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Monitoring Design for Riparian Forests in the Pacific Northwest

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Research Plan

United States Environmental Protection Agency, Research and Development

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16. Abstract: The goal of this project is to recommend a broadly-acceptable efficient and effective methodology for characterizing streamside riparian attributes in forested settings at the site grain for regional monitoring. Streamside forested riparian areas have extraordinary ecological value richly reflected in management practice. The absence of a methodology to characterize these systems in a uniform way, presents a major obstacle to improving or evaluating both regional management decisions and regional understanding.

We consider monitoring design in the context of three interacting r\constraints: ecological functions, capabilities of technologies, and user needs. Each of these constraints is imperfectly known and has multiple facets -- ecosystems have more than one function, users have multiple needs. The three constraints are an interacting set. To enhance the ability to identify these interactions, the research is implemented with structured consultation with the broader scientific community and with the broader community of potential users. The research is organized so that ecological characteristics of riparian systems are generally defined early on. These requirements constrain the choice of monitoring systems from among the set of systems available. The focus is on fine grained remote methods. Comparison between candidate selected monitoring systems provides for an initial formulation of a monitoring design. A series of evaluations of these initial formulations provides for an initial recommendation. With the state's interest in the status of coastal fishes, and the programmatic interest of EPA's Western Ecology Division, the areas selected for study are in the Oregon coastal province and the Willamette basin. While the design of this research is specific to this area, the insights and procedures developed should be applicable elsewhere.

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1. Preface

This document describes research to define monitoring methods for riparian forests in the Pacific Northwest. It focuses on a habitat-based approach using fine resolution remote sensing techniques. Questions regarding this research should be directed to Paul Ringold, US Environmental Protection Agency, Office of Research and Development, National Health and Ecological Effects Research Laboratory, Western Ecology Division, 200 SW 35th St., Corvallis, OR 97333. Phone 541-754-4565, Fax 541-754-4716, email: ringold@mail.cor.epa.gov.

This document is divided into four major components:

- Summary of the research and the background and rationale for pursuing it (Section 2).
- Approach to achieving the goal, and the research tasks (Sections 3 to 7).
- Administrative information including linkages to other research and potential users, and personnel (Section 8).
- Appendices (Section 9) provide supporting information including a glossary which provides the full wording of acronyms and definitions of key terms (Section 9.7).

The Table of Contents also serves as a project outline; a series of flow charts (Figures 3, 4, 10, and 17) introduce the major sections and show how the parts are related to one another; Table 7 provides information on the timing of key elements. Quality assurance documents and detailed field and safety protocols are being developed separate from this plan.

This project is embedded in a larger research program (Baker and others 1995; Gregory and others 1996).

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2. Executive Summary and Introduction

The goal of this project is to:

> **Recommend a broadly-acceptable efficient and effective methodology for characterizing streamside riparian attributes in forested settings at the site grain for regional monitoring.**

We pursue this goal by developing monitoring methods and evaluating their performance in western Oregon.

2.1. Background and Rationale

Ecosystem management requires monitoring to ensure that long-term goals are being achieved. Because specific policy uses, ecological requirements and technologies may not be well specified ecosystem management may require that monitoring design be an iterative process (Ringold and others 1996; Ringold and others In Review). The research described in this plan focuses this iterative process on monitoring design for riparian ecosystems in forested settings.

Streamside forested riparian areas have extraordinary ecological value richly reflected in management practice (Steiner and others 1994; USDA/FS and USDI/BLM 1994; Oregon 1996; Gregory 1997). The absence of a methodology to characterize these systems in a uniform way, presents a major obstacle to improving or evaluating both regional management decisions and regional understanding (Mulder and others 1995; Smith and others 1997).

2.1.1. Characteristics of Riparian Areas

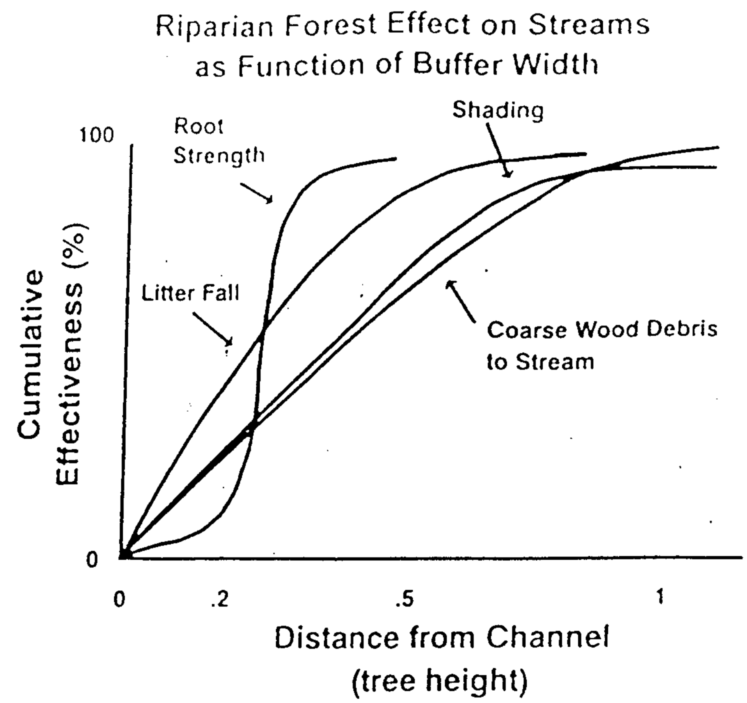
Riparian areas are the interface between aquatic and upland ecosystems. Their structure is important in affecting three major values -- water quality, aquatic habitat, and terrestrial habitat. Riparian areas are characterized by bands of structures associated and interacting with aquatic and upland systems. The relationship between the structure of these bands and their functions is illustrated in Figure 1. The spatial character of this relationship varies with the specific attribute of interest, and with the position in the watershed, but is generally important at very fine grains -- on the order of tens of meters in distance away from the stream. Appendix Section 9.2 elaborates on the relationship between this fine grain spatial pattern and multiple ecological functions.

Riparian sites are diverse, comprising a range of vegetation types and canopy structural elements. Banks, terraces, slopes and other geomorphic features associated with streams create a variety of microsites in riparian areas which are typically less evident upslope. This range of environmental conditions results in a relatively high degree of diversity in riparian community structure and composition

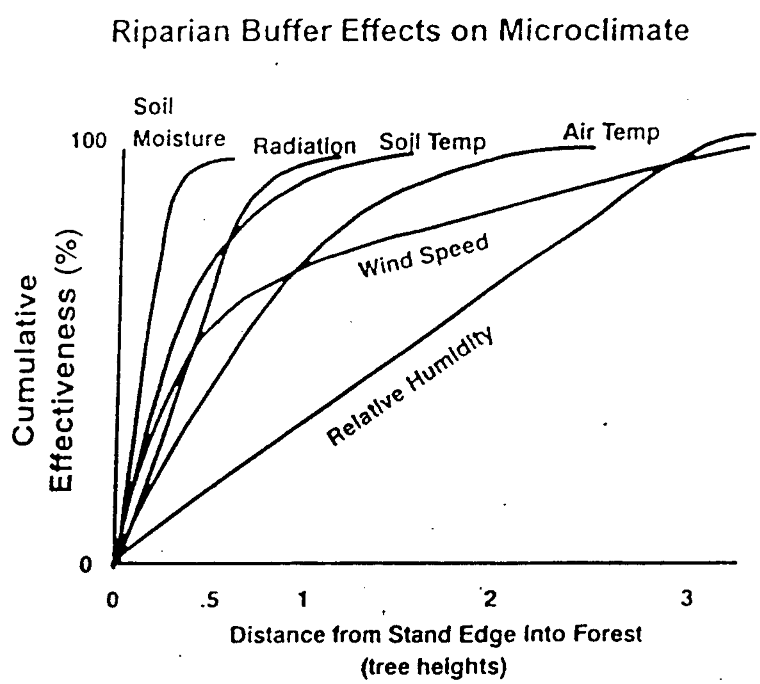
Figure 1 Riparian Structure and Ecological Functions

Fine-grained detail of riparian systems has an effect on ecological function. For an array of functions the importance is greatest near the channel edge and drops sharply as distances from the channel increase. Figure 1A illustrates this for riparian effects on streams; 1B for the effects of riparian structure on stand microclimate. Figure 1C shows that root wads are recruited within a distance of about 6 m of the channel edge. Root wads greatly effect the stability of woody debris in streams and may constitute up to 40% of the debris volume in the channel. Figure 1D shows that stream shading (as measured by angular canopy density) approaches old growth levels within about 20 to 40 meters from the stream. Figure 1E shows that woody debris input from streamside stands comes from trees within 25 m in mature hardwood stands, 50 meters in mature conifer stands, and 55 m in old-growth conifer stands.

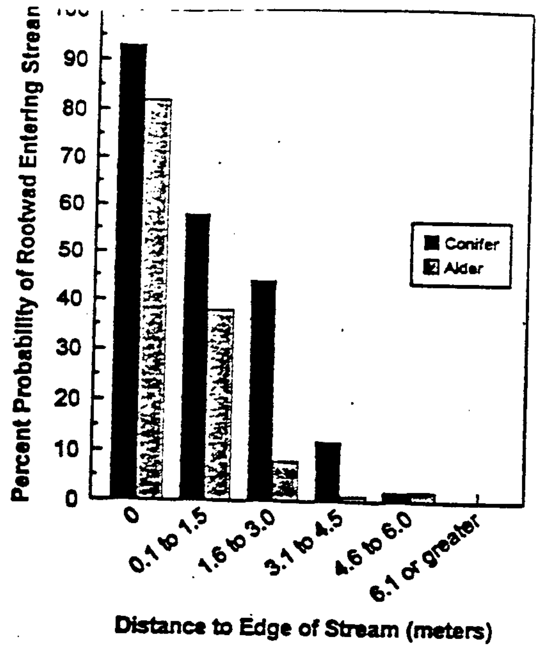
Sources: 1A and 1B (USDA and others 1993); 1C (Andrus, pers. comm.); 1D (Beschta and others 1987), and 1E (McDade and others 1990).



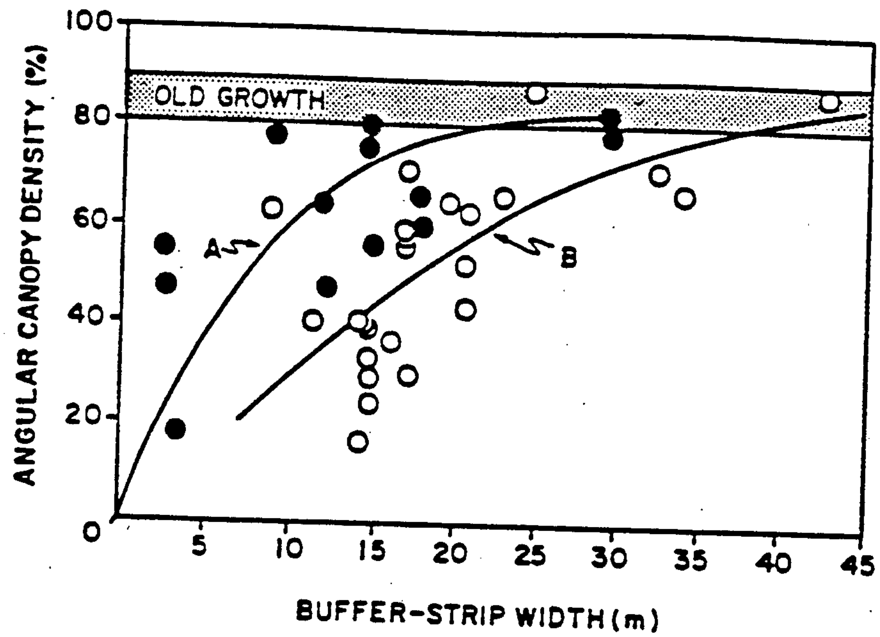
A. Generalized curves indicating percent of riparian ecological functions and processes occurring within varying distances from the edge of a forest stand.



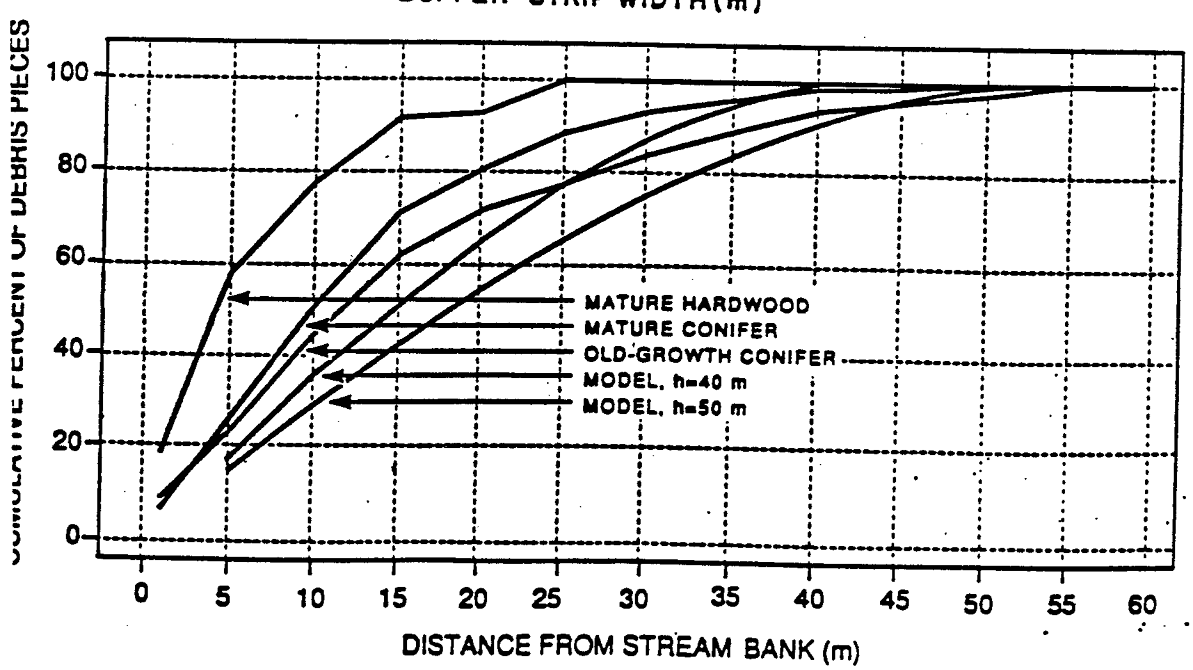
B Generalized curves indicating percent of microclimatic attributes occurring within varying distances of the edge of a riparian forest stand (after Chen, J 1991).


Percent Probability of Rootwad Entering Stream
90
80
70
60
50
40
30
20
10
0
Conifer
Alder
0
0.1 to 1.5
1.6 to 3.0
3.1 to 4.5
4.6 to 6.0
6.1 or greater
Distance to Edge of Stream (meters)

C


ANGULAR CANOPY DENSITY (%)
100
80
60
40
20
0
OLD GROWTH
A
B
5
10
15
20
25
30
35
40
45
BUFFER-STRIP WIDTH (m)

D


100
80
60
40
20
0
MATURE HARDWOOD
MATURE CONIFER
OLD-GROWTH CONIFER
MODEL, h=40 m
MODEL, h=50 m
0
5
10
15
20
25
30
35
40
45
50
55
60
DISTANCE FROM STREAM BANK (m)

E

(Gregory and others 1991). Riparian vegetation types and structure can vary both along the aquatic system and upslope. High disturbance rates in riparian areas, and steep environmental gradients contribute to this unusually complex structural pattern (Agee 1988; Swanson and others 1988). For some functions, for example shading or the provision of coarse woody debris, riparian systems may have a role which is more clearly distinct from the rest of the watershed, while for other functions, especially for terrestrial habitat, the distinct role of the riparian system may be more subtle, particularly west of the Cascades where water is in plentiful supply (Smith, and others 1997).

The interaction between riparian vegetation and streams is influenced by a range of factors, including stream size and flood plain width, variable disturbance regimes, and landuse patterns. The variable nature and intensity of riparian-stream interactions makes it difficult to draw distinct boundaries around riparian sites in a manner which encompasses all functions at each site. For example, in small headwater streams where the forest canopy can cover the channel, riparian vegetation adjacent to the channel influences inputs of matter and energy into the aquatic system, thereby affecting in-stream nutrient levels and water temperatures. The nature of the riparian-stream interaction changes in downstream portions of the system due to increasing flows and wide channels. In these wide valley areas vegetation adjacent to the channel often exerts less direct influence on nutrient levels and water temperatures. In contrast, the stream, by virtue of its larger volume, may exert more influence on the riparian stand than it does in small headwater streams.

Riparian function is important not only at individual "sites", but also in the integration of sites. The site is important because it is the scale at which much of our understanding is based and the scale at which many management actions occur. The integration of these sites into features of greater extent allows for the consideration of key ecological functions at larger extents. For example, the forest structure at a site contributes to the quantity and quality of the coarse woody debris available to a stream -- see Figure 1. Coarse woody debris is an important in structuring aquatic habitat. However, aquatic habitat in a stream network as a whole -- the scale of relevance to fish populations -- is dependent upon the status of the fine grained structure of the riparian system as a whole. Thus, sites can be viewed as the individual links of a more extensive chain. Each link has a function; so does the chain as a whole. Each link is tens of meters wide --the length of the chain (the length over which a function should be described) is not well defined, but is likely to be hundreds to thousands of meters long. Thus, we are interested in monitoring a feature narrow in width but quite long, making it particularly challenging to develop an effective and efficient monitoring design.

This richness in fine-grained pattern and process must be captured in a monitoring program, if that program is to provide information on the ecological values of the system. The proposed research focuses on the "site", consistent with the recommendations of (Mulder and others 1995; Smith and others 1997). The dimensions of a site and the aggregation of sites to larger extent are subjects of the proposed research. Specifically, we need to (1) capture important features at the site level (i.e. individual links in the chain) before we can aggregate that information to larger scale indicators; and (2) identify the value of additional detail at the site level. Later in the research, we begin looking at indicators which have a site grain, but larger extent, i.e. looking at the status of the chain, in addition to the status of the individual links.

2.1.2. The Management of Riparian Areas

Considerable policy attention and direction has been developed to improve the management of riparian systems. For example, the Northwest Forest Plan (hereafter referred to as the Forest Plan) establishes a number of ecological goals which require the maintenance and restoration of key functional attributes of riparian areas (See Table 1). An extensive network of riparian reserves is one approach to providing these functions. Riparian reserves not only have ecological value, they also have great economic significance. Management practices for these areas significantly restrict timber harvests on approximately 1 million hectares; more than one-quarter of the land which would otherwise be available for harvest on Federally administered lands operating under the Forest Plan.

Concern for appropriate management and conservation of riparian areas derives from sources other than the Forest Plan, and extends to other regions. Operating under their own authorities, and under the Federal Clean Water Act, states have established a set of protective policies for riparian areas. Steiner and his colleagues (Steiner and others 1994) note the great degree of general significance which policy has assigned to riparian areas, and a concomitant lack of quantitative information underlying the range of state policies. A monitoring methodology which accommodates a range of concerns will be of great use in supporting recommendations for effective riparian management programs.

Table 1 Forest Plan Objectives for the Aquatic Conservation Strategy and Indicator Scale.

Aquatic Conservation Strategy Objectives	Spatial Scale of Indicator		
	Reach/ Site	Watershed	Landscape
1. Maintain and restore the distribution, diversity, and complexity of watershed and landscape-scale features to ensure protection of the aquatic systems to which species, populations and communities are uniquely adapted.		XXX	XXX
2. Maintain and restore spatial and temporal connectivity within and between watersheds. Lateral, longitudinal, and drainage network connections include floodplains, wetlands, upslope areas, headwater tributaries, and intact refugia. These network connections must provide chemically and physically unobstructed routes to areas critical for fulfilling life history requirements of aquatic and riparian-dependent species.		XXX	XXX
3. Maintain and restore the physical integrity of the aquatic system, including shorelines, banks, and bottom configurations.	XXX	XXX	
4. Maintain and restore water quality necessary to support healthy riparian, aquatic, and wetland ecosystems. Water quality must remain within the range that maintains the biological, physical, and chemical integrity of the system and benefits survival, growth, reproduction, and migration of individuals composing aquatic and riparian communities.	XXX	XXX	XXX
5. Maintain and restore the sediment regime under which aquatic ecosystems evolved. Elements of the sediment regime include the timing, volume, rate, and character of sediment input, storage, and transport.	XXX	XXX	
6. Maintain and restore in-stream flows sufficient to create and sustain riparian, aquatic, and wetland habitats and to retain patterns of sediment, nutrient, and wood routing. The timing, magnitude, duration, and spatial distribution of peak, high, and low flows must be protected.	XXX	XXX	
7. Maintain and restore the timing, variability, and duration of floodplain inundation and water table elevation in meadows and wetlands.	XXX		
8. Maintain and restore the species composition and structural diversity of plant communities in riparian areas and wetlands to provide adequate summer and winter thermal regulation, nutrient filtering, appropriate rates of surface erosion, bank erosion, and channel migration and to supply amounts and distributions of coarse woody debris sufficient to sustain physical complexity and stability.	XXX	XXX	
9. Maintain and restore habitat to support well-distributed populations of native plant, invertebrate, and vertebrate riparian-dependent species.	XXX	XXX	XXX

Forest Plan (USDA/FS and USDI/BLM 1994) objectives for Aquatic Conservation and the spatial scale of the indicator that must be observed to report on the pursuit of those objectives. This research plan focuses initially on site scale objectives for riparian features. It focuses on constructing fine-grained indicators at this spatial scale to capture ecologically significant detail. These features are necessary to address the riparian issues included inside the double lines of this table. The approach in this plan to pursue larger scale indicators is to aggregate site grain indicators into indicators of larger extent. Thus indicators of watershed or landscape extent may require a site grain although less detail than when describing site characteristics

2.2. Approach to the research

We consider monitoring design in the context of three interacting constraints (Figure 2): ecological functions, capabilities of technologies, and user needs. The design of an operational method must accommodate all three of these constraints. Notably, each of these constraints is (and always will be) imperfectly known and has multiple facets -- ecosystems have more than one function, users have multiple needs.

The approach to the research and the organization of the research plan is illustrated in Figure 3. The research is organized so that ecological characteristics of riparian systems are generally defined early on. These requirements constrain the choice of monitoring systems from among the set of systems that are available. The focus is on fine grained remote methods -- aerial photography and ADAR, a fine resolution aircraft mounted multiband sensor and an extensive set of field plots. Comparison between candidate selected monitoring systems provides for an initial formulation of a monitoring design. A series of evaluations of these initial formulations provides for an initial recommendation.

The three constraints -- ecological, technological and user -- are an interacting set. To enhance the ability to identify these interactions, the research is implemented with structured consultation with the broader scientific community and with the broader community of potential users. This allows for interacting needs to be more clearly identified. Consideration of the interactions between the constraints is important in developing a broadly acceptable method. The ecological features most clearly related to function may be the most difficult to monitor. The most tractable management features may have a less well defined ecological function. The most precise monitoring methodology may have analytical requirements which are not realistically achievable. The result of addressing these constraints in an iterative manner is intended to be a recommendation which accommodates and acknowledges these interacting constraints.

Figure 2 Constraints on Monitoring Design

We consider monitoring design in the context of three interacting constraints: ecological functions, capabilities of technologies, and user needs. The design of an operational method must accommodate all three of these constraints. Notably, each of these constraints is (and always will be) imperfectly known and has multiple facets – ecosystems have more than one function, users have multiple needs.

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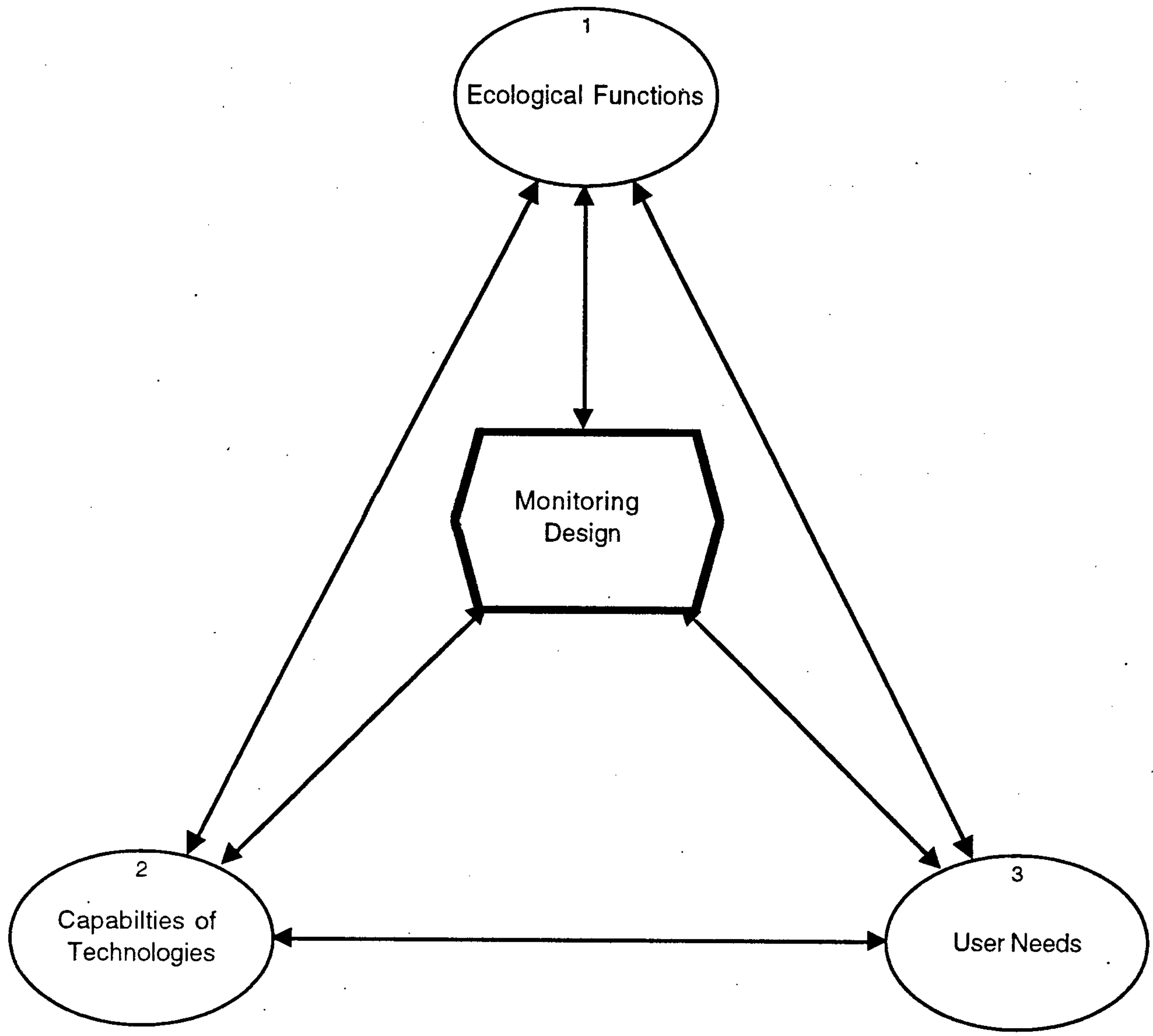
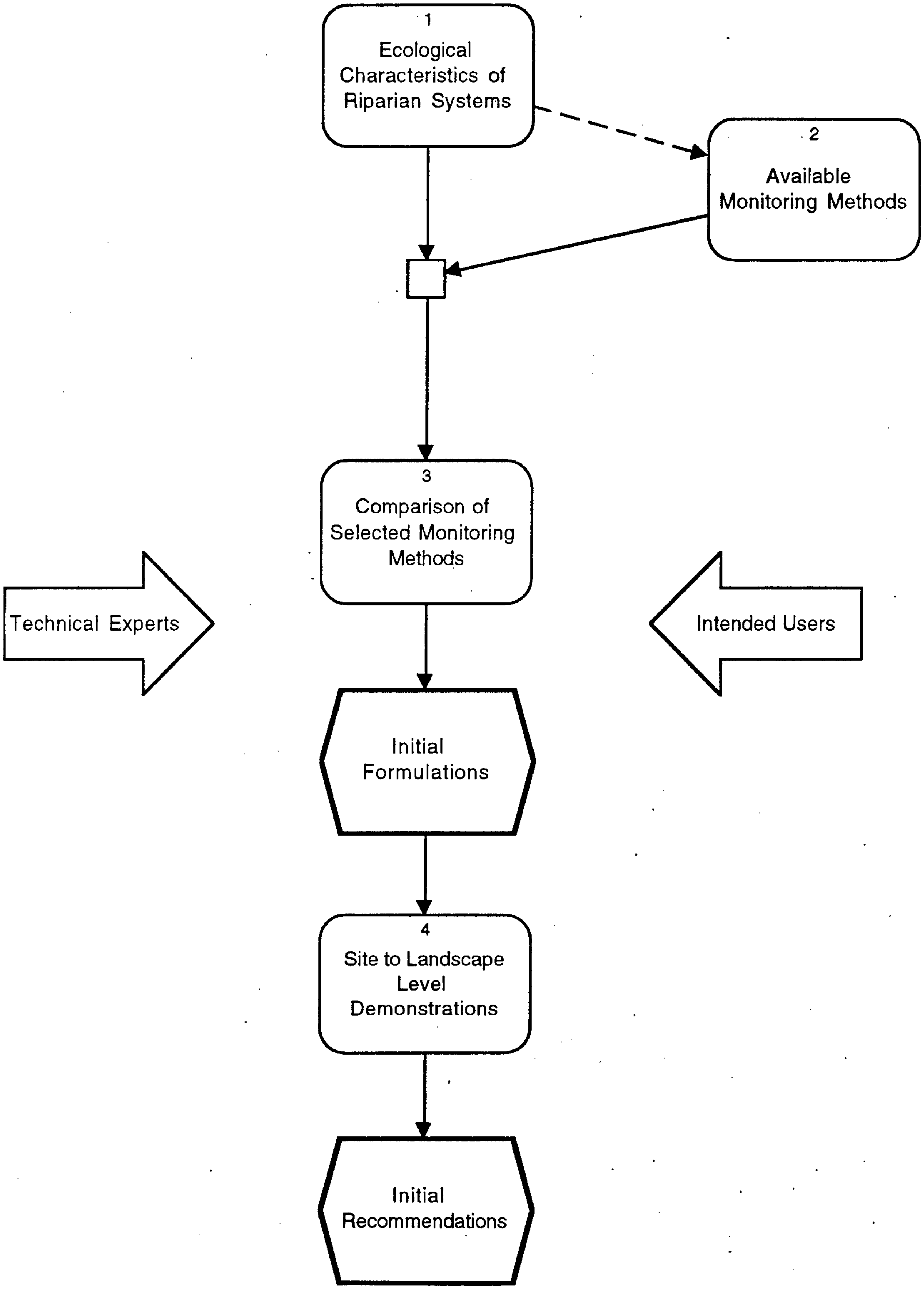
The result of addressing these constraints in an iterative manner is intended to be a recommendation which accommodates and acknowledges these interacting constraints.

Figure 3 Overall Design of the Research

The research is organized so that ecological characteristics of riparian systems are generally defined early on. These requirements constrain the choice of monitoring systems from among the set of systems that are available. Comparison between candidate selected monitoring systems provides for an initial formulation of a monitoring design. A series of evaluations of these initial formulations provides for an initial recommendation.


1
Ecological Functions
Monitoring
Design
2
Capabilties of
Technologies
3
User Needs


1
Ecological Characteristics of Riparian Systems
2
Available Monitoring Methods
3
Comparison of Selected Monitoring Methods
Technical Experts
Intended Users
Initial Formulations
4
Site to Landscape Level Demonstrations
Initial Recommendations

2.3. General Project Implementation

Riparian systems have a great deal of variability in their composition and function throughout the nation and within the Pacific Northwest. Not all this variability can be evaluated within the scope of this project. Therefore, this project develops riparian monitoring methods in an area with more limited variability. To complement the Forest Plan, the state's interest in the status of coastal fishes, and the programmatic interest of EPA's Western Ecology Division (Baker and others 1995), the areas selected for study are in the Oregon coastal province, and the Willamette basin. While the design of this research is specific to this area, the insights gained and procedures developed should be applicable elsewhere.

Finally, and most importantly, this project is being implemented with a high degree of user consultation (See Section 8.2). Such consultation is essential to achieve our goals. To facilitate this consultation a standing user committee will be established in consultation with the Research and Monitoring Committee responsible for implementing the Northwest Forest Plan, with the states Oregon and Washington, and with private parties in the region.

More detail on project administration is provided in Section 8.

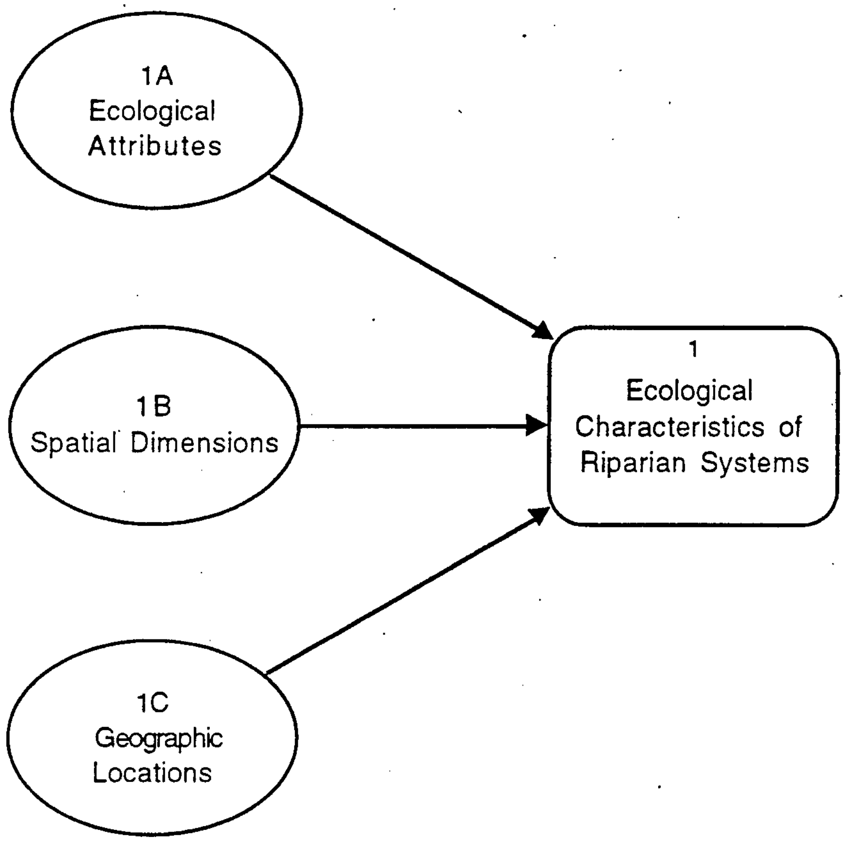


Figure 4 Definition of the Ecological Characteristics of Riparian Systems

Section 3 defines the ecological characteristics of riparian systems which need to be accommodated in a monitoring design. They are tied to the ecological functions constraint in Figure 2.

3. Task 1 Definition of the Ecological Characteristics of Riparian Systems

Definition of the ecological characteristics of riparian systems is necessary for two reasons. First, it provides the information that allows for a general specification of the requirements for a monitoring system, i.e. what are the attributes that need to be monitored and what are their spatial dimensions. Second, in concert with the examination of the specific capabilities of the monitoring systems, we provide a recommended set of indicators of the functional status of riparian systems. The first result is developed within this research plan; the second will be developed during the course of the research described within this plan.

An indicator is defined as "any environmental measure that can be used to quantitatively estimate the condition of an ecological resource."(Barber 1994). Key steps in the process of developing indicators from among the broader set of possible environmental measures are (Barber 1994):

- Identifying environmental values and assessment questions of concern
- Construction of conceptual models which describe the relationship between the structure and function of ecological resources
- Systematic evaluation of candidate indicators including:
    - evaluation of the feasibility of implementing the indicator in a routine monitoring and assessment program,
    - evaluation of the indicator's statistical behavior, and
    - evaluation of the indicator's utility in resource assessments

The first of these steps is developed in (Mulder and others 1995) and successor documents (Effectiveness Monitoring Team 1997) which identify the need for research to provide a riparian monitoring methodology and discuss how it will be used in resource assessments. This section (Section 3) of the research plan discusses the construction of conceptual models and outlines the evaluation questions driving the statistical analysis of candidate indicators. Later parts of the research (especially Section 5) evaluate the feasibility of implementing candidate indicators in the context of an overall design. Figure 5 is our representation of this process[1].

The discussion of each question describes the rationale for the specific question, the elements of the approach taken to addressing the question, the current status of the research, and any significant results to date. Research Question 1A and 1B are presented jointly; although they are distinct questions, they are developed and approached in a tightly integrated manner. Under research question 1C this section also discusses research to consider approaches to identifying the location of the population of interest.

[1] "Ecological functions" are defined in the conceptual models; "capabilities of technologies" is equivalent to the feasiblity and statistical behavior step; "user needs" is equivalent to the first and last bullets of the EMAP process.

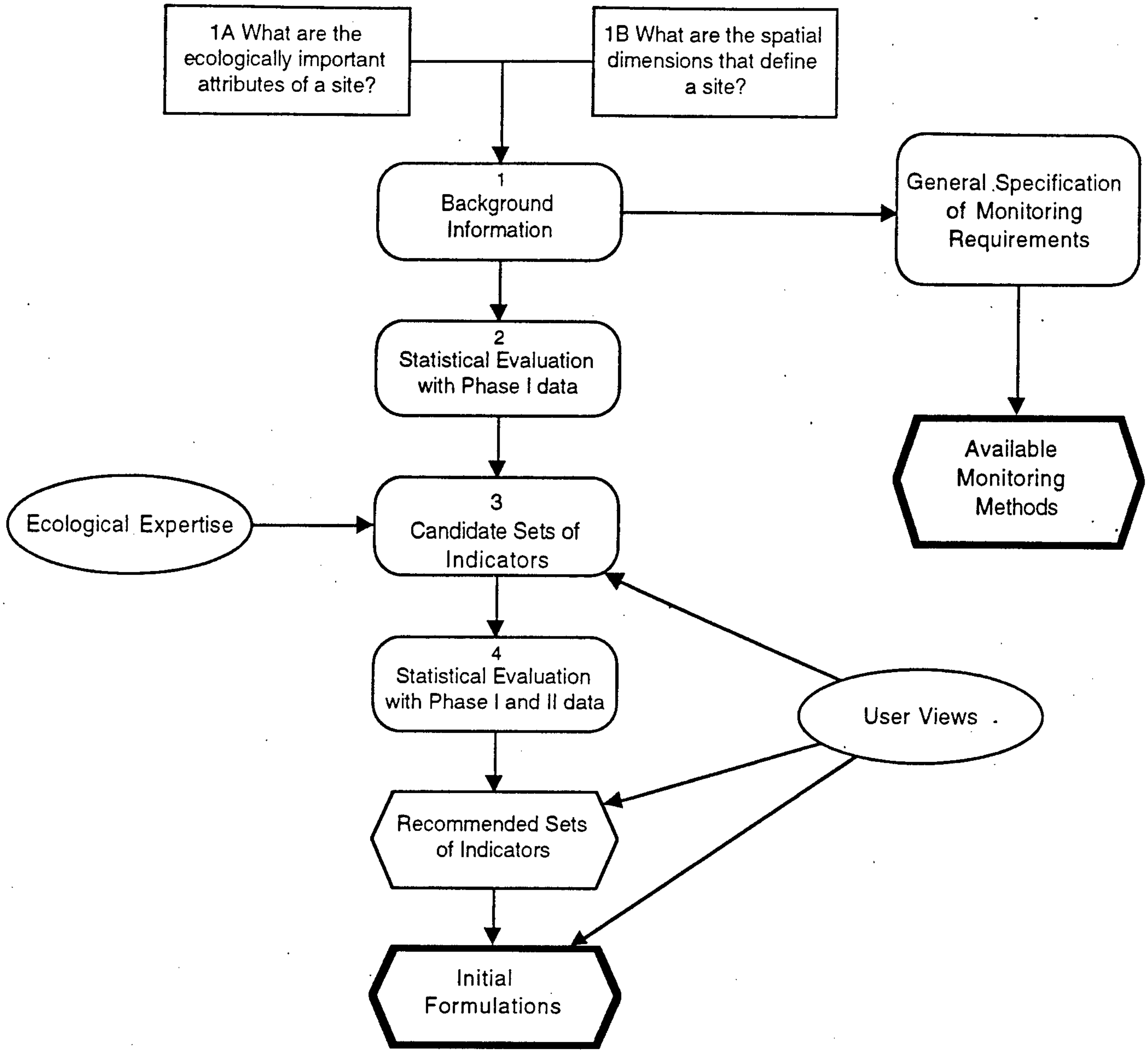


Figure 5 Development of Ecological Indicators

Research described in section 3.1 goes through a sequence of steps to define initial indicators of the ecological condition of riparian areas.

3.1. Research Questions 1A and 1B: What are the ecologically important attributes of a site (A)? What are the spatial dimensions of a site (B)?

This section outlines an ecological approach to addressing two of the key design issues for a monitoring program: What features should be monitored? What are the sample dimensions of a riparian site? The result of addressing these questions will be an ecological perspective on riparian indicators. Figure 5 illustrates the overall approach to implementing these two research questions:

1. Development of background information which includes:
    - Development of a preliminary conceptual model which relates riparian values to candidate indicators of those values.
    - Specification of the quantitative relationships between candidate indicators and ecological values.
    - Development of a preliminary land cover/vegetation classification scheme.
    - Development of a theory and approach to defining the spatial dimensions of a site.
2. Initial construction and statistical evaluation of candidate indicators from Phase I remote and field data.
3. Refinement of the candidate indicators in an expert workshop
4. Refined statistical evaluation of the indicators based on phase I and phase II remote and field data.

Timing of the steps is provided in Section 8.3

3.1.1. Background Information

The development of background information has been completed. Its components are summarized below. Its value is in providing a context for subsequent research and for the specification of the requirements of a monitoring methodology. This specification is provided in Sections 4.1 and 4.2.

3.1.1.1. Conceptual Model Development

The conceptual model identifies three values of riparian ecosystems -- terrestrial and aquatic habitat, and water quality. The attributes of riparian systems which support these values are identified, and the structures which support these attributes are then identified and formulated as the initial set of indicators. In this way riparian structures can be identified and characterized in a monitoring program and related to the values, or goods and services, that riparian systems provide. Initial conceptual model development was completed in 1996, and is provided as Appendix 9.4 and in Figure 6.

Figure 6 Conceptual Models of Riparian Systems

These conceptual models describe the way in which site level indicators are linked to functional attributes are linked to three different ecological values. These models are developed in section 9.4 and are used to identify the features to be measured in a monitoring program. Figure 6 has three parts, one for each ecological value affected by riparian systems -- aquatic habitat, water quality, and terrestrial habitat.

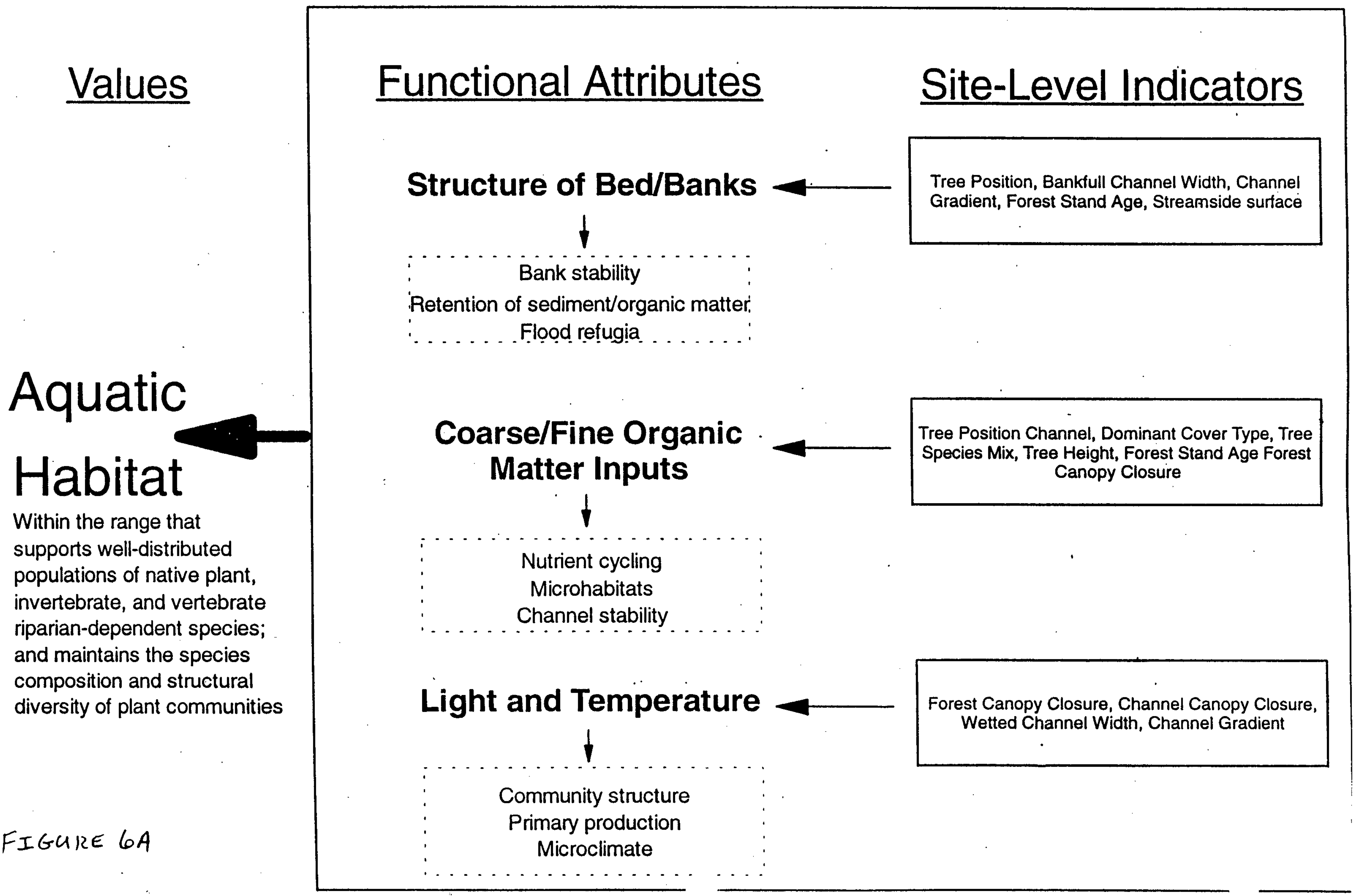
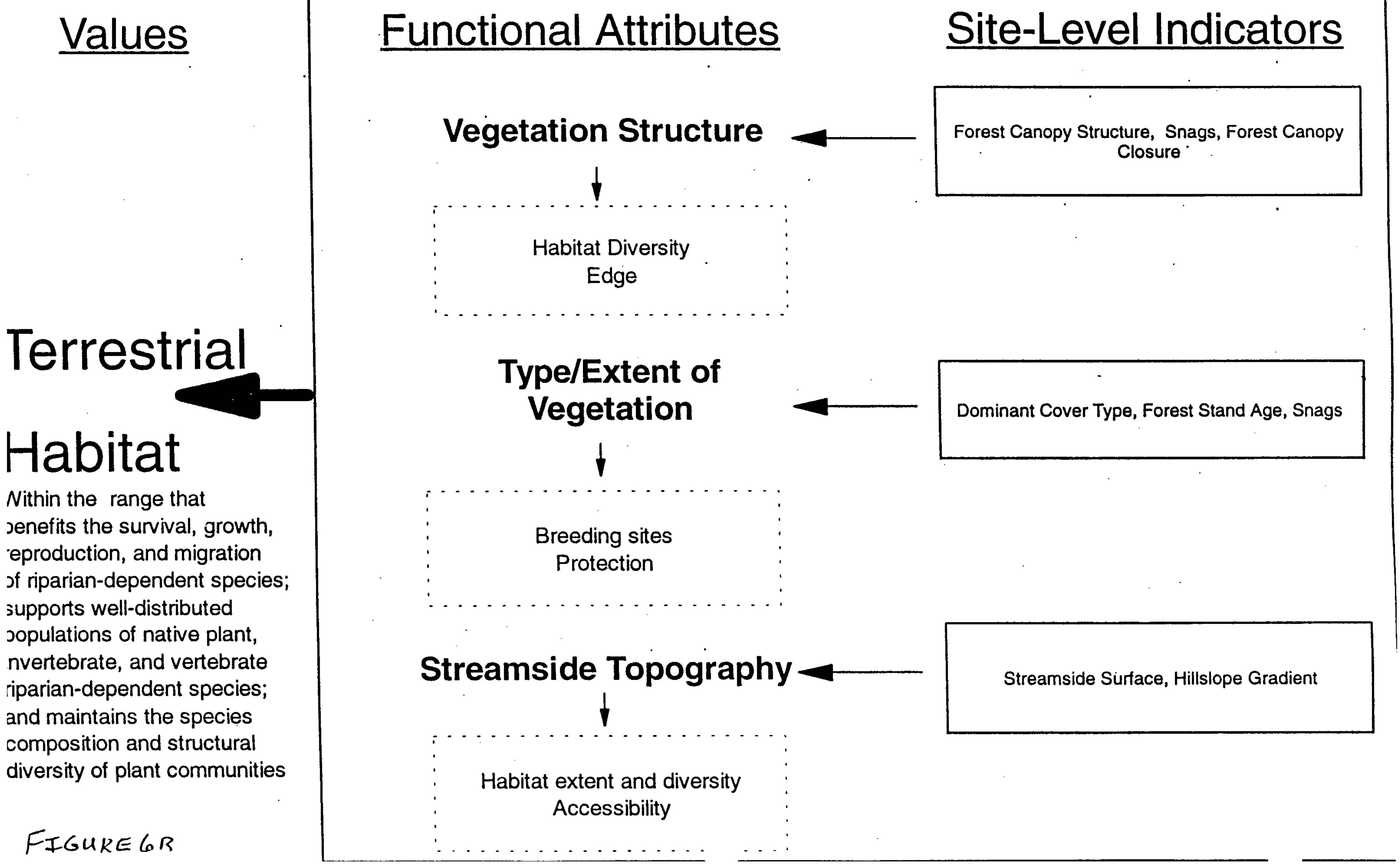

Values
Functional Attributes
Site-Level Indicators
Structure of Bed/Banks
Bank stability
Retention of sediment/organic matter
Flood refugia
Tree Position, Bankfull Channel Width, Channel Gradient, Forest Stand Age, Streamside surface
Aquatic Habitat
Within the range that supports well-distributed populations of native plant, invertebrate, and vertebrate riparian-dependent species; and maintains the species composition and structural diversity of plant communities
Coarse/Fine Organic Matter Inputs
Nutrient cycling
Microhabitats
Channel stability
Tree Position Channel, Dominant Cover Type, Tree Species Mix, Tree Height, Forest Stand Age Forest Canopy Closure
Light and Temperature
Community structure
Primary production
Microclimate
Forest Canopy Closure, Channel Canopy Closure, Wetted Channel Width, Channel Gradient

FIGURE 6A



Values
Functional Attributes
Site-Level Indicators
Vegetation Structure
Forest Canopy Structure, Snags, Forest Canopy Closure
Habitat Diversity
Edge
Terrestrial Habitat
Within the range that benefits the survival, growth, reproduction, and migration of riparian-dependent species; supports well-distributed populations of native plant, invertebrate, and vertebrate riparian-dependent species; and maintains the species composition and structural diversity of plant communities
Type/Extent of Vegetation
Dominant Cover Type, Forest Stand Age, Snags
Breeding sites
Protection
Streamside Topography
Streamside Surface, Hillslope Gradient
Habitat extent and diversity
Accessibility

FIGURE 6R

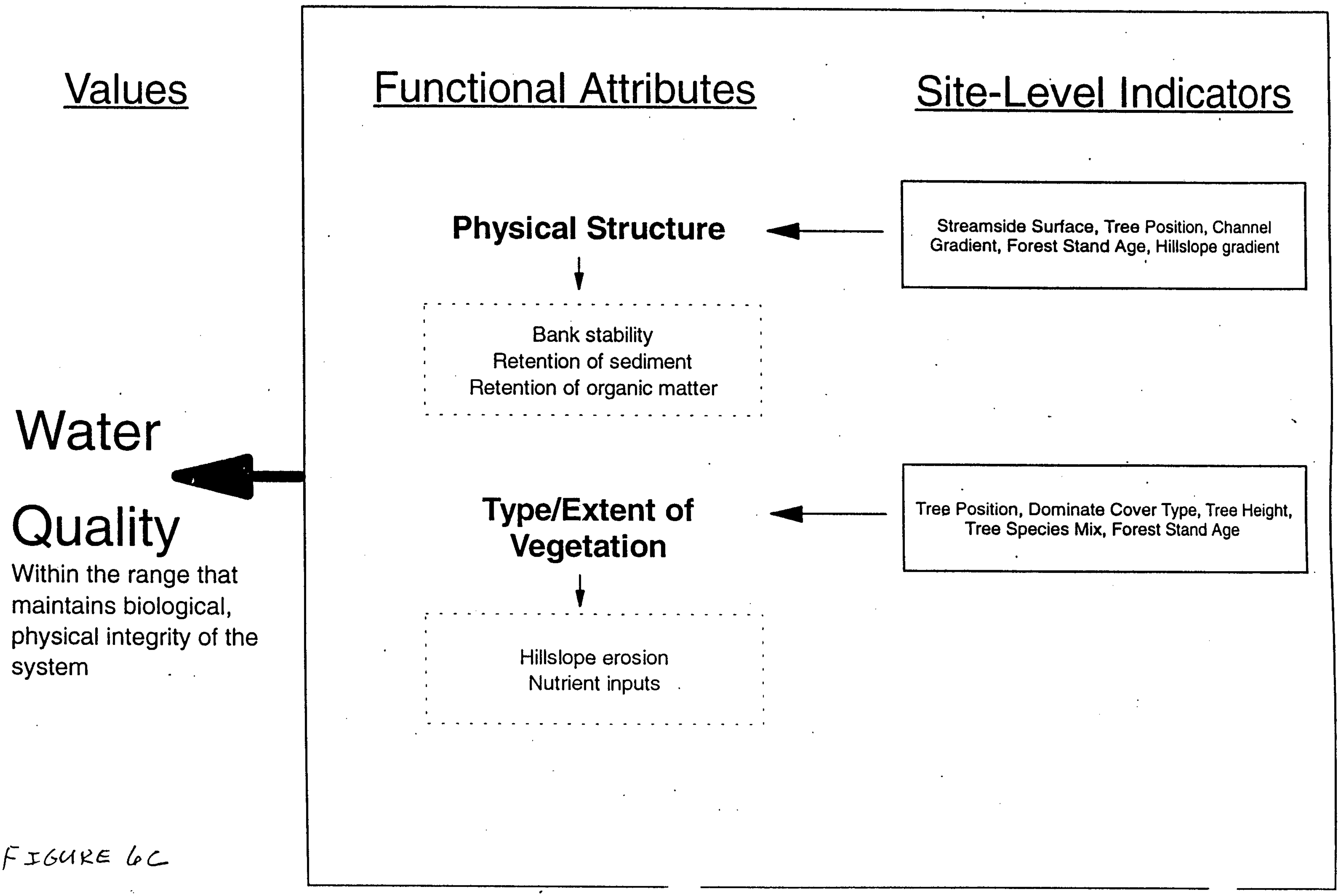

Values
Functional Attributes
Site-Level Indicators
Physical Structure
Streamside Surface, Tree Position, Channel Gradient, Forest Stand Age, Hillslope gradient
Bank stability
Retention of sediment
Retention of organic matter
Water
Quality
Within the range that maintains biological, physical integrity of the system
Type/Extent of Vegetation
Tree Position, Dominate Cover Type, Tree Height, Tree Species Mix, Forest Stand Age
Hillslope erosion
Nutrient inputs

FIGURE 6C

The conceptual model suggests a focus on positional indicators (channel size, tree and snag position) topographic indicators (channel and hillslope gradient), and thematic indicators (canopy closure, type and structure, and geomorphic structure of the plot). Some of these indicators describe the context of the site (e.g. stream size, gradient and geomorphic structure of the plot), while others describe the way in which the riparian system effects terrestrial and aquatic habitat, and water quality. The initial set of measures which are derived from this review are listed in Table 2. Subsequent steps will evaluate formulations of these measures in the form of candidate indicators of ecological function.

3.1.1.2. Land cover and vegetation classification

Land cover and vegetation classification is important because thematic indicators require that land cover types be described. Figure 7 presents the results of that analysis as developed in the initial research plan. The classification scheme proposed is a hierarchical one commonly used in the analysis of digital imagery (Maus 1995). This classification scheme is organized along the lines of forest structure. While it might be more desirable to develop a classification scheme based on function (e.g. Frissell and others 1986; Gebhardt and others 1989; Gregory and others 1991) the multiple functions, and our changing understanding of them is considered to be more effectively served by using a scheme which is more universally in use (Federal Geographic Data Committee 1996) and which is clearly achievable with existing technology. The structural features which organize this hierarchy are: % vegetation cover, tree or not tree dominant, canopy openness, deciduous/conifer mix, stand age, canopy complexity (Figure 7). In fact, while this classification scheme is organized along structural lines, it makes a great deal of sense for describing riparian vegetation cover given our conceptual model. This classification scheme, however is a vegetative one, and does not include consideration of geomorphic or stream features which also control the function of riparian systems.

3.1.1.3. Quantitative Literature Review

A second component of the literature review was conducted in 1997 to identify quantitative values for candidate indicators identified in the conceptual model, and to further define the relationships among the candidate indicators. A summary of the conclusions of the literature review is included as Appendix section 9.2.

One significant refinement to the conceptual model is to account for the network or landscape character of streams (e.g. Vannote and others 1980; Gregory and others 1991; Bradshaw and Fortin In Review). This is important because features that would function in a particular way in one location within the network, e.g. stream shading in low order streams, could have an entirely different function elsewhere in the network.

Figure 7 Initial Classification Scheme

A classification scheme is used for structuring information on thematic or categorical indicators listed in Table 2. See section 3.1.1.2.

Riparian Thematic Element	Definition
Forest Canopy Closure	
Closed	Greater than 85 percent canopy closure
Semi-Open	30 percent to 85 percent canopy closure
Open	Less than 30 percent
Tree Species Mix	
Conifer	Greater than 70 percent conifer canopy cover
Mixed	At least 31 percent of the canopy cover is comprised of deciduous species
Deciduous	Greater than 70 percent deciduous canopy cover
Conifer Stand Age	
Old	Greater than 180 years
Mature	60 to 180 years
Pole	30 to 60 years
Young	15 to 30 years
Regeneration	Up to 15 years
Deciduous Stand Age	
Mature	Greater than 30 years
Young	15 to 30 years
Regeneration	Up to 15 years
Forest Canopy Structure	
Multiple/Complex	Multiple canopy layers, numerous canopy gaps
Simple	Single canopy layer, few canopy gaps

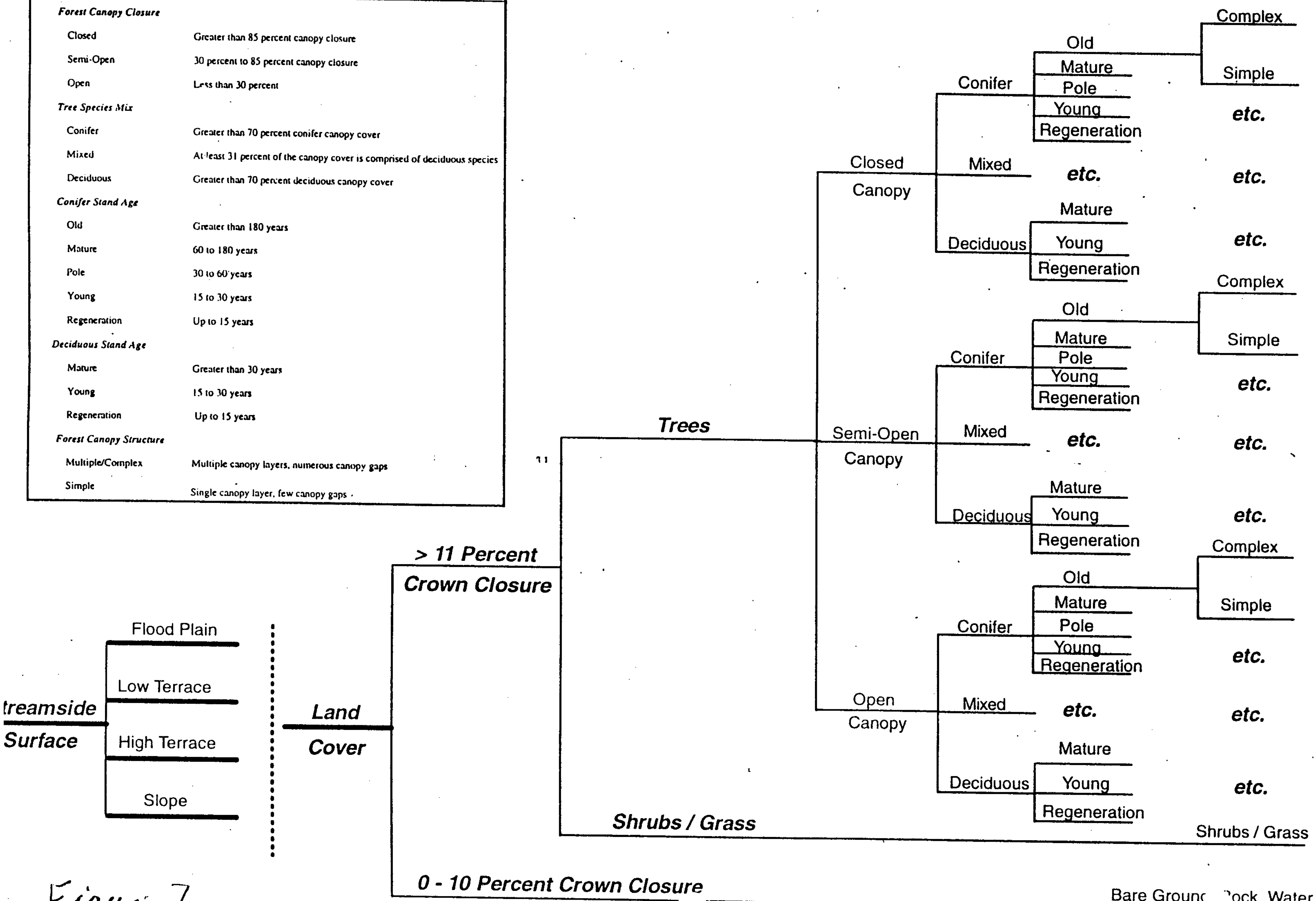


Figure 7

Table 2. Field measures to support indicator development.

Site-level Indicator	Metric for Measurement at Riparian Sites
<u>Positional</u> *In-Channel* Bankfull channel width	Average width of channel to edge defined by yearly average high flow point
Wetted channel width	Average wetted channel width during the measurement period
Streamside Tree position	Distance of all tree(s) from the edge of the bankfull channel, placed into 5m x 5m cells
Tree/stand height	Height of top of tree crown above the ground; average height of tree crowns above the ground.
Snags	Distance of all snags from the edge of the bankfull channel Total number of snags at site
<u>Topographic</u> ***In-Channel*** Channel gradient	Average gradient of the channel bottom
Streamside Hillslope gradient	Average gradient of hillslopes greater than 30%, measured in 10m intervals
<u>Thematic</u> ***In-Channel*** Channel canopy closure	Average canopy closure over the channel: 0- 100%
Streamside Streamside surface	Mapped flood plain, low terrace, high terrace and slope break onto plot map, using cell flagging as a guide to distance
Dominant cover type	Cover type covering the surface area: Non- vegetated (<11% canopy closure); Vegetated (>11% canopy closure): Shrubs/grass; or Trees
Forest canopy closure	Average canopy closure over area: 0-100%
Tree species mix	Dominate canopy cover by deciduous (broadleaf) species group or conifer species group over area: Conifer: >70% conifer; Deciduous >70% deciduous; mixed; 31%-70% deciduous cover (this was derived from the data, not from measurement)
Forest stand age	Average overstory conifer stand age from initiation date over area: calculated for plots where cores were taken
Canopy structure	Average forest canopy structure over area: Simple: Single canopy layer, few canopy gaps; complex: Multiple canopy layers, numerous canopy gaps (this was derived from the data, not from measurement)

List of all indicators presented in conceptual models for describing functional attributes of riparian areas in Oregon's Coast Range and the field metric that will be measured to quantify each indicator. These indicators are preliminary; the indicators and spatial relationships will be clarified through the course of the research. See more detail in the field protocols.

Our literature review specifically explored the issue of spatial dimension in riparian function. We consider riparian areas in two dimensions, width and length. Key components to the function of riparian systems have a width of tens of meters and a length whose conceptual foundation is not well developed and whose empirical foundation is weak.

3.1.1.4. Spatial Dimensions

A monitoring method must include a description of the spatial dimensions of the sampling and reporting units. This must include issues of grain, and extent; where grain is the size of an individual observation and extent is the area over which an observation is applicable. When a measurement is taken should it be taken from a 1 m plot, or a 10 m plot? Should information be integrated over the plot or should an index be developed which describes the spatial arrangement of individual features within the plot. The overriding factor in addressing this question should be to identify the spatial scale of influence of each of the functions.

There has been little or no work on how the spatial structure of forest stands and streams interact in a way that is useful for sampling design. This is in marked contrast to the development of such approaches for streams and forests. The structure and spatial hierarchy of stream systems is relatively well developed (e.g. Leopold and others 1964; Frissell and others 1986) and the implications of this structure have been considered for sampling design (e.g. Kaufmann 1987; Kaufman 1993; Reynolds and others 1993; Herlihy and others 1997). Similarly, there is a rich literature on forest stand structure and sampling design (e.g. Hazard and Law 1989). Within this region, there are excellent descriptions of riparian forest types (e.g. Kovalchik 1987; Diaz and Mellen 1996) and developing work by the Oregon Natural Heritage Program (Kagan 1995) but no parallel work on sampling dimensions. The approach taken in considering sampling design for forests and streams has been to identify the scale of various patterns in streams and forests in a way that is sensibly related to the ecological functions of streams or forests. The purpose of this task is to begin to develop the theory and practice of this issue for riparian areas; we will follow the example established in stream and forest sampling.

Our approach provides support for descriptions of the reach by subdividing a reach into "sites", characterizing those sites and then aggregating site descriptions (or simplifications of site descriptions) up to a description of a larger extent, e.g., a reach. Therefore, to quantify and reduce sample variability, criteria need to be developed that can be used to select sub-units of the reach that are meaningful with regards to ecological processes. Many times these sub-units will be relatively homogenous with respect to geomorphology (which is reflected in the development of stream classification and sampling approaches) and vegetation (which is reflected in the development of stand classification and sampling approaches). Identification of the scale of homogeneity in the intersection between geomorphology and vegetation will contribute to an ecological definition of the site. The ability to define a site is important not only in the need to monitor or characterize sites, but also to develop the ability to describe the units which could be aggregated to meaningful descriptions of larger areas such as reaches or watersheds.

3.1.2. Construction and evaluation of potential indicators from Phase I remote and field data.

A key step in indicator development is the statistical evaluation of candidate indicators. This supports not only the evaluation of indicators, but also analyses of spatial dimensions. The statistical analysis in this step is nested within the more mechanistic analysis that was undertaken as part of the conceptual model development noted above, the expert workshop on indicator select described below, and the evaluations that are described in Section 5.

3.1.2.1. Questions for indicator development

- What are the values for each measurement for each sampled site? How do these values vary over space within a site?
- How do variable values vary as a function of site characteristics (stream size, management class, soil type, plot slope gradient, land cover class, and so on)?
- What are the associations between variables? Can a subset of the of variables serve as an effective surrogate for a larger set of variables?

This analysis is proceeding using standard parametric and non-parametric statistical techniques. Results at this point are necessarily preliminary because the range of sites sampled in the first phase of this research in Drift Creek, Oregon (See Section 6.2 and Figure 16) is not representative of the full range of sites over which the methodology is intended to be applicable, and because data continue to be analyzed. Also, the data are available only from one mode of sampling, field observation, and not yet from remote observations.

3.1.2.2. Preliminary Results

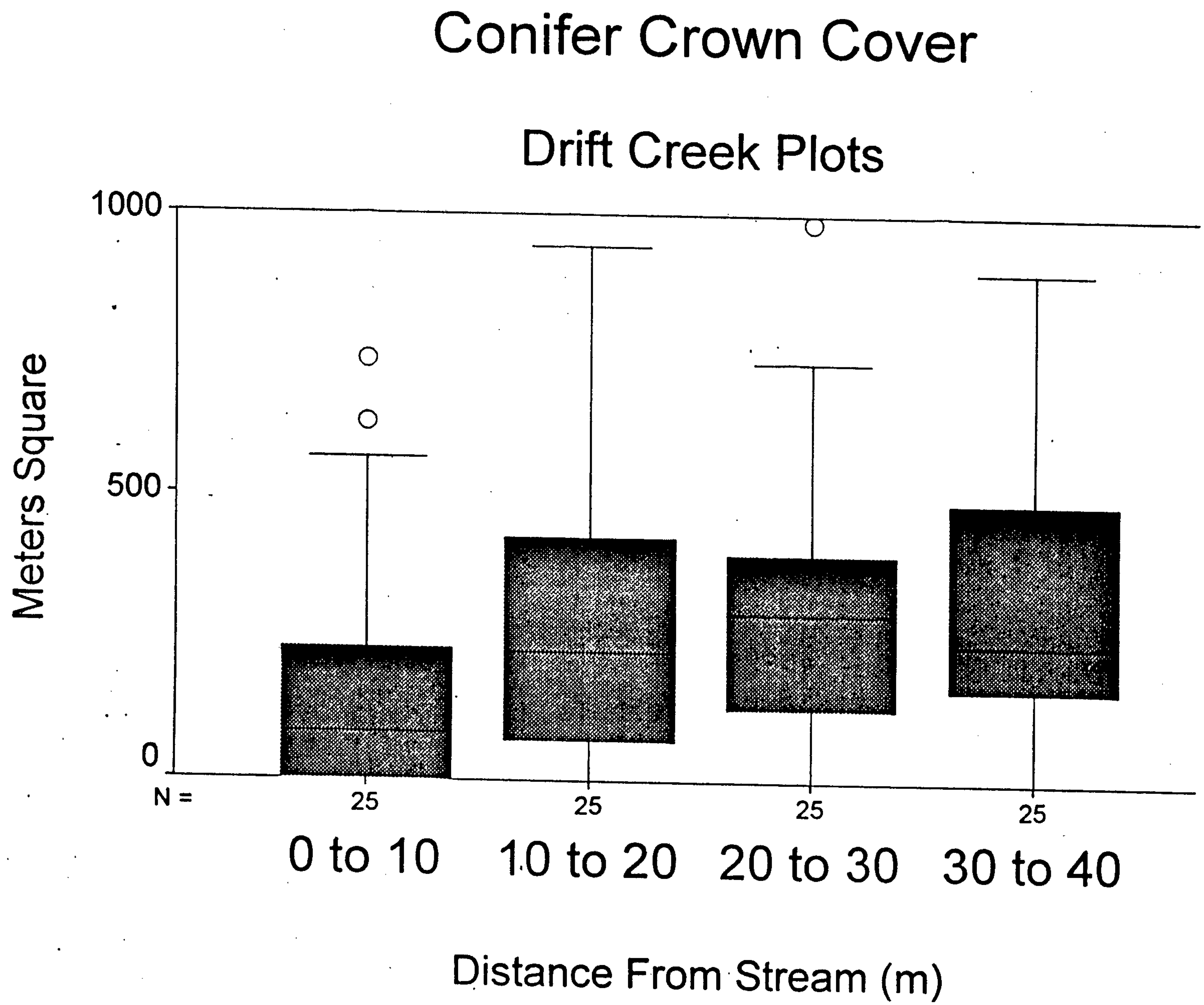
Analysis of the field data from Phase I provides two important results to date. First, important features, such as conifer crown cover, vary as a function of distance from the stream as shown in Figure 8, even when the data for all 25 plots are pooled. This is important, because it provides insight into the spatial structure of variability in riparian systems which may have a functional consequence. Monitoring methods

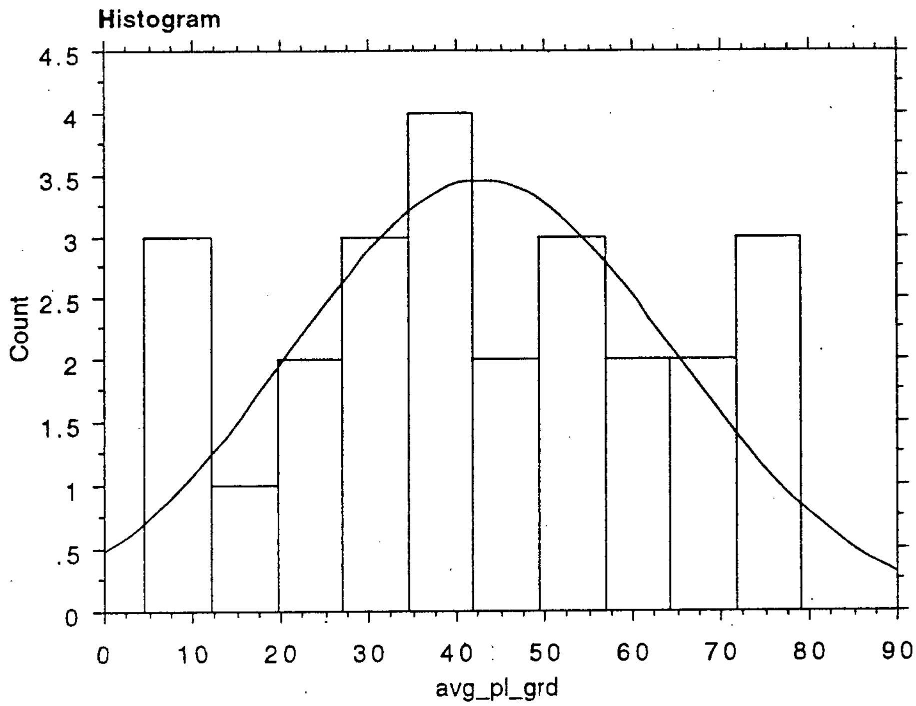
Figure 8 Conifer crown cover in Drift Creek as a function of distance from the stream

This figure shows the crown cover derived from field measurements for 25 plots in Drift Creek. Box plots are provided for the crown cover in each of 4 10 m zones. The zone or band closest to the stream has significantly less conifer crown cover than the other bands. This suggests a level of fine-grained variability that should be considered for capture in a monitoring program.

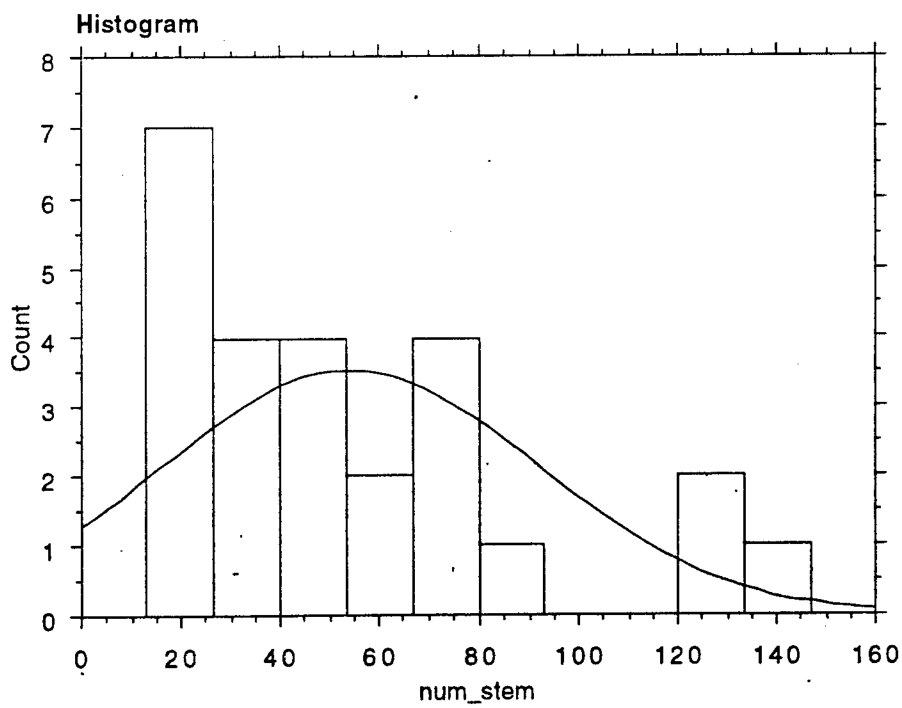
Figure 9 Distribution of observations in Drift Creek Field Data

The distribution of observations for average plot gradient and number of stems per plot. The observations are from the 25 Drift Creek sites visited in the summer of 1996. The observations are widely distributed; such a distribution is the goal in a methods development program. It means that methods are being developed and tested for a wide variety of conditions.


Conifer Crown Cover
Drift Creek Plots
Meters Square
1000
500
0
N =
25
25
25
25
0 to 10
10 to 20
20 to 30
30 to 40
Distance From Stream (m)



Histogram
Count
4.5
4
3.5
3
2.5
2
1.5
1
.5
0
0
10
20
30
40
50
60
70
80
90
avg_pl_grd



Histogram
Count
8
7
6
5
4
3
2
1
0
0
20
40
60
80
100
120
140
160
num_stem

should be able to describe patterns which have a functional significance. Second, Figure 9 illustrates that the values for the variables at the plots are well distributed, an important consideration in the collection of data for methods development. In methods development, one wants to ensure that one has a method that has been tested against a broad range of conditions. Figure 9 shows several measures for which the range of observations is an order of magnitude or more.

3.1.3. Expert Workshop

We will organize a workshop of riparian experts for the purpose of extending the development of the conceptual models and applying it to indicator development. Indicator development requires that indicators be developed which are well embedded in conceptual mechanistic models. A literature review has provided a conceptual model, but scientists currently working in the field are likely to be able to extend these conceptual models on the basis of their experiences, interactions with one another and with the rich data set developed in this project or from their own research. The workshop will draw on experts within the region in considering the formulation of sets of candidate indicators, and the spatial dimensions of riparian systems. This workshop will be structured by using the existing and developing work as a starting point and asking experts to identify reasonable sets of indicators based on their experience. Their views will serve to refine the research on indicators within this project. As appropriate, experts from this workshop will be consulted during the refinement of the indicators. This workshop will be developed in collaboration with parallel research on Agricultural Riparian areas supported by this program -- the PNW Ecosystem Management Research Program (Baker and others 1995). The workshop will be held in January, 1998.

3.1.4. Refined evaluation of indicators

After the expert workshop, we will reiterate and expand upon the analytical phases of earlier steps to continue to refine the development of indicators. This expansion will include data from a broader set of sites and additional focused consultations with potential users as a prelude to coming to conclusions about recommendations on which indicators are appropriate for use. In addition, this step will also accommodate results from our analyses at larger scales as it develops under research questions listed in Section 7. Experts from the workshop will be consulted as appropriate.

3.1.5. Recommendation on indicators for operational use

Recommendations on indicators to be used will be made in conjunction with recommendations on methods to be used in describing those indicators. These recommendations will reflect the balance of constraints illustrated in Figure 2.

3.2. Research Question 1C: How can riparian sites be identified across a region?

The goal of this research is to recommend a methodology that could be used for reporting on site-scale characteristics of stream-side riparian areas over larger areas, e.g. a watershed, a province, or a region. Sites selected on the basis of tradition, or expert knowledge may result in serious errors in evaluating the status of a population of sites within a larger area (Paulsen and others In Review). The purpose of this task is to summarize methods of site selection that allow for statistically valid extrapolation from a set of sites to a larger extent. This requires definition of the population to be sampled and geographic information on the locations where that population occurs.

This question will be pursued by two approaches. First, summarizing existing approaches for identifying sample sites within a region and empirically evaluating them in the context of existing data. The second approach will consider efficient approaches to the development of databases which contain a finer level of detail. More detail in databases is important because small and intermittent streams play an important role in landscape function. As a result, the Forest Plan establishment of a riparian reserve system includes reserves around these features. Despite their significance, their distribution is not well described by existing data.

3.2.1. Existing Data

The first approach to conducting this task will be to review the existing literature and summarize it in a manner to address this objective. Issues such as probability based approaches (e.g. Stehman and Overton 1994; Stevens 1994; Landers and others 1995) and model based approaches to site selection will be considered. These approaches to site selection are constructed around the notion that there is consistently available data on the distribution of a feature of the population of interest, and that feature can be sampled in a statistically meaningful manner. For example, for riparian areas around streams, probability sampling can be constructed around widely available information on stream location (or hydrolayers) such as Reach Files 3 or USGS hydrolayers. The existing literature on designing surveys to achieve specified levels of precision and accuracy in an estimate of a population of interest will be summarized (e.g. Larsen and others 1995). Wherever possible data from this and similar projects will be used to illustrate and quantify the approaches outlined in the existing literature. This effort will result in a summary of usable approaches for selecting sites to conduct a survey of riparian sites and report on the status of those sites with known probability over a larger area, e.g. a watershed, a waterbasin, a region or a province based on existing widely available datasets. The limitations of the existing datasets will be highlighting by comparing multiple datasets at least from the Drift Creek Basin.

3.2.2. Development and Evaluation of New Databases

The research approach to addressing this question recognizes the limitations of the existing information. Given that the headwaters and sources of streams have important functions which are influenced by riparian areas and protected in the Forest Plan, it is reasonable to ask what is our ability to detect smaller or intermittent streams in an efficient and reliable manner. Digital photogrammetry (Greve 1997) is a newly available technique which uses scanned (i.e. digitized) air photos in a digital setting -- a digital photogrammetric workstation or DPW. One of the most powerful features of this technology is its ability to describe topography with very fine resolution (e.g. 0.05 m accuracy is expected to be achievable with 1:4,000 air photos.). A DPW will be used to define fine resolution digital elevation models (DEMs), calibrated to very fine resolution information (Oregon Department of Forestry 1994) for half of the eight subbasins for which we have complete coverage within the Drift Creek basin using 1:24,000 imagery and evaluated on the other half of the basin. This will result in an analysis of the extent to which fine resolution digital elevation models developed from commonly available airphotos (e.g. 1:40,000 or 1:12,000) can accurately identify the location of fine hydrologic features, e.g. intermittent streams and potentially unstable areas.

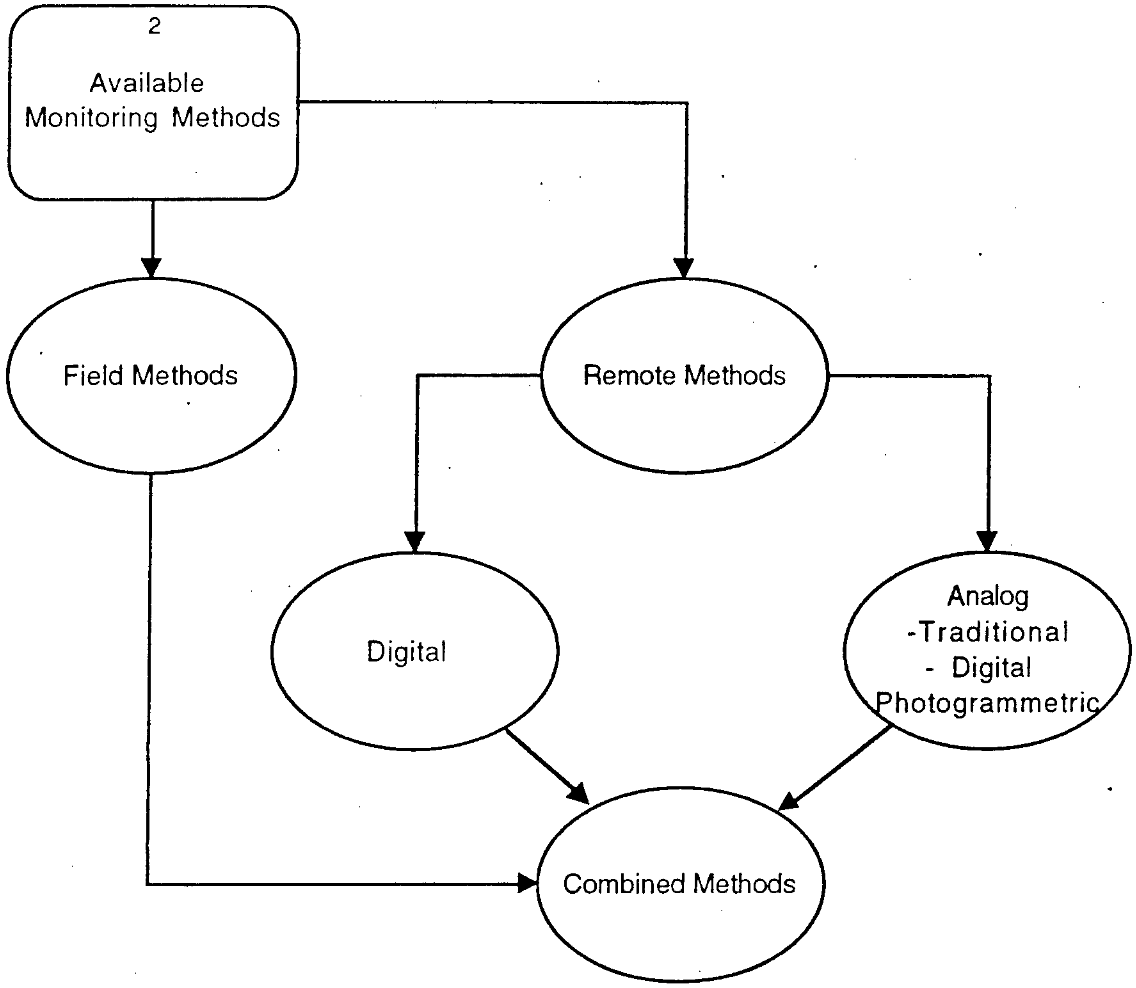


Figure 10 Available Methods

Section 4 Defines the sets of methods available to monitor riparian systems on a regional basis.

4. Task 2 Identification of approaches available to monitor a riparian site over a large extent?

This section casts the information for riparian characteristics Sections 2 and 3 into specific requirements and identifies sampling technologies that respond to these specifications. It outlines the requirements for field and remote data collection in the context of the three recurring issues -- ecological attributes, spatial dimensions, and geographic location. The first two issues, ecological attributes and spatial dimensions -- how large an area should be sampled and with what resolution -- are considered first for field collection and then for remote imagery. The section concludes by describing the approaches that will be used to data collection.

This research effort is focused on the application of remote sensing for describing riparian areas throughout a large extent; it also includes an extensive field component which secondarily includes the consideration of alternative methods of collecting data by direct field observation. The utility and merits of various field methods will be compared and contrasted to that for various methods of remote imagery in reports from this project. The design of the project allows for the possibility that the most effective approach for operational regional monitoring may be to use only field data or to combine both field and remote imagery.

4.1. Field Requirements

Field data serves two purposes in this project. The first and primary purpose is to provide a benchmark against which to compare remote imagery. The secondary purpose is to collect information on the fine-grained small-extent ecological and spatial character of resources within riparian systems to assist in responding to research question 1A and 1B.

Field data come from two sources, first, by design within this project, and secondly from "found" data in other projects. This section discusses the design of our collection of field data, the management section (8) discusses the potential for the development and use of found data.

4.1.1. Criteria for the design of a field sampling program.

4.1.1.1. Ecological Attributes -- What to measure?

Measurements from the field data need to be designed to be consistent with the initial formulation of indicators as presented in Table 2. They also need to recognize that this is an initial formulation and subject to change as the research progresses. The field data also need to describe features that can be compared to an aerial view so that comparisons between field and remote data can be made. For example, field crews describe tree size by measuring trunk dimensions (diameter at breast height, or basal area) while remote imagery is more likely to describe tree size by describing canopy diameter. The conclusion to be drawn from this consideration is that field data collection should include a detailed and precise description of an area that supports comparisons with high resolution imagery, and that can be reformulated to provide a range of different interpretations as candidate indicators are evaluated against the three constraints shown in Figure 2.

4.1.1.2. Sample Dimensions -- How large an area should be described?

4.1.1.2.1. Field Plots

The size of the area described should be large enough to capture the variability in riparian areas relevant to the way these areas function. Our literature review suggests that this would result in a description of an area 40 m from a stream as a minimum. The literature review would suggest that the plot should be as long as the patch of homogenous forest or as long as a stream reach. Either length definition would impose an undefined large burden on the field crews when patches are large or stream reaches are long. From an analytical perspective, the ground truth sites should contain at least 25 pixels (assuming a square configuration) to ground truth digital imagery (Mouat 1997). If we assume that one dimension of the sample unit (the dimension away from the stream) is 40m, then Table 3 shows the width that would be required to secure 50 pixels[2] as a function of pixel size of the remote sensor. Dimensions larger than those shown are better.

Table 3. Sample Dimensions as a function of Pixel Size.

This table describes the sample dimensions of a rectangular plot or a steam required to provide a 50 pixels, a rule-of-thumb number of pixels to serve as a basis for ground truthing digital imagery of different pixel sizes when the ground plot is not a square. Key assumptions are that the plot is a rectangle whose other dimension is 40m, or that the length of channel sampled is 40 channel widths.

Pixel Size	Dimension of Plot Along the Stream to Achieve 50 Pixels <u>or</u> Minimum Channel Width to Achieve 50 Pixels
Area (m^2)	(m)
1	1.25
9	11.25
64	80

4.1.1.2.2. Stream sampling

The length of stream sampled should be 40 channel widths (Kaufmann 1987; Kaufman 1993; Reynolds, and others 1993; Herlihy and others 1997) to provide a

[2]50 pixels is used as the standard in this table rather than 25 because some of the configurations depart drastically from a square configuration.

reasonable ecological characterization. From a remote sensing perspective, we benefit by sampling a length of stream which is not obscured by forest cover. If we apply the 50 pixel rule of thumb, Table 3 shows the minimum channel width that would provide 50 pixels as a function of different pixel sizes.

4.2. Remote Requirements

Remote imagery can provide a way to characterize features which are not easily observable. There are two barriers to ease of observation, first, a feature (such as canopy texture or topography) may be inherently difficult to observe, or second, the feature may be of such extent that the aggregation of individual easy observations is costly. Remote imagery provides a possible way to overcome these barriers. Remote imagery also provides a valuable and flexible archive of raw data for future generations of managers and scientists. This raw archive is supportive of the requirement for temporal and regional consistency in descriptions. Such descriptions are of great importance in monitoring for ecosystem management. (Ringold and others In Review).

Remote imagery is available in a wide range of resolutions, covering a range of spectra from a variety of sensors and platforms. An extensive literature discusses these methods (Murtha 1972; Sayn-Wittgenstein 1978; Jensen 1986; NOAA and NASA 1987; Beier and others 1992; Richards 1993; Hoffer 1994; Kramer 1994; Lillesand and Kieffer 1994; Maus 1995; Maleki 1997)

For our purposes, there are three key criteria for determining which technology to choose: First, we need a method whose spatial and spectral resolution can detect ecological characteristics of riparian areas; second, we need to consider the operational requirements associated with feasible instruments. Operational status is important because our goal is to provide a method that can be used by organizations with minimal ability to develop a major new infrastructure.

Table 4 lists a range of aircraft, space shuttle and satellite mounted sensors. The resolution, type of instrument and operating status of each method is listed. Considering each entry of Table 4 in light of the requirements for monitoring provides the foundation for selecting remote imaging methods of interest. The requirements are discussed in terms of ecological characteristics, and sample dimension. In sample dimension the focus is on spatial resolution rather than on how large an area should be considered (as it is in field sampling), because resolution is a more limiting factor in the use of remote imagery and is linked to the extent of coverage[3].

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[3] For standard large format aerial photography the coverage of is about 36,000 times the resolution of an image scanned at 12.5 microns. 1:4,000 imagery covers an area 914 m on a side (>500 times the area of a 40m field plot); scanned at 12.5 micron resolution, its pixel size is 0.025 m on a side.

Table 4. Finer resolution remote imaging instruments, resolution, type, and dates operational.

Sensor System	Spatial Resolution*		Instrument Class	Dates	Owner	Platform
	P/R	MS				
Air Photos 1:10,000	0.1		1A	<1950 -	----	Air
ALT	0.1		3A	1975 -	US	Sat
JPROP1-ADALT	0.1		3A	>1998	Japan	Sat
Air Photos 1:100,000	1		1A	<1950 -	----	Air
ADAR		>.7	1B	1991-	Comm	Air
M7 Mapper		1	1C	1998	Comm	Air
Space Imaging	1	4	1B	1998	Comm	Sat
GDE	1		1B	1998	Comm	Sat
Earthwatch	1	4	1B	1997	Comm	Sat
IFSAR	1.3		3B		Comm	Sat
OrbView	1	8	1B	1998	Comm	Sat
RESURS-F	2		1B	1989	Russia	Sat
CTA Clark	3	15	1B	1997	Comm	Sat
MIVIS/Daedalus		2.5	1B	1993-	Comm	Air
CASI		5	1C	1990-	Comm	Air
Almaz2	5		1B	1997	Russia	Sat
TRW Lewis	5	30	1C	1997	Comm	Air
SPOT 5A	5	10	1B	1999	France	Sat
SPOT 5B	5		1B	2004	France	Sat
Radarsat	9		3B	1996	Canada	Sat
SPOT 4	10	20	1B	1986	France	Sat
Resource 21		10	1B	1998	Comm	Sat
KOMPSAT	10	10	1B	1998	Korea	Sat
IRS-1D	10	20	1B	1999	India	Sat
JPL AirSAR	10		3B	1990-	US	Air
Landsat 7	15	30	1B	1998	US	Sat
EOS AM-1	15	15	1B	1998	US/Japan	Sat
AVNIR	8	16	1B	1996	US	Air
SIR-C	17		3B	1994 **	US/Italy	Shuttle
AVIRIS	20		1C	1989-	US	Air
CBERS	20	20	1B	1997	China-Brazil	Sat
SIR -B	25		3B	1984 **	US	Shuttle
ATSR-M		21	2	1991-	US	Sat
TM		30	1B	1982-	US	Sat
ATM		30	1B	1976-	US	Air

Notes:

Full names are provided for sensor systems in the glossary;

* Spatial resolutions are divided into two groups: P/R = Panchromatic or Radar and MS = Multispectral

** SIR-B and C were active only for the week or two period of these two shuttle missions

Instrument Class Codes:

1 Optical Sensors
- 1A Analog
- 1B Digital
- 1C Hyperspectral

2 Passive Microwave Sensors

3 Active Microwave
- 3A Altimeters
- 3B Synthetic Aperature Radar

Owners are listed either as nations or as Comm for commercial ownership. Platforms are aircraft (Air), shuttle (Shuttle) or satellite (Sat)

The internet provides an effective means to access the rapid evolution of sensors. For example: a complete list of imaging spectrometers is located on the internet at: http://www.itc.nl:80/~bakker/is_list.html; information about planned high resolution remote sensing satellites is available at: http://glenn.uwaterloo.ca/~mwulder/hirespres.html

4.2.1. Ecological Attributes-- What to Measure

The sensor of interest must be able to describe the candidate indicators. This capability arises from the spatial resolution of the sensor and the region of the electromagnetic spectrum within which it operates. Certain regions of the spectrum are better for obtaining information on biophysical characteristics than others -- See Figure 1.8 in (Lillesand and Kieffer 1994) or Figure 2.5 in (Maus 1995). For example, the near infrared region is best for discriminating between conifer and deciduous trees.

Candidate indicators can be described with technologies operating in the visible spectrum. This includes instruments in class code 1 (optical sensors), although HRVIR and AVNIR operate only in a single narrow near- infrared band and are unlikely to provide insight on many of the indicators of interest. Class code 3 (active imagers) includes altimeters (3A), and synthetic aperture radar (3B). Each of these technologies has the potential to provide insight about the status of riparian forests, particularly with regard to fine resolution topographic features, vegetation structure or moisture (e.g. Waring and others 1995; Means 1996). To the extent that they penetrate both cloud and forest cover, they have special interest in regard to this set of features. Class code 2 (passive microwaves) has only one instrument with the requisite resolution, the ATSR-M. It is designed for marine observations, rather than for analyses of vegetation or of the terrestrial environment. Merging information from different technologies also has promise (e.g. NASA 1997).

4.2.2. Sample Dimensions -- Spatial Resolution

At the outset, we do not know the required resolution of the sensor to best characterize riparian structure. The appropriate course of action is to be biased in favor of technologies which can observe finer detail rather than coarser detail. This strategy is appropriate because the usefulness of coarser resolution technology can be inferred from finer resolution technology, but not the reverse. The literature review and field data (See Figure 8) suggest that the appropriate technology must have a spatial resolution that can lead to the characterization of ecological features of about ten meters, and so the technology should have a resolution of less than 10 m, preferably closer to 3 m. Note in Table 3 that 3 m pixels (9 m^2) could be ground truthed with a plot of 40 m x 11 m and a stream channel of 11 m or more.

Table 4 lists pixel sizes i.e. resolution, associated with the imaging approach. Standard practice in the interpretation of digital remote imagery is to describe or classify objects on the basis of the characteristics of a single pixel, although some techniques (e.g. texture analysis) use a neighborhood filter or window which is at least 3 pixels square (3 pixels by 3 pixels) (Frank 1988; Cohen and Spies 1992). Thus a method could reasonably be expected to describe features which are three times the size of its resolution. Thus, Table 4 is limited to sensors with resolution of less than 30; finer resolution sensors are more capable of describing finer grained features.

4.2.3. Status of the Technology

Since our goal is to provide an operational[4] methodology, operational methods should be favored for consideration over emerging technologies; and technologies which are in more routine use should be favored over operational technologies which are operating more as research tools. A number of attributes combine to make an approach more operational these are discussed in general in (Barber 1994) and are reflected in this research plan under the evaluation criteria (Section 5).

4.2.3.1. Aerial Photography

Aerial photography has been in widespread use for precision purposes for 4 decades or more (e.g. Dilworth 1956). Aerial photography is often considered to provide the "ground-truth" against which coarser resolution imagery should be evaluated (e.g. Maus 1995). Aerial photography also provides a historical record, since archives exist which provide coverage through the 1950's and in some cases through the 1940's. Archives provide a foundation for evaluating questions for systems with long or unknown time lags. A large number of vendors provide access to aerial imagery, and data collection can be commissioned with ease for any specific time and place.

There are two difficulties with analog imagery. The first difficulty is that the cost of analyzing each parcel is roughly identical. Thus, while it may be relatively easy to

[4]"Operational" in the context of this project means operational for routine use organizations particularly including Federal land management or regulatory agencies, by similar state agencies, by groups of such agencies or by other organizations with a mandate to protect natural resources.

interpret a small area with great precision, interpreting a large area would be very difficult. A second difficulty with aerial imagery is that because it is an analog image, it does not tie well to GIS systems which are extremely valuable for managing and analyzing spatially explicit information. The advent of digital photogrammetry in the 1990's (Heipke 1995; Greve 1997) has begun to eliminate this barrier and represents a promising new method for using analog imagery and is one that will be explored in this project.

4.2.3.2. Digital Imagery

Digital imagery is provided by many sensor types and conveys a wider variety of information than traditional analog image analysis and allows for more tractable treatment of the data. Most of the sensors on Table 4 provide digital information. Digital imagery for civilian terrestrial application has been available since the mid 1970's with the launch of the Landsat series of satellites. (See TM sensors in Table 4). Digital imagery requires the use of training or calibration sites (which may be true ground observations or air photos) so that digital descriptions of a parcel of land can be compared to "ground-truth". This supports the creation of a predictive model which predicts ground characteristics given digital descriptions. Thus, while efforts must be made to develop a method, once it is developed, it can be applied over large areas with relative ease. Digital sensors in class 1 are considered to be more operational than digital sensors in class 3 for our applications.

4.4 Field Data Collection Methods

Riparian characteristics can be described from direct ground observation. This project provides for the comparison of three methods[5]:

[5]It must be noted that these methods can be used in different formulations than used in this project and so the discussion here refers to our implementation of these methods rather than to the application of these methods by others.

Table 5 Field Methods used in this research

Method	Description	Time Required	Area Covered	Detailed Description
Plot	Detailed Description of Vegetation and Topography; location of all trees ± 2m	8+ person-hours	40m x 40 m; 1600 m^2	(Barker and Bollman 1996)
Point Center Quarter on Transects (PCQ)	General Description of Vegetation and Topography	<1 person-hour	20 meter radius circle; 1260 m^2	(Mueller-Dombois and Ellenberg 1974)
EMAP/REMAP characterization	General Description of Vegetation Structure	<0.25 person-hour	20m x 10m; 200 m^2	(Hayslip and others 1994)

The plot method provides the high resolution characterization that provides the best foundation for ground truth. The PCQ method is a much more rapid method although in our application providing a less finely resolved characterization. The EMAP/REMAP characterization is a quick description whose value for ground truthing may be minimal. Its value for this project will be greater in comparing a coarser to a finer level of description, and for determining the representativeness of the vegetation of our plots. The value for EMAP will be to provide some insight into the nature of variability associated with their quicker characterization.

The project will compare and contrast the quality of the information developed by these three methods.

4.3 Image Selection Strategy

Our image selection strategy has chosen to focus on multiple approaches using technologies with different characteristics. operational maturities all of which are capable of the required resolution and detection of ecological characteristics. We have chosen to focus on:

1. Aerial photography is the standard for accuracy and precision in measurement and classification. Traditional air photo interpretation has documented its value in riparian characterization (Mereszczak and others 1990; Clemmer 1994). We intend to analyze it with traditional approaches (e.g. Avery and

Berlin 1992; Lillesand and Kieffer 1994) and with more recently available digital approaches (e.g. Greve 1997).

2. ADAR (Positive Systems April 10, 1997), a fine resolution (1m and 3 m in our use) aircraft mounted sensor whose spectra match the 3 visible spectra and one of the near IR bands of the existing Landsat Thematic Mapper, but whose spatial resolution is much finer. ADAR is selected not only because of its own characteristics, but also because it allows for the examination of the value of fine spatial resolution information of the type that is likely to be commercially available in satellite sensors in a few years. More detail on this sensor is provided in Appendix 9.3.
3. Emerging technologies -- by placing a request with the US government Civilian Applications Committee to explore the application of more sophisticated technology. (See Appendix 9.5) In addition, we are exploring the availability of existing imagery, particularly SAR datasets for the sites which will be visited this year[6].

These technologies are used differently in different phases of our research. Specifically, the initial focus is on the first and second technologies -- these are ones that are more likely to provide an operational payoff in the short-term. In contrast, emerging technologies, such as radar, laser, and fine resolution infrared sensors may provide more effective or complementary approaches in the longer run.

Our approach is to use both air photos and ADAR at multiple resolutions in one basin in the first phase of our effort and then to use a single resolution in the more extensive second phase. In addition, Thematic Mapper data and classifications are unusually well developed for this region (Cohen and others 1995) and provide a basis for comparing a broad range of image resolutions.

The use of 3 m (i.e. 9 m^2) digital imagery means that field plots whose dimensions are 40 m by 11 m would presumably provide a sufficient areal basis for terrestrial ground truth, and that streams wider than 11 m would provide a basis for stream characterization ground truth. 1 m imagery would allow for a smaller field plot and for smaller streams.

[6] Neither SLICER (a laser altimeter) nor Shuttle SAR data are available for our sites in Drift Creek.

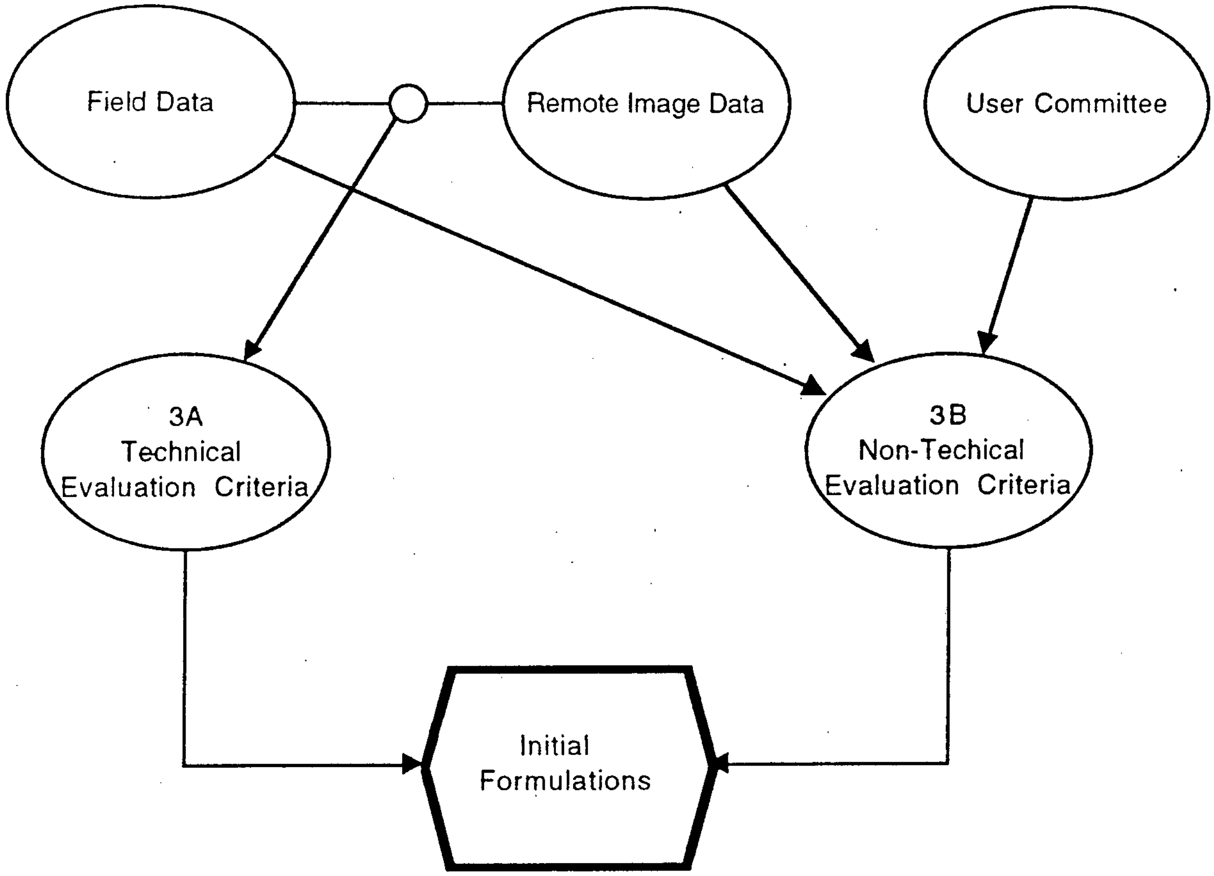


Figure 11 Evaluation of Results

Section 5 discusses the ways in which results from different methods will be compared. There are two categories of evaluation criteria - technical and non-technical. The former can be evaluated solely on the basis of the field and remote data and reflect the technological constraint illustrated in Figure 2. The latter require user inputs and reflects the user constraint and its interaction with the other constraints illustrated in Figure 2.

5. Task 3. Comparison of Selected Monitoring Methods

The goal of this project is to make a recommendation on a method to be used for operational monitoring. It is important that the criteria and rationale for such a method be clearly stated and transparent. This task provides for that information to be developed. We split the criteria into two categories - technical characteristics are those which can be more objectively identified and non-technical characteristics. The general approach to this comparison is provided in Figure 11.

The following text lists the key individual elements in the evaluation. However, there is no clear procedure for aggregating these evaluations of the quality of individual indicators and individual methods into an overall evaluation or recommendation. Given the multiple values supported by riparian systems, any such evaluation would have strong subjective elements. Thus, our approach to reporting on the merits of methods will classify and identify the strengths and weaknesses of different methods in the most transparent possible manner. These criteria are described with a comparison of field and remote data in mind -- the primary emphasis of this portion of our research. They will be appropriately adapted for comparisons of one field method to another and for one remote method to another.

The technological criteria represent the empirical evaluation of "Capabilities of Technologies" as shown in Figure 2. The other criteria are representative of the other two constraints shown in Figure 2. Thus, the application of these criteria are the means by which the tension between these three constraints will be illuminated and evaluated.

These sets of criteria will be applied not only to the development of the initial formulation, but have also been applied to the selection of technologies to compare (Section 4) and will be applied to the formulation of the initial recommendations -- see Figure 3.

5.1. Research Question 3A What are the technological characteristics of each method?

Candidate approaches can be objectively evaluated against these "technological criteria". In terms of Figure 2, these steps link technological capabilities with monitoring design.

5.1.1. Technical evaluation step 1 Does the imagery accurately locate and encompass the site?

The first step in the technical evaluation is to match the locations of the field data and the remote imagery. This step is important not only in methods development in which one set of spatially explicit data is compared to another set, it is also important in an operational monitoring program. If sites are selected on a probability basis, we must have some level of confidence that the data collected actually represent the specified site.

This step will be conducted qualitatively and quantitatively. Qualitatively, image analysts will describe the extent to which they can confidently match image locations to ground locations using GPS information, prominent features within the image (not necessarily within the field plot), or lastly reference to finer resolution or other types of imagery.

Quantitatively we will analyze the magnitude of change in plot or subplot statistics introduced by displacing the location of interpretation from the estimated best location. Digital descriptions of the plot will be developed which are the best match to the site, and compared to descriptions of the plot that are displaced from the estimated best match by a series of pixels in multiple directions allowing up to 50% displacement from the best estimate. A similar approach will be applied to air photo interpretations.

The result of this analysis will be a qualitative and quantitative discussion of the issues in matching each category of remote imagery or field data to specified field locations.

5.1.2. Technical evaluation step 2. Can the indicator be observed with the candidate approach?

A range of indicators could be derived from the measurements taken from the field and from the remote imagery. The first question in remote image interpretation is to determine which indicators can and cannot be formulated from the remote imagery.

Image analysts will view analog images directly to determine if the set of initial indicators can be identified. The procedure will be more complex for digital imagery because the approach by which it is determined if indicators can be observed is inextricably linked with the determination of the nature of the relationship. With digital imagery, sets of digital descriptions of a location are developed. These are statistically compared to independent estimates of the character (or characters) of interest to determine if a relationship exists.

The result of this analysis will be a screening matrix which describes the ability of indicators to be observed by standard air photo interpretation methods and by digital imagery. Conclusions will be drawn separately for each technology and for each major cover type sampled.

5.1.3. Technical evaluation step 3. What is the relationship between ground and remote image data?

Where estimates of indicators can be developed in common between methods, we can plot the estimate derived from one method (from remote imagery) against that for another method (ground data or fine resolution aerial photography) to determine the relationship and particularly to inspect this relationship to identify ranges of the values of the indicator for which a method may be more appropriate. Figure 12 illustrates how scatterplots might vary as a function of the resolution of the method under consideration. It may be that a fine grained and coarse grained method perform equally well in describing an indicator over one range, but that the ability of the coarser resolution method is less discriminating for some values of the potential indicator.

The implementation of this step will vary according to the source of the imagery and the analytical technique as described below.

5.1.3.1. Analog imagery

Using standard photointerpretation and photogrammetric methods, (Sayn-Wittgenstein 1978; Aldrich and others 1984; Avery and Berlin 1992; Lillesand and Kieffer 1994; Carson 1995) estimates of each indicator that can be observed will be developed. The procedure for the use of this imagery is shown in Figure 13.

5.1.3.2 Digital imagery

Estimates of indicators will be developed using standard statistical and image processing routines (Richards 1993; Cohen and others 1996)}. The procedure for the use of this imagery is shown in Figure 13 and 14. Relationships between field indicators and digital representations will be examined with scatterplots. Transformations of the original digital data, such as texture, band rations, and vegetation indices will also be evaluated to see if it enhances our ability to measure indicators and if so, under what circumstances. the nature of the relationship, (linear or non-linear, univariate or multivariate...) between the indicators and digital descriptions will determine the best classification techniques to use. Possibilities include regression, discriminant function, and maximum likelihood analyses. Where indicators are logically continuous, the digital measurements will be continuous. Where our exploratory analyses show that this is not feasible, or when the indicator is of a categorical nature (e.g. cover type), the digital measurements will be categorical.

The result of this step will be a series of plots which relate estimates of indicators from one method to other methods and a set of qualitative and quantitative judgments about the range of indicator values which may be more usable from a particular method.

Figure 12 Example of comparison of methods

This figure is a hypothetical comparison between methods. It suggests that a finer resolution method may have a broader range of applicability with regard to a measure (in this case tree density) than a finer resolution method. This type of analysis representative of a broader and more detailed analysis that will be conducted comparing results from different methods.

Figure 13 Use of Phase I Data for Analog and Digital Analyses

Estimates of indicators from the field data and from the analog imagery using widely available techniques (Sayn-Wittgenstein 1978; Aldrich and others 1984; Avery and Berlin 1992; Lillesand and Kieffer 1994; Carson 1995) can be developed (2,4). After coregistration checks (which support technical evaluation step 1) scatterplots can be developed and inspected and regressions developed(5) to describe the quality of, and the limits for use of, analog imagery for each candidate indicator. The result is a set of indicators of defined quality (6). Then, for the purpose of a more extensive description, and as a foundation for evaluating digital imagery, analog interpretations can be made a broader set of sites -- termed the A sites -- see box 7.

Digital image analysis differs from analog analysis in that it does not allow for the direct interpretation of information from the image. Rather, a range of techniques are available which allow numerical descriptions of a specified location (or plot) to be developed (9). These numerical descriptions are compared to estimates of the characteristics of the plot and models describing the relationship between the "true" estimates and the numerical descriptions are developed. "Calibration" is the name assigned to this process and the result is a series of models which relate numerical descriptions of a location to the characteristics of that location (11). Just as in the case of the analog imagery coregistration and statistical evaluations (10) need to be made. These models (11) can be applied to the numerical descriptions at the larger number of sites where field data does not exist and estimates of the status of these locations can be developed (12). Estimates of these indicators at the A sites (12) will be compared to estimates of the indicators made by standard photointerpretation techniques whose quality is known. Once again, coregistration and statistical evaluations will have to be made (13). This comparison will further document the quality of the estimates made by the digital methods (14). Once the quality of the numerical estimation procedure is documented estimates of known quality of the indicators at other sites can be provided (15). As desired and as the methods allow, fine grained descriptions of riparian areas could be developed for an extensive area.

Figure 14 Use of Phase II data for Digital Analysis

Digital imagery will be treated slightly differently in phase II than in phase I for forest types sampled in both phases. Treatment of digital data for forest types which are new in phase II will follow the procedures outlined under the phase I heading. In phase II, we can apply the estimation procedure developed in phase I to new digital information and compare it to a new set of field data resulting in a set of comparisons between digital estimation and ground data independent of the calibration field data.

Numerical descriptions of a specified location (or plot) will be developed (4).. The indicator estimation procedure developed in phase I will be applied (5), and estimates of indicators at phase II plots will be made (6). In parallel estimates of indicators from phase II field data will be developed (2). Just as in phase I coregistration and statistical evaluations (7) need to be made. This provides for a more robust estimate of the quality of the indicator estimation procedure (8). Depending on the outcome of this step, we may choose to modify the digital estimation procedure (9). This revised procedure can be used to make more extensive descriptions.

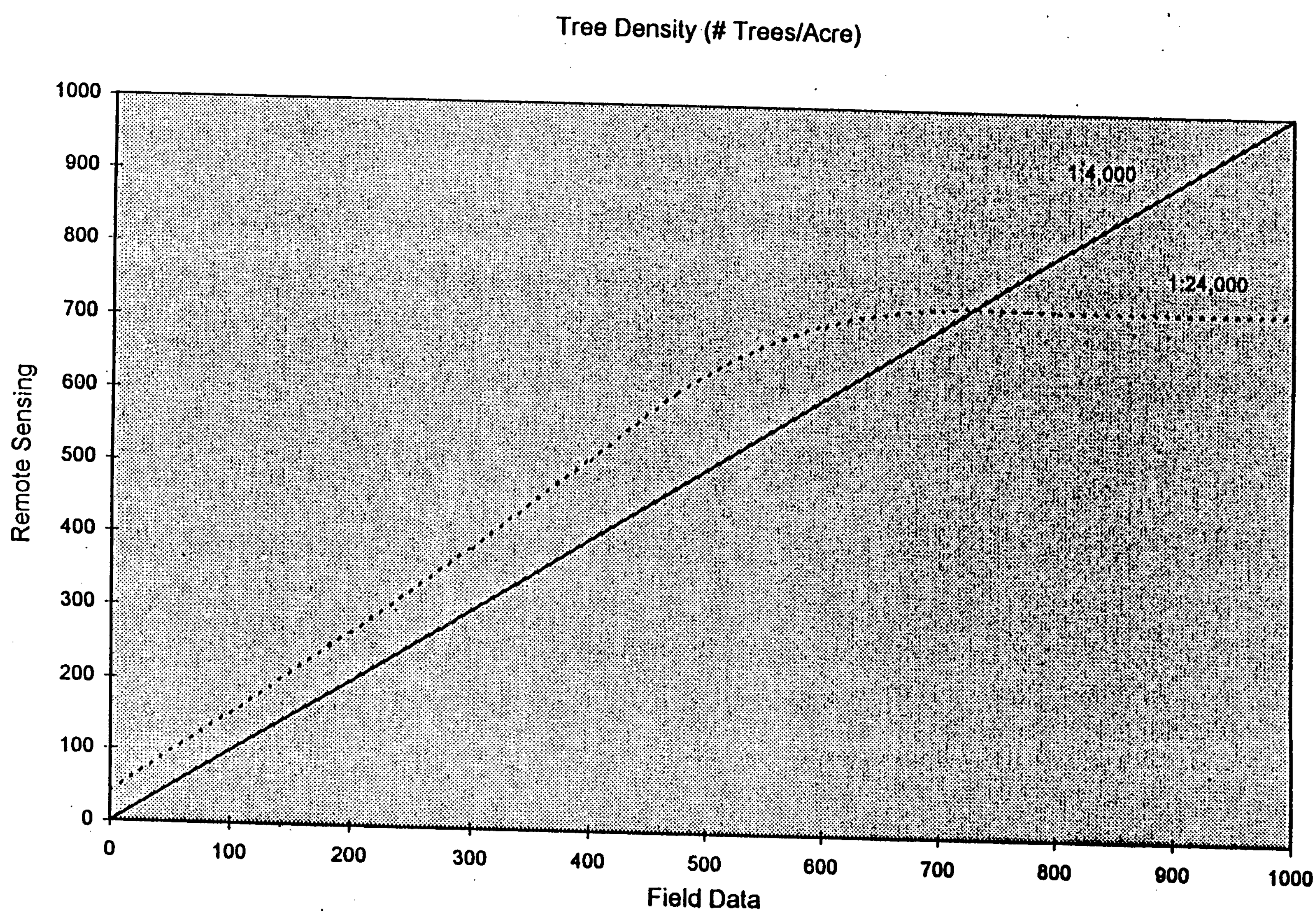
The use of phase II data for analog imagery will be the same as in phase I.

Figure 15 Digital analysis of analog imagery

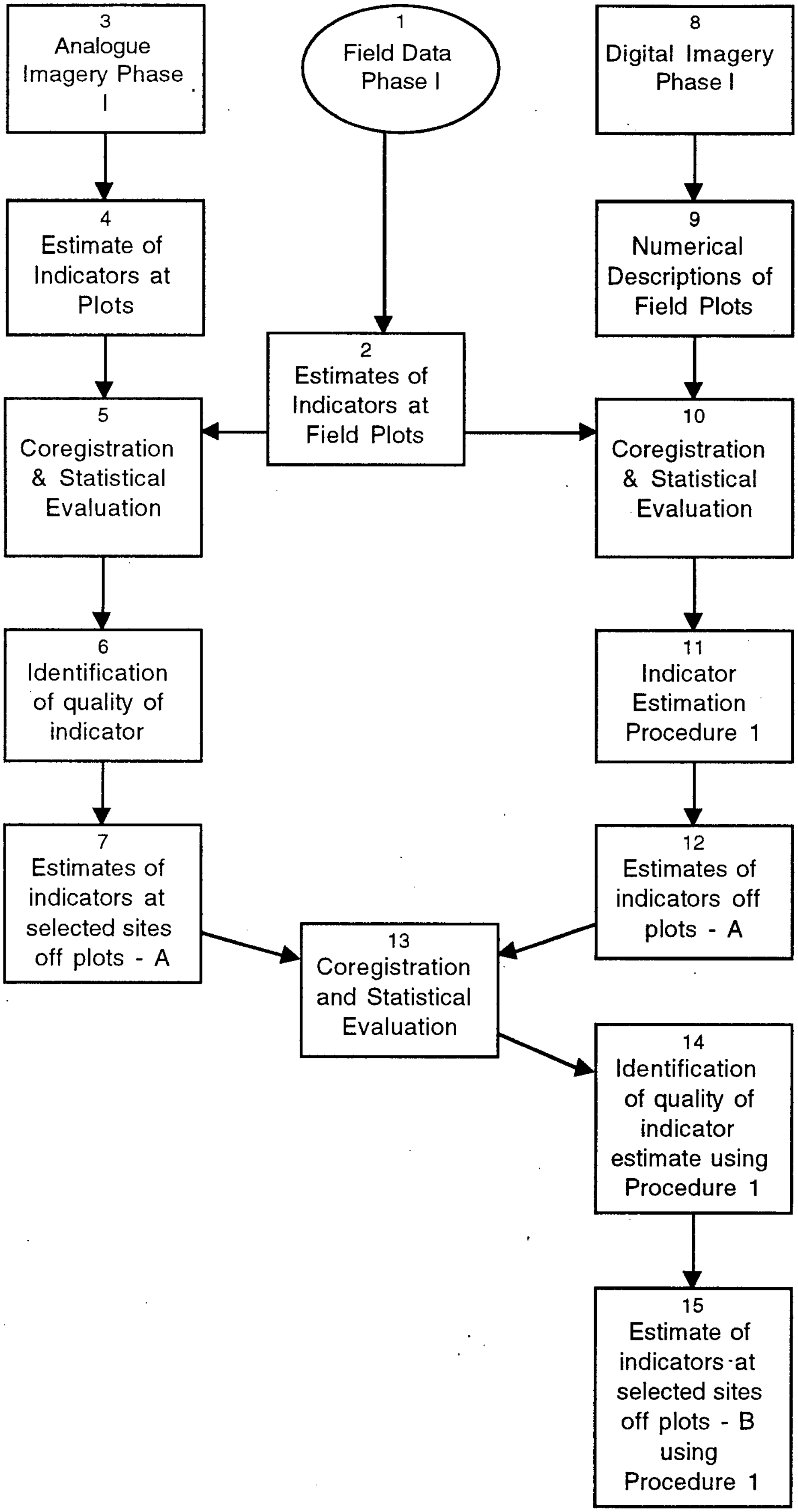
Digital photogrammetric workstations (DPW's) offer the opportunity to combine the advantages of digital imagery with the advantages of analog imagery (Helava Leica 1996; Greve 1997). Their use is shown in Figure 15. As such their use and application requires an approach which combines aspects of these two technologies. The use of a DPW requires that analog imagery be scanned with high resolution and precision. Estimates of indicators of riparian status can be developed using a DPW in two modes. The first mode is equivalent to the approach used for analog imagery. Here, software routines (see box 5) (rather than a human air photo interpreter) developed for use with a DPW provide estimates of indicators (7). One such indicator might be the topography of the ground[7]. The quality of this measure can be compared directly to easily collectable field data (2). Another indicator that a DPW can easily provide is a digital description of the topography of a forest canopy (6). This is an indicator which cannot be verified against easily collected field data within this or similar projects. However, the accuracy of the estimates can be inferred from similar applications in which field data can be compared to a DPW estimates.

DPW information can also be treated in the same manner as digital imagery. Specifically, digital estimates of a plot can be provided and compared to field data to create predictive models (12). These models are analogous to those described in box 11 of Figure 13. An example might be that a 1 m horizontal resolution digital elevation model might be a good predictor of forest type, or canopy complexity. These estimates can be used just as other estimates of digital imagery as discussed above and as shown in box 15 of Figure 13.

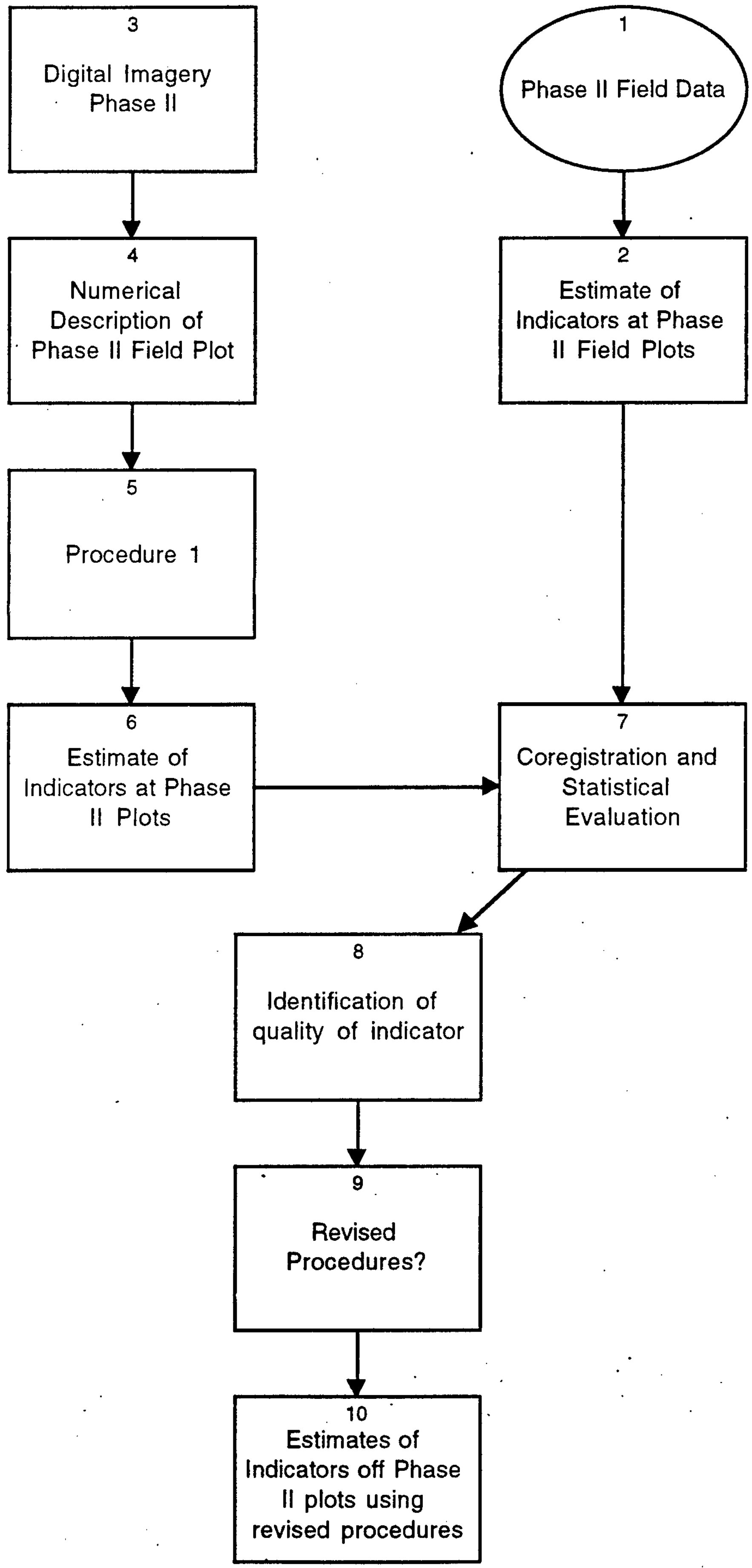
[7]Yes, this does require that the ground be visible in the image.

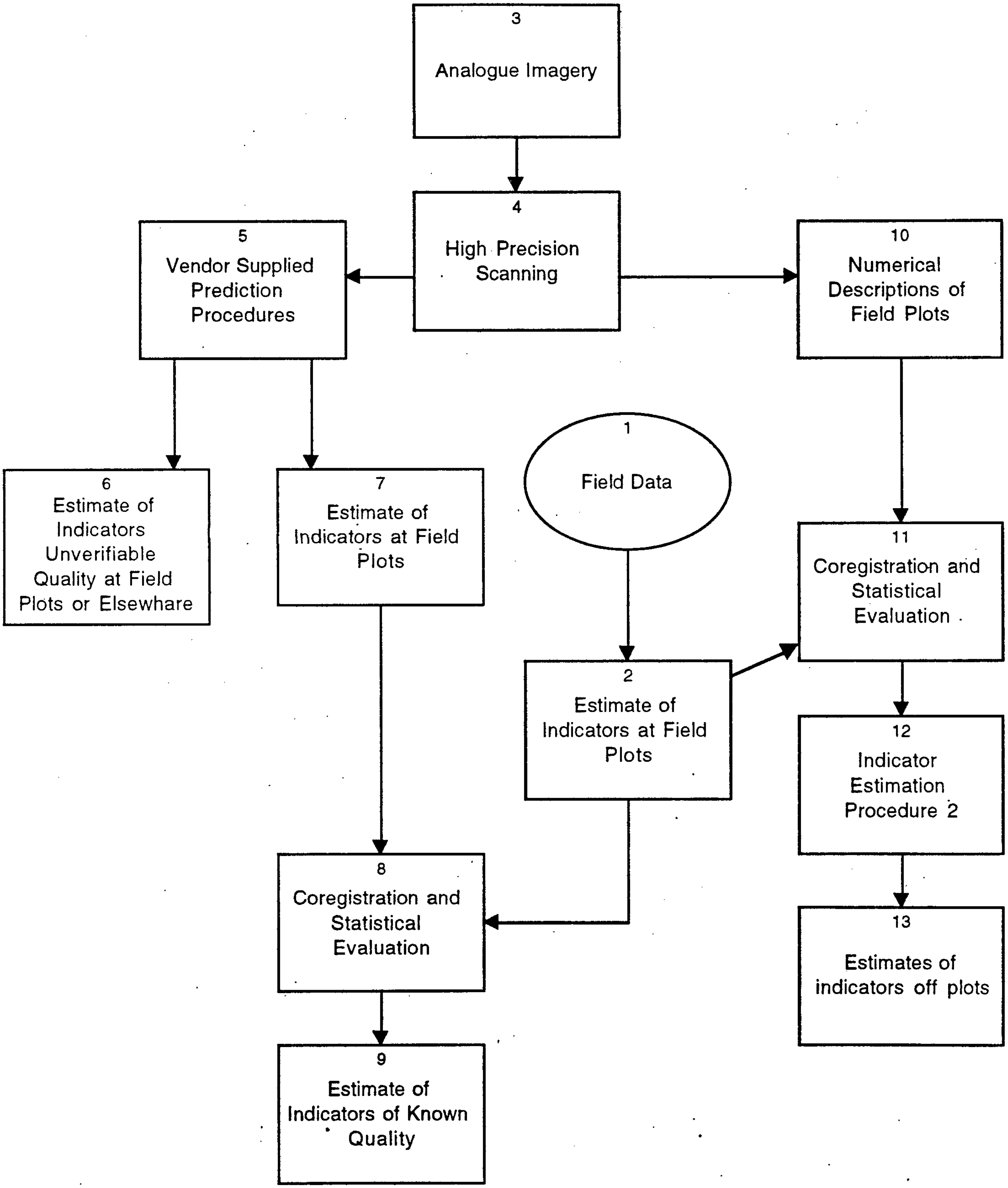

Tree Density (# Trees/Acre)
1:4,000
1:24,000
Remote Sensing
Field Data
0
100
200
300
400
500
600
700
800
900
1000

Use of Phase I Data



Use of Phase II Data and Digital Imagery




3
Analogue Imagery
4
High Precision Scanning
5
Vendor Supplied Prediction Procedures
10
Numerical Descriptions of Field Plots
6
Estimate of Indicators Unverifiable Quality at Field Plots or Elsewhare
7
Estimate of Indicators at Field Plots
1
Field Data
11
Coregistration and Statistical Evaluation
2
Estimate of Indicators at Field Plots
12
Indicator Estimation Procedure 2
8
Coregistration and Statistical Evaluation
13
Estimates of indicators off plots
9
Estimate of Indicators of Known Quality

5.1.3.3 Digital Treatment of Analog Imagery

Digital photogrammetric workstations (DPW's) offer the opportunity to combine the advantages of digital imagery and analog imagery (Helava Leica 1996; Greve 1997). Their use and application requires an approach which combines aspects of these two technologies -- see Figure 15. The use of a DPW requires that analog imagery be scanned with high resolution and precision.

If this approach produces reasonable quality estimates, we will be able to utilize the enormous archive of aerial photography to reconstruct riparian forest condition over long periods and over large spaces with minimal cost. This will provide a cost effective approach to addressing components of research question 5 (See Section 7), especially those having a historical component.

5.1.5. Technical evaluation step 4. What is the quality of each estimate?

Resource management is supported by estimates of known, not necessarily high quality. The purpose of this step is to define the quality of each estimate.

This procedure will differ as a function of method as shown in Figures 13, 14 and 15 and in the QA plan. Estimates of indicator characteristics can be derived by direct inspection of photographs and the quality of these estimates can be compared directly to ground observations. In contrast, the estimation of indicator values from digital imagery requires a calibration data set -- the field plot data. Thus, for analog imagery the phase I field data can be used as an evaluation dataset. For digital imagery, the phase I field data will have already been used to calibrate the estimation procedure. Thus, the phase I digital data will be calibrated against estimates of the indicators for locations in which the finest resolution imagery exists and for indicators which are interpreted with high precision and accuracy. Table 6 summarizes the approaches to evaluation.

One option for a third phase of data collection will be to collect a dataset to support additional evaluation of digital image analysis especially over larger scales. (See Section 7 and Figures 13, 14 and 15)

The key and obvious uncertainty in this scheme is the extent to which reliable indicator procedures can be developed for two methods which overlap in spatial scale and in ecological characteristics. If a set of indicators can be identified in common, then estimates of the status of the riparian areas at a large number of sites can be developed.

Table 6 Sources of information for estimating method quality[8].

Medium	Quality Estimation Approach
1. Air Photos (See Figure 13) 2. Digital Imagery or Digital Analysis Techniques (See Figures 13, 14, and 15)	• Ground Observation • Finer Resolution Air Photos • Statistical relationships with calibration (or training) ground observation • Statistical relationships with calibration (or training) air photos • New datasets

5.2. Research Question 3B: What are the non-technological constraints in recommending a feasible method?

The non-technical characteristics to be considered at the outset in a comparison of methods areas are no less important than the technological ones. Candidate approaches can be subjectively evaluated against these "non-technological criteria". The user committee will be asked to assist in the development and implementation of several of these steps, particularly the second and third. In terms of Figure 2, these criteria link monitoring design to user needs and to ecological functions.

5.2.1. Non-technical evaluation criterion 1: What is the cost of each method

Our reports will include the acquisition, data management and analytical costs from our work and from literature sources. We will describe the costs for single and multiple sites. Discussions on the comparative costs in operational use will also be provided.

5.2.2. Non-technical evaluation criterion 2: How well would each method fit within the context of the existing infrastructure?

The requirements for analyzing each data set will be outlined and compared to the level of capability existing and foreseen within the Federal resource management agencies.

5.2.3. Non-technical evaluation criterion 3: How well would each method respond to management needs?

[8] See the project QA plan for more detail on the treatment of quality assurance and error estimation.

It is not uncommon for specific management requirements for information to be subject to refinement, especially as new management approaches, such as ecosystem management are implemented (Grumbine 1994; Brunner and Clark 1997). Discussions based on demonstrations of tangible results between information users and information producers can assist this refinement. (e.g. Ringold and others 1997). Thus, alternative formulations of indicators will be discussed with land managers to seek their views on the usefulness of different methods.

5.2.4. Non-technical evaluation criterion 4: How well would each method respond to change in ecological understanding?

Ecological understanding will improve over time not only as a result of the general development of science, but also as a result of acquiring and using information from a monitoring program. This suggests that future generations of scientists and managers may wish to restructure archived information to respond to this new understanding. If some methods provide data which is more amenable to reanalysis, or reformulation, then those methods might be favored.

5.2.5. Non-technical evaluation criterion 5: How likely are the methods to provide consistent results over large areas and long periods of time?

Ecosystem management places a premium on the development of regionally and temporally consistent information. We will evaluate the likely consistency of methods in application over relatively large scales. One approach to this evaluation will be to consider the results achieved with multiple analysts.

5.2.6. Non-technical evaluation criterion 6: How well does each method lend itself to cross-scale and cross issue analyses?

The Forest Plan requires monitoring of numerous features at numerous scales (USDA/FS and USDI/BLM 1994; Mulder and others 1995) . This is a general feature of landscape monitoring, and it reflects the operation of ecological patterns at multiple spatial scales. To the extent that monitoring or characterization at one scale can shed light on features at other scales, that method should be favored. Our analysis will highlight the compatibilities of each method with other methods that could be used for monitoring or landscape characterization. Initially this issue will be addressed qualitatively, section 7.1.1 outlines a quantitative approach to addressing this issue that will be addressed later in the research.

6. Task 4. Site Selection

Our dominant purpose in selecting sites is to identify the locations where data sets from remote imagery and field observation will be compared.

6.1. How should sites be distributed for methods development?

In methods development sites should be distributed across space to be representative of the variety of conditions within the area and population of interest. A wider variety of test conditions supports broader applicability in the recommended method, and a more robust statistical foundation for evaluation[9].

6.2. Site Designation -- Phase I

Phase I samples (summer '96) provided for a selection of sites across ecosystem types within one basin. Twenty five sites were selected on a stratified probability basis within Federally administered land from the Drift Creek Basin in Western Oregon. This basin is outlined in Figure 16. The Drift Creek Basin was selected because it has a long and continuing history of research (e.g. Hall and others ; Moring and R.L. Lantz 1975; Moring and R.L. Lantz 1975; Moring and R.L. Lantz 1975), a variety of cover types (including never logged wilderness areas and recent clear cuts), and geographic relevance to the Forest Plan. The Basin is about 140 km^2 and has about 260 km of streams (Oregon Department of Forestry 1994). It is one of 520 fifth field waterbasins within the President's Northwest Forest Plan region.

To ensure that a wide variety of representative cover types were sampled, we designed a stratification scheme, and took equal numbers of samples from each of the strata. The stratification scheme was designed around land cover type, and stream size. Vegetation cover is a major determinant of riparian function. Stream size is a useful stratification factor for several reasons. It is a reasonable surrogate for geomorphic setting, an important determinant of riparian function (Gregory and others 1991). Stream size is also related to local topography with smaller streams being associated with steeper terrain. Third, the Forest Plan establishes riparian buffers which are a function of stream size and which extend to intermittent streams (USDA/FS and USDI/BLM 1994), a class which we wanted to sample.

The data which enabled us to describe the existence of the strata within the Drift creek basin came from two sources. Stream size was divided into two levels based on data from the Oregon Department of Forestry (Oregon Department of Forestry 1994). TM classifications (Cohen and others 1995) were grouped into four levels (Large and Very Large Conifer/Mixed, Medium Conifer/Mixed, Small

[9]This is in contrast to a design which seeks to describe the status of resources as they exist in an area in which each type of area would be selected on the basis of its existence in the region (at least if the objective is to minimize the variance associated with the overall description (Stehman 1997).

Conifer/Mixed, and Broadleaf and other). These cover types were found on 31%, 7%, 19%, and 42% of the study area respectively[10]. Three sites were selected on a probability basis from each of the eight cells of this land cover by stream size stratification. Actual sites visited were modified from this selection when the field observations did not match the TM classification.

6.3. Site Designation -- Phase II

Site designation in the second phase (summer '97) will continue to sample a diversity of sites from a broader area. This will be accomplished by collaboration with an EMAP stream sampling program occurring during the summer of 1997. The second phase will sample sites within two provinces (34,000 km^2) rather than sites within a single watershed as was done in the first phase. The candidate sites are shown on Figure 16. The provinces will include the Oregon coastal province, and the Willamette Basin. The Willamette Basin is not only the province immediately adjacent to the coastal province, it is also one of the case study areas of the PNW Ecosystem Management Research Program. The design for the second phase of the field sampling will be integrated with the sampling effort of the EMAP PNW effort during the summer of 1997. The advantages of this coordination include significant logistical and scientific synergies.

The EMAP sampling is expected to occur on approximately 17 coast range streams, 32 Willamette Basin Streams (See Figure 16). Eighty percent of the sites are located on lower order streams. No intermittent streams will be sampled as was done in phase I -- EMAP sampling does not include intermittent streams.

The exact number of sites to be sampled will be determined by the ability to coordinate visits with the EMAP field crews, and by the ecological characteristics of the EMAP sites; the more fully site visits can be coordinated, the larger the number of sites can be visited by the RIM crews[11]. The number of plots may be greater than the number of sites, if multiple plots can be sampled at each EMAP site. Plots with fewer trees on easier terrain can be sampled in a shorter period of time, and multiple plots may therefore be sampled in the one day allotted to each EMAP visit.

As in the phase I effort site selection will be aided by examining the TM classifications of the selected sites. We have identified the TM classification of each site as one way to determine if the sites are forested or not and to ensure that a diversity of forest types is covered by the EMAP sample. These classifications are being verified and refined by examination of existing recent air photos. This

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[10] The "other" category was <5% of the total area. The study area is not the basin as a whole, rather just the pixels adjacent to the ODFW identified streams.

[11] For safety reasons a field crew must consist of three people, although the plot sample can be developed by two people. If our field visits are coincident with EMAP visits, then two person field crews will be able to do the work. If site visits are not coincident, the total number of sites that can be visited will decrease.

procedure suggests that the EMAP sample provides for a variety of forest cover types. Therefore, it would seem that our requirements for representative sites in a variety of terrain types well dispersed in the area of interest can be met by using the EMAP sample. Additional effort will be allocated to refine our judgments about which sites to visit prior to field work. If necessary, additional field sites will be identified outside of the EMAP sample to ensure adequate coverage of cover types.

As a result of the collection of phase II site data we will be able to develop:

- a more robust evaluation of the estimation procedure developed from the phase I data (for the forest types covered by phase I and phase II sites),
- improved estimation procedures (for the forest types covered by phase I and II sites), and
- digital estimation procedures for more forest types (those covered by the phase II data but not by the phase I data).

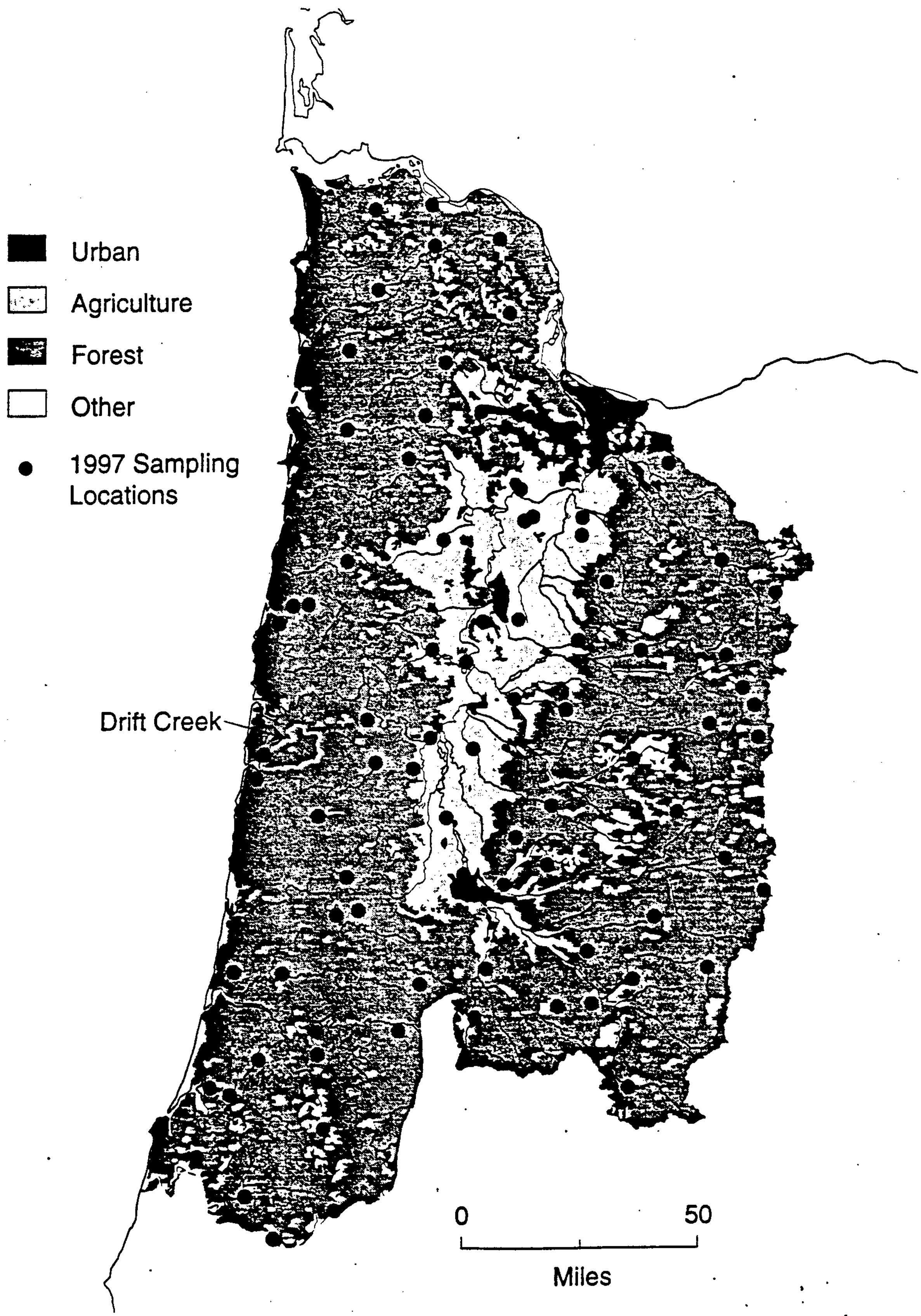

Figure 16 Phase II sampling locations

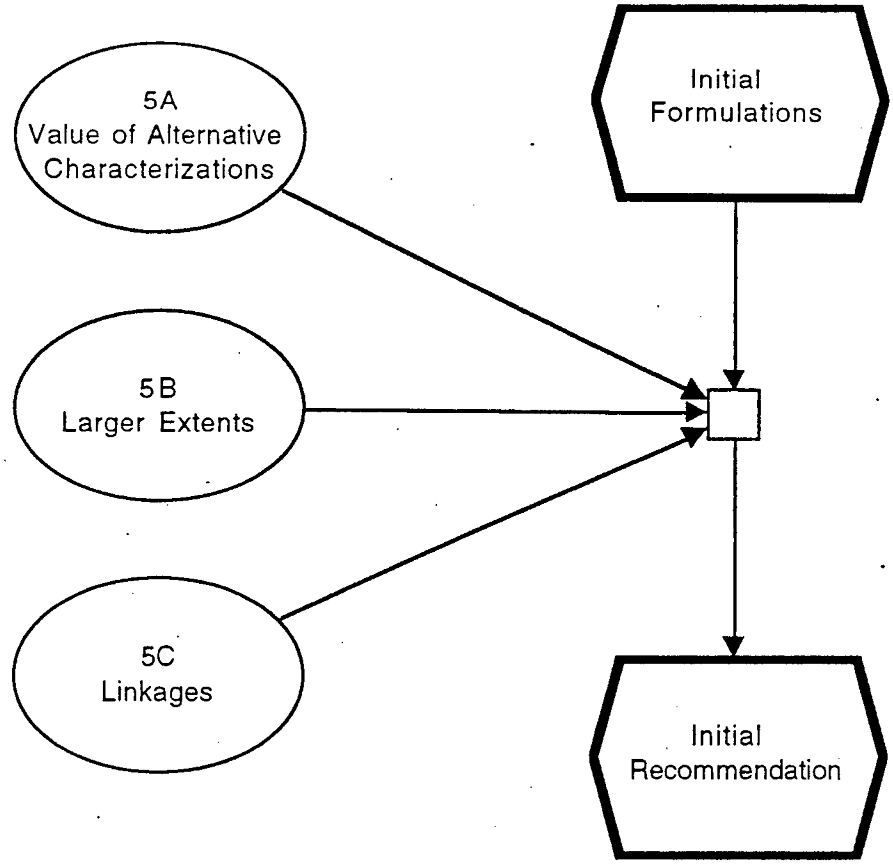

Figure 17 Initial Recommendation. Section 7 discusses a series of evaluations and demonstrations using initial formulations of methods and indicators to provide an initial recommendation on a monitoring method.

7. Task 5: Demonstrations and Evaluations

The research described above would result in an initial formulation of monitoring methods. From a users' perspective it will have several shortcomings: it will not have been demonstrated that the method can perform as promised (Brunner, 1992), that it can be used to effectively and efficiently describe ecologically meaningful features across a large area; it will contain no evaluation of the value of higher cost finer resolution imagery, and it will contain no consideration of any approach to defining the concatenation or chaining together of individual sites to larger extents.

The research described in this section is intended to begin to reduce these shortcomings and as a result provide revised recommendations for monitoring and assessment.

This research is divided into 3 parts:

1. What is the value of alternative resolution riparian characterizations?

2. What is the condition of riparian sites over larger extents?

    - What are the indicators of riparian sites over larger extents,
    - What are the reference conditions for these features, and
    - What is the status of riparian sites using small and large extent indicators over a large extent?

3. What are the linkages between current riparian conditions and other ecological features, i.e. do riparian indicators predict the status of other features of the environment?

While members of the existing research team (See Sections 8 and 9.6) will play an active role in addressing these questions, the effort for the second question will be significantly enhanced and focused by a two year NRC post doctoral fellow. The research on the second and third questions will be more fully developed and subject to external peer review as part of the process of selecting the post doctoral fellow.

7.1. Research Question 5A: What is the value of alternative resolution riparian characterizations?

Different methods will inevitably characterize the same area in different ways, either because methods differ in spatial or ecological resolution, or in the accuracy or precision of the estimates which they provide. If maximization of precision or accuracy were to be the dominant criterion for evaluation, then generally finer resolution methods would be the most desirable. Finer resolution methods though inevitably have higher costs associated with them including higher acquisition and handling costs. One is obligated therefore to consider the value associated with this higher cost.

This research task will be to take two approaches to addressing this question. The first approach will explore changes in information content as a function of the scale of the method. The second approach will utilize a range of quantitative models which relate riparian stand structure to one of the three values described in the conceptual models. These models cover multiple functions and scales. The sensitivity of model output to different resolutions input data will be evaluated.

7.1.1. Research Question 5A1: Do different characterizations vary in information content?

Currently there are many efforts underway among agencies, universities and the private sector to utilize satellite derived imagery for monitoring and inventory of forested ecosystems. These programs seek to characterize stream, aquatic, and forest ecosystems within a watershed or across watersheds. The imagery employed for these objectives span a range of platforms and resolutions including imagery of resolution less than one meter (FLIR on helicopters) to three satellite mounted sensors -- 10 m (SPOT) to 30 m (TM) to one kilometer (AVHRR). The challenge remains to integrate these varying media and how to relate information across spatial scales. At the interface between stream and forest, the riparian zone reflects both terrestrial and aquatic elements of the watershed. Subsequently, remotely sensed information will need to be related and integrated with information gathered from terrestrial and stream monitoring studies. To this end, we propose to investigate how to relate high resolution information to the larger-scale (i.e., coarser grain) imagery such as TM currently employed by federal agencies for forest inventory and monitoring.

We will undertake a signal processing analysis to examine how information is translated from high resolution imagery (e.g., scanned aerial photos [1:4000], and digital imagery [1 m] to lower resolution [30 m]). Several methods of scaling from high to low resolutions will be employed to examine the interaction between pattern (e.g., vegetation cover) and change in resolution (e.g., moving from one meter to 25 m resolution). Methods employed to emulate scaling resolution include wavelet analysis and standard methods common to image processing software (e.g. IMAGINE™).

The result of this analysis will be several fold. We will quantify information loss as a function of decreasing resolution; identify type of information loss or retention as a function of decreasing resolution; assess comparability of classification across resolution, and assess efficacy of lower resolution imagery to complement high resolution imagery and ability to capture riparian-upland patterns. This analysis is also a quantitative version of non-technical evaluation question 6 (see section 5.2.6)

7.1.2. Research Question 5A2. Do different characterizations make a difference in ecological models?

Models embody a defined level of understanding about ecological patterns and processes. They use this understanding to describe or predict. A number of models relate riparian structure (i.e. features that can be monitored) and ecological functions (things we care about -- see Figure 6). These models can be adapted to compare the consequences of using riparian structural characterizations of different resolution on the features that they predict. Specifically, we intend to use models that relate riparian structure to ecological values to explore model output as a function of the resolution in riparian spatial structure. If, for example, models which relate riparian structure to coarse woody debris input predict the same amount of coarse woody debris entering streams for finely resolved data as compared to coarse data, then there would be little value in the finer resolution data from this perspective.

There are several models that allow for this type of exploration. These include:

- Bradshaw and Weaver (Program 1997) have developed a simple temporally dynamic model of riparian vegetation and a number of measures of aquatic habitat quality.

- Andrus (pers. comm.) and Van Sickle (VanSickle and Gregory 1990) and Figure 1) have developed estimates of the probability that a falling tree will enter a stream given information about its size, position from the stream bank, and membership in the conifer or deciduous categories. .

- David Chen and his colleagues have developed a model (Chen and others Submitted; Chen and others Submitted) which describes the effect of riparian shading on stream temperature. The model distilled information every 100 m along the stream and this effected the accuracy and precision of the calibrated model. The modelers concluded that they could not more accurately simulate temperature without better resolution of the riparian shade effects (McCutcheon 1997). We are exploring a collaborative project with them.

- Nathan Schumaker has developed a model which relates habitat to species viability at the landscape level (Schumaker In Review). This model has been used to develop landscape indices (Schumaker 1996). We are developing a joint project to explore its application for riparian species (Regional Interagency Executive Committee 1997) which will also be used to explore the consequences of finer and coarser grained descriptions of riparian habitat on the viability of riparian dependent species. It will also be used to contribute to the development of riparian indicators at larger scales as noted under research question 3.

- Gap models are based on the concepts of plant succession and competition. Gap models simulate forest succession in an opening (typically 0.1 ha) of a forest canopy caused by death of a tree. Succession is based on the relative growth rates of competing trees as constrained by a variety of environmental conditions. Our use of a gap models such as Zelig (Urban 1990) would be to assess the dynamics of deciduous and coniferous trees after a gap is created due to tree blowdown of flooding. We would compare simulations with data of varying levels of spatial resolution.

- Finally, as the alternative futures assessment for the Pacific Northwest Program develops (See Section 8 -- Program Management and Program 1997), we will work with our collaborators to identify other models which relate riparian structure to ecological function to explore this issue.

The data to support these evaluations can be derived from our phase I and phase II data.

7.2. Research Question 5B: What is the condition of riparian areas over larger extents?

This research question is divided into three parts. The first provides for the development of indicators, the second defines reference conditions, or expectations for those indicators at both sites and larger extents, and the third provides for a description of the riparian areas within an area using fine grained indicators at both site extent (as developed under Section 3) and larger extent (as developed under Section 7.2.1).

7.2.1. Research Question 5B1: Larger extent indicators

The need for larger extent indicators is similar to that for site grained small extent indicators[12] -- there are important ecological functions at this scale and there is a concomitant need to manage, monitor, and assess at this scale.

The approach to developing larger scale indicators of riparian state (and ideally function) will follow that used for site scale indicators as listed above under research questions 1A and 1B and described in Figure 5. A literature review which includes the development of a conceptual model will be developed, existing remote and field data will be evaluated, and experts and potential users will be consulted. In addition, landscape scale models will be applied that will support the identification and evaluation of indicators of riparian function at larger scales (as in Schumaker 1996). This research will be supported by current and historic information developed during the course of this project (and others) as listed above.

7.2.2. Research Question 5B2: What are the reference conditions of riparian areas?

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[12]In the metaphor of a chain, larger extent indicators are indicators of the status of multiple links of the chain, while the site or small extent indicator is an indicator of the status of an individual link of the chain. See section 2.1.1 for an amplification of this issue.

Reference conditions help to define limits on achievable conditions, and temporal and spatial patterns of natural variability. The value of reference conditions have been widely noted (Hunsaker and others 1993; Angermeier and Karr 1994; USDA/FS and USDI/BLM 1994; Omernik 1995; Christensen and others 1996; Wallin and others 1997). (Gregory 1997) specifically notes the potential value of reference conditions in managing riparian forests in Oregon. Reference conditions can accommodate the range of natural variability and, can be viewed as an expected distribution of conditions over specified time and space. One would not compare a single site to a single reference condition, but rather the distribution of sample of sites across a region to a reference distribution. The purpose of this task is to begin to define reference conditions for riparian forests.

The approach to developing reference conditions will be to describe riparian conditions in less disturbed watersheds so that fine-grained small and large extent indicators of riparian condition can be identified and serve as a foundation for this definition. It is important for this effort that the information be developed from an entire watershed, so that watershed position can be an explicit part of the development of riparian reference condition. It is also important that the nature of disturbance in the watershed whether from fire, insects, or management action be known.

7.2.3. Research Question 5B3: What is the current condition of riparian areas within a demonstration area?

Ultimately, a recommended monitoring method is intended to be used to describe the status of riparian areas over a large extent, e.g. a watershed, a province, or a region. Research under this heading will develop such a description using candidate monitoring methodologies for the purpose of evaluating the merits of candidate methodologies for such use. This description can be developed with or without using the fine-grained but larger extent indicators developed under research question 5B1 and evaluated with or without the context of the reference conditions developed under 5B2, The area(s) in which such descriptions will be developed will be selected in conjunction with the user committee.

7.3. Research Question 5C: What are the linkages between riparian condition and stream habitat over large scales.

One of the reasons to monitor riparian areas is that at least in concept, they are early warning indicators. Riparian condition in one location provides insight into a range of other ecological values in other places. Similarly, today's riparian condition provides great insight tomorrow's riparian condition and therefore the ecological status or constraints on a range of other ecological values. The purpose of these research tasks is to evaluate this conceptual understanding empirically.

Interest in riparian condition reflects the role they play in controlling aquatic and terrestrial habitat and water quality. The relationship between riparian condition and these three values has poorly quantified spatial and temporal linkage. While we know that the coarse woody debris in streams does not come from today's riparian or upland forest, we don't know well the temporal or spatial "zone of influence" (in the sense of (Bradshaw and Fortin In Review) . Any improvement in the quantification of this linkage would be most useful for management of riparian reserves, for setting expectations about rates of recovery, for formulating restoration strategies, or for projections of alternative futures.

This research will pursue a correlational approach by identifying predominately forested watersheds in a range of conditions with known (or knowable) disturbance histories. The data from the eight sixth field subbasins (~ 20 km^2) of Drift Creek fit this description and additional sixth field watersheds from the Willamette basin will be selected. If watersheds with a history of biological data can be selected, then attempts to correlate riparian and watershed condition with biological states can be pursed. If there are too few basins with biological data, then historic reconstructions will focus only on the relationship between riparian and watershed condition and stream habitat as it is visible in air photos. This will limit our analysis to looking only at the open portions of the streams likely to be only towards the mouth of these sixth field watersheds when they are in less disturbed conditions.

7.4. Sources of Data for Research Question 5B and 5C

Datasets to support these three analyses will come from:

- Descriptions of known quality of the current riparian areas of the basins within Drift Creek digital remote imagery,
- Descriptions of known quality of the current and historic riparian areas of the basins within Drift Creek using analog imagery,
- Data on the status of stream chemistry, aquatic habitat, and biota for specific portions of Drift Creek being developed by compiling historical records, and by current sampling from the REMAP and EMAP programs,
- Data on the status of stream chemistry, aquatic habitat, and biota for basins within the Willamette Valley (see PNW-ERC Project #2 in (Program 1997) with a historical record and with an archive of aerial photography, and
- TM descriptions of western Oregon (Cohen and others 1995) for 1988 and underway for earlier periods of time going back to 1974. (This information is being developed outside of the effort described in this research plan and will require the development of a collaborative effort.)

8. Project Management

This section describes the management of this project in terms of the organizational setting of the research, the personnel participating in it, and the resources available to the project.

8.1. Technical Liaison

Technical liaison ensures that this research extends rather than duplicates existing findings and ongoing research. It also ensures the appropriate interpretation of primary research conducted by others and used in this project, particularly as described in Section 3. Technical liaison is enhanced by the organizational setting of the research, the affiliations and backgrounds of the personnel conducting the research, the establishment of consultative meetings during the development of the plan, the circulation of draft plans to other research personnel in the region, and the design of the implementation of the research. Major elements of this linkage are described below:

8.1.1. Organizational Setting

This research is part of the research program of the U.S Environmental Protection Agency's Office of Research and Development Regional Ecology Branch. As a result of the Interagency Memorandum of Understanding which implemented the Northwest Forest Plan, this Branch developed a research strategy (Baker and others 1995) to address ecosystem management within the region. This research is designed to develop alternative futures of the Willamette Basin in Oregon, and the Willapa Basin in southwest Washington. In addition, it is designed to have a component oriented towards monitoring design (Program 1997). This research originated with the component oriented towards monitoring design and has increasingly close linkages with the development of the alternative futures research. Specific linkages include:

- Development of fine resolution small extent indicators of riparian status in forested ecosystems.
- Development of fine resolution large extent indicators of riparian status in forested landscapes.
- Analysis of the responses of models to finer and coarser resolution data.
- Definition of benchmark conditions for riparian forests .
- Illustrations of the loss of information in describing the case study areas with coarser resolution imagery.

- Use of other ground data and remote imagery to extend our conclusions about the applicability of remote imagery for describing riparian areas.

- Correlations between riparian condition and stream condition in predominately forested basins over large spatial and temporal scales.

This research is designed and implemented through the Pacific Northwest Research Consortium which is a cooperative program between EPA's Regional Ecology Branch and three universities within the region -- Oregon State University, the University of Oregon, and the University of Washington.

8.1.2. Ongoing technical collaboration

Other organizations are collecting field data and remote imagery on riparian vegetation within the region. Of special interest are other efforts in the coast range, the richest source of data for this project, and the Willamette Province. Linkage with these organizations has been initiated in early consultative meetings and will be continued through the course of the project. Circulation of drafts of the plan has identified other personnel with an interest in this research and coordination meetings have been established as appropriate.

8.2. User Linkages

Linkage to user needs are essential for successful monitoring design. This project has strong linkages with potential users. It's origin lies with multiple needs analyses (Mulder and others 1995; Smith and others 1997). Consultative meetings with potential users were held during its development and drafts have been sent to potential users[13] during its development. A user committee will be established in consultation with the Research and Monitoring Committee implementing the Northwest Forest Plan. This committee will help to ensure that the initial linkage to user needs is sustained throughout the implementation of the project. Finally, project managers will brief potential users on project progress throughout the implementation of the project.

8.3. Personnel

Key personnel working on this project and the time the percentage of their time devoted to it include:

Gay Bradshaw, USDA FS PNW	25%
Jerry Barker, Dynamac Co.	70%

[13]Potential users are members of regioanl Federal and state land management and regulatory agencies, interagency organizations, and private organizations.

Maria Fiorella, OSU	90%
Mike Bollman, Dynamac Co.	90%
Paul Ringold, EPA REB	50%
Steve Cline, EPA REB	30%
Ward Carson, OSU	25%

The personnel committed to this project are listed in Section 9.6. In addition to these personnel resources are available within this project for a 4 month assignment devoted to photointerpretation of phase I imagery, and to a two-year National Research Council Fellow to focus on key elements of the large scale indicators development and demonstration. Field personnel are also assigned to this project.

Personnel working on this project meet as necessary to coordinate their efforts. Table 8 lists major research activities and identifies their timing and personnel assigned.

8.4. Resources

This plan assumes that $250,000 per year is available from EPA's Office of Research and Development for Fiscal Years 98 and 99 (Program 1997).

Table 7. Project Questions, Timing and Personnel

		1996				1997				1998				1999+	Lead	Contributers
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4			
3	**Ecological Characteristics of Riparian Systems**															
1A	What are the key ecologically important attributes of a riparian site?															
1	Conceptual Model		X												McAllister	
2	Classification Scheme		X												Runyon	
3	Literature Review					X									Bollman	
4	Evaluation of Phase I Data				X	X	X	X	X	X	X	X	X	X	Field Data -- Barker Remote Data -- Fiorella	Ringold, Bradshaw, Carson
5	Expert Workshop						X	X							Barker, Bollman	Ringold
6	Refined Evaluation of Data								X	X	X	X	X	X	Field Data -- Barker Remote Data -- Fiorella, Miewald	Ringold, Bradshaw, Carson
7	Recommendations on Indicators												X		Ringold, Bradshaw	
1B	What are the spatial characteristics that define a site?															
1	Literature Review					X									Bollman	
2	Evaluation with Phase I Data				X	X	X	X	X	X	X	X	X	X	Field Data -- Barker Remote Data -- Fiorella, Miewald	Ringold, Bradshaw, Carson
3	Expert Worshop						X	X							Barker, Bollman	Ringold
4	Refined Evaluation of Data								X	X	X	X	X	X	Field Data -- Barker Remote Data -- Fiorella, Miewald	Ringold, Bradshaw, Carson
5	Recommendations on Spatial Scale of Monitoring												X		Ringold, Bradshaw	
1C	How can sites be identified across a region?															
1	bases									X					Ringold, Faure	
2	Generation and evaluation of new databases									X	X	X	X		Carson, Faure	Bollman
4	**Identification of Available Approaches**															
	What methods are feasible?	X					X								Barker, Bradshaw, Carson, Ringold	
5	**Comparison of Selected Methods**															
1	Technological Comparisons			X	X	X	X	X	X	X	X	X	X	X	Digital - Fiorella; Analog - Miewald, Field Barker, Overall - Cline	Bollman, Carson, Bradshaw, Ringold

Tab. 7. Project Questions, Timing and Personnel

		1996				1997				1998				1999+	Lead	Contributers
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4			
2	Non-Technological Comparisons			X	X	X	X	X	X	X	X	X	X	X	Ringold, Bradshaw	Barker, Bollman, Cline, Fiorella, Carson
6	**Site Selection**															
	Data Acquisition		X	X			X	X			?	?			Barker, Bollman	Field Crews
7	**Demonstrations and Evaluations**															
5A	Do different characterizations make a difference?															
1	Information Content									X	X	X	X	X	Bradshaw	Fiorella
2	Ecological Modeling								X	X	X	X	X	X	Ringold, NRC, Barker, Bradshaw	
5B	What is the status of riparian forests over larger scales?															
1	Indicators of Larger Scales										X	X	X	X	NRC	Fiorella, Bradshaw, Barker, Bollman, Ringold, Cline
2	Reference conditions										X	X	X	X	NRC	Fiorella, Bradshaw, Barker, Bollman, Ringold, Cline
3	Current Conditions											X	X	X	NRC	Fiorella, Bradshaw, Barker, Bollman, Ringold, Cline
5C	Linkages between riparian condition and stream habitat over large scales												X	X	NRC	Fiorella, Bradshaw, Barker, Bollman, Ringold, Cline

		1996				1997				1998				1999+	Lead	Contributers
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4			
8	**Management**															
	Overall														Ringold	
	Digital Imagery														Fiorella	
	Analog Imagery														Carson	
	Field Data Management														Bollman	
	Field Data Analysis														Barker	
	Field Design														Barker	
	Field Implementation														Bollman	

This table lists key research activities, when they will be performed and who will perform them. In the left hand colum, large numbers in boldface (e.g. **8**) refer to sections of the plan; smaller numbers (e.g. 1A) refer to research questions or to components of research questions.

9. Appendices

9.1. Preliminary Evaluation of Phase I Field Data

Research Question 1A and 1B use the field data to explore the statistical characteristics of potential indicators (Section 3). This includes addressing questions such as:

1. What are the values for each indicator for each plot, subplot, and transect station? How do these values vary over space at a site and among sites? For example, what are the values for each geomorphic surface, subplot, aggregations of subplots, and each plot?

2. What are the statistical associations between and among variables?

3. How do variables vary as a function of site characteristics (stream size, management class, soil type, plot slope gradient, land cover class, and so on)?

4. Can one or two variables serve as an effective surrogate for a larger set of variables? For example, is stream-side vegetation an effect surrogate for canopy cover, bank stability, woody debris, etc.?

5. How does one method of characterizing a site, (the plot method) compare to other ways of characterizing a site (the point center quarter method)?

This analysis is proceeding using standard parametric and non-parametric statistical techniques. Results at this point are necessarily preliminary because the range of sites sampled in Drift Creek is not representative of the full range of sites over which the methodology is intended to be applicable. However, the information gained thus far is valuable in formulating hypothesis concerning the use of certain indicators.

Preliminary general conclusions for each question are:

1. The values of the indicators are highly diverse, plots of their distribution show a high degree of non-normality, usually due to elongated tails (see, for example Figure 9 which shows the distribution and provides univariate descriptive statistics for number of stems and plot gradients).

This is consistent with our desire to sample with equal effort a wide array of systems. If the original site selection had not been stratified by stream size and forest type then the data may have met the assumptions of a normal distribution.

However, as pointed out, we felt it important to have equal sampling effort for all situations.

3. Tree composition is influenced by stream side surfaces such as flood plain and slope break. Direct ordination shows that tree density, basal area and frequency change by species with distance from the bankfull width. The general characteristics of the vegetation within 10 m of the baseline differ as a function of standtype for number of stems and average dbh in most analyses. However, basal area does not vary with stand type. Measures of canopy cover do not vary as a function of stand class in any analysis ($p > .1$ in all cases).

4. Factor analysis and other analyses are underway to explore the statistical ability of one variable to represent many variables.

5. On the basis of a wide range of standard statistical comparisons it can be concluded that the point center quarter method and the plot method generally provide the same information, but the point center quarter method provides estimates with less precision. This comparison is summarized in the following portion of this appendix.

9.2. Indicator Literature Review.

by Michael Bollman, Dynamac Corporation March, 1997

9.2.1. Approach

A literature review was conducted to identify quantitative values for the indicators identified in the conceptual model, and to further define the relationships among the different identified indicators. The scope of the review included peer-reviewed literature, as well as methods manuals, agency reports, and other "gray" literature. (Number of references: 80)

The starting point for the review was the indicator list associated with the initial conceptual model (see Sections 9.4 and 3.1.1.1). However, an attempt was also made during the review to identify other indicators or functions provided by riparian ecosystems. Little additional riparian function in addition to that identified in the conceptual model was identified in the review, suggesting that the conceptual model is in general alignment with the bulk of the literature regarding the functions of riparian stands.

9.2.2. Conclusions

The conclusions are provided in two parts, one relating to research question 1A, (What are the key ecologically important attributes of a riparian site?), and research question 1B (What are the spatial characteristics that define a site)

9.2.2.1. What are the key ecologically important attributes of riparian areas:

The literature review suggested that indicators can be placed into three categories:
1) functions that can be clearly associated with a discrete, quantifiable spatial distance from the edge of the channel,
2) functions that cannot be so associated, and may be more easily or appropriately described at the watershed level, and
3) a third somewhat different category, which is useful for the indicators identified in the conceptual model which could be termed "environmental modifiers" or "contextual indicators". This latter group could include indicators which are not riparian stand attributes or watershed-level characteristics, but are physical conditions of the stream or site that will affect the function of one or more specific riparian stand attributes.

These three categories are discussed below and in Table 8 which summarizes this work.

The functions associated with the initial conceptual model that can be clearly associated with a discrete distance from the stream channel include stream shading, litter input, and large woody debris input. Stand attributes and contextual indicators that have an effect on the quality of these three functions (or how the functions are "played out") include bankfull (channel) width, tree position, tree size, and tree species. These three functions, in turn, influence a series of other functions. For example, woody debris input influences pool formation, water velocity, winter refugia for juvenile salmonids, sediment movement, etc.; and sediment movement in turn influences pool formation, spawning bed quality, aquatic productivity, etc. The primary functions of the riparian stand from which many other functions and interactions arise, however, are stream shading, litter input, and large woody debris input. The functions most directly tied to riparian forests stands and that are most prevalent in the literature revolve around stream shading, which blocks direct solar radiation keeping water temperatures low for aquatic biota, particularly salmonids; and input of large woody debris, which performs several functions, the most important of which are creation of aquatic habitat and flow modification which controls fine sediment transport (important for maintaining salmonid spawning beds), among other things. Certain other functions commonly associated with riparian zones or buffers in agricultural landscapes, such as filtering of excess nutrients or chemicals, were not discussed in the literature in detail in the context of forested landscapes. One reason that there may be few studies on excess nutrients in forest systems is that forests streams are usually nutrient limited.

Functions which may be associated with entire watershed processes or conditions rather than processes or conditions in a discretely defined riparian zone include hillslope sediment movement (and subsequent sediment input to streams) and terrestrial wildlife habitat. In general, the literature suggests that upslope processes are very important in sediment input into streams in the mountainous west, and

Table 8 Summary of indicator analysis literature review. This review is described in sections 3.1 and 9.2

Indicator (conceptual model)	Function	Relationship or value
Bankfull width	Modifier	Describes stream size, which effects size of LWD required for stability, height of riparian stand for shade, relative expected influence of riparian stand to affect shade or LWD input (on larger streams, shade is less important in controlling stream temperature, and direct wood input is less important in habitat creation). LWD length should be 1.5-2x stream channel width to be stable.
Wetted width	Modifier	Similar to above. Drainage area and flow are alternative measures of stream size, and may have advantages because they are not prone to local variation "noise" (this may also be a disadvantage), but they are not as direct a measure.
Tree Position	Indicator of LWD, organic input; shade	The closer the tree, the greater the probability it will provide shade, LWD, and organic matter to the stream. Tree size (DBH, height) and species are important "co-indicators" of LWD and organic matter input quality. Probability of LWD input nears 0 at 1 tree height distance. Maximum shading within less than about 40 meters (but tree density and height better indicators -- direct measurement is best). Tree position may also affect bank stability, in that banks with trees growing on them may be more stable. The relative importance of trees versus other vegetation in this regard is not clear. In general, vegetated banks are more stable.
Tree/stand height	Indicator of LWD input, shade	Similar to tree size. The larger the tree, the more stable the LWD. Also, the taller the stand, the more shade for the stream. Tree height and stand height may be interchangeable for shade, but not for LWD input -- individual sizes, species, and locations may be a better alternative in multi-species stands. LWD length should be 1.5-2x stream channel width to be stable.

Snags	Indicator of wildlife habitat -- not riparian specific	Snags are important for wildlife nesting, roosting, and foraging. Many wildlife species frequent or prefer riparian areas. Snag sizes or densities specific to riparian areas were not found in the literature, but recommendations exist for stands in general, which might be assumed to apply equally to riparian areas. Notable exception: snags in riparian areas are important roosting and perching locations for raptors -- no quantities noted.
Channel gradient	Modifier	Channel gradient is often, but not always, related to stream size and to geomorphic surface or soil type, and to stream substrate. Steeper-gradients streams often are more boulder-dominated, which effects the amount of LWD need for pool formation and flow modification. Steeper gradient streams are also often sediment and LWD sources rather than sinks. It is probably a poor surrogate for stream substrate or stream size, however, as a modifier of stand attribute values pertinent to those attributes. Channel gradient is directly related to the probability and travel distance of channelized debris flows in headwater ravines, and thus might be an important modifier of stand attributes effecting bank stability. Scouring generally occurs at gradients above 10 degrees and deposition below gradients of 7-8 degrees.
Hillslope gradient	Modifier, non-riparian specific	The hillslope gradient, coupled with road density and placement, soil type and geology, precipitation, and land use, effect the frequency and magnitude of sediment inputs into streams at the watershed level, most importantly in western Oregon through slides and channelized debris torrents. Most debris slides are initiated on slopes of 30-36 degrees. It may not be directly related to any riparian-specific stand function. It is part of some models of stream shading. It may be related to the probability of a tree falling into the stream, but some sources suggest it is not.
Channel canopy closure	Indicator of shading	The amount of channel canopy closure is an indicator of the amount of shading provided by the canopy, and integrates channel width and tree height and density. Optimal shading is considered to be that which approaches old-growth shade levels -- about 85% canopy closure.

Streamside surface	Indicator of soil type, plant community; modifier of stand attributes	Hardwoods are associated with floodplains and terraces, conifers with slopes, although management actions probably make this generalization functionally useless for stand categorization -- direct measurement of tree species is probably better. Geomorphic surface or soil type may be useful in determining optimal or appropriate tree species. Streamside surface is related to stream size -- larger streams are more likely to have floodplains and terraces, but it is probably a poor surrogate for stream size. Floodplains are usually depositional areas for LWD and sediment, and could thus be indirectly related to stand valuation (influence of riparian stand for wood input relatively less). No values of streamside surface related to any riparian function were observed in the literature.
Dominate cover type	Indicator of shade, LWD input	Too general to be of much use for either shade or LWD input except in most extreme instances -- tree position would cover this.
Forest Canopy closure	Indicator of shade, stand structure	Forest canopy closure may be an indicator of tree density and thus potential stream shade, although direct measurement of tree size and position would probably be better -- direct measurement of closure over the stream probably is best. Gappy canopy may related to stand complexity, but tree size distributions is probably better.
Tree species mix	Indicator of LWD input quality, organic input quality, stand complexity	Without a spatial component, (where each species is in relation to the stream) or a size component (what are the sizes of the different species), the tree species mix for the stand as a whole may be of little value in identifying LWD or litter input probability by species, except in single-species stands. Likewise, without density and size distribution by species, canopy complexity is probably only very loosely related. Actual tree position, size, and species measurements allows more quantitative analysis, or percent mix in spatially explicit bands (e.g. 5 m). Multiple species stands provide more niches for wildlife.
Forest Stand Age	Indicator of LWD input size	Forest stand age could be a generalized indicator of the probable size of LWD input, but without a tree position component may be of lesser value. Older forests generally have larger trees, more complex structure, and multiple species. Over a certain age (180+ years) forests are said to be in a natural condition -- generally considered inherently optimum. Direct measurement of tree size is also probably more directly related to LWD size. Classifying a mixed age or size class stand with one stand age is difficult.

Canopy structure	Indicator or wildlife habitat, potential LWD input	Complex canopy structure is directly related to wildlife habitat, but defining canopy structure is difficult. Tree size distributions by species may be less subject to subjective interpretation. Canopy structure can probably be related to LWD input quality in a general sense but would work best at the extremes.
Indicator -- not from conceptual model		
Tree species	Indicator of LWD and litter quality	Cedar LWD is more decay resistant than other conifers, which are more decay resistant than hardwoods. Conifer LWD is generally larger and thus more stable in stream channels (modified by channel width). Hardwoods have higher quality litter, and input LWD at a younger age than conifers. Recommendations can be found in the literature for numbers and basal area of conifers per unit stream length (perpendicular distance of about 1 site-potential tree) that should provide adequate LWD. Multiple species stands provide more niches for wildlife.
Tree size	Indicator of LWD stability, and stand complexity	Larger trees make more stable LWD. LWD length should be 1.5-2x stream channel width. Coupled with tree species and tree position, tree size can be used for direct evaluation or derivation of individual and stand cumulative LWD persistence (decay rate), LWD size, litter input quality, shade potential, stand structure, and stand species composition. The location, size, and species of the trees in a stand are the basic components that can be used to quantitatively describe or classify the stand in terms of riparian function. Individual tree data is the most direct means of such evaluation, subject to the least error through generalization. The generalizations required for estimating stand complexity, species mix, stand age, and canopy closure, although all loosely related to the same basic functions, allow for sources of error that are not encountered when individual trees are directly measured.

Pool frequency	Indicator of aquatic habitat, modifier of stand attributes	Streams with 50% or greater pool frequency are considered to have good habitat. NMFS recommends pool frequencies scaled to channel width. Habitat unit classification could be used to derive this, but pool frequency is more directly related to riparian stands, in that LWD is the primary cause of pool formation in non-bedrock- or boulder-dominated, smaller streams. Existing pool frequency can be used to evaluate existing habitat, and the degree to which LWD recruitment from streamside stands would be required to achieve acceptable frequency.
Pool-forming element	Indicator of aquatic habitat, modifier of stand attributes	The literature suggests that pool frequency is primarily related to the amount of LWD and the number of bedrock- or boulder- formed pools, although other pool-forming elements, such as beaver dams, can be significant. The number of non-LWD-formed pools could be used to evaluate the LWD input required to achieve acceptable pool frequency
Large woody debris	Indicator of aquatic habitat	LWD provides several functions, primarily formation of pools and sediment retention in smaller streams. Much of the LWD in streams can be from previous stands. Measurement of the amount of current LWD, its size, location, species, and decay class, can be used both to evaluate current conditions, and estimate stand recruitment needs over time. There is considerable literature on the relationship of LWD size to stream size, and recommended sizes and amounts.
Downed terrestrial wood	Indicator of wildlife habitat -- may be non-riparian specific	Some amphibians and small mammals are associated with downed logs. Large downed logs provide nest and den areas. Large downed logs are important in some forest communities for regeneration of trees (nurse logs). In general, downed logs are not riparian specific, although there may be some small mammals and amphibians which are found more frequently in riparian areas also have their frequency correlated with downed wood. There are non-riparian-specific recommendations for amounts and sizes of downed wood.
Aspect or Stream azimuth	Modifier	Shade from streamside stands is related to the stream azimuth or the aspect of the slope. Also effects water availability and potential or optimal plant community or tree species mix. There are other similar modifiers such as elevation, annual precipitation, temperature extremes, etc.
Soil type	Modifier	The soil type may modify the optimal plant species mix for riparian function. Certain plant species grow better on certain soils, often associated with moisture regime and soil productivity.

Shrub and groundcover	Indicator of wildlife habitat, litter input quality, bank stability, shade	Shrub litter input is very high quality. Shrubs provide nesting habitat for several species of birds and forage for large mammals; although this may be a non-riparian-specific function, some shrub communities are more common in riparian areas. Shrubs can provide stream shade and cover for aquatic organisms, but the relative importance of this to canopy shade and LWD input in forested systems may be minor. Shrub and groundcover vegetation may be important for bank stability, but the relative contribution of this to the contribution of trees (or to soil disturbances such as roads) is not known, particularly in steep 1st and 2nd order ravines where debris torrents commonly originate. Distinct shrub, groundcover, and tree associations have been related to soil type, landform, elevation, aspect, and water availability (e.g. precipitation regime). No values of shrub cover or species mix related to any riparian function were observed in the literature.

that riparian stands or buffers may have a limited ameliorating effect, although overland sediment flows associated with roads and logging may be controlled by riparian buffers. The reason for this is that the principal sediment producing processes in the mountainous west are channelized flows and mass wasting (O'Laughlin and Belt 1994). There are three general groups of mass wasting processes: slumps/earthflows, debris avalanches, and debris torrents (Swanston 1991). Slumps and earthflows are slow moving processes which develop in deeply weathered bedrocks with a dominant clay fraction, and usually are not influenced much by individual storms. Debris avalanches are shallow, rapid landslides which originate during high runoff events at steep headwalls or road cuts, rather than in the riparian zone. Debris torrents are large, powerful, fast-moving, channelized slurries originating from debris avalanches or mobilization of existing debris at high flows in steep channels. Debris torrents generally terminate at abrupt tributary junction angles (e.g. 70-90 degrees) or where there is an reduction of channel gradient to less than 6 degrees. Riparian buffers have little impact in reducing debris avalanches or channelized flows (Belt and O'Laughlin 1992). In the Alsea Watershed Study, where stream temperature in a watershed with riparian buffers was similar to the control watershed, sediment loads in the buffered watershed increased significantly following road construction (Moring and Lantz 1975), although not as much as in the clear-cut watershed with no buffers. The integrity of the vegetation on sites prone to debris avalanches may be an important factor in reducing sediment delivery to streams. Other researchers (Andrus, pers. com.) note that debris torrents only occur in limited areas, and that the most common sediment input processes are continual bank undercutting and soil creeping or slumping. Bank stability is sometimes related to streamside vegetation, but the relative influences of trees vs shrubs vs ground cover was less clearly defined in the literature, although ground cover vegetation directly on the bank itself at a limited spatial scale may be an important component. Regardless, in forested ecosystems west of the Cascade Range, sediment input to streams is likely to be as influenced by watershed-scale conditions or processes as it is by immediate bankside vegetation.

Attributes of the riparian zone that have been identified as being responsible for the greater wildlife diversity and disproportionately higher wildlife use in these areas are diverse vegetative structure and species, and the presence of food, cover, and water (Bull 1978). Other edge habitat within the watershed with similar vegetation characteristics may also show this trend, however. Because of the diverse ecological niches occupied by different species of wildlife, it is not possible to identify a single set of habitat characteristics optimum for all species. Several authors emphasized the need for between stand vegetation diversity (e.g. Kauffman 1988), although most studies focused on wildlife abundance related to within-stand vegetation diversity. Spatial buffer width requirements were generally species specific, and it was unclear whether such requirements were applicable only in the riparian zone or whether they were generalized spatial habitat requirements. Many literature sources did not specifically address wildlife habitat in the riparian zone, but rather in a non-riparian-specific context (e.g. Ruggiero and others 1991). One notable exception to this is where a wildlife species may be dependent on riparian zones for habitat, and in that case the particular habitat characteristics in the riparian zone may be a spatially distinct function of the riparian forest stand. Demonstration of dependence on riparian habitats, rather than simply a preference for those habitats, was not strongly supported. The literature (e.g. Cross 1988; Raedeke and others 1988) suggests that some small (e.g. water vole) and large (e.g. beaver, otter) mammals may be restricted to, or considered dependent on, riparian habitats, but it is unclear whether it is simply the presence of water that is responsible for the association, or some specific habitat attributes of the riparian vegetation found only in those areas. There are also documents which suggest that snags and other perches in the riparian zone are important for raptors (e.g. Knight 1988). Riparian areas are the preferred habitat of reptiles and amphibians in the Pacific Northwest, but none appear to be obligatory riparian species for which breeding and cover requirements are found only in the riparian zone, although some are dependent upon water (Bury and Corn 1988). Because of the relative importance of riparian vegetation for litter input and shade in headwaters and creeks in the Pacific Northwest, the streamside vegetation can be considered to act as part of the aquatic ecosystem for these smaller waters, and so far as the herpetofauna is concerned the aquatic and riparian zones are functionally one unit (Bury and Corn 1988). Species dependent on water in these areas could thus be considered to be dependent on riparian vegetation. One study (Carey 1988) in the Oregon coast range showed no pattern of positive or negative upland avian community response to stands with the presence of water, although several individual species showed some positive response to stands with water, depending on the stand condition and time of year.

For both sediment input and wildlife habitat, the riparian zone may not be functionally distinct from the upslope ecosystem, and the function may be related to the riparian zone primarily in that the riparian zone is a part of the entire drainage. Within the riparian zone, as well as upslope, however, the stand attributes which both help control sediment delivery and provide wildlife habitat are centered on intact, structurally diverse plant communities, which can be related to tree (and snag) density and size by species, and associated shrub and ground cover communities.

Indicators in the conceptual model that could be considered environmental modifiers or contextual indicators include bankfull channel width, wetted channel width, channel gradient, and hillslope gradient. There are also a large number of similar modifiers which were not specifically identified in the conceptual model, including elevation, soil type (perhaps indirectly identified by streamside surface), annual precipitation, underlying geology, aspect (perhaps indirectly identified by stream azimuth), etc. These environmental variables influence site vegetation and physical processes, and may have a direct or indirect effect on the functions of the riparian stand, in that in a different environmental context the stand attributes or indicators may need to have different values or quantities to be at a specific functional level. For example, a piece of large woody debris must be a larger size in a larger stream to be stable enough to modify stream flow, and bankfull width is a descriptor of stream size, thus bankfull width might best be considered a modifier of a stand attribute (tree size) which is an indicator of a function (LWD input). Certain environmental modifiers were discussed more frequently in the literature than others, usually in conjunction with specific functions. Noteworthy in this regard is the importance of channel width (or more loosely, stream size) relative to the importance of streamside vegetation for temperature control; and relative to the importance of LWD (and its size) in creating diverse aquatic habitat and modifying flow and fine sediment transport. Wildlife species ranges could also be considered an environmental modifier of sorts, and such a perspective may reflected in the different riparian buffer requirements by most regulatory agencies for fish-bearing versus non-fish-bearing streams. It may be appropriate to gather data in the field or from remote sensing for a limited number of site-specific environmental modifiers that have a direct linkage to riparian stand attributes, while data for others might be best acquired from other sources.

Table 8 lists the indicators in the conceptual model, the type or function of the indicator as described above (riparian-specific, non-riparian-specific, or environmental modifier), and any qualitative relationships of quantifiable values associated with the indicator. Selected other indicators, functions, attributes, or modifiers are also identified.

9.2.2.2. What are the spatial characteristics that define a site?

9.2.2.2.1. Riparian Width

Riparian stand indicators or attributes are functionally important in varying perpendicular distances from the streambank depending on each specific function associated with the attribute (attributes may influence multiple functions), although the importance appears to be greatest nearest the channel edge, and sharply dropping to a distance equal to about 1 site-potential tree height (See e.g. Figure 1). Woody debris input (McDade and others 1990) and stream shading (e.g. Brazier and Brown 1973) models which identify the distance from the stream for these functions as being about 1 site-potential tree height and about 30-40 meters respectively, are well represented in the literature. Root wads, which greatly increase the stability of woody debris and which may constitute up to 40% of the total LWD volume in the channel, are recruited within a spatial distance of about 6 meters from the channel (Andrus, pers com.). FEMAT notes that no spatial distance relative to litter input to streams was found in the literature, but citing studies by (Erman and others 1977) which report than benthic invertebrate communities in streams with 100 foot buffers were indistinguishable from those with intact forests, conclude that the spatial distance for litter input is also within about 1 site-potential tree height. Other literature reviews suggests that most of the functions described in the conceptual model operate within a distance of about 40 meters from the streambank (e.g. Johnson and Ryba 1992). As mentioned above, certain riparian functions, such as terrestrial wildlife habitat, microclimate modification, and sediment input may be important farther away, perhaps in a manner which does not make it possible to distinguish between riparian stand function and upslope stand (or entire watershed) function.

9.2.2.2.2. Riparian Length

Defining a riparian site spatially along the stream is much more difficult than defining riparian width. Stream length (parallel) distances for any riparian function was not found to be addressed often, with the exception of some pool and wood quantities optimal per mile of stream, and distances for water to cool under a canopy after passing through a clear-cut (*National Marine Fisheries Service* 1995; Robison and others 1995). Researchers have suggested that for stream temperature control and LWD recruitment, the length of the stream that should have a certain set of stand attributes should reflect the natural proportion of that set of attributes along the stream length (Andrus, pers. com.). For example, if the natural, historic condition of a stream was mature conifer stands along 80% of its length and alder stands along 20%, that proportion should be the target condition. From this perspective, riparian conditions cannot be evaluated exclusively at the stand level, but each stand must be considered in the context of the entire stream length. Applying a single set of stand attributes along the entire length of a stream would result in a riparian zone with no along-stream spatial heterogeneity (regardless of the within-stand heterogeneity), which would probably not reflect the natural riparian system because natural riparian systems are typically characterized by frequent disturbance resulting in a mosaic of different stand types. Regardless of the target proportion of a stream's entire length for a given stand condition, however, it is important to identify, if possible, a stream length distance which will allow for appropriate measurement of the stand attribute. For describing riparian areas, some researchers have suggested that the stand may be the appropriate scale, and each distinct streamside stand should be characterized. Within a stand, the number and length of plots to describe it may be related to its heterogeneity; for most stands which were initiated by a single event, a relatively limited number of measurement sites may be representative (Andrus, pers. com.).

9.3. ADAR Imagery

by John Runyon, Mantech Corporation from (RIM Research Group 1996)

Digital imaging systems, typically using a two-dimensional detector array of charge-coupled devices (CCDs) or a scanner technology, provide a means of direct digital image collection. Currently, though the image resolution of digital imaging is quite good, the images are not as detailed as large scale photographic film (Light 1996). The resolution of digital sensors is currently limited by the capabilities of the CCD arrays and scanner configurations. In addition, very little work has been done to assess the geometric quality of digital images in photogrammetric applications were photography is the standard medium (Heipke 1995). Planned deployment of 1-meter resolution satellite imaging systems means that high-resolution digital imagery will soon be available for a variety of applications. Both single channel and multi-spectral satellite sensors are under development, with launches projected for the end of this century (Corbley 1996).

High resolution digital imagery will be collected to test the current technology and to explore the implications of detailed satellite sensors. Multispectral sensors will be used to assess the value of the additional spectral data. The system will employ four sensors to capture imagery in separate bands selected to mimic the spectral range of LANDSAT TM imagery. The spectral range of TM was chosen for two reasons. First, the study area has current TM coverage (e.g. Cohen and others 1995), which will facilitate examining the issues of scaling from the fine resolution digital to the 30 m satellite pixels. Secondly, because there is a rich source of historical LANDSAT imagery available for the region, this spectral range will continue to be an important source of data. The digital imagery will be selected with the following bands:

Band 1:	Blue	450 - 520 nm
Band 2:	Green	520 - 600 nm
Band 3:	Red	630 - 690 nm
Band 4:	NIR	760 - 900 nm

Imagery was collected at two pixel resolutions in phase 1: 1 meter and 3meters.. Phase 2 imagery will be restricted to 1 m resolution pixels since preliminary indications are that this resolution provides a better ability to detect features of interest. These resolutions will provided a reasonable range for testing. One meter pixel imagery is a common resolution target for digital imagery capture. This resolution also closely corresponds with the pixel resolution of 1:24000 aerial photography scanned at 600 dpi (1.01 m). Digital sensors vary in their configuration, but a typical system such as Positive System's (Whitefish, Montana) ADAR system has an array of 1000 by 1500 imaging elements. This system provides an image area at 1-meter pixels of 1000 m by 1500 m (150 ha).

[See also (Benkelman and others 1990; Benkelman and others 1994; Waring and others 1995; Hyyppa and Hallikainen 1996; Stille 1996; Positive Systems April 10, 1997)]

9.4. Conceptual Development of Riparian Indicators of Forested Landscapes

by Lynne McAllister, Mantech Corporation[14] from (RIM Research Group 1996)[15]

9.4.1. Site-Scale Riparian Indicator Identification

[14]Now with Dynamac Corporation

[15]Taken verbatim, except for explanatory footnotes and changes in figure and table numbers to match the figure numbering in this document.

9.4.1.1. Introduction

This task contributes to fulfilling objectives 1 and 3. Riparian sites will be characterized by quantifying attributes that can be used to evaluate three riparian values: aquatic habitat support, terrestrial habitat support, and water quality maintenance. The research project focuses on method development for characterizing sites with remotely-sensed information. It is not designed to test the suitability of indicators for evaluating functional attributes or to conduct actual functional assessments rather it is the intent to evaluate the capabilities of various data-capture technologies to characterize identified attributes. It is therefore necessary to carefully design the conceptual framework based on existing information and use it to provide the ecological foundation and rationale for 1) the selection of indicators that can be used to evaluate functions and 2) the linkages of selected indicators with functional performance. This section presents conceptual models and justification for selection of indicators that can be measured both on the ground and from the air

The riparian indicators described here are preliminary and are intended to structure the research process. These indicators are intended to describe a limited but not complete set of ecological interactions. The indicators were selected based on their link to ecological function and feasibility for detection with remote imagery. The spatial nature of the indicators, in relationship to ecological function, is discussed in more detail in Section 3.1. The indicators will be modified in Phase 2 based on the analysis of data from Phase 1 of the research.

9.4.1.2. Objectives

The objectives of this task are to:

- Develop a framework for addressing ecologically relevant objectives, particularly those of FEMAT,
- Develop conceptual models for three functions to describe the linkages between and rationale for the primary functional attributes and indicators of functional performance,
- Identify indicators that relate unambiguously to their respective functions,
- Select metrics for quantifying indicators.

The conceptual models represent one possible framework for organizing information, showing linkages among ecological components, and justifying proposed indicators. They are a simplified way to describe a complex interaction of ecological components. Their purpose is not to be the single definitive representation of all ecological interactions in a riparian system, but to provide structure, guidance, and rationale during the assessment. The classification scheme to be presented in the next task emphasizes structural and compositional features of vegetation that relate to indicators of ecological function for a range of streamside sites. The classification scheme is designed to provide sufficient information on riparian overstory vegetation characteristics and proximity to the channel to help gauge the type and magnitude of interaction with the stream. This information is useful in the interpretation of the analysis of function performance. While the defined classes are intended to emphasize riparian-stream linkages they will also offer insight into terrestrial features such as near-stream wildlife habitat.

9.4.1.3. Conceptual Design

9.4.1.3.1. Task Objective 1

The FEMAT Aquatic Conservation Strategy Objectives (Table 1) can be addressed through the evaluation of three general riparian values: aquatic habitat support, terrestrial habitat support, and water quality maintenance. The relation of the FEMAT questions to riparian values is self evident. This is the general framework that ties monitoring objectives and questions to a quantifiable procedure for assessing riparian values.

9.4.1.3.2. Task Objectives 2 and 3

The conceptual models provide the framework for quantifying and assessing riparian functions. Each conceptual model is presented in a subsection below. A consistent terminology will be used to distinguish different components of the models (see glossary -- Section 9.7). Attributes are characteristics of the riparian system that are considered important for providing a specific value. Each value is described with three major attributes. For example, the major attributes of aquatic habitat are considered to be structure of bed/banks, coarse/fine organic matter inputs, and water temperature. The models list the ecological processes and characteristics under each attribute that influence functional performance. Indicators are characteristics of the system that can be measured to quantitatively describe an attribute. For example, vegetation distance from the channel is an indicator for the amount of organic matter input to a stream. Some indicators can be used to describe attributes of more than one function, but it is the aggregate of indicators that is important for evaluating functional performance. Indicators are not the actual metric for measurement. Selected metrics are presented in Section 3. Specific field protocols are presented in a field operation manual, which is a separate document.

The indicators that we propose are those that we have selected from a larger pool of potential indicators that can be measured to describe a process or attribute. Our choice of indicators from the larger pool was guided by the following criteria: 1) For comparison purposes, the indicator must be feasible to measure in the field and from remote imagery, and 2) The indicator must appear to be more desirable for remote monitoring than for field monitoring. These criteria eliminate from consideration many measurements that are traditionally used in the field. For example, incident light over the stream and water temperature can be best measured directly in the stream with light and temperature meters, but this is not possible with remotely-collected information. Rather, it must be inferred more indirectly by estimating the extent of canopy that shades the stream. Bank structure and microhabitat can be described in detail on the ground by measuring bank morphological characteristics, but it must be inferred from aerial imagery based on potential bank stability created by associated vegetation. Vegetation structure can be estimated with various field techniques which consider all layers within a forest, including understory trees and shrubs and herbaceous ground cover, most of which are not visible on aerial imagery. Therefore, surrogate measurements that can be extracted from aerial imagery, such as the number of canopy layers and number of snags, must be used.

9.4.1.4. Conceptual Model for Aquatic Habitat

The conceptual model for aquatic habitat is shown in Figure 6. The riparian attributes considered important for defining aquatic habitat in the Coast Range ecosystem are 1) structure of streambeds and banks, 2) coarse and fine organic matter input, and 3) water temperature.

9.4.1.4.1. Structure of Beds and Banks.

As depicted in the model, the structure of streambeds and banks influences bank stability, retention of sediment and organic matter, and the presence and extent of flood refugia. The following discussion of each of these includes a description of the indicator(s) that will be used to describe them.

Bank stability influences sediment and organic matter (course and fine debris) inputs to the stream. Stable banks typically are well-vegetated (Sullivan and others 1987). A complex rooting system helps prevent erosion of the bank and contributes to the formation of a diversity of aquatic microhabitats. The development of a complex rooting system is dependent on the succession stage of the bank cover. Older stands of trees have more developed and complex root systems and are generally more effective in stabilizing banks. Erosion of unstable banks, caused by disturbances on the hill slopes, can be detrimental to aquatic habitat by burying fish spawning sites and aquatic insect substrates. Continuous sedimentation leads to turbidity, which is detrimental to some species of fish and can affect temperature and primary productivity in the stream. Bank stability can also contribute to the formation of microhabitats under banks, which provide protection and shade for aquatic organisms. Because bank stability is closely related to the proximity of vegetation and complexity of the rooting system that forms much of the bank structure, the site-level indicators that will be used to measure bank stability are tree distance from the channel and forest stand age. Both of these indicators can be measured on aerial photographs.

Retention of sediment and organic matter that is input to streams is important for providing nutrients and microhabitats essential for aquatic organisms. Sediment can transport nutrients to the stream that are cycled and utilized by aquatic organisms. A certain degree of sediment retention is also important for maintaining spawning surfaces and other microhabitats on the streambed that are utilized by insects and fish (Bilby 1988). Large woody debris contributes primarily to microhabitat formation and channel morphology (Sullivan and others 1987). It can change flow direction and speed, thus forming pools, contributing to the retention of sediments, and enhancing aquatic habitat diversity and structure. Pools are essential to aquatic organisms for refugia and breeding. Habitat structure and diversity promote abundance and species diversity of aquatic organisms.

Retention is influenced by the amount of stream energy that moves materials through the system, which depends on the streamside surface. Streamside surface encompasses valley landform and constraint. Clear delineation of streamside surfaces, which provides information about position in the riparian area, is necessary for interpreting riparian vegetation patterns (Hupp 1988), which can indicate the likelihood that the system is disturbed and might not be maintaining processes necessary for normal function. There is evidence, for example, that specific streamside landforms are characterized by distinct zones of riparian vegetation (Fonda 1974; Hawak and Zobel 1974; Rot 1995). Floodplains, which are more likely to occur in unconstrained valley segments, are the most disturbance prone and are often colonized by fast-growing deciduous species such as alder. Conversely, deciduous species along streams in constrained valley segments may suggest past harvest practices (Bilby and Ward 1991).

The degree of valley constraint helps determine the freedom of the channel to adjust its shape and gradient and helps determine the magnitude of interactions with riparian vegetation and hill slope processes. Streamside surfaces can vary from broad and flat (unconstrained) or steep and narrow (constrained). Constrained reaches tend to move wood and sediment through the stream system. Unconstrained reaches are more retentive and thus become long-term storage sites for sediments and large wood (Montgomery and Buffington 1993). Unconstrained stream segments often have wide floodplains and side channels. The bed and banks of unconstrained channels are usually composed of material transported by the stream which usually results in more complex streamside surfaces (Sullivan and others 1987; Montgomery and Buffington 1993). More complex streamside surfaces result in a greater number of microhabitats for aquatic organisms, which provide diversity, protection, and spawning habitat. Valley width can determine if hill slope processes are directly coupled to the stream system. Narrow valleys, for example, can channel debris flows directly into the channel (Benda 1990; Bradley and Whiting 1992). In situations with wide valley floors debris flows coming off of the slopes can rest on the valley bottom without directly entering the channel, increasing retention in the system. A steeper channel gradient results in more energetic flows, which can dislodge sediments and woody debris and carry it downstream. The indicators selected for retention of sediment and organic matter are streamside surface and channel gradient. Bankfull channel width is an indicator for the degree of valley constraint, and channel gradient is an indicator of the potential flow energy.

Flood refugia refers here to areas in which floodwaters can dissipate and where fish can find refuge from flow energy until floodwaters subside so that they are not forced downstream. As discussed above, water dissipates and flow rates are lower in wide, unconfined channels and in channels with a lower gradient. The indicators for flood refugia will thus be streamside surface, which measures the degree to which water can dissipate outward from the channel during floods, and channel gradient.

9.4.1.4.2. Coarse and Fine Organic Matter Inputs

Coarse and fine organic matter inputs influence nutrient cycling, microhabitats such as pools and refugia, and channel stability. Fine woody debris, leaf litter, and cones contribute food for some species of aquatic insects, which process it for use by other species of insects. Insects are in turn prey for fish. Nutrients are thus processed and cycled through the food chain, supporting numerous and diverse aquatic organisms. Conifer and deciduous trees have different patterns of litter input to the system. Needle fall occurs throughout the year, while leaf fall occurs primarily in the autumn (Murphy and others 1991). The input and stability of large wood entering streams is influenced by tree type. While conifer species vary in their decay rates, they generally decay slower than deciduous species, and they are usually longer and larger in diameter (Harmon and others 1986; Bilby and Ward 1991). Indicators selected for the likelihood of input at a site are tree distance from channel, dominant cover type, and forest canopy closure; indicators selected for the amount and type of organic matter inputs to streams are tree species mix, forest stand age, and tree height.

Organic matter is input to a greater extent and on a more regular basis by trees that are closer to the stream. Nutrients are input directly to the stream and are directly available to aquatic organisms if the organic matter falls there to begin with. The tree species present influence the type of organic matter input. For example, large woody debris input is more likely in conifer stands than in hardwood stands, although leaf litter input in more likely in hardwood stands. The dominant cover type (i.e., non-vegetated or vegetated by trees, shrubs or grass) affects the relative amounts of fine litter and wood that can potentially enter the stream and therefore the nutrient input and degree of cycling in the stream system and potential microhabitats within the stream. Forest stand age and tree height affect the ability of the riparian area to contribute large wood to the aquatic system. Older, taller stands contribute a more volume of wood, which directly affects stream habitat creation (Bilby and Ward 1991). Large wood decays slower than smaller pieces, promoting a greater permanency of the habitat created. Canopy closure is an indicator of tree density, which, when combined with information about tree species mix and forest stand age, helps determine potential for large wood loading, root strength, and nutrient inputs (Vannote and others 1980).

9.4.1.4.3. Light and Water Temperature

Light and water temperature, the third attribute of the aquatic habitat support function, influences community structure of aquatic organisms, primary production, and microclimates important for breeding and refugia (Figure 6). Water temperature influences the metabolism, development, and activity of stream organisms, which are adapted to live and breed in specific thermal environments. The regulation of temperature in streams is essential for some aquatic organisms. Water temperature also affects oxygen availability, which is important for maintaining the communities that are adapted to live in a particular oxygen regime. The amount of light reaching the stream surface affects primary productivity , which influences water turbidity and the community of aquatic insects. Water temperature is expected to be lower in smaller and narrower, low-order streams, which occur at higher elevations. These streams are normally narrower than higher order streams, and trees along banks form a full canopy over the stream. Small streams have relatively cool but stable daily temperatures and low rates of primary productivity (Vannote and others 1980; Beschta and others 1987). In wider, mid-sized streams, the riparian canopy is less extensive, which allows more radiation to reach the stream. However, as rivers grow in size, their depths tend to increase, which restricts the warming of the entire water column. Characteristics of the adjacent riparian forest also affect evaporation, convection, conduction, and advection in the riparian system (Naiman and others 1992). For example, openings created in the forest alter the heat exchange with the atmosphere, which reduces the stability of the stream temperature. The influence of light and temperature on aquatic habitat support must be evaluated simultaneously with position in the stream network, taking into consideration the organisms expected to be present and their habitat requirements. The indicators that will be used at the site level for water temperature are forest canopy closure, channel canopy closure, and wetted channel width.

9.4.1.5. Conceptual Model for Terrestrial Habitat

The conceptual model for terrestrial habitat is shown in Figure 6. The primary riparian functional attributes that affect terrestrial habitat are vegetation structure, type and extent of vegetation, and streamside topography. The discussion of each of these below includes proposed indicators for evaluating the function.

9.4.1.5.1. Vegetation Structure

Vegetation structure influences habitat diversity and edge. Edges typically represent ecotones, which are rich in wildlife because of their diversity. Wildlife use of a habitat for nesting and cover is largely dependent on the structure of vegetation (MacArthur and MacArthur 1961; Wilson 1974; Roth 1976; Swift and others 1984).

Increased horizontal and vertical structure provides a greater diversity of nesting, feeding, and protective habitats than does a uniform structure, and it allows the coexistence of more diverse and abundant wildlife populations. A variety of canopy layers, canopy openings, and vegetation forms help to create edges, ecotones, and diverse patch types, all of which enhance habitat diversity. The indicators chosen for vegetation structure are canopy structure and forest canopy closure.

A simple canopy structure has few gaps and only one canopy layer of the overstory trees. Complex canopies, in contrast, have multiple canopy layers, numerous gaps, and usually a number of snags and dead crowns in the stand (Spies and Franklin 1991). Complex canopies are associated with old-growth forests (Franklin and Spies 1991). Young stands, however, often have complex canopy composition as well. Disturbances are important for creating complex stand structures. Stands initiated through harvest usually have a simplified canopy structure.

The extent and interspersion of different cover types (trees, shrubs, grasses) influences habitat diversity, interspersion of habitats, and edges or ecotones available, which are all structural attributes of the vegetation. A greater diversity and interspersion of habitats vertically and horizontally promotes wildlife abundance and diversity and ensures that different types of habitat are available, for example feeding habitat, breeding habitat, wintering habitat, and shelter from predators. Ecotones are often found where one general habitat type changes to another, such as the change from forest to a grass/shrub habitat. Forest canopy closure is the proposed indicator for the interspersion of different cover types. An intermediate canopy closure is likely to have gaps and openings that are associated with the presence of younger trees, shrubs, or herbaceous vegetation.

9.4.1.5.2. Type and Extent of Vegetation

The type and extent of different kinds of vegetation influence breeding sites, protection, and travel corridors, all of which are important components of terrestrial habitat support. Wildlife needs a diversity and interspersion of these components. Although this study will not collect species-specific information on vegetation, some general categorizations of vegetation type can provide information on the potential for habitat support. Indicators selected for type and extent of vegetation are dominant cover type, forest stand age, and snag position and number.

Dominant cover type can serve as an indicator of protection and breeding sites. A site providing minimal cover will not provide either of these habitat components as well as a more vegetated site, although it might still provide enough cover for travel protection. A site dominated by shrubs might provide excellent dense cover for protection and breeding habitat for some species. A site dominated by grasses is less likely to provide a diversity of breeding and protected habitats or travel access, except for very small wildlife. Forest stand age is an indicator of the successional stage of the site, which can affect vegetation density and continuity of protective habitat. Snag position is important for use as breeding sites. Osprey, for example, prefer nest sites close to the channel. The number of snags is also an indicator of potential nesting habitat for other species of birds.

9.4.1.5.3. Streamside Topography

In the conceptual model for terrestrial habitat support (Figure 6), streamside topography is shown to influence accessibility, and habitat extent and diversity. Accessibility describes the potential for mammals in particular to use the site as habitat for breeding, foraging, protection, and travel. For many species of wildlife, a very steep slope would likely be a less suitable habitat than an area in a broader, flatter valley. Steep slopes receive more disturbance and are often not vegetatively diverse. The indicator for accessibility will be hillslope gradient.

Habitat extent and diversity is a function of the width of the valley and its potential vegetative diversity. Wider valleys provide a greater extent of usable habitat that is directly associated with a riparian area. It provides easier access for travel by mammals and is less prone to catastrophic disturbances than steep, narrow valleys. A greater number of vegetative zones can potentially develop in different levels of a wider valley, forming a more complex and diverse plant community, which has a greater potential for providing breeding sites, foraging habitat, and travel routes for terrestrial wildlife. The streamside surface will serve as the indicator for habitat extent and diversity.

9.4.1.6. Conceptual Model for Water Quality

The conceptual model for the water quality is shown in Figure 6. The water quality function is distinguished from the aquatic habitat function by focusing solely on characteristics and processes in the riparian system that influence sediments and nutrients in water used as aquatic habitat and for human consumption. The riparian functional attributes that affect water quality are physical structure and type and extent of vegetation. The discussion of each of these below includes proposed indicators for evaluating the function.

9.4.1.6.1. Physical Structure of the Bed and Banks

Physical structure influences bank stability, retention of sediment, and retention of organic matter. Bank stability affects erosional deposition of sediments into the stream. A complex rooting system in contact with the channel helps stabilize banks and affects the amount of sediments that will dislodge during storm events. The indicators selected for bank stability are tree position and forest stand age.

Retention of sediment and organic matter in the system influences water quality downstream. Excessive sediment loads are detrimental to aquatic habitat and drinking water. Organic matter, particularly large woody debris can increase maintenance costs of small drinking water reservoirs downstream. Retention of materials in the system keeps nutrients important for aquatic organisms in the system and prevents water quality problems for drinking water supplies. The retention of the leaves near their origin helps prevent water quality problems downstream. Retention is influenced primarily by the landform and the potential for materials to be moved out of the system during storm events. Steeper, constrained valleys allow disturbance events to move materials through the system. The indicators for retention will be streamside surface, hillslope gradient, and channel gradient.

9.4.1.6.2. Type and Extent of Vegetation

As shown in Figure 6, the type and extent of vegetation influence hillslope erosion and nutrient inputs, which in turn affect water quality. Hill slopes with denser, more well-developed vegetation have a greater capacity to buffer the stream against sediment and nutrient inputs. They show less erosion than those with less vegetation or with younger vegetation which has less developed root systems. The vegetation indicators that will be used to describe the potential for hillslope erosion are dominant cover type and forest stand age. Both of these indicators describe the development of the forest vegetational structure and root system and the ability of the vegetation to attenuate erosion on the hill slopes.

Nutrient inputs are influenced by the type and extent of vegetation and its position relative to the stream, which affect the kinds and amount of litter that are input to the stream. The type of vegetation can be described by the extent and type of cover type (e.g., unvegetated, forested, or shrubs/grass) and the dominant tree type (coniferous, deciduous). The leaf litter of some hardwoods, such as alder, can cause excessive tannin and nutrient loads, which can be a problem where water is impounded for drinking supplies. The indicators that will be used to describe nutrient inputs at a site are tree species mix, dominant cover type, and tree position.

9.5. Request to the Civilian Applications Committee for the acquisition of remote imagery in the Drift Creek Basin (Dated November, 1996)

1. Site Name: Drift Creek Basin, Oregon

2. Site Location: Watershed bounded by the coordinates on attachment 1

3. Description of Existing Research at this site:

Research at this site includes intensive field work at 24 sites and the collection of fine resolution unclassified remote imagery (e.g. CIR photography at 1:4,000, ADAR imagery with 4 bands matching the TM visible spectrum bands with 1 and 3 m pixel resolution) to compare the ability of different technologies to describe riparian ecosystems. The methods are compared in terms of their ability to describe the ecologically important features of the forested riparian system (tree species composition, ground topography, forest canopy structure) and the adjacent stream condition (width, depth, bottom texture, large wood in the channel). A high and known degree of precision and accuracy in each of these parameters is desired. For example, we wish to be able to be able to identify the species of each tree and its position relative to the stream within 2 m. Some of the analyses are done using a Helava-Leica Digital Photogrammetric Workstation

4. Type of Technology

A. Fine resolution stereo imagery in the visible spectrum or digital imagery with bands matching TM bands.
B. Fine spatial resolution thermal infra-red to identify the stream boundary, stream condition, and the influence of stream waters over adjacent land.
C. Fine resolution laser altimetry or other active sensor that can describe the ground topography and the forest canopy structure

5. Area of Coverage

Maximum

A, and B. Entire Drift Creek Basin as described in attachment 1
C. Transects 1000 m long perpendicular to the stream azimuth at each of the 24 sites listed in attachment 1.

Minimum

A, and B. A 1000 m radius around the 25 sites listed in attachment 1, or as many of the 24 sites as possible.
C. Transects perpendicular to the stream azimuth through as many of the 25 sites as possible.

6. Resolution

Maximum (=finest)

A. 1 m
B. 0.25 m
C. 0.1 m vertical, 0.5 m horizontal

Minimum

A. 3 m
B. 1 m
C. 1 m vertical, 3 m horizontal

7. Frequency

A. On a sunny day within two hours of solar noon between June 1, and July, 10; and on a sunny day within an hour of solar noon between December 1 and April 15. Every year

B. On a sunny day within an hour of solar noon in between June 1, and July 10, and on a sunny day after leaf off in November within an hour of solar noon

C. Once every three years at each 3 year interval once in mid-summer and once in mid-winter

Contact:

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Attachment 1

The Drift Creek Basin is circumscribed by the following points:

1	-124.015282	44.425362
2	-123.936836	44.426617
3	-123.849464	44.431984
4	-123.773071	44.465324
5	-123.775101	44.495182
6	-123.765678	44.525703
7	-123.792046	44.537827
8	-123.835403	44.535172
9	-123.872581	44.557152
10	-123.910782	44.538109
11	-123.885017	44.513126
12	-123.929047	44.502235
13	-123.973701	44.480778
14	-124.006912	44.461746

UTM Zone 10 Coordinates of 25 field sites in Drift Creek. Datum is NAD 27.

UTM-x	UTM-y
420544	4920864
428337	4931186
427792	4927832
433215	4923114
436786	4931310
428228	4926744
438071	4928020
433283	4929197
436380	4927681

421927	4922783
437182	4929941
425001	4924962
432399	4931824
435312	4930840
432306	4926169
421393	4923581
424330	4924888
434642	4923296
435216	4930792
427684	4927492
435648	4930744
433421	4929176
424408	4924648
432060	4932336
433421	4929176

Datum is NAD27.

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9.7 Glossary

ADAR Airborne Data Aquistion and Registration.

Altimeter An active microwave or laser remote sensing system used primarily for oceanic research. An altimeter provides data by measuring the interval between an emitted signal and its echo.

Analog Data Remotely sensed data that is captured on film.

ATM Airborne Thematic Mapper.

AVIRIS Airborne Visible/Infrared Imaging Spectrometer

AVNIR Advanced Visible and Near Infrared Radiometer.

Band 1) An area adjacent to a stream, and 2) in remote sensing terms, an area within the electromagnetic spectrum which is used for obtaining spectral information on a target.

BDR Bi-directional reflectance.

CASI Compact Airborne Spectrographic Imager.

CBERS China-Brazil Earth Resource Satellite.

Classification Scheme A system of grouping land cover units based upon common attributes. For example, the United States Geological Survey Anderson system.

Conceptual Model A means for relating riparian characteristics to indicators of those characteristics.

CWD Coarse woody debris

DBH Diameter at Breast Height.

Digital Data Remotely sensed data that is acquired in digital format.

Digital Photogrammetry The technique of obtaining quantitative information and measurements from photography.

Disturbance Any process which interrupts the existing functioning of an ecosystem.

EOS AM-1 Earth Observing System Ante Meridian (10:30 AM equator crossing).

Ecological Attribute A physical characteristic that plays a role in ecosystem functioning.

Ecological Process Events in which a significant interaction between biotic and abiotic components of the ecosystem occur. Examples include disturbance, nutrient cycling, productivity.

Ecological Values The broad set of goods or services that an ecosystem provides. For riparian systems, these include: Aquatic Habitat, Water Quality, Terrestrial Habitat.

Ecoregion A landscape of relatively homogenous character as defined by a balance between geology, climate, hydrology, and ecology.

Ecosystem Diversity Pertains to number and distribution of ecosystems within a landscape.

Emerging Technology A technology that has not been implemented, tested, and verified.

Error Matrix A commonly used method in remote sensing to assess the accuracy of a classification in which ground data and classified data are compared. Errors of omission and commission can be obtained from this matrix.

Field Approaches *In- situ* methods for acquiring information about riparian areas. As opposed to remote sensing approaches.

Forest Plan The President's Northwest Forest Plan as defined by United States Department of Agriculture Forest Service and Department of Interior Bureau of Land Management (1994).

Functional Attributes Patterns, structures, or processes that support ecological values.

Geomorphic Feature Physical characteristics of land forms. In riparian systems geomorphic features include channels, flood plains, slopes, and terraces.

GIS (Geographic Information System) A computer based system for managing, analyzing, and displaying spatial information.

GPS Global Positioning System

Grain The scale at which a feature is observed.

Ground Truth See Field Approaches

IFSAR Interferometric Synthetic Aperature Radar.

Indicator "Any environmental measure that can be used to quantitatively estimate the condition of an ecological resource" (Barber, 1994).

Intermittent Stream A stream that does not flow continuously.

IRS-1D Indian Remote Sensing Satellite.

JPL-AirSAR Jet Propulsion Laboratory Airborne Synthetic Aperature Radar.

Landscape A heterogeneous land area composed of interacting ecosystems that is repeated in similar form throughout. (from Forman and Godron, 1986)

Mature Technology A technology that has wide acceptance and its advantages and disadvantages are widely recognized.

Measurements Quantitative descriptions of an object.

MIVIS Multi-spectral Infrared and Visible Spectrometer

Operational Technology A technology that is currently used on a regular basis, yet is still evolving.

NIR Near-Infrared

Non-Technological Criteria Criteria that cannot be obtained objectively.

Northwest Forest Plan See Forest Plan

PCQ Point Center Quarter

Photogrammetry The technique of obtaining information and estimates from photography.

Pixel The smallest fundamental unit in digital remote sensing analysis. The pixel size is synonomous with the instantaneous field of view of the sensor in digital image processing and is related to spatial resolution (c.f. spatial scale).

Plot The unit of spatial coverage for detailed collection of data.

President's Northwest Forest Plan See Forest Plan.

Province a landscape of relatively homogenous character, approximated by ecoregions.

Reach, or Stream Reach A stretch of stream within a geomorphically homogenous unit; a stretch of stream within one watershed.

Reference Conditions Conditions characterizing ecosystem composition, structure, and function and their variability (from Kauffman *et al*, 1994 , "An Ecological Basis for Ecosystem Management")

Region A geographic area that shares one or more characteristic, for example, a watershed, c.f. ecoregion.

Regional Monitoring Obtaining synoptic information over a broad geographic area.

Remote Sensing The science and art of obtaining information about a target from a distance.

Research and Monitoring Committee The Federal interagency committee responsible for overseeing and coordinating research and monitoring supporting the implementation of the forest plan.

Riparian Area An area directly associated with a stream, river, or waterway. The interface between aquatic and upland ecosystems.

Riparian Attributes Abiotic and biotic characteristics of the riparian area.

Riparian Reserve A riparian area that is being managed in order to conserve ecosystem integrity.

SIR-A,B,C Shuttle Imaging Radar missions A, B, C

Site A stretch of stream smaller than a reach, the scale at which the attributes listed for sites in Table 1 operate. See plot.

Spatial Hierarchy The quantum steps in the spatial scale continuum related to function. For aquatic systems, these would include: site, reach, stream, watershed, landscape, region.

Spatial Scale In remote sensing, this term refers to the resolving power of the sensor. It can also refer to the relationship between map or photograph distance to real world distance. For example, 1:12,000 (c.f. pixel). In a broader sense, it refers to size of an object. It is often used to include either grain, the size of an individual object, or extent, the size of an area being evaluated

Spatial Structure Relates to the physiognomy of assemblages of plants, with characteristics such as leaf shape and growth form.

SPOT Systeme Probatoire d'Observation de la Terra

Stressor A process from outside of the ecosystem which causes a change.

Subplot A finer unit of measure (5 x 5 meters) that is imbedded within the larger 40 x 40 meter plots.

Synthetic Aperture Radar (SAR) An active remote sensing system which uses wavelengths in the microwave region.

Technological Criteria Criteria which can be objectively identified.

Temporal Scale The level of resolution in time perceived or considered (Kaufman, et al, 1994); or extent.

TM Thematic Mapper.

Tree Cover The amount of ground covered by the tree's foliage.

Watershed An area that is characterized by a common drainage basin.

Woody Debris Debris from fallen trees that are ecologically significant, especially for providing habitat

Vegetation Dynamics The temporal characteristics of vegetation cover, such as phenology.

Videography Acquiring imagery in video format.

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