Unmanned Aerial Systems for Pipeline Inspection, Monitoring, and Landscape Analysis

Contract Number: 693JK31950007CAAP

Research team members

- Team Project Manager
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- Faculty
  - Dr. Paul Kinder, Director, Natural Resource Analysis Center, West Virginia University
  - Dr. Shawn Grushecky, Assistant Professor, Energy Land Management Program, West Virginia University

Graduate student research team members

- Anthony Mesa, MS in Energy Environments
- Matt Boothe, MS in Energy Environments
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- Joseph Kimmett, MS in Energy Environments
- Lucas Kinder, MS in Energy Environments
- Isaac Kinder, MS in Energy Environments
- Matt Walker, PhD in Resource Management

Challenge of project

- We evaluated the accuracy at which unmanned aerial vehicles replicated inspector classifications to evaluate their use as a complementary tool in the pipeline inspection process. We investigated the use of various sensors to determine the most cost-effective methodology for performing pipeline monitoring and analysis in Appalachia.

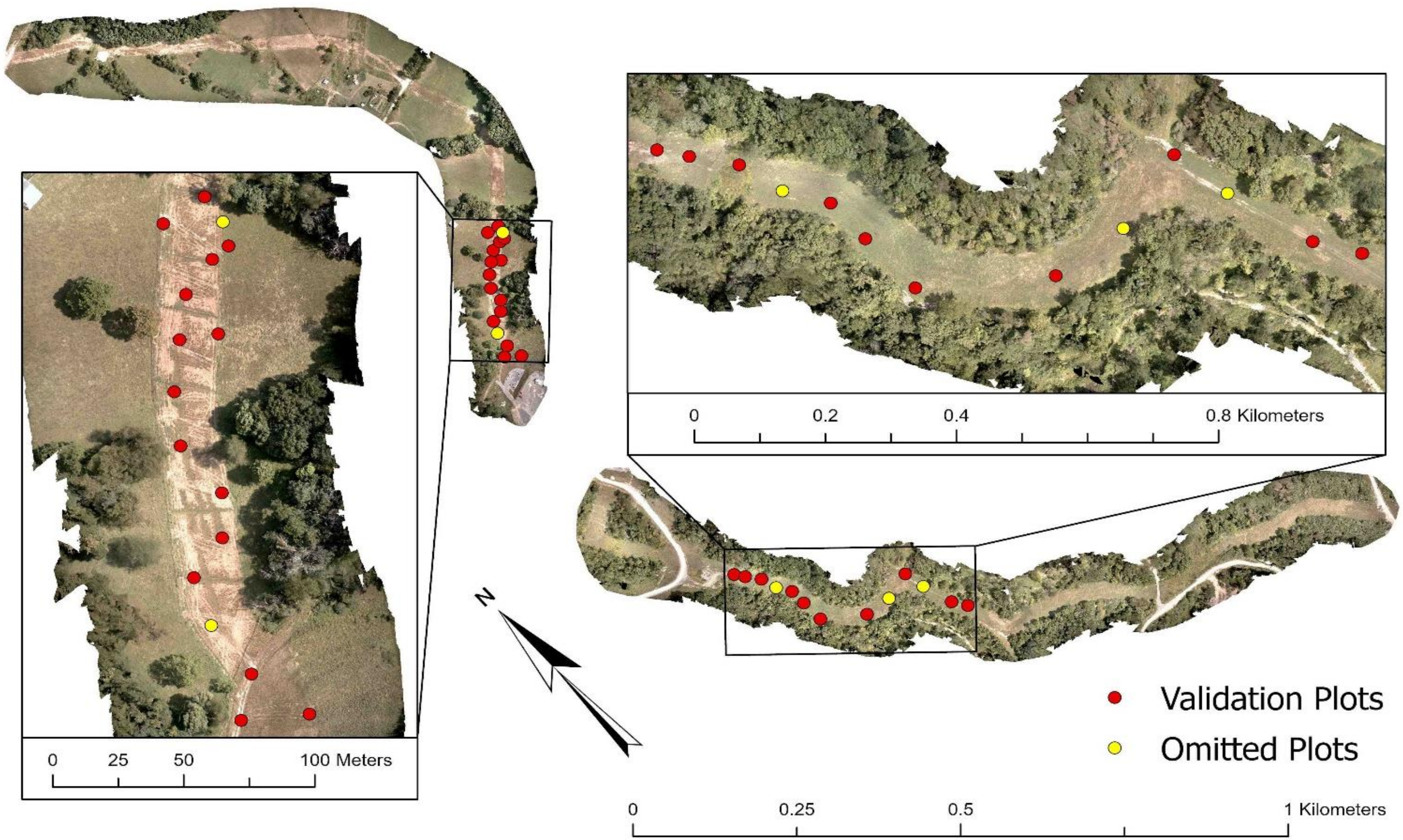
Main objective

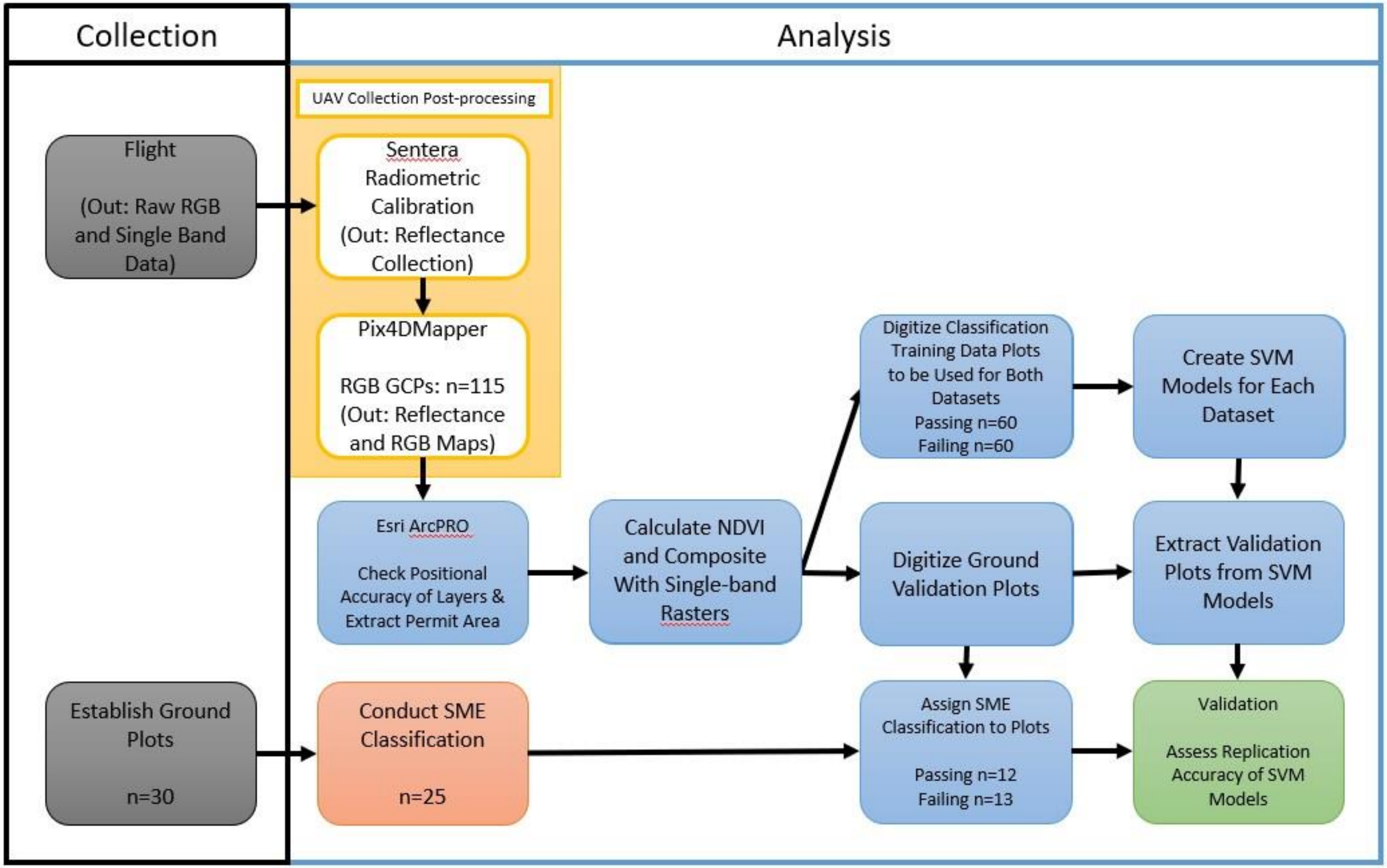
- Determine the most cost-effective combination of Unmanned Aerial System (UAS) sensors to monitor and evaluate pipeline conditions.

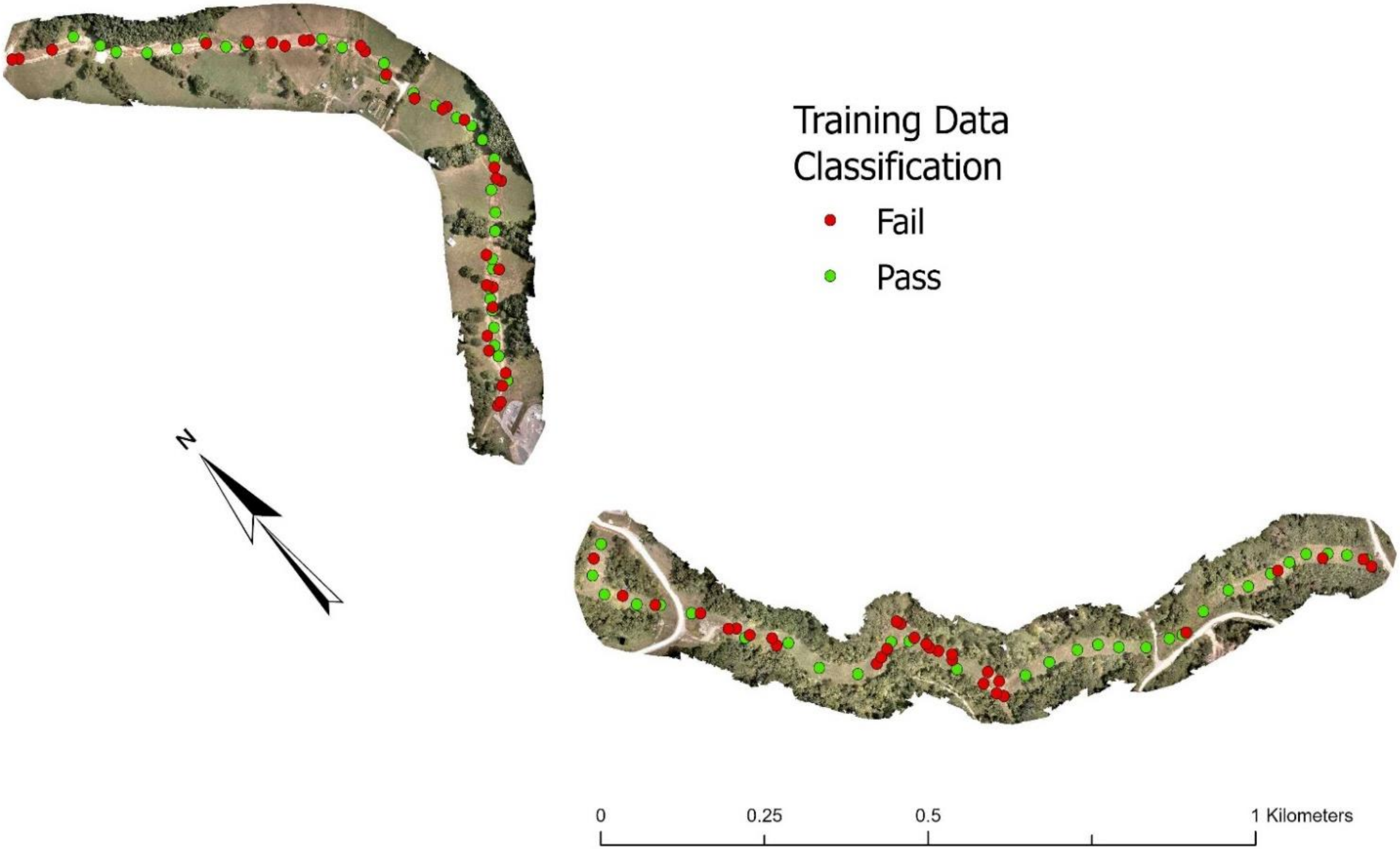
Tasks

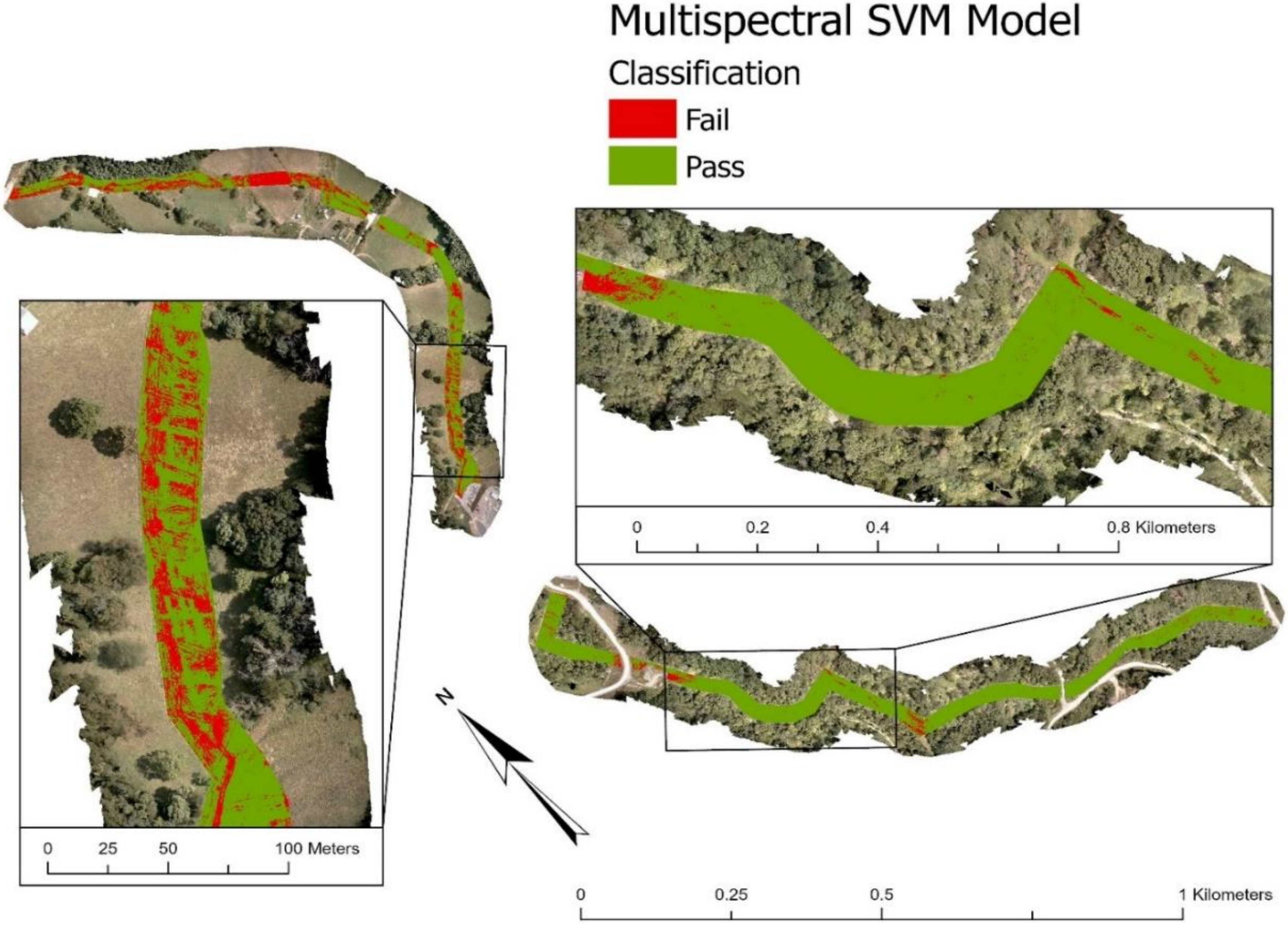
I. Vegetation Classification
II. Sediment Modeling
III. Cost Effectiveness

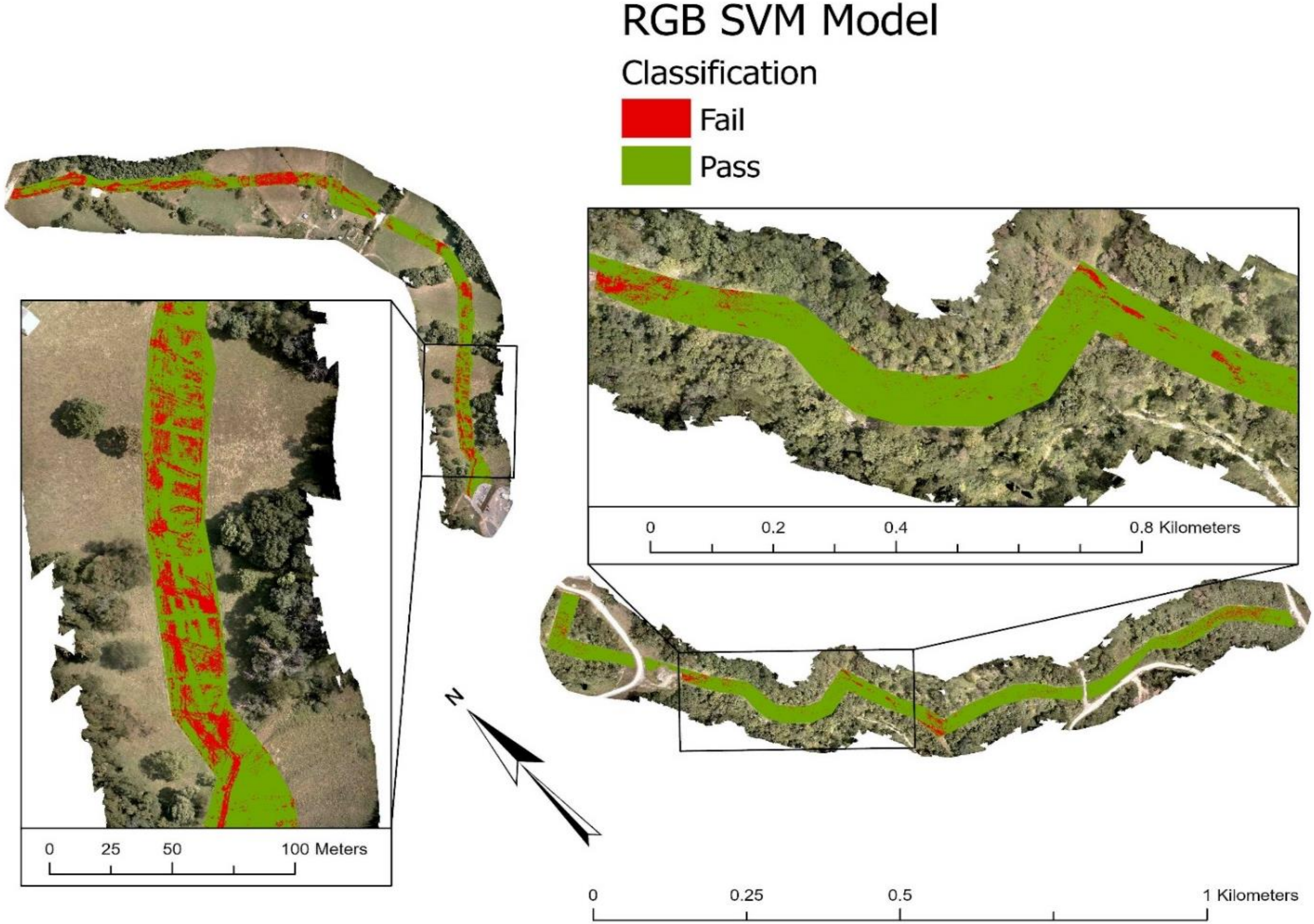
I. Vegetation classification




Collection
Analysis
UAV Collection Post-processing
Flight
(Out: Raw RGB and Single Band Data)
Sentera Radiometric Calibration
(Out: Reflectance Collection)
Pix4DMapper
RGB GCPs: n=115
(Out: Reflectance and RGB Maps)
Esri ArcPRO
Check Positional Accuracy of Layers & Extract Permit Area
Calculate NDVI and Composite With Single-band Rasters
Digitize Classification Training Data Plots to be Used for Both Datasets
Passing n=60
Failing n=60
Create SVM Models for Each Dataset
Digitize Ground Validation Plots
Extract Validation Plots from SVM Models
Establish Ground Plots
n=30
Conduct SME Classification
n=25
Assign SME Classification to Plots
Passing n=12
Failing n=13
Validation
Assess Replication Accuracy of SVM Models

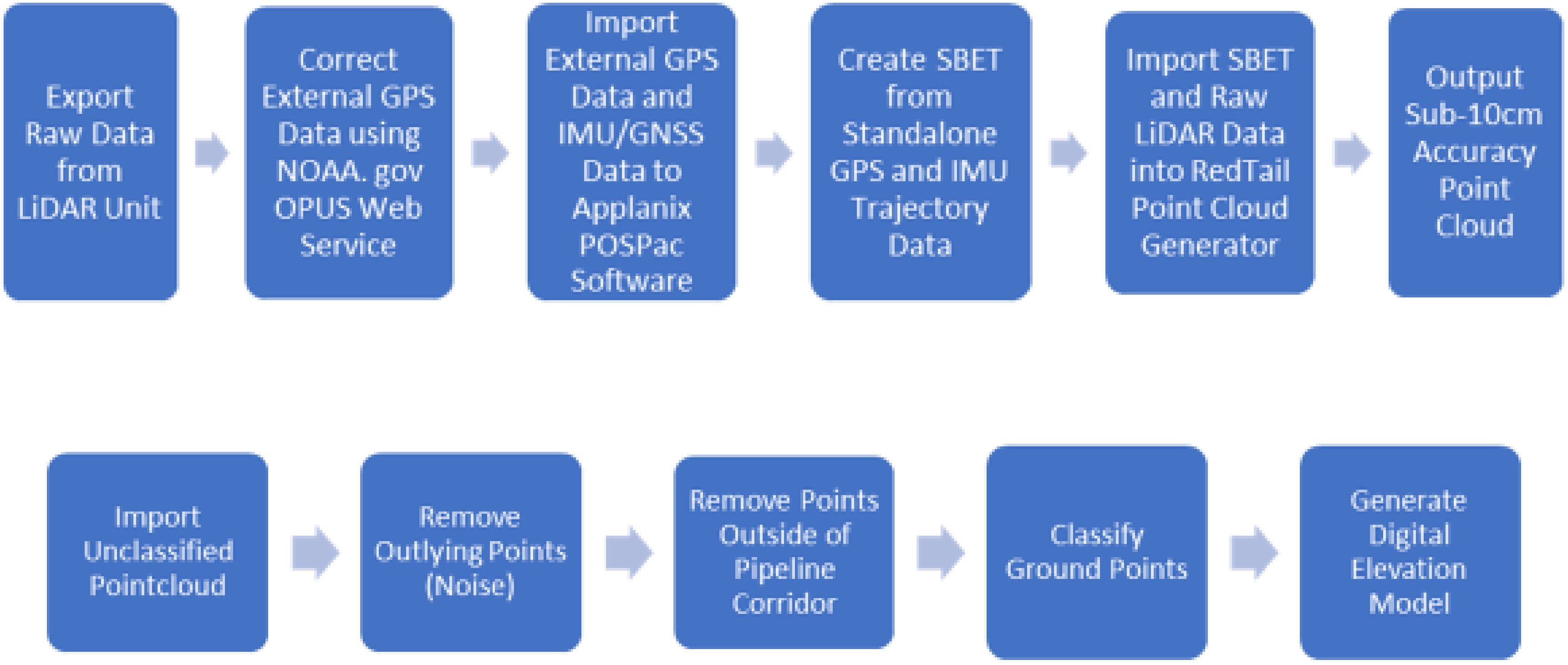

Training Data Classification
Fail
Pass
N
0
0.25
0.5
1 Kilometers

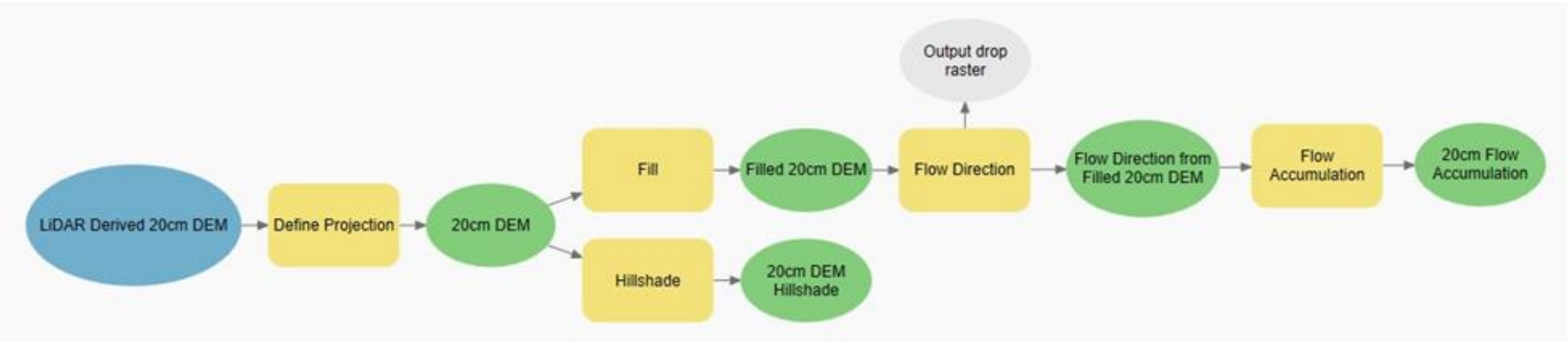

Multispectral SVM Model
Classification
Fail
Pass
0
0.2
0.4
0.8 Kilometers
0
25
50
100 Meters
N
0
0.25
0.5
1 Kilometers

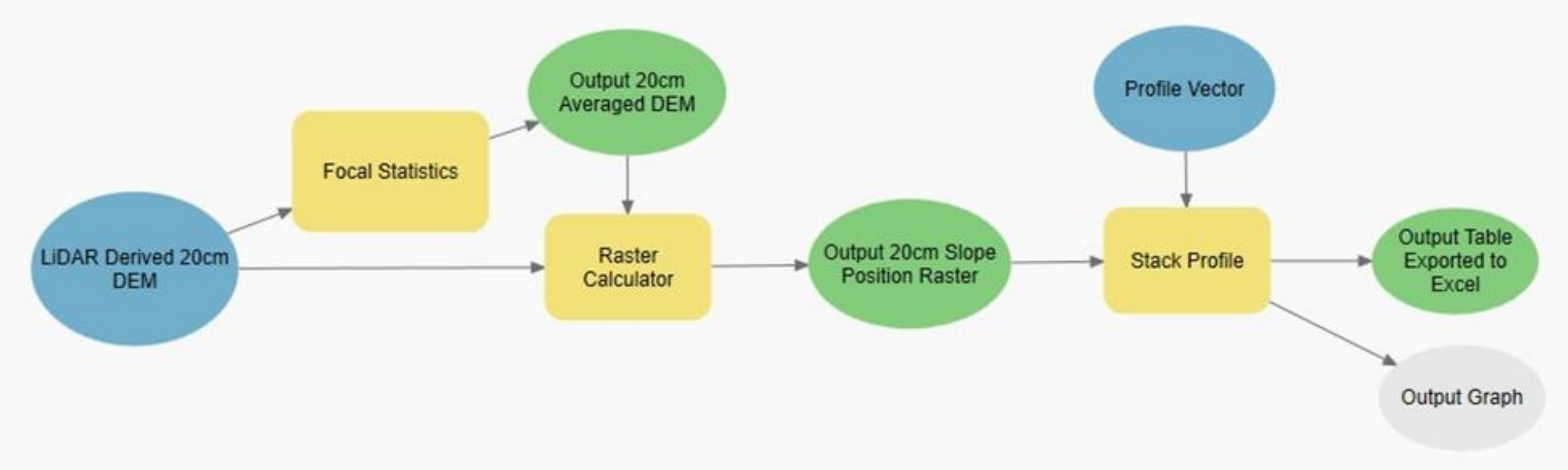


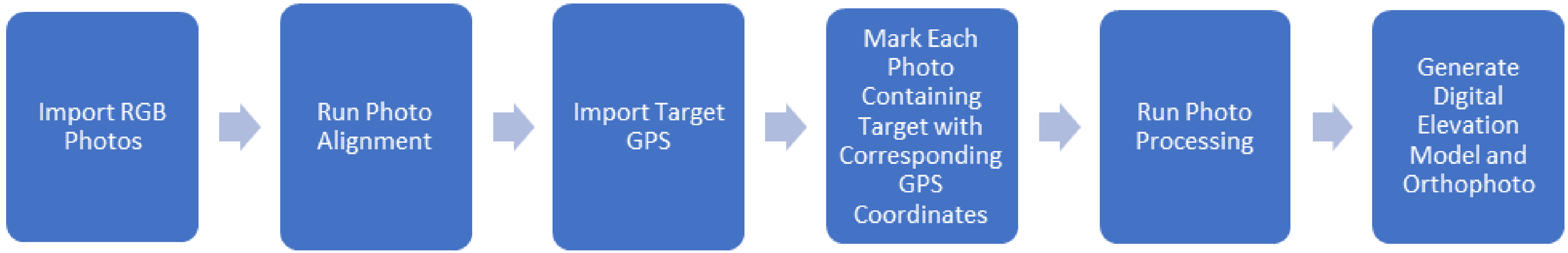
RGB SVM Model
Classification
Fail
Pass
0
0.2
0.4
0.8 Kilometers
0
25
50
100 Meters
N
0
0.25
0.5
1 Kilometers

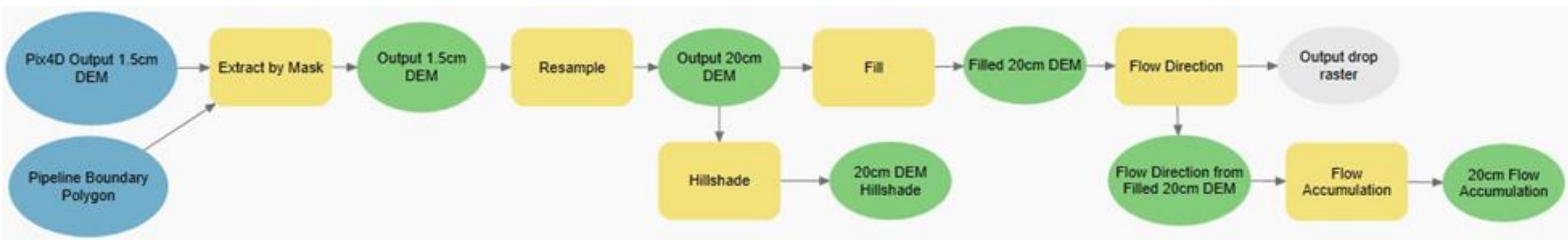
II. Sediment modeling

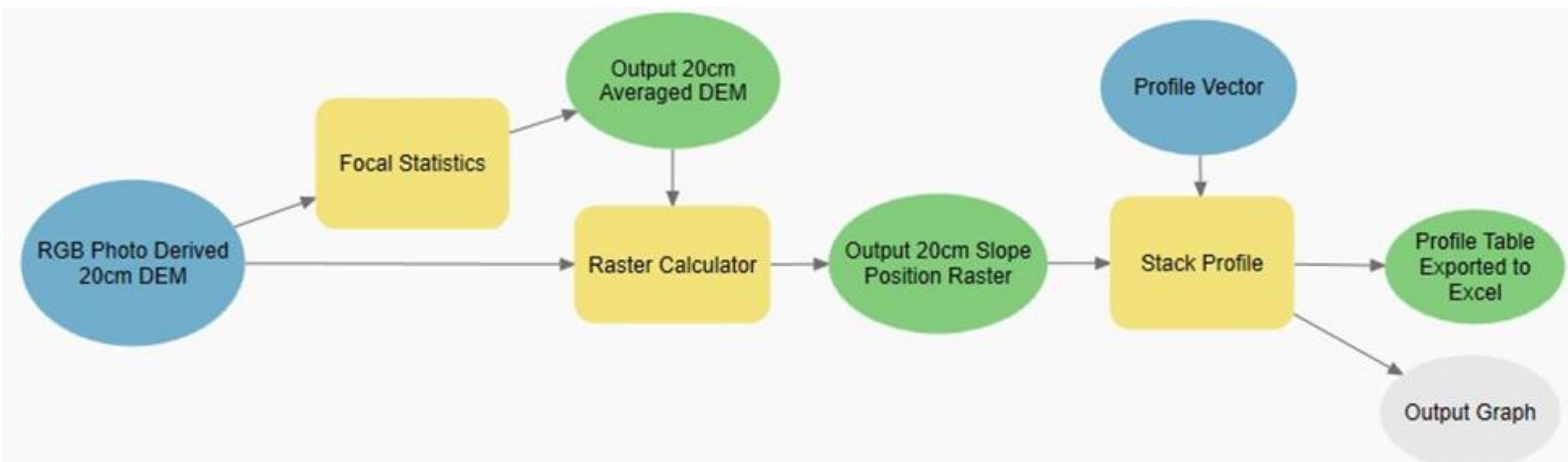



Output drop raster
LiDAR Derived 20cm DEM
Define Projection
20cm DEM
Fill
Filled 20cm DEM
Flow Direction
Flow Direction from Filled 20cm DEM
Flow Accumulation
20cm Flow Accumulation
Hillshade
20cm DEM Hillshade


Output 20cm Averaged DEM
Profile Vector
Focal Statistics
LiDAR Derived 20cm DEM
Raster Calculator
Output 20cm Slope Position Raster
Stack Profile
Output Table Exported to Excel
Output Graph


Import RGB Photos
Run Photo Alignment
Import Target GPS
Mark Each Photo Containing Target with Corresponding GPS Coordinates
Run Photo Processing
Generate Digital Elevation Model and Orthophoto


Pix4D Output 1.5cm DEM
Pipeline Boundary Polygon
Extract by Mask
Output 1.5cm DEM
Resample
Output 20cm DEM
Fill
Filled 20cm DEM
Flow Direction
Output drop raster
Hillshade
20cm DEM Hillshade
Flow Direction from Filled 20cm DEM
Flow Accumulation
20cm Flow Accumulation


RGB Photo Derived 20cm DEM
Focal Statistics
Output 20cm Averaged DEM
Raster Calculator
Output 20cm Slope Position Raster
Profile Vector
Stack Profile
Profile Table Exported to Excel
Output Graph

III. Cost effectiveness

- In the region containing the study area, there were 182 total rain events greater than 0.25 inches for 2019, 2020, and 2021, setting the number of average weather inspections to 61.
- From this a total of 113 total inspections were projected for this study area.
- Each inspection was flown in two branches, meaning the total number of inspection flights at this site would be 226 annually.

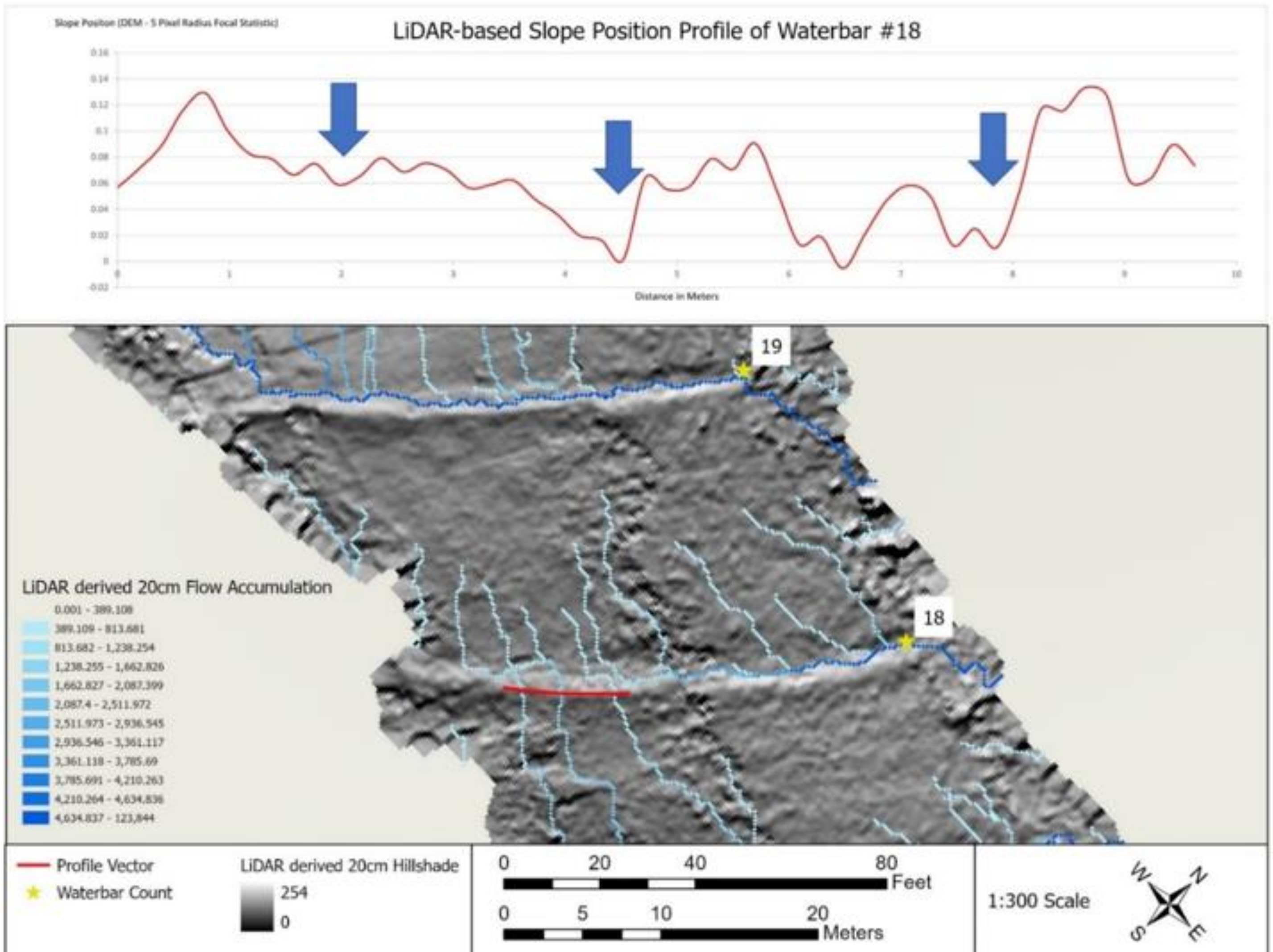
cont.

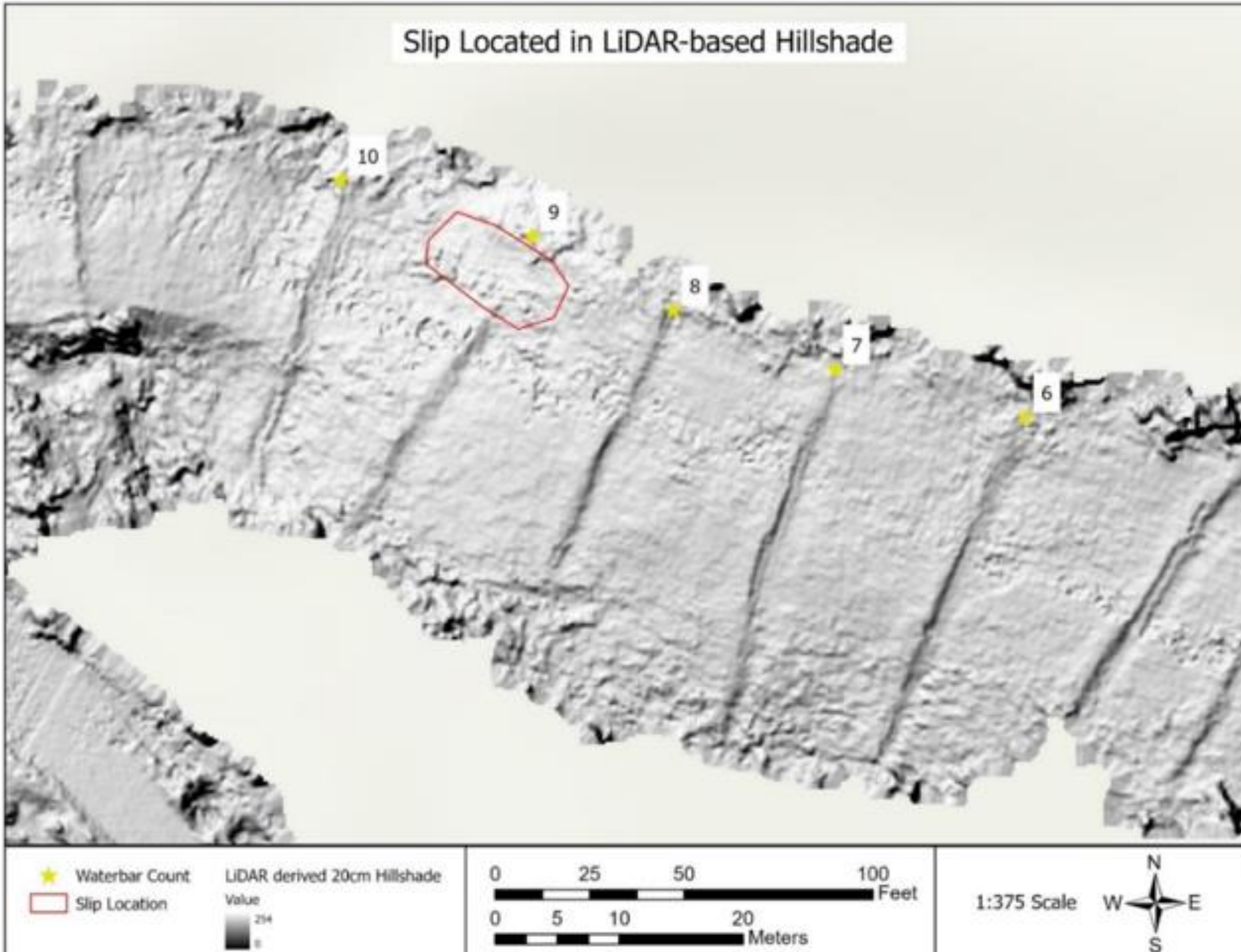
- Expert input placed UAV lifespan to be 1,000 flight hours before costly maintenance leads to a likely replacement of the drone system. With each flight in the study area covering approximately 1 km in a period of 20 minutes of flight, the drone would be expected to last 13.25 years until replacement was required.

Results – Vegetation classification

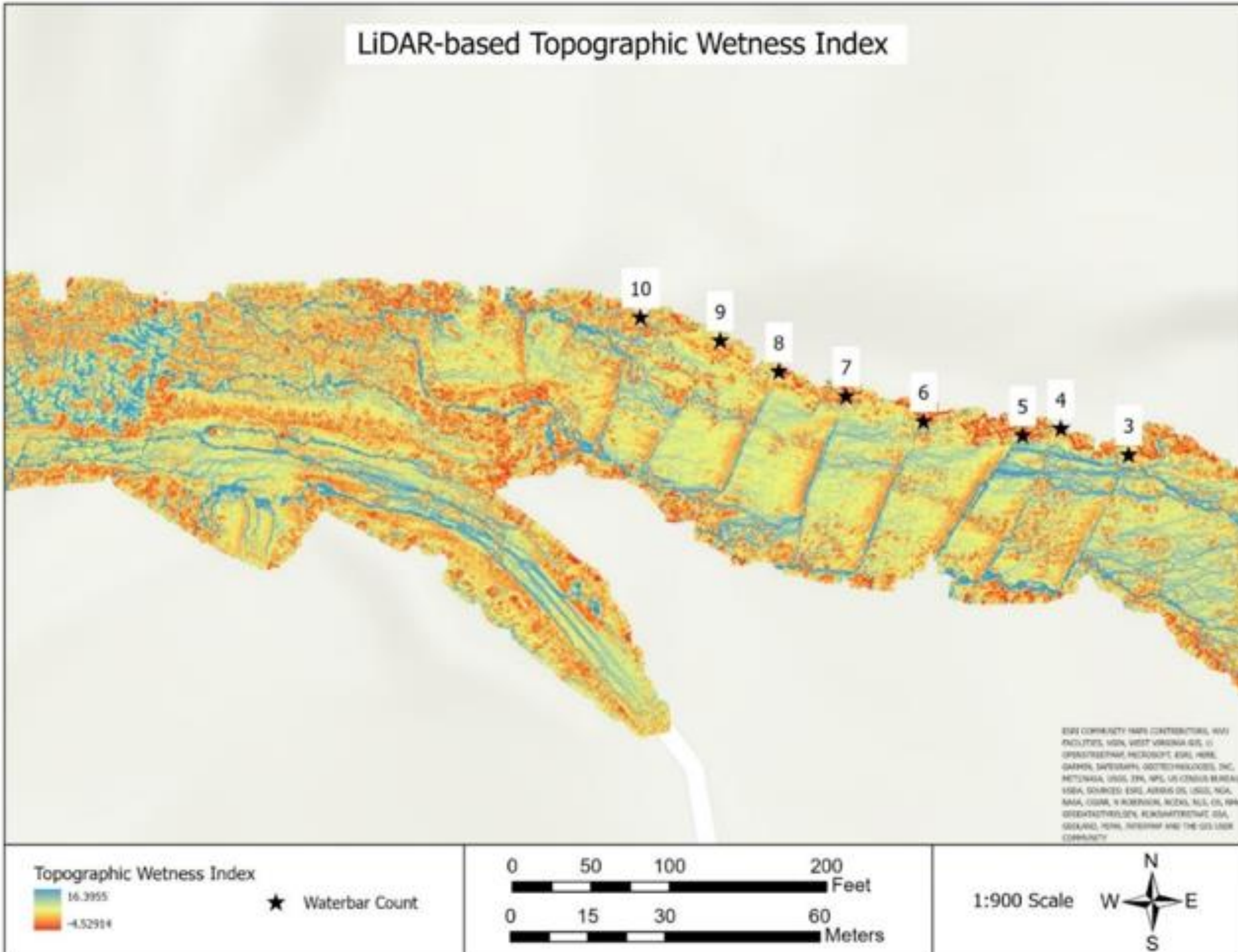
		True			
		Fail	Pass	Totals	User Accuracy
Predicted	Fail	11	0	11	1.0000
	Pass	2	12	14	0.8571
	Totals	13	12		
	Producer Accuracy	0.8462	1.0000	**Overall Accuracy->**	0.9200
				Kappa ->	0.8408

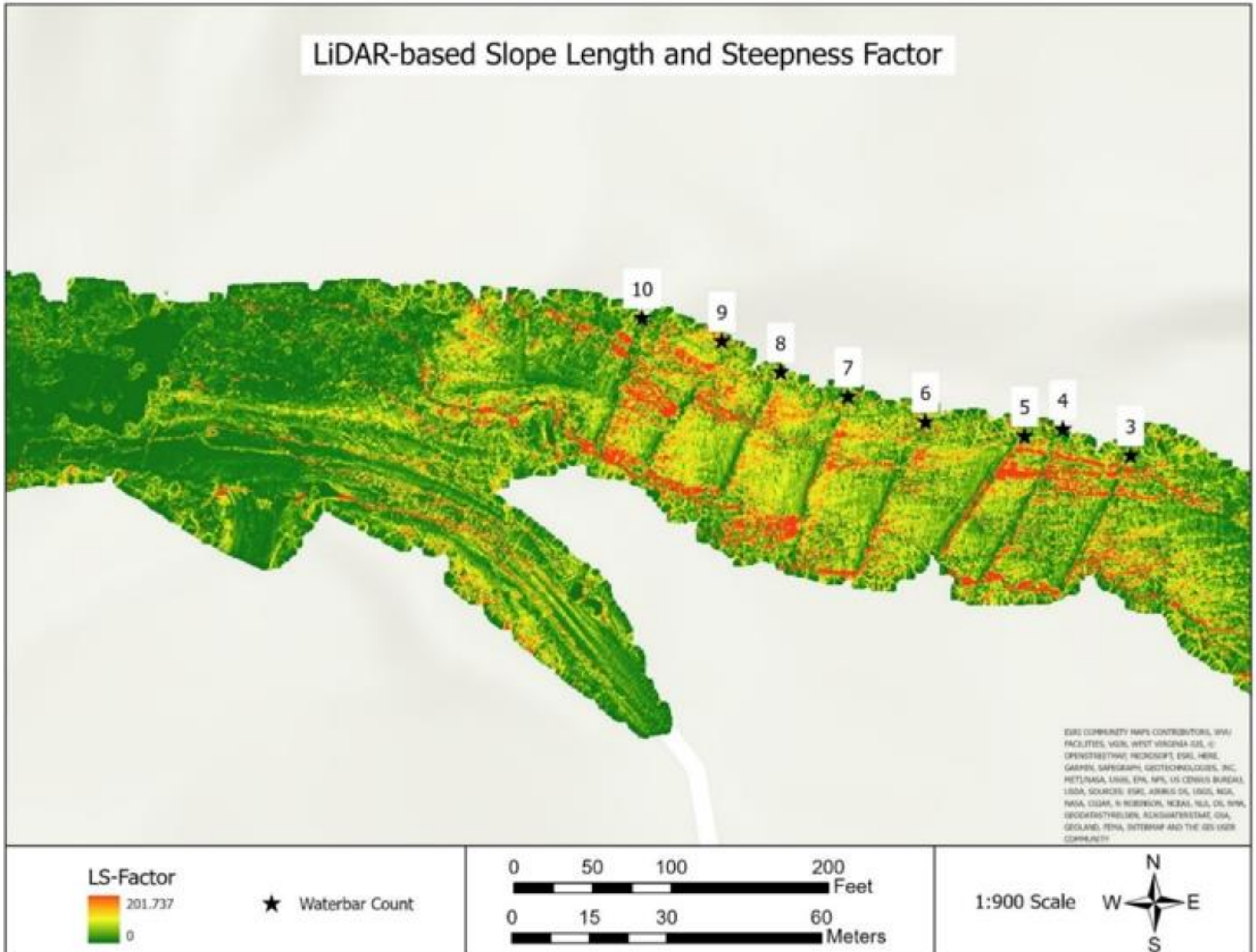
Results – Sediment modeling

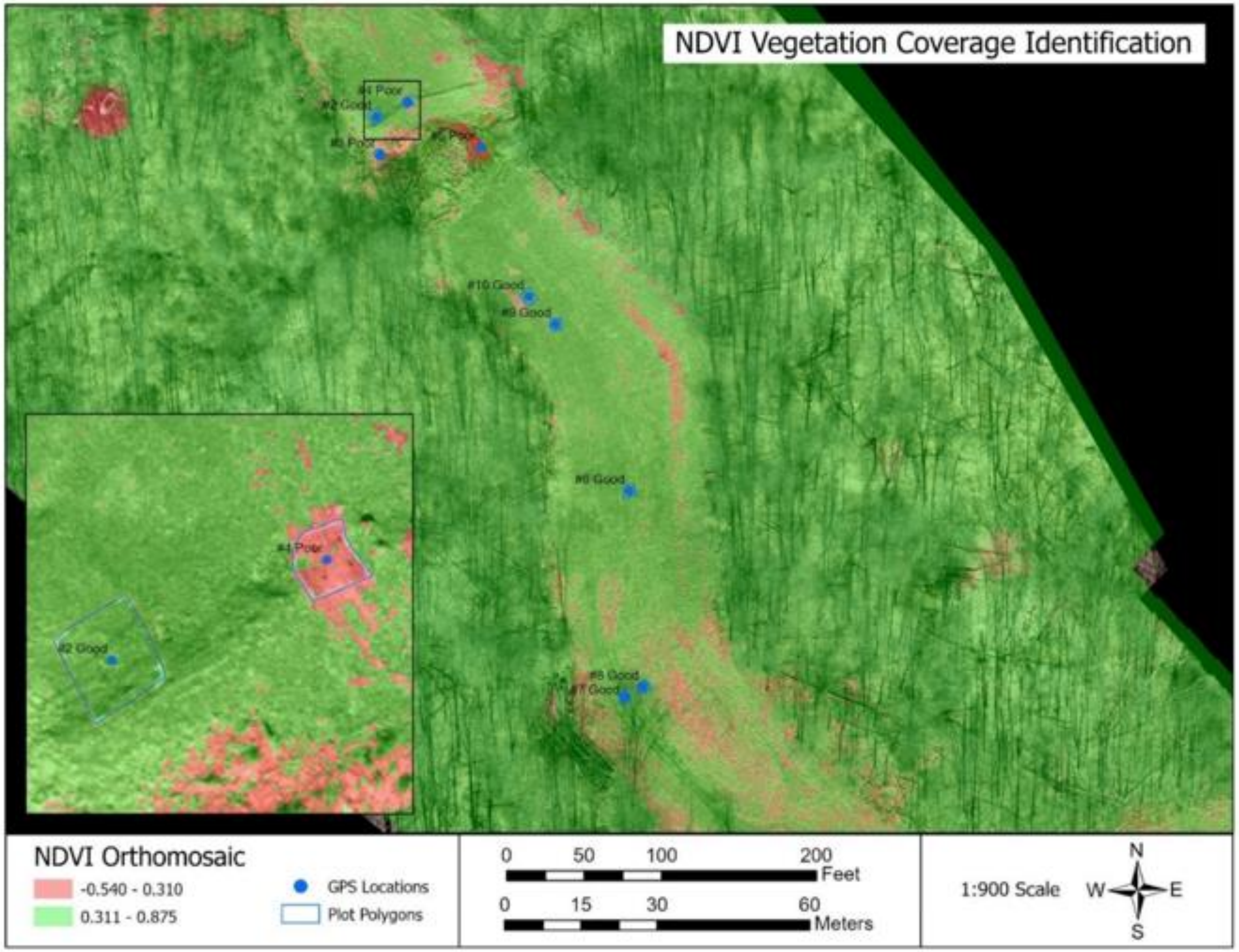


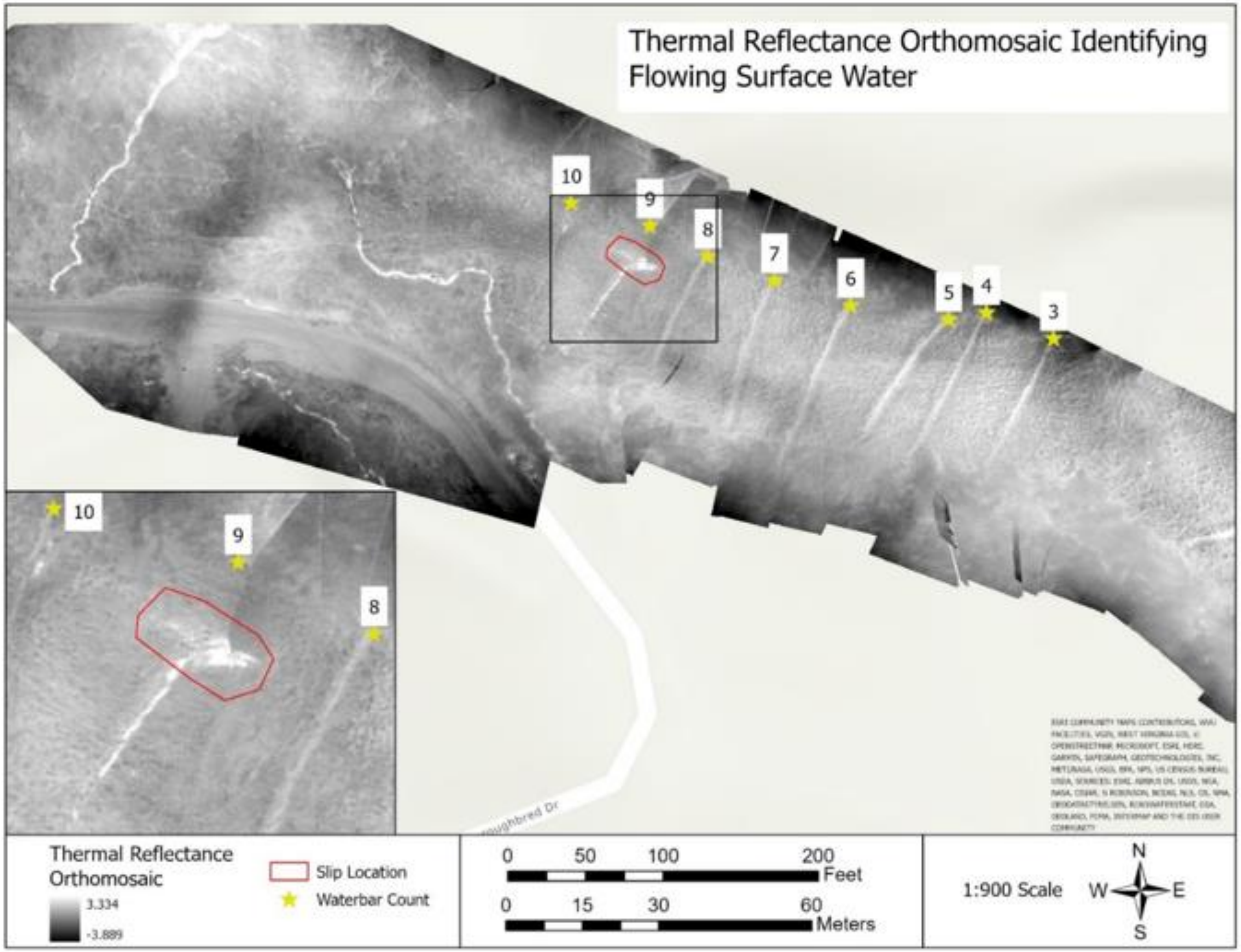


Slip Located in LiDAR-based Hillshade
10
9
8
7
6
Waterbar Count
Slip Location
LiDAR derived 20cm Hillshade
Value
0 25 50 100
Feet
0 5 10 20
Meters
1:375 Scale
N
W
E
S

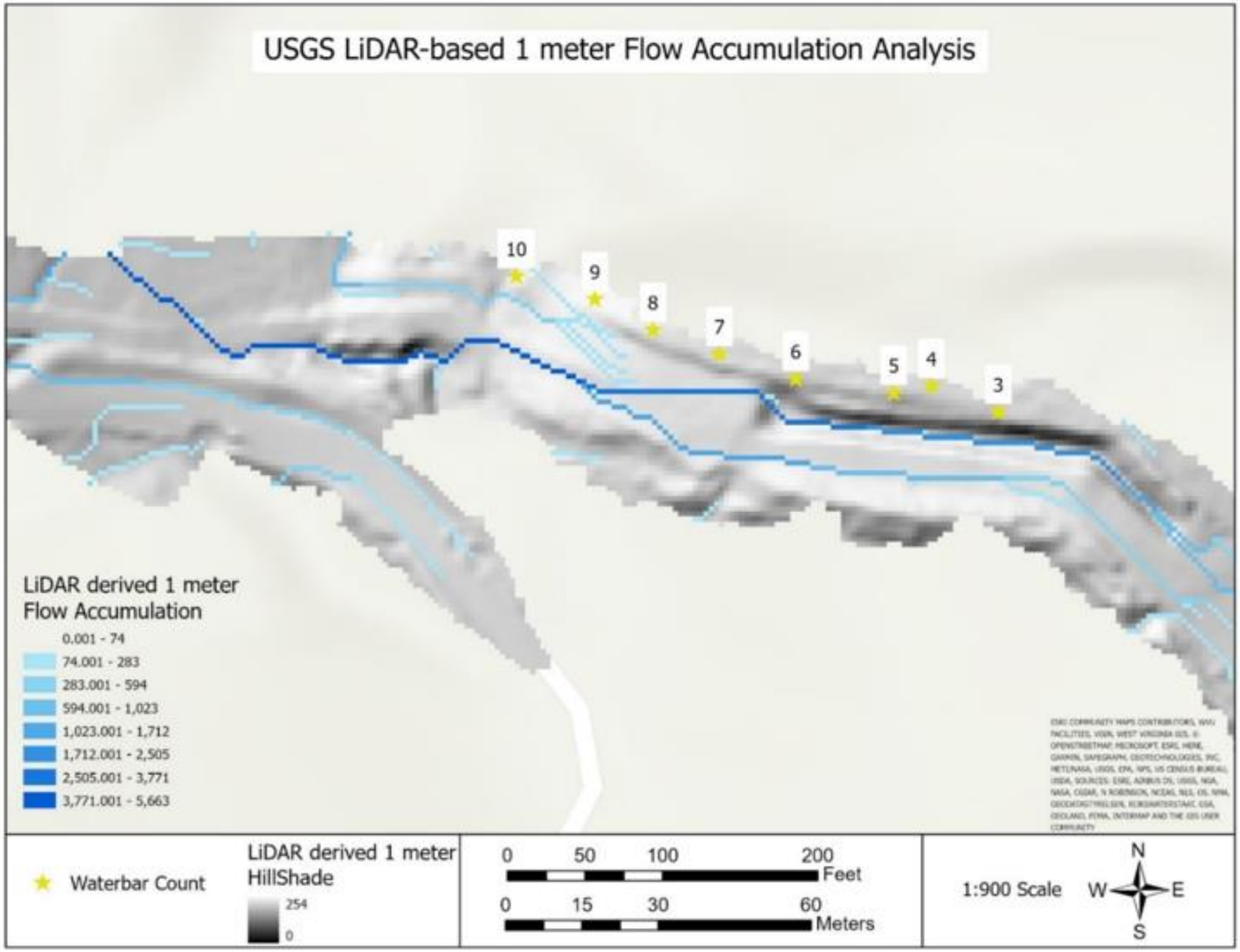

LiDAR-based Topographic Wetness Index
10
9
8
7
6
5
4
3
Topographic Wetness Index
16.3955
-4.52914
Waterbar Count
0 50 100 200 Feet
0 15 30 60 Meters
1:900 Scale
N
W
E
S

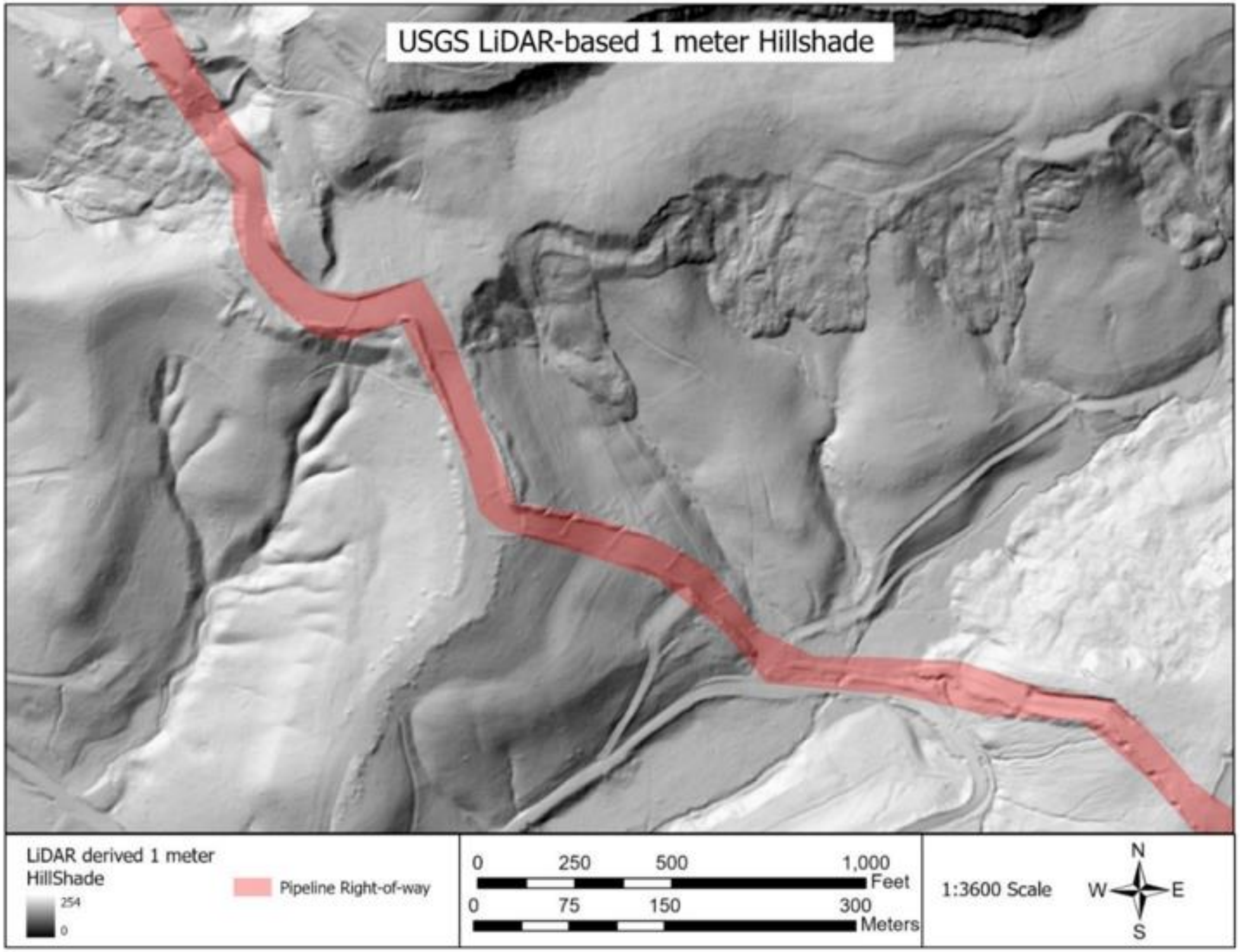

LiDAR-based Slope Length and Steepness Factor
10
9
8
7
6
5
4
3
LS-Factor
201.737
0
Waterbar Count
0
50
100
200
Feet
0
15
30
60
Meters
1:900 Scale
N
W
E
S


NDVI Vegetation Coverage Identification
NDVI Orthomosaic
-0.540 - 0.310
0.311 - 0.875
GPS Locations
Plot Polygons
0
50
100
200
Feet
0
15
30
60
Meters
1:900 Scale
N
W
E
S
#10 Good
#9 Good
#6 Good
#8 Good
#4 Poor
#2 Good



Thermal Reflectance Orthomosaic Identifying Flowing Surface Water
10
9
8
7
6
5
4
3
10
9
8
Thermal Reflectance Orthomosaic
3.334
-3.889
Slip Location
Waterbar Count
0
50
100
200
Feet
0
15
30
60
Meters
1:900 Scale
N
W
E
S

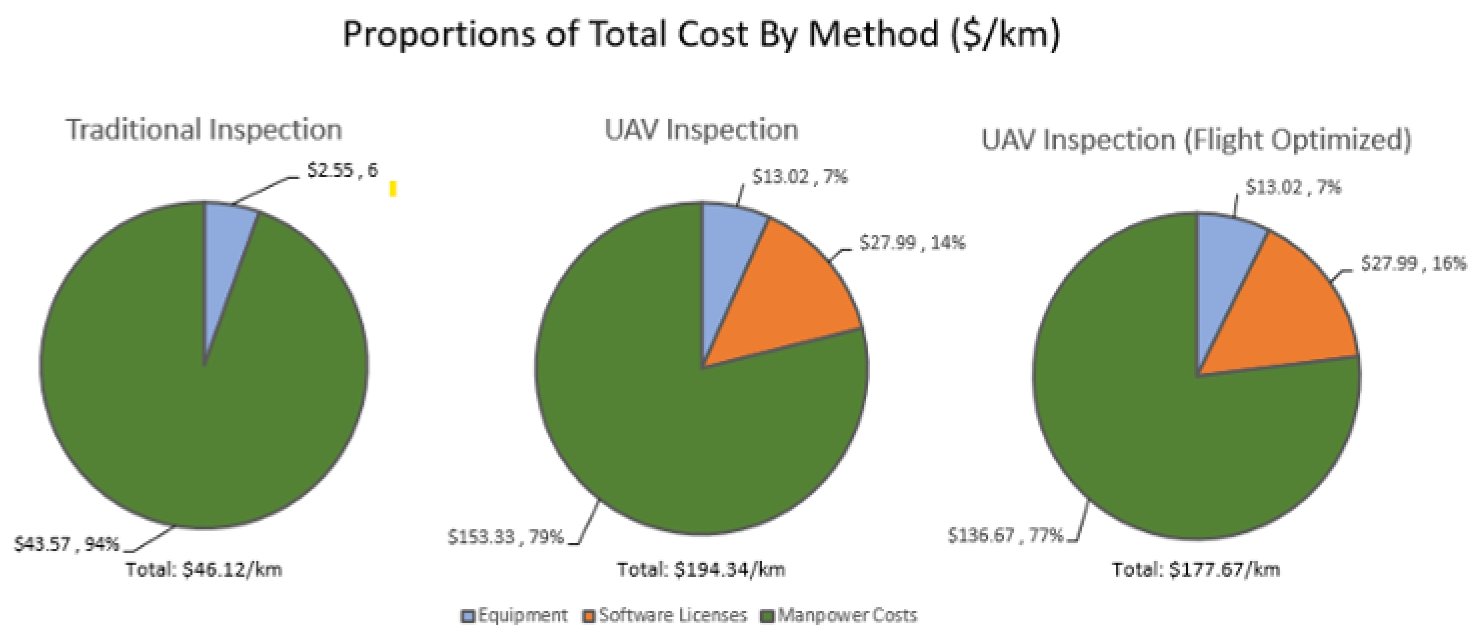

USGS LiDAR-based 1 meter Flow Accumulation Analysis
10
9
8
7
6
5
4
3
LiDAR derived 1 meter Flow Accumulation
0.001 - 74
74.001 - 283
283.001 - 594
594.001 - 1,023
1,023.001 - 1,712
1,712.001 - 2,505
2,505.001 - 3,771
3,771.001 - 5,663
Waterbar Count
LiDAR derived 1 meter HillShade
254
0
0 50 100 200 Feet
0 15 30 60 Meters
1:900 Scale
N
W
E
S


USGS LiDAR-based 1 meter Hillshade
LiDAR derived 1 meter
HillShade
254
0
Pipeline Right-of-way
0
250
500
1,000
Feet
0
75
150
300
Meters
1:3600 Scale
N
W
E
S

Results – Cost effectiveness

Drone Inspection							
Equipment Costs							
	Item/License	Cost ($)	Qty	Replacement Period (yrs)	$/yr	$/Km	% Of Method Total
	DJI M200 v2	$ 6,000.00	1	13.25	$ 452.83	$ 1.71	1%
	Drone Insurance	$ 728.06	1	1	$ 728.06	$ 2.75	1%
	M200 Battery	$ 480.00	2	1.7	$ 564.71	$ 2.14	1%
	Sentera 6x Multispectral Sensor	$ 13,550.00	1	13.25	$ 1,022.64	$ 3.87	2%
	iPad	$ 599.00	1	1	$ 599.00	$ 2.27	1%
	Apple iCare	$ 149.00	1	2	$ 74.50	$ 0.28	0%
	Pix4d Mapper	$ 3,600.00	1	1	$ 3,600.00	$ 13.61	7%
	Esri ArcGIS Pro License	$ 3,800.00	1	1	$ 3,800.00	$ 14.37	7%
				Equipment Cost Subtotal ($/Km)		$ 41.00	21%
Manpower Costs							
	Position	Hourly Rate	Hourly Rate + 25%		Hrs/Km	$/Km	
	Pilot	$ 20.00	$ 25.00		1.28	$ 32.08	17%
	GIS Analyst	$ 40.00	$ 50.00		2.43	$ 121.25	62%
				Manpower Cost Subtotal ($/Km)		$ 153.33	79%
				Drone Inspection Cost Total ($/Km):		$ 194.34	

Traditional Inspection							
Equipment Costs							
	Item/License	Cost ($)	Qty	Replacement Period (yrs)	$/yr	$/Km	% Of Method Total
	iPad	$ 599.00	1	1	$ 599.00	$ 2.27	5%
	Apple iCare	$ 149.00	1	2	$ 74.50	$ 0.28	1%
				Equipment Cost Subtotal ($/Km)		$ 2.55	6%
Manpower Costs							
	Position	Rate ($/hr)	Rate + 25% ($/Hr)		Hrs/Km	$/Km	
	Pipeline Inspector*	$ 20.00	$ 25.00		1.74	$ 43.57	94%
				Traditional Inspection Cost Total ($/Km):		$ 46.12	



Collection (Adjusted to min/Km)		
	Time (Min)	Time (Hr)
Set Up	30	0.50
Calibration	2	0.03
Flight	20	0.33
Moving Pics to Computer	25	0.42
Pilot Total (Hr/Km):		1.28

Processing (Adjusted to min/Km)		
	Time (Min)	Time (Hr)
Align	45	0.75
Set GCP	30	0.50
Products	20	0.33
Processing Subtotal (Hr/Km):		1.58
Modeling		
	Time (Min)	Time (Hr)
Load	15	0.25
Mosaic	2	0.03
Calculate NDVI	1	0.02
Clip	1	0.02
Check Training Features	20	0.33
Train SVM	1	0.02
Reclassify	1	0.02
Total	41	0.68
Modeling Subtotal (Hr/Km):		0.34
Analysis and Report Creation		
	Time (Min)	Time (Hr)
Analysis (Review)	30	0.50
Report	30	0.50
Total	60	1.00
Analysis and Report Subtotal (Hr/Km):		0.50

GIS Analyst total (Hr/Km):	2.43

		$/Km Proportional Cost Comparison								
		Drone Processing Efficiency Increase								
		0%	5%	10%	20%	30%	40%	50%	60%	70%
Inspector Speed (km/hr) 25% Overhead	0.40	0.72	0.74	0.75	0.80	0.84	0.89	0.95	1.02	1.10
	0.80	0.40	0.41	0.42	0.44	0.47	0.50	0.53	0.57	0.61
	1.20	0.29	0.30	0.31	0.32	0.34	0.36	0.39	0.41	0.44
	1.60	0.24	0.24	0.25	0.26	0.28	0.30	0.32	0.34	0.36
	2.01	0.21	0.21	0.22	0.23	0.24	0.26	0.27	0.29	0.31
	2.41	0.18	0.19	0.19	0.20	0.22	0.23	0.24	0.26	0.28
	2.81	0.17	0.17	0.18	0.19	0.20	0.21	0.22	0.24	0.26
	3.21	0.16	0.16	0.17	0.17	0.18	0.20	0.21	0.22	0.24

Optimized Collection (Adjusted to min/Km)		
	Time (Min)	Time (Hr)
Set Up	15	0.25
Calibration	2	0.03
Flight	10	0.17
Moving Pics to Computer	10	0.17

Pilot Total (Optimized, Hr/Km):	0.62

		$/Km Proportional Cost Comparison								
		Drone Processing Efficiency Increase with Flight Optimization								
		0%	5%	10%	20%	30%	40%	50%	60%	70%
Inspector Speed (km/hr) 25% Overhead	0.40	0.78	0.81	0.83	0.88	0.94	1.00	1.08	1.16	1.26
	0.80	0.43	0.45	0.46	0.49	0.52	0.55	0.60	0.64	0.70
	1.20	0.32	0.33	0.34	0.36	0.38	0.41	0.44	0.47	0.51
	1.60	0.26	0.27	0.27	0.29	0.31	0.33	0.36	0.38	0.42
	2.01	0.22	0.23	0.24	0.25	0.27	0.29	0.31	0.33	0.36
	2.41	0.20	0.21	0.21	0.23	0.24	0.26	0.28	0.30	0.32
	2.81	0.18	0.19	0.20	0.21	0.22	0.24	0.25	0.27	0.30
	3.21	0.17	0.18	0.18	0.19	0.21	0.22	0.24	0.26	0.28

Conclusions and discussion – Vegetation classification

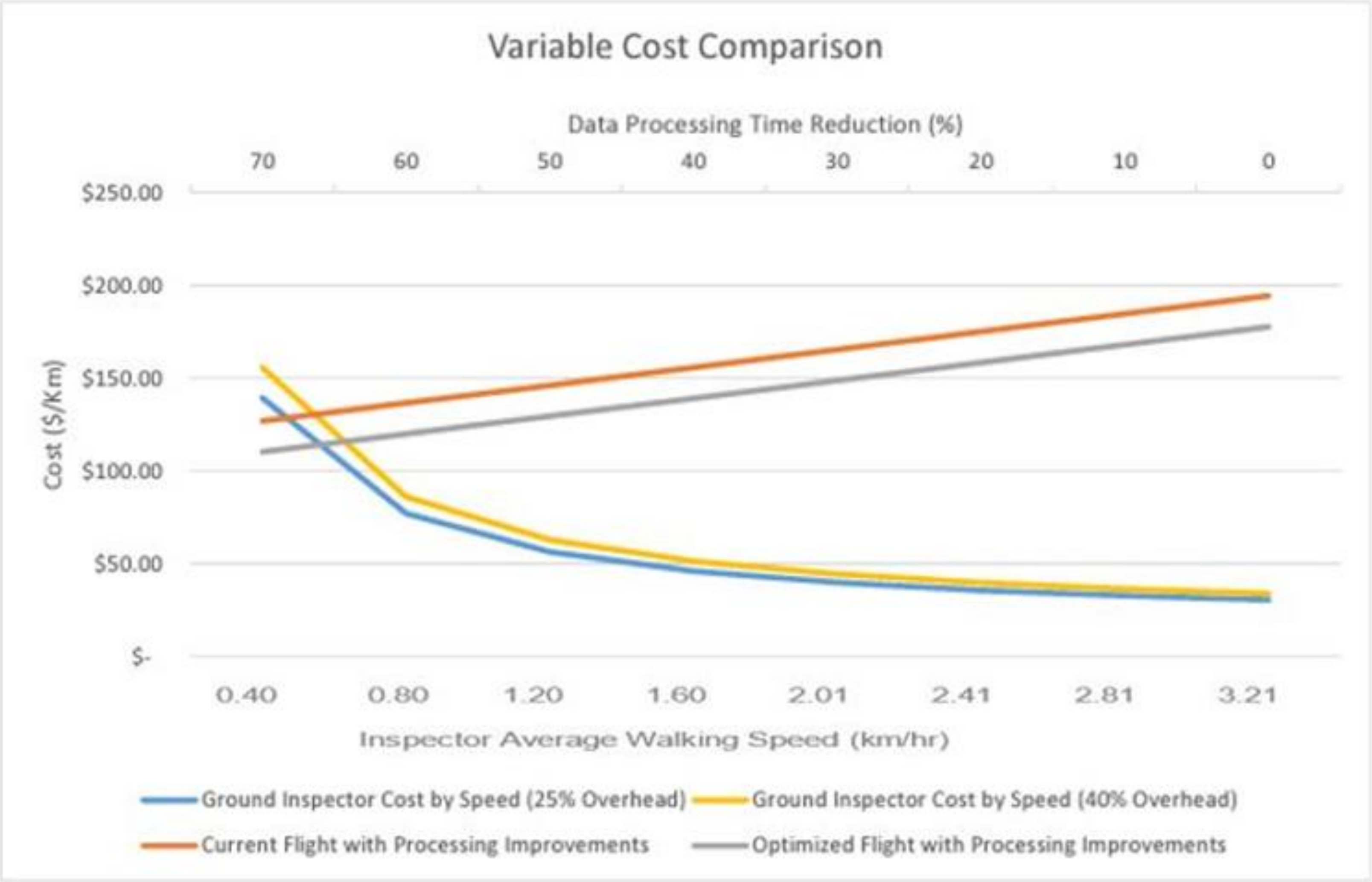
- The accuracy assessments of both models suggest the ability of either multispectral or RGB equipped UAVs to provide pipeline vegetation inspections at high accuracy
- Results indicate that the applied technique is capable and SVM does appear to be an appropriate classification approach at this small spatial resolution

Conclusions and discussion – Sediment modeling

- UAV-based LiDAR and RGB photogrammetry products are highly useful for spatial analyses and aid in surveying, construction, monitoring, and change detection of a pipeline.
- UAV-based LiDAR is the preferred remote sensing system to use for inspecting, monitoring, and managing structural features including those specific to sediment control within a pipeline right-of-way.

Conclusions and discussion – Cost effectiveness

- The tested UAV pipeline inspection approach will be fiscally difficult to implement in all but the most complex terrain. From the factors included, the analysis suggests that the traditional inspection approach, using a simple equipment set and lower inspector pay rate, is likely to produce lower costs than the UAV approach per kilometer.



Variable Cost Comparison
Data Processing Time Reduction (%)
70
60
50
40
30
20
10
0
$250.00
$200.00
$150.00
$100.00
$50.00
$-
Cost ($/Km)
0.40
0.80
1.20
1.60
2.01
2.41
2.81
3.21
Inspector Average Walking Speed (km/hr)
Ground Inspector Cost by Speed (25% Overhead)
Ground Inspector Cost by Speed (40% Overhead)
Current Flight with Processing Improvements
Optimized Flight with Processing Improvements

Impact of this research project/technology on pipeline safety

- We found that UAV-based remote sensing systems and their array of valuable data outputs display an immense opportunity to increase safety, efficiency, and accuracy within the oil and gas industry.

Future research opportunities

- Though current analysis shows UAV based inspections to be more costly than traditional approaches, the evaluation of additional identified factors may create a more complete picture of the relationship between these two techniques, and aid in reducing this cost differential.
- After determining effective performance and cost optimization, a purpose-built drone could be deployed over a pipeline stretch using a previously created flight plan on a regular basis. From this, models of a reasonably high accuracy are derived, which could in turn be used to identify larger issues requiring immediate responses.
- This tasking could cover some weekly and post-rain inspections, where there is a time sensitive nature to detecting large failures. Trained and certified professionals will still be needed in inspections, as they can seek-out conditions which the drone may miss; however, their time spent traversing difficult terrain would be reduced.

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