QUANTIFYING STRUCTURAL PHYSICAL HABITAT ATTRIBUTES USING LIDAR AND HYPERSPECTRAL IMAGERY

Robert K. Hall [1], Russell Watkins [2], Daniel T. Heggem[3], K. Bruce Jones[3], and Phil Kaufmann[4]

[1]USEPA Region IX, WTR2, 75 Hawthorne St., San Francisco, CA 94105

[2]Spectrum Mapping, LLC.., 3907 SW 5th Place, Gainesville, FL 32607

[3]USEPA ORD Environmental Science Division, Landscape Ecology Branch, Las Vegas, NV 89119

[4]USEPA ORD Environmental Sciences Division, Corvallis, OR

Structural Physical Habitat Parameters

- Structural physical habitat characterization includes measurements of:
  - stream size,
  - gradient,
  - channel substrate type and size,
  - riparian vegetation cover,
  - structure and complexity,
  - and anthropogenic alterations.

- These physical characteristics strongly influence water quality and the capacity of a stream to support a diverse biological community.

Stream Characterization

- There are multiple methodologies in assessing stream habitat characteristics
  - Qualitative approach of the USEPA Rapid Bioassessment Protocol (Barbour, et al., 1999; Barbour, et al., 1997; Barbour and Stribling, 1991; Pflakin, et al., 1989),
  - Modified forms which obtain qualitative and quantitative information used by several state (California, Oregon, Washington, Arizona, Ohio EPA, 1987; Oklahoma, 1993) and tribal programs,
  - to the more systematic quantitative approach as described by Kaufmann and Robison, 1998, Fitzpatrick, et al., 1998, Klemm, et. al., 1997, and Meador, et al., 1993.
- Each of these protocols has been developed dependent on the spatial and temporal demands of the program they were designed for.
- Kaufmann, et al., 1999, state that “…integrity and repeatability of qualitative information is dependent on the knowledge and experience of the field observer.”
- How to increase resolution, accuracy and spatial coverage?

High resolution remote sensing

- High resolution remote sensing – multispectral, hyperspectral and Light Detection and Ranging (LIDAR) - provides unique capabilities in detecting a variety of features:
  - Vegetation type and condition
  - Sedimentation and sediment sources
  - Landscape associated point and nonpoint sources
  - Stream morphological features
  - Invasive species
  - Habitat integrity

- Using synoptic remote sensing in conjunction with stream assessments it is possible to garner a greater understanding of habitat conditions over larger spatial areas and temporal scales.

High resolution RS: Advantages

- There are multiple advantages to hyperspectral and LIDAR data
  - 100% coverage of the ground surface to approximately 1 meter pixel resolution
  - Spatially accurate (DGPS), and covers larger areas then single reach stream assessment
  - Narrow, contiguous spectral bands in hyperspectral imagery allows better discrimination of vegetation types, land cover and water clarity.
  - Measure canopy height and density, riparian width and fragmentation.
  - Can measure channel form and reveal subtle changes in topography
  - Can develop quantitative water quality indicators
  - Major advantage is the cost to benefit relative to high density ground sampling assessment to cover the same land area:
    - increases resolution accuracy of more qualitative sampling programs
    - increases spatial interpolation and extrapolation of point-based ground measurements.

High Resolution RS: Disadvantages

- Limitations of hyperspectral and LIDAR data for measurement of physical habitat parameters:
  - Resolution – approximately 15 cm in the vertical and approximately 1 meter in the horizontal
  - Remotely sensed data cannot measure all things. Hyperspectral and LIDAR imagery will have difficulty in measuring:
    - standing litter
    - snag number, diameter, type and distribution
    - density of emergent aquatic macrophytes
    - current velocity

Methods

- Collection of digital geospatial allows automated processing and analysis of data
- Standard and specialized algorithms and scripts are used to analyze and quantify watershed and stream reach features of interest
- Hyperspectral, Lidar, existing geospatial data and field data are integrated to derive needed regional, basin, sub-basin and reach scales
- Derivative data layers are validated through existing field programs
- GIS and visualization software is used to develop innovative data presentations for managers and stakeholders (e.g. fly through with data classifications)

Reach Length

- Depending on the objective of the stream bioassessment study and protocol used reach length can vary from:
  - 20 x wetted width
  - 40 x wetted width
  - 5 riffles
  - Minimum of 150 meters to a maximum of 500 meters for wadeable streams.
- For this study the EMAP protocol of 40 times the wetted width is used with a minimum reach length of 150 meters.
- Remotely sensed data can be used for many programs:
  - Design random or targeted
  - Targeted habitat or non-targeted
  - or to represent another ecological region within the same watershed.

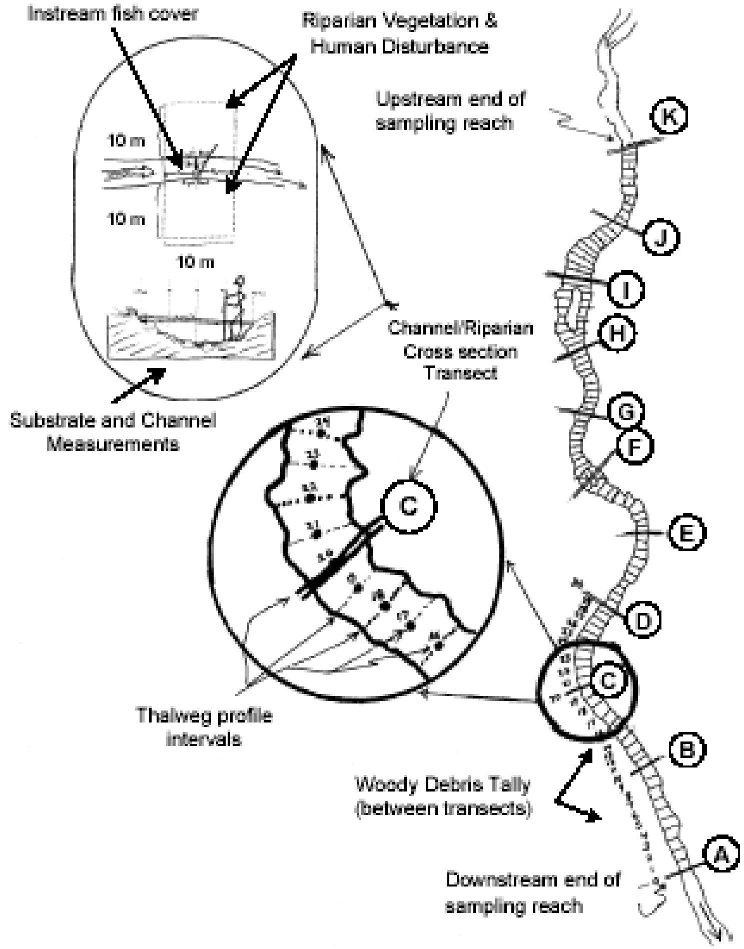


Figure 1. Sample reach layout (plan view). From Kaufmann and Robison, 1998.

Stream Reach: 150m

Stream Dimensions

- Streams are dynamic and subject to relatively rapid change in channel shape.
- Kaufmann, et al., 1999, recommends:
  - measuring wetted width
  - bankfull height and width,
  - thalweg depth,
  - depth cross-sections,
  - and flow rates as indicators of stream size.
- The stream longitudinal profile and cross-sections provide a measure of a streams dimensions.

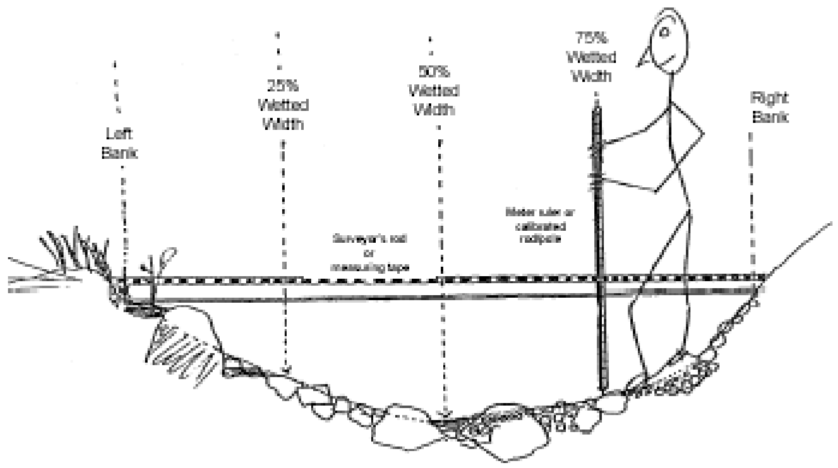
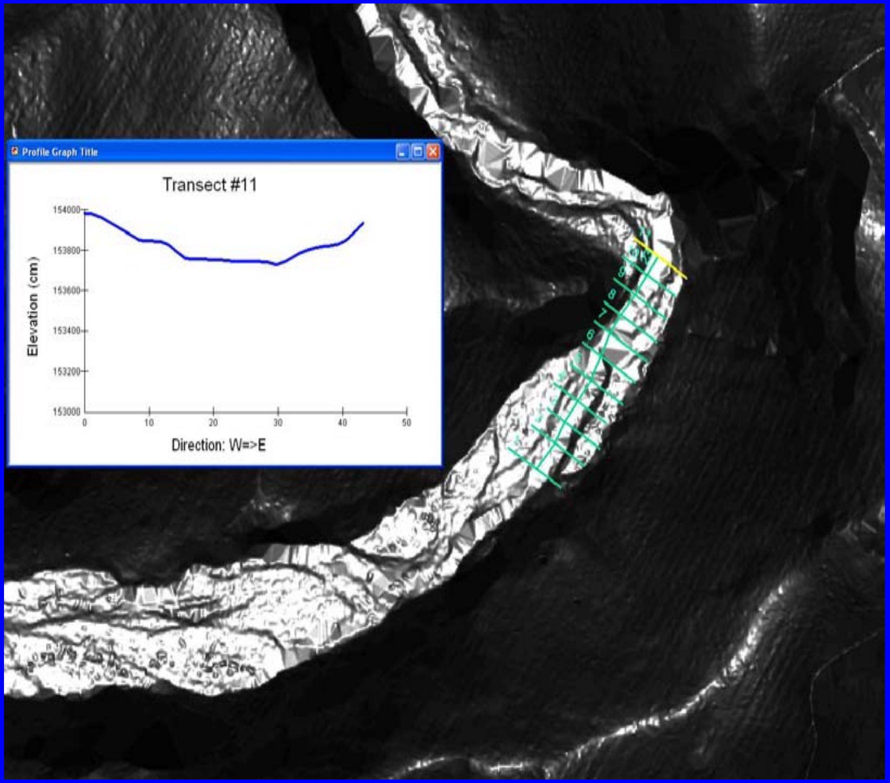
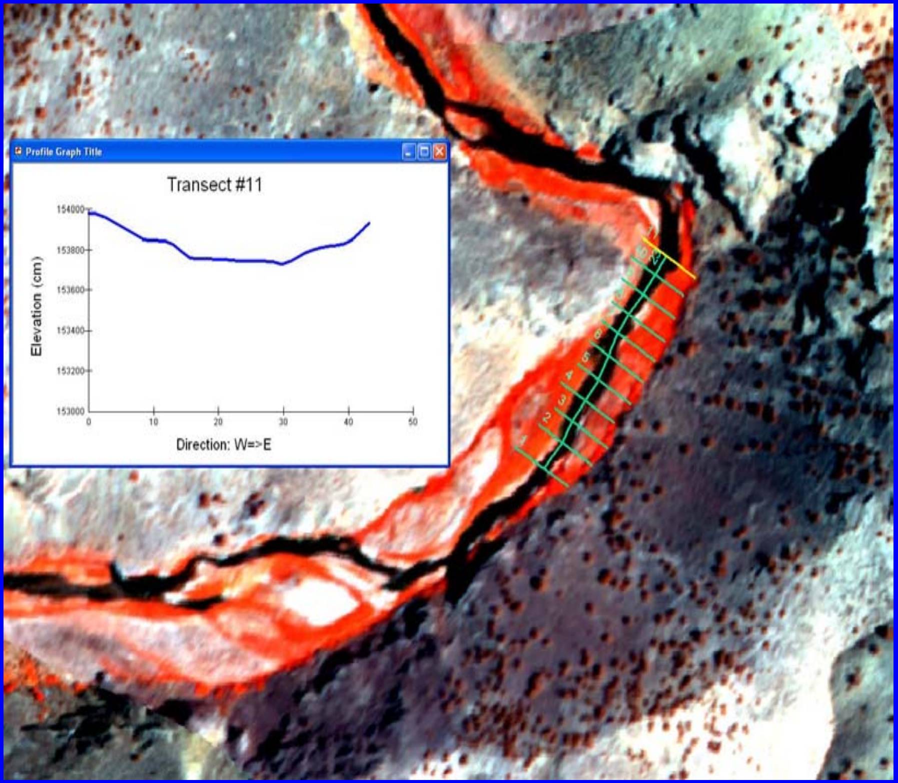


Figure 2. Substrate sampling cross-section. From Kaufmann and Robison (1998).

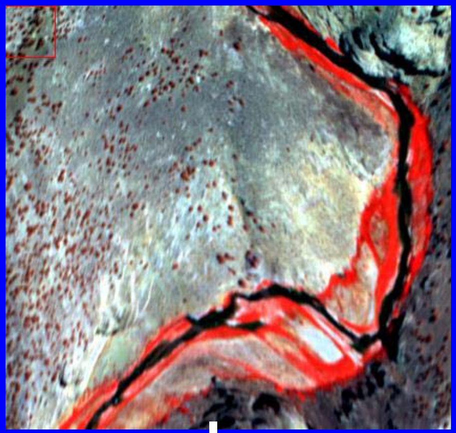
Transect #11: Lidar and CIR





Wetted width at #11 = 18m

Feature extraction: wetted width, water and vegetation spatial characteristics



Hyperspectral Image:
58 10nm bands

Unsupervised Classification:
10 classes

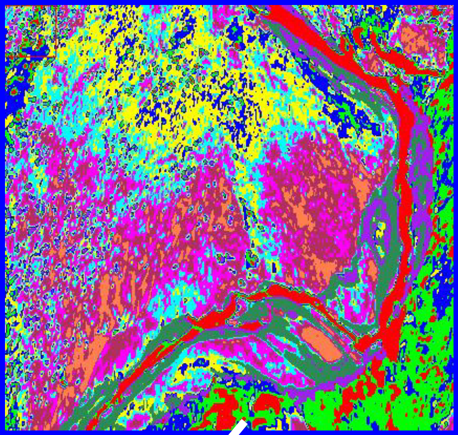
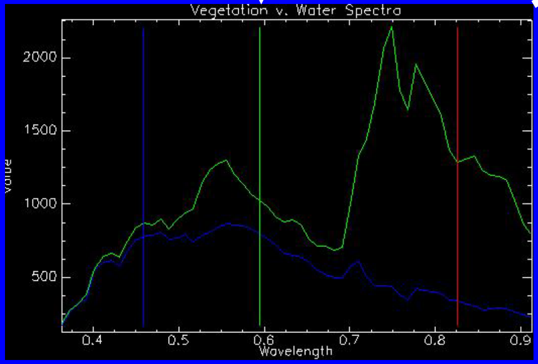
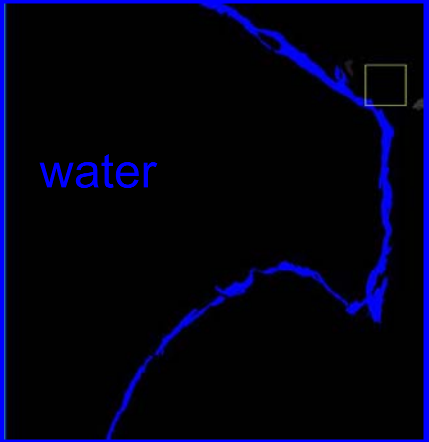


Image segmentation and density slice

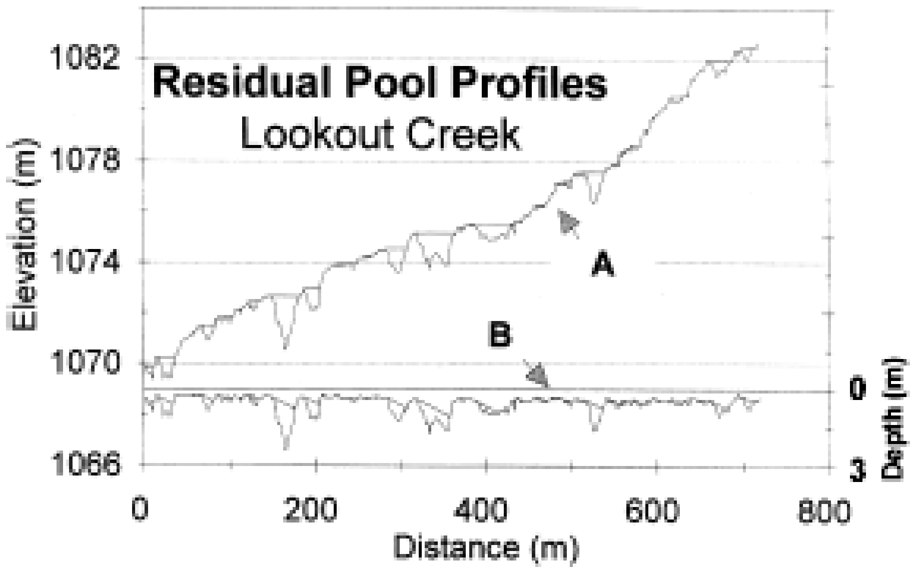


Spectral signatures

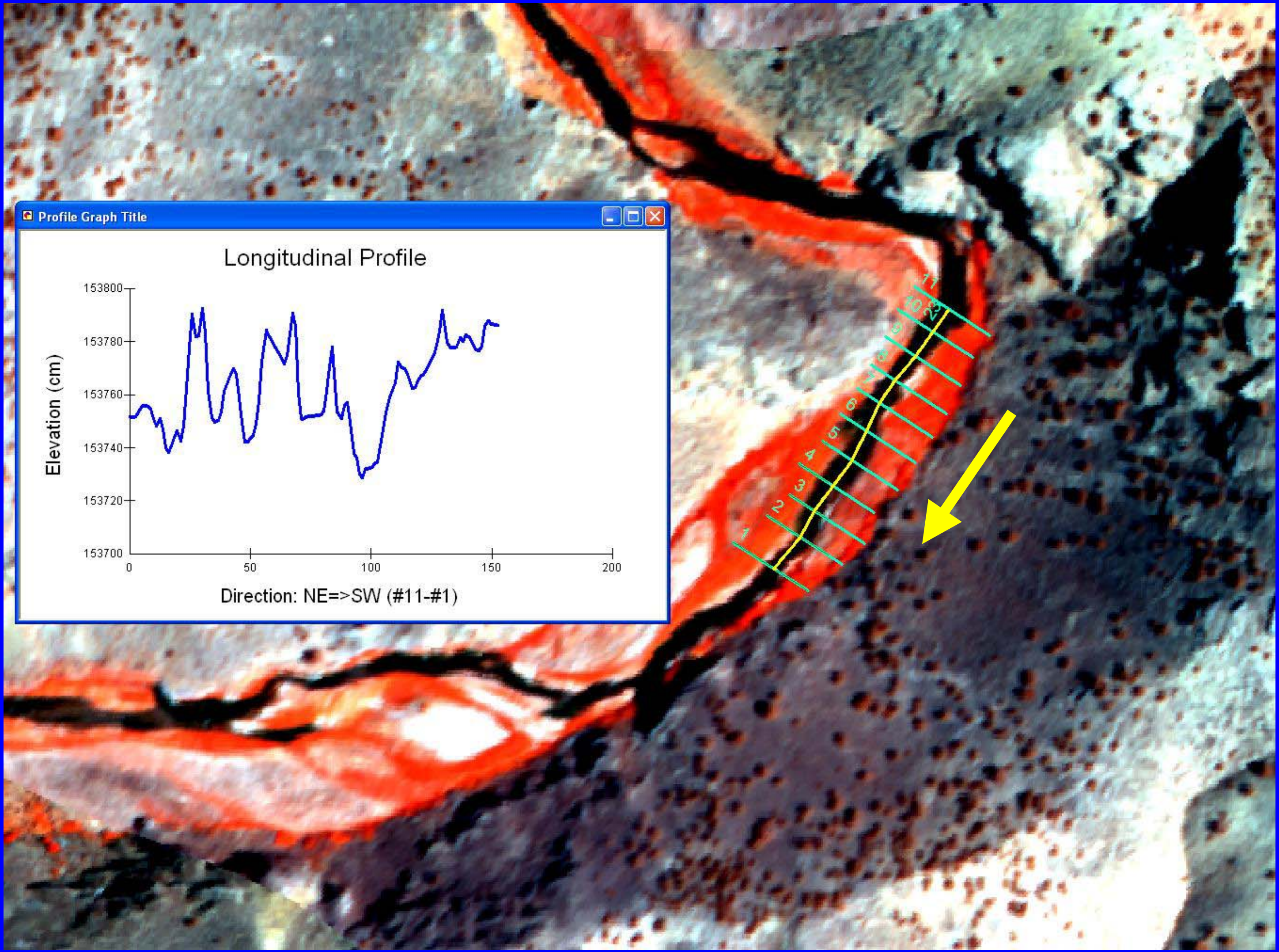


Channel Gradient/Sinuosity

- Gradient is essential in determining stream stability, bedload transport and potential particle size mobility (i.e., power).
- Sinuosity is the ratio of reach length / the straight line distance from point A (bottom of reach) to point k (top of reach)
- EMAP field methodology:
  - backsite slope measurements between the transects for gradient measurements.
  - backsite compass directions for sinuosity.
- Using the longitudinal profile, from the lidar DEM, stream channel slope and sinuosity is determined over the whole reach.


Residual Pool Profiles
Lookout Creek
A
B
Elevation (m)
1082
1078
1074
1070
1066
0
200
400
600
800
Distance (m)
0
3
Depth (m)

Longitudinal Profile: CIR image



Gradient = 35cm; Sinuosity = 1.0

Sediment/Channel Substrate

- Because of the resolution of the remotely sensed data it is difficult to measure channel substrate.
- High resolution data is an excellent tool in measuring and identifying sediment inputs from bank erosion, slumps and slides.
- Substrate – Research:
  - Multiple returns – classification of LIDAR returns (up to 4) to determine bed substrate.
  - bed roughness


Hyperspectral imagery of the Humboldt River with Lidar DEM

Habitat Complexity

- Habitat complexity is the distribution of various types of features providing fish concealment. For instance, large woody debris, undercut banks, overhanging vegetation, boulders, and residual pools.
- Hyperspectral imagery can be used to detect and map the distribution of large woody debris (> 15 cm diameter) and overhanging vegetation.
- LIDAR is used to measure large boulders greater than 1 meter and and residual pool depth, size distribution and frequency.
- Integrating the two data files provides a means to estimate residual pool volume, exposed mid-channel gravel and/or sand bars, reach-scale indices of slackwater volume, channel complexity.
- Cross-sections - LIDAR data can quantitatively measure wetted width, bank slope, incised height greater than 15 cm, bankfull height and width at bankfull stage.

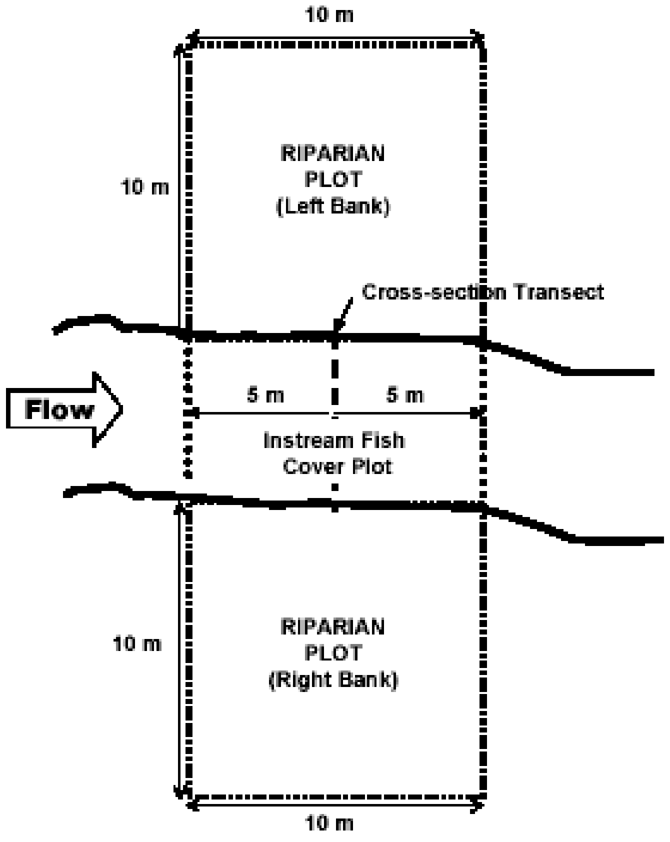
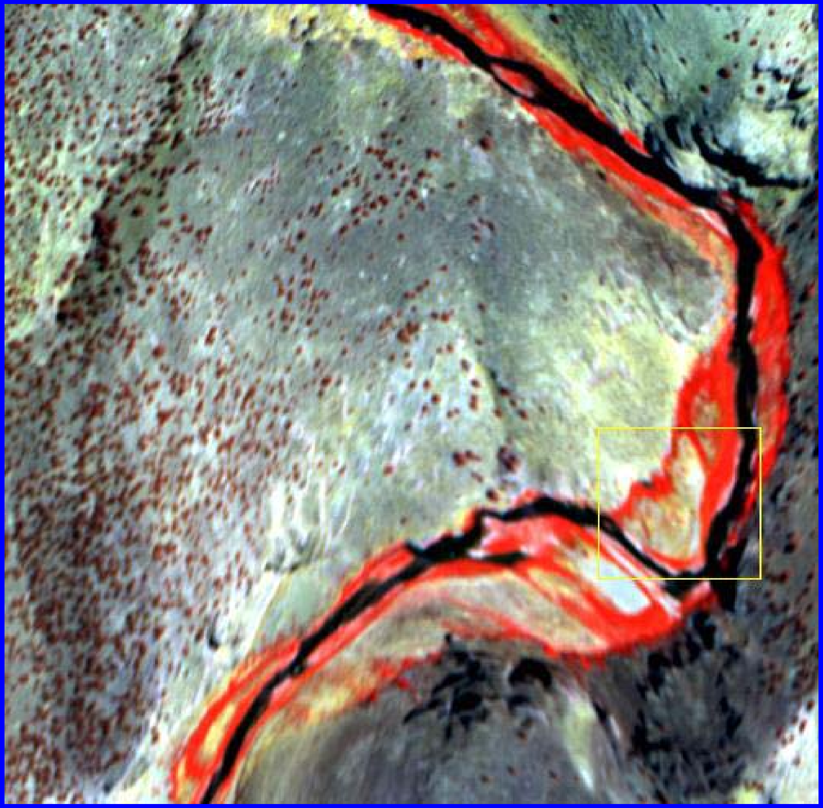


Figure 3. Boundaries for visual estimation of riparian vegetation, instream fish cover, and human influences (plan view). From Kaufmann and Robison (1998).

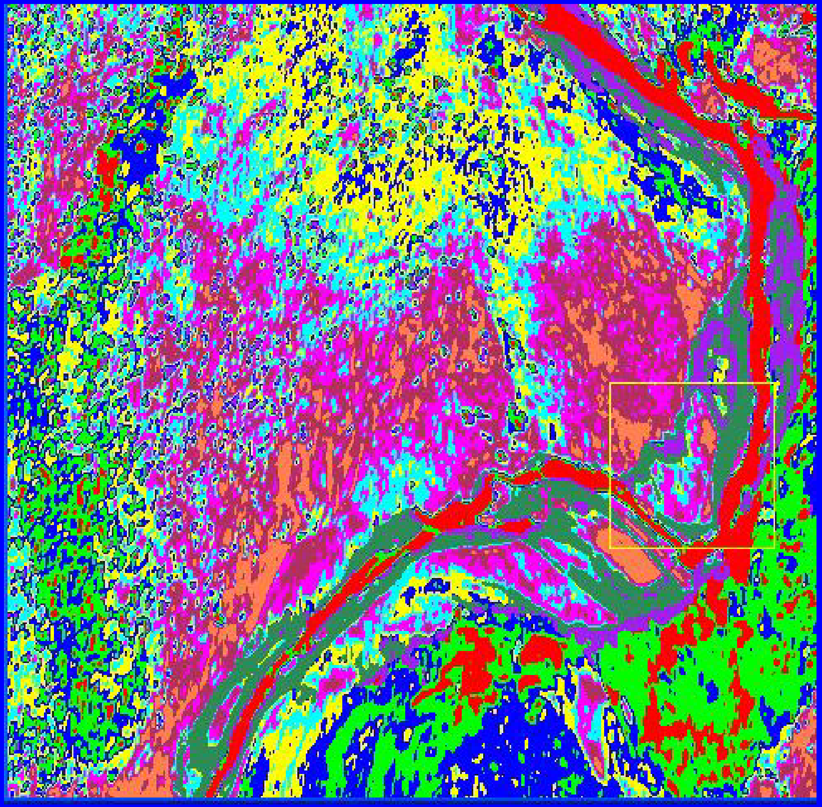
Riparian Vegetation

- Canopy cover is essential for moderating stream temperatures, providing habitat and an indicator of potential aquatic community present.
- Kaufmann, et al., 1999, note that the field measurements "...tell little about the type or structure of this vegetation."
- To determine riparian vegetation structure, EMAP protocols:
  - 10 square meter block centered on the cross-section each side of the stream
  - The riparian vegetation is identified into three layers 1. Canopy Cover (> 5 meters), 2. Understory (0.5 - 5.0 meters) and 3. Ground Cover (< 0.5 meters).
- Hyperspectral imagery integrated with LIDAR data can determine vegetation type, structure, height and distribution.
- Invasive species

Riparian Land Cover

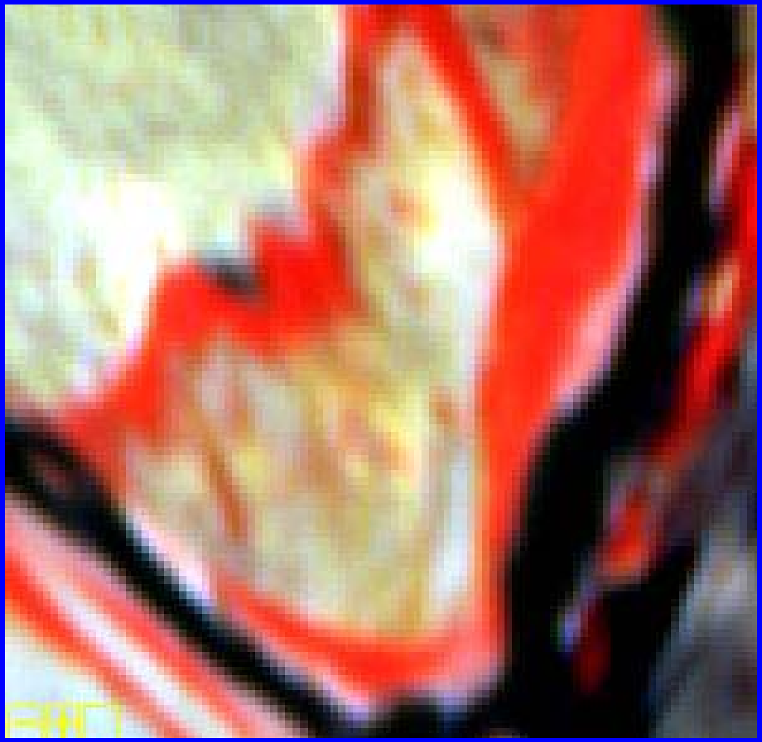


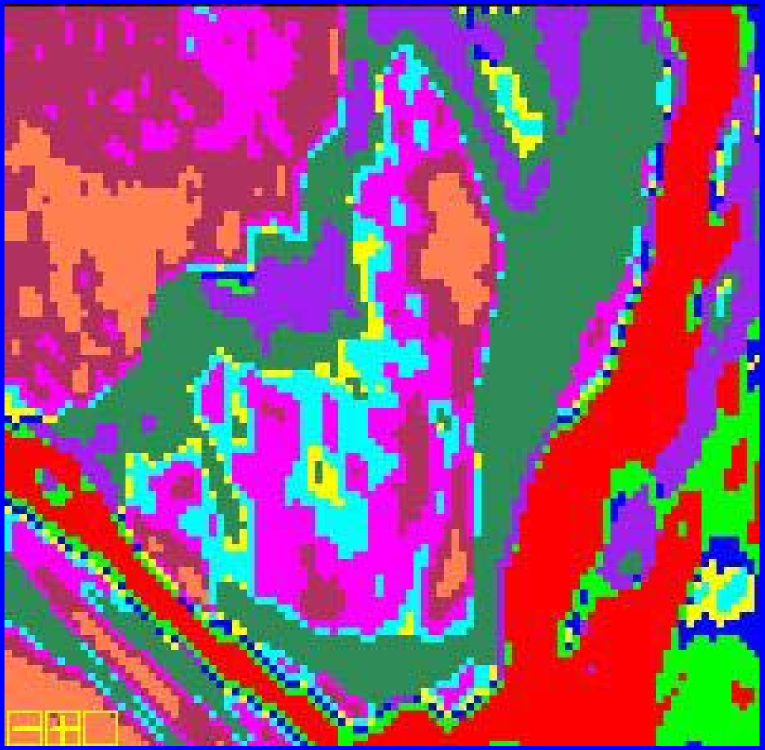
CIR image



10-class unsupervised classification

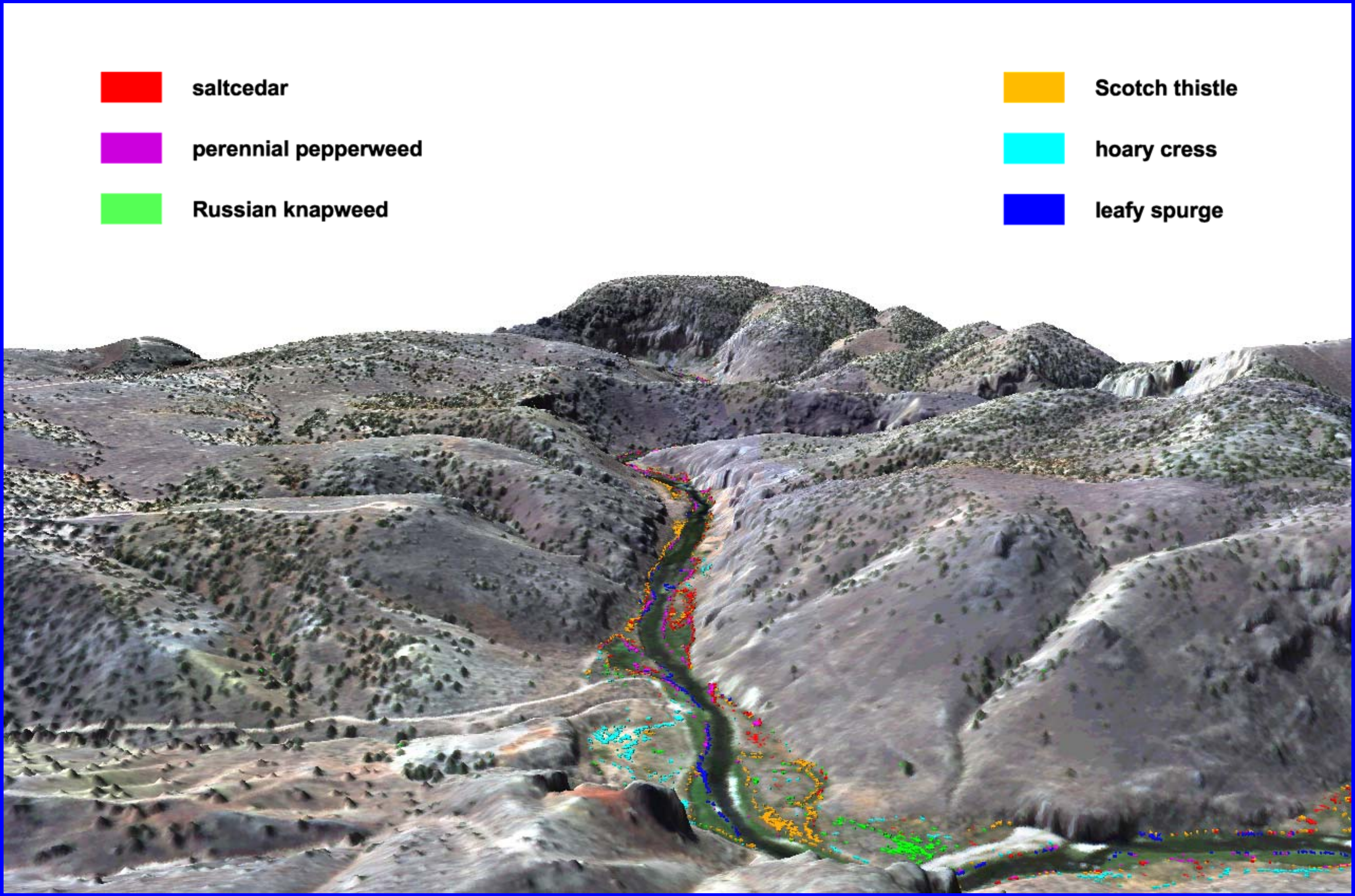
Zoom View of Land Cover





Note: examples of all 10 classes are found in this zoom

Watershed Morphology and Invasive Species Classification: Humboldt River, NV



Area shown is part of the Special Recreation Management Area Near Elko, NV

Source: BLM Nevada State Office and BAE Systems Advanced Technologies Inc.

Anthropogenic Alterations

Field evaluations include the presence and proximity of various types of human land use activities within the 10 meter square riparian assessment plots at each cross-section:

- Walls/dikes/revetments
- Buildings
- Pavement
- Roads/railroads
- Pipes
- Landfills/trash
- Parks/lawns
- Row Crops
- Pasture/range/hay fields
- Logging operations
- Mining activities

Remote Sensing and Landscape Modeling

- Remote sensing methods provide the key parameters necessary for construction of landscape-level models to assess the condition and function of a complete watershed.
- The hyperspectral and lidar imagery are analyzed to derive these parameters including:
  - land cover (e.g., vegetation type, bare soil, urban, pervious/impervious surface, etc.)
  - water quality (e.g., sedimentation, chlorophyll, detectable chemical constituents)
  - watershed characteristics (e.g. elevation, slope length, angle and aspect, stream channel features)
- The interrelationships of water quality, land cover and watershed characteristics will be examined and model results will be validated using field data collected as part of ongoing assessment and monitoring programs.

Conclusions

- Quantitative structural and biological stream data acquired over a given spatial area and temporal period is a fundamental information need to determine:
  - Reference conditions
  - Stream stability
  - Changing conditions of the stream channel and riparian zones over time
- The need for most state and tribal bioassessment programs is to maximize the return on investment of acquiring this data.
- A geospatial database comprised of:
  - remote sensing and ground reference data,
  - stream assessments,
  - historical imagery (e.g., satellite, digital orthophotos) and
  - innovative derived products

  can meet that need by detection, measurement and quantification of physical habitat parameters.