

Watershed Health: an Evaluation Index for New Mexico

Bill Fleming

Abstract—Although watersheds are not equally healthy, there are no generally accepted criteria for evaluating and comparing them. This paper suggests several criteria which numerically evaluate watersheds in four ways: (1) riparian health, (2) aquatic macroinvertebrate biodiversity, (3) hillslope soil loss and (4) upland land use/flood peak potential. Each criterion is semi-quantitatively evaluated on a scale of 1 to 10, with 1 the healthiest and 10 the least healthy. The index is applied to two subalpine watersheds near Santa Fe, New Mexico, comparing them using the four numerical criteria. The Rio en Medio, site of the Santa Fe Ski Basin, was rated “good” (with a score of 4.1), while an adjacent undeveloped watershed, the Rio Tesuque was rated “excellent” (with a score of 2.5).

Methodology

Four methodologies for evaluating watershed health are described and then combined to form a watershed health index. An example is presented comparing two adjacent watersheds with different land uses near Santa Fe, New Mexico.

Riparian Health

Several authors, such as Barbour and Stribling (1991), have suggested criteria for evaluating the health of riparian habitats in the Western United States. Although their criteria is heavily weighted toward stream habitats for fish, the index has been adapted for a wider range of species by others (Fleming and Schrader, 1998). Ten criteria are described in table 1, beginning with stream discharge necessary to support a healthy aquatic habitat for macroinvertebrates and fish. For an optimum environment, several authors, including Barbour and Stribling (1991) consider that 0.05 m³/sec (2 cfs) are necessary to support a high-quality, coldwater fishery. If less than 0.01 cfs are flowing, the habitat is considered “poor.”

Streambed geology and embeddedness are critical for the maintenance of necessary void spaces in the substrate for macroinvertebrate habitat. If more than 50 percent of the material is comprised of grain sizes in the gravel, cobble and boulder categories, the habitat is considered “optimum.”

In: Finch, Deborah M.; Whitney, Jeffrey C.; Kelly, Jeffrey F.; Loftin, Samuel R. 1999. Rio Grande ecosystems: linking land, water, and people. Toward a sustainable future for the Middle Rio Grande Basin. 1998 June 2-5; Albuquerque, NM. Proc. RMRS-P-7. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Bill Fleming is Associate Professor, School of Architecture and Planning, University of New Mexico, Albuquerque NM 87131.

Streams reaches are evaluated with a “random walk” method, in which the investigator crosses the stream in a zigzag pattern, stopping every two steps to determine the size of material in front of the instep of the wader (Sims and others 1995). At least 20 samples should be chosen in each reach and a range of grain size percentages calculated. If more than 50 percent of the substrate is sand size or smaller, the habitat is considered “poor.”

Structural vegetation diversity is important for birds and if grasses, shrubs and trees are present in the riparian zone, this criterion receives an optimum rating. Vegetation cover, expressed as a percent, is estimated by randomly choosing a transect direction to walk, noting at every other step whether or vegetation cover exists. Ninety percent vegetation cover is optimum, while less than 50 percent is considered poor. Vegetative diversity is evaluated by determining whether at least 10 different species occur in the riparian zone, which is scored as optimum (less than 3 species is considered poor). The width of the vegetation buffer is considered optimal if it exceeds 18 meters and poor if it is less than 6 m. Canopy shading is considered optimal if a mix of sun and shade, while full sun is considered poor.

The ratio of bankfull channel width to depth is optimal if less than 7 (Rosgen, 1994) and poor if more than 25 (a very wide and shallow stream). If the ratio of distance between riffles to stream width is between 5 and 7, heterogeneity for aquatic insects is optimal, while a ratio of more than 25 is considered a poor habitat (Barbour and Stribling, 1991). Upper bank stability is considered excellent if there are no vertical and unvegetated banks, while more than 50 percent of bank area in an unstable and eroding condition is rated poor.

Table 1—Riparian health indices.

Parameter Score	Excellent 0-0.1	Good 0.1-0.4	Fair 0.4-0.7	Poor 0.7-1.0
Flow (m ³ /sec)	>0.05	0.03-0.05	0.01-0.03	<0.01
Streambed geology	>50% boulders cobbles gravel	25-50%	10-25%	<10%
Embeddedness	<25%	25-50%	50-75%	>75%
Width/depth	<78-15	15-25	>25	
Bank stability	>90% stable	70-90%	50-70%	<50%
Buffer width	>18m	12-18m	6-12m	<6m
Vegetation diversity	>10 species	5-10	3-5	<3
Structural diversity	3 height classes	21	1 sparse	
Vegetation percent cover %	>90 %	70-90 %	50-70 %	<50
Canopy shading	mixed sun/shade	sparse canopy	mostly sun or shade	no shade

Biodiversity of Aquatic Insects

An important indicator of the long term health of a watershed are species of aquatic macroinvertebrates. Insects remain in streams during transitory periods of floods, drought, periods of turbidity or heavy metal inflow. The benthic insects are affected by chemical pollution and physical changes such as temperature pH, discharge and sediment resulting from upstream land use activities. Whether or not sensitive families of insects remain in a stream over the long term is a useful indicator of upstream watershed health.

Stoneflies are generally the order of insects most sensitive to human impacts such as organic sewage pollution, and if some of the more sensitive families are absent, it may be indicative of nitrogen or phosphorus in higher than natural concentrations. Usually stoneflies are a smaller percentage of the insects (10-20 percent) and may be the first to disappear with increased human impacts. Mayflies are also sensitive to watershed disturbances, but may be 20-40 percent of the total number, and may be the next to disappear in a stressed watershed. Caddisflies also include species sensitive to sedimentation, in particular, but some families are very tolerant and can live under highly disturbed conditions (for example Hydropsychidae). If an insect collection is dominated by midges or worms, the watershed and stream may be very degraded. The different families, and percentages of each family, are indicators of the health of the watershed.

The tolerance to watershed disturbance of the families of aquatic insects occurring in New Mexico is shown in table 2 (based on Winget and Mangum, 1979 and interpreted by Jacobi, personal communication, 1996). Higher numbers mean the insect is more tolerant to watershed disturbance, and those with an index of 10 may survive in stream systems with high concentrations of sediment, nutrients and metals. Low indices indicate that the family is sensitive to watershed disturbances (such as the Pteronarcyidae family of giant stoneflies which dominates the upper Pecos watershed).

To determine the biotic tolerance index for a watershed above a sampling site, at least 100 insects are collected and the numbers of each family determined. Numbers of each family are multiplied by the tolerance index, and these values added. The total number is then divided by the number of insects collected to determine a biotic index for the watershed or stream reach. If the index is less than 3.5, the watershed condition may have little upstream disturbance, whereas values exceeding 7.5 may be highly impacted.

Hillslope Soil Loss

The Universal Soil Loss Equation has been used to predict erosion rates in the Midwest for over 40 years, but only recently has been adapted for Western forest and range lands (Brooks and others 1997). In the West, the form of the equation is usually the "modified" variety because the vegetation factor is better suited to forest and range lands than the "agricultural practice" factor validated for hundreds of erosion plots in the Midwest. The "modified universal soil loss equation" (MUSLE) is used here as an indicator of

Table 2—Tolerance index for New Mexico macroinvertebrates.

Order	Family	Tolerance index (10= most tolerant)
Ephemeroptera (Mayflies)	Tricorythidae	10.0
	Baetidae	6.7
	Siphonuridae	6.7
	Caenidae	6.7
	Ephemerellidae	4.4
	Heptageniidae	4.4
	Leptophlebiidae	3.3
Plecoptera (Stoneflies)	Perlodidae	4.4
	Taeniopterygidae	4.4
	Nemouridae	3.3
	Capniidae	3.0
	Pteronarcyidae	2.2
	Chloroperlidae	2.2
	Perlidae	2.2
	Leuctridae	1.7
	Hydropsychidae	10.0
Trichoptera (Caddisflies)	Limnephilidae	10.0
	Psychomyidae	10.0
	Leptoceridae	5.0
	Brachycentridae	2.2
	Lepidostomatidae	1.7
	Rhyacophiliidae	1.7
	Elmidae	10.0
Coleoptera (Beetles)	Hydrophilidae	6.7
	Dytiscidae	6.7
	Halplidae	5.0
Odonata (Dragonflies and Damselflies)	most families	10.0
Diptera (Aquatic Flies)	most families	10.0
Non-insects (snail, leeches, aquatic worms etc.)	most families	10.0

upland watershed health because it integrates four factors critical in evaluating hillslopes: (1) precipitation intensity, (2) slope steepness and length, (3) soil stability, and (4) vegetation cover.

The power of high-intensity, short-duration rainstorms to erode soil in New Mexico watersheds has been evaluated by the Soil Conservation Service (now the National Resource Conservation Service, USDA, 1977), and dimensionless values generally increase with elevation. In the Rio Grande Valley near Albuquerque, rainfall intensity corresponds to a contour with a value of "20", whereas the crest of Sandia Peak has a value of "60" with much more powerful summer rainfall impact on soil.

With steeper and longer slopes, runoff will attain higher velocities and erode more soil, if other factors remain the same. Watershed management texts interpret "slope factors" to be used in the soil loss equation (Brooks and others 1997). Slope steepness is quickly measured in the field with a clinometer and slope length determined with topographic maps.

Depending on the grain size composition, percent of organic matter and infiltration capacity of soil, erosion potential changes (Brooks and others 1997). Soil surveys evaluate the "K factor", or erodibility factor, for soils, or publish grain size compositions which allow K factors to be calculated.

While the previous three factors in the soil loss equation usually remain the same with watershed disturbance, the vegetation cover may change significantly when development occurs. Activities such as logging, grazing, ski trail construction, roads, and housing development reduce the vegetation cover, sometimes eliminating the most important factor in protecting soil from intense rainfall. Watershed management texts list vegetation cover factors with varying grass cover percentages and types of overstory protection (Brooks and others 1997). Field surveys of cover percent are made by randomly choosing several hillside transects and pacing 10 steps per transect, noting whether or not the front of the pace has vegetation cover or bare soil.

The four factors are then multiplied together, resulting in soil loss in tons/acre/year. While forest and range landscapes in the Western United States have not been validated with same rigor as agricultural lands in the Midwest, values of relative erosion rates are useful in rating watershed health. The NRCS estimates that “tolerable” soil losses are those exceeding 5 tons/acre/year, while Pimentel (1995) cites evidence that 0.5 tons/acre/year is an average worldwide value for the rate of soil formation (lower in arid regions and higher in humid landscapes).

A simplified health index for soil loss relates erosion rates to a what could be considered a sustainable rate of 1 ton/acre/year, which receives an “excellent” rating of one. As rates increase, the rating increases, with a soil loss of 10 tons/acre/year having a rating of 10 (poor watershed condition). It is important to realize that many landscapes in New Mexico have erosion rates exceeding 10 tons/acre/year, resulting in a “poor” rating for these areas.

Upland Land Use and Flood Peak Impacts

Land use in upper watersheds clearly has impacts on watershed health and downstream flood peaks. For watersheds of less than a square mile, the “rational equation” is often used by planners to predict downstream flood peaks, based on watershed area, hourly rainfall intensity and a land use factor. For larger and more diverse watersheds, a method developed by the former US Soil Conservation Service (now the NRCS), using runoff curve numbers, is a generally accepted approach (Brooks and others 1997). The SCS approach is similar to the rational method, but uses a “runoff curve number” to evaluate land use and the watershed’s hydrologic response in the form of flood peaks.

Since the objective here is not to predict changes in flood peaks with land use alterations, but only to indicate the critical factor involved in flood peak modifications, the curve number will be used as an indicator for upland land use as it relates to flood peak generation. As published by the SCS in 1972, runoff curve numbers range from 6 to 94, depending on the type of land use and how it impacts the infiltration of surface runoff into the vegetation/soil cover. Lower numbers indicate high infiltration rates and high numbers low infiltration rates and consequent high flood peaks (Brooks and others 1997). Table 3 shows one version of curve numbers, and these are modified simply by division by 10 so the index will correspond to the other three parameters in this analysis.

Table 3—Runoff curve numbers and watershed land use (Marsh, 1998 and Brooks and others 1997).

Land use	Curve number
Commercial (roads, shopping centers)	7.0-9.5
Residential (single family)	3.5-5.0
(multifamily)	6.0-7.5
Industrial (light)	5.0-8.0
(heavy)	6.0-9.0
Parks	1.0-2.5
Playgrounds	2.0-7.5
Cultivated farmland (flat)	1.0-4.0
(rolling: 5-10 percent slope)	2.5-5.0
(hilly: 10-30 percent)	3.0-6.0
Rangeland (poor condition)	7.0-9.0
(fair condition)	5.0-8.5
(good condition)	4.0-8.0
Forest (poor condition)	4.5-8.5
(fair condition)	3.5-8.0
(good condition)	2.5-7.5

Application to Watersheds Near Santa Fe

The methodology is applied to two adjacent watersheds in the Santa Fe National Forest, 15 miles northeast of Santa Fe, New Mexico in the Sangre de Cristo Mountains. Each watershed is slightly over one square mile in area, ranging in elevation from 9,800 feet to 11,100 feet. The Rio en Medio watershed is the site of the Santa Fe Ski Basin, in which approximately 35 percent of watershed area has been developed with parking lots, lodges, septic tank fields, ski runs and lifts. The Tesuque watershed is in a relatively undeveloped condition, with one road used only for hiking, ski touring and the maintenance of telecommunications antennae on Tesuque Peak. Table 4 summarizes the results.

Riparian health: Two riparian surveys were done in each watershed, one at the base and a second approximately 0.3 miles upstream. Results of the two surveys were averaged for each watershed. The Rio en Medio had an average rating of 2.6 and Tesuque Creek 0.7. Major differences were less riparian vegetation and more sediment and embeddedness in the Rio en Medio.

Biodiversity of aquatic insects: A total of 486 insects were collected from the Rio en Medio and 518 from the

Table 4—Watershed health indices for Santa Fe watersheds.

Watershed health index	Rio en Medio	Rio Tesuque
Riparian health	2.6	0.7
Macroinvertebrate biodiversity	4.3	3.1
Hillslope erosion rates	2.2	0.7
Land use/flooding potential	7.3	5.5
Total (divided by 4 indices)	4.1	2.5

Rio Tesuque by the Santa Fe Preparatory School during 1993-94. Rio en Medio had an index of 4.3 and Tesuque Creek 3.1, mainly resulting from a greater percentage of stoneflies in the Tesuque (29 percent compared with 19 percent in the Rio en Medio).

Hillslope soil loss: Surveys on three slopes in both watersheds indicate an average erosion rate in the Rio en Medio of 2.2 tons/acre/year, compared with 0.7 tons/acre/year in the Tesuque. The difference results from hillslopes in the Rio en Medio which have lower vegetation cover percentages than the Tesuque.

Upper land use and flood peak impacts: Evaluations of land use in the Rio en Medio resulted in a runoff curve number of 7.3 because of the extensive ski area development. The relatively undeveloped Tesuque watershed had a lower curve number of 5.5. The flooding potential of both watersheds is relatively high for forested areas because of thin soil covers which don't store large amounts of soil moisture and ground water for later baseflow.

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