# RIPARIAN ECOTONE: A FUNCTIONAL DEFINITION AND DELINEATION FOR RESOURCE ASSESSMENT

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**Abstract.** We propose a geomorphic basis for defining riparian areas using the term: riparian ecotone, discuss how past definitions fall short, and illustrate how a linked sequence of definition, delineation, and riparian sampling are used to accurately assess riparian resources on the ground. Our riparian ecotone is based on the width of the valley (its floodprone area width) plus 30 meters on each side to encompass the important adjacent riparian functions, and 15 meters around obvious landslides. A functionally consistent riparian definition and delineation does not derive from land adjacent to a stream, rather it derives from the valley the stream runs through.

**Keywords:** floodprone area, geomorphology, riparian corridors, riparian ecosystems, riparian resources, streams, streamside management area, streamside management zone, riparian area, valleys

## 1. Introduction

We propose riparian ecotone delineation based on the geomorphology of the stream and its valley. It includes the width of the valley *floodprone area* plus 30 meters on each side of the valley to encompass the important adjacent riparian functions. This riparian ecotone contains all aquatic (channel), floodprone (flood dispersal of sediment, plants, and animals) and many upland functions (slumps, slides, subsurface water and nutrient flow) that interact strongly with the water during average, bankfull, and flood flow conditions.

The contemporary concept of riparian cannot fully derive from its Greek root, 'life on the bank', nor can it fully derive from its legal beginnings when Germanic tribes granted landownership to members along central European rivers (riparian rights) (Whitney, 1994). Neither can it persist on the American legal concepts of riparian rights adapted from English common law (state law granting water-adjacent landowners the right to use water from streams and lakes, nor on the various attempts of Federal agencies in the latter part of the 20th century to tie riparian to wetland.

Historically the term riparian area has profoundly different meanings depending on occupation, agency use, and research discipline. Ranchers in the semi-arid West

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consider riparian equal to only moist grass or shrubland near channels and exclude both wetland and dry land next to channels. This view is promoted by the USDI F&WS and BLM in the semi-arid West but rejected by the same agencies in humid Alaska or by the USDA FS in the humid East and humid West. Foresters in the humid East consider riparian areas as all land adjacent to the water. Researchers studying riparian functions are nearly universal in relating values to distance from the water's edge. This approach ignores differences in v-shaped versus floodplain valleys, has historically emphasized land influences on the river and only recently river influences on the land (e.g., floodwater redistribution of large woody debris) and ignores large resource estimation errors associated with sinuous streams.

A comprehensive definition of riparian must derive from our understanding of stream and valley geomorphology and the plant and animal associations that respond to the valley environment whether they derive from the water or the land. The concept of riparian must tie definition, delineation, and resource data aggregation together into a logical sequence. In riverine systems we believe riparian is a concept tied to the valley the stream runs through rather than a concept tied to the side of a stream. Norman Maclean (1976) was right: *'Eventually, all things merge into one, and a river runs through it'*.

## 2. Gaining Rigor by Linking the Definition-Delineation-Population Estimation Sequence

Riparian definitions are conceptual and fuzzy. Definitions are easy to write especially if you don't have to point them out on the ground, in a wide variety of landscapes. There is the promise of rigor if we think in the context of a conceptual and on-the-ground continuum of definition-delineation-resource estimation.

Riparian delineation (aerial mapping or on-the-ground sample plot delineation) typically draws lines or estimates areas based on arbitrary, socially-derived, width criteria. These are associated with BMP (best management practice), RMZ (riparian management zone), or SMZ (streamside management zone) widths, or with other conceptual boundaries (e.g., floodplain, hillslope, and vegetation type). In the conceptual riparian continuum, delineation moves from concepts without testable rigor to on-the-ground judgment calls with measurable errors.

On-the-ground judgment calls include location of the water body edge, the floodplain edge, or the vegetation type edge and varies with the experience of the individual. Similarly, GIS data layers (e.g., 100 m or 30 m DEMs (digital elevation models) and Landsat overlays incorporate 'detection limit' errors that fuzz boundaries. Air photo interpretation is more precise than GIS data layer rendition where spectral signatures are distinct and sharp boundaries show, but indecisive where they are not. Even with specific protocol guides these judgment calls vary, but are, in a practical sense, much better than conceptual definitions alone. In all cases, field experience and ground-truth measurements tighten the application of riparian delineation.

Population estimation invokes still a greater level of rigor in the definition-delineation-population estimation continuum. However, this step can either improve or worsen the final estimate of state variables such as hectares per county or hectares per regional plot.

Air photo polygon maps (e.g., the USDI F&WS riparian-wetland maps; Dall *et al.*, 1998) are directly accumulated to a county, forest, or state level without any error beyond the original delineation on a photo. On the other hand, errors in original delineation are carried on to the accumulated data. Over time, changes in the riparian-wetland base (e.g., conversion of willow sites to agricultural land or vise versa) will engender bias in trend interpretation because only natural vegetation is considered riparian, while anthropogenic vegetation is not, even when the two vegetation types occupy the same topographic feature. Additionally, errors of omission occur where significant lengths of streamside are left with neither a moist riparian area nor a wetland because they occur on terraces or steep slopes and are not wet enough to map as riparian-wetland.

Stream length (in GIS hydrography layers) is often multiplied by RMZ, BMP, or SMZ width to estimate riparian area (e.g., Hanowski, *et al.*, 2002). However, this method routinely yields errors of 10% to 150% above actual resources on the ground. The source of error is the faulty assumption that land bordering a stream occurs in a rectangular projection perpendicular to the stream edge.

For example consider a conceptual pair 30-m square sample plots on either side of a stream channel. If the stream channel is straight, the multiplication of hectares in these plots times the number of 30-m plots occurring on both sides of the channel is mathematically correct. However, if the stream channel meanders, such that adjacent plot areas overlap each other (like the overlapping segments of an airport baggage belt), the mathematical answer is in error proportional to stream sinuosity. Stream sinuosity is a measure of channel curvature; it is the channel length divided by straight-line valley length. Over long distances, the straight-line distance may 'dog-leg' with the valley.

The error is not only the mathematical error of plots overlapping (or separating); it is an error in concept failing to recognize riparian is a function of the stream's valley rather than the stream alone.

Stream sinuosity typically varies from 1.1 to 2.5 hence possible resource over estimates of 10% to 150%. Whether this error is realized depends on the scale of base maps and the detail of stream delineation captured in the map or GIS hydro layer. The stream length times buffer width technique can be adjusted if hydro layer sinuosity and true sinuosity are both known. On average, actual sinuosity errors may be in the 20 to 40% range because many streams have, in fact, straightened in the last century in response to land use change and/or dredging projects (Verry 2000, in press). True sinuosity is measured on the ground and on air photos if the

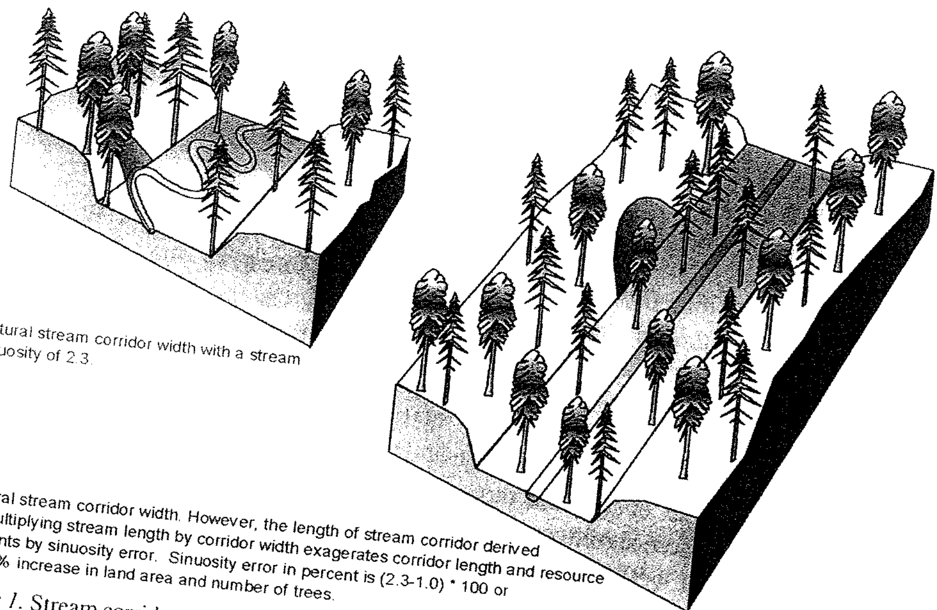


*Figure 1*. Stream corridor or riparian width should be based on valley length instead of stream length. If the valley length in the left diagram is 1 km mathematically it becomes 2.3 km when stream length (2.3 km in the left diagram) is multiplied by a streamside width to estimate area. A 130% over-estimate of riparian area!

entire stream can be seen. Measurements from maps will always under estimate sinuosity unless the map river is double lined.

Sinuosity errors (Figure 1) plead for a fundamental change in measuring and interpreting riparian resources. The riparian plot is a sample of the stream valley not land next to the stream! The stream is an aquatic subunit of the stream valley.

Mapping polygons on air photos does not have a sinuosity error (USDI F&WS method for the semi-arid West). However, either an inability to see riparian land in densely wooded humid regions or omission of 'non- (wetland-wetter riparian)' (Dall *et al.*, 1998) areas can skew estimates of functional riparian area.

Reconciliation of previous definitions of riparian, previous delineation of riparian, and previous population estimates of riparian resources must address all three needs as one system.

## 3. A Century of Riparian Concepts and Definitions

Previous riparian definitions and mapping protocols largely begin with vegetation community and then invoke real, but vague, zone of influence functions (e.g., shading, litter fall, large woody debris, landslides and soil moisture conditions) in the form of conceptual descriptions rather than on-the-ground criteria located in the field.

Table I shows trends in riparian (or wetland definition) in the last three decades. Three decades of riparian definitions.

The definitions in Table I contain the words: riparian area, riparian zone, riparian reserve, riparian system, riparian ecosystem, and riparian corridor. Each author understood exactly what they meant; however, the same words (e.g., riparian area) mean very different things to people across the country.

For example, the USDI F&WS system maps exposed point bars (side bars, or mid channel bars) as wetland. They map one polygon for 'a sometimes underwater' wetland on the point bar and another polygon for the water portion of the channel at the time of the photo. Together they are mapped as wetland because the NWI classification of wetlands includes open water as much as 2 m deep below the low water mark (Figure 2). These delineated polygons (dark gray in Figure 2) are explicitly excluded from the term riparian area.

In contrast the medium gray polygons in Figure 2 (also labeled R2U?? in the sketch portion) are called riparian areas because they are 'not as wet as wetlands', but 'wetter than adjacent upland'. Furthermore, some streamside areas (white in Figure 2 (top) and labeled PEM??) are mapped as upland.

All of the riparian definitions in Table I except the USDI F&WS definition (Dall *et al.*, 1998) consider all streamside land as a riparian area. Hence there is a rift among federal agencies and various academic disciplines. Most in the humid East (and humid West) would call all channel-adjacent land a riparian area, while most in the semi-arid West would include only land wetter than upland, but not wetland, in the term riparian area and explicitly exclude dry land adjacent to channels. In the semi-arid ranching world, the term riparian area means something entirely different than riparian area in the humid forestry world.

The USDI F&WS system is an example of basing classification on vegetation and accepting changes in polygon area over time when the vegetation changes. Trends in land amounts are inevitably compromised as the land base continually changes.

The USDI F&WS mapping protocol does well in sampling vegetation underwater at bankfull flow; a robust emergent vegetation at average and low water flows. Something very important to grazing animals, of virtually no interest to forestry, yet critical to ecological and geomorphic processes. In-channel vegetation below the bankfull elevation includes trees, shrubs and herbaceous life forms - in eastern or western landscapes.

Vegetation in the channel is critical to fish, mollusk, and the aufuchs (bacterial and algal slimes coating vegetation). The vegetation and the sediment deposition it fosters perform an important physical function in the concept of riparian (an interaction of earth and water forming the channel) and they are critical sites for vegetation propagation along the riparian corridor. The air photo method of the USDI F&WS accounts for these small units down to 0.4 ha and smaller if viewable on a photo.

TABLE I
Three decades of riparian definitions

| | |
|---|---|
| Hack and Goodlett, 1960 | Their tracing of vegetation theory strengthens the geomorphic tenets of vegetation habitat and adaptation of vegetation to moisture regimes engendered by geomorphology. They document strong relationships between geomorphology and vegetation citing Gilbert's (1909) dual domains of erosion: the domain of stream sculpture causing concave hillslopes and the domain of soil creep causing convex hillslopes. Further, they separated the forests of first order V-shaped stream valleys from forests in higher order stream valleys containing floodplain forests. |
| Cowardin *et al.*, 1979 | Classification of wetlands and deepwater habitats in the United States. The word riparian is never used in this reference, yet it forms the basis for subsequent F&WS and some BLM riparian mapping protocols. |
| Gebhardt, *et al.*, 1989 | Used the words 'riparian system' and pointed out the deficiency of many riparian classifications based primarily on vegetation and argued for the inclusion of hydrologic and geomorphic process descriptions to provide the fundamental underpinning of riparian systems. These authors with BLM, USFS, and White Horse Associates in Idaho and Utah included flood frequency occurrence (5 to 50 years), hillslopes occurring within an elevation 3 m above the maximum channel depth (at a riffle), and hill-slope erosion and mass wasting as very significant influences on the formation and character of substrate for riparian vegetation. |
| Debano and Schmidt, 1989 | Considered the attributes necessary for riparian health without explicitly defining riparian. They included channels with efficient shapes, stream power less than critical levels, channels with relatively narrow width/depth ratios, channels connected to their floodplains in well-developed meandering systems, and with constant log steps in confined channels. |
| Hunter, 1990 | addressed the issue of scale. The riparian zone, at the smallest scale, is the immediate water's edge, where some aquatic plants and animals form a distinct community. At the next scale, the riparian zone includes those areas periodically inundated by high water. At the largest scale (and in forested regions), the riparian zone is 'the band of forest that has a significant influence or conversely is significantly influenced by the stream. |
| USDA NRCS, 1991 | Riparian areas are ecosystems that occur along watercourses and water bodies. They are distinctly different from the surrounding lands because of unique soil and vegetation characteristics that are strongly influenced by free or unbound water in the soil. Riparian ecosystems occupy the transitional area between the terrestrial and aquatic ecosystems. Typical examples include floodplains, stream banks, and lakeshores. |
| Gregory *et al.*, 1991 | Recognized the ecosystem aspect of riparian zones. |

TABLE I
*(Continued)*

| Author | Definition |
|---|---|
| USDI BLM, 1993 | . . . a form of wetland transition between permanently saturated wetlands and upland areas. |
| Naiman *et al.*, 1993 | The riparian corridor encompasses the stream channel and that portion of the terrestrial landscape from the high water mark toward the uplands where the elevated water tables or flooding may influence vegetation and the ability of the soils to hold water. |
| US EPA, 1993 Coastal Zone Mgt. Act Guidance | . . . vegetated ecosystems along a water body through which energy, materials and water pass; characterize riparian areas as having a high water table, subject to periodic flooding and encompassing wetlands. |
| Forest Mgt. Assessment Team (FEMAT, 1993) | Riparian reserves are portions of watersheds where riparian-dependent resources receive primary emphasis and where special standards and guidelines apply to attain Aquatic Conservation Strategy objectives. Riparian Reserves include those portions of a watershed required for maintaining hydrologic, geomorphic, and ecologic processes that directly affect standing and flowing water bodies such as lakes and ponds, wetlands, and streams. |
| USDA FS, 1994 | Riparian areas *include the aquatic ecosystem*, the riparian ecosystem and wetlands. While this broadly defined riparian areas, it also defined 'riparian ecosystem' as restricted to those areas with soil characteristics or distinctive vegetation that requires free or unbound water. |
| Brosofske, 1997 | . . . land, inclusive of hydrophytes, and/or with soil that is saturated by groundwater for at least part of the growing season within the rooting depth of potential native vegetation. |
| Hupp and Osterkamp, 1996 | Endorse the ecological concept for defining riparian areas because doing so recognizes the importance of fluvial processes in shaping the character of the riparian zone. |
| Gregory, 1997 | Includes the aquatic ecosystem and that portion of the terrestrial ecosystem, beyond the influence of elevated water tables that has a functional connection to the water. |

TABLE I
*(Continued)*

| Author | Definition |
|---|---|
| USDI F&WS, 1997 | Riparian areas are plant communities contiguous to and affected by surface and subsurface hydrologic features of perennial or intermittent lotic and lentic water bodies (rivers, streams, lakes, or drainage ways). Riparian areas have one or both of the following characteristics: (1) distinctly different vegetative species than adjacent areas, and (2) species similar to adjacent areas but exhibiting more vigorous or robust growth forms. Riparian areas are usually transitional between wetland and upland. |
| USDA FS, Region 9 (Parrott *et al.*, 1997) | Riparian areas are composed of aquatic ecosystems, riparian ecosystems and wetlands. They have three dimensions: longitudinal extending up and down streams and along the shores; lateral to the estimated boundary of land with direct land-water interactions; and vertical from below the water table to above the canopy of mature site-potential trees. |
| USDI F&WS Dall, Elliot, and Peters, 1998 | Riparian areas lack the amount or duration of water usually present in wetlands, yet are 'wetter' than adjacent upland. |
| Ilhardt *et al.*, 2000 | Riparian areas are three-dimensional ecotones of interaction that include terrestrial and aquatic ecosystems that extend down into the groundwater, up above the canopy, outward across the floodplain, up the near-slopes that drain to the water, laterally into the terrestrial ecosystem, and along the water course at a variable width. |
| USDA FS, 2000 | Riparian areas are geographically delineated areas, with distinctive resource values and characteristics that are comprised of the aquatic and riparian ecosystems. They give special attention to the area within a horizontal distance of 30 m from the edge of perennial streams or other water bodies. A riparian ecosystem is a transition between the aquatic ecosystem and the adjacent terrestrial ecosystem; identified by soil characteristics or distinctive vegetation communities that require free and unbound water. (Revision of 1994.) |
| National Research Council, 2002 | Riparian areas are transitional between terrestrial and aquatic ecosystems and are distinguished by gradients in biophysical conditions, ecological processes, and biota. They are areas through which surface and subsurface hydrology connect water bodies with their adjacent uplands. They include those portions of terrestrial ecosystems that significantly influence exchanges of energy and matter with aquatic ecosystems (i.e., a zone of influence). Riparian areas are adjacent to perennial, intermittent, and ephemeral streams, lakes, and estuarine-marine shorelines. |

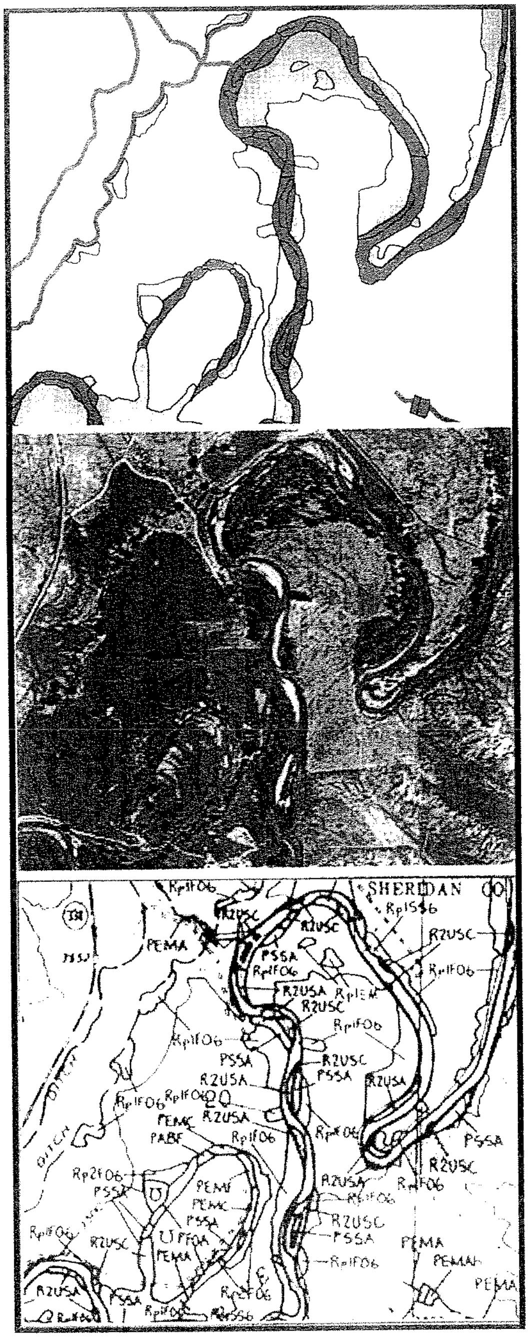


*Figure 2.* NWI map with wetland and riparian classification units (bottom), as digitized and color-coded for the same area (top; wetland and water are dark gray, riparian is medium gray), and the original (National High Altitude Program) air photo for a portion of the Tongue River, WY (center). The upper edge of the photo is the Wyoming-Montana border north of Sheridan, Wyoming.

The word zone also has multiple meanings. In forestry it is associated with a zone where BMPs are applied, in county regulations (zoning) it is associated with building exclusion or land treatments in a zone next to water. In EPAs Coastal Zone Management Act it is associated with land near oceans or large lakes.

## 4. Building a New Riparian Definition and Delineation

In 2000, the Forest Health Management (FHM) (USFS) began a process to test a riparian plot protocol for possible inclusion into the national FIA survey system carried out in all states. From the beginning, it sought to incorporate EPA EMAP sampling principles (hexagon plot division for the Earth and accumulation of data) and USGS-NAWQA (National Water Quality Assessment) stream monitoring sites, including a pilot test in watersheds of the Delaware Basin in 2001. FHM's goal is development of a nationally standardized resource monitoring system to investigate the status and trend (changed condition) of riparian systems, through repeated measurements over time.

Let us begin with Ilhardt *et al.*'s (2000) definition (Table I) and explore field-testing, and field reviews tested for a national plot-based assessment system. Their definition is an attempt to include the biotic response (vegetation, animal, and nutrient) and cause (geomorphic and hydrologic drivers) for the important functions in riparian areas. As a definition, it is conceptual and fuzzy but evokes conflict in two aspects. First, it includes part of the upland above the floodplain in a strong functional way. Second, it uses the words riparian and area together, a sequence viewed differently in the semi-arid West from several views in the humid East or humid West. Conceptually, Ilhardt *et al.*'s definition is parallel to river corridor concepts: Smith and Helman (Figure 3), Forman (Figure 4), and Sparks (Figure 5).

In Figure 3, Smith and Hellmund's transitional upland fringe is synonymous with Forman's toeslope, hillslope and upland. In Figure 4, Sparks' bluff is also synonymous with Forman's toeslope, hillslope and upland. Note that prairie (mesic or hill) or upland forest occurs on any of Forman's hill positions.

Can we improve these concepts? Perhaps. Instead of riparian area, could we use riparian corridor? On the other hand, could we simply use Forman's stream corridor instead? Forman (1995) also uses the term lake corridor in the same sense, but does it apply, in a language sense, equally well to seasonal pond corridor; wetland corridor?

There is a word embedded in the Ilhardt *et al.* definition that would serve in all landscape settings-ecotone. Riparian Ecotone. The ecotone concept avoids the word area and zone, and uses the word riparian as an adjective. In addition, riparian ecotones are equally applicable to streams, lakes, wetlands, estuaries, and seasonal ponds.

Riparian ecotone is unquestionably an ecological term, derived from the academic literature. Riparian ecotone is less likely to be confused with regionally

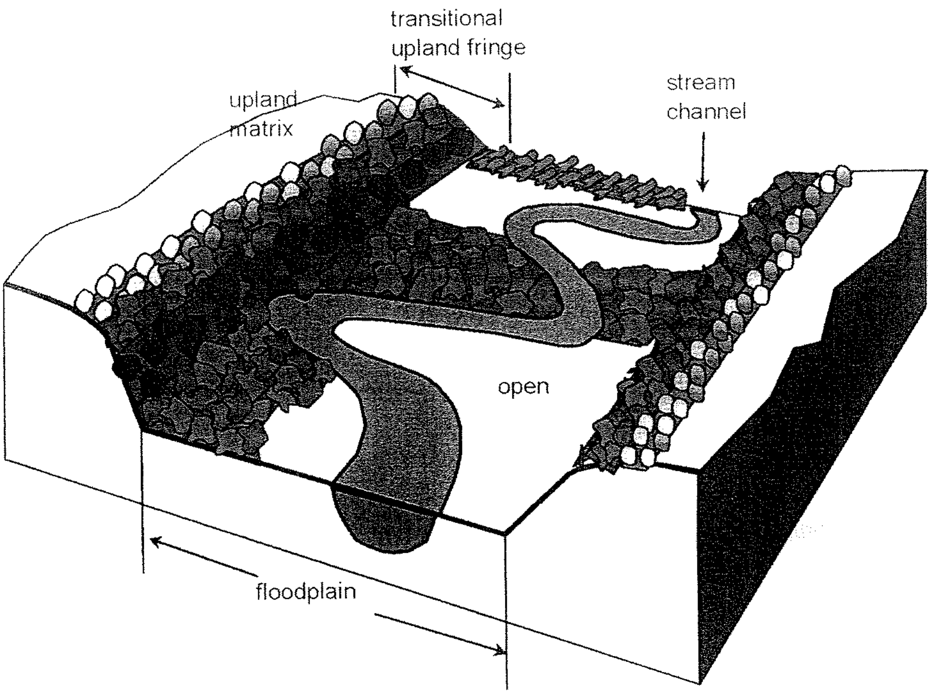


*Figure 3.* Connections across a stream corridor. Modified from Smith and Hellmund (Univ. of Minnesota Press, 1993) for geomorphic consistency.

different meanings of riparian area. Meanings fostered by regional offices of various agencies, embedded in different professions (e.g., ranching and forestry) or simple differences in colloquial use. Riparian ecotone is a corollary with stream corridor, lake corridor, or greenway used in the human dimensions discipline.

Ecotone and ecosystem are two concepts we ought to touch on. Ecosystem has that troublesome characteristic of being applicable at all scales: single cell, Earth, universe and most everything in between. That pretty much covers it. What we need to remember is that ecotone is a gradient across ecosystems (e.g., the prairie-forest ecotones; the estuary, salt-fresh water ecotone). Riparian is not an ecosystem, but a collection of ecosystems, an ecotone, describing a three dimensional space we (society) have given special value to. Pick your own scale (e.g., see Hunter, 1990). Delineation is where understanding of a definition is internalized; however, delineation has suffered from a lack of rigor in its application.

## 4.1. Delineation old and new

Ilhardt *et al.* (2000) offered a pictorial key to accomplish delineation in the field (Figure 6). It requires on-the-ground knowledge of the water body, extent of the floodplain, length of hillslopes adjacent to the floodplain and extends the riparian ecotone a mature tree length landward at the top of the hillslope.

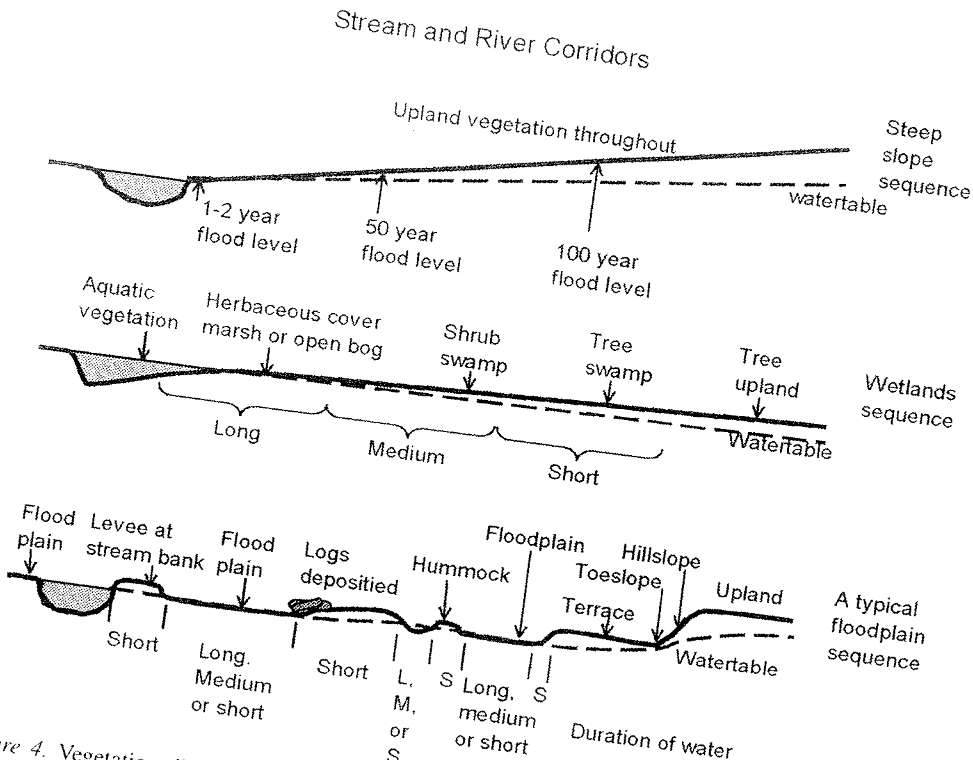


*Figure 4.* Vegetation diversity reflecting valley structure and length of inundated soil. Long (L), medium (M), and short (S) indicate the relative persistence of the water table at or above the soil surface – annual average of a highly variable water table. Modified from Forman (1995) to show geomorphic, floodplain surface.

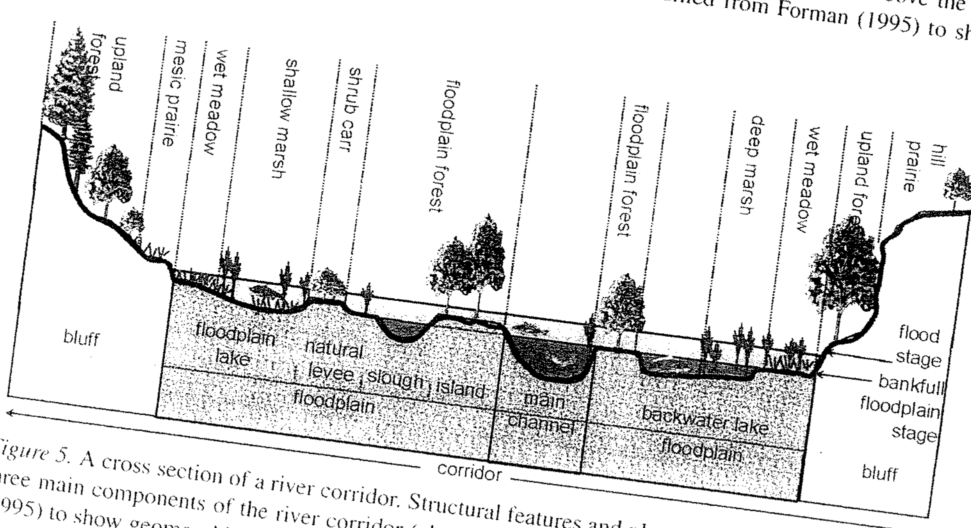


*Figure 5.* A cross section of a river corridor. Structural features and plant communities subdivide the three main components of the river corridor (channel, floodplain, and bluff). Modified from Sparks (1995) to show geomorphic consistency.

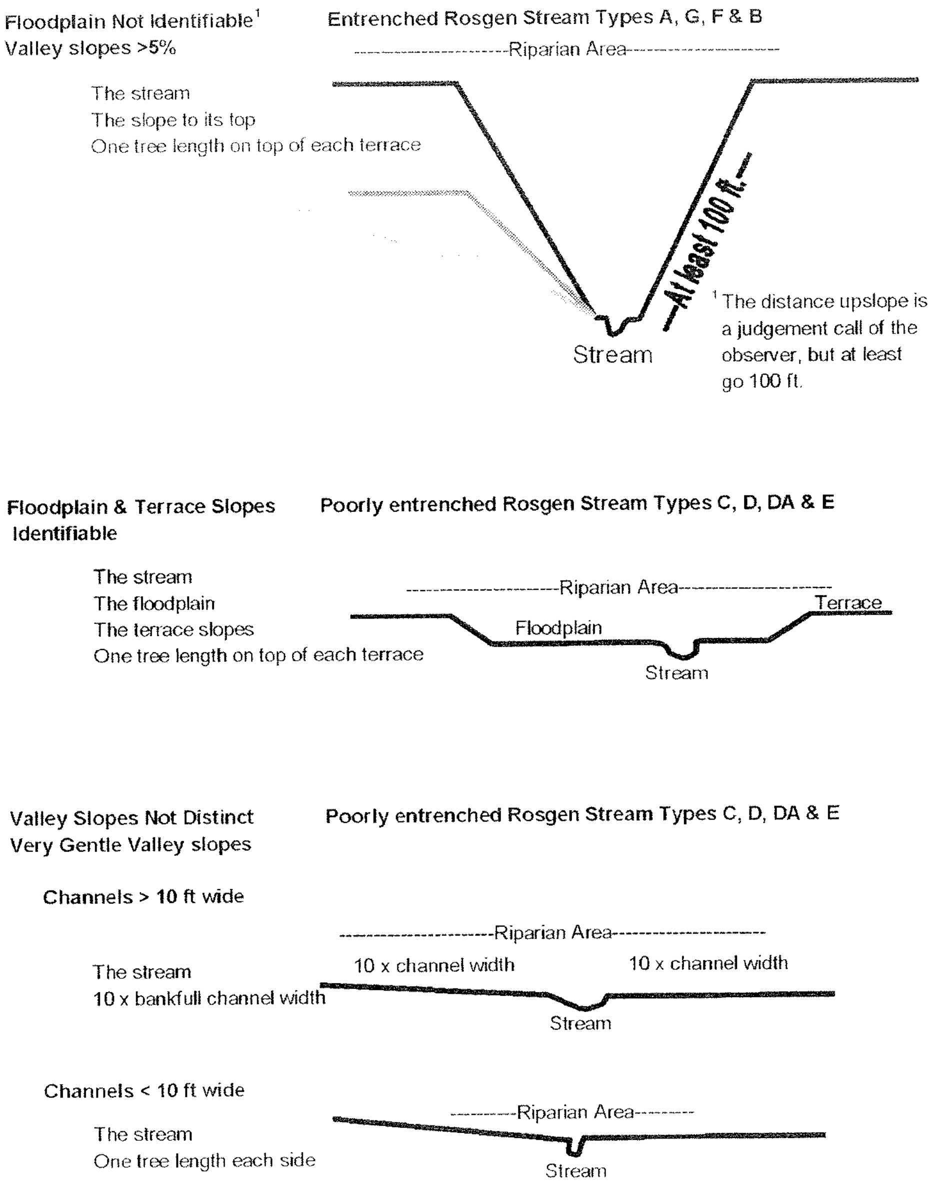


*Figure 6.* A field key to identify riparian areas for streams (after Ilhardt *et al.*, 2000).

This key was meant to help timber sale layout in riparian areas without any prior knowledge of stream and floodplain geomorphology. However, the key is actually based on a physical relationship between the valley and stream using entrenchment ratios defined by Rosgen (1994). Entrenchment ratios are the width of the valley at the 50- to 60-yr flood stage compared to the bankfull width of the stream. The ratio indexes how the stream and its valley handle the energy of flowing water, sediment, and debris.

The key in Figure 6 divides streams into those with high or moderate entrenchment ratios (v- or u-shaped valleys with steep and high hillslopes) and those with low entrenchment (floodplain valleys). The upper valley diagram applies to Rosgen stream types A, G, F, and B, and the lower diagrams to Rosgen stream types C, D, DA, and E.

The upper diagram in Figure 6 appears to recommend extending the riparian area all the way to the top of the mountain. However, the footnote: 'at least a 100 foot minimum' was often overlooked. In fact, text accompanying the key left delineation of riparian area extent to the observer that could place the riparian boundary anywhere between 100 feet (30 m) from the stream edge to 100 feet landward from the slope break depending on the degree and length of slope and whether there were intervening terraces.

The second diagram applies to streams with an obvious floodplain and terraces on either side. These streams meander across the floodplain. The key calls for delineating the riparian area as a tree length back from the upper slope break on the terrace top. This was meant to encompass existing or potential areas along the valley wall where the channel erodes into the terrace slope and gains large amounts of sediment and woody debris.

The lower two diagrams are for channels where terrace slopes are not obvious. Half of the meander way gives a default riparian area width if floodplain and terrace features are not obvious. The meander way (the width between outside bends as a river courses through the valley) is measured in plan view. An average meander way ratio (meander way width:bankfull channel width) is about 20 (Rosgen, 1996). Half of this (10 times the channel width on each side) estimates a default riparian width.

For small streams the 'mature tree' width (nominally as 100 ft or 30 m) sets the riparian width even if narrow floodplains exists and small terraces are close to the channel. The mature tree length derives from summaries of riparian studies relating functions (shade, leaf litter, bird habitat, invertebrate canopy space, etc.) to streamside forests. Strong functional riparian relationships occurred within 30 m of the channel (Richards 1996). However, the 'mature tree length' is a lousy analogy for national application. We are sure folks in the Pacific Northwest will opt for 300 feet, some of us will demand at least 125 feet, and still others are happy with 75 feet. It's a hopeless analogy and one not needed.

Virtually every riparian width study has ignored the stream's floodplain, opting instead to use distance from the stream as an independent variable. Unlike Hack and Goodlett's (1960) concept of valley *and* stream, most riparian studies seem to divorce the stream from its floodplain (or floodprone area if the valley is v-shaped). Important riparian functions are related to the entire floodplain (e.g., floodwater recruitment of large woody debris, predator stalking at the upper terrace break, sediment spreading and deposition) and not distance from streamside. From an

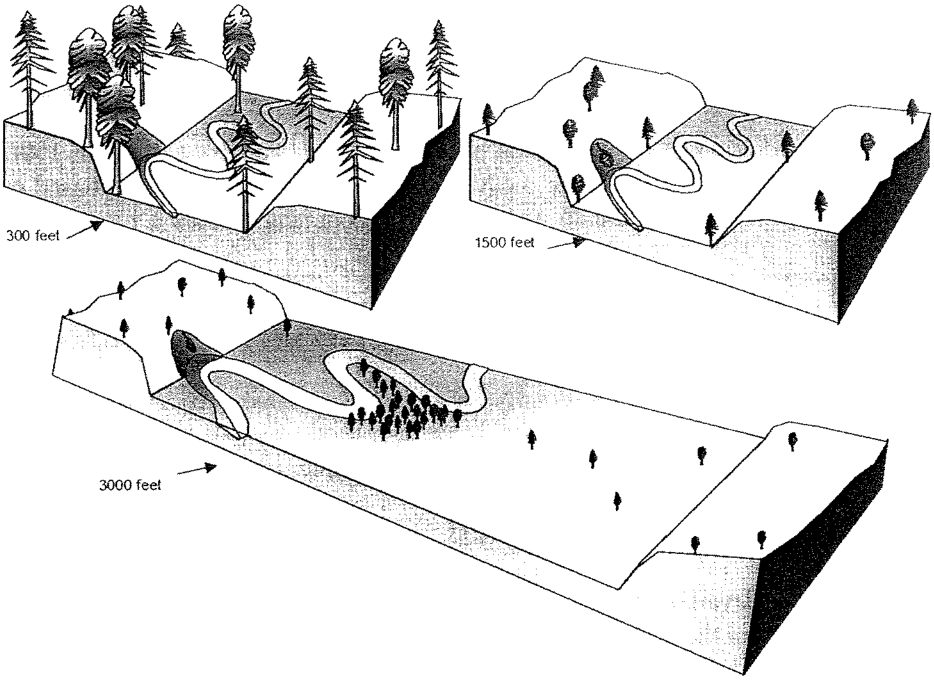


*Figure 7.* Stream and valley diagrams at corridor widths of 300, 1500, and 3000 feet.

ecological and geomorphic perspective, the stream's immediate valley provides the template on which strong functional relationships are imposed, rather than the stream itself.

How we perceive the application of riparian delineation criteria (Fig. 6) depends on the scale of the stream and valley system. Consider Figure 7 with three floodplain systems at different scales.

The 300-foot (28 m) wide riparian ecotone (Figure 7) includes an area 100 feet (30 m) back from the top edge of the terrace because tree, predator, and landslide functions easily reach or use this relatively short distance from the stream.

The 1500-foot (139 m) wide stream corridor is identical to the 300-foot wide corridor except the scale of valley and stream (it's a wider stream) is 5 times larger. The trees are the same actual size (e.g., 30 m tall), and drawn at 1/5th the scale in 300-foot wide corridor diagram. The riparian ecotone might include a portion of the left side where the landslide (slump) occurs.

The 3000-foot (279 m) wide corridor (Figure 7, bottom) depicts a still larger stream but it occurs on one side of the floodplain. Even when the river is on one side of the valley and a long way from the opposite terrace, strong floodplain functions and landslides delivering sediment suggest including the floodplain and part of the upland as part of the riparian ecotone.

The keys in Figure 6 are applicable to streams in all landscapes, but they do not offer a rigor sufficient to delineate lines on the ground for a consistent, routine, measurement of resources within stream-associated riparian ecotones in any landscape. However, the minimum distance upslope from the *floodplain* (100 ft in Figure 6) combined with the definition of *floodprone* extent (Rosgen, 1994, 1996) does offer a consistent, repeatable method to delineate riparian ecotone based on geomorphic principles of stream and valley development. It uses a piece of the valley as the riparian ecotone template rather than a piece of the stream.

### 4.2. Using Floodprone Area Width as a Base

Floodprone area differs from floodplain area. Floodprone area is based on a physical stream measurement that yields the elevation of a 50- to 60-year recurrence interval (R.I.) flood. It is determined by simple, direct measurements on the ground, but is subject to minor errors, in the same way a direct measurement of tree diameter is. Floodprone area width is the standard for measuring stream entrenchment.

Floodprone elevation, a relatively new term, is obtained by measuring the vertical distance from the deepest part of a channel (always at the mid-riffle position where bankfull width is usually minimum) to the bankfull elevation (e.g., 0.6 m). Extending this distance above the bankfull elevation (e.g., 1.2 m above the deepest part of the channel) is a consistent, repeatable estimate of the floodprone elevation (Rosgen 1994). The width of the valley at this elevation is the floodprone width, and it is the basis for estimating stream entrenchment within its valley (entrenchment ratio = the floodprone width/bankfull stream width).

Stream width varies with stream type and with watershed size and climate. However, maximum stream depth at a riffle indexes for every stream the minimum depth required for the stream to carry its bankfull flow. Average stream depths at the riffle have long been used to measure channel flow (Leopold, 1994). However, the measurements and computations required are time consuming. For quick and consistent field measures, and for the classification of natural rivers, maximum stream depth is particularly useful (Rosgen 1994, 1996).

For stream types with a floodplain (C, D, Da, and E) the floodprone area width can be measured on a topographic map or air photo as the meander way of the river. However, stream types without a floodplain (A, G, F, and B) have no floodplains and the elevation of land adjacent to the channel may extend higher than bankfull discharge elevation. Thus, while floodprone measurements can be used in every case, meander *ways* can approximate the floodprone width in only half of the natural stream types.

We propose using floodprone width and 30 m beyond as the basis for delineating riparian ecotones in stream valleys (Figure 8). Obvious slumps or landslides that reach the channel are added (15 m around the existing slump) to include all strong functional areas within the ecotone. Figure 9 illustrates the delineation of riparian

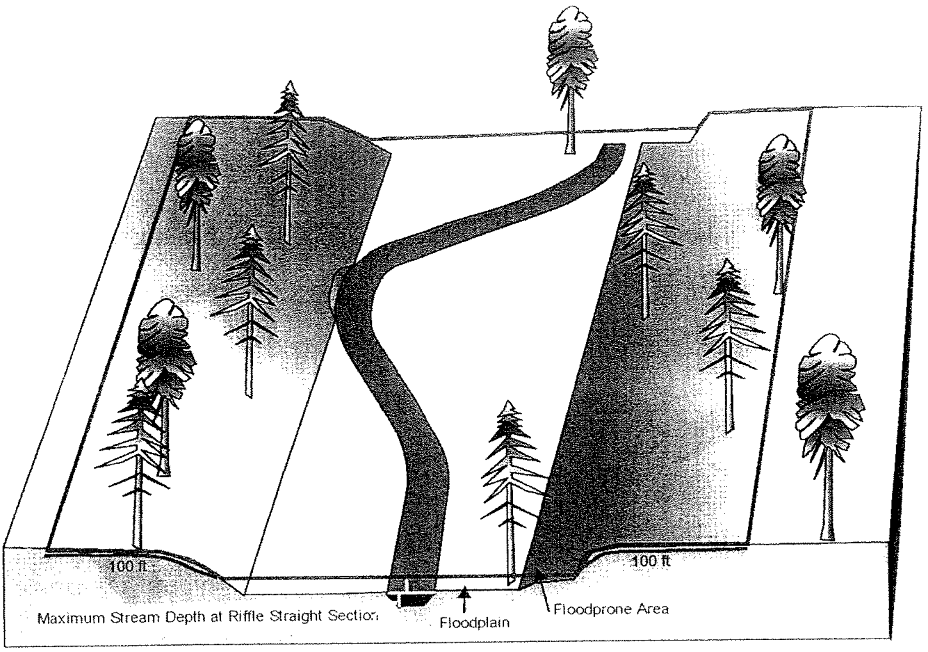


*Figure 8.* Twice the vertical distance from the thalweg (deepest part of a channel measured at a riffle section) to the bankfull elevation marks the elevation of the floodprone area (note the two vertical gray lines in the channel in the lower diagram). Floodprone areas are outlined and shown as a transparent plane above the stream and its floodplain. In flat valleys like these, there is not much difference in the area covered by a 25- or 50-year flood. The floodprone areas can be viewed as valleys carrying floodwater every 25 years or so, just as channels carry bankfull flows every year and a half or so.

ecotones in three floodplain valleys of differing scale, and Figure 10 illustrates the delineation in two v-shaped valleys of different scale.

Note the delineation for the 100 ft (30 m) wide corridor in Fig. 9 did not change because the slump is already included in the 100 ft (30 m) addition to the floodprone area. A recent draft of an Aquatic/Riparian Effectiveness Monitoring Plan (Reeves *et al.*, 2001) for the Northwest Forest Plan does not explicitly define or delineate riparian, but includes mass wasting, erosion and debris flow in their concept of riparian/floodplain. A similar word combination (riparian/floodplain) including mass wasting processes is used in an interagency riparian workshop proceedings for biological indicators in Pacific Northwest riparian forests (Barker *et al.*, 2000).

Identical relationships in Figure 9 exist for streams without floodplains in steep v-shaped valleys. The delineation is based on the floodprone area rather than the floodplain area since these stream and valley types have either no, limited, or discontinuous floodplains (Figure 10).

These riparian ecotone delineations meet the Ilhardt *et al.* (2000) definition and provide a rigorous, field delineation applicable in any landscape; one that encompasses all the processes strongly influencing or influenced by the stream.

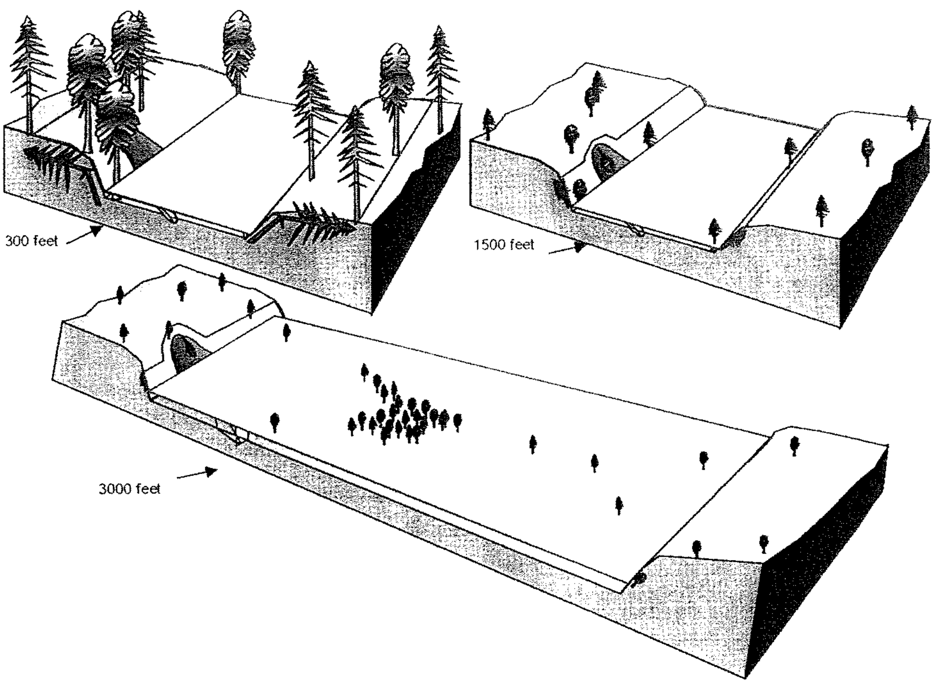


*Figure 9.* Floodprone area and its width are surveyed at an elevation that is twice the maximum bankfull channel depth (measured at a straight riffle section of the stream). The width of the floodprone area plus 100 ft (30 m) on either side provides a consistent, on-the-ground method to survey the attributes of riparian ecotones in any landscape. Including a 50 ft- (15 m)-wide band around known landslides or slumps completes riparian ecotone delineation. This recognizes their large impact on sediment flux in the channel.

It represents a fundamental change in view, from historical applications of riparian area or zone, or streamside management zone. Note the width of the riparian ecotone is different on either side of the stream (Figures 9 and 10).

The riparian ecotone is derived from valley and stream geomorphology.

In contrast with previous riparian or BMP definitions, it is not based on road erosion (the classical Trimble and Sartz (1957) approach, variable by slope). It is not derived from streamside shading (the Brown *et al.*, 1980) approach based on tree heights. It is not derived from a hydric soils approach. It is not derived from a vegetation approach (Dall *et al.*, 1998) using wetland or wetland facultative species.

In Figure 10, especially, the narrow side is on the steepest slope! The wide side is on the lesser slope! When multiple disciplines and multiple impacts are viewed in total, we see a picture of riparian different from traditional single discipline or single impact approaches. Our ecotone approach may conflict with some SMZs where the widely applied slope gradient approach for sediment travel from roads is used to set widths away from the stream (Trimble and Sartz, 1957). The

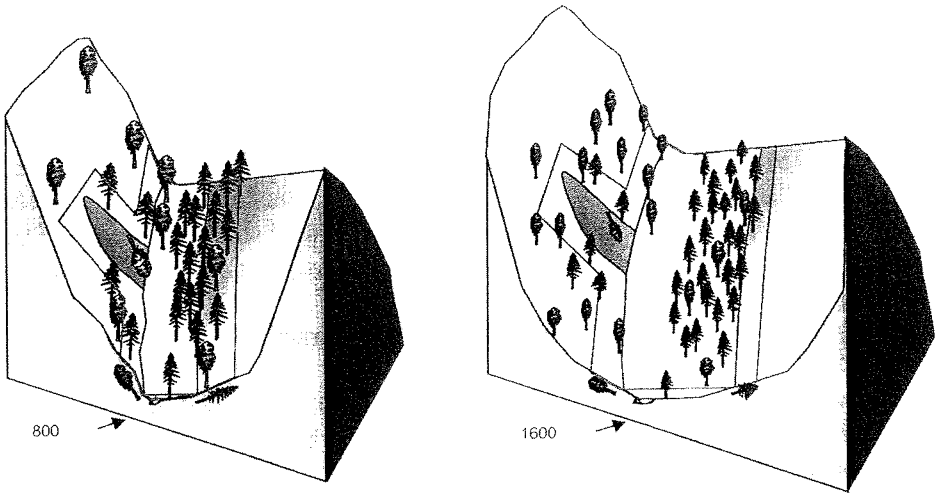


*Figure 10.* Two steep valleys are shown, one twice the size of the other. In both diagrams, the trees are actually the same nominal size (30 m) and look smaller (scaled) in the wider 1600 ft (533 m) valley than in the 800 ft-wide valley. Two vertical lines in and above the channel define the elevation of the floodprone area and the 50-ft (15 m) addition for slide and slump areas (see Figure 8).

slope method is a broadly applicable system to evaluate road placement, but not to broadly define riparian ecotone. One might perceive the flatter, wider side in Fig. 14 is too wide, but that is where the fish are during flood.

Gebhardt *et al.*'s (1989) words (riparian system, see Table I) encompass the broader definition of Ilhardt *et al.* (2000). What we have offered in Figures 9 and 10 is a rigorous field-defined delineation based on 'two times maximum channel depth' definitions of floodprone area and entrenchment ratios; concepts that did not exist in 1989. In combination with the 100 ft (30 m) strong influence distance, this approach affords a rigorous method of applying descriptive concepts to delineations on the ground.

Learning to find the bankfull and floodprone elevation within a 1-foot (30-cm) elevation bracket is not overly difficult. Over the last 15 years, it has been taught to at least 3,000 resource professionals including foresters, fishery biologists, engineers, hydrologists, county commissioners, soil scientists, recreationists, human dimension scientists, restoration specialists, and many others (view the websites www.stream.fs.fed.us and www.wildlandhydrology.com for opportunities to learn).

This could end our discussion of riparian ecotone definition and delineation, but real world testing and a need to aggregate riparian resources illustrates why the entire continuum: definition-delineation-resource estimation needs tying together.

## 5. Field Testing and Resource Aggregation in the Real World

This system of riparian ecotone delineation was tested in 2001 in southern New York's Catskill Mountains. The streams and valleys looked similar to the 1600-foot corridor in Figure 10. In Rosgen's stream type classification terminology (Rosgen, 1996), many Catskill streams were B channels having small, hard to distinguish, floodplains (a meter in width and length) that defined the bankfull elevation. This is critical because bankfull elevation is the point to measure up from and determine the floodprone area.

A new, two-person, FHM-Riparian field crew was trained in 3 days to identify, level-survey, and sample various aspects of the stream and valley riparian ecotone. Normal weeklong training for vegetation and soil sampling in FHM plots (phase 3) was done earlier in the summer. Cobble and boulder B channels are perhaps the most difficult stream channels to measure and classify. Though often filled with anxiety on their unassisted forays into the world of the riparian ecotone, their delineation and measurement of bankfull elevations were over 90% accurate.

During testing of FHM and USGS-NWQA riparian resource plot protocols in New York (plant, animal, and physical resources, and riparian vegetation plot protocols in Pennsylvania), two troublesome aspects showed themselves in need of change: the width of the riparian ecotones and vegetation in the channel.

The first tests utilized the Ilhardt *et al.* (2000) key (Figure 6) to outline extent of the riparian ecotone. However the top of the hill or even a flatter part on the hill leads to widths far in excess of 100 ft. Judging the flatter part of a hillside leads to much variation. Hence, we recommend using the default 30 m (100 ft) attached to the floodprone area width. We could have attached it to the stream, but meandering channels (even a little bit) caused a significant loss of time in plot layout, and widely variable outer edges of the attachment as the riparian ecotone is estimated up and down the valley. More importantly it ignores the fact that riparian ecotones are valley units not stream units.

The trial tested a variety of vegetation plot layouts and two are discussed below. However, our obvious, original bias toward upland, FHM perspectives of vegetation sampling, led us to ignore vegetation in the channel. Vegetation in the channel (e.g., below the bankfull elevation) is an important part of riparian ecotones everywhere. The USDI F&WS National Wetland Inventory (NWI) mapping protocol routinely maps this vegetation as a palustrine wetland. Figure 11 illustrates the basic design of vegetation plot layout tested in New York.

### 5.1. Laying Out Riparian Plots and Expanding Riparian Plot Data

EPA's EMAP program divides the Earth's surface into large hexagonal plots whose boundaries lay over the earth as the stitching covers the surface of a soccer ball with equal-sized hexagons. Each large hexagon is further subdivided into smaller hexagons and so on. The four FIA phase 2 & 3 subplots (totaling 1/6th acre) are

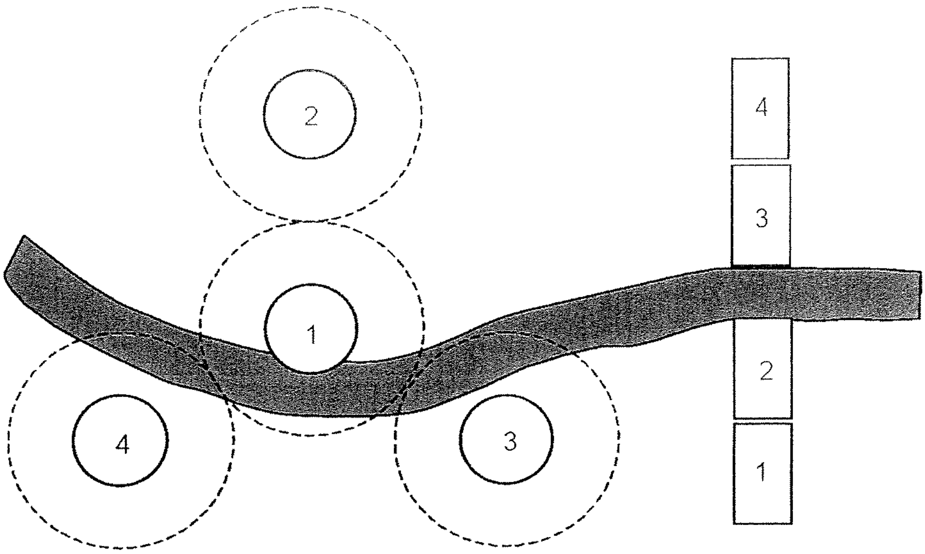


*Figure 11.* Circular plots laid out in a triangle constitute the standard FIA phase 2 and 3 vegetation plot arrangement (additional variables are measured in phase 3 plots). Subplots 1–4 total 1/6th acre and annular plots (dashed circles) are reserved for sampling of items requiring a larger footprint, such as very large diameter trees. The four annular plots total 1 acre. An alternative plot arrangement with rectangular plots (30 plots (30 ft by 60 ft) also total 1/6th of an acre, about the smallest plot size and replication (4) that will adequately sample the normal range of tree sizes and smaller life forms. The stream meanders through the plots.

a subsample of the four, 1/4-acre, annular plot areas. The amount of resources on the subplots times six is an estimate of the amount of resources per acre. That value times the acres represented in the hexagon plot are an estimate of the total resources.

A fundamental and critical question that all riparian sampling programs must answer is what larger area does the riparian plot cluster represent when it is applied randomly to a point on a stream? Furthermore, how can 'upland' vegetation below the bankfull elevation be handled?

Figure 12 illustrates how the riparian rectangular plots are arranged at a stream location. Plots 2 and 3 (1/24th acre each) are placed with their ends at the bankfull edge of the stream. Plots 5 and 6 (whose width varies with bankfull stream width) are placed across the stream where vegetation within the aquatic plot is inventoried. Plot 5 is between plots 2 and 3 and samples a riffle area in the stream. Plot 6 is between bankfull elevations and samples vegetation in the channel at a bend (point bar) location. The arrangement of plots 5 and 6 allows the range of exposed sediment surface (and plant occupation) in the channel to be captured, and avoids the bias that occurs if only a riffle or only a pool site is sampled. In step/pool systems without significant meanders, plots 5 and 6 can be placed at the first narrow and wide places on the channel.

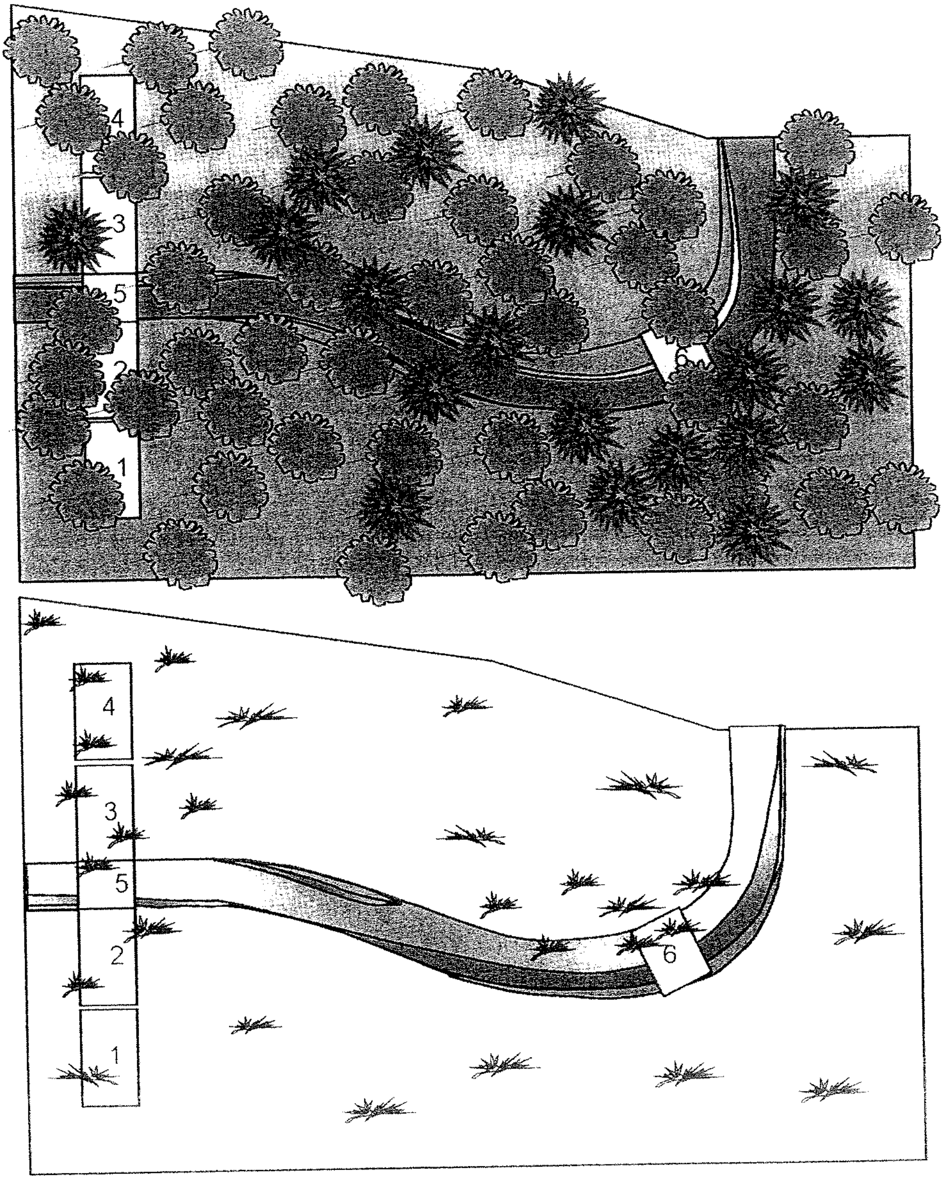


*Figure 12.* A conceptual layout of rectangular plots in a humid (top) or semi arid (bottom) environment. Plots 1–4 are 1/24th acre each (30 ft × 60 ft) and are always placed at the bankfull edge of the stream on a riffle section of the stream. Plots 5 and 6 are the same width as plots 1–4, but their length (width on smaller streams) is the bankfull width of the stream as measured on the ground. As a result, their width will vary with the bankfull width.

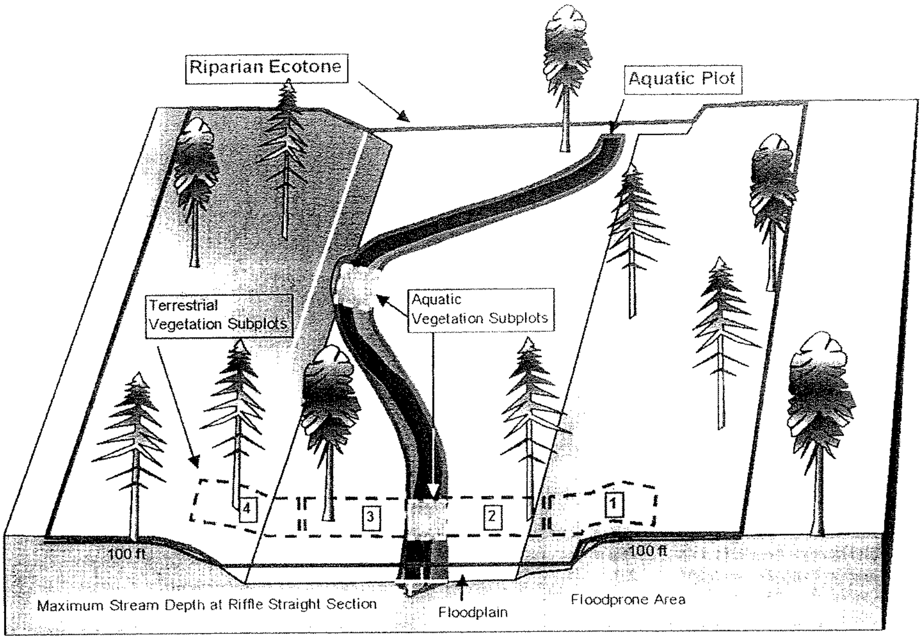


*Figure 13.* Example of a combined terrestrial and aquatic subplot sampling system for riparian ecotones. Terrestrial plots (1–4) are a subsample of the terrestrial portion of the entire riparian ecotone (bold outline). Aquatic vegetation plots (5 and 6) are a subsample of the aquatic area (bold outline in light gray). The terrestrial area is the riparian ecotone area less the aquatic area. The riparian ecotone is derived by adding 30m to the floodprone area of the valley.

An example of plot layout in relation to riparian ecotone illustrates the area each set of plots (1–4, 5 and 6) represents (Figure 13).

Field measurement of the entire riparian ecotone establishes its length and width (a simple, crew-determined average width applied during the valley cross section measurement). Similarly, stream measurements establish the length (thalweg length) and width (bankfull width) of the aquatic portion of the riparian ecotone. The difference is the terrestrial portion of the riparian ecotone. The aquatic plot may include small tributaries (or distributaries) if they are less than 20% of the main channel width. Where larger tributaries occur, the riparian ecotone plot is moved above the confluence so that all parts of the main channel represent the same watershed area of contribution.

The terrestrial vegetation subplot layout in Figure 13 applies to all stream sizes. Where floodplains are very large, circular FIA P2 plot clusters will also fall on the floodplain. If this is coded as floodplain during sampling and cross referenced to a riparian ecotone of the same stream order, these vegetation and soil data can be averaged with the rectangular terrestrial plot data. The subplot intensity will increase; however, the area they represent is defined as the riparian ecotone boundary

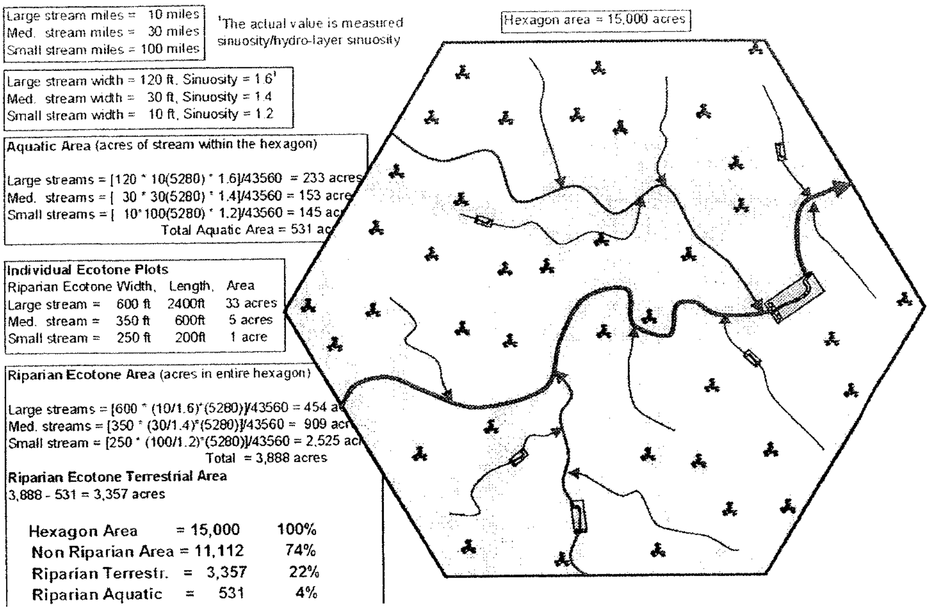


*Figure 14.* Diagram and calculations for aggregating plot level data to a hypothetical 15,000-acre hexagon surface on the earth. FIA P2 plots ($n = 40$) are the clusters of 4 plots. Each subplot including its annual larger portion for trees is 1acre. The blowup factor for the entire hexagon is 278 (11,112/40). For the FIA P2 plots sampling resources outside of the riparian ecotone only the non-riparian area within the 15,000-acre hexagon is used (15,000–3,888 = 11,112). The six riparian ecotone plots (totaling 3,888 acres) are variable in width and length depending on stream and valley size and encompass 1, 5, and 33 acres. For the entire hexagon, they represent 454, 909, and 2,525 acres, thus their blowup factors are 631 (2525/4), 182 (909/5), and 14 (454/33), respectively. Note, plot sizes and stream widths are exaggerated relative to the hexagon.

in Figure 13 (see also Figure 14 for riparian ecotone area within large medium and small streams).

In an EMAP approach to sampling, the area of the riparian ecotone represents a piece of all the stream miles within a particular hexagonal plot. The location of a riparian plot is derived from hydrography layers (GIS layers of all the blue lines on 1:24,000 topographic map(s) covering the hexagonal plot). In concept (and in a computer file), all the streams are run together (with their position remembered) and a random number locates a point on the conceptual single stream within the hexagonal plot. In this system, riparian ecotone sample areas are derived from stream length. As such, area must be corrected for sinuosity to render a riparian ecotone area as a sample of the valley rather than the stream.

The sinuosity error associated with the hydrography layer can be corrected (assuming the stream miles in a hexagonal plot are taken from a hydrography layer based on maps of the same scale). Correcting for sinuosity error requires two steps, one for the area of the *aquatic* portion of the riparian ecotone and one for the *total riparian ecotone* area. The same correction factor is used for each. In the first instance (aquatic portion) it is a multiplier; in the second instance (total riparian ecotone) it is a divisor.

A simple case for the sinuosity correction factor illustrates it derivation and application. Sinuosity is channel length divided by straight-line valley length. True sinuosity is field-measured in each riparian ecotone. Hydrography sinuosity is the same measurement taken from the GIS layer (or from a map). If the map or GIS layer has a sinuosity of 1.1 and true sinuosity is 1.8, the correction factor is 1.8/1.1 = 1.6.

Assume the stream sinuosity correction factor is 1.6. The resource attributes for the *aquatic portion* of the total riparian ecotone area are corrected by multiplying the aquatic area (hydrograph layer length times width) by 1.6. In other words, the true aquatic 'plot' is really 1.6 times longer than the map (or GIS) derived stream length. Conversely, for the entire *riparian ecotone area*, resource attributes must be *divided* by the sinuosity correction factor (see calculations in Figure 14).

The true *aquatic* area (bankfull stream channel) of the riparian ecotones is 531 acres (see calculations is Figure 14). The true *terrestrial* area of the riparian ecotones is 3,357 acres or 22% of the entire 15,000-acre hexagon sample region. Without the sinuosity correction factor (weighted by stream size) the estimate of terrestrial area in the riparian ecotones would be 5,030 acres or 34% of the entire hexagon – a 55% overestimate!

The totally random assignment of FIA P2 plots in the landscape needs rethinking if hydro-layer stream lengths and stream order stratify riparian ecotones. Even though sample location on hydro-layers is random, measuring riparian ecotones on the ground, in effect, stratifies the entire hex plot. The significance of the sinuosity error requires rethink sampling procedures and data aggregation before we report riparian resource amounts.

## 6. Summary and Discussion

By changing only two words in the Ilhardt *et al.* (2000) definition we have a definition that fully describes a physical valley template that drives riparian resource response.

> *Riparian ecotones are a three-dimensional space of interaction that include terrestrial and aquatic ecosystems that extend down into the groundwater, up above the canopy, outward across the floodplain, up the near-slopes that drain to the water, laterally into the terrestrial ecosystem, and along the water course at a variable width.*

When tied to an on-the-ground delineation criteria it gains considerable rigor applicable in any valley in any climate.

*Riparian ecotones include the floodprone area and 30 m landward along the valley. Obvious landslide or slump areas are added with a 15 m band around their edge.*

Combined with random upland resource sampling plots, and randomly located riparian ecotones in a data base stratified by stream order, the definition, delineation, and a mechanism for sinuosity error correction we have a . . .

*. . . linked sequence of definition, delineation, and data aggregation that accurately assess riparian ecotone resources on the ground.*

The system includes the measurement of 'upland' vegetation in the aquatic portion of the riparian ecotones; similar to the US F&WS air photo mapping of riparian polygons, but avoids the wetter, wet, dry vegetation base relating to wetland, riparian, and upland respectively. Although these vegetation plots in the stream are subject to errors engendered by the growing season progression of plants, they do provide plant diversity information essential to a full evaluation of riparian ecotones.

The proposed method might be abbreviated by substituting floodplain for floodprone. In many cases there is little difference. However, in just as many other cases (the v-shaped valleys) the field crew is left in limbo using a warm and fuzzy definition of floodplain to actually find edges on the ground that don't exist. In a procedural context, for the sanity of field crews, and because some federal and state agencies have adopted the floodprone-entrenchment ratio method of stream classification, the floodprone approach is a universal standard applied by field measurement resulting in less error across the entire landscape.

Our recommendations derive from an integration of valley and stream geomorphology with the functional ecology of a variety of ecosystems within the riparian ecotone. It is a functionally consistent integration (both abiotic and biotic) of riparian definition, delineation, and accurate riparian resource aggregation. Riparian is a concept tied to the stream's valley rather than the stream.

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