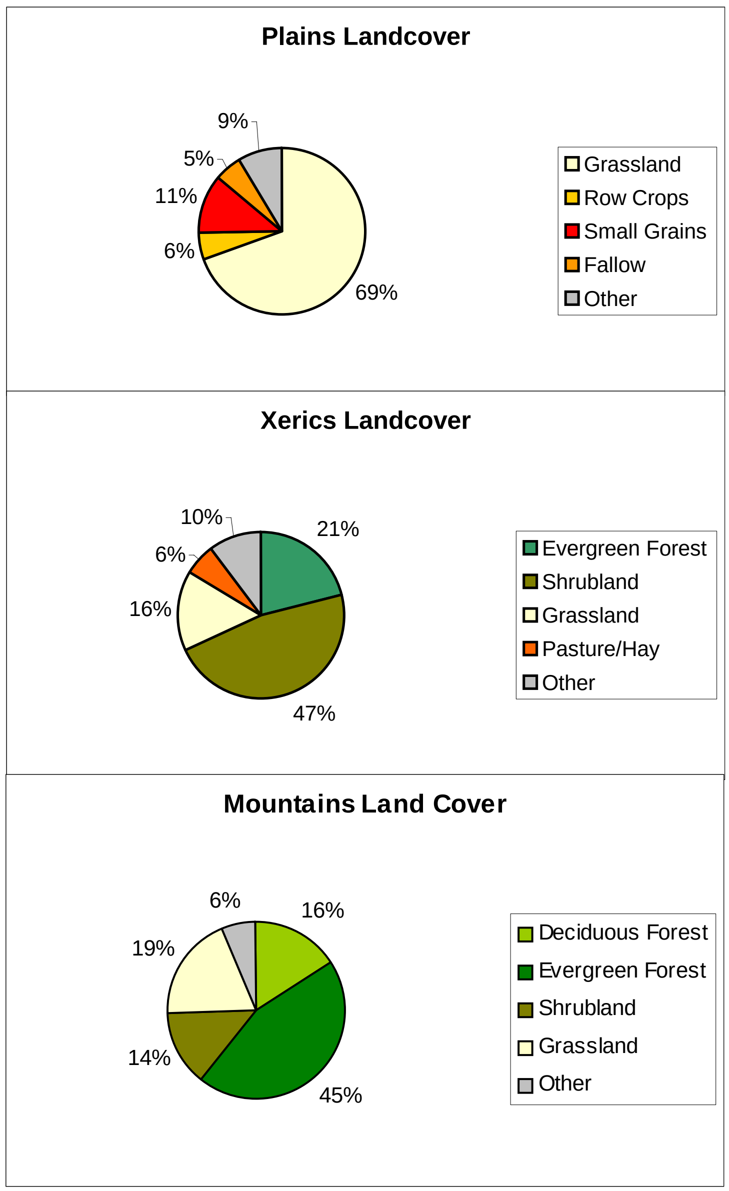


Figure 5—Bioregional Land Cover

disturbed. This weighting allowed sites' biological indicator scores to be compared without a bias resultant from varying degrees of land cover disturbance. This technique was applied in all four bioassessment tool threshold development procedures. However, land cover weighting was not used when determining the moderately/most disturbed threshold for the macroinvertebrate MMI. Cover types can be seen by type and bioregion in **Figure-5.**

The Fish IBI thresholds were set using the 25th (least-/moderately-disturbed boundary) and 5th (moderately-/most-disturbed boundary) percentiles of reference site scores. These percentiles have been used as thresholds in past bioassessment studies by the EPA (i.e., WEMAP and Southern Rockies Assessment). As development of a Fish IBI for the mountains bioregion was unsuccessful, thresholds were set for both the Xeric and Plains bioregions. Since only four reference sites existed in the Colorado Xeric bioregion; Xeric EMAP reference sites from Utah and Wyoming were utilized to solidify the threshold determination within the region. Site additions were beneficial, as threshold (25th percentile score) accuracy increases when more reference sites are used in threshold determination. The bioregional thresholds shown in **Table-11,** were based on a total of thirteen Plains reference sites. Neither bioregion had normally distributed Fish IBI scores, with natural breaks occurring at the moderately-/most-disturbed threshold. This distribution aligned with the established thresholds, which contributed to the confidence placed in our tools, although relatively few reference sites were utilized.

Table 11—Disturbance Class Thresholds

Index	Least-Moderate	Moderate-Most
MMI	55.76	43.02
OE	0.69	0.57
IBI_X	52.21	41.56
IBI_P	66.76	28.79
Periphyton	51.10	25.00

The Macroinvertebrate MMI and O/E as well as the Periphyton MMI thresholds were set utilizing the 25th percentile of reference sites and the mean of all sites below the 25th percentile of reference sites. The scores for each site were weighted for percentage of disturbed land cover within a 1km radius around the site. These percentile based threshold values were calculated to differentiate least- and moderately-disturbed sites as well as moderately- and most-disturbed sites. MMI and O/E thresholds were set using reference sites from across the entire state with all bioregions combined into one set of scores. This allowed designations to be based on a robust set of 24 reference sites statewide.

Stressor thresholds were defined by Stoddard and Herlihy of the USEPA's ORD (Stoddard et al. 2005). These were initially designed as reference site screening thresholds for the ten ecological regions of the West (USEPA Level III ecoregions) and were comprised of chemical and physical habitat parameters (**Table-12**).

Table 12—Physical and Chemical Stressor Thresholds

Colorado EMAP Sites			**Chemical/Physical Habitat Parameter**								
Ecoregion	**Threshold**	P total ug/L	N total ug/L	Cl ueq/L	SO_4 ueq/L	pH	Turbidity NTUs	Riparian Disturbance	Fines (%)	Relative Bed Stability	Bank Canopy Density
S. Rockies	Least-Disturbed	<25	<750	<200	<200	<9	No Std*	<1.0	<15%	>-2.0	>50%
S. Rockies	Most-Disturbed	>100	>1000	>1000	>1000	<6,>9	>10	>3.0	>50%	<-3.0	<10%
N. Plains	Least-Disturbed	<150	<2000	<1000	No Std*	<9	<50	<2.0	<90%	>-3.5	>25%
N. Plains	Most-Disturbed	>500	>4000	>2750	No Std*	<6,>9	>100	>3.0	>99%	No Std*	<5%
Xeric	Least-Disturbed	<50	<1500	<1000	<10000	<9	<25	<1.5	<50%	>-2.0	>50%
Xeric	Most-Disturbed	>150	>4000	>2500	>15000	<6,>9	>50	>3.0	>90%	<-2.8	<10%

***** No disturbance category standard was developed for these parameters; therefore, stressor extent and relative risk calculations did not include data from these instances. Calculations relied on values derived from the available standards for each parameter within each bioregion.

Ecological Condition

Table 13—Ecological Condition

Index	Stream Length (Km)		Disturbance Class
Macroinvertebrate MMI	26456.68	[85.82%]	Least-Disturbed
	2013.92	[6.53%]	Moderately-Disturbed
	2356.12	[7.64%]	Most-Disturbed
Macroinvertebrate O/E	24871.13	[80.68%]	Least-Disturbed
	2821.19	[9.15%]	Moderately-Disturbed
	3134.4	[10.17%]	Most-Disturbed
Fish IBI	3178.5	[10.31%]	Least-Disturbed
	2348.71	[7.62%]	Moderately-Disturbed
	2213.46	[7.180%]	Most-Disturbed
	23086.04	[74.89%]	No Index
Periphyton MMI	12424.22	[40.30%]	Least-Disturbed
	12797.67	[41.51%]	Moderately-Disturbed
	4867.94	[15.79%]	Most-Disturbed
	736.89	[2.39%]	No Data

Following the development of Colorado's MMI, IBI, and O/E model, generation of scores, and subsequent determination of thresholds, a final statewide output was compiled. Ecological condition was reported for only those sites that fell within the probability design of the EMAP Study. Of the X# of sites used to develop the Periphyton MMI, the 717 sites of the Macroinvertebrate MMI and O/E model, and the 91 sites the Fish IBI, only 67 were reportable, non-target, probability sites. These sites met the requirements of the study design and could be reported on as part of the EMAP project. Each of the 67 sites represented a given number of river miles, determined by the site's location

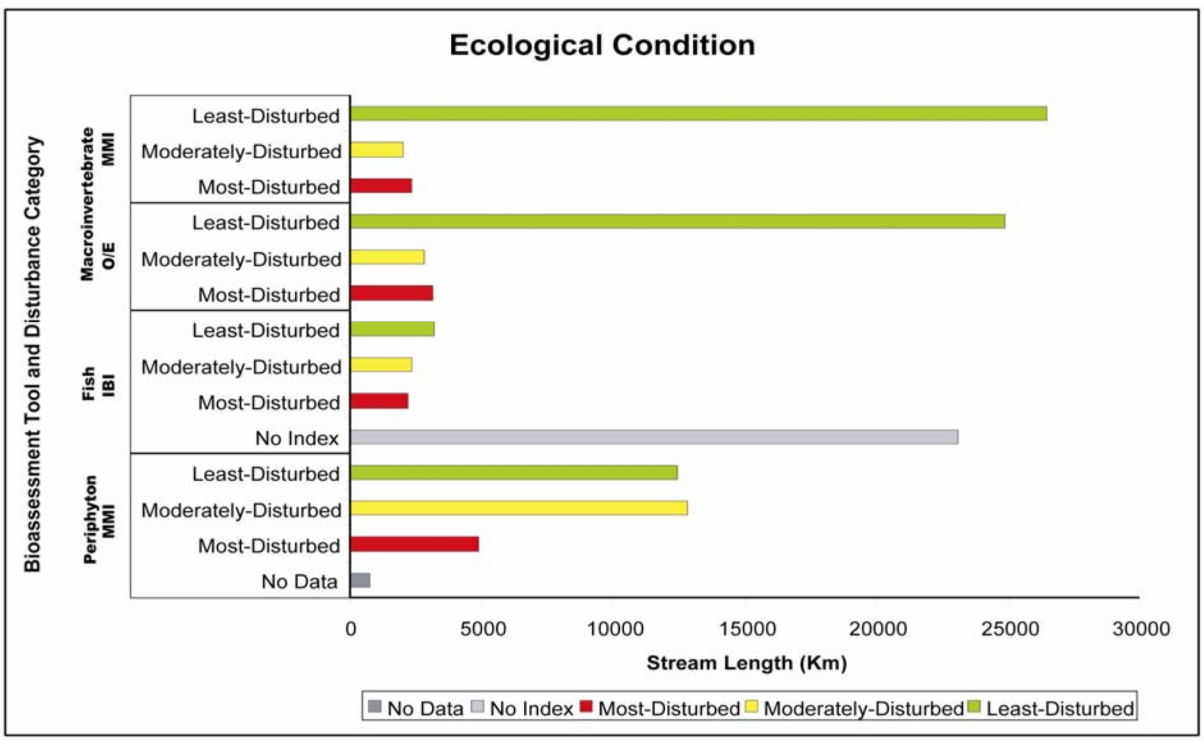


Figure 6—Macroinvertebrate, Fish, and Periphyton Condition Statewide

within the watershed and stream type. River miles were then totaled for sites representing each disturbance class for all bioassessment tools (Table-13, Figure-6).

Although repeated sampling is needed for a comprehensive assessment of a site, the tools developed in this study give scientists a better understanding of biologic communities at a given time and place. In general, biotic condition throughout the state is quite good, with well distributed sites with little overall impairment. There were groupings of degraded sites where the South Platte flows out of the Denver metro area, along the lower Arkansas in southeastern Colorado, as well as on the Colorado River near the Utah border. This is most likely due to the high demand placed on streams as they pass through highly developed locations with extensive land cover degradation and flow control. Industrial and domestic discharges can account for 100 percent of flows in the South Platte at times of high demand, resulting in altered water chemistry, temperature, and flow regimes in these reaches. When this is coupled with diversions for agriculture and water supply storage, stress on the biota of the stream can lead to stifled macroinvertebrate and fish communities.

The Mountains bioregion is generally an area of lower pollution and land cover degradation due to limited agricultural land use and sparse residential and commercial development. These low disturbance conditions in the mountains may be the result of widespread publicly owned lands and areas of high forest density where human perturbation is reduced due to restrictions placed on use of public lands (**Table-14**). Although human induced disturbance is low, ambient levels of pollutants or compounds from abandoned mining sites or natural sources continue to pose risks to aquatic organisms. Human disturbance increases as streams flow out of headwater areas into the Plains and Xerics. Increased population density at lower elevations leads to increases in agricultural runoff; diversions and dams; residential and commercial development; and industrial and municipal discharges. These compounding factors degrade water quality and reduce overall biotic condition at sites in downstream bioregions. The impact of increased degradation at lower elevations was reflected in each of the bioassessment tools developed in the study.

Table 14—Colorado Government Land ownership

Owner	Acreage	Percentage of State
State Parks (40)	214,245	0.3%
US Bureau of Land Management	8309082	12.5%
US Forest Service	14471811	21.8%
US Fish and Wildlife Service	63910	0.1%
US Park Service	592207	0.9%
Colorado total	66485760	35.6%

Source: GSA FRPP 2004

Fish IBI scores were generally lower than scores generated by the Periphyton MMI and Macroinvertebrate MMI and O/E model. The lack of a Fish IBI in mountains may have lowered the mean index score of the Fish IBI statewide. Macroinvertebrate and periphyton assessment tools showed that fewer sites of the most-disturbed condition category were seen in the Mountains bioregion than were seen in either of the state's other bioregions. Without these potential positive scores weighting the overall output, scores from the Fish IBI tended to be lower than their periphyton or macroinvertebrate counterparts.

As more data becomes available through monitoring by CDPHE, these bioassessment tools should be recalibrated with additional reference sites to decrease the standard deviation of the thresholds and to ensure that the metrics currently comprising the indexes are the most informative of biological condition. Many factors contribute to degradation in streams (see **Impacts to Streams**), but it is important to understand which parameters are of the greatest importance to stream biota in order to mitigate degradation and develop management and regulatory practices that protect designated uses and aquatic life. By re-examining metrics and thresholds as more data is collected throughout the state, more accurate output will be generated by these tools, producing an increased efficiency in biological condition assessment in Colorado.

Stressor Extent

Stressors were ranked using the screening criteria developed by the USEPA's ORD's Stoddard and Herlihy (Stoddard et al. 2005). These criteria were then applied to the 67 probability sites, and associated stream length representations were totaled (**Table-15**). Stressors were then ranked based on the proportion of stream length that fell in the most-disturbed class to Colorado's stressor conditions. Turbidity, total phosphorous, and sulfate had nearly equal lengths of stream classified as most-disturbed, indicating that these parameters are the most widespread stressors in the state. It should be noted that a threshold was not designated for least-disturbed turbidity levels in the Mountains and for least- and most-disturbed sulfate levels in the Plains bioregion.

Relative Risk

Relative Risk is a comparison of biological and stressor condition at sites where both parameters were assessed. Relative Risk values are derived from calculations that compare proportions of stream length that are classified as least- and most-disturbed at a single site (see **Table–21** in the **Appendix**). The Relative Risk calculation output value is described as the risk of having a poor biological condition when a poor ecological stressor condition exists. This comparison provides insight into which chemical and physical habitat parameters influence biotic condition to the greatest degree (**Figure-7**).

Table 15—Extent of Stressors throughout Colorado

Colorado EMAP Sites		Chemical/Physical Habitat Parameter									
Chemical/Physical Habitat Stressor Extent		P ug/L	N ug/L	CL ueq/L	SO4 ueq/L	pH	Turbidity NTUs	Riparian Disturbance	Fines %	Relative Bed Stability	Canopy Density
Disturbance Rank (Most to Least)		2	5	4	3	10	1	7	6	9	8
Reach Length (Km)	Least-Disturbed	24196	29100	27079	20132	30827	7053	20373	22390	25450	21045
	Mod-Disturbed	5109	807	1605	7224		1077	6984	4443	1021	6331
	Most-Disturbed	1521	919	942	1401		1524	376	901	300	357
	No Std				2070		21173			105	
	No Data			1201				3094	3094	3951	3094
Total Length Km		30827	30827	30827	30827	30827	30827	30827	30827	30827	30827
Disturbed Length %	Least-Disturbed	78%	94%	88%	65%	100%	23%	66%	73%	83%	68%
	Mod-Disturbed	17%	3%	5%	23%		3%	23%	14%	3%	21%
	Most-Disturbed	5%	3%	3%	5%		5%	1%	3%	1%	1%
	No Std applied				7%		69%				
	No Data			4%				10%	10%	13%	10%

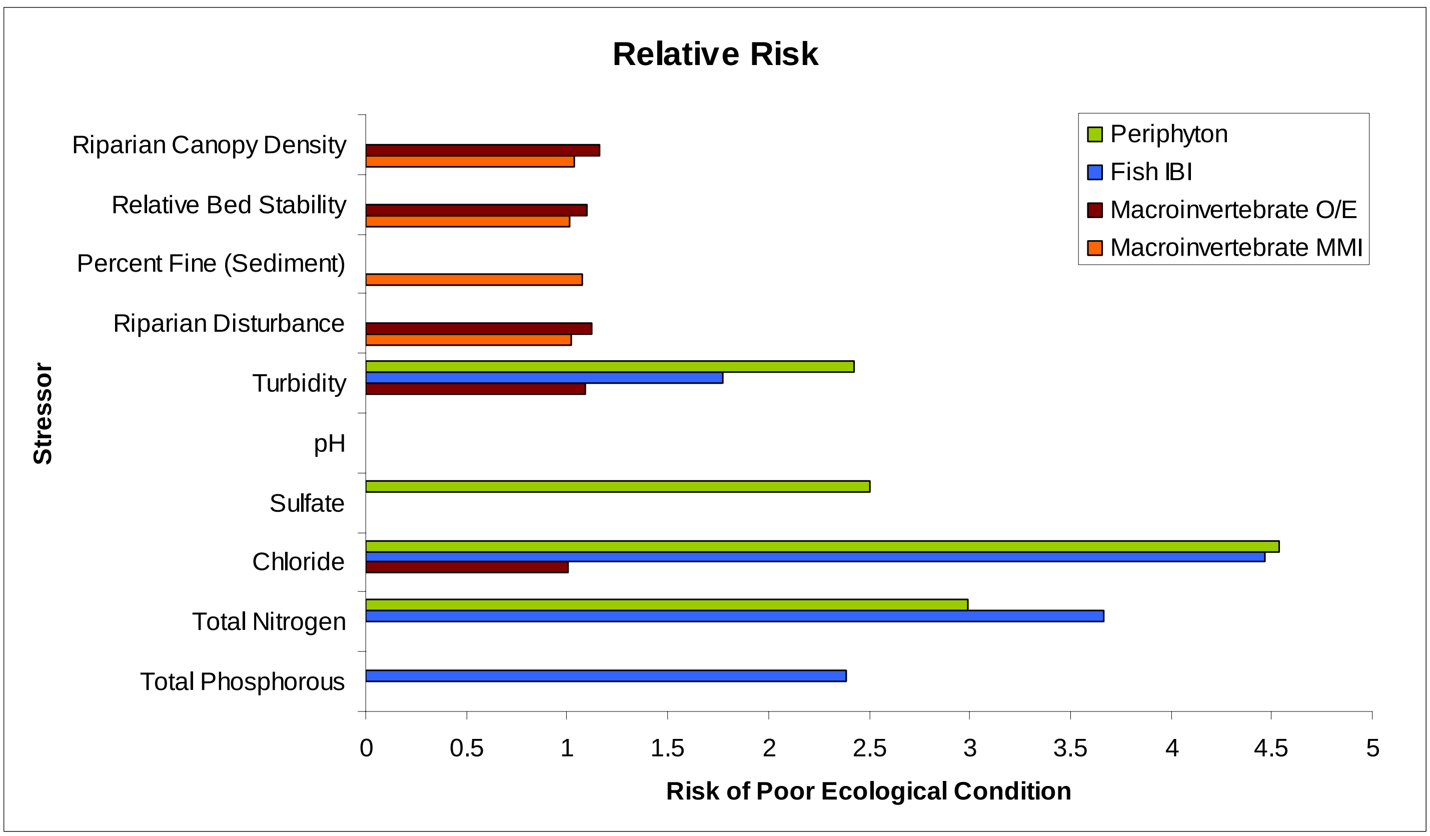


Figure 7—Relative Risk of Chemical and Physical Habitat Stressors

Discussion

Streams statewide were found to be in good condition, with only three groups of localized degradation and otherwise randomly distributed sites of the most-disturbed condition. Scores between the MMIs, IBI, and O/E tools exhibited poor correlation, which further emphasizes the need for continued recalibration of these tools to ensure accuracy. Six percent of sites were designated in the same disturbance class by all four indicator tools and twenty-one percent of sites showed agreement between three tools (see **Table–16** in the **Appendix)**. These percentages were higher when only the Macroinvertebrate IBI and O/E tools were examined, exhibiting sixty-two percent agreement.

The lack of bioassessment tool agreement may prove to be a benefit of using unique metrics for each bioregional index and using separate biological communities as indicators of stream condition. It is possible that this method allows for the resolution of assessment to be much higher as specific components of each community in each region can be inferred. The varied response of different biologic communities to conditions and stress at a single site may provide some novel insight to preferences and tolerances of the given community. (Hawkins, Personal Communication 2007)

Relative risks of ecological stressors on aquatic life were shown to be generally low in most instances. When stressor and biological condition were compared, turbidity, total phosphorous, and sulfate were shown to pose the most significant risks to biologic communities. These stressors also have the greatest extent in Colorado, thus making them more likely to have the greatest impact on stream biota.

As part of further tool refinement by CDPHE, inclusion of additional index metrics should be considered. Currently, metrics focus on composition and richness of biological communities, which may mask presence of rare species. This presence has been intentionally deleted in an effort to increase taxa prediction accuracy by using a capture threshold (<0.5) in the O/E model and perhaps unintentionally by subsampling data used in the MMI and IBI tools. While this increases predictive capability and allows for inclusion of information from data sets of varying resolution, it ignores pertinent information available within the current data set by disregarding the presence of highly specialized and sensitive species.

Processes leading to reference site determination should be examined as more candidate sites become available through continued monitoring. Incorporation of best professional judgment within this study may have led to erroneous *a priori* site classifications, namely within the Fish IBI development, on which these bioassessment tools were based. Consistent values such as table value standards should be utilized to eliminate inconsistencies incurred through judgment decisions during reference site determinations. This could potentially allow for new metric compositions within indexes, which could lead to more accurate scores and better inter-index agreement. More accurate reference designations would also benefit O/E output as probabilities of capture and expected (E) values would more accurately reflect reference conditions in streams within each region.

Continued sampling of streams statewide will contribute greatly to the index and model framework established within this project. As additional reference (least-disturbed) and stressed (most-disturbed) sites are added to Colorado's EDAS database, metric discrimination efficiency and threshold designation can be reevaluated, ensuring the accuracy of scores generated for future regulatory purposes. Additional reference sites within the Mountains bioregion could lead to the development of a Fish IBI for this region, filling a gap in the existing IBI and creating a viable statewide index.

Colorado's EMAP Project resulted in the development of bioassessment tools that will be immediately useful in monitoring and assessing streams statewide. A data management program has been developed to assign metric values and generate IBI scores from validated fish data to supplement the existing MMI (CDPHE's EDAS) and O/E (USU website) data processors. A periphyton data management tool is also possible, using the template that was developed for the fish data management program. This set of tools will allow the State to make rapid assessments of sites and determine general ecological condition based on a single sample with some degree of confidence. This rapid screening of sites will allow regulators to focus on stream segments where ecological conditions are poor. Specific parameters can then be researched in detail to provide information for management alteration as well as permitting and compliance issues.

Appendix

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EMAP Station	RT_Mod	Bioregion	Stream Length Represented (Km)	Land Cover (%)	Macroinvertebrate MMI	Macroinvertebrate O/E	Fish IBI	Periphyton MMI
WCOP01-0722	T	Plains	85.33127922	72.94	47.39	0.57	11.88	13.80
WCOP01-0734	S	Plains	56.88751948	13.88	70.01	0.56	57.04	70.31
WCOP01-0739	S	Plains	75.85002597	0.00	49.73	0.90	57.64	41.54
WCOP01-0765	S	Plains	56.88751948	100.00	58.04	0.44	71.11	38.01
WCOP01-0768	T	Plains	85.33127922	100.00	44.77	0.56	42.16	62.72
WCOP01-0769	S	Plains	75.85002597	83.32	81.81	0.97	66.73	63.72
WCOP01-0775	S	Plains	75.85002597	0.00	60.96	1.07		69.25
WCOP01-0777	R	Plains	136.5300468	21.96	15.23	0.68	66.67	83.23
WCOP01-0779	S	Plains	75.85002597	0.00	57.60	0.90	53.25	46.33
WCOP01-0809	R	Plains	56.88751948	24.79	55.37	0.88	69.13	29.06
WCOP01-0812	T	Plains	136.5300468	62.15	44.30	0.33	67.02	44.54
WCOP01-0817	T	Plains	105.0231129	0.00	30.66	0.56	54.01	25.36
WCOP01-0819	R	Plains	136.5300468	100.00	55.76	0.69	66.76	
WCOP01-0833	S	Plains	136.5300468	0.00	69.34	0.87		51.10
WCOP01-0836	T	Plains	136.5300468	53.41	41.75	0.62	57.88	24.92
WCOP01-0838	S	Plains	136.5300468	96.44	77.45	0.91	45.66	89.03
WCOP99-0501	S	Xeric	720.4303671	0.20	60.43	1.00	50.74	31.90
WCOP99-0502	S	Mountains	1200.717278	0.00	93.80	0.84		49.24
WCOP99-0503	R	Mountains	1200.717278	0.00	87.28	0.73		100.00
WCOP99-0505	S	Mountains	1200.717278	0.00	91.71	0.86		37.77
WCOP99-0506	T	Xeric	300.1793196	0.00	70.31	0.93		56.22
WCOP99-0507	S	Mountains	1200.717278	0.00	75.48	0.77		51.60
WCOP99-0508	S	Mountains	600.358639	0.00	92.06	0.73		34.42
WCOP99-0510	T	Plains	56.88751949	98.01	45.30	0.56	15.25	15.26
WCOP99-0511	S	Mountains	600.358639	0.00	94.99	0.95		50.00
WCOP99-0512	S	Mountains	480.2869112	0.00	92.10	0.80		35.15
WCOP99-0513	S	Mountains	1200.717278	0.00	94.08	1.02		39.84
WCOP99-0515	S	Mountains	600.358639	0.00	68.97	0.58		14.92
WCOP99-0516	S	Xeric	720.4303671	0.00	75.91	1.00	82.37	71.69
WCOP99-0518	R	Mountains	600.358639	0.00	91.08	0.91		88.02
WCOP99-0563	S	Plains	56.88751949	0.00	48.93	0.68	66.71	50.48
WCOP99-0565	S	Xeric	300.1793196	0.00	82.70	0.90		25.33
WCOP99-0566	S	Xeric	300.1793196	0.00	73.51	0.74		75.00
WCOP99-0567	S	Mountains	600.358639	0.00	82.25	1.02		72.84
WCOP99-0568	S	Xeric	300.1793196	64.80	52.48	0.79	79.24	73.82
WCOP99-0569	S	Plains	56.88751949	59.26	57.11	1.13	47.25	65.43
WCOP99-0571	T	Mountains	800.4781855	12.09	80.14	0.76		21.36
WCOP99-0572	S	Mountains	600.358639	0.00	91.83	0.47		14.92
WCOP99-0574	S	Mountains	480.2869112	0.00	78.21	0.78		43.48
WCOP99-0577	S	Mountains	800.4781855	0.00	80.85	0.96		91.71
WCOP99-0578	S	Mountains	800.4781855	0.00	85.33	1.20		23.25
WCOP99-0591	S	Mountains	480.2869112	0.00	86.21	0.90		38.58
WCOP99-0593	S	Mountains	480.2869112	12.45	92.08	0.67		35.64
WCOP99-0594	T	Xeric	450.2689795	0.00	30.53	0.78	34.15	26.57
WCOP99-0595	R	Xeric	300.1793196	0.00	72.19	1.24	55.81	96.11
WCOP99-0597	S	Mountains	600.358639	0.00	90.89	0.83		53.75

EMAP Station	RT_Mod	Bioregion	Stream Length Represented (Km)	Land Cover (%)	Macroinvertebrate MMI	Macroinvertebrate O/E	Fish IBI	Periphyton MMI
WCOP99-0599	S	Mountains	480.2869112	0.00	63.51	0.77		59.29
WCOP99-0601	R	Xeric	450.26898	71.55	69.13	0.97	41.56	41.27
WCOP99-0621	T	Xeric	720.43037	0.00	74.88	0.78	39.50	22.88
WCOP99-0622	T	Xeric	300.17932	14.83	55.72	1.11	48.56	53.99
WCOP99-0624	S	Xeric	450.26898	70.56	49.18	0.78	69.94	45.49
WCOP99-0626	S	Mountains	600.35864	0.00	82.02	0.87		
WCOP99-0627	T	Mountains	600.35864	0.00	76.93	0.50		26.28
WCOP99-0629	R	Plains	56.887519	0.00	43.02	0.67	58.69	73.25
WCOP99-0632	S	Mountains	600.35864	0.00	82.57	0.20		50.66
WCOP99-0633	R	Mountains	600.35864	0.00	82.50	0.65		61.88
WCOP99-0634	S	Mountains	1200.7173	0.00	90.92	0.99		61.86
WCOP99-0637	S	Mountains	480.28691	54.79	87.66	0.64		12.76
WCOP99-0638	S	Xeric	720.43037	30.51	39.30	0.80	62.21	30.90
WCOP99-0646	T	Xeric	300.17932	56.50	33.11	0.51	76.27	58.59
WCOP99-0647	R	Mountains	1200.7173	2.60	81.89	0.72		66.30
WCOP99-0648	S	Xeric	450.26898	0.00	26.44	0.44	37.72	17.84
WCOP99-0649	R	Mountains	600.35864	0.00	90.87	0.93		65.01
WCOP99-0650	S	Mountains	480.28691	50.48	90.70	0.82		27.80
WCOP99-0670	S	Mountains	600.35864	0.00	85.65	1.04		49.15
WCOP99-0671	T	Plains	136.53005	100.00	45.68	0.81	47.94	23.25
WCOP99-0672	R	Plains	136.53005	0.00	51.44	0.67	64.96	30.83

Least_Disturbed		Moderately-Disturbed		Most-Disturbed	

Table 16—EMAP Site Summary Table. Shows final scores for each bioassessment tool as well as their corresponding designations and classifications. These scores do not represent an assessment of each site's ecological condition, rather a snapshot of the biological communities at the specific time and location of each sampling event. RT_Mod is the *a priori* designation that was assigned for each site in Colorado and used in the Fish IBI and Periphyton MMI development as well as threshold determination for all tools. Representative stream length was used to determine each site's represented stream length for reporting condition of biological indicators and extent of stressors. Land Cover (Colorado Gap Project) was used to weight each tool's score when determining thresholds.

Developmental Component	Macroinvertebrate MMI			Macroinvertebrate O/E
Data Source	717 CDPHE, EMAP, STARR, NAWQA, REMAP Sites			717 CDPHE, EMAP, STARR, NAWQA, REMAP Sites
***A priori* Designation Process**	Use Best Professional Judgement, Chemical and Physical Habitat Screening to designate each site either R, S, or T			
***A priori* Sites**	102 Reference Sites (R)			102 Reference Sites (R)
Tool Development	Select metrics based on Discrimination Efficiency, coefficient of variability, examine correlation			Classify taxonomic similarity of sites, estimate taxonomic occurrence frequency and probability of capture
Bioregion	Plains	Xeric	Mountains	All Bioregions
Selected Metrics/Predictor Variables	Percent Chironomidae	Percent Coleoptera	Percent Oligochaete	Longitude (Decimal Degrees)
	EPT Taxa	Diptera Taxa	Total Taxa	Mean annual air temperature (^{o}C x 10)
	Hilsenhoff Biotic Index	Percent Dominant Taxon	Percent Climbers	log watershed area (km^2)
	Percent Burrowers	Percent Climbers	Percent Trichoptera which are Hydropsychidae	
	Percent Predators	Predator Taxa	Percent Oligochaete	
	Percent Chironomidae	Percent Coleoptera		
		Diptera Taxa		
Score Generation	For Metrics that Decrease with Increasing Stress = 100 x (95th Percentile/Metric Value) For Metrics that Increase with Increasing Stress = 100 x ((95th Percentile-Metric Value)/(95th Percentile-5th Percentile))			Observed Taxa/Expected Taxa
Threshold Determination	25th and 5th Percentile of Reference Sites			25th and 5th Percentile of Reference Sites
Thresholds	Least-Moderate Disturbed Threshold = 55.76 Moderate-Most Disturbed Threshold = 43.02			Least-Moderate Disturbed Threshold = 0.69 Moderate-Most Disturbed Threshold = 0.57
Condition	85.82% Least-Disturbed 6.53% Moderately-Disturbed 7.64% Most-Disturbed			80.68% Least-Disturbed 9.15% Moderately-Disturbed 10.17% Most-Disturbed
Stressors	Physical: Turbidity (NTU), Riparian Disturbance--Sum of All Types (Proximity Weighted Presence), Substrate Fines--Silt/Clay/Muck (%), Log10 [Relative Bed Stability], Mean Bank Canopy Density (%) Chemical: Total Phosphorus (ug/L), Total Nitrogen (ug/L), Chloride (ueq/L), Sulfate (ueq/L), Closed Headspace pH			
Relative Risk	RR=(A) / ((B) Where A=(MBMS) / ((MBMS) + (LBMS)) and B=(MBLS) / ((MBLS) + (LBLS)) LB=Least disturbed biologic condition LS=Least disturbed stressor condition MB=Most disturbed biologic condition MS=Most disturbed stressor cognition			

Table 17—Biological Assessment Tool Development Process. Shows development process for each bioassessment tool.

Developmental Component	Fish		Periphyton		
Data Source	123 EMAP Sites		250 CO, WY, UT EMAP Sites		
***A priori* Designation Process**	Use Best Professional Judgement, Chemical and Physical Habitat Screening to designate each site either R, S, or T				
***A priori* Sites**	39 Reference Sites (R)		32 Reference Sites (R)		
Tool Development	Select metrics based on Discrimination Efficiency, coefficient of variability, examine correlation		Select metrics based on Discrimination Efficiency, Range test, Signal to noise ratio, examine correlation		
Bioregion	Xeric	Plains	Plains	Xerics	Mountians
Selected Metrics/Predictor Variables	Number of individuals of intermediate tolerance to nutrients and prefer cool water habitat Percent of hider individuals Percent of long-lived species with intermediate tolerance to sediment Percent of species that are lithophilic	Number of nonnative individuals Percent of species that are native herbivores Percent of hider individuals Percent of native species that are long-lived and tolerant to sediment Percent of native individuals that prefer warm-water habitats Number of individuals that are benthic and tolerant to sediment	Cymbella (old taxonomic classification) Richness Cymbella (new taxonomic classification) Percent Taxa Van Dam Trophic Class 5&6 Number of Individuals Van Dam Oxygen Class 1 Percent Taxa	Navicula (old taxonomic classification) Richness Cymbella/(Cymbella+Navicul a) (new taxonomic classification) Percent Taxa Bahls Mod. & Highly Motile Number of Individuals Van Dam Trophic Class 5&6 Richness	Navicula (new taxonomic classification) Richness Achnanthes (old taxonomic classification) Percent of Individuals Bahls Mod. & Highly Motile Number of Individuals Van Dam Trophic Class 1&2 Percent Taxa
Score Generation	For Metrics that Decrease with Increasing Stress = 100 x (95th Percentile/Metric Value) For Metrics that Increase with Increasing Stress = 100 x ((95th Precentile-Metric Value)/(95th Percentile-5th Percentile))		For Metrics that Decrease with Increasing Stress = 100 x (95th Percentile/Metric Value) For Metrics that Increase with Increasing Stress = 100 x ((95th Precentile-Metric Value)/(95th Percentile-5th Percentile))		
Threshold Determination	25th Percentile of Reference sites, Mean of all remaining sites (Very few Reference Sites)		25th Percentile of Reference sites, Mean of all remaining sites (Very few Reference Sites)		
Thresholds	Least-Moderate Disturbed Threshold = 52.21 Moderate-Most Disturbed Threshold = 41.56	Least-Moderate Disturbed Threshold = 66.76 Moderate-Most Disturbed Threshold = 28.79	Least-Moderate Disturbed Threshold = 51.10 Moderate-Most Disturbed Threshold =25.00		
Condition	13.77% Least-Disturbed 10.17% Moderately-Disturbed 9.59% Most-Disturbed		40.30% Least-Disturbed 41.51% Moderately-Disturbed 15.79% Most-Disturbed		
Stressors	Physical: Turbidity (NTU), Riparian Disturbance--Sum of All Types (Proximity Weighted Presence), Substrate Fines--Silt/Clay/Muck (%), Log10[Relative Bed Stability], Mean Bank Canopy Density (%) Chemical: Total Phosphorus (ug/L), Total Nitrogen (ug/L), Chloride (ueq/L), Sulfate (ueq/L), Closed Headspace pH				
Relative Risk	RR=(A) / ((B) Where A=(MBMS) / ((MBMS) + (LBMS)) and B=(MBLS) / ((MBLS) + (LBLS)) LB=Least disturbed biologic conditon LS=Least disturbed stressor conditon MB=Most disturbed biologic condition MS=Most disturbed stressor conition				

Table 17(cont.)—Biological Assessment Tool Development Process. Shows development process for each bioassessment tool.

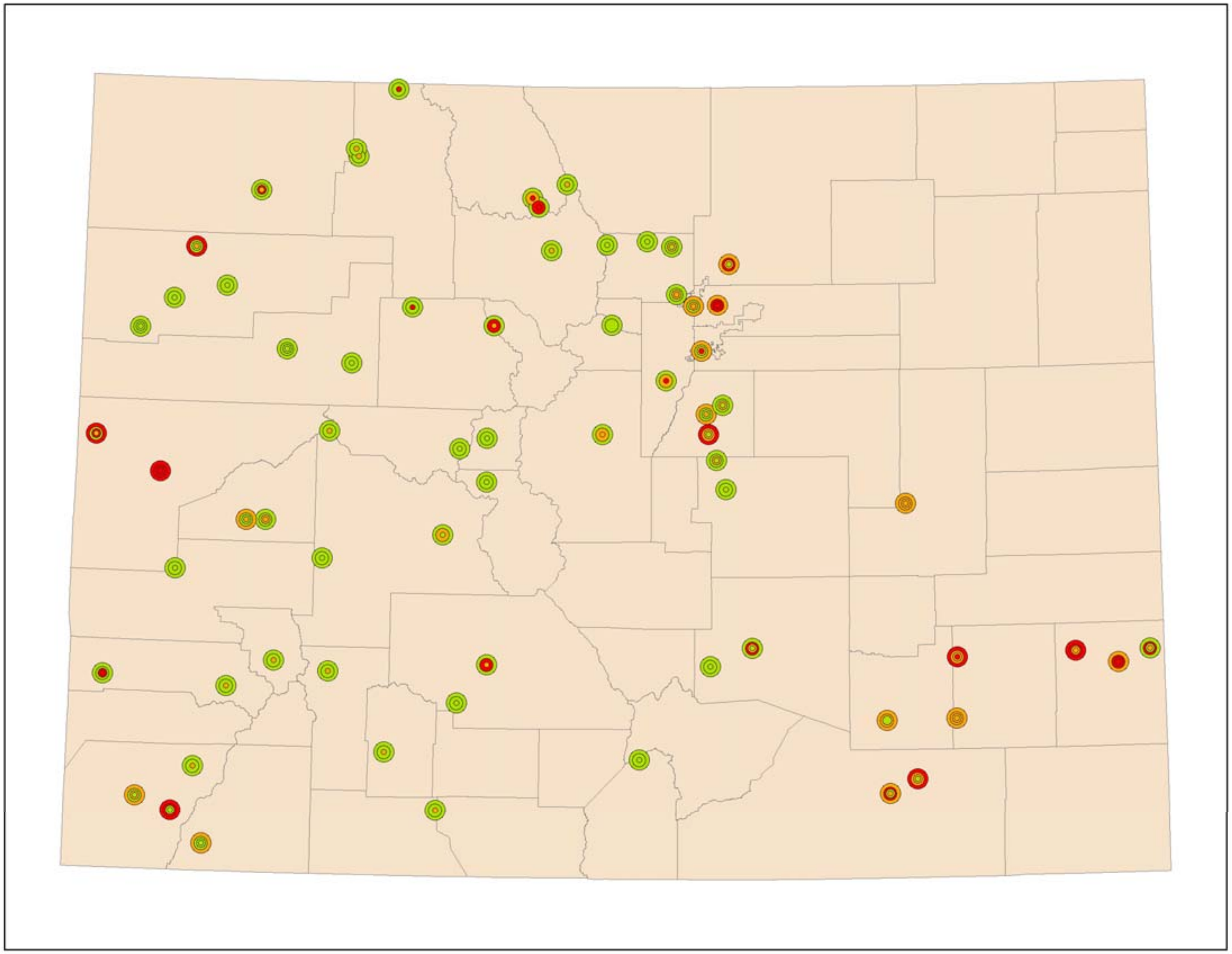

Figure 8—Final Classifications for each Bioassessement tool

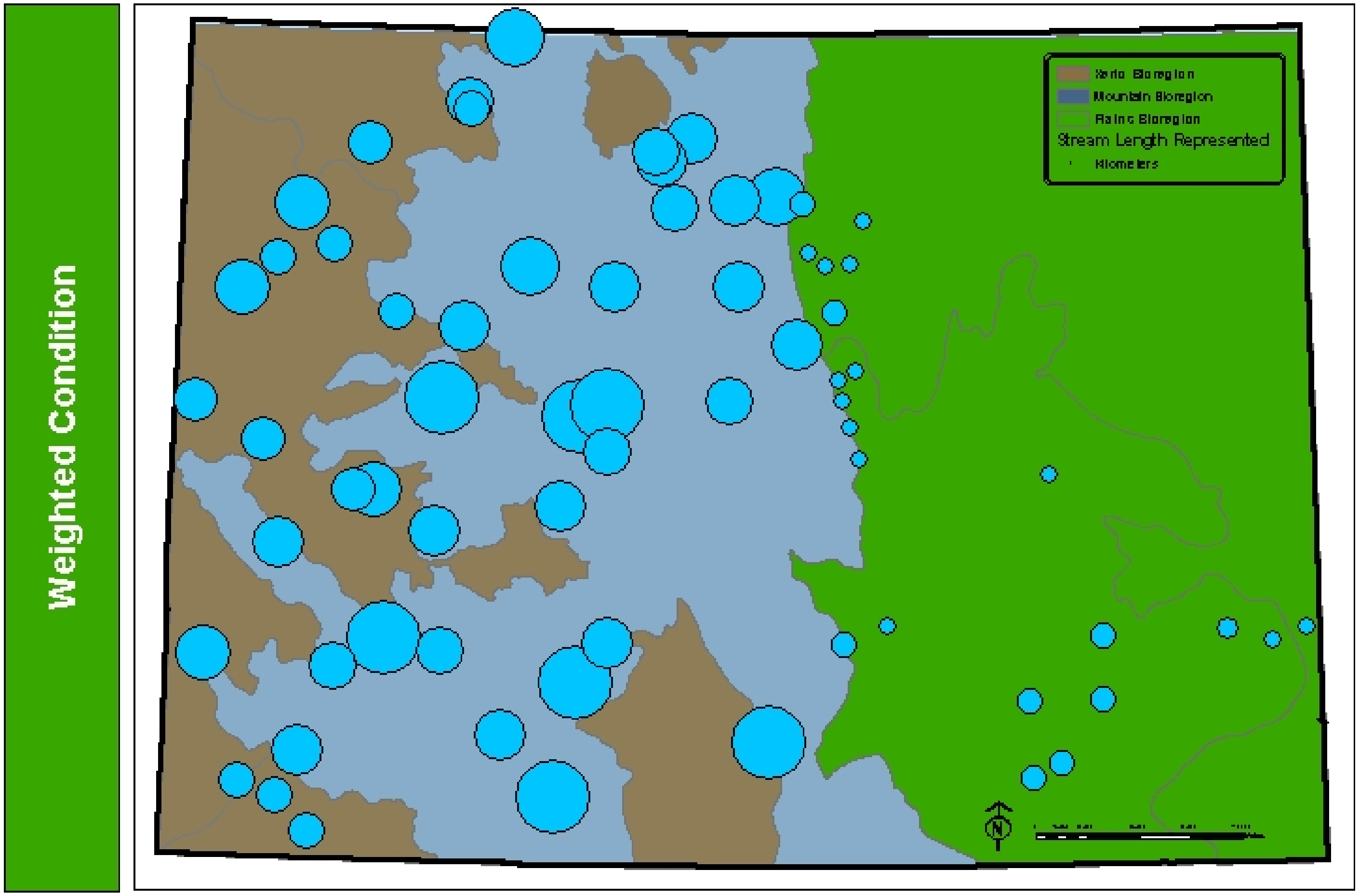

Figure 9—Stream Length Represented by EMAP Sites (WGT_Cond)

Colorado Dams

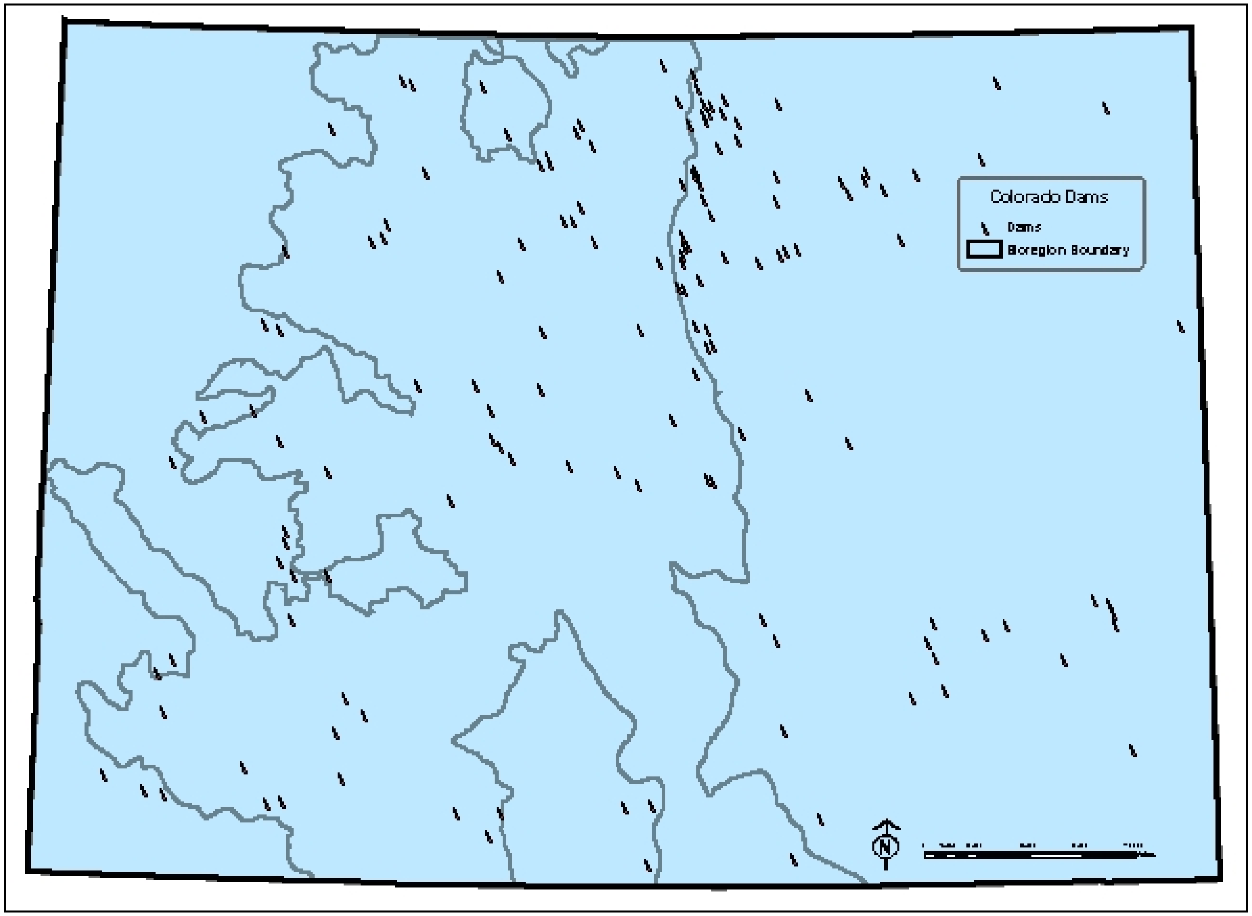

Figure 10—Dams in Colorado

Colorado Forest Density

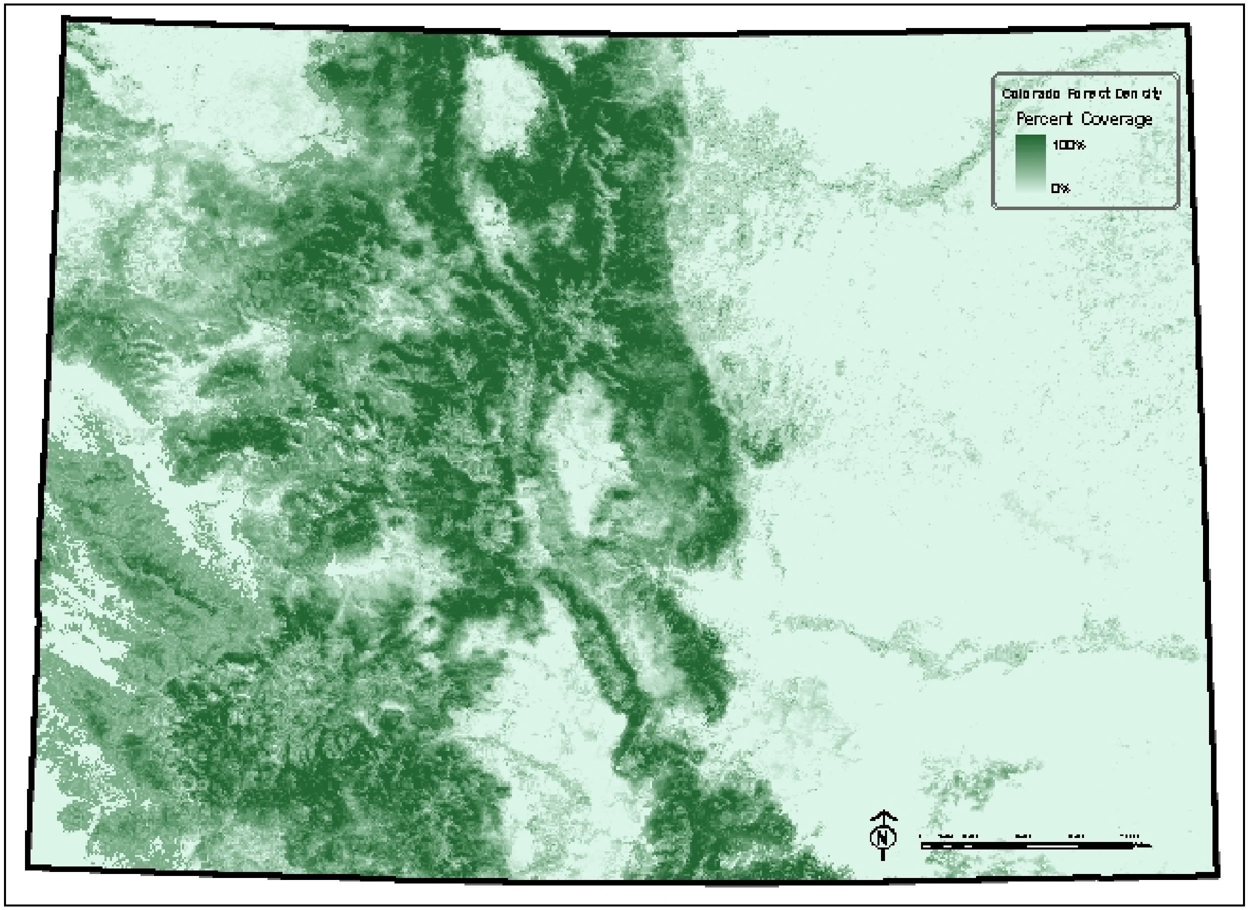

Figure 11—Colorado Forest Density

Colorado Disturbed Landuse

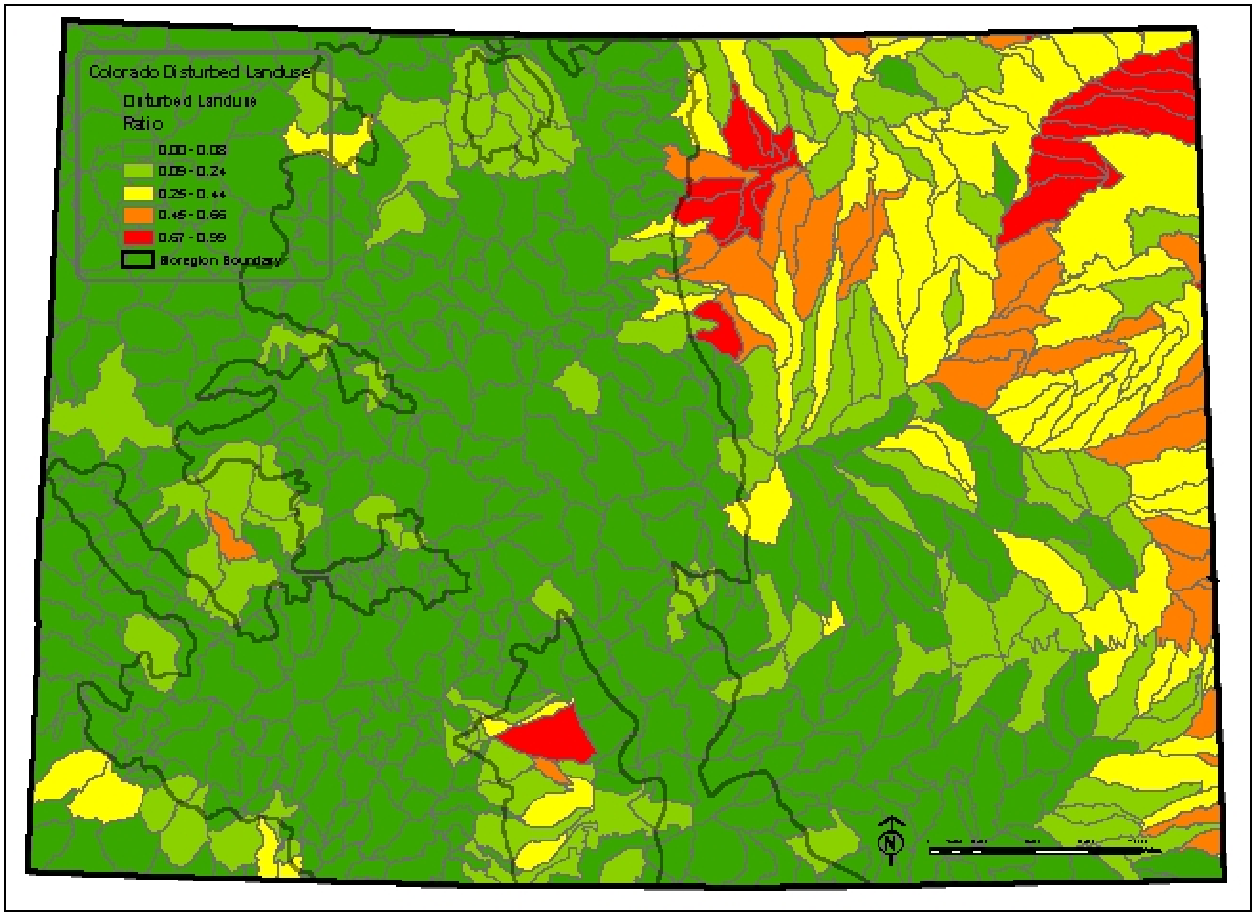

Figure 12—Colorado Disturbed Landuse Ratio

EMAP Site Land Cover Disturbance

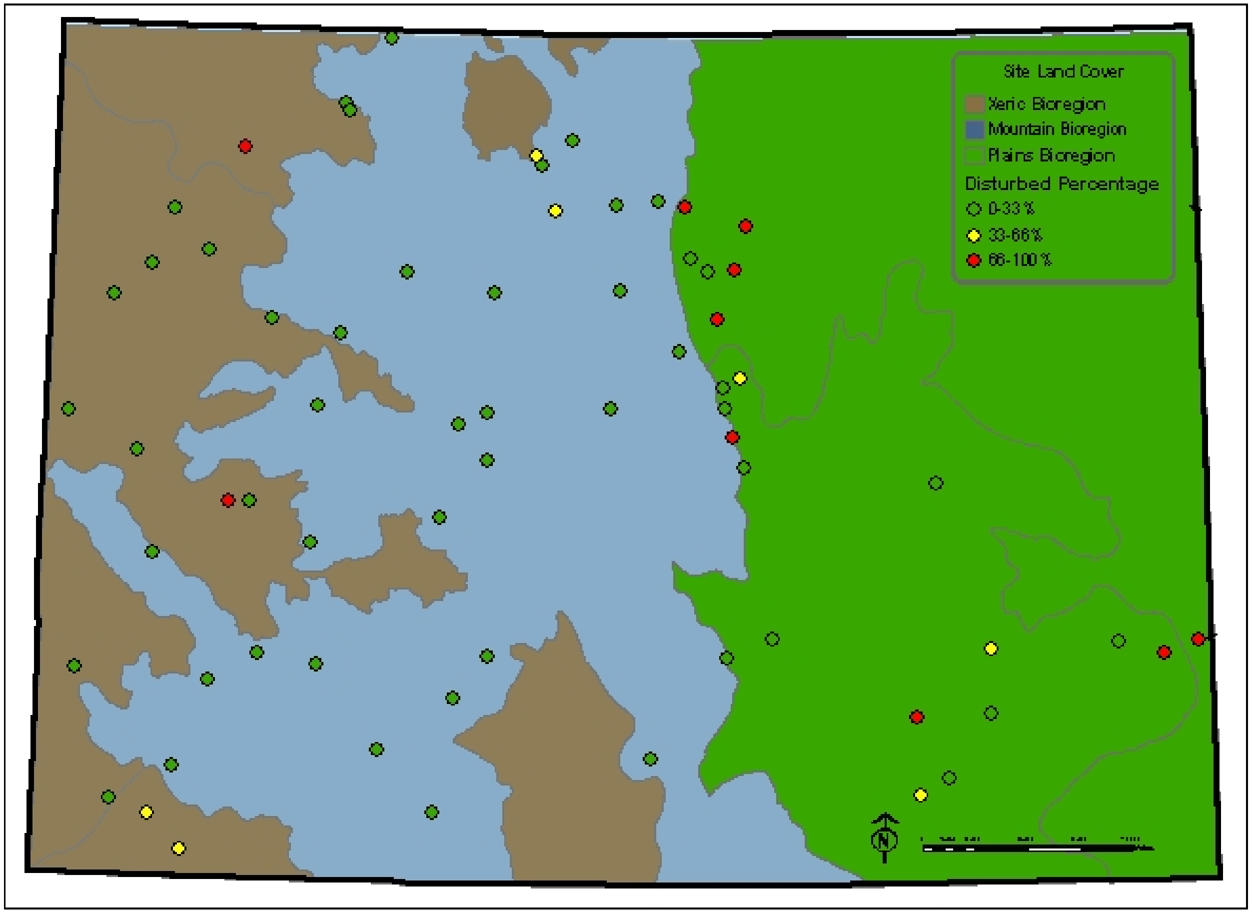

Figure 13—EMAP Site Land Cover Disturbance
Disturbance of land cover within 1 km radius buffer around each site.

Cause Category	Metals and pH Ammonia and organic enrichment Pesticides Pathogens Nitrate and sulfate Siltation
Source Category	Point sources (ie., WWTF) Agriculture / silviculture Urban and road runoff Resource Extraction
"Source" means the activities, facilities, or conditions that contribute pollutants or stressors. "Cause" means the pollutants and other stressors that contribute to the non-attainment of classified uses in a water body.	
Source: Colorado 2002 305b Report	

Table 18—Causes and sources affecting water bodies not protecting designated uses

Agriculture	•Non-irrigated crop production •Irrigated crop production •Specialty crop production (e.g. truck farming and orchards) •Pasture land •Animal feeding operations (unless permitted) •Aquaculture •Animal holding/management areas •Rangeland •Stream bank erosion
Silviculture	•Harvesting, reforestation, residue management •Forest management •Road construction/maintenance
Construction runoff	•Highway/road/bridge •Land development •Stream bank erosion
Urban runoff	•Storm sewers (source control) •Combined sewers (source control) •Surface runoff •Stream bank erosion
Resource extraction/exploration/development	•Surface mining •Subsurface mining •Placer mining •Dredge mining •Smelters •Mill tailings •Stream bank erosion
Land disposal (runoff/leachate from areas)	•Sludge •Wastewater •On-site wastewater systems (septic tanks, etc.)
Hydrologic modifications	•Channelization/dredging •Dam construction •Stream bank erosion •Bridge construction •Riparian modification •Flow regulation/modification
Other	•Highway maintenance and runoff •Off road vehicles
Source: Colorado 2002 305b Report	

Table 19—Non-point source human impacts to streams

*a priori** **Reference Designation (Study basis and input)**	**Description**	**Eclological Condition (Output of developed bioassessment tools)**	**Description**
Reference	Sites that are most representative of natural conditions within a given bioregion.	Least-Disturbed	Determined by specific bioassessment tool to exhibit minimally impacted biological communities.
So-So	Sites that are moderately impacted. These represent the majority of sites within each bioregion.	Moderately-Disturbed	Determined by specific bioassessment tool to exhibit moderately impacted biological communities.
Stressed	Sites that are degraded and represent a higher level of human impact.	Most-Disturbed	Determined by specific bioassessment tool to exhibit highly impacted biological communities.

Table 20—Reference Categories

A=	(MBMS) / ((MBMS) + (LBMS))	LB=	Least-disturbed biologic conditon
B=	(MBLS) / ((MBLS) + (LBLS))	LS=	Least-disturbed stressor conditon
Relative Risk=	(A) / (B)	MB=	Most-disturbed biologic condition
		MS=	Most-disturbed stressor conition

Table 21—Relative Risk Calculation

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