Ecosystem Analysis at the Watershed Scale

Federal Guide for Watershed Analysis

Section II
Analysis Methods and Techniques

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Overview

Introduction

Watershed analysis is a procedure used to characterize the human, aquatic, riparian, and terrestrial features, conditions, processes, and interactions (collectively referred to as "ecosystem elements") within a watershed. It provides a systematic way to understand and organize ecosystem information. In so doing, watershed analysis enhances our ability to estimate direct, indirect, and cumulative effects of our management activities and guide the general type, location, and sequence of appropriate management activities within a watershed.

By memorandum dated August 28, 1995, Section I of *Ecosystem Analysis at the Watershed Scale: Federal Guide for Watershed Analysis* (*Federal Guide*) was transmitted to Federal agency field managers and supervisors to guide new watershed analyses initiated within the area covered by the Northwest Forest Plan (NFP). Section I of the *Federal Guide* provides an overview of the analysis process and related considerations, including detailed descriptions of the six steps for conducting ecosystem analysis at the watershed scale. The six steps lead investigators through a series of questions to characterize the watershed, focus the analysis on essential issues, describe and understand current and historical conditions and processes, interpret the results, and develop recommendations for subsequent action by responsible officials.

This document represents the first installment of Section II of the *Federal Guide,* Analysis Methods and Techniques. Section II is a technical supplement to Section I, providing a "tool box" of optional analytical methods and techniques to address core topics and questions, as well as other pertinent issues identified by watershed analysis teams. The goals of Section II are to meet NFP goals, ensure scientific credibility, provide "methods and techniques," and provide for cooperation and coordination with other watershed analysis processes.

Section II is not a comprehensive set of methods and techniques for addressing all core topics or other aspects of watershed analysis. Analysis teams are encouraged to use any standard analysis methods and techniques that are widely accepted by local resource specialists and that are appropriate to analyze issues in their watersheds. Modules from other analysis processes (e.g., Washington DNR's process) may have utility and can be used if appropriate.

As existing analysis methods and techniques are revised or new ones developed in the future, they will be issued as subsequent installments to this initial set.

Levels of Analysis

Many of the methods and techniques include multiple levels of analysis, referred to as Level I, Level II, and, in some cases, Level III. Level I methods generally represent preliminary assessment procedures that may be appropriate for watershed characterization (step 1 in the analysis process) or cases where the issues in the watershed (identified in step 2 of the analysis process) require only a cursory assessment of the topic. Levels II and III methods generally represent more detailed assessment procedures that may be appropriate for steps 3, 4, 5, or 6 of the analysis process or when issues require a more thorough assessment of the topic.

Teams planning to conduct watershed analysis should first review both Sections I and II of this *Federal Guide*. The process is intended to be flexible and adaptable but still follow a consistent overall approach. Teams can be most efficient by developing an understanding of the entire six-step process, anticipating information and analysis needs, and planning for ways to synthesize the analysis at each step along the way.

Analysis Methods and Techniques

The following analysis methods and techniques are organized by the core topics they address. For example, the methods and techniques for analyzing landslides, debris flows, bank erosion, gully erosion, and sediment yield are grouped under the heading "Erosion Processes." Methods and techniques that do not directly address core topics are included under the heading "Other Topics."

All of the methods and techniques generally follow a similar format. The **purpose** statement describes the intent and limitations of the analysis method. It may reference specific core questions or analysis steps addressed by the method. **Assumptions** considered by the authors of the method are described. **Data needs** to perform the method are defined. Expected **products** that would result from the method are listed. Step-by-step **procedures** are described. Finally, **references** used in the development of the procedure are listed.

Erosion Processes

Landslides

Level I

Prior to detailed evaluation of specific landslide types (debris flows and deep-seated landslides), a general assessment of landslide occurrence is required for the analysis area that includes consideration of all forms of mass wasting. The following qualitative evaluation example applies to this module and to the Debris Flows module.

Purpose

The following methods and techniques can be used to characterize and assess the current conditions and trends of erosion processes related to landslides in the watershed by lithologic unit, landform type, and slope position. The relative probability of landslide occurrence for the analysis area is rated using a low to high or extreme scale. The influences and relationships between landslide processes and other ecosystem processes are evaluated by estimating sediment delivery to streams by landslide type and slope position relative to streams.

Data Needs

1. Topographic maps (1:62,500).

2. Recent aerial photography (1:24,000 or 1:12,000).

3. Geologic map(s) (1:500,000 to 1:100,000). Define rock types according to specific physical characteristics; not just geologic/formation name.

   Note: The State Geology Map is not at a scale that can be used for detailed watershed assessment. Generally, more detailed mapping is needed to do an adequate analysis of slope stability at the larger scales. Where rock structure or orientation is critical to understanding the effects of natural landslide occurrence and management activities on slope stability, a structural geology layer should also be included in the Data Needs assessment prior to analysis.

4. Existing landslide inventory maps, descriptive reports, or analyses, if any.

5. Existing analyses of groundwater/wells/aquifers in the watershed.

Products

1. A 1:62,500 scale map displaying areas of equivalent landslide occurrence potential as a function of lithology and slope angle.

2. Tabulations of the approximate number of occurrences of each landslide type by lithology, slope class, slope position (upper, middle, or lower third of the slope), landform, and land-use activity.

3. Brief narrative descriptions of landslide sizes and types, distributions, and associations.

4. Brief narrative description of sediment delivery potential.

Procedure

1. Scan any existing landslide reports and/or inventory maps of the area for information about types and patterns of mass movement.

2. Using geologic maps at 1:100,000 to 1:500,000 scale, identify the major lithologic units for the analysis watershed. According to the generalized grain-size, durability, and jointing and fracture patterns for each unit, assign one of the following terms indicating susceptibility to mechanical and chemical processes: resistant, intermediate, weak, or unconsolidated.

3. Scan aerial photographs (1:12,000 or 1:24,000 scale) of representative areas in each lithology. Observe and record the association of landslides with typical landforms or geologic structure, typical landslide type(s) (shallow-rapid or deep-seated), relative number of landslide occurrences, slide locations relative to position on the slope or landform. Note associations between type of land-use and slides where present. Estimate minimum, maximum, and average sizes of landslides for each lithology and slide type.

4. Talk to geomorphologists and road maintenance personnel working in the area to get their view of landslide distribution in the area, their causes, and the types of storms and antecedent conditions that generate them.

5. Review all records of groundwater studies or site specific investigations made in unstable terrain.

6. Obtain or develop a slope zone map for the area; use slope classes pertinent to increased incidence of slope failure where that information is available. Otherwise, the following slope classes may be used: 0-30%, 31-50%, 51-70%, and greater than 70%.

7. Rate the relative landslide potential of each slope class for each lithologic unit, according to the following rating matrix:

Relative Landslide Potential Matrix

Slope Class /Rock Type	Resistant	Intermediate	Weak	Unconsolidated
<30%	Low	Low	Low	Low
30-50%	Low	Moderate	Moderate	Moderate
51-70%	Moderate	Moderate	High	High
>70%	Mod-High	High	Extreme	Extreme

NOTE: Modify the ratings as necessary to reflect field conditions observed during aerial photo interpretation.

While the criteria for high, medium, and low do not have to be consistent across the Region, they should be consistent within broad geomorphic areas where geology, climate, slope morphology, and soils are similar. Definitions of relative landslide occurrence must be developed cooperatively with other agencies and Forests involved in watershed analysis on similar terrain.

8. Display landslide potential ratings on 1:62,500 scale maps by lithologic unit. Estimate percentages of the analysis watershed's area in each rating class.

9. Estimate landslide sediment delivery to streams (in terms of percent failed material delivered) based on patterns of slide locations relative to streams. Tabulate the information according to lithologic units, subdrainages, or other associations that appear.

Mechanistic Modeling

Models that estimate probability of landslide occurrence, such as LISA, may be helpful in the evaluations if they are already calibrated for the area, if analysts are experienced in the model's use, and if the data required can be generated within the timeframe of the Watershed Analysis. Such models can be useful for defining stratification criteria and screening for slope stability, and integrating their use with field- and aerial-photo-based analyses can refine results of both approaches. GRID and TIN modules available in ARC/INFO provide the capability to electronically generate slope configuration needed to determine groundwater properties as well as sediment delivery. In watersheds where data for modeling are absent, each Forest should work to develop the data so LISA and other models can be calibrated. The results of the modeling and calibration can be used later in the analysis process to improve project level assessments.

References

Hammond, C, Hall, D., Miller, S.,and Swetik, P. 1992. Level I Stability Analysis (LISA) documentation for version 2.0. Gen. Tech. Rep. INT-285. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 190 p.

Lloyd, J.C., in review, Basin Study Checklist for Level I; In: National Slope Stability Guide; Prellwitz, R.W., and Koler, T.E., coordinators; U.S.D.A. Forest Service, Washington D.C. Office.

Schuster, R.L., and Krizek, R.J., ed. 1978. Landslides: Analysis and Control. Transportation Research Board Special Report 176, National Academy of Sciences, pp. 12-80.

Way, D.S. 1978. Terrain Analysis. Dowden, Hutchinson, and Ross. Stroudsburg, PA. 438 pp.

Level II

Purpose

The following methods and techniques can be used for a more detailed assessment of landslide processes and their influence on sediment delivery. This is accomplished by estimating the spatial and temporal frequency of landslide types and sediment production from landslides in different parts of the watershed.

Assumption

"Landslide" as defined here, includes all hillslope failures such as slumps, earth flows, block failures, and rockfall. Debris flows are considered in another module. Surface erosion and gully erosion are also considered in other modules.

Data Needs

In addition to data needs listed in the Level I section:

1. Topographic maps.

2. Vegetation map.

3. Rainfall map.

4. Land-use map.

Products

1. A tabulation of landslide characteristics by landslide type within each stratification unit, including size, incidences per unit area (sampled average and range), sediment delivery category, and association with topography, land use, vegetation, and cause. Note that the landslide incidence is not a rate, since ages of the slides are not known. Instead, it is an index of landslide susceptibility.

2. A discussion of the distribution, intensity, and cause of landslides in each stratum and their association with land-use activities.

3. A map (1:24,000) of the landslide stratification units that shows relative values (high, medium, low) of sediment production to streams from landsliding. While the criteria for high, medium, and low do not have to be consistent across the Region, they should be consistent within broad geomorphic areas where geology, climate, slope morphology, and soils are similar. Definitions of relative sediment production must be developed cooperatively with other agencies and Forests involved in watershed analysis on similar terrain.

4. A tabulation of landslide characteristics by landslide type and land use within each stratification unit, including size, sediment delivery category, and association with topography, vegetation, and cause.

5. A tabulation of landslide rates by landslide type and land use within each stratification unit, including annual incidences per unit area, annual volume of sediment mobilized per unit area, and annual volume of sediment delivered per unit area of the land use. Results will be good to well within an order of magnitude, and are likely to be valid to plus or minus 50%.

Procedure

1. Carry out a Level I evaluation, as described earlier.

2. Randomly select areas within each stratification unit for mapping of landslides from aerial photographs. It is useful to select at least three sites within each stratum for mapping so that the consistency of results can be assessed within a stratum. A "site" is usually the area depicted on an aerial photograph, although entire subwatersheds may be sampled, or specified lengths of road. The type of sampling site used depends on the types, distribution patterns, and number of landslides present, and is selected to best represent that information.

3. For each cataloged landslide, tabulate size (to order of magnitude: <10 m^2, 10-100 m^2, 100-1000 m^2, >1000 m^2; this is easiest if a template is drawn on acetate that shows the cut-off sizes for each class at the scale of the photos being used. Other size classes or more finely divided classes may be used if they are more relevant to the types of landslides present), sediment delivery category (high, medium, low), topographic position (e.g., swale, planar slope, inner gorge), association with land use (e.g., clearcut, road fill, grazing), vegetation type (e.g., forest, grassland, young second-growth conifer), apparent age (obviously recent: 0-10 years, fresh scars; recent-historic: 10-50 years, distinct successional vegetation; older: mature revegetation), and perceived cause if evident (e.g., undercutting, road drainage).

4. Measure or estimate the area of each land-use type and vegetation type in each sampled area, and the length of road present. If this information is not available from a GIS, linear features can be measured using methods such as those presented by Mark (1974), and areas by using point counts (Van der Plas and Tobi 1965).

5. Landslides portrayed on existing landslide maps can be tabulated by stratum in a similar fashion where appropriate data are available.

6. Compare results for each of the samples within a stratum. If they agree relatively well (i.e., patterns of distribution are similar and frequencies agree to within an order of magnitude), then the stratum is relatively well characterized. If results vary widely and some frequencies are high, then additional photos from the stratum should be scanned to determine whether the stratum should be subdivided further to better reflect controlling variables, or whether a larger sample set is required to characterize the stratum. If landslide frequencies in the stratum are variable but low, no further work is necessary. "High" and "low" are relative to values in other stratification units.

7. Estimate the minimum size of recognizable landslides of each type in each of the stratification units or land-use/vegetation categories.

8. Use the tabulated results to describe the association of landslides of various types with land-use activities or vegetation in each of the strata, and note the resolution. Factor in existing map data or knowledge about landslide types that could not be effectively analyzed at this intensity of analysis (e.g., small stream-bank failures) and their probable contribution of sediment to the fluvial system; comment on the likelihood of small, undetected, sediment-producing slides. Consider the effects of landslides on groundwater transmission and local wells. Aquifer protection may be critically important in some watersheds.

9. Map landslide distribution on sequential photo sets in the previously sampled areas, and note the type and size of each landslide. Tabulate age category (years since the landslide occurred; use the midpoint of the interval between the last photo that does not show the slide and the first that does). If land use is relatively stable and no extreme storms or prolonged droughts have occurred within the period, two photo sets spanning a 15-year period may be sufficient. If there has been an extreme climatic event, photos should be selected to closely bracket the event, and this period should be evaluated independently.

10. Measure the area of each land-use type and vegetation type for each date sampled, and the length of road present. Linear features can be measured using methods such as those presented by Mark 1974, and areas by using point counts (Van der Plas and Tobi 1965).

11. Examine climatic records to identify the major storms in each photo interval.

12. Randomly select for field visits about five examples of each important landslide class,

making sure that each important stratification unit is well represented. Inaccessible examples can be replaced by similar accessible ones, but this must be noted.

13. At each field site, estimate the average depth of the landslide (plus or minus 25%), the area of the scar (plus or minus 25%), and the volume of sediment remaining in storage on the slope (plus or minus 25%). Look for evidence of the cause of failure.

14. Characterize landslide types by average volume and delivery ratio for different stratification units. A geometric average will be more useful than an arithmetic one if volumes are distributed log-normally.

15. For landslides not associated with linear features such as channel banks or roads, calculate landslide delivery per unit area of the associated land type (e.g., land-use or vegetation subcategory), and divide by the sampled interval duration to calculate average input per year. If the area of the land type (e.g., clearcut area) changed between photo sets, use the average value.

16. For landslides associated with linear features, calculate input rate per unit length of the feature.

17. Tabulate average annual input per unit area for each land use in each stratification unit by multiplying the average rate by either the proportion of the stratum in that land category or the length of linear features per unit area of the stratum. This shows the overall importance of sediment production from each land-use type in the stratum.

18. Estimate the size and shape of sediment particles that are likely to result from slides and channel scour for each soil/geologic component of the watershed. Determine potential for deposition of those sediments throughout the stream system.

Link to Project Level Analysis

Increased knowledge of specific portions of a watershed analysis area will occur as projects, such as restoration and vegetation management are implemented. The conclusions developed in the preliminary and detailed phases of watershed analysis as outlined in this *Federal Guide* must be reassessed in light of that new information. All facets of watershed condition, and protection and restoration needs are open for discussion and change during project investigation and analysis.

References

Amaranthus, M.P., Rice, R.P., Barr, N.R., and Zeimer, R.R. 1985. Logging and forest roads related to increased debris slides in southwest Oregon. Journal of Forestry, Volume 83, Number 4, pp. 229-233.

De la Fuente, J, and Haessig, P. May 1993. Salmon Sub-basin Sediment Analysis. Final Report for Interagency Agreement #14-16-0001-91522 between the U.S. Forest Service and the U.S. Fish and Wildlife Service, Project No. 91-HP-911333-1331-1046.

Dietrich, W.E. et. al. August 1992. Erosion Thresholds and Land Surface Morphology. Geololgy, v. 20, p. 675-679.

Foggin, G.T., and R.M. Rice. 1979. Predicting slope stability from aerial photos. Journal of Forestry 77(3):152-155.

Furbish, D.J., and Rice, R.M. Predicting landslides related to clearcut logging, northwestern California. Mnt. Res. Develop. 3(3):253-9, 1983.

Gallegos, A.G., and Barnes, J. Watershed analysis & fish habitat study for the Pilot Creek EIS. Six Rivers National Forest, open file report, 1993.

Hack, J.T., and Goodlett, J.C., 1960, Geomorphology and Forest Ecology of a Mountain Region in Central Appalachians, Geological Survey Professional Paper 347.

Hammond, Carol. et.al. April 1992. Level I Stability Analysis (LISA) Documentation for Version 2.0. Intermountain Research Station, General Technical Report INT-285.

Mark, D.M. 1974. Line intersection method for estimating drainage density. Geology 2(5):235-236.

Montgomery, D.R., and Dietrich, W.E. 1989. Source Areas, Drainage Density, and Channel Initiation, Water Resources Research, Vol 25, No. 8, pages 1907-1918.

Prellwitz, R., and Koler, T. (Coordinators) In Press, National Slope Stability Guide. USDA Forest Service.

Raines, M.A., and Kelsey, H.M. Sediment budget for the Grouse Creek basin. Humboldt County, California. Dept. of Geology, Western Washington Univ., M.S. thesis, 1991.

Reid, L.M., and T. Dunne. 1992. Rapid evaluation of sediment budgets. Draft dated May 29,1992.

Rice, R.M., and Pillsbury, N.H. Predicting landslides in clearcut patches. In: Proceedings of the Exeter Symposium; July 19-30, 1982. IAHS Publ. 137, p.308-11.

Selby, M.J. 1982. Hillslope Materials and Processes. Oxford University Press. 264 pp.

Slosson, J.E. 1979. Recognition of landslides. Pp. 113-127 in: D. Buesch (ed.), Geomorphic Applications in Engineering Geology. Short course held at Cal. State University Los Angeles, Nov. 10-11, 1979. Reprinted by the Southern California Section of the Association of Engineering Geologists.

Swanson, F., Janda, R.J., Dunne, T., and Swanston, D., 1982, Sediment budgets and routing in forest drainage basins: Gen. Tech. Report PNW-141. PNW For. and Range Exp. Stn., Portland OR, 165 p.

Swanson, F.J. 1980. Geomorphology and Ecosystems, in Forest: Fresh Perspective from Ecosystem Analysis. Proceedings 40th Annual Biology Colloquium 1979, Richard W. Waring, ed. OSU 1980.

Swanston, D.N. 1981. Effect of Geology on Soil Mass Movement Activity in the Pacific Northwest. USDA, Forest Service, Pacific Northwest Forest and Range Experiment Station, Forestry Sciences Laboratory, Corvallis, OR.

Swanston, D.N. tech.ed. Proceedings of a workshop on slope stability: problems and solutions in forest management. USDA Forest Service, General Technical Report PNW-180, 121 pp, 1985.

USDA Forest Service. August 1980. An Approach to Water Resources Evaluation of Non-point Silvicultural Sources (A Procedural Handbook). Lee A. Mulkey, Project Officer, EPA-600/8-80-012.

USDA Forest Service. 1993. Slope Stability Reference Guide for National Forests in the United States. Washington D.C.

Van der Plas, L., and A.C. Tobi. 1965. A chart for judging the reliability of point counting results. American Journal of Science 263:87-90.

Way, D.S. 1978. Terrain Analysis. Dowden, Hutchinson and Ross. Stroudsburg PA, 438 pp.

Debris Flows

Level I

Prior to detailed evaluation of specific landslide types (debris flows and deep-seated landslides), a general assessment of landslide occurrence is required for the analysis area that includes consideration of all forms of mass wasting. The following qualitative assessment example applies to this module and to the Landslides module.

Purpose

The following methods and techniques can be used to characterize and assess the current conditions and trends of erosion processes related to debris flows in the watershed by lithologic unit, landform type, and slope position. The relative probability of debris flow occurrence for the analysis area is rated using a Low to High or Extreme scale. The influences and relationships between debris flow processes and other ecosystem processes is evaluated by estimating sediment delivery to streams by debris flow type and slope position relative to streams.

Data Needs

1. Topographic maps (1:62,500).

2. Recent aerial photography (1:24,000 or 1:12,000).

3. Geologic map(s) (1:500,000 to 1:100,000). Define rock types according to specific physical characteristics; not just geologic/formation name.

   NOTE: The State Geology Map is not at a scale that can be used for detailed watershed assessment. Generally, more detailed mapping is needed to do an adequate analysis of slope stability at the larger scales. Where rock structure or orientation is critical to understanding the effects of natural landslide occurrence and management activities on slope stability, a structural geology layer should also be included in the Data Needs assessment prior to analysis.

4. Existing landslide inventory maps, descriptive reports, or analyses, if any.

5. Existing analyses of groundwater/wells/aquifers in the watershed.

Products

1. A 1:62,500 scale map displaying areas of equivalent landslide occurrence potential as a function of lithology and slope angle.

2. Tabulations of the approximate number of occurrences of each landslide type by lithology, slope class, slope position (upper, middle, or lower third of the slope), landform, and land-use activity.

3. Brief narrative descriptions of landslide sizes and types, distributions, and associations.

4. Brief narrative description of sediment delivery potential.

Procedure

1. Scan any existing landslide reports and/or inventory maps of the area for information about types and patterns of mass movement.

2. Using geologic maps at 1:100,000 to 1:500,000 scale, identify the major lithologic units for the analysis watershed. According to the generalized grain-size, durability, and jointing and fracture patterns for each unit, assign one of the following terms indicating susceptibility to mechanical and chemical processes: resistant, intermediate, weak, or unconsolidated.

3. Scan aerial photographs (1:12,000 or 1:24,000 scale) of representative areas in each lithology. Observe and record the association of landslides with typical landforms or geologic structure, typical landslide type(s) (shallow-rapid or deep-seated), relative number of landslide occurrences, slide locations relative to position on the slope or landform. Note associations between types of land use and slides where present. Estimate minimum, maximum, and average sizes of landslides for each lithology and slide type.

4. Talk to geomorphologists and road maintenance personnel working in the area to get their view of landslide distribution in the area, their causes, and the types of storms and antecedent conditions that generate them.

5. Review all records of groundwater studies or site specific investigations made in unstable terrain.

6. Obtain or develop a slope zone map for the area; use slope classes pertinent to increased incidences of slope failure where that information is available. Otherwise, the following slope classes may be used: 0-30%, 31-50%, 51-70%, and greater than 70%.

7. Rate the relative landslide potential of each slope class for each lithologic unit, according to the following rating matrix:

Relative Landslide Potential Matrix

SlopeClass/ Rock Type	Resistant	Intermediate	Weak	Unconsolidated
<30%	Low	Low	Low	Low
30-50%	Low	Moderate	Moderate	Moderate
51-70%	Moderate	Moderate	High	High
>70%	Mod.-High	High	Extreme	Extreme

NOTE: Modify the ratings as necessary to reflect field conditions observed during aerial photo interpretation.

While the criteria for high, medium, and low do not have to be consistent across the Region, they should be consistent within broad geomorphic areas where geology, climate, slope morphology, and soils are similar. Definitions of relative landslide occurrence must be developed cooperatively with other agencies and Forests involved in watershed analysis on similar terrain.

8. Display Landslide Potential Ratings on 1:62,500 scale maps by lithologic unit. Estimate percentages of the analysis watershed's area in each rating class.

9. Estimate landslide sediment delivery to streams (in terms of percent failed material delivered) based on patterns of slide locations relative to streams. Tabulate the information according to lithologic units, subdrainages, or other associations that appear.

Mechanistic Modeling

Models that estimate probability of landslide occurrence, such as LISA, may be helpful in the assessments if they are already calibrated for the area, if analysts are experienced in the model's use, and if the data required can be generated within the timeframe of the watershed analysis. Such models can be useful for defining stratification criteria and screening for slope stability, and integrating their use with field- and aerial-photo-based analyses can refine results of both approaches. GRID and TIN modules available in ARC/INFO provide the capability to electronically generate slope configuration needed to determine groundwater properties, as well as sediment delivery. In watersheds where data for modeling are absent, each Forest should work to develop the data so LISA and other models can be calibrated. The results of the modeling and calibration can be used later in the analysis process to improve project level assessments.

References

Hammond, C., Hall, D., Miller, S., and Swetik, P. 1992. Level I Stability Analysis (LISA) Documentation for Version 2.0. Gen. Tech. Rep. INT-285. Ogden, UT: USDA Forest Service, Intermountain Research Station. 190 p.

Lloyd, J.C. In review, Basin Study Checklist for Level I; In: National Slope Stability Guide. Prellwitz, R.W., and Koler, T.E., coordinators; USDA Forest Service, Washington D.C. Office.

Schuster, R.L., and Krizek, R.J. ed. 1978. Landslides: Analysis and Control. Transportation Research Board Special Report 176, National Academy of Sciences, pp. 12-80.

Way, D.S. 1978. Terrain Analysis. Dowden, Hutchinson, and Ross. Stroudsburg, PA. 438 pp.

Level II

"Debris Flow" includes all shallow, planar slides such as debris slides, debris avalanches, and debris torrents. Other deep-seated landslides such as slumps, earth flows, block failures, and rockfall are considered in another module. Surface erosion and gully erosion are also considered in other modules.

Purpose

The following methods and techniques can be used for a more detailed assessment of debris flow processes and their influence on sediment delivery. This is accomplished by estimating debris flow frequency as a function of land use type, storm size, or other relevant variables and estimating sediment production from debris flows in different parts of the watershed.

Assumption

Aerial photos can be used to estimate debris flow frequencies and field measurements to estimate sediment production from debris flows in each stratification unit.

Data Needs

1. Topographic maps (1:24,000).

2. Recent set of aerial photos (Ideal: 1:12,000 color or false-color IR).

3. Earlier sets of aerial photos for the sample sites.

4. Geologic map. Define rock types according to specific physical characteristics, not just geologic/formation name.

   Note: The State Geology Map is not at a scale that can be used for detailed watershed assessment. Generally, more detailed mapping is needed to do an adequate analysis of slope stability at the larger scales. Where rock structure or orientation is critical to understanding the effects of natural landslide occurrence and management activities on slope stability, a structural geology layer should also be included in the Data Needs assessment prior to analysis.

5. Vegetation map.

6. Rainfall map.

7. Land-use map.

8. Maps of landslide distribution, if available.

9. Any existing analyses of landsliding in the area.

10. Precipitation records for period with aerial photographic coverage.

Products

1. A tabulation of debris flow characteristics within each stratification unit, including size, relative frequency for the period sampled, and association with topography, land use, vegetation, and cause.

2. If analysis showed a relation between flow length and confluence geometry, indicate the portions of the watershed that are particularly likely to generate large debris flows (Benda and Dunne 198). A map (1:24,000) of stratification units used to characterize debris flows and the location of the mapped debris flows, color-coded by photo interval. Units can be portrayed as having high, medium, and low debris flow rates. While the criteria for high, medium, and low do not have to be consistent across the Region, they should be consistent within broad geomorphic areas where geology, climate, slope morphology, and soils are similar. Definitions of relative landslide occurrence must be developed cooperatively with other agencies and Forests involved in watershed analysis on similar terrain.

3. A tabulation of debris flow characteristics by land use within each stratification unit, including size, frequency, primary erosion, secondary erosion, and association with topography, vegetation, and cause.

4. A graph of flow frequency versus storm size for the most important stratification units.

5. A discussion of debris flow distribution and cause.

6. The data could also be used to evaluate the timing of debris flows in relation to timing of road construction or logging.

Procedure

1. Carry out a Level I assessment to evaluate debris flow distribution.

2. Debris flows are usually uncommon and evident enough after a major storm that their distribution over an entire watershed can be quickly mapped. If there are too many to conveniently map the entire population, select random areas within each stratum for sampling.

3. Map and number the debris flows in the sample area.

4. For each cataloged debris flow, tabulate the length, topographic setting of the source slide (e.g., swale, planar slope, inner gorge), association with land use (e.g., clearcut, road fill, grazing), topographic setting of the terminal deposit (right-angle confluence, acute-angle confluence, mid-reach), and perceived cause, if evident (e.g., undercutting, road drainage).

5. Measure the area of each land-use type and vegetation type in each sampled area, and the length of road present. If this information is not available from a GIS, linear features can be measured using methods such as that presented by Mark (1974), and areas by using point counts (Van der Plas and Tobi 1965).

6. Debris flows portrayed on existing landslide maps can be tabulated by stratum in a similar fashion where appropriate data are available.

7. Use the tabulated results to describe the association of landslides of various types with land-use activities or vegetation in each of the strata.

8. Use the tabulated results to test whether debris flow length in the area is determined by the geometry of confluences, as described by Benda and Dunne (198). Map debris flow distribution on sequential photo sets in the previously sampled areas, and note the size of each. Tabulate age category (years since the flow occurred; use the midpoint of the interval between the last photo that does not show the debris flow and the first that does).

9. Measure the area of each land-use type and vegetation type for each date sampled, and the length of road present. Linear features can be measured using methods such as that presented by Mark 1974, and areas by using point counts (Van der Plas and Tobi 1965).

10. Examine climatic records to identify the major storms in each photo interval.

11. Randomly select for field visits about 10 percent debris flows, making sure that each important stratification unit is well represented. Inaccessible examples can be replaced by similar accessible ones, but this must be noted.

12. At each field site, estimate the volume of the triggering landslide (plus or minus 25%), the volume of sediment scoured from the channel (plus or minus 25%; often possible by comparing the morphology of neighboring, unscoured channels), the depth of colluvium removed from channel banks, and the volume of sediment deposited along the channel and in the terminal debris fan (plus or minus 25%). Estimate the size and shape of sediment particles that are likely to result from slides and channel scour for each soil/geologic component of the watershed. Determine potential for deposition of those sediments throughout the stream system. Look for evidence of the cause of failure.

13. Calculate the primary erosion (original slide scar plus colluvium removed from channel banks), secondary erosion (volume of channel deposits removed), and volume redeposited for each flow observed in the field. Regress each parameter against the debris flow length.

14. For debris flows not associated with linear features such as channel banks or roads, calculate primary debris flow erosion per unit area of the associated land type (e.g., land-use or vegetation subcategory), and divide by the sampled interval duration to calculate average input per year. If the area of the land type (e.g., clearcut area) changed between photo sets, use the average value.

15. For debris flows associated with linear features, calculate primary erosion rate per unit length of the feature.

16. Tabulate average annual primary debris flow erosion per unit area for each land use in each stratification unit by multiplying the average rate by either the proportion of the stratum in that land category or the length of linear features per unit area of the stratum. This shows the overall importance of debris flow sediment production from each land-use type in the stratum.

17. Plot debris flow frequency in the most important stratification units (usually roads) in a photo interval against the maximum storm size in the interval. Try different descriptors of storm size: precipitation per month, per week, or per day may be useful.

Link to Project Level Analysis

Increased knowledge of specific portions of a watershed analysis area will occur as projects, such as restoration and vegetation management, are implemented. The recommendations developed in the preliminary and detailed phases of watershed analysis as outlined in this *Federal Guide* must be reassessed in light of that new information.

References

Benda, L., and Dunne, T. 1987. Sediment routing by debris flows. Pp. 213-223 in Beschta, R.L., T. Blinn, G.E. Grant, G.G. Ice, and F.J. Swanson (eds.): Erosion and Sedimentation in the Pacific Rim. International Association of Hydrological Sciences Publication 165.

Foggin, G.T., and Rice, R.M. 1979. Predicting slope stability from aerial photos. Journal of Forestry 77(3):152-155.

Mark, D.M. 1974. Line intersection method for estimating drainage density. Geology 2(5):235-236.

Reid, L.M., and Dunne, T . 1992. Rapid evaluation of sediment budgets. Draft dated May 29, 1992.

Selby, M.J. 1982. Hillslope Materials and Processes. Oxford University Press. 264 pp.

Slosson, J.E. 1979. Recognition of landslides. Pp. 113-127 in: D. Buesch (ed.), Geomorphic Applications in Engineering Geology. Short course held at Cal. State University Los Angeles, Nov. 10-11, 1979. Reprinted by the Southern California Section of the Association of Engineering Geologists.

USDA Forest Service. 1993. Slope Stability Reference Guide for National Forests in the United States. Washington D.C.

Van der Plas, L., and Tobi, A.C. 1965. A chart for judging the reliability of point counting results. American Journal of Science 263:87-90.

Way, D.S. 1978. Terrain Analysis. Dowden, Hutchinson and Ross. Stroudsburg PA. 438 pp.

Bank Erosion

Level I

Purpose

The following methods and techniques can be used to characterize and assess bank erosion processes in the watershed. They will also help identify the natural and human causes of bank erosion in the watershed.

Assumption

The streams in the watershed can be stratified into zones likely to have relatively uniform patterns of bank erosion.

Data Needs

1. Topographic maps (1:24,000).
2. Recent set of aerial photos (Ideal: 1:12,000 color or false-color IR).
3. Older set of aerial photos at a similar scale.
4. Geologic map.
5. Vegetation map.
6. Rainfall map.
7. Land-use map.
8. Soil maps.
9. Any existing analyses of bank erosion in the area.

Products

1. A map (1:24,000) of stratification units used to characterize bank erosion.
2. A tabulation of bank erosion intensity (high, low, absent) on different channel orders, vegetation types, and land uses within each stratification unit.
3. A discussion of the distribution, likely intensity, and cause of bank erosion in each stratum.

Procedure

1. Talk to geomorphologists, soil conservation specialists, road maintenance personnel, channel-side residents, floodplain landowners, and hydrologists working in the area to collect their observations on bank erosion and gullying. Tie observations to vegetation types, location, land use on the banks, and topographic position. Identify periods of rapid erosion.
2. For high-order channels (generally fourth order and higher, but depends on extent of riparian cover), use recent and old sets of aerial photographs (1:12,000 to 1:16,000) to map reaches that have changed form or migrated, and reaches with high, steep banks. It may be desirable to acquire large scale aerial photography taken after leaf-fall to assist in interpreting channel character and change in subsequent analyses. Note the association of these sites with topography, channel order, channel form, land-use activities, geology, and riparian vegetation. It is most useful if the photo interval includes large floods.
3. Scan the recent and old sets of aerial photographs, identify areas of gully erosion, and note their association with topography, channel order, land-use activities, geology, and vegetation.
4. Use the collected observations of gully erosion, bank erosion, and associated characteristics in low-order channels to identify two or three variables that are likely to most closely control its distribution. These usually include some combination of soil type, topography, channel order, and land use, but they may also include vegetation, elevation, or other characteristics.
5. Stratify the low-order channels in the watershed according to the identified characteristics. Land use and riparian vegetation are often treated as subdivisions within a stratification unit, since they often vary over relatively small distances and times. If gullying is not common and no useful observations were reported, then an arbitrary stratification based on geology and topography is usually appropriate.
6. Select readily accessible field sites to observe low-order channel bank conditions associated with different land-use activities and channel orders in each stratification unit. Make sure that several locations in undisturbed or less disturbed tributary catchments are selected.
7. Gully erosion itself is considered under "gully erosion." However, accelerated gully erosion usually provokes accelerated bank erosion in downstream reaches as those channels adjust to altered sediment load and flow. If gully erosion is present, make sure that such sites are adequately represented during field work.
8. At each field location, describe bank morphology and estimate the length and area of bank showing evidence of recent erosion. Note any indicators of erosion intensity or any visible association with factors that might influence the distribution of bank erosion.

Level II

Purpose

The following methods and techniques can be used for a more detailed assessment of bank erosion processes and their influence on sediment delivery in the watershed.

Data Needs

1. Topographic maps (1:24,000).
2. Recent set of aerial photos (Ideal: 1:12,000 color or false-color IR).
3. Older set of aerial photos at a similar scale.
4. Geologic map.
5. Vegetation map.
6. Rainfall map.
7. Land-use map.
8. Soil maps.
9. Any existing analyses of bank erosion in the area.

Products

1. A map (1:24,000) of stratification units used to characterize bank erosion and a relative rating of input rates in each.
2. A tabulation of estimated bank erosion rates on different channel orders, vegetation types, and land uses within each stratification unit.

Procedure

1. Carry out the Level I assessment of bank erosion as described above, but visit additional sites in low-order channels to better characterize areas of eroding bank at these sites. Look carefully for evidence of the age of erosive activity and the depth of material removed at these sites. Root exposure of datable vegetation, datable vegetation growing on scars or deposits, and deposit volumes may all be useful in establishing these values (Reid and Dunne 1992).
2. Statistically sample each stratification unit on aerial photographs to determine the average length of channel in each substratification. Mark (1974) describes a rapid method for estimating the areal density of a linear feature.
3. For the high-order channels for which areas of bank erosion were mapped, measure the areas involved. Locate representative sites for field checking. Also note high-order reaches that could not be evaluated because the banks were not visible ("invisible reaches") and locate several sites for field checking in these reaches.
4. Visit the selected sites in the field to determine the thickness of sediment removed and its type: bedrock, colluvium, recent alluvium, or alluvium deposited under "paleo" conditions. Estimate the area of bank showing evidence of erosion per unit length of channel along the reaches not visible on aerial photographs.
5. Calculate an average bank erosion input for high-order channels by dividing the volume change between photo sets by the photo interval. For the calculation, group the "invisible reaches" with whichever substratum has a similar value of eroding bank area per unit stream length. Calculate values separately for recent alluvial and for other bank materials: erosion of recent alluvium may not contribute to the sediment yield since it is often balanced by deposition elsewhere. However, both contribute to downstream sediment loads. These values are useful primarily as indicators of the order of magnitude of sediment input from this source, and of the relative contribution from different types of channel reaches.
6. Calculate an average input for low-order channels by multiplying average area eroding per unit length by the length of each channel substratum, and by the estimated retreat per year. Again, these values are useful primarily as indices.

References

Mark, D.M. 1974. Line intersection method for estimating drainage density. Geology 2(5):235-236.

Reid, L.M., and Dunne, T. 1992. Rapid evaluation of sediment budgets. Draft dated May 29, 1992.

Gully Erosion

Level I

Purpose

The following methods and techniques can be used to characterize and assess gully erosion processes in the watershed by identifying distribution patterns of gullies and land-disturbing activities with which gullies are associated.

Assumptions

1. Aerial photographs and interviews can be used to get an overview of the types and location of gullying likely to be active in the area.

2. The watershed can be subdivided into subareas likely to behave similarly with respect to gullying.

Data Needs

1. Topographic maps (1:24,000).

2. Recent set of aerial photos (Ideal: 1:12,000 color or false-color IR).

3. Geologic map.

4. Soil map.

5. Vegetation map.

6. Rainfall map.

7. Land-use map.

8. Any existing analyses of gullying in the area.

Products

1. A map (1:24,000) of stratification units used to characterize gullying. Units can be portrayed as having high, medium, or low gully incidence.

2. A description of gully characteristics within each stratification unit, including size, frequency, association with topography, land use, vegetation, and cause.

Procedure

1. Talk to geomorphologists, hydrologists, farmers, ranchers, and personnel working in the area to get their view of the causes, distribution, and age of gullying in the watershed.

2. Scan the most recent set of 1:12,000 (or similar scale) aerial photographs to identify areas of gullying and to observe their association with topography, land-use activities, geology, and vegetation. Earlier photographs that show the results of an extremely intense storm might also be used. This step could also be done efficiently by an overflight if positions are carefully noted on a topographic map or on aerial photographs. Generally, only gullying in grassland areas can be evaluated efficiently on aerial photographs or from the air.

3. Use the observed associations between gullying and land characteristics to identify two or three characteristics that seem to most closely control gully distribution. These are likely to be soils, vegetation and land use; but they may include geology, topography, elevation, or other characteristics.

4. Stratify the watershed according to the identified characteristics. Soils and vegetation are usually strongly correlated, and only one is likely to be useful as a stratification parameter. Land use is usually treated as a subdivision within a stratification unit, since it often varies over relatively small distances and times. Topographic setting may be used as a parameter either for stratification or substratification, depending on the scale over which its influence is evident.

5. Briefly visit sites in each of the stratification units to examine road drainage networks, low-order channels, agricultural drainage networks, meadows, rangelands, and other types of sites likely to be gullied if gullying is active in the area. Describe the type, age, size, frequency, topographic setting, extent of revegetation, and evidence of cause for gullies in each substratum. Document evidence of sediment delivery to channels from gullies while on site.

References

Heede, B. H. 1976. Gully Development and Control: The Status of Our Knowledge. USDA Forest Service Res. Paper RM-169. 42 pp.

Heede, B. H. 1979. Deteriorating Watersheds Can Be Restored: A Case Study. Environmental Management, vol. 3, no. 3, pp. 271-281.

Mark, D.M. 1974. Line intersection method for estimating drainage density. Geology 2(5):235-236.

Reid, L.M., and Dunne, T. 1992. Rapid evaluation of sediment budgets. Draft dated May 29, 1992.

Selby, M.J. 1982. Hillslope Materials and Processes.

Oxford University Press. 264 pp.

Way, D.S. 1978. Terrain Analysis. Dowden, Hutchinson and Ross. Stroudsburg PA. 438 pp.

Level II

Purpose

The following methods and techniques can be used for a more detailed assessment of gully erosion processes. This is accomplished by describing gully incidence as a function of land-use type or other relevant variables and estimating sediment production from gullies in different parts of the watershed.

Assumption

Fieldwork and aerial photographic interpretation can be used to characterize gully size, age, sediment delivery ratio, and frequency in different substratification units.

Data Needs

1. Topographic maps (1:24,000).
2. Recent set of aerial photos (Ideal: 1:12,000 color or false-color IR).
3. Earlier sets of aerial photos for the sample sites.
4. Geologic map.
5. Soil map.
6. Vegetation map.
7. Rainfall map.
8. Land-use map.
9. Any existing analyses of gullying in the area.
10. Precipitation records for period with aerial photographic coverage.

Products

1. A map (1:24,000) of stratification units used to characterize gullying. Units can be portrayed as having high, medium, and low gully incidence.
2. A map similar to the first, but which portrays sediment production to streams from gullying. This will be useful only if it differs in pattern from the first map.
3. A tabulation of gully characteristics by land use within each stratification unit, including size, extension rate, association with topography, vegetation, and cause, incidence per unit area, annual volume of sediment mobilized per unit area, and annual volume of sediment delivered per unit area of the land use. Results will be good to well within an order of magnitude, and are likely to be valid to plus or minus 50%.
4. A tabulation of sediment input rates from gullies from each land-use type in a stratification unit, per unit area of the stratification unit. This differs from (3) in that it takes into account the present extent of the land-use activity. Thus, the tabulation in (3) may show an extremely high rate of sediment input from road-related gullies per unit area of road surface in a particular stratum, while the tabulation in (4) may show that since there are very few roads present there, the net input from this source is not large.
5. A discussion of gully types, distribution, and cause.
6. The data could also be used to evaluate the timing of gullying in relation to timing of land-use changes and major storms.

Procedure

1. Carry out a Level I evaluation, as described above.
2. For types of gullies visible on aerial photographs: compare the distribution and size of gullies in representative areas on sequential photographs. Determine the age of the features, the extension rate, and the extension style (i.e., is it relatively continuous, or does it extend rapidly during some periods?). Note any changes in land use associated with altered extension rates. Gullies may be randomly subsampled for rate measurements and dimensions.
3. Measure the area of each land-use type and vegetation type for each date sampled, and the length of road present. Linear features can be measured using methods such as that presented by Mark 1974, and areas by using point counts (Van der Plas and Tobi 1965).
4. Visit a characteristic selection of the measured gullies, making sure that each important stratification unit is well represented. At each field site, estimate the depth and width of the gully (plus or minus 20%) at a succession of distances from the gully headwall and sketch the cross-sectional form. These measurements will provide a basis for estimating gully volumes from aerial photographs. Describe the type, age, size, frequency, topographic setting, extent of revegetation, sediment delivery to the channel system, and evidence of cause for the gullies.
5. For types of gullies not visible on aerial photographs: on the basis of the gully distribution identified during the Level I evaluation, select field sites in each of the important substratification units. Visit enough sites to estimate the order of

magnitude of gully incidence per unit area of the substratum.

6. At each field site, estimate the length, volume, maximum depth and maximum width of the gully (plus or minus 20%) and sketch the cross-sectional form. Describe the type, age, size, topographic setting, extent of revegetation, sediment delivery to the channel system, and evidence of cause for the gullies.

7. Characterize gully types by average volume and delivery ratio for different stratification units. A geometric average will be more useful than an arithmetic one if volumes are distributed log-normally.

8. For gullies not associated with linear features such as channel banks or roads, calculate erosion per unit area of the associated land type (e.g., land use or vegetation subcategory), and divide by the sampled interval duration to calculate average input per year. If the area of the land type (e.g., clearcut area) changed between photo sets, use the average value.

9. For gullies associated with linear features, calculate an input rate per unit length of the feature.

10. Tabulate average annual input per unit area for each land use in each stratification unit by multiplying the average rate by either the proportion of the stratum in that land category or the length of linear features per unit area of the stratum. This shows the overall importance of sediment production from each land-use type in the stratum.

References

Mark, D.M. 1974. Line intersection method for estimating drainage density. Geology 2(5):235-236.

Reid, L.M., and Dunne, T. 1992. Rapid evaluation of sediment budgets. Draft dated May 29, 1992.

Selby, M.J. 1982. Hillslope Materials and Processes. Oxford University Press. 264 pp.

Van der Plas, L., and Tobi, A.C. 1965. A chart for judging the reliability of point counting results. American Journal of Science 263:87-90.

Way, D.S. 1978. Terrain Analysis. Dowden, Hutchinson and Ross. Stroudsburg, PA. 438 pp.

Sediment Yield

Level I

Purpose

The following methods and techniques can be used when assessing general sediment transport and deposition processes in the watershed by estimating the magnitude of sediment yield in different parts of the watershed. Influences and relationships between sediment processes and human activities in the watershed are also identified.

Data Needs

1. Topographic maps (1:24,000).
2. Recent set of aerial photos (Ideal: 1:12,000 color or false-color IR).
3. Geologic map.
4. Soil map.
5. Vegetation map.
6. Rainfall map.
7. Land-use map.
8. Any existing sedimentation measurements in the area.
9. Compilations of sedimentation measurements in similar areas.

Products

1. A map (1:24,000) of stratification units used to characterize sediment yield. Units can be portrayed as having high, medium, or low sediment yield.
2. A tabulation of estimated sediment yield from each stratification unit.
3. A description of erosion processes likely to be active within each stratification unit, including likely sediment delivery category (high, medium, low), and association with topography, land use, vegetation, and cause.

Procedure

1. Talk to geomorphologists and hydrologists working in the area to get their view of the sources of erosion in the watershed and their relative importance.
2. Scan the most recent set of 1:12,000 (or similar scale) aerial photographs to identify major sediment sources and to observe their association with topography, land disturbance, geology, and vegetation. Also, note the location of stock ponds and other impoundments. A 1:15,840 map may be needed to adequately display sediment sources from key small or linear sources like streams, roads, slides, or riparian areas.
3. If analyses of individual sediment sources have been carried out, superimpose the stratification maps for each of them, refine the boundaries where necessary (e.g., pay less attention to unimportant processes and group together strata with low erosion rates), and skip the next two steps. You should end up with no more than 5 to 8 strata.
4. Use the observed associations between erosion sources and land characteristics to identify two or three characteristics that seem to most closely control the distribution of erosion processes. These are likely to be topography, geology, and land use, but they may include soils, vegetation, elevation, or other characteristics.
5. Stratify the watershed according to the identified characteristics. Land use and vegetation are usually not considered primary stratification parameters, since they often vary over relatively small distances and times. Characterize the geology, topography, vegetation, and land disturbance distribution of each stratification unit.
6. Examine existing data compilations (e.g., Dendy and Champion 1978, Larson and Sidle 1980) to find sediment yield measurements from areas similar to each of the stratification units. In the absence of published data, estimate the sediment delivery rate from each stratification unit using established methods such as that found in USEPA-USDA Forest Service, 1980.
7. If impoundments exist in the watershed, acquire sedimentation measurements from those who manage them. It may be possible to estimate infill rates in recently built stockponds from the dimensions of deltas exposed during the dry season.

References

Dendy, F.E., and Champion, W.A. 1978. Sediment deposition in U.S. reservoirs. Summary of data reported through 1975. U.S.D.A. Miscellaneous Publication 1362. 84 pp.

Larson, K.R., and Sidle, R.C. 1980. Erosion and sedimentation data catalog of the Pacific Northwest. U.S.D.A. Forest Service, Pacific Northwest Region; R6-WM-050-1981; 64 pp.

Reid, L.M., and Dunne, T. 1992. Rapid evaluation of sediment budgets. Draft dated May 29, 1992.

USEPA-USDA Forest Service. 1980. An Approach to Water Resources Evaluation of Non-point Sources - Silviculture. EPA-IAG-D6-0660. Washington D.C.

Level II

Purpose

The following methods and techniques can be used for a more detailed assessment of a sediment yield as a function of land-use type or other relevant variables in the watershed.

Data Needs

1. Topographic maps (1:24,000).
2. Recent set of aerial photos (Ideal: 1:12,000 color or false-color IR).
3. Earlier sets of aerial photos that span a 10- to 20-year storm.
4. Geologic map.
5. Soil map.
6. Vegetation map.
7. Rainfall map.
8. Land-use map.
9. Any existing analyses of erosion processes in the area.
10. Any existing sedimentation measurements in the area.
11. Compilations of sedimentation measurements in similar areas.

Products

1. A map (1:24,000) of stratification units used to characterize a sediment yield. Units can be portrayed as having high, medium, and low sediment yields, or can be mapped by order of magnitude of the sediment yield per unit area.
2. Flowcharts showing sediment production, transport, and deposition for each stratification unit.
3. A tabulation showing the relative magnitudes of sediment inputs from different processes and substrata within each stratification unit.
4. A description of erosion processes active within each stratification unit, including sediment delivery category (high, medium, low), and association with topography, land use, vegetation, and cause.
5. A tabulation of estimated sediment yields per unit area for each stratification unit calculated by summing inputs and subtracting deposition. Also show estimated yields from the Level I evaluation.
6. A discussion of influences on a sediment yield in each stratification unit.

Procedure

1. Carry out a Level I evaluation, as described above.
2. Visit representative sites in each stratification unit and describe the types of erosion processes and areas of deposition associated with different topographic settings and types of land use in each. Note the proportion of the area and the types of topographic settings and land use associated with sheetwash erosion. Measure characteristic landslide depths, and evidence of sheetwash erosion rates (e.g., exposed datable roots). Note the proportion of gravel-road surface drainage that makes it to the channel network. Measure backcut retreat rates using root exposure of datable vegetation both on typical road cuts and on those with characteristics similar to channel banks. Note the area of colluvial and alluvial streambank (per unit stream length) showing evidence of erosion in low-order channels. Measure gully widths and cross-sectional areas for those visible on aerial photographs. Estimate gully frequencies, ages, and volumes for those that are not. Construct a flowchart for erosion and sediment transport processes and sediment deposition and storage in each stratification unit, and note their relative importance (high, medium, low).
3. Compile existing rate measurements for each process type in each type of stratification unit or associated with each type of land disturbance present (e.g., Saunders and Young 1983, or previous analyses in the watershed).
4. Select the most important erosion processes in each stratification unit for further analysis. In general: any process that contributes less than one-tenth the sediment of another in a substratum can be ignored. Preliminary estimates of order of magnitude can generally be carried out quite quickly using available data and worst-case assumptions.
5. If landslides are important in stratification units,

scan two sets of aerial photographs spanning approximately 10 years and including a moderately large storm (e.g., 10- to 20-year recurrence interval). Count and estimate size classes and delivery ratios of landslides occurring during that period in representative sample areas in each of those stratification units. Estimate input rates from landsliding per unit area of land-use type or topographic setting with which they are associated. Multiply these values by the proportion of that land-use type or topographic setting within the stratification unit. These values should be within an order of magnitude of the long-term input from landsliding in the area.

6. If sheetwash erosion is important in stratification units, multiply the area subject to sheetwash erosion by the estimated rates from field observations. Multiply these values by the proportion of that land-use type or topographic setting within the stratification unit. Also, estimate sheetwash erosion rates for those areas using the Universal Soil Loss Equation, if appropriate. Apply measured road-surface erosion rates (normalized by rainfall or the USLE R-factor) to the area of the road surface that drains to the channel network.

7. If bank erosion is important in stratification units, multiply the observed characteristic areas of eroding bank for different channel orders by the retreat rates measured for bank-like roadcuts. Also, multiply characteristic soil creep rates (Saunders and Young 1983) by the drainage density times two by the proportion of the channel bank impinging on colluvial deposits.

8. If gullying is important in stratification units and the important gullies are visible on aerial photographs, scan two sets of aerial photographs spanning approximately 10 years and including a moderately large storm (e.g., 10- to 20-year recurrence interval). Measure the expansion of the gully network over the period, measure approximate widths; and use the field measurements of gully widths and cross-sectional areas to estimate gully erosion over the period. Estimate input rates from gullying per unit area of land-use type or topographic setting with which they are associated. Multiply these values by the proportion of that land-use type or topographic setting within the stratification unit. These values should be within an order of magnitude of the long-term input from gullying in the area.

9. If gullying is important in stratification units and the important gullies are visible on aerial photographs, use field measurements of gully incidence, age, and size to estimate the sediment input from gullying per unit area of land use or topographic setting with which they are associated. Multiply these values by the proportion of that land-use type or topographic setting within the stratification unit.

10. If dry ravel is important in stratification units, multiply the area susceptible in each stratum by estimates of retreat rates for each type of source (such as those measured using root exposure on roadcuts or measured accumulations of ravelled debris). Estimate sediment delivery for roadcut erosion from information on the continuity of road drainage with the channel network. For other sources, estimate delivery on the basis of microtopography and the size of debris accumulations.

11. Tabulate average annual input per unit area for each land use in each stratification unit by multiplying the average rate by either the proportion of the stratum in that land category or the length of linear features per unit area of the stratum. This shows the overall importance of sediment production from each land-use type in the stratum.

12. Note major areas of deposition downstream of the erosion sources, and estimate order of magnitude of deposition rates there. This would include aggrading reaches and lakes. Proportional deposition may vary by grain size.

13. Calculate order of magnitude of sediment yields from each stratification unit.

References

Dendy, F.E., and Champion, W.A. 1978. Sediment deposition in U.S. reservoirs. Summary of data reported through 1975. USDA Miscellaneous Publication 1362. 84 pp.

Larson, K.R., and Sidle, R.C. 1980. Erosion and sedimentation data catalog of the Pacific Northwest. USDA Forest Service, Pacific Northwest Region; R6-WM-050-1981; 64 pp.

Mark, D.M. 1974. Line intersection method for estimating drainage density. Geology 2(5):235-236.

Reid, L.M., and Dunne, T. 1992. Rapid evaluation of sediment budgets. Draft dated May 29, 1992.

Saunders, I., and Young, A. 1983. Rates of surface processes on slopes, slope retreat, and denudation. Earth Surface Processes and Landforms 8:473-501.

Selby, M.J. 1982. Hillslope Materials and Processes. Oxford University Press. 264 pp.

Van der Plas, L., and Tobi, A.C. 1965. A chart for judging the reliability of point counting results. American Journal of Science 263:87-90.

Way, D.S. 1978. Terrain Analysis. Dowden, Hutchinson and Ross. Stroudsburg PA. 438 pp.

Sheet and Rill Erosion

In Development ...

Hydrology

Streamflow Characteristics

Level I

Purpose

The following methods and techniques can be used to characterize and assess the dominant hydrologic characteristics in the watershed, specifically streamflow amount and timing.

Assumptions

1. There is a high probability that there will not be current or historic flow records for streams within the watershed.

2. There is a high probability that there will be streamflow data available for streams within an acceptable distance, thereby allowing inferences and comparative statistics to be developed.

Data Needs

1. Daily flow records, as published by the USGS or State Water Resource Departments.

2. Published summaries of streamflow data.

Data Sources:

- USGS annual streamflow summaries: paper or electronic versions.
- Any State Water Resource Department streamflow data, including available crest gage data.
- Any data available from university or research installations.

Products

Tables and graphs showing:

1. Monthly streamflow averages and extremes.

2. Annual streamflow amounts and extremes.

3. Flow duration curves or tabulated percentile values.

4. Information about instantaneous peaks for each year of record.

5. Information about diversions or regulation effects at each gage.

Procedure

1. Obtain the most recent copy of the annual USGS Surface Water Supply Paper or State publication of streamflow for the area in which the watershed of concern resides.

2. Familiarize yourself with the list of existing stations within and near the watershed of concern. Look at the map provided to gain an appreciation for the spatial relationship of the stations you will use.

3. For each station of interest, read the entire summary text at the top of the page. Pay particular attention to the period of record, notes on station location changes, notes about regulation, and the basic statistics of annual and peak flows. As a minimum, build a table showing: station name, station number, gage datum, area, period of record, average annual flow, average peak flow (annual and instantaneous) for each gage within or near the watershed of concern.

4. If this is the only source of flow information you have or can get, write down the average monthly flow values and the total annual yield for each station of interest. Look at the array of daily flows and record the date of the highest five (5) streamflows during the year. Record the date of lowest flow and the value.

5. Determine if summary streamflow publications have been prepared for the state or the area of concern. If you do not know, call the nearest USGS or Water Resource office and ask. These publications will generally include information on streamflow extremes, averages, duration, and timing. If a summary is not available, arrange to purchase or obtain a copy.

6. Record monthly values for each station of interest for each year of record. Also, tabulate the annual and instantaneous peak values and the annual low value for each year of record. This information can be used to define streamflow timing, volume, and extremes. The tabulated data provides a basis for evaluating the range of flow variability for each station or group of stations.

7. Prepare a table showing average monthly streamflow, peak and base flow amounts, and timing for each station of interest. Graph the monthly flows. It is very helpful to show the range of monthly values on this graph to quickly illustrate

the range of flows by time period. Be sure to include all the station statistics you wrote down and include a map showing where each of the stations are relative to the watershed being studied.

8. If you have access to an electronic version of the USGS streamflow records, such as those sold commercially by a variety of CD-ROM purveyors, the summary of monthly and extreme flow statistics is made very easy. Data can be exported to commercial spreadsheets or databases for analysis and presentation. Data for discontinued, as well as active stations, are generally available electronically. Also, the USGS can process requests for data summaries for a station or group of stations.

Level II

Purpose

The following methods and techniques can be used for a more detailed assessment of streamflow characteristics through a detailed statistical description of streamflow amounts, timing, and variability. The Level II methods allow development of relationships between streamflow and channel geometry for each gaged site and graphical and mathematical relationships for estimating characteristics of ungaged areas.

Assumptions

1. Data are available in electronic form and the analyst is computer conversant. The suggested analyses are feasible if data must be entered manually; electronic access greatly facilitates the task.

2. Appropriate hardware and software are available.

Products

Same as developed in Level I evaluation plus:

1. Area-wide relationships useful for estimating streamflow values at ungaged sites.

2. Relationships between streamflow and channel geometry.

3. Understanding of changes in channel geometry over time.

Procedure

1. Prepare the data in a format which is usable by available analysis and presentation software (spreadsheets, databases, graphics). This may be accomplished by downloading data from commercial CD-ROM packages, by special request to the USGS office (may take too much time to get the data), or by manually entering data from annual publications. Practically, daily data for any more than 20 station years for 5 or more stations will require too much time for manual entry. The most desirable means of preparing the data is to access a CD-ROM source. The data should be stored in a format that is usable by available models or analytic software.

2. Analyze the data to provide descriptive statistics of choice. Particularly useful representations include: flow duration curves, streamflow magnitude-frequency graphs and tables, percentile curves, box and whisker plots of monthly or seasonal flows, time series presentations of daily, monthly, and annual flows.

3. Attempt to stratify the data sets to develop streamflow characterizations for major elevation bands associated with different precipitation regimes (i.e., rain dominated, rain-on-snow, snow dominated).

4. Correlate peak flows (annual and partial duration series) with precipitation and other meteorological data during and preceding the flows.

5. Develop graphical relationships, nomographs or regression relationships between watershed area, elevation, and streamflow values associated with selected streamflow return periods. These graphs can quickly summarize relationships that are useful for estimating streamflow regime in ungaged areas of the analytic watershed.

6. Acquire copies of field stream gaging record summaries for the stations of interest from the USGS. These records will allow the development of relationships between channel width, depth, and area over a range of flows. This information is also useful to show changes in cross-section at a given site over time and the range of flows experienced.

Peak Flow

Level I

Purpose

The following methods and techniques can be used to assess current conditions and trends of peak flows in the watershed. The influences and relationships between peak flows and the hydrologic performance of forested watersheds are identified. This is done by determining what portions of the analysis area are potentially contributing the highest increase in peak flow magnitude. The natural and human causes of incremental changes in peak flow magnitude are evaluated.

Assumptions

1. Delivery of water to the forest is controlled by climate; i.e., quantities and delivery rate of rain and snow.
2. Delivery of water to the forest floor is determined by interception and snowmelt (changes in vegetation).
3. Hydrologic efficiency of the watershed is largely determined by vegetation, soils, drainage network, and pathway roughness. Runoff efficiency is affected significantly by road density by drainage extension and flow rerouting.
4. Analysts have access to an operational GIS and its associated database.

Data Needs

1. Map of analysis watershed with streams (1:63,360).
2. Vegetation age distribution table by vegetative series and subwatershed.
3. Elevation zone/precipitation-type map and data table.
4. Road density and stream density tables by subwatershed.
5. Aspect table by subwatershed.
6. USGS published streamflow data (annual publications or electronic version; e.g., CD-ROM).

Products

1. A table of the magnitude of experienced peak flows over time within the watershed or for nearby watershed with similar physiography.
2. A map at the 1:63,360 scale showing rain dominant, rain-on-snow dominant, and snow-dominant zones.
3. A map at the 1:63,360 scale showing which subwatersheds have the greatest potential for experiencing altered peak flows as the result of altered vegetative state and/or road construction.
4. A matrix display of factors that went into determining degree of watershed impact by subwatershed.

Procedure

1. Produce a map at 1:63,360 (1"=1 mile) of the entire watershed with the streams shown. Detailed subwatershed maps may be mapped at 1:24,000 depending on the analysis intensity.
2. Divide the large watershed into subwatersheds based on stream order using "blue line" streams on the topographic map. Divisions should be done on 3rd to 4th order basins. All data from this step forward should be tabulated by subwatershed and totaled for the entire watershed.
3. Talk with local hydrologists and other district personnel, as well as Weather Service and State officials, to obtain information about historic rain-on-snow elevation levels.
4. Delineate the watershed by elevation zones into areas that can be classified as rain dominated, rain-on-snow dominated, and snow dominated. Rain-on-snow dominated areas and the percent occupied by this zone within the basin are particularly important contributors to peak flow increases.
5. Delineate the watershed by aspect classes. Total the acres for each aspect class for each subwatershed. In situations where a GIS is not operational, broad aspect classes can be defined from topographic maps.
6. Develop a road-density table for each subwatershed.

7. Develop a vegetative-condition table for each subwatershed showing the age distribution of vegetation-by-vegetative series. Suggested categories for vegetation-age breakout are: 0-10 yrs, 11-40 yrs, 40-100 yrs, 100-200 yrs, and 200+ yrs.

8. For each of the elevation classes associated with the precipitation zones (rain, rain-on-snow, snow), tabulate the vegetative condition, drainage density, road density, percent of subwatershed in each 3rd to 4th order subbasin.

9. From the data matrix produced in step 8, determine the potential for change in peak streamflow for each subwatershed. This can be done by assigning relative weights to each of the tabulated categories. Record the results. An example of a weight scheme is provided in the Washington State watershed analysis procedure (Washington State Forest Practices Board, 1992). Ranking the subwatersheds or grouping the subwatersheds into categories of potential for change in peak flows may be helpful for presentation of the results. This subjective procedure is most useful for evaluating the risk of altering streamflow. If significant areas of high risk are found, a more detailed analysis of conditions and possible effects should be undertaken.

References

Christner, Jere. 1981. Changes in Peak Streamflows from Managed Areas of the Willamette National Forest. August 1981.

Environmental Protection Agency. 1980. An Approach to Water Resources Evaluation of Non-point Silvicultural Sources. EPA-600/8-80-012, Chapter III Hydrology. August 1980.

Grant, Gordon. 1986. Assessing Effects of Peak Flow Increases on Stream Channels: A Rational Approach. Proceeding of California Watershed Management Conference.

Standard Methodology for Conducting Watershed Analysis: Version 1.10. October 1992. Washington Forest Practices Act Board Manual. Washington State Forest Practices Board. 1992.

Level II

Purpose

The following methods and techniques describe a more detailed assessment of peak flow conditions by estimating the change in available water for runoff as a result of current vegetative conditions for all subwatersheds within a watershed analysis area.

Data Needs

Data identified in Level I plus:

1. Existing hydrologic summaries and USGS streamflow data either from Water Supply papers or other sources.

2. USGS publication with regional flow prediction equations such as Magnitude and Frequency of Floods in Western Oregon, Open File Report 79-553.

3. NOAA precipitation atlas (Miller, et. al.) or digital files available for GIS.

4. Topographic maps (1:24,000).

Products

1. Products as described in the Level I evaluation.

2. A semi-quantitative narrative of watershed conditions and peak flow magnitude and frequency by subwatershed. The narrative will describe the potential effects of roads and vegetation changes on peak flow magnitude and frequency.

3. A streamflow magnitude-frequency relationship for a gaged watershed or for one that can be used as a surrogate.

4. A determination of weather conditions contributing to flows of various magnitude.

Procedure

1. Evaluate any historic aerial photographs taken after major flood events. This will allow the analyst to see aerial extent of flooding, as well as the overall watershed condition of the watershed at the time of the flood(s).

2. Carry out the Level I evaluation of the watershed by subwatershed as described above.

3. Develop a table for each subwatershed showing the amount of road considered mid-slope, which would potentially have more impact in rerouting subsurface flow and increasing the drainage efficiency. (This could be set up to include all road positions; i.e., ridge top and valley bottom, as well as mid-slope.)

4. Identify existing stream gaging stations in the area and develop a return frequency relationship for 1.25-, 2-, 5-, 10-, 25-, 50-, and 100-year return periods.

   Note: Regionally developed curves are available, but the standard error for most of these equations is very high.

5. Using NOAA weather data (rainfall and air temperature) and streamflow data from USGS, determine the time of occurrence and type of individual flood events over the entire period of record. This information will be very helpful to those who are assessing potential channel changes or evaluating the biological effects of historic flows.

6. If there are sufficient streamflow data available, a flood-frequency analysis can be performed. A partial-duration series would use the largest peak flows above a certain arbitrary level. Plotting each event according to its cause would give a rough idea of the cause(s) of peak flows with different return periods. For example, a flood-frequency analysis for a particular watershed might indicate that 90 percent of peak flows with a return period of less than 2 years are caused by rain, 50 percent of peak flows with a return period of 2-5 years are caused by rain alone and 50 percent by rain-on-snow, and 80 percent of peak flows having a return period of more than 5 years are caused by rain-on-snow.

7. Talk with local long-term residents of the area to gather additional information about various storm events.

8. Document all information about the frequency and probable cause of peak flows for each subwatershed. This information will be critical to anyone who is assessing channel form or aquatic habitat condition changes.

References

Miller, J.F., Frederick, R. H., and Tracey, R.J. 1973. Precipitation-frequency atlas of the western United States. Volume....(by State). National Oceanic and Atmospheric Administration, NOAA.

Friday, John. 1972. Crest-Stage Gaging Stations in Oregon. USGS Open File Report.

Overland Flow

Level I

Purpose

The following methods and techniques can be used to assess current conditions and trends relative to overland flow in the watershed. Influences and relationships between overland flow and other processes and activities in the watershed are identified.

Assumptions

1. Anecdotal reports and soil descriptions can be used to identify areas likely to generate overland flow.

2. Brief site visits to each type of site can be used to compile evidence of overland flow.

Data Needs

1. Topographic maps (1:24,000).
2. Recent set of aerial photos (Ideal: 1:12,000 color or false-color IR).
3. Geologic map.
4. Vegetation map.
5. Rainfall map.
6. Land-use map.
7. Soil maps.
8. Soil descriptions.
9. Any existing analyses of runoff generation in the area.
10. Any existing analyses of sheetwash, rill, or gully erosion in the area.

Products

1. A map (1:24,000) of stratification units used to characterize overland flow generation.

2. A tabulation of overland flow mechanism and likely intensity (high, low, absent) on different landforms, vegetation types, and land uses within each stratification unit. Also, tabulate the areal coverage of each landform, vegetation type, and land use.

3. A discussion of the distribution, likely intensity, and cause of overland flow in each stratum.

Procedure

1. Read any existing reports on runoff generation or sheetwash and rill erosion in the area.

2. Talk to geomorphologists, soil scientists, soil conservation specialists, and hydrologists working in the area to collect their observations on runoff generation, overland flow distribution, and the distribution of sheetwash erosion, rilling, and gullying. In particular, ask for observations about bare ground, burned hillslopes, hillslope swales, floodplains, roads, grazed areas, cultivated areas, and seasonally saturated areas. If possible, identify the storms for which flow was observed.

3. Talk to woods-workers or others who commonly work outdoors during storms to collect their observations on the location of standing water and surface flow during storms or snowmelt. Tie observations to vegetation types, location, and topographic position.

4. Examine soil reports to identify shallow soils seated on impermeable bedrock, soil types with particularly low infiltration capacities, those with horizons that impede infiltration, those that may become hydrophobic after burning, and those characterized by gleying.

5. Examine a detailed map of the channel network, if available, to identify areas with particularly high drainage density.

6. Scan the most recent set of 1:12,000 (or similar scale) aerial photographs to identify areas of extensive gully erosion and observe their association with topography, land-use activities, geology, and vegetation. Also note the locations of areas of bare ground and of abnormally high drainage density. This step could also be done efficiently by an overflight if positions are carefully noted on a topographic map or on aerial photographs.

7. Use the collected observations of overland flow and associated characteristics to identify two or three variables that are likely to most closely control its distribution. These usually are soil type and land use, but they may include topographic position, vegetation, elevation, geology, or other characteristics.

8. Stratify the watershed according to the identified characteristics. Land use and topographic

position are usually treated as subdivisions within a stratification unit, since they often vary over relatively small distances and times. Soil and vegetation often vary together, so soil type can often be used to characterize both. Ideally, there will be 3 to 5 different stratification units. Detailed soil map units will need to be grouped into similar types.

9. Select readily accessible field sites to observe soil profiles and surface conditions associated with different land-use activities and landforms in each stratification unit.

10. At each field location, search for evidence of overland flow and sheetwash erosion on planar hillslopes, floodplains, and in swales. Observe the distribution of vegetation associated with seasonal saturation. Use a soil auger to check for gleying in different topographic positions. Look for other indicators described by Dunne et al. (1975).

11. Statistically sample each stratification unit on aerial photographs to determine the average length or areal cover of the land-use types, vegetation types, or topographic features found to be associated with overland flow, and of impermeable developed surfaces and exposed bedrock. Linear features can be measured using methods such as that presented by Mark 1974, and areas by using point counts (Van der Plas and Tobi 1965).

12. Use the tabulated results to describe the likely association of overland flow runoff with different land disturbances, vegetation types, or topographic features in each of the strata.

13. Note that this whole process becomes moot if you can do reconnaissance fieldwork during a single high-intensity storm or during the peak snowmelt season.

References

Dunne, T., Moore, T.R., and Taylor, C.H. 1975. Recognition and prediction of runoff-producing zones in humid regions. Hydrological Sciences Bulletin 20(3):305-327.

Gleason, C.H. 1953. Indicators of erosion on watershed land in California. American Geophysical Union Transactions 34(3):419-426.

Mark, D.M. 1974. Line intersection method for estimating drainage density. Geology 2(5):235-236.

Reid, L.M., and Dunne, T. 1992. Rapid evaluation of sediment budgets. Draft dated May 29, 1992.

Van der Plas, L., and Tobi, A.C. 1965. A chart for judging the reliability of point counting results. American Journal of Science 263:87-90.

Level II

Purpose

The following methods and techniques can be used for a more detailed assessment of overland flow as source of runoff in the watershed. This is done by identifying the conditions under which overland flow is likely to be generated. Influences and relationships between overland flow processes, landforms, and land disturbance are also evaluated.

Data Needs

1. Topographic maps (1:24,000).
2. Recent set of aerial photos (Ideal: 1:12,000 color or false-color IR).
3. Geologic map.
4. Vegetation map.
5. Rainfall map.
6. Land-use map.
7. Soil maps.
8. Soil descriptions.
9. Any existing analyses of runoff generation in the area.
10. Any existing analyses of sheetwash, rill, or gully erosion in the area.
11. Precipitation records.

Products

1. A map (1:24,000) of stratification units used to characterize overland flow generation. Units can be portrayed as having high, medium, and low intensity (indexed by the estimated proportion of rainfall that runs off as overland flow) of overland flow. If certain mechanisms for overland flow generation are particularly important in some areas, separate maps can be prepared for these.
2. A tabulation of overland flow potential for different landforms (e.g., swales, floodplains), vegetation types, and land uses within each stratification unit.
3. A tabulation of overland flow intensity for each land-use type in a stratification unit, per unit area

of the stratification unit. This differs from (2) in that it takes into account the present extent of the land-use activity. Thus, the tabulation in (2) may show an extremely high intensity of overland flow on roads in a particular stratum, while the tabulation in (3) may show that since there are very few roads present, the overall importance of this source is not large.

4. A discussion of the distribution, intensity, and cause of overland flow in each stratum, and of the conditions under which it is generated.

Procedure

1. Carry out a Level I evaluation, as described.

2. Observe drainage paths of road runoff downslope of roads for a random sample of road segments to assess the proportion of drainage structures that convey surface runoff to channels. Assess the proportion of the road surface at these sites that contributes flow to drainage structures, rather than dispersing runoff across the hillslope.

3. Estimate the proportion of impermeable developed surfaces and exposed bedrock in each stratum that contributes surface runoff to the channel system rather than allowing it to disperse across hillslopes.

4. Estimate the duration of saturated conditions for seasonally saturated sites and soils with impeded drainage based on anecdotal reports, precipitation patterns, water-table depth, and soil-moisture storage capacity. Calculate overland flow runoff as precipitation falling during the saturated period.

5. For areas generating Horton overland flow, estimate infiltration capacities using published reports, anecdotal reports of flow during storms of known intensity, or infiltrometer measurements. Use precipitation records to estimate the proportion of the annual rainfall with higher intensity.

6. Calculate average overland flow intensity (indexed as the proportion of annual precipitation that runs off as overland flow) per unit area for each land use in each stratification unit by multiplying the average intensity by the proportion of the stratum in that land-use category.

References

Dunne, T., Moore, T.R., and Taylor, C.H. 1975. Recognition and prediction of runoff-producing zones in humid regions. Hydrological Sciences Bulletin 20(3):305-327.

Gleason, C.H. 1953. Indicators of erosion on watershed land in California. American Geophysical Union Transactions 34(3):419-426.

Mark, D.M. 1974. Line intersection method for estimating drainage density. Geology 2(5):235-236.

Reid, L.M., and T. Dunne. 1992. Rapid evaluation of sediment budgets. Draft dated May 29, 1992.

Van der Plas, L., and Tobi, A.C. 1965. A chart for judging the reliability of point counting results. American Journal of Science 263:87-90.

Way, D.S. 1978. Terrain Analysis. Dowden, Hutchinson and Ross. Stroudsburg, PA. 438 pp.

Base Flow

In Development ...

Stream Channel

Channel Condition

In Development ...

Vegetation

Blowdown

Level I

Purpose

The following methods and techniques can be used to help characterize and assess the role of blowdown in shaping the landscape pattern of plant communities by identifying distribution patterns of blowdown in the watershed. These methods and techniques can also assist in the assessment of natural and human causes of change between historical and current vegetative conditions by identifying land-use activities with which blowdown is associated.

Assumption

Aerial photographs taken after a major windstorm can be used to assess the relation between blowdown and various landscape and land-use parameters.

Data Needs

1. Topographic maps (1:24,000).
2. Recent set of aerial photos (Ideal: 1:12,000 color or false-color IR).
3. Sets of aerial photos postdating major windstorms.
4. Geologic map.
5. Vegetation map.
6. Soil map; some SRIs have a windthrow hazard risk interpretation.
7. Information on wind directions and intensities.
8. Land-use map.
9. Any existing analyses of blowdown in the area.
10. Information about past blowdown salvage sales.

Products

1. A map (1:24,000) of stratification units used to characterize blowdown. Units can be portrayed as having high, medium, or low blowdown incidence.
2. A tabulation of relative blowdown frequency within each substratum. Note that the measured frequencies provide only an index of relative susceptibility during a single storm, and, in part, reflect the character of that storm.
3. A discussion of the association of blowdown with topography, soils, rooting depth, water table, land use, vegetation, insects, disease, and other relevant variables.
4. A discussion of the implications of blowdown distribution for Riparian Reserve widths in each substratum.

Procedure

1. Determine the dates and characteristics of major windstorms in the area, particularly during the period since the second to last aerial photos set. Acquire aerial photographs (1:12,000 scale color or false-color infrared are most useful) immediately postdating the largest windstorms of the past several decades.
2. Scan the aerial photographs to identify areas of blowdown and to observe their association with topography, land-use activities, geology, soil type, and vegetation. Note areas of particularly high blowdown frequencies.
3. Talk to silviculturists and others working in the area to get their view of the causes and distribution of treefall.
4. Use the observed associations between blowdown and land characteristics to identify two or three characteristics that seem to most closely control blowdown distribution. These are likely to be topography (including landform and aspect), vegetation, and land use, but they may include geology, soil type, elevation, or other characteristics. If the concerns over treefall are primarily channel- or riparian-related, then the stratification parameters should be relevant to these areas.
5. Stratify the watershed or channel network according to the identified characteristics. Land use and vegetation may be treated as subdivisions within a stratification unit if they vary widely over short distances and times. Particularly relevant substrata often include various types of silvicultural margins.
6. Randomly select areas within each substratum for mapping treefall on aerial photographs taken after a major windstorm. This information will be used to determine relative sensitivity of different types of sites to blowdown. No two storms are exactly the same, so information should be interpreted with respect to the characteristics--such as wind direction--of the sampled storm. Blowdown often is patchily distributed during the largest storms. If

large tracts are blown down in patches, it may be most useful to map the blowdown patches throughout the area, rather than counting individual treefalls in sampled subareas.

7. Silvicultural margins (and especially the edges of clearcuts) are particularly susceptible to blowdown. Note the ages of the cuts affected and the distance of toppled trees from the original cut margin.

8. Measure the area or length of the sampled substrata. If this information is not available from a GIS, linear features can be measured using methods such as that presented by Mark (1974), and by using point counts (Van der Plas and Tobi 1965).

9. For each stratum, tabulate blowdown frequency by substratum.

10. Compare results for each of the samples within a stratum. If they agree relatively well (i.e., patterns of distribution are similar and frequencies agreed to within an order of magnitude), then the stratum is relatively well characterized. If results vary widely and some frequencies are high, then additional photos from the stratum should be scanned to determine whether the stratum should be subdivided further to better reflect controlling variables, or whether a larger sample set is required to characterize the stratum. If blowdown frequencies in the stratum are variable but low, no further work is necessary. "High" and "low" are relative to values in other stratification units.

11. Use the tabulated results to describe the association of blowdown with land-use activities, topography, vegetation, and other relevant variables in each of the stratification units.

Level II

Purpose

The following methods and techniques can be used to evaluate the influences and relationships between vegetative and seral patterns as affected by blowdown and other ecosystem processes in the watershed, by assessing the susceptibility of Riparian Reserves to blowdown as a function of setting and land use and by assessing the width of the margins affected by blowdown. These methods and techniques can also assist with the development of specific management recommendations by estimating the time required for silvicultural margins to become wind-firm after disturbance.

Assumption

Observations of blowdown distribution on aerial photos can be supplemented with information from additional storms and field observations.

Data Needs

1. Topographic maps (1:24,000).

2. Recent set of aerial photos (Ideal: 1:12,000 color or false-color IR).

3. Sets of aerial photos postdating major windstorms.

4. Geologic map.

5. Vegetation map.

6. Soil map; some SRIs have a windthrow hazard risk interpretation.

7. Information on wind directions and intensities.

8. Land-use map.

9. Any existing analyses of blowdown in the area.

10. Information about past blowdown salvage sales.

Products

1. A map (1:24,000) of stratification units used to characterize blowdown. Units can be portrayed as having high, medium, and low susceptibility to blowdown.

2. A tabulation of relative blowdown rates for different types of settings, vegetation types, and land-use activities within each stratification unit.

3. A discussion of the relative susceptibility of different site types and land-use activities to generating blowdown.

4. Plots of blowdown frequency as a function of distance from a silvicultural margin for different types of margins and different orientations with respect to wind direction within each important stratification unit.

5. A discussion of the implications of the plots in (4) to design riparian leave strips associated with different land-use activities (e.g., clearcutting versus selection cutting) and settings (e.g., first-order versus second-order channels).

6. A discussion of the time required for silvicultural margins to become wind-firm after disturbance.

Procedure

1. Carry out a Level I evaluation, as described.

2. Redo the aerial photograph analysis for additional windstorms.

3. Use weather records and mapped orientation of blowdown to characterize the "typical" important windstorm. This information may be useful for refining substratification units. For example, if major storms tend to have the same wind direction, the orientation of ecotones will be an important variable in determining their stability.

4. Randomly select for field visits about five examples of each important substratum, making sure that existing buffer strips and other silvicultural margins are well represented. Also make sure that linear features are represented in a variety of orientations with respect to the effective wind directions. A few sites should also be visited within subunits that show few blowdowns to verify their absence.

5. Look for evidence of blowdown in unmanaged stands where soils, vegetation, and topographic factors may contribute to blowdown susceptibility. Signs of past blowdown are pit/mound topography with or without evidence of tree boles.

6. At each field site, note the location, frequency, age, size, orientation, and species of recent blowdowns. Approximate ages can be categorized by the condition of the bole and ages of colonizing plants. Note associated conditions that might have influenced the blowdown. If the substratum represents an ecotone, as is the case with a silvicultural margin, estimate the distance of the fallen trees from the boundary.

7. Plot the frequency of blowdowns as a function of distance from a silvicultural margin for different types of margins and different orientations with respect to wind direction.

8. Compare blowdown intensity from a windstorm on silvicultural margins of different ages to estimate susceptibility as a function of disturbance age.

References

Mark, D.M. 1974. Line intersection method for estimating drainage density. Geology 2(5):235-236.

Van der Plas, L., and Tobi, A.C. 1965. A chart for judging the reliability of point counting results. American Journal of Science 263:87-90.

Curtis, James D. 1943. Some observations on wind damage. Journal of Forestry. 41:877-882.

Gratkowski, H.J. 1956. Windthrow around staggered settings in old-growth Douglas-fir. for. Sci. 2 (1):60-73.

Harris, A.H. 1989. Wind in the Forests of Southeast Alaska and Guides for Reducing Damage. Gen. Tech. Rep. PNW-GTR-244, Portland, OR. USDA Forest Service, Pacific NW Forest, and Range Experiment Station.

Mergen, Francois. 1954. Mechanical aspects of windbreakage and windfirmness. Journal of Forestry, 52 (2):119-125.

Ruth, R.H., and Yoder, R.A. 1953. Reducing wind damage in the forests of the Oregon Coast Range. USDA Forest Service. PNW Forest and Range Experiment Station. Research Paper No. 7. 30 p.

Ruth, R.H., and Harris, A.S. 1979. Management of western hemlock-sitka spruce forest for timber production. PNW FRES USDA-FS, Gen. Tech. Rpt. PNW-88:127-195.

Steinblums, I.J., Froehlich, H.A., and Lyons, J.K. 1984. Designing stable buffer strips for stream protection. Journal of Forestry. Vol. 82. No. 1.

Steinbrenner, E.C., and Gessel, S.P. 1956. Windthrow along cutlines in relation to physiography on the McDonald Tree Farm. Weyerhaeuser Company. Forestry Research Note 15. 19 p.

Fire Disturbance and Fire Risk Module

Purpose

1. Establish the natural role(s) of fire within the watershed. Characterize the range and mosaic of vegetation patterns that resulted from the natural fire regime(s) within the watershed.

2. Determine natural fuel and vegetation conditions, and document trends and changes from these conditions.

3. Establish the level of risk of large-scale high-severity fire, and the consequences of such an event within the watershed.

Assumptions

1. Fire histories can be established at the watershed scale by using or compiling existing data and can be reconstructed in an acceptable amount of time; or knowledge of fire regimes at a larger scale can be applied to the watershed with a reasonable level of confidence.

2. Analysts can use established aids to determine fuel conditions and models for estimating fire behavior. Fire risk and fire behavior computer models are useful at the watershed scale.

3. Available sources of knowledge and information, such as completed National Fire Management Analysis System (NFMAS) tables, will be used to the fullest extent possible and adapted to the landscape scale whenever possible.

Data Needs

1. Oldest available and current aerial photographs.

2. Local historical photographs.

3. Existing vegetation (GIS layer).

4. Stand maps, stand exams, and other vegetation inventories.

5. Fuel inventories and maps.

6. Fire occurrence databases and other agency fire occurrence records (e.g., atlases and reports).

7. Fire intensities derived from occurrence databases and large fire rehabilitation assessments.

8. Fire effects and fire severity information (e.g., Fire Effects Information System (FEIS), First Order Fire Effects Model (FOFEM), literature, and administrative surveys, reports, and records).

9. Records of past activities, including reforestation/revegetation and fuel treatment records.

10. NFMAS tables to establish fire occurrences and size classes by fire intensity level (FIL).

Products

1. Maps, tables, and descriptions of fire history of the watershed and/or fire regime(s) characteristic of the watershed.

2. Map of points of origin and causes of fires in the recent past (1970 to present), stratified into fire occurrence classes.

3. Maps and descriptions of fire intensities of large fires (>100 acres), and vegetation patterns that portray stand replacement fire events.

4. Maps of fuel models, and descriptions of fuel and vegetation conditions.

5. Descriptions of changes in natural fire regimes resulting from past management activities.

6. Descriptions of potential fire behavior.

7. Maps and descriptions of risk of large-scale, high-severity fire, and descriptions of potential consequences of these fires.

8. Descriptions of management actions for, and capabilities of, mitigating the risk of large-scale high-severity fires.

Procedures

1. a. Compile fire history (size, location, and intensity) from agency records and databases, and stratify fire occurrence into frequency classes; and/or

   b. Establish natural fire history (presuppression era and presettlement era) from studies, site records, and historical references, to a reasonable extent, and stratify fire occurrence into frequency classes; and/or

   c. Characterize the natural role(s) of fire (ecosystems, plant associations, and some individual species) and natural fire regime(s) (frequency/periodicity, size distribution, and distribution of severity classes) of the watershed. Natural fire regimes may need to be inferred from potential natural vegetation, American Indian occupancy, resource use patterns, and from climatic regimes. The use of existing plant association inventories, guides, and maps is highly encouraged.

2. Establish a natural range of fuel characteristics considering potential natural vegetation conditions and distributions (including patch size distribution), and potential natural coarse woody debris amounts and distributions.

3. Use Existing Vegetation Module to establish existing live biomass types, distributions, and conditions as they relate to fire ignition, spread, intensity, and severity.

4. Compile current fuel loading and distribution information, considering the history of disturbance and other fuel modifications, and assign or develop fuel model descriptions. This will include characteristics and distributions of coarse woody debris, standing snags, and existing vegetation.

5. Analyze changes in fire regimes (especially occurrence, size, and severity) due to altered fire history, vegetation, and fuel characteristics.

6. Using the natural role of fire, the natural fire regimes, the observed historical fire occurrence distribution, and the vegetation and fuel conditions derived in the above sections, develop stratified probabilities of fire occurrence across landscapes within the watershed.

7. Identify key resources (ecosystem and cultural/socioeconomic) that may be at risk under various levels of fire intensity.

8. Develop stratified expected effects on natural ecosystem components, based on natural fire regimes, altered fire occurrence and intensity, and resource susceptibility to fire.

9. Develop the probabilities that resources can be protected from fire under present altered fire regimes, existing vegetation, and fuel conditions.

10. Develop the probabilities that resources can be protected from fire under present altered fire regimes, with varying levels of management intensity, under currently directed land management guidance.

11. Describe potential/apparent conflicts between probable resource protection outcomes and current land management goals and objectives.

Note: Items 8-10 may be addressed by using the NFMAS and other fire-occurrence modeling, through the Fuel Appraisal Process (FAP) or its components, which will be particularly useful to simulate outcomes under different management scenarios. Stochastic systems modelling (such as SYSDYN5 [Wiitala, 1994]) can also be used to estimate probabilities of specific outcomes.

References

Fischer, William C. and Anne F. Bradley. 1987. "Fire Ecology of Western Montana Forest Habitat Types." USDA Forest Service Gen. Tech. Rep. INT-223.

Keane, Robert E., James K. Brown, Elizabeth D. Reinhardt, and Kevin C. Ryan. 1990. "Predicting First Order Fire Effects in the United States," The Compiler 8(4):11-15.

National Advanced Resource Technology Center (NARTC). 1994. National Fire Management Analysis System: Historical Analysis Course. Marana, Arizona.

National Wildfire Coordinating Group: Prescribed Fire and Fire Effects Working Team. 1994. Fire Effects Guide. National Interagency Fire Center, Boise, Idaho, NFES #2394.

Parker, V. Thomas. 1989. "Maximizing Vegetation Response on Management Burns by Identifying Fire Regimes." 87-91 pp. In USDA Forest Service Gen. Tech. Rep. PSW-109.

USDA Forest Service, Intermountain Research Station, Intermountain Fire Sciences Laboratory. 1996. First Order Fire Effects Model (FOFEM), Version 4.0. P.O Box 8089, Missoula, Montana 59807. (406)329-4800.

Rothermel, Richard C. 1983. "How to Predict the Spread and Intensity of Forest and Range Fires." USDA Forest Service, Intermountain Research Station, Gen. Tech. Rep. INT-143.

USDA Forest Service, Region 6. 1996. Development of the Fire Emissions Trade-off Model (FETM) and Application to the Grande Ronde River Basin. Portland, Oregon. Contract with CH2M-Hill (Contract Number 53-82FT-03-2).

Wiitala, Marc R., Mark H. Huff, and R. Gordon Schmidt. 1994. "Modeling the Response of Ecosystems to Random Fire Events Using System Dynamics." 291-298 pp. In Proceedings of the 12th International Conference on Fire and Forest Meteorology, October 26-28, 1993, Jekyll Island, Georgia. Society of American Foresters.

Vegetation

In Development ...

Terrestrial Coarse Woody Debris Levels and Recruitment

In Development ...

Water Quality

Water Quality Assessment

Purpose

The purpose of this module is to describe water quality assessment in the context of watershed analysis. Water quality is often viewed from two perspectives (Figure WQ-1). The first centers on setting objectives. This involves describing the aquatic resources (i.e., streams, lakes, etc.), the beneficial uses associated with these resources, and a set of indicators which reflect conditions. The objectives set are usually reflected in State water quality standards.

The second water quality assessment perspective relates to program management and implementation. Here, the focus is on how watershed processes and disturbance activities, through changes to input variables (e.g., sediment, water, wood, chemicals, etc.), affect beneficial uses as reflected through the same indicators used to assess conditions.

In conducting water quality evaluations associated with watershed analysis, the key is to focus on linkages. Much of the information needed for water quality assessment is available from other core topic areas (or modules). For instance, core topics such as human uses and species and habitats also describe beneficial uses dependent on aquatic resources. Likewise, watershed processes, such as hydrology, erosion, and vegetation, are core topic areas in watershed analysis with information which relates to source inputs that affect water quality. Lastly, assessment of stream channel, another core topic area, utilizes many of the same indicators associated with aquatic life uses in water quality assessments.

Water quality assessment within watershed analysis, under the Federal process, consists of three components: characterization, condition assessment, and interpretation. The assessment attempts to identify, for waterbodies occurring in the watershed, those situations where beneficial uses dependent on water quality are, or are likely to be, impaired as a result of disturbance activities. This includes not only forest practices, but also other land management activities such as agriculture, grazing, or urban development. The approach taken in this module is to evaluate information on how water quality within the watershed is affected by the cumulative effects of disturbance activities.

The following critical questions help frame the assessment of water quality in watershed analysis:

- What beneficial uses dependent on aquatic resources occur in the watershed and which water quality parameters are critical to these uses?
- What are the current conditions and trends of beneficial uses and associated water quality parameters?
- What were the historic water quality characteristics of the watershed?
- What are the natural and human causes of change between historic and current water quality conditions?
- What are the influences and relationships between water quality and other ecosystem processes in the watershed (e.g., mass wasting, fish habitat, stream channel, etc.)?

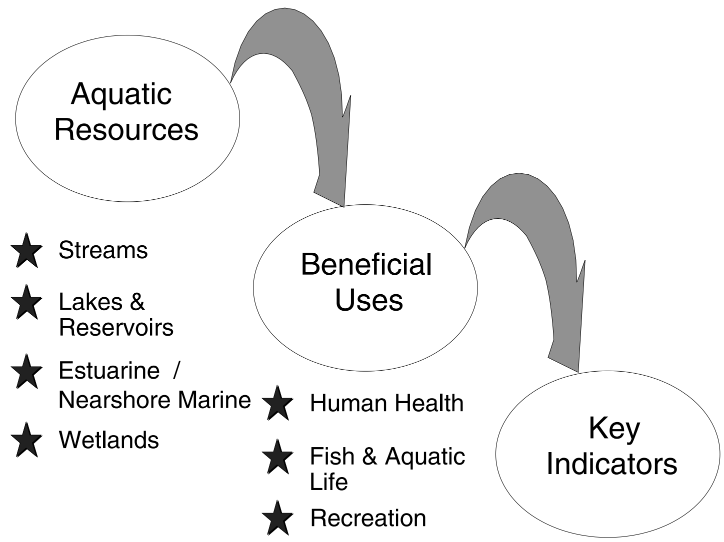
Assumptions

A number of fundamental assumptions underlie the approach developed within this module. The most fundamental assumption is that the analysis be based on the best available scientific information and techniques. Therefore, the analysis methods presented are designed to change as newer, more refined methods are developed. This module provides a framework for the assessment of the physical, chemical, and biological components of water quality based on several principal assumptions.

A water quality module proposed in the State of Washington (TFW [draft], 1995) described an initial set of assumptions. These assumptions represent a valid starting point and include the following:

- State and Federal water quality standards (beneficial uses and the criteria to protect these uses) embody key water quality concerns.
- Water quality parameters can vary significantly, both in short-term time and in space.
- All land use activities, as well as natural processes, can cause changes in water quality.
- The condition of a waterbody represents its response to past and current watershed processes. Current condition and historical changes are indicators of the potential of the waterbody to be influenced by watershed processes and land use activities.

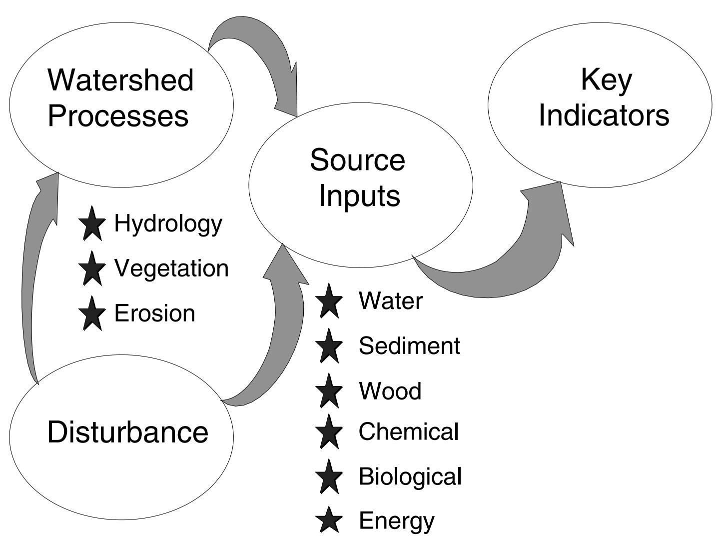
***Figure WQ-1*: Water Quality Assessment -- The Context**



Key Indicators

Categories

- ***Water Column***
- ***Sediment***
- ***Aquatic Organisms***



- Waterbodies differ in their functional characteristics. These characteristics influence the beneficial uses of a particular waterbody and determine its vulnerability to changes in input variables.

- Changes in water quality result from changes in input variables (e.g., sediment, energy, water, wood, chemicals) to each waterbody of concern.

- Important watershed-influencing waterbodies can be identified, and current / historical conditions of some parameters assessed using aerial photography and remote sensing.

- Waterbodies differ in their likely changes in functional characteristics resulting from watershed processes and land use activities.

- Wetlands readily observed from aerial photos should be part of the water quality assessment, to the extent feasible. However, some wetlands (e.g., small, isolated, forested wetlands, or cedar/spruce riparian wetlands in U-shaped valleys) are not readily identified using remote sensing methods. Where these wetlands are known to exist, they should be mapped and included in the assessment.

Information Resources (for all levels)

Water quality is best described in the context of how it affects a beneficial use. Identifying specific resource concerns (e.g., coho salmon) and affected uses (e.g., loss of rearing habitat) allows a focused analytical framework to be developed relative to water quality concerns. Initial information requirements for water quality assessment include topographic maps, aerial photographs, and existing water quality data. In developing information to address water quality / beneficial use questions, procedures from other modules could also prove useful. Potential sources of information include:

Maps

- Topographic Maps

- GIS hydrography layers

- Soil Survey Maps, Soil Descriptions, and Hydric Soils List

- Land Use Maps

Aerial Photographs

- Most recent coverage (1:12,000 or better, if available)

- Historic photos (if available)

- Color or false-color infrared photography for locating wetlands (if available)

Water Quality Data and Other Information

- State Water Quality Management Agencies

- Local Tribal Water Quality Data

- U.S. Geological Survey Miscellaneous Water Quality Data, National Water Quality Assessment (NWQA) Data, and Flow Records

- Wetland inventories

- Other general sources including:
  - Slope Class and Flood Plain Maps
  - State resource catalogs
  - Adjacent shoreline information

Level I Analysis

Characterization

The water quality assessment process begins by addressing characteristics in the watershed that are important to water quality. Characterization involves describing the distribution of aquatic resources and beneficial uses dependent on water quality in the watershed. Characterization also involves identifying which water quality parameters are critical to assessing the condition of key beneficial uses in the watershed.

Products

1. An aquatic resource identification map showing streams, lakes, ponds, reservoirs, nearshore marine waters, readily detectable wetlands, and potential wetlands. Include locations of water supply or water use facilities on the map.

2. A waterbody summary table containing information such as subwatersheds, miles of rivers and streams, number/acreage of lakes / reservoirs / ponds, wetland acreage, and square miles of estuarine / nearshore marine waters (if applicable).

3. Maps and tables identifying key beneficial uses and land use activities.

4. Narrative description of stream channel and wetland types (including a functional assessment of each wetland or wetland/riparian complex).

5. Table of available data showing waterbodies monitored, stations monitored, parameters measured, period of record, QA assessment, and a reference.

6. List of waterbodies included on State §303(d) list.

Procedures

1. Aquatic Resource Identification and Mapping.

   A key first step in assessing water quality is to identify and map aquatic resources in the watershed. The Northwest Forest Plan has identified five categories of aquatic resources for Federal lands which include:

   - Fish-bearing streams.
   - Permanently flowing, nonfish-bearing streams.
   - Constructed ponds and reservoirs, and wetlands greater than 1 acre.
   - Lakes and natural ponds.
   - Seasonally flowing or intermittent streams, and wetlands less than 1 acre.

   Identifying and mapping aquatic resources involves a preliminary screening of topographic maps to detect any obvious and/or previously mapped water features. One approach to begin the mapping exercise is to review the USGS hydrography displayed at the 1:24,000 scale. GIS is also a powerful tool to assist with aquatic resource identification, but not essential at this stage.

2. Beneficial Use/Applicable Standards Summary.

   Consideration of State water quality standards, both beneficial uses and criteria, represents a general basis for describing water quality-related issues. The success of developing a meaningful water quality assessment, however, hinges on the ability to move from general resource issues to specific priority concerns for the watershed. A logical starting point is to address simple questions about key resources, such as *what* (i.e., key fish species), *where* (i.e., location of areas within the watershed important to priority resource concerns), and *when* (i.e., description of timing considerations for priority resource concerns).

   A common starting point involves identifying the distribution of specific beneficial uses in the watershed. In general terms, resource concerns dependent on water quality refer to key beneficial uses such as water supply, recreation, and aquatic life.

   Water quality should be described in the context of how it affects a beneficial use. Identifying specific resource concerns (e.g., coho salmon) and affected uses (e.g., loss of rearing habitat) allows a focused analytical framework to be developed. The framework, relative to water quality concerns, can help guide analysis activities.

   Beneficial uses dependent on water quality are generally assessed with a set of key indicators which reflect conditions. Table WQ-1 summarizes key indicator/beneficial use relationships.

3. Area Categorization.

   When organizing water quality data for streams, area categorization focused on the channel network can be useful. Stream channels tie key pieces of information together in the water quality/beneficial use assessment process. Different approaches can be used for categorization of other types of waterbodies.

4. Existing Water Quality Data Inventory.

   A fundamental step in the assessment process is to inventory existing water quality data. This inventory provides a perspective on water quality data collection activities in the watershed. The inventory should identify stations (by subwatershed, if possible), parameters, frequency, and objectives.

Level II Analysis

Condition Assessment

The second level of analysis involves assessing conditions of waterbodies and their associated water quality parameters. Existing data should be the starting point to assess current water quality conditions. Review of scientific literature plus professional experience are also used to identify watershed situations (e.g., soils, vegetation, land use, or flow) where adverse change to a water quality parameter may occur.

Table WQ-1: WQ Parameters / Beneficial Use Relationships

Water Quality Parameter	Water Supply	Recreation	Aquatic Life		
			Cold Water Fish	Warm Water Fish	Biological Integrity
Flow					
Peak Flows			xx	--	xx
Low Flows	■■■■■■		xx	xx	--
Water Column					
Temperature	--	xx	■■■■■■	--	■■■■■■
Dissolved Oxygen	xx	xx	■■■■■■	■■■■■■	■■■■■■
Nutrients	xx	xx	--	--	xx
pH	■■■■■■	--	--	--	--
Toxic Contaminants	■■■■■■	xx	xx	xx	■■■■■■
Aquatic Organisms / Communities					
Bacteria / Pathogens	■■■■■■	■■■■■■			--
Algae	xx	■■■■■■	xx	xx	■■■■■■
Invertebrates		--	■■■■■■	■■■■■■	■■■■■■
Fish		■■■■■■			■■■■■■
Sediment					
Turbidity	■■■■■■	■■■■■■	■■■■■■	■■■■■■	■■■■■■
Sedimentation	■■■■■■	xx	■■■■■■	xx	■■■■■■
Bedload	--	--	xx	xx	xx
Channel Characteristics					
Width / depth			xx	xx	xx
Pool metrics			■■■■■■	■■■■■■	xx
Woody debris			■■■■■■	■■■■■■	xx

Key:
■■■■■■ Use is directly related & highly sensitive to the parameter in almost all cases.
xx Use is closely related & somewhat sensitive to the parameter in most cases.
-- Use is indirectly related & not very sensitive to the parameter in most cases.
<blank> Use is largely unrelated to the parameter.

Waterbodies identified on a State §303(d) list are automatically considered in the assessment because impairment of designated uses are known to have occurred or will likely occur. The analysis may validate or refine results of these determinations.

The condition assessment may be an iterative process that requires repeated evaluation of information. Follow-up analyses may be targeted for appropriate monitoring techniques. Opportunities for additional measurement may be seasonally influenced because many water quality parameters are highly variable over the course of a year.

Information Resources

Data identified for all levels plus results from the *Characterization* phase of the assessment.

Products

Products from this phase of the water quality assessment include the following:

1. Same products as Level I, but refined with additional information.

2. A completed condition assessment for key waterbodies or subwatersheds identified in the *Characterization* phase. Data should be reported at a scale commensurate with the scale of features and processes within the watershed.

3. Map showing areas where beneficial uses dependent of aquatic resources are fully supported, partially supported, or not supported according to the condition assessment.

Procedures

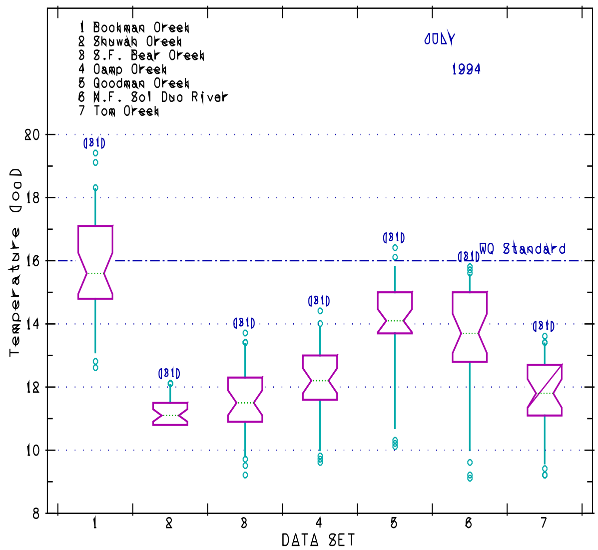
Procedures for Level II analysis are the same as Level I with the following refinements:

1. Existing Water Quality Data Analysis.

   The first step in water quality condition assessment is to evaluate existing data. Availability of data will vary by waterbody and by the relative importance of beneficial uses in the drainage. Extensive flow and chemical data may be available if water supplies exist in the watershed. More often, data may be limited or non-existent. If a waterbody is on the State §303(d) list, then impairment of designated uses has already been established.

To assess how well water quality conditions support beneficial uses in the watershed, it is essential that relevant parameters be evaluated. Existing information is used to describe the characteristics (e.g., frequency, magnitude, duration, seasonal patterns) of key indicators used to assess conditions *(Figure WQ-2)*. These characteristics should be analyzed for spatial differences or trends.

Figure WQ-2: Example WQ Data Summary



In reviewing data from various parameter groups, it is important to maintain linkages to beneficial uses dependent on aquatic resources. Key points in assessing water quality conditions relative to each parameter group include:

- Flow.

  Indicators of flow conditions in the watershed are a key part of assessing water quality. Flow parameters are included in the water quality assessment because of sensitivity to management activities, the relationship to beneficial uses, and general concern to the public. An increase in summer low flows, for instance, generally can reduce peak temperatures and increase available fish habitat. The size of peak flows also have important implications for the stability of stream channel, size and quantity of bed material, and sediment transport rates.

- Water Column.

  The physical properties and chemical constituents of water traditionally have served as the primary means for monitoring and evaluating water quality. This is due both to their sensitivity to management activities and the importance in aquatic ecosystems.

- Aquatic Organisms.

  Can be very useful in assessing water quality conditions because they effectively integrate a large number of habitat characteristics. If the habitat requirements of a particular organism are known, the presence of that organism can be used to define conditions in that particular waterbody.

- Sediment.

  Increased sediment loads are often the most important adverse effect of land management activities on aquatic resources. Large increases in the amount of sediment delivered to stream channels can greatly impair, or even eliminate, fish habitat.

  The physical effects of increased sediment loads can also be significant. Fine sediment can impair the use of water for municipal or agricultural purposes. Indirect effects of increased sediment loads may include increased stream temperatures and decreased intergravel dissolved oxygen.

- Channel Condition.

  It is generally recognized that characteristics of physical habitat influence potential beneficial uses; e.g., the density and survival of fish. Channel morphology reflects, as well as integrates, processes operating in the watershed because eroded material is ultimately delivered to, and routed through, the channel network. As a result, channel type / condition provides a useful framework for assessing water quality in watershed analysis.

2. Coarse Screening for Potential Data Gaps.

   Once actual water quality data has been reviewed, the next step is to examine *watershed conditions* that are reasonably likely to produce adverse water quality conditions. The connection is based on possible changes in watershed input variables (sediment, water, energy, chemical, etc.) that affect specific qualities of water. In conducting coarse screening, two factors should be considered:

   - Watershed processes and functions relevant to the beneficial use

   - Disturbance activities in the watershed

Level III Analysis

Interpretation

Interpretation is the place to synthesize water quality information in the context of watershed processes. In interpretation, similarities, differences, and trends in water quality conditions are explained. Interpretation also involves identifying the capability of the system to achieve water quality management objectives.

To accomplish this, the natural and human causes of change between historical and current water quality conditions are analyzed. Differences in the range, frequency, and distribution of relevant historical, current, and natural water quality conditions should be explained. In addition, influences and relationships between water quality and other ecosystem processes in the watershed (e.g., mass wasting, fish habitat, stream reach vulnerability) are evaluated. Data gathered and analyzed from other modules (or technical tools) should be quantitatively compared. Causal mechanisms that best explain the differences and how these factors affect the watershed's capability to achieve water quality management objectives also should be identified.

Information Resources

- Watershed characterization from Level I.

- Data and descriptions from Level II.

Products

Products from the Level III water quality assessment include the following:

- Description and explanation of key patterns and trends in water quality, including waterbody specific considerations.

- Written narrative on criteria used to select waterbodies for detailed assessment, which waterbodies are naturally vulnerable, and some description of cause / effect relationships.

- Discussion and display of the dominant processes and causal mechanisms that explain the relationship between current and historical conditions with the issues and key questions.

- Discussion of major natural and human-related changes in the system that have fundamentally altered the capability to achieve desired conditions or key management plan objectives.

- Description of the discrepancies between the current resource conditions and relevant management objectives.

- A prioritized list of monitoring / field surveys needs, including those needed to verify remote sensing and aerial photo information.

Procedures

1. Aquatic Resource Considerations.

   Interpretation of water quality information depends on the aquatic resource or water type. Water quality assessment generally begins with streams, followed by examination of any other receiving waterbodies that may occur in the watershed (i.e., lakes, ponds, reservoirs, wetlands, and nearshore marine / estuarine waters). Sensitivity of any given parameter depends on the type of waterbody (Table WQ-2).

2. Role of Source Inputs.

   To fully interpret conditions, the role of source inputs which affect water quality should be evaluated. Here, the focus of the assessment shifts to identifying the connections between the array of water quality parameters and the associated input variables (e.g., sediment, energy, and chemicals) which can potentially be influenced by disturbance activities.

   As an example, stream temperature is the common water quality indicator where potential connections to multiple source inputs should be considered. Characterization of stream temperature traditionally focuses on riparian shading (or heat) as a primary input. Although riparian shading may be important, temperature problems also tend to occur during low flow conditions. Consequently, the role of water quantity (or lack thereof) in contributing to temperature problems should be considered. In addition, the analysis should also consider the effect of channel changes due to excessive sedimentation. This could also lead to temperature problems as a result of wide, shallow streams.

   As mentioned earlier, many of these input variables (water, sediment, wood, etc.) are also considered in other module reports or core topics.

3. Relationship to Watershed Processes.

   Interpretation continues by putting water quality conditions into the context of the relationship to watershed processes.

   As an example, assessment of water quality with respect to sedimentation must rely on integrating information from several other core topic areas. Inputs which could affect fisheries and aquatic life uses are the result of interactions between vegetative, hydrologic, and erosion processes. The channel network and condition provides information on the conduits from sources, the transport potential of the system, and areas where responses would be observed. Finally, indicators used to evaluate fish habitat are often the same parameters utilized in water quality assessment. Thus, determination of beneficial use support must look at all pieces of the sediment picture.

4. Summary.

   The key to addressing water quality issues in watershed analysis is to describe, in a logical manner, relevance to the resources dependent on water quality. The analysis should logically link the beneficial uses of greatest concern to key indicators, processes of interest, disturbance activities, restoration opportunities, and protection needs. Figure WQ-2 is presented as an example which could, based on interpretation, help guide watershed activities relative to water quality issues. Of particular interest are recommendations on monitoring and restoration.

Table WQ-2: Water Quality Parameters and Input Variables

Water Quality Parameter	Input Variable	Waterbody Type			
		Streams	Lakes & Ponds	Wetlands	Nearshore Marine/ Estuarine
Water Column					
Temperature	Heat energy	X	X		X
Dissolved Oxygen	Organic matter / Nutrients	X	X		X
Nutrients	Nitrogen / Phosphorus / Fine sediment	X	X		X
pH	Acids / Bases	X	X	X	X
Toxic Contaminants	Organic & synthetic chemicals	X	X	X	X
Sediment					
Turbidity	Fine sediment	X	X		X
Sedimentation	Coarse & fine sediment Bedload	X	X	X	X
Aquatic Organisms					
Bacteria / Pathogens	Fecal coliform / E. coli	X	X		X
Invertebrates	Sediment Toxic chemicals	X	X	X	X
Fish	Heat energy Sediment Toxic chemicals	X	X		X
Flow					
Peak Flows	Water yield	X			
Low Flows	Water yield	X			
Channel Characteristics					
Width / depth	Sediment	X			
Pool metrics	Sediment	X			
Woody debris	Riparian inputs	X			

Table WQ-3: WQ Parameters / Watershed Process Relationships

Water Quality Parameter	Hydrology	Erosion	Vegetation
Flow			
Peak Flows	■■■■■■		xxx
Low Flows	■■■■■■		xxx
Water Column			
Temperature	xxx	xxx	■■■■■■
Dissolved Oxygen	xxx	xxx	
Nutrients	xxx		xxx
pH			xxx
Toxic Contaminants	xxx	xxx	
Aquatic Organisms			
Bacteria / Pathogens	xxx		
Algae	xxx	xxx	xxx
Invertebrates	■■■■■■	■■■■■■	xxx
Fish	■■■■■■	■■■■■■	■■■■■■
Sediment			
Turbidity	xxx	■■■■■■	---
Sedimentation	xxx	■■■■■■	xxx
Bedload	xxx	■■■■■■	---
Channel Characteristics			
Width / depth	xxx	■■■■■■	
Pool metrics	xxx	■■■■■■	
Woody debris			■■■■■■

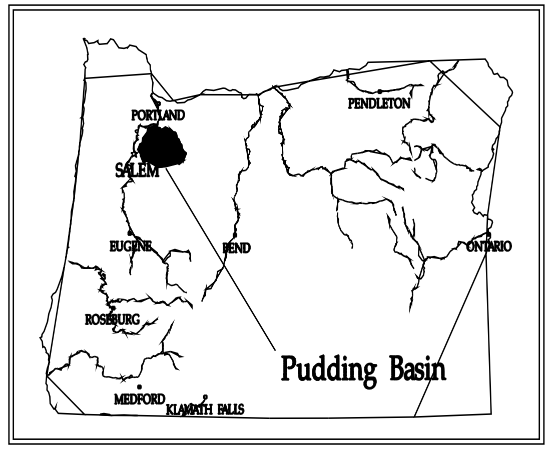
Key: ■■■■■■ Parameter is directly related & highly sensitive to the watershed process.
xxx Parameter is closely related & somewhat sensitive to the watershed process.
-- Parameter is indirectly related & not very sensitive to the watershed process.
<blank> Parameter is largely unrelated to the watershed process.

Figure WQ-2: Example Summary of CWA Issues

Pebble Creek

WATERSHED AT A GLANCE:

Province:	*Willamette*
Sub-basin:	*Mollala / Pudding*
Watershed Size:	*165 sq. miles*
Land Ownership:	*Mt. Hood N.F. (38%)*
	BLM -- Salem (22%)
	Other (40%)
Major Communities:	*Duckville*
	Rainport



ISSUES

RESOURCE CONCERNS:
- Spring Chinook
- Coho
- Rainport Municipal Water Supply

AFFECTED USES:
- Loss of rearing habitat

KEY INDICATORS:
- Residual pool volume
- Water temperature

PROCESSES OF INTEREST:
- Mass wasting
- Surface erosion
- Riparian functions

DISTURBANCE ACTIVITIES:
- Harvest on steep slopes
- Fine sediment from roads & ditches
- Harvest of riparian areas

RESTORATION OPPORTUNITIES:
- Decommission roads 2341, 2863, 2976, 3026
- Revegetate and stabilize lower toe slopes on Slimy Draw roads
- Re-establish side channels and create adjacent ponds on mainstem and tributaries
- Re-establish riparian vegetation at eight sites

PROTECTION NEEDS:
- Maintain full riparian reserves on all fish-bearing streams
- Fully implement S&G's for maintenance of stream crossings & road surface drainage structures

References

EPA. 1980. An Approach to Water Resources Evaluation of Nonpoint Silvicultural sources. EPA-600/8-80-012, Washington, D.C.

EPA. 1986. Quality Criteria for Water: 1986. EPA, Office of Water Regulations and Standards, Washington, D.C.

EPA. 1987. Surface water monitoring: A framework for change. EPA Office of Water, Regulation and Standards. Washington, D.C. 41 p.

EPA. 1993. Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters, Chapter 3 Management Measures for Forestry. EPA-840-B-92-002, Washington, D.C. pp 3-1 to 3-121.

EPA. 1993. Guidelines for Preparation of the 1994 State Water Quality Assessments [§305(b) Reports]. EPA841-B-93-004. USEPA Office of Water. Washington, DC.

EPA. 1996. Federal Guide for Watershed Analysis -- Water Quality Assessment Supplement (DRAFT). EPA Region 10. Seattle, WA.

Hatten, J.R. and R.H. Conrad. February 1995. A Comparison of Summer Stream Temperatures in Unmanaged and Managed Sub-Basins of Washington's Western Olympic Peninsula. Hoh Indian Tribe and Northwest Indian Fisheries Commission.

Karr, J.R. et al. 1986. Assessing Biological Integrity in Running Waters: A Method and its Rationale. Ill. Nat. Hist. Surv. Spec. Publ. 5. Urbana.

Lloyd, D.S., J.P. Koenigs, and J.D. LaPerriere. 1987. Effects of turbidity in fresh waters of Alaska. N.Amer.J.Fish.Mgmt. 7:18-33.

MacDonald, L.H., A.W. Smart, and R.C. Wissmar. 1991. Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska. EPA 910/9-91-001. 166 pp.

Plotnikoff, R.W. 1994. Instream Biological Assessment Monitoring Protocols: Benthic Macroinvertebrates. Washington Department of Ecology. Pub. # 94-113.

Reid, L.M. and T. Dunne. 1992. Rapid Evaluation of Sediment Budgets. Draft dated May 29, 1992.

Timber/Fish/Wildlife. 1995. Water Quality Module (Review Draft).

Washington State Forest Practices Board. 1994. Standard Methodology for Conducting Watershed Analysis: Version 2.1. November 1994.

Species and Habitats

Habitat Assessment for Terrestrial Plants and Animals

Purpose

Level I techniques and methods can be used to characterize the distribution and character of habitats for terrestrial species of concern that are important in the watershed (e.g., threatened or endangered species, special status species, species emphasized in other plans). Levels II and III approaches can help assess current habitat conditions and trends for the identified species of concern.

Assumptions

1. Habitat for animals can be described in terms of vegetation composition and structure and/or non-vegetative structure such as cliffs, caves, talus, etc.

2. Habitat for plants can be described in terms of soils, geology, topography, seral stage, etc.

3. Amount, distribution, and pattern of habitat effects occurrence of species.

Data Needs

1. Maps of current, historical, and future vegetation.

2. Maps of "Special Habitats."

3. Habitat relationships information.

4. Species occurrence/range maps or information.

5. Roads and trails map (for some species).

6. Data on coarse woody debris levels.

7. Soils map.

8. Geology map.

9. Topographic map.

Level I

Level I represents a qualitative characterization of habitat capability in the watershed for species of concern or interest.

Products

1. A map of areas within the watershed where habitat for the species occurs.

2. A qualitative narrative on habitat availability for species of concern or interest including discussion of general historical and future trends in habitat. Discussion should include special habitat (e.g., wetlands, meadows, talus, etc.) and specific habitat components (e.g., snag, down logs, etc.).

Procedure

1. Determine those species that occur in the watershed that are of concern or interest.

2. Collect and compile habitat relationship and occurrence data for those species.

3. Create a map of where the habitats occur in the watershed.

4. Collect any available information on historical occurrence of habitat in the watershed.

5. Determine the effect land allocations and standards and guidelines from the NFP, or other applicable plans, has on future habitat for the species.

6. Discuss current condition of habitat for the species in the watershed and how habitat in the watershed relates to habitat at the Province and Regional scales.

7. Using information from steps 3-5, qualitatively discuss trends in habitat availability and quality over time.

References

The following are sources of habitat relationship information:

Brown, E.R., tech. ed. 1985. Management of wildlife and fish habitats in forests of western Oregon and Washington. USDA Forest Service. Pacific NW Region. Pub. No. R6-F&WL-192-1985.

Oregon Department of Fish and Wildlife. Oregon Species Information Database. Corvallis, OR. Contact Wanda McKenzie (503) 757-4186.

Rodrick, E., and Milner, R. tech. eds. 1991. Management Recommendations for Washington's Priority Habitats and Species. Washington Department of Wildlife. Olympia, WA.

Ruggiero, L.F. et al. 1991. Wildlife and vegetation of unmanaged Douglas-fir forests. USDA Forest Service. PNW Research Station. Portland, OR. PNW-GTR-285.

Thomas, J.W., tech. ed. 1979. Wildlife habitats in managed forests, the Blue Mountains of Oregon and Washington. USDA Forest Service. Pacific NW Region. Ag. Handbook No. 553.

Level II

Level II analysis is similar to Level I, but also includes a quantitative assessment of habitat capability. The quantitative assessment may include using existing habitat capability models for some species.

Products

1. A map of areas within the watershed where habitat for the species occurs.

2. A quantitative summary of habitat availability for species of concern or interest including an assessment of historical and future trends in habitat. Assessment should include special habitat (e.g., wetlands, meadow, talus, etc.) and specific habitat components (e.g., snag, down logs, etc.).

3. Species-specific habitat capability indices.

Procedure

1. Determine those species that occur in the watershed that are of concern or interest.

2. Collect and compile habitat relationship and occurrence data for those species.

3. Create a map of where the habitats occur in the watershed.

4. Quantitatively summarize historical habitats using a map of historical vegetation.

5. Quantitatively summarize future habitats from a map of future vegetation that incorporates the effect of land allocations and standards and guidelines from the NFP, or other applicable plans.

6. Run habitat capability models for species that have available models. Models exist for elk and cavity nesting species. (See references below.)

7. Quantitatively summarize current condition of habitat for the species in the watershed, and qualitatively discuss how habitat in the watershed relates to habitat at the Province and Regional scales.

8. Using information from steps 3-5, quantitatively summarize and discuss trends in habitat availability and quality over time.

Additional References

Marcot, Bruce. Snag Recruitment Simulator Model - SRS2. USDA Forest Service, PNW Research Station, Portland, OR.

Wisdom, Mike. et al. 1986. A model to evaluate elk habitat in western Oregon. USDA Forest Service, Pacific NW Region, Portland, OR. Pub No. R6-F&WL-216-1986.

Level III

Level III analysis includes generalized habitat analyses for all species potentially occurring in the watershed with individual species analysis similar to Level II for species of concern or interest in the watershed. The generalized habitat analysis would be used to help screen for species of concern based on trends in habitat from historic, current, and predicted future habitat capability.

Products

1. A map of habitat for groups or guilds of species,

and species of interest or concern in the watershed.

2. A quantitative summary of habitat availability for groups or guilds of species and for species of concern or interest including an assessment of historical and future trends in habitat. Assessment should include special habitat (e.g., wetlands, meadow, talus, etc.) and specific habitat components (e.g., snag, down logs, etc.).

3. Species-specific habitat capability indices.

Procedure

1. Collect and compile habitat relationship and occurrence data for those species potentially occurring in the watershed. Computerized databases are available, see references below.

2. Run group or guild level habitat relationships model for the watershed or tier to results of the model run at the basin or province scale. See references for available habitat relationships models. The model should be run for historic, current, and projected future vegetation.

3. Determine if any groups or guilds of species are of concern due to trends in habitat availability or rarity of habitat.

4. Conduct species-specific habitat capability analysis for those species of concern or interest. Run habitat capability models for species that have available models.

5. Quantitatively summarize current condition of habitat for the species in the watershed and qualitatively discuss how habitat in the watershed relates to habitat at the Province and Regional scales.

6. Using information from steps 2-4, quantitatively summarize and discuss trends in habitat availability and quality over time.

Additional References

<u>Databases</u>

Manley, Pat and Davidson, Carlos. AVESBASE: A conservation database for California birds. USDA Forest Service, Pacific SW Region, San Francisco, CA.

Mt. Hood National Forest. Wildlife Habitat Relationship - Life History Database. USDA Forest Service, Gresham, OR. Contact Kim Mellen (503) 666-0670.

<u>Models</u>

Garman, Steve. Wildlife Habitat Modeling - Augusta Creek Watershed. Computerized model. OSU Forest Science Department, Corvallis, OR.

Mellen, Kim; Huff, Mark; and Hagestedt, Rich. 1994. Spatial Analysis of Wildlife Habitat Relationships. Computerized model. Mt. Hood National Forest, Gresham, OR.

Mt. Baker-Snoqualmie National Forest. Habitat Condition module. Computerized model. USDA Forest Service, Mountlake Terrace, WA. Contact Charlie Vandemoer (206) 744-3426.

Terrestrial Population Viability

Purpose

Once the distribution and current habitat conditions and trends for the species of concern are identified in the analysis, the following methods and techniques can be used to assess the causes of change between historical and current species distribution to determine the likelihood of species persistence, both within the watershed and as part of a larger population.

Assumptions

Analyses of population viability must be conducted at appropriate scales; i.e., it is not appropriate to analyze viability of wide-ranging species within a site-specific analysis. Therefore, analysis of viability at the scale of a watershed assumes that either:

1. The species has a very localized distribution, and a large portion of the species' range is contained within the watershed, or;
2. The analysis done within the watershed for a wide-ranging species can be placed within the appropriate context and address the contribution of the watershed to overall species viability.

Data Needs

(common to all levels and methods)

1. Existing vegetation map.
2. Species range map.
3. "Special habitats" map.
4. Historical disturbance maps.
5. Potential vegetation map.
6. Land allocation map.
7. Land ownership map.
8. Life history information.
9. Viability assessments from other efforts; i.e., regional or provincial analyses.

Level I

Products

1. A map of areas within the watershed where the species is likely distributed.
2. A map of areas that likely support species movements (animals) or other dispersal (plants) within the watershed and between this watershed and surrounding areas.
3. A qualitative assessment of the likelihood of species persistence within the watershed, contribution to overall species persistence, and of the conditions that significantly increase or decrease the likelihood of persistence.

Procedure

1. Review life history information to determine: (a) habitats most likely to support the species, and (b) species characteristics that influence its vulnerability to extinction threats. Extinction threats could be classified as follows:
   - Demographic
     - Random variation in birth and death rates
   - Genetic
     - Inbreeding depression and genetic drift
   - Environmental
     - Loss of habitat
     - Systematic chronic effects
     - Random catastrophic events
     - Biological interactions
     - Pollutants, toxicants
2. Overlay species range map, existing vegetation map, and "special habitats" map to determine: (a) potential species distribution within the watershed, (b) areas where the species is most likely to occur based on current habitat conditions, (c) areas of possible connection with other watersheds, and (d) areas where habitat for the species could potentially be restored. Produce a map of these areas.
3. Based on the areas mapped in step 2 above, and available information on species density, provide a crude estimate of possible population levels in the watershed.

4. Use historical disturbance maps and information to assess likely historical variation in species habitat within the watershed.

5. Overlay land allocation and land ownership maps on the areas mapped in step 2 above to determine possible effects of management on habitat for the species.

6. Based on the above information, provide qualitative assessments of :

   - The importance of the watershed in providing for species persistence.
   - Primary factors that could place the species at risk within the watershed and in surrounding watersheds.
   - Areas within the watershed that are key to species persistence.
   - Possible effects of management on the species, both positive and negative.
   - An overall assessment of the likelihood of species persistence within the watershed.

Level II

Additional Data Needs for Level II Analysis

1. Species occurrence map and survey data.
2. Habitat relationships information.

Products

1. Same products as Level I, but refined with additional information.
2. A quantitative assessment of the capability of habitats within the watershed to support the species.

Procedure

Procedures for Level II analysis are the same as Level I with the following refinements:

1. In step 2 of Level I analysis, use species occurrence map and survey data to refine the assessment of species distribution pattern and habitat use within the watershed.

2. In step 3 of Level I analysis, use habitat relationships models and information to improve the estimate of population size that could be supported within the watershed.

Level III

Additional Data Needs for Level III Analysis

1. Local habitat use information.
2. Population information, including trends.

Products

Level III analysis will generate the same products as Level II analysis, and, in addition, will provide a projection of likely population trend over time.

Procedure

1. Utilize local habitat use information to improve the assessments done in steps 2, 3, and 4 of Level I analysis.

2. Use demographic or density information to provide an assessment of past population trends.

3. Use available population modeling techniques, demographic information, and habitat information to develop assessments of possible future trends in the population. Models could be either nonspatial (e.g., VORTEX, Ramas/age) or spatial (e.g., Ramas/GIS).

4. Use information from step 3 to improve the overall assessment of the likelihood of species persistence within the watershed.

References

Akcakaya, H.R. 1992. Population viability analysis and risk assessment. Pages 148-157 in Wildlife 2001: Populations. D.R. McCullough and R.H. Barrett, eds. Elseverier Publishers, London.

Akcakaya, H.R. 1994. RAMAS/GIS: Linking Landscape Data With Population Viability Analysis (version 1.0). Applied Biomathematics, Setauket, New York.

Boyce, M. 1992. Population viability analysis. Ann. Rev. Ecol. Syst. 23:481-506.

Ferson, S. and Akcakaya, H.R. 1990. Modeling fluctuations in age-structured populations: RAMAS/age user manual. Applied Biomathematics, Setauket, New York.

Lacey, R.C., Hughes, K.A, and Kreeger, T.J. 1994. Vortex users manual, second edition for version 6. Captive Breeding Specialist Group. Apple Valley, MN. 65p.

Soule, M.E. 1987. Viable populations for conservation. Cambridge University Press, Cambridge. 189p.

Physical Stream Habitat

Purpose

The following methods and techniques provide a consistent framework to characterize and evaluate the current condition, distribution, and connectivity of key physical stream habitat features in the watershed. Reference conditions are developed and compared with current conditions. Ecological processes and human activities responsible for observed differences are explained and management opportunities identified.

Assumptions

1. The evaluation methods and techniques are limited in scope to physical habitat variables for which utility has been demonstrated in assessing the effects of land management (MacDonald, Smart, and Wissmar, 1991) and are of known importance in aquatic systems (e.g., off-channel habitat is important for overwintering juvenile salmonids, including coho salmon [Cederholm and Scarlett 1982, Nickleson et al. 1992, Swales et al. 1990]).

2. These methods and techniques compare current habitat conditions with reference conditions and identify processes most likely responsible for the observed differences. The processes identified will subsequently need to be evaluated using other methods and techniques as appropriate. Depending upon identified issues, key questions, and the results of this Physical Stream Habitat evaluation, additional stream channel variables (e.g., temperature, flow, bank stability) may also need to be evaluated.

3. Physical habitat characteristics of other aquatic systems (e.g., wetlands, lakes, ponds, or reservoirs) will be assessed using other methods and techniques (e.g., those for water quality).

Data Needs

1. Mapped hydrography information that includes:

   - Streams by class, including nonfish-bearing and intermittent streams
   - Lakes and ponds
   - Wetlands
   - Reservoirs (including status of fish passage facilities)

2. Results of stream reach classification (Rosgen 1993, Montgomery and Buffington 1994) used to stratify the watershed into process-relevant reach types.

3. Stream inventory data (e.g., Level II Stream Inventories, Forest Service, R-6).

4. Historic photos, recent and historic aerial photos, and orthophotos.

5. Criteria for judging the quality of physical stream habitat, for example:

   - Peterson, N.P.; Hendry, A.; Quinn, T.P. 1992.
   - Washington Forest Practices Board. 1993. (Watershed Analysis appendices, Table F-1.)
   - Riparian Management Objectives in PACFISH (USDA, USDI. 1995).

Products

1. Characterization of physical habitat features at the watershed scale. This should include an updated hydrography map layer that identifies significant watershed-scale physical habitat features such as:

   - Migration routes
   - Productive flats or "hot spots" for fish production
   - Refugia (e.g., cold-water springs)
   - 100-year floodplains

C Estuaries

C Barriers to connectivity (e.g., dams, water diversions)

2. Characterization of physical habitat features at a reach scale. This includes current conditions for the following features, stratified by reach type:

   C Off-channel habitat/edge habitat

   C Pools and quality

   • Substrate

   C Large wood

   C Width:depth ratio

3. Description of reference conditions for watershed-scale and reach-scale physical habitat features.

4. Discussion of how current conditions for these features compare to reference conditions, including maps, and tabular presentations of results. Discussion of how the distribution and connectivity of these features compare to reference conditions.

5. Discussion of possible processes that explain the observed differences between current conditions and reference conditions. Methods and techniques to subsequently evaluate these processes are identified.

Procedures

1. Stratify streams by channel type, stream reach, and/or subwatershed.

2. Establish existing conditions for watershed-scale and reach-scale feature. Data collection methods for most of these variables can be found in stream inventory handbooks of the Forest Service or Bureau of Land Management (e.g., USDA. 1996. Stream Inventory Handbook, Level I & II). Additional references are provided in the following table:

Reach-Scale Features	Representative Data Collection Methods
Off-Channel Habitat	C Maps of side channels, backwater sloughs, oxbow lakes
Edge Habitat	C Variance in bankfull widths C Other indicators of channel complexity, including channelization & sinuosity
Pools: Pool Quality	C Peterson, N.P.; Hendry, A.; Quinn, T.P. 1992. C Washington Forest Practices Board. 1993. C USDA. 1994. C MacDonald, L.H.; Smart, A.W.; Wissmar, R.C. 1991.
Pools: Pool Frequency	C Bisson et al. 1982. C Hawkins et al. 1993.
Pools: Residual Pool Depth or Volume	C Lisle, T.E. 1987.
Substrate: Surface Fines	C Peterson, N.P.; Hendry, A.; Quinn, T.P. 1992. C Washington Forest Practices Board. 1993. C MacDonald, L.H.; Smart, A.W.; Wissmar, R.C. 1991.
Substrate: Cobble Embeddedness	C MacDonald, L.H.; Smart, A.W.; Wissmar, R.C. 1991. C Rhodes, J.J.; McCullough, D.A.; Espinosa, F. Al Jr. 1994.

Reach-Scale Features	Representative Data Collection Methods
Substrate: Dominant Substrate Size	C Washington Forest Practices Board. 1993.
Number and/or Volume of Large Wood	C Peterson, N.P.; Hendry, A.; Quinn, T.P. 1992. C Washington Forest Practices Board. 1993. C USDA. 1994. C MacDonald, L.H.; Smart, A.W.; Wissmar, R.C. 1991. C Robison, G.E. and Beschta, R.L. 1990.
Width: Depth Ratio	C Peterson, N.P.; Hendry, A.; Quinn, T.P. 1992. C Washington Forest Practices Board. 1993. C USDA. 1994. C MacDonald, L.H.; Smart, A.W.; Wissmar, R.C. 1991.

3. Estimate reference conditions for watershed-scale and reach-scale physical stream habitat features for the present climatic period. The entire scope of system behavior relative to these physical habitat stream features should be addressed. Reference conditions should not be defined only by the endpoints of a natural variation range. Physical habitat conditions in most streams, regardless of the degree of land management impact, will fall into this very broad range. To be of value in planning land management activities and restoration, reference conditions for physical habitat features should also include information describing the frequency, duration, distribution, and areal extent of conditions.

   Historical stream inventories, aerial photos, and observations from relatively undisturbed watersheds are among the best data sources for developing reference conditions. For many of the physical habitat features, quantitative data may be difficult to obtain. In such cases, professional judgment that is systematic and well documented by a decision-support system such as a Bayesian Belief Network (Lee and Rieman, in prep. 1994) may be advantageous.

   Only those streams that are similar to each other and to the stream of interest should be used in establishing reference conditions for a particular watershed analysis. Streams should be classified according to geology, climate, drainage pattern and area, elevation, etc., and information for physical habitat variables extrapolated to comparable systems. Ecoregion or subregion classifications should also be used to help develop reference conditions.

   Reference conditions are not synonymous with management objectives (e.g., PACFISH Riparian Management Objectives) or diagnostic criteria (e.g., Washington Forest Practices Board. 1993. Standard methodology for conducting watershed analysis. Board Manual Version 2.0. Watershed Analysis appendices, Table F-1.). However, these may be helpful in establishing reference conditions. Management objectives and diagnostic criteria are seldom specific to a basin or watershed. Consequently, these may not be suitable for use in a watershed unless refined based on watershed-specific geologic, geomorphic, and climatic conditions.

   The biological significance of physical habitat features should be understood and incorporated into reference conditions. Although all of the physical habitat features identified in these methods and techniques have relevance for aquatic species, some have been more strongly linked to species-specific life history requirements than others. For example, fine sediment has been clearly demonstrated to reduce survival to emergence from salmonid spawning redds (Lotspeich and Everest 1981, Shirazi and Seim 1981, Tappel and Bjornn 1983, Chapman 1988, Young et al. 1991). This effect has generally been attributed to trapping alevins within redds and limiting dissolved intergravel oxygen flow (Bjornn and Reiser 1988). The effect of a given level of certain size class of fine sediment in spawning areas seems basically independent of context, whereas impacts on aquatic biota of increased width:depth ratios may be more ambiguous and influenced by other factors, such as canopy cover and flow.

4. Discuss possible processes most likely to explain

differences between current conditions, reference conditions, and observed trends. Identify methods and techniques to subsequently evaluate these processes. A comparison of current conditions and reference conditions for physical stream habitat features should be considered only one step in a watershed analysis. Once relationships between channel conditions and processes have been hypothesized, the next step is to apply other methods and techniques for further evaluation.

5. Identify linkages with upslope processes. While these Physical Stream Habitat evaluation methods focus on channel habitat features, the consequences of recent upslope land management actions may not yet be visible in the stream channel. To anticipate impacts and plan accordingly, it may be necessary to expand the scope of investigation beyond the stream channel. Even if no problems with physical habitat features may be apparent, it is still essential to examine riparian and upslope conditions and processes responsible for creating and maintaining functional aquatic habitat. There is often a time-lag between certain land management activities and channel degradation (e.g., debris torrent-induced channel effects may appear several years following timber harvest when diminished root strength triggers mass wasting).

6. Establish management targets, opportunities, and/or recommendations. The comparison of current and reference conditions, along with knowledge of causal processes, may subsequently be used to establish watershed-specific management targets, opportunities, and/or recommendations. It is important to recognize the difference between reference conditions and management targets. The former merely describes system behavior, while the latter incorporate understanding of ecosystem potential generated by this description with that which is necessary to meet applicable management objectives on Federal lands. In some circumstances, management targets and reference conditions may be identical. The more likely event is that management targets will be within the scope of reference conditions, allowing systems to exhibit characteristics necessary for providing sufficient high-quality habitat to sustain aquatic ecosystems. Management opportunities or recommendations can then be identified to achieve the management targets, which represent a tailoring of management plan objectives with ecosystem capability.

References

Bjornn, T.C. and Reiser, D.W. 1991. Habitat requirements of salmonids in streams. pp 83-138 In: Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats. American Fisheries Society Special Publication 19.

Bisson, P.A.; Nielsen, J.L.; Palmason, R.A.; Grove, L.E. 1982. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low streamflow. pp 62-73 in N.B. Armantrout (ed.), Acquisition and utilization of aquatic habitat inventory information. Proceedings of a Symposium, October 28-30, 1981, Portland, OR. Hagen Publishing Co., Billings, MT.

Cedarholm, C.J and Scarlett, W.J. 1982. Seasonal migrations of juvenile salmonids into four small tributaries of the Clearwater River, Washington, 1977-1981. Proceedings of the Salmon and Trout Migratory Behavior Symposium, June 3-5, 1981. School of Fisheries, University of Washington, Seattle, WA.

Chapman, D.W. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. Transactions of the American Fisheries Society 117:1-21.

Hawkins, C.P.; Kershner, J.L.; Bisson, P.A.; Bryant, M.D.; Decker, L.M.; Gregory, S.V.; McCullough, D.A.; Overton, C.K.; Reeves, G.H.; Steedman, R.J.; Young, M.K. 1993. A hierarchical approach to classify stream habitat features. Fisheries 18(6):3-12.

Lee, D.C. and Rieman, B.E. in prep. 1994. Population viability assessment using Bayesian belief networks: an example application to salmonids.

Lisle, T.E. 1987. Using "residual depths" to monitor pool depths independently of discharge. USDA Forest Service Research Note PSW-394.

Lotspeich, F.B. and Everest, F.H. 1981. A new method for reporting and interpreting textural composition of spawning gravel. USDA Forest Service Research Note PNW-369.

MacDonald, L.H.; Smart, A.W.; Wissmar, R.C. 1991. Monitoring guidelines to evaluate the effects of forestry activities on streams in the Pacific Northwest and Alaska. Environmental Protection Agency, Region 10, Seattle, WA. EPA/910/9-91-001. 166 p.

Montgomery, D.R. and Buffington, J.M. 1993.

Channel classification, prediction of channel response, and assessment of channel condition, Washington State Department of Natural Resources, Olympia, WA. TFW-SH10-93-002, 84 p.

Nickleson, T.E.; Solazzi, M.F.; Johnson, S.L.; Rodgers, J.D. 1992. Seasonal changes in habitat use by juvenile coho salmon (*Oncorhynchus kisutch*) in Oregon coastal streams. Can. J. Fish. Aquat. Sci., 49:783-789.

Peterson, N.P.; Hendry, A.; Quinn, T.P. 1992. Assessment of cumulative effects on salmonid habitat: some suggested parameters and target conditions. Center for Streamside Studies, University of Washington, Seattle, WA. TFW-F3-92-001. 75 p.

Rhodes, J.J.; McCullough, D.A.; Espinosa, F. Al Jr. 1994. A coarse screening process for evaluation of the effects of land management activities on salmon spawning and rearing habitat in ESA consultations. Columbia River Inter-tribal Fish Commission, Portland, OR. Technical Report 94-4. 127pp + 2 appendices.

Robison, G.E. and Beschta, R.L. 1990. Characteristics of coarse woody debris for several coastal streams of southeast Alaska, USA. Can. J. Fish. Aquat. Sci. 47:1684-1693.

Rosgen, D.L. 1994. A classification of natural rivers. Amsterdam, The Netherlands: Elsevier Publications. 50 p.

Shirazi, M.A. and Seim, W.K. 1981. Stream system evaluation with emphasis on spawning habitat for salmonids. Water Resources Research 17:592-594.

Swales, S.; Caron, F.; Irvine, J.R.; Levings, C.D. 1987. Overwintering habitats of coho salmon (Oncorhynchus kisutch) and other juvenile salmonids in the Keogh River System, British Columbia. Can. J. Zool. 66:254-261.

Tappel, P.D. and Bjornn, T.C. 1983. A new method of relating size of spawning gravel to salmonid embryo survival. North American Journal of Fisheries Management 3:123-135.

USDA. 1996. Stream Inventory Handbook Level I & II, Version 9.5. Forest Service, Region 6. Portland, OR.

USDA. 1994. Section 7 fish habitat monitoring protocol for the upper Columbia River basin. R6-F&W-CRB-TP-10-94. Portland, OR. 61 p.

USDA, USDI. 1995. Decision Notice for the Environmental Assessment for the interim strategy for managing anadromous fish-producing watersheds in eastern Oregon, Washington, Idaho, and portions of California. February, 1995. Washington, D.C.

Washington Forest Practices Board. 1993. Standard methodology for conducting watershed analysis. Board Manual Version 2.0.

Washington Forest Practices Board. 1995. Standard methodology for conducting watershed analysis. Board Manual Version 3.0.

Young, M.K.; Hubert, W.A.; Wesche, T.A. 1991. Selection of measures of substrate composition to estimate survival to emergence of salmonids and to detect changes in stream substrates. North American Journal of Fisheries Management 11:339-346.

Aquatic Populations and Viability

Purpose

Once the distribution and current habitat conditions and trends for species of concern are identified in waterhsed analysis, the following Level I methods and techniques can be used to assess the status of aquatic species within the watershed. For anadromous and resident salmonids, Levels II and III methods and techniques can be used to estimate species viability within the watershed.

Assumptions

1. Analyses of species viability must be conducted at appropriate scales. It may not be appropriate to analyze viability of wide-ranging species within analyses at the watershed or site scale. Analysis of viability at the watershed scale can be of great importance when:

   The species has a very localized distribution and a large portion of the species range is contained within the watershed, or

   The analysis done within the watershed for a wide-ranging species can be placed within the appropriate context and address the contribution of the watershed to overall species viability.

2. Existing data are adequate to accurately assess the current and historical status and distribution of aquatic species.

Data Needs

1. Information is needed regarding the current and historical presence, distribution, and status of aquatic species in the watershed. Sources of such information include:

   - Resource Managers
   - State fish and wildlife agencies
   - Tribes
   - Regional agencies such as Bonneville Power Administration (BPA) and Northwest Power Planning Council (NWPPC)
   - Federal agencies such as National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife (FWS), National Biological Service (NBS)
   - State, regional, national, and international fisheries management organizations such as the Pacific Salmon Commission (PSC) and the Pacific States Marine Fisheries Management Commission (PSMFC)

   Research and literature

   Surveys

2. Compile existing viability assessments from other efforts; e.g., regional or provincial analyses.

Level I

Products

1. Maps of species presence and distribution within watershed.

2. Maps of life history use, by species, within watershed.

3. Maps and text describing the status of species within watershed.

4. Description of trends in abundance.

5. Identification of T&E species or stocks.

6. Qualitative assessments of:

   The importance of the watershed relative to the range of species, including its contribution to species persistence.

   Primary factors that could place the species at risk within the watershed and in surrounding watersheds.

   Areas within the watershed that are key to species persistence.

   Possible effects of management on the Species, both positive and negative.

   An overall assessment of the likelihood of species persistence within the watershed.

Procedures

1. Review life history information to determine: (a) habitats most likely to support the species and (b) species characteristics that influence its vulnerability to extinction threats. Extinction threats could be classified as follows:

   Demographic
   - Random variation in birth and death rates

   Genetic
   - Inbreeding depression and genetic drift

   Environmental
   - Loss of habitat
   - Systematic chronic effects
   - Random catastrophic events
   - Biological interactions
   - Pollutants, toxicants

2. Overlay species range maps and existing habitat maps to determine: (a) potential species distribution within the watershed, (b) areas where the species is most likely to occur based on current habitat conditions, (c) areas of possible connection with other watersheds, and (d) areas where habitat for the species could potentially be restored. Produce a map of these areas.

3. Based on the areas mapped in step 2, above, and available information on species density, provide a rough estimate of possible population levels in the watershed. Describe the level of uncertainty associated with the estimate, based on the quality of available data.

4. Use maps and information on historical disturbance to assess likely historical variation in species habitat within the watershed.

5. Overlay land allocation and land ownership maps on the areas mapped in step 2, above, to determine possible effects of management on habitat for the species. Describe potential risks to the species.

6. Based on the above information, provide qualitative assessments of:

   The importance of the watershed in providing for species persistence.

   Primary factors that could place the species at risk within the watershed and in surrounding watersheds.

   Areas within the watershed that are key to species persistence (rank areas according to their importance to species persistence).

   Possible effects of management on the species, both positive and negative.

7. Using the results of the previous steps, provide an overall assessment of the likelihood of species persistence within the watershed.

Level II

Additional Data Needs for Level II Analysis

1. Species occurrence map and survey data.

2. Habitat relationships information.

3. Data regarding local species characteristics:

   Spawning conditions

   Incubation success

   Early rearing and incubation survival

   Habitat capacity for early rearing

   Sub-adult survival

   Adult survival

   Age of first maturity

   Fecundity

   Initial population size

   Expected population size

   Variation in first-year survival

   Variation in adult numbers

   Catastrophic risk

Products

1. Same products as Level I, but refined with additional information for anadromous and resident salmonids.

2. A quantitative assessment of the capability of habitats within the watershed to support the species.

Procedures

Procedures for Level II analysis are the same as Level I with the following refinements:

1. Refine the assessment of species distribution and habitat use within the watershed described in step 2 of the Level I analysis using the additional data described above (i.e., species occurrence map and survey data).

2. Improve the estimate of population size that could be supported within the watershed described in step 3 of the Level I analysis using data on local population characteristics and habitat relationship models.

Level III

Procedures

A method for performing viability analysis for resident and anadromous fish at the watershed or greater scale is under development (Lee and Riemen, unpublished). The process is currently envisioned to contain five steps:

1. Define the scale of analysis, relevant species, and ocal and regional populations of interest.

2. Complete the survey of local population characteristics.

3. Complete quantitative analysis for each local population of interest.

4. If desired, identify alternative hypotheses concerning state of the system and rerun analysis.

5. If regional analysis is required, complete analyses for all local populations or for a representative subsample of populations. Complete qualitative analysis of risk for the regional population.

References

Lee, Danny C. and Bruce E. Rieman. unpub. Bayesian Viability Assessment Module (BayVAM): A tool for assessing the population viability of resident salmonids. USDA Forest Service, Intermountain Research Station, Boise, ID.

Human Uses

Roads

Purpose

The following methods and techniques can be used to characterize and assess roads, a major human use in the watershed. The resultant data can be used to evaluate the influences and relationships between roads and other ecosystem processes and features in the watershed. The contents of a road database to support these analyses are shown in the accompanying table.

Assumptions

1. Roading histories can be constructed from aerial photographs.

2. Road information is essential for many of the other modules.

Products

1. A map of the road network with maintenance classes of roads identified.

2. A tabulation of road characteristics for each road class or stratum.

3. A series of maps showing the growth of the road network through time.

Procedure

1. Gather as much data about the transportation system as is available. Request information from private landowners as well.

2. Often private road networks will need to be mapped, using recent aerial photographs. Photos can also be used to map landings and skid trails. If time is available, it is useful to map this information throughout the watershed. Otherwise, stratify the watershed into areas having uniform road character (this might be on the basis of ownership, age of developments, or topography) and map the distribution of such features in representative areas.

3. Visit sample lengths of various road types within each stratification unit to characterize the roads in the unit. Note the following at each site:

   - Drainage type (outslope, inslope/ditch, ripped, etc.).
   - Distance to streams (e.g., within 200, 500, & 1000 feet).
   - Whether road drainage reaches the stream.
   - Character of the roadcut.
   - Character of the road ditch.
   - Cut and fill erodibility classes.
   - Road surfacing material and extent of armoring.
   - Length of flow along the bearing surface.
   - Other characteristics that influence erosion rates and sediment delivery to streams.
   - Number, type, and condition of stream crossings.
   - Road and fill area and condition in the proximity of stream crossings.

4. Many applications require information about the ages of roads. Approximate ages can be determined by comparing the road network on sequential aerial photograph sets. Network extension can be mapped comprehensively or can be mapped in representative subareas.

Data	Need for data	Difficulty to obtain*	What to do if you don't have it/ can't get it	Resources needed to obtain (time)
Route number	routine	L.	n/a	Trivial if available.
Length	routine - essential	L. Existing info/ map/ GIS.	Must have this.	Trivial from aerial photos. If photos not on hand, may require 2-6 weeks to order and obtain photos.
Density (by subwatershed)	routine - essential	L. Existing info/map/GIS.	Calculate	Trivial from information on watershed-subwatershed area and road length.
Location	routine - essential	L. Existing info/map/GIS.	Must have this.	Trivial from aerial photos or maps.
Jurisdiction	M	L. Existing records or ownership maps.	Best guess based on ownership maps.	Trivial from landownership records. Road management jurisdiction could require 2-5 days to sort out in intensively roaded watersheds.
Width of travelway	H	L-M. Existing records or field sampling correlated to use class.	Best guess based on existing records and field sampling.	Requires 1-2 days to sample. Months for complete inventory (which would provide other data as well).
Surface type (aggregate, native, paved, etc.)	H	L. Existing records usually include.	Best guess based on use class and maintenance Level Info.	Requires 1-2 days to sample. Months for complete inventory (which would provide other data as well).
Maintenance Level	L-M	L. Existing records usually include.	Ignore if not available.	N/A
Road grade	M-H	M-H . Not usually included in existing records. Tedious and inaccurate from topo maps.	Make estimates based on field sampling, local knowledge and topo maps.	Requires 1-2 days to sample. Months for complete inventory (which would provide other data as well).
Road construction / reconstruction date(s)	M-H	M. Not usually included in regular road records. Can be age-bracketed with sequential aerial photos.	Bracket with sequential aerial photos. Correlate with age of other management features (such as timber cutting).	Requires 2-5 days, depending of the intensity of roading.
Traffic volume by season of use (ADT) (H=>50, M=5-50, L=<5)	M-H	L. Occurs in existing records often. Simple to estimate based on local knowledge.	Estimate based on local knowledge.	Could require 1-2 days to develop good estimate.
Surface drainage type	H	M-H. Seldom included in existing records. May be common knowledge in many locations.	Best guess based on interviews and field sampling, date of construction.	Requires 1-2 days to sample. Months for complete inventory (which would provide other data as well).
Ditchline length	H	M-H. Based on surface drainage type (above).	Best guess based on interviews and field sampling, date of construction.	Requires 1-2 days to sample. Months for complete inventory (which would provide other data as well).
Ditchline continuity with channel system	H	M-H. Based on surface drainage type (above) and proximity to streams.	Best guess based on interviews and field sampling, date of construction, and road length within given distance of stream (based on map and field sampling).	Requires 1-2 days to sample. Months for complete inventory (which would provide other data as well).
Slope class	H	L-H. GIS simplifies. Without GIS estimates must suffice.	Make estimates based on review of topo maps.	Trivial with GIS. 1-2 days without GIS.

Data	Need for data	Difficulty to obtain*	What to do if you don't have it/ can't get it	Resources needed to obtain (time)
Cut and fill length and slope	M-H	L-H. Based on slope of land into which roadway is built and local knowledge of design standards.	Best guess based on estimates derived for slope class.	Requires 1-2 days to sample. Months for complete inventory (which would provide other data as well).
Rock types	M-H	L. Use bedrock geology maps that exist for most areas.	Use the most detailed map available. Default to regional-scale maps if better maps are not available.	N/A
Soil types	M-H	L. Soil maps exist for most locations. Use most detailed maps available.	Default to geology maps if no detailed (order-3 or better) maps are available.	N/A
Landslide hazards	M-H	L-M. If maps exist, flag length of roads in landslide-prone terrain.	Study aerial photographs and flag areas where roads seem to be involved in mass instability.	2-5 days for sampling. 1 day to 1 month to develop good hazard map.
Erosional events				
- landslides	H	L-H. Use landslide maps or maintenance records may be helpful in reconstructing landslide occurrence.	Derive from landslide maps, aerial photos, and/or maintenance records.	1 day to 2 months to conduct field inventory, depending on frequency and accessibility.
- surface erosion of travelway, cuts, & fills	H	L-H. Must be sampled in the field. Maintenance records may be helpful to target trouble spots.	Use literature or previous sampling in similiar terrain.	2-5 days for sampling.
- fluvial erosion of ditchline	H	L-H. Must be sampled in the field. Maintenance records may be helpful to target trouble spots.	Use literature or previous sampling in similar terrain.	2-5 days for sampling.
Sediment Delivery Factor	H	L-M. Develop from field sampling and maps.	Calculate road length within given distance of stream (based on map and field sampling), and assign SDF based on field sampling or estimates based on local knowledge.	2-5 days for sampling.
Stream crossings				
- location		L. Based on map data or existing field inventory.	Find intersections of stream and road networks.	About 2 crossings per hour for inventory and analysis. Crossing frequency is 1.5-6 per mile of road.
- flow capacity	H	L-H. Requires culvert diameter, road fill height, watershed area, and hydrologic parameters for peak flow prediction.	Make estimates based on existing analysis or age of roads and prevailing design standards when roads were built.	About 2 crossings per hour for inventory and analysis. Crossing frequency is 1.5-6 per mile of road.
- diversion potential	H	H. Requires field work at each site.	Make estimates based on other surveys with similar construction history, or plan to collect this during project analysis or as part of road maintenance inspections.	About 2 crossings per hour for inventory and analysis. Crossing frequency is 1.5-6 per mile of road.

Data	Need for data	Difficulty to obtain*	What to do if you don't have it/ can't get it	Resources needed to obtain (time)
- consequence of failure	M-H	Requires detailed field information including fill volume, diversion potential (above), channel characteristics, downstream uses.	Make estimates based on aerial photo and field review of the effects of previous crossing failures.	About 2 crossings per hour for inventory and analysis. Crossing frequency is 1.5-6 per mile of road.
Fish migration barriers	M-H	Inventories exist in many locations.	Plan to get it. Use stream crossing and fish use data to project possible trouble spots to review in the field.	Only crossings of fish-bearing streams required, but analysis may be complex. 2 hours per crossing.

* For agency-managed roads on public lands. Obtaining these data for other roads in the watershed will likely be more time consuming. There are at least 4 categories of roads we must address in most watersheds:

1. Those on the public land "transportation system" for which basic data usually exist.
2. Those on public land, but not in the "system" (temporary roads, mining roads, abandoned roads, etc.).
3. Those on public land, but managed by others (counties and private landowners).
4. Those in the watershed, but not on public lands.

Only roads in the first category generally have good data to start with. Others may have little or no data (with exceptions) and we may not have access to them. We should be able to collect data on all roads on public lands, though we may be starting from scratch and aerial photos for uninventoried watersheds. For roads on private lands, cooperative agreements should be sought if preliminary analysis suggests that they may be an important influence on watershed processes and beneficial uses.

Tribal Cultural Resources

Purpose

The following techniques and methods provide guidance on involving tribes in the identification and analysis of cultural resource issues during all six steps of the watershed analysis process, including:

1. Characterizing tribal cultural issues in the watershed.
2. Involving tribes in the identification and prioritiziation of tribal cultural issues.
3. Obtaining and organizing information regarding current and reference conditions of cultural resources and uses; providing tools and techniques for assessing cultural resources.
4. Explaining causal mechanisms which influence cultural resources.
5. Consulting with tribes to develop recommendations for cultural resources, including the identification of historic properties eligible for the National Register.

Assumptions

1. Cultural resource issues will vary widely from watershed to watershed and from tribe to tribe.
2. Tribes that have cultural resources within a watershed will be fully involved in each step of watershed analysis.
3. Data concerning cultural locations important to the tribe(s) will be subject to confidentiality and data security desires of the tribe(s).
4. The watershed analysis team will include tribal policy and technical representatives.

Data Needs

1. Tribal knowledge of cultural resources as identified during tribal consultation process.
2. Existing basin, forest, or regional cultural resource plans and assessments.
3. Site-specific cultural resource information and assessments.
4. Identification of known or potential cultural resources, including archeological sites, historic structures, cultural landscapes, traditionally used areas, and other places of interest to tribes.
5. Cultural resources identified during prior public and tribal involvement.

Products

1. A list of cultural resource issues addressed in the watershed analysis.
2. A list of key questions relevant to the issues.
3. A definition of cultural resources for the purposes of the watershed analysis.
4. A list of cultural resource issues which were deferred or not analyzed.
5. Map or description of cultural uses or potential uses.
6. Description of trends in cultural uses.
7. Description of the relationships and interactions between cultural uses and other elements of the ecosystem including human uses, aquatic and terrestrial resources, etc.
8. A prioritized list of recommendations regarding cultural resources including restoration, monitoring, research, and protection of sensitive areas and resources.

Procedure

1. Identify and consult with tribes with possible cultural resources within a watershed. This should occur during the planning stages of a watershed analysis. Tribal participation should begin at the earliest phases of watershed analysis. Since cultural resources are often a sensitive issue, sufficient time must be allowed for developing a cooperative strategy between agencies and tribes.
2. Define key players within tribes and within participating agencies, and establish a cultural resources module working group.
3. Develop with the tribes a cooperative working process for including tribes in watershed analysis, and for respecting the need or desire for confidentiality of cultural resource information by the involved tribes.

4. Jointly define cultural resources.

5. Jointly define key issues and questions (Analysis step 2). Identify cultural resource components, as well as related biological, physical, and social ecosystem components.

6. Determine jointly with the tribes the types of data available and how data will be used and presented in light of concerns regarding data confidentiality or security.

7. Characterize the current cultural resources within the watershed.

8. Characterize the historic cultural resources.

9. Identify the influences of other ecosystem elements on the use and availability of cultural resources.

10. Jointly develop recommendations for maintaining, protecting, and restoring cultural resources within the watershed.

Additional Comments

It is critical to identify and respect the needs of the tribes when asking for their involvement. This includes identifying tribal sensitivities regarding data security and confidentiality.

This module largely describes a consultation process with affected tribes regarding cultural resources. It is important to begin this process as early as possible to allow time for development of jointly acceptable procedures for including cultural resources in the analysis.

Integrate cultural resources as soon as possible with other modules. Tribal cultural uses are tightly linked with the condition and trends of other ecosystem elements such as fisheries, water quality, wildlife, recreation, vegetation, etc.

If watershed analysis is considered a federal undertaking, National Historic Preservation Act (NHPA) definitions, procedures, and other legal requirements apply.

Other legal authorities that may apply include:

- American Indian Religious Freedom Act.

- Archeological Resources Protection Act.

- Native American Graves Protection and Repatriation Act.

Recreation

In Development ...

Commercial Uses

In Development ...

Other Topics

Air Quality

Purpose

The following techniques and methods can be used to characterize air quality in the watershed, including levels of contaminants, sources, trends, and statutory and regulatory boundaries. They can also be used to determine the impacts of contaminants to the watershed, as well as potential air quality impacts from the watershed. Impacts may include effects on all ecosystem components (i.e., biophysical and social).

Assumptions

Coordination with air quality analyses at larger scales than a watershed is generally essential. Without systematic, region-wide monitoring and data collection, and interagency coordination, air quality analyses at the watershed level will be difficult. Information that may not be available now should be obtained for subsequent watershed analyses.

Data Needs

1. Maps of nonattainment areas, PSD Class I Areas, state-specified special air quality areas.

2. Database sources:

   - Air Quality Instrument data: IMPROVE, National Atmospheric Deposition Program (NADP), TEOM, nephelometers, and ozone monitors.

   - Biomonitoring: Lichens/mosses, invertebrates, fungi, leaf tissue, tree cores, and forest health monitoring program indicators.

   - Water Quality Instrument data: Chemistry.

   - State/EPA: Atmospheric Information Retrieval System (AIRS), and Air Toxics.

   - Soil: Chemistry and pH.

   - Weather/Climate: FIRDAT, WIMS, National Weather Service, and Western Regional Climate Center.

3. Descriptions and analyses of the effects of physiography on atmospheric stability, dispersion, and pollutant transport.

<u>Level I</u>

Products

1. Maps of Class I airsheds, nonattainment areas, and state-specified special air quality areas within or nearby the watershed.

2. Status of air quality in the watershed including levels of contaminants, their sources, and trends, if known.

3. Data gaps, monitoring needs, and coordination needs between other administrative and regulatory units, and coordination needs with other geographic scales (e.g., province or regional level).

Procedure

1. Gather information from relevant administrative databases and planning documents. Contact regional offices as well as other landowners. Collect existing Air Quality Related Values (AQRV), existing emissions information, pollutant concentrations, and biological indicator information.

2. Gather information on attainment status, Class I areas, airsheds, and pollutant concentrations from EPA, state, and local air pollution control agencies. Useful reference documents include State Implementations Plans (See Reference 1) and Smoke Management Plans (See Reference 2).

3. Develop a map of regulatory boundaries for the watershed within a regional context. Include nonattainment designations, Class I areas, state-specified special air quality areas. Include locations of monitoring sites.

4. Using the information gathered from above, identify the status of air quality in the watershed including the levels of contaminants and their sources and trends, if known. Depending on pollutant and transport, consider sources up to 150 miles away. Use knowledge of the effects of physiography and climate on dispersion. For example, carbon monoxide has localized impacts, but sulfur and particulate matter can be transported long distances. Contaminants of interest include: ozone, nitrogen oxides, sulfur oxides, particulate matter, volatile organic compounds and toxic metals.

Level II Analysis

Products

1. To the extent it is possible, a list of existing known or potential air quality impacts to the watershed. Effects of contaminants may include cumulative impacts, effects on the status and trends of ecosystem and forest health, and baseline information related to health-based standards

(NAAQS) and visibility impairment.

2. To the extent it is possible, a list of existing known or potential air quality impacts from the watershed. Effects of contaminants may include cumulative impacts, baseline data for general conformity determinations, and baseline information related to health-based standards (NAAQS) and visibility impairment.

Procedure

1. If it is not possible to identify the levels of contaminants, then identify data gaps and needs, and prioritize data gathering.

2. Using existing data, list known or potential air quality impacts to the watershed. Some impacts to look for include (See References 5 and 6):

   - Ozone/sulfur damage to indicator tree species (e.g., leaf tissue).
   - Effects on timber volume or quality.
   - Absence or effects on sensitive lichens, mosses, fungi (See References 3 and 4).
   - Insect or pathogen infestations.
   - Tree ring data showing effects on growth.
   - Water Quality: changes in pH, chemistry and acid neutralizing capacity of rainfall, lakes, streams, and snow packs (See Reference 7).
   - Soil Quality: changes in cation exchange capacity or pH.
   - Changes in amphibian health/populations.
   - Changes in microbes, zooplankton, and algae (See Reference 7).
   - Smoke intrusions into human population areas.
   - Impacts on human visitors and aesthetics.
   - Impacts from visitor activities, such as transportation and camp fires.
   - Impacts from agency activities, including transportation and construction.

3. Using existing data, list known or potential air quality impacts from the watershed. Some impacts to look for include:

   - Impacts on NAAQS concentrations.
   - Smoke intrusions into human populations.
   - Impacts on regional visibility.
   - Impacts of emissions from federal permittees on neighboring areas (e.g., sulfur from energy development).

References

State Implementation Plans (SIP) can be obtained from Regional EPA or State air quality agency.

Smoke Management Plans, usually contained in an SIP.

Geiser, Darr, and Dillman. 1994. Air Quality Monitoring on the Tongass National Forest, Methods and Baselines Using Lichens. USDA Forest Service, Alaska Region, R10-TB-46. September 1994.

Stolte, K. et al. 1993. Lichens as Bioindicators of Air Quality, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, General Technical Report RM-224. March 1993.

Peterson, Schmoldt, Peterson, Eilers, Fisher, Bachman. Guidelines for Evaluating Air Pollution Impacts on Class I Wilderness Areas in the Pacific Northwest. USFS General Technical Report, PNW-GTR-299, 1992.

Kozlowski, T.T. Impacts of Air Pollution on Forest Ecosystems in: Bioscience, 30(2) February 1980.

Nichols, D.S. 1990. Estimating Lake Susceptibility to Acidification Due to Acid Deposition. Research Paper, NC-289.

Forest Health Monitoring Program Lichen Indicator.

The Plain English Guide to the Clean Air Act. EPA 400-K-93-001. April 1993.

Eilers, J.M, Rose, C.L., and Sullivan, T.J. Status of Air Quality and Effects of Atmospheric Pollutants on Ecosystems in the Pacific Northwest Region of the National Park Service. Technical Report NPS/NRAQD/NRTR-94/160, November 1994.

Horner, D., and Peterson D.L. Goat Rocks Wilderness Air Quality Monitoring Plan. College of Forest Resources in cooperation with the Gifford Pinchot National Forest.

Biologic Markers of Air-Pollution Stress and Damage in Forests. 1989. National Academy Press.

Smith, W.H. 1990. Air Pollution and Forests - Interactions Between Air Contaminants and Forest Ecosystems. Springer-Verlag, NY.