Feasibility of applying remote sensing to a riparian stand conditions assessment

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Summary: The proposed project will focus on assessing the feasibility as well as data and analytical costs associated with monitoring riparian stand conditions on private lands in Washington State through remote sensing approaches by summarizing existing published methods and results associated with the methods. These will be compared with field based methods. The project will extend upon the summary matrix presented in tables 1 through 4.

Goals and objectives: The main goal of the project is to provide basic background information to guide the development of a Washington State riparian forests status and trends monitoring pilot project based on remote sensing methods.

Specific objectives of the project will include:

1. A simple comparable cost assessment for all data types covered.
2. Summary of specifications of all sensors covered in the assessment.
3. Literature review documenting the accuracies in tables 1 through 4.
4. A break out of outcomes for direct and modeled methods for each indicator in tables 2 and 4.
5. Focused synthesis, per indicator identified in tables 2 and 4, summarizing the costs of data, costs of analysis, methods, accuracies and feasibility for Washington State.

Deliverables: The final deliverables will include

1. Revised tables 1 through 4 in a database format with documented methods and accuracies based on the literature review.
2. Focused synthesis (1 page) for each of the indicators with a feasibility assessment for the state of Washington.
3. A table of costs for data and analysis, broken out for methods and sensors.

Time Period: April 1, 2015 - June 30, 2015

Budget:

For the Period:		**April 1, 2015 - June 30, 2015**			
1	**Salaries**				**$ 25,368**
		A. Cooke	3 months @ 100%	16,224	
		L. M. Moskal	1 month @ 100%	9,144	
7	**Benefits**				**$ 6,570**
		A. Cooke	0.277	4,494	
		L. M. Moskal	0.227	2076	
4	**Travel**				**$ 500**

5	**Supplies and Materials**		**$ -**
6	**Equipment**		**$ -**
3	**Other Direct Costs/ Contractual Services**		**$ -**
	Total Direct Costs		**$ 32,438**
25	**Indirect Costs @**	26%	**$ 8,434**
	TOTAL BUDGET		**$ 40,871**

Budget Justification: The literature review and cost assessment would be performed at 1 FTE over the 3 months by Andrew Cooke, a research scientist at the University of Washington, Precision Forestry Cooperative, Natural Resource Spatial Informatics Group. Dr. Moskal will assist with the literature review, synthesis of the literature, summary table and cost analysis at 0.33 (1 month) FTE over the three month period. The $500 travel will cover multiple trips to Olympia to meet with the DNR. The proposal and project would be submitted through the Washington Cooperative Fish and Wildlife Research Unit (WACFWRU) at an indirect rate of 26%, UW indirect rate is 54.6%.

Table 1. Generalized characteristics for aerial sensors.

Purple in all tables indicates the Precision Cooperative at the University of Washington is either currently working on or has directly worked on such projects in the past.

	Aerial Imagery			Aerial LiDAR		Aerial IfSAR
	NAIP	*NAIP Stereo*	*Other*	*pre 2005*	*post 2005*	
Spatial Resolution	1 m	1 m or better, original imagery might be higher resolution than the 1m delivered NAIP product	better than 1m	0.5-1 point/m, resulting grids ~10m	8+ points/m, resulting grids 1m	1-5m
Spectral Resolution	false color near-infrared (NIR) currently, color 2010 and older, 2000 and older black and white	false color NIR currently, color 2010 and older, 2000 and older black and white	thermal imagery can be acquired to measure things such as surface stream temperatures under open canopies	NIR	NIR, green, blue for bathymetry, only one vendor in PNW can fly two types at once, NIR still most useful for forestry and terrain modeling	radar
Temporal Resolution	every 2 years or better	most years collected with 10-20% overlap, few years collected 60%+ overlap, availability depends on vendor	as needed	only few areas in WA	no state wall-to-wall coverage, Puget Sound LiDAR Consortium best source, very few areas flown more than once	as needed, small acquisitions in PNW, Intermap has USA wall-to-wall from 2007-2009

Intensity	N/A	N/A	N/A	not always available (recorded but not archived)	mostly available but some acquisitions did not specify as deliverable, might be recovered from vendors at a price	N/A

	Aerial Imagery			**Aerial LiDAR**		**Aerial IfSAR**
	NAIP	*NAIP Stereo*	*Other*	*pre 2005*	*post 2005*	
Ground points	N/A	can be achieved by 'surface from motion' techniques but is dependent on image quality and difficult in dense canopies	data dependent, needs stereo coverage	mostly available, sometimes just gridded surface (terrain or ground) models	majority of the time available	N/A gridded surface (ground or terrain) models only
All points (+canopy)	N/A	can be achieved by 'surface from motion' (SFM) techniques but is dependent on image quality and difficult in dense canopies	data dependent, needs stereo coverage	not available for a large number of acquisitions	majority of the time available	in some circumstances canopy points can be derived

Flight & Acquisition Cost	~$1/acer, larger acquisitions cheaper per acer cost	same as NAIP for 10%-20% stereo overlap, greater overlap will cost more	varies but usually per acer costs higher than NAIP	N/A data already acquired, might need to pay for data recovery if need all points	new acquisitions about $4/acer but prices are coming down and can be reduced by collaborative acquisitions and consortia; acquiring NIR imagery at same time can limit the time at which LiDAR can be flow and could increase costs	new acquisitions about $1-2/acer but prices are coming down and can be reduced by collaborative acquisitions and consortia

	Aerial Imagery			Aerial LiDAR		Aerial IfSAR
	NAIP	*NAIP Stereo*	*Other*	*pre 2005*	*post 2005*	
Already Flown Data Costs	publically available and mostly free, might have to pay small processing fee, example: $800/WA State 2011 coverage	recovery costs can be high as original files might have to be accessed through an archive	free if publically available, but might have to pay archive recovery fees	if from Puget Sound LiDAR Consortium than data is free	if from Puget Sound LiDAR Consortium than data is free, other datasets might have recovery and archival costs associated with them	Calculator, per area or shape file is available on the Intermap website
Pre-Processing Cost/Time	none needed	extensive cost and time involved in SFR to derive point clouds	varies but usually per acer costs higher than NAIP	can be moderate and are dependent on the number of metrics required, not all metrics are achievable thus lower costs	can be high and are dependent on the number of metrics required	costs included by vendor in data price
Analysis/Modelling Time	moderate because not all metrics possible	moderate to high	varies	moderate to high	high	moderate to high

Table 2. Simplified feasibility of indicator extraction from aerial sensor data

	Aerial Imagery			Aerial LiDAR		Aerial IfSAR
	NAIP	*NAIP Stereo*	*Other*	*pre 2005*	*post 2005*	
Vegetation Class	feasible classification accuracies in low 80% for conifer/deciduous distinction for large crowns, plot, stand and area if NIR imagery, change analysis is feasible	same as NAIP, but structure from point clouds derived through SFM could increase accuracies	can be very good 80%+ accuracies with expensive hyperspectral data (example of sensors: casi, Hymap, AVRIS), this requires hyperspectral field data collection	not feasible due to low probability of availability of intensity and crown structure data	possible with high accuracies (80%+) when good intensity data is available, combining intensity with structure from point clouds increases results, change analysis is feasible	not effective, but might be modeled based on topography, some promising research on this has been published , change analysis feasible but multi date data is needed
Snag Detection	Unlikely	Unlikely	Stereo and non-stereo 10cm imagery has been shown to work	Unlikely	Has been show feasible especially with the additional of the intensity data	Unlikely
Species	Mixed results using NIR, with accuracies in the mid 60%, when number of species increases this becomes more difficult	same as NAIP, but structure from point clouds derived through SFM could increase accuracies	can be very goof 80%+ accuracies with expensive hyperspectral data (casi, Hymap, AVRIS), this requires hyperspectral field data collection	not feasible due to low probability of availability of intensity and crown structure data	possible with low accuracies (mid 60%) if good intensity data is available, intensity + structure from point clouds increases results, difficult when the species complexity increases (two types of pine)	not effective

	Aerial Imagery			Aerial LiDAR		Aerial IfSAR
	NAIP	*NAIP Stereo*	*Other*	*pre 2005*	*post 2005*	
Stand Density	good results, accuracies in 70%+, image texture can be calculated (extra processing time) and boost the accuracies by at least 10%, topography can be problematic, change analysis over longer periods (decadal) should be feasible	not seen research but should be similar if not slightly better than NAIP	data dependent but approaches using hyperspectral data produce results similar to NAIP	if all points or canopy points are available good results are expected	excellent results with accuracies in the low 90%, date to date analysis is feasible but there detail of investigation is impacted by the coarser resolution date of LiDAR	good results, but issues can arise in areas of high topography, I have not seen change analysis, but theoretically it is feasible
Age	not directly measured but can be modeled with allometric equations, accuracies are moderate (in the 60%), decadal change analysis feasible but will be impacted by the different spectral resolutions (black and white, color, NIR) from decade to decade, only major changes in age classes could be resolvable	not seen research but should be similar if not slightly better than NAIP	data dependent but approaches using hyperspectral data produce results similar to NAIP	if all points or canopy points available plot and stand level results based on canopy metrics related to roughness (and similar) are good, increase in number of classes reduces results, sensitive to species diversity and site characteristics	individual crown and plot, stand and area level results based on canopy metrics related to roughness (and similar) are good, increase in number of classes reduces results, sensitive to species diversity and site characteristics, little work has been done on change analysis to date but it is feasible, will be impacted by the date of coarsest resolution of LiDAR, multi date data availability is an issue	moderate results based on modeling, but issues can arise in areas of high topography, change analysis might be feasible but data availability is an issue

	Aerial Imagery			Aerial LiDAR		Aerial IfSAR
	NAIP	*NAIP Stereo*	*Other*	*pre 2005*	*post 2005*	
DBH	allometrically determined for plot, stand and area levels, low to moderate accuracies impacted by stand density, topography, amount of shadow in imagery (in some studies shadows improve results when image texture is a variable used)	not seen research but should be similar if not slightly better than NAIP	data dependent but approaches using hyperspectral data produce results similar to NAIP	slightly lower results than age from pre 2005 LIDAR	same as age analysis with post 2005 LIDAR	moderate results based on modeling, but issues can arise in areas of high topography
Height	can be modeled but accuracies are poor, only very major categories (tall, short)	SFM point clouds can be used to achieve per-crown measurements, shadows can reduce accuracies, stand density impacts ability to generate ground points and thus make height measurements, topography can impact accuracies	data dependent but results similar to NAIP	if all points available stand level heights with an error of less than 1m can be achieved, reprocessing ground models likely necessary adding to costs	sub 20cm accuracies, stand density can impact ability to do individual crown measurements, difficult to elevate per-crown accuracies due field to LIDAR data matching issues, manual attribution is feasible but adds time and cost	not for individual crowns but plot and stand level accuracies within 1m are feasible
Buffers	5 m increments	5 m increments	data dependent can be as low as 1 m	10 m increments, sometimes finer can be achieved but depends on data specks	1 m increments	5 m increments

	NAIP	*NAIP Stereo*	*Other*	*pre 2005*	*post 2005*	
Crown Diameter	feasible in canopies for large crowns and non-dense canopies, difficult due to changing shadows in multi date imagery	not seen research but should be similar if not slightly better than NAIP	very good results if high spatial resolution	not feasible on data with less than 4 points per m	excellent results, hard to validate because field data tends to be less accurate, change analysis feasible but issues with wind would play a role in interpreting change on short temporal (yearly) intervals	possible per stand or area, results slightly higher than NAIP, requires field data, change analysis not feasible
Basal Area	feasible results tend to range in +65% accuracies, requires field data, decadal changes might be observable	not seen research but should be similar if not slightly better than NAIP	very data dependent but in some circumstances possible	only possible for large stands and areas if canopy points available results similar to NAIP, requires field data	results are promising and higher than NAIP or pre 2005 LiDAR, requires field data, changes are detectable but limited by the date of the coarsest resolution LiDAR data	possible per stand or area, results slightly higher than NAIP, requires field data, change analysis unlikely due to data availability
Canopy % Cover	feasible results tend to range in 70% accuracies, higher when general categories used, not feasible per crown	not seen research but should be similar if not slightly better than NAIP	very data dependent but in some circumstances possible	only possible for large stands and areas if canopy points available results similar to NAIP, decadal change might be observable	results are good and higher than NAIP or pre 2005 LiDAR, can be performed per crown, changes are detectable but limited by the date of the coarsest resolution LiDAR data, crown position due to wind can be interpreted as change	possible per stand or area, results slightly higher than NAIP, change analysis unlikely due to data availability

	Aerial Imagery			Aerial LiDAR		Aerial IfSAR
	NAIP	*NAIP Stereo*	*Other*	*pre 2005*	*post 2005*	
Large Woody Debris	only very large stems manually detectable, but can be measured for length, width, potential can be modeled (automated)at a stand level at minimal effectiveness	only very large stems manually detectable, but can be measured for length, width, potential can be modeled (automated)at a stand level at moderate effectiveness	very data dependent but in some circumstances possible	large stems and piles detectable and potential can be modeled for stand level but only if canopy points are available, change analysis in presence and absence feasible	stems can be detected and some measurements can be made, difficult to automate at a local scale but can be modeled at a landscape scale, potential can be derived for stem or area	very large stems and piles might be detectable (this was likely 'cleaned' up from the data during post-processing), potential can be modeled for stand level but only if canopy points are available, no change analysis
Hydrology (Streams)	only major hydrological features possible in low canopy densities and moderate topography, change analysis is often performed manually and very time consuming	major hydrological features and down to 3rd order streams are possible, but can be impacted by topography and canopy density	very data dependent but in some circumstances possible	major hydrological features and down to 3rd order streams are possible, topography and canopy density play a major role	down to 1st order streams can be networked by analyzing LiDAR-based terrain models, processing can be time consuming and manual corrections are needed, this is the most efficient method to cover large areas, DNR has done an extensive amount of work on this, validation is difficult and expensive but shows positive results for LiDAR, topography/canopy density plays a role, change analysis impacted by resolution and flight characteristics, unknown change accuracy	major hydrological features and down to 3rd order streams are possible, topography and canopy density play a major role

Table 3. Generalized characteristics for satellite sensors

Blue text is used to ease comparisons between aerial (black) sensors in Tables 1 and 2 and blue (satellite) sensors in Tables 3 and 4.

	High Resolution <-----------------Satellite Data--------------> Coarse Resolution				
	GeoEye/DigitalGlobe/IKONOS/RapidEye	*RapidEye*	*Spot*	*LandSAT*	*EOS(Terra)*
Spatial Resolution	~0.5m-1m	5m	0.5 m and up	15 m and up	250 m and up
Spectral Resolution	panchromatic at highest spatial detail, color and NIR at coarser resolution can be used to produce pseudo-color, this can be problematic for NIR	see GeoEye	see GeoEye	see GeoEye	color and NIR
Temporal Resolution	at nadir only one image per ~16 days, clouds are an issue, in the PNW one cloud free image per year is to be expected, with some years having more images and other fewer, data beginning to be continuously acquired around 2010 (could have some historical coverage), more satellites means that cloud free images are becoming more common	similar to GeoEye	imagery available ~16 days, longer historical span to the 1980	imagery available ~16 days, back to 1972 but at coarser spatial resolution, in the PNW 1 good image per year on average	bi-weekly, some indices such as NDVI interpolated for cloudy dates, historical data as far back as 2000
Intensity	N/A	N/A	N/A	N/A	N/A
Ground points	some potential through SFM, no reported research results	N/A	N/A	N/A	N/A
All points (+canopy)	N/A	N/A	N/A	N/A	N/A

Flight & Acquisition Cost	Usually orders need to be over $5000, costs start at about $5/acre but can be as low as $1.4/sq. km, bigger acquisitions take precedence of where the sensor will be pointed	see GeoEye	Some free if already acquired, prices starting at ~ $1000/scene	free	free
	High Resolution <-----------------Satellite Data--------------> Coarse Resolution				
	GeoEye/DigitalGlobe/IKONOS/RapidEye	*RapidEye*	*Spot*	*LandSAT*	*EOS(Terra)*
Already Flown Data Costs	if acquired through a consortia or public funds it might be free	see GeoEye	see above	free	free
Pre-Processing Cost/Time	costs included by vendor in data price, additional high costs/time if SFM analysis were to be tried	costs included by vendor in data price	costs included by vendor in data price	low	low
Analysis/Modelling Time	moderate	moderate	low	low	low

Table 4. Simplified feasibility of indicator extraction from satellite sensor data

	High Resolution <-----------------Satellite Data--------------> Coarse Resolution				
	GeoEye/DigitalGlobe/IKONOS/RapidEye	*RapidEye*	*Spot*	*LandSAT*	*EOS(Terra)*
Vegetation Class	feasible accuracies in low 80% for conifer/deciduous distinction for plot, stand and area, change analysis feasible but multi date data adds to costs, work on additional vegetation classes beyond Conifer and deciduous is promising	feasible accuracies in low 80% for conifer/deciduous distinction for stand and area, landscape level change analysis (yearly or more frequent dependent on imagery availability) often performed with high accuracies	feasible accuracies in low 70% for conifer/deciduous distinction for large areas, landscape level change analysis (yearly or more frequent dependent on imagery availability) often performed with high accuracies	feasible accuracies in low 70% for conifer/deciduous distinction for large areas, landscape level change analysis (yearly or more frequent dependent on imagery availability) often performed with high accuracies	feasible accuracies in low 60% for conifer/deciduous distinction for landscapes, seasonal regional level change analysis often perform but difficult to validate due to lack of field data
Snag Detection	Unlikely	see GeoEye	not feasible	not feasible	not feasible
Species	some work has been done but results are poor	see GeoEye	research has been done, but to get results in the 70% extensive modeling and even pixel unmixing is needed, a hyperspectral technique requiring hyperspectral field data collection	research has been done, but to get results in the 70% extensive modeling and even pixel unmixing is needed, a hyperspectral technique requiring hyperspectral field data collection	not feasible
Stand Density	results similar to NAIP, same issues as well	slightly lower results, fewer stand density groupings possible compared to GeoEye and NAIP, similar lowering results in change analysis	modeled with moderate accuracies in the high 60%, similar lowering results in change analysis	modeled with moderate accuracies in the high 60%, similar lowering results in change analysis	poor results

	High Resolution <-----------------Satellite Data--------------> Coarse Resolution				
	GeoEye/DigitalGlobe/IKONOS/RapidEye	*RapidEye*	*Spot*	*LandSAT*	*EOS(Terra)*
Age	various studies attempt modeling, moderate results in uniform age classes with low species variability and slight topography (plantations), change analysis is feasible but data is costly thus not much research in this area	marginal results	moderate results when modeled at landscape level, cost issues of multi date data deter change analysis	moderate results when modeled at landscape level, coarse age class changes at a landscape level are feasible	poor results
DBH	same as age with GeoEye	marginal results	moderate results when modeled at landscape level, cost issues of multi date data deter change analysis	moderate results when modeled at landscape level, change analysis is unlikely	not feasible
Height	usually modeled based on other derived variables and image texture, accuracies in mid 60%, only general relative height classes (5 classes on average) achievable	similar to GeoEye but fewer high classes and reduced accuracies	model based for stand and landscape level, accuracies in the high 60%, only major changes captured by image texture would be detectable on decadal or greater intervals	model based for stand and landscape level, accuracies in the high 60%, change analysis results similar to Spot	not feasible
Buffers	10 m increment	10 m increment	100 m increments	100 m increments	only at 0.5km increments
Crown Diameter	possible per stand or area, results slightly lower then NAIP, change analysis not feasible	no	no	no	no

	High Resolution <-----------------Satellite Data-------------> Coarse Resolution				
	GeoEye/DigitalGlobe/IKONOS/RapidEye	*RapidEye*	*Spot*	*LandSAT*	*EOS(Terra)*
Basal Area	possible per stand or area, results slightly lower then NAIP, requires field data, decadal change might be observable	see GeoEye	has been modeled for extensive areas with+70% accuracies, requires field data or calibration from finer resolution imagery, data processing and model development is intensive, decadal change might be observable	has been modeled for extensive areas with+70% accuracies, requires field data or calibration from finer resolution imagery, data processing and model development is intensive, decadal change might be observable	no
Canopy % Cover	possible per stand or area, results slightly lower then NAIP	see GeoEye	has been modeled for extensive areas with+70% accuracies, requires field data or calibration from finer resolution imagery, data processing and model development is intensive, decadal change might be observable	has been modeled for extensive areas with+70% accuracies, requires field data or calibration from finer resolution imagery, data processing and model development is intensive, decadal change might be observable	no

Large Woody Debris	only very large stems manually detectable, but can be measured for length, width, potential can be modeled (automated)at a stand level at minimal effectiveness, change analysis including re-measurements feasible	see GeoEye	no	no	no
Hydrology (Streams)	only major hydrological features possible in low canopy densities and moderate topography	see GeoEye	major water bodies and rivers detectable	major water bodies and rivers detectable	large lakes and very wide rivers detectable

Definitions:

NAIP	National Agricultural Imagery Program
IfSAR	Interferometric synthetic aperture radar
LiDAR	Light Detection and ranging
multispectral	Operating in or involving several regions of the electromagnetic spectrum
NIR	Near infrared
OBIA	Object Based Image Analysis also known as feature extraction
panchromatic	Single band image generally displayed as shades of gray, often the image spans the visible portion of the electromagnetic spectrum
PNW	Pacific Northwest
pseudo-color	Image is derived by mapping each pixel value to a color according to multispectral image
SFM	Surface From Motion technique to generate 3D point clouds from imagery