Predicting Soil Erosion Potential from Military Vehicle Tracking and Terrain Impacts

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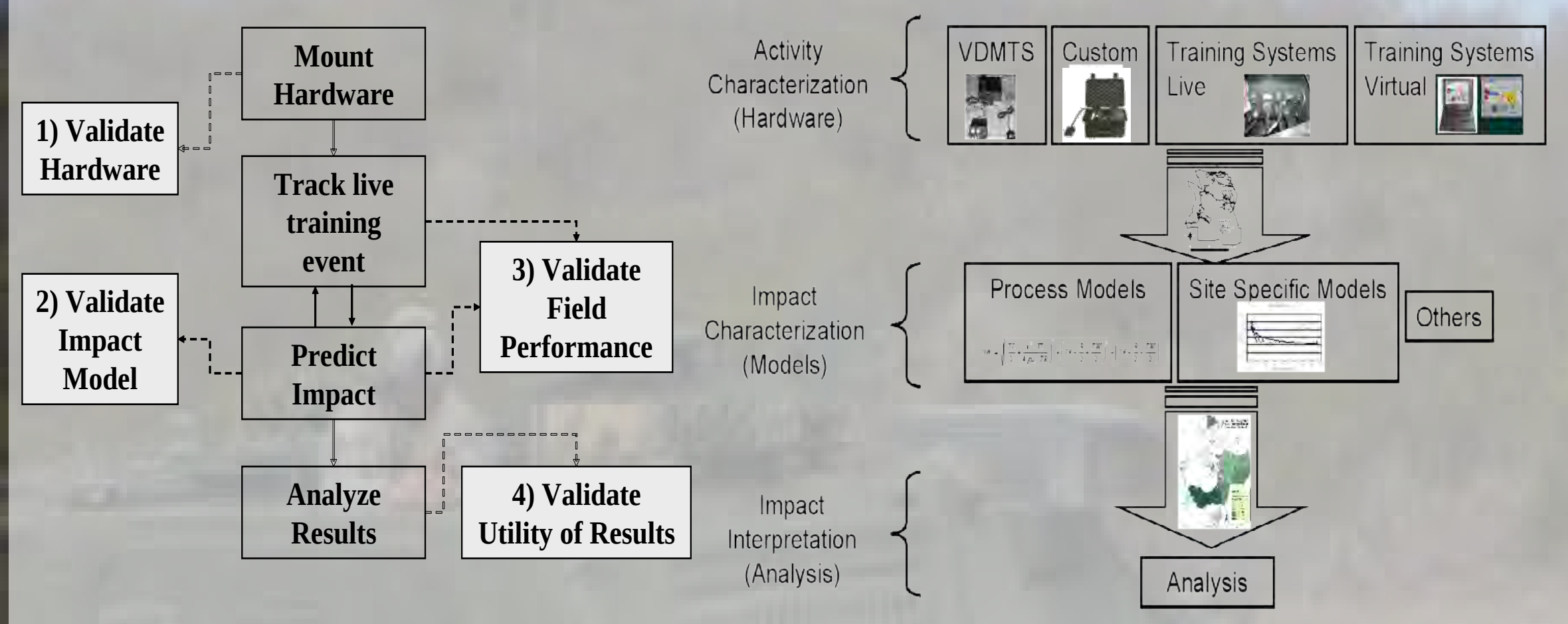
ABSTRACT. Military vehicle maneuvers remove vegetation and increase the potential for soil erosion. Quantifying the vegetation removed during military maneuvers is needed to assist land managers in maintaining the environmental integrity of the training area. A terrain-vehicle impact model was used to predict terrain impacts (disturbed width and impact severity), based on vehicle properties, operating characteristics and soil strength properties. The cumulative impact width (CIW), a product of the disturbed width and impact severity, is the width of vegetation removed resulting from a passing wheeled or tracked vehicle. The vegetation removed is a direct indicator of increased soil erosion from the training area. By tracking military vehicles during maneuvers, the vehicle movement pattern and the resulting vegetation removed can be determined. The approach was used to determine the vegetation removed during an eight-wheeled Stryker military maneuver at Pohakuloa Training Area in Hawaii. A Stryker reconnaissance platoon (3 vehicles) of the 2nd Brigade of the 25th Infantry Davison was tracked during an off-road proofing mission on the Keamuku parcel using GPS-based tracking systems to determine vehicle movement patterns and estimate soil loss impacts. Total vegetation removed was estimated from the vehicle operating characteristics (velocity and turning radius) determined from the GPS data. An average of 1,251 square meters of vegetation removed per vehicle during the proofing maneuver was estimated. An average of 9.1 km of off-road travel distance was measured per vehicle, with an average speed of 3.69 m/s. Off-road travel accounted for less than 10 percent of the total distance travelled. Spiral impacts were conducted to evaluate the influence of vehicle velocity and turning radius on terrain impact. Sharper turns and higher speeds produced more vegetation removed. A vegetative recovery study was conducted indicating over 90 percent of the vegetation returned in the following the 15 month period.

VEHICLE TRACKING APPROACH.

The Vehicle Dynamics Monitoring and Tracking System (VDMTS) consists of three components: 1) vehicle tracking hardware, 2) vehicle impact models, and 3) vehicle tracking data analysis methods. The vehicle tracking approach spatially characterizes short-term, direct impacts resulting from vehicles by monitoring individual vehicle locations and dynamic operating characteristics (i.e. turning radius and velocity). Vehicle impact models are used to predict area impacted, vegetation loss, and rut depth based on vehicle operating characteristics and location. Analysis routines summarize use patterns and severity of cumulative impacts. ESTCP project RC-200815 demonstrates and validates each component of the approach. The figures below illustrate the impact assessment approach and related validation tests.



VEHICLE TRACKING HARDWARE.

The VTS developed for vehicle tracking consists of a WAAS differential Global Positioning System (DGPS) receiver, a serial data recorder, a data storage card, batteries(s), and a waterproof case. The system was developed to be lightweight, mobile, and flexible. It is a completely self-contained system requiring no electrical connection to the vehicle power supply and can collect 8 days of GPS positional data depending on the configuration.

The Garmin GPS18-PC GPS receiver can be attached to the vehicle with a magnet, has a wide range of operating temperature (-30°C to 85°C), and a wide range of input voltage (6 VDC to 40VDC unregulated). The Acumen Serial Data Recorder (SDR) is used for the vehicle tracking systems. A Compact Flash card is used for data storage in the vehicle tracking system. Oddessey rechargeable Drycell 12 volt battery (P/N PC625) are used as a 12V power supply for the system. A Kinetics dry case houses the vehicle tracking system equipment.

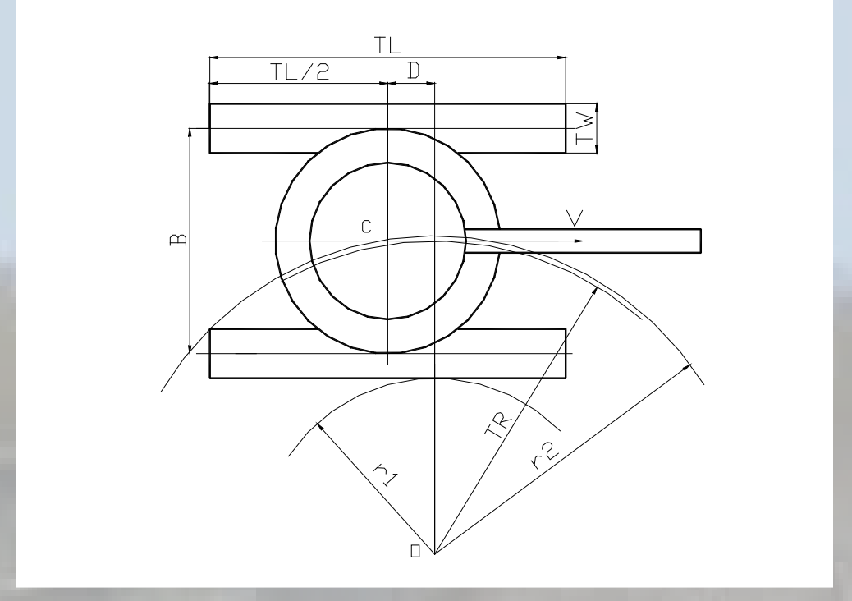

Garmin G18


Mounting Tracking Hardware

VEHICLE IMPACT MODELS.

Theoretical vehicle impact models predict site impacts in terms of area disturbed, vegetation loss, and rut depth. Impact models predict severity of impact based on vehicle static properties (i.e. vehicle type, weight, dimension), vehicle dynamic properties (i.e. turning radius, velocity), and site conditions (i.e. soil strength). Data collected by the vehicle tracking hardware are used with the impact models to predict spatially explicit site impacts. Equations below illustrate the impact models for a specific vehicle type.

$$DW = \sqrt{\left(\frac{TL}{2} + \frac{v^2 \cdot TL}{4gu_l \cdot TR}\right)^2 + \left(TR - \frac{B}{2} + \frac{TW}{2}\right)^2} - \left(TR - \frac{B}{2} - \frac{TW}{2}\right)$$



Where DW is disturbed width
TR is turning radius
TL is track length
TW is track width
B is tread width
V is velocity of the vehicle
g is acceleration of gravity
u_l is coefficient of lateral resistance

$$IS = \left(1 - e^{-j/K - 0.223}\right) \times 100\%$$

Where IS is vegetation loss (impact severity)
j is shear displacement
K is the shear deformation modulus

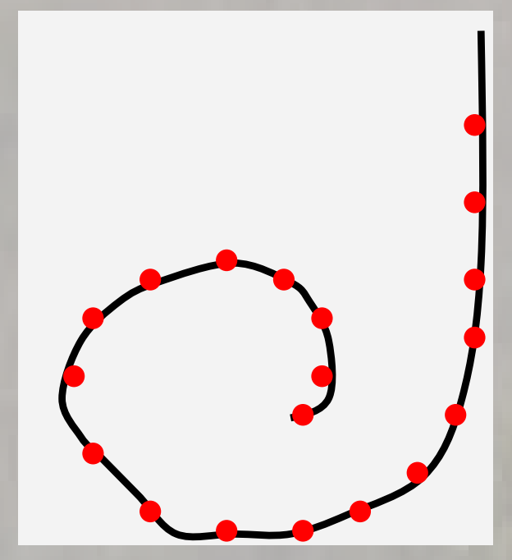
Cumulative Impact Width (CIW) can be calculated by multiplying the DW by IS. CIW can then be multiplied by distance traveled to determine area of vegetation removed.

Site Measure	Theoretical Models Mean Difference	Theoretical Models Mean Abs. Difference	Statistical Models Mean Difference	Statistical Models Mean Abs. Difference
Disturbed Width (cm)	2.6	11.5	2.4	6.4
Vegetation Loss (%)	-3.8	8.6	-1.2	5.7
Rut Depth (cm)	0.3	0.9	-0.2	0.6

Off-Road Positional Accuracy
Position Acc: 1.6m (±0.1m)

VEHICLE IMPACT SITE SPECIFIC MODEL.

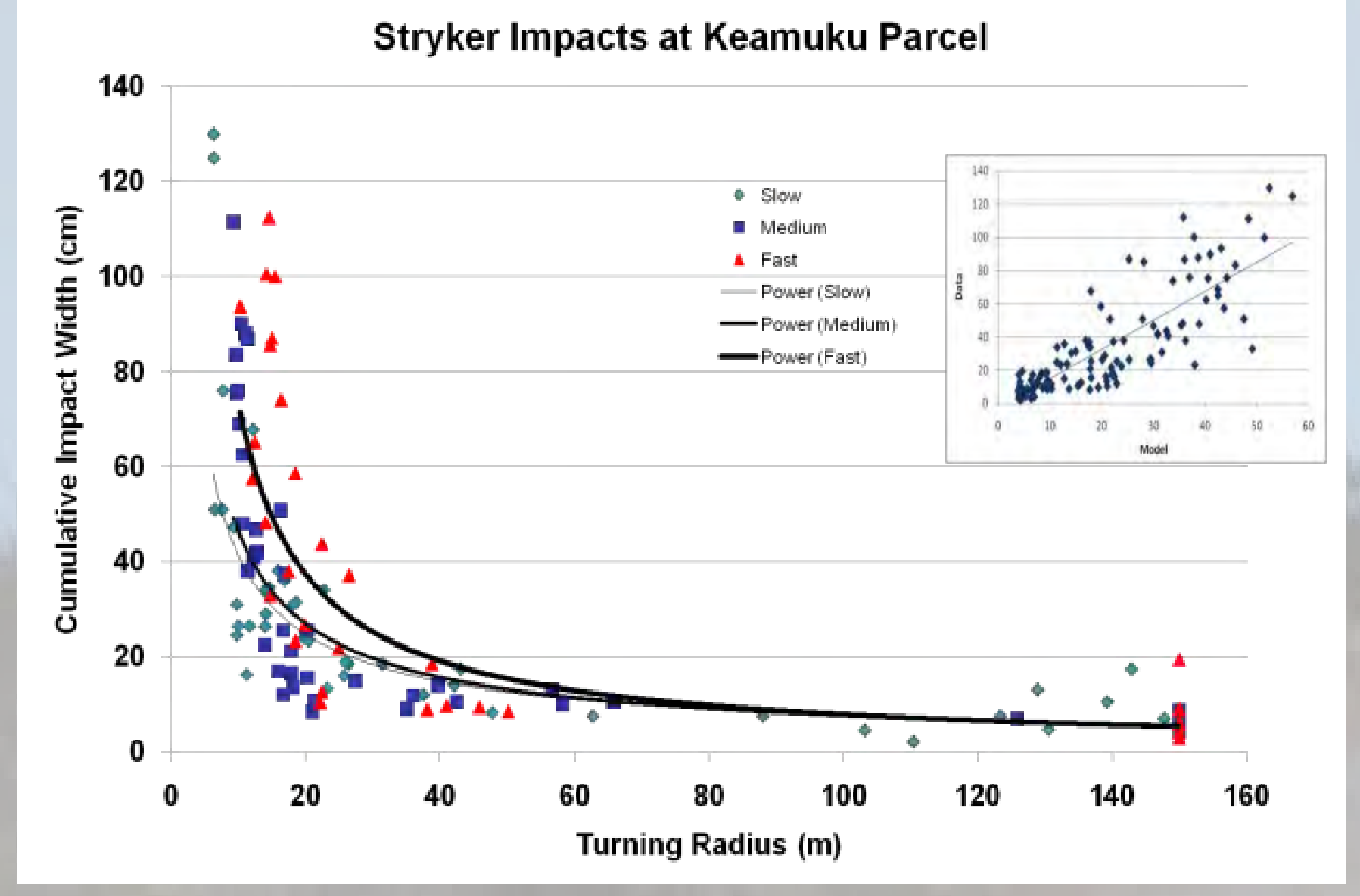
To evaluate the influence of speed and turning radius on vegetative impacts, the Stryker conducted spirals at 3 speeds, low, medium and high. A total of 8 spirals were conducted (3 low, 3 medium and 2 high speeds). The vehicle was initially driven straight, then proceeded to turn with a continuously deceasing turning radius. At approximately 15 points along each spiral the disturbed width and impact severity was determined. The cumulative impact width (CIW) was calculated as the product of the disturbed width times the impact severity, and was matched to the vehicle turning radius.


Vehicle Impact Model Validation Spiral Course


Measuring Vehicle Impacts

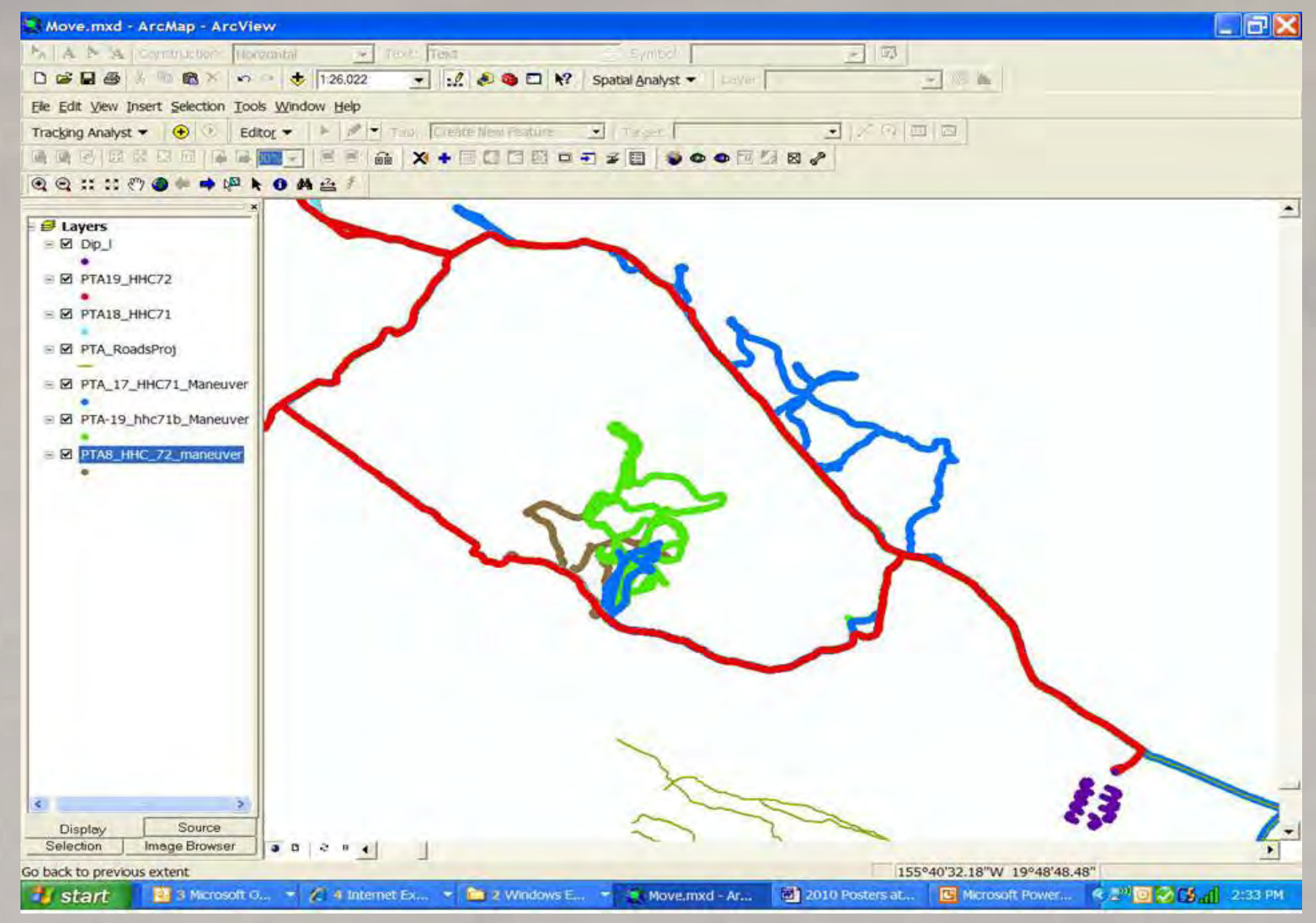
RESULTS.

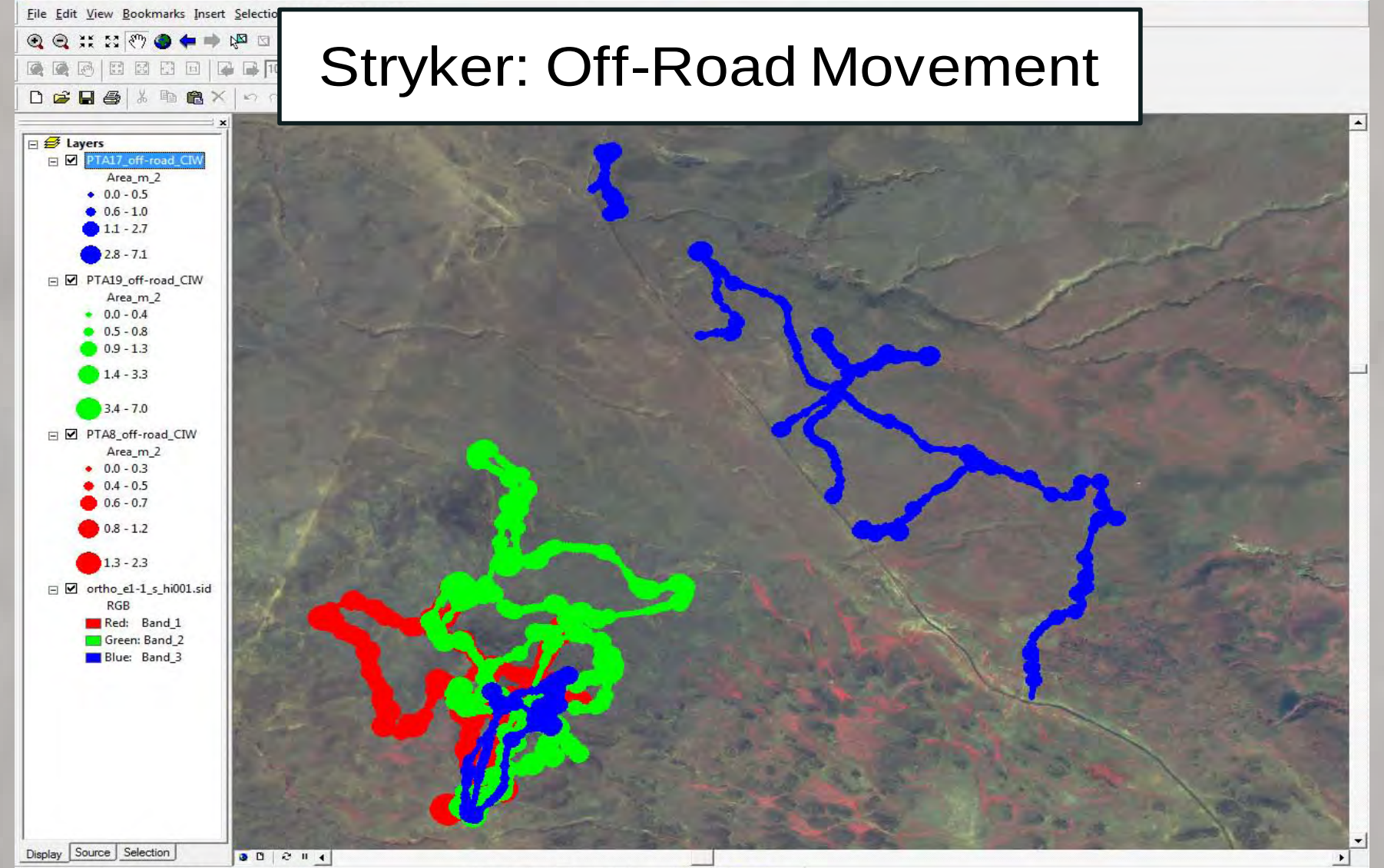
The results of the spiral study are shown in the figure below Higher speeds and lower turning radii tended to produce higher vegetative impacts. Relationships between the vegetation removed (cumulative impact widths) and the vehicle operating conditions (velocity and turning radius) were determined.



Stryker impacts resulting from spiral maneuvers.

The figures below illustrates the amount and location of the vegetation removed during the Stryker proofing mission. The first figure represents on and off-road tracks while the second represents only the off-road vehicle movement.


Vehicle tracks during Stryker proofing maneuver.



Cumulative impact width (vegetation removed) for the off-road portion of the Stryker proofing maneuver.

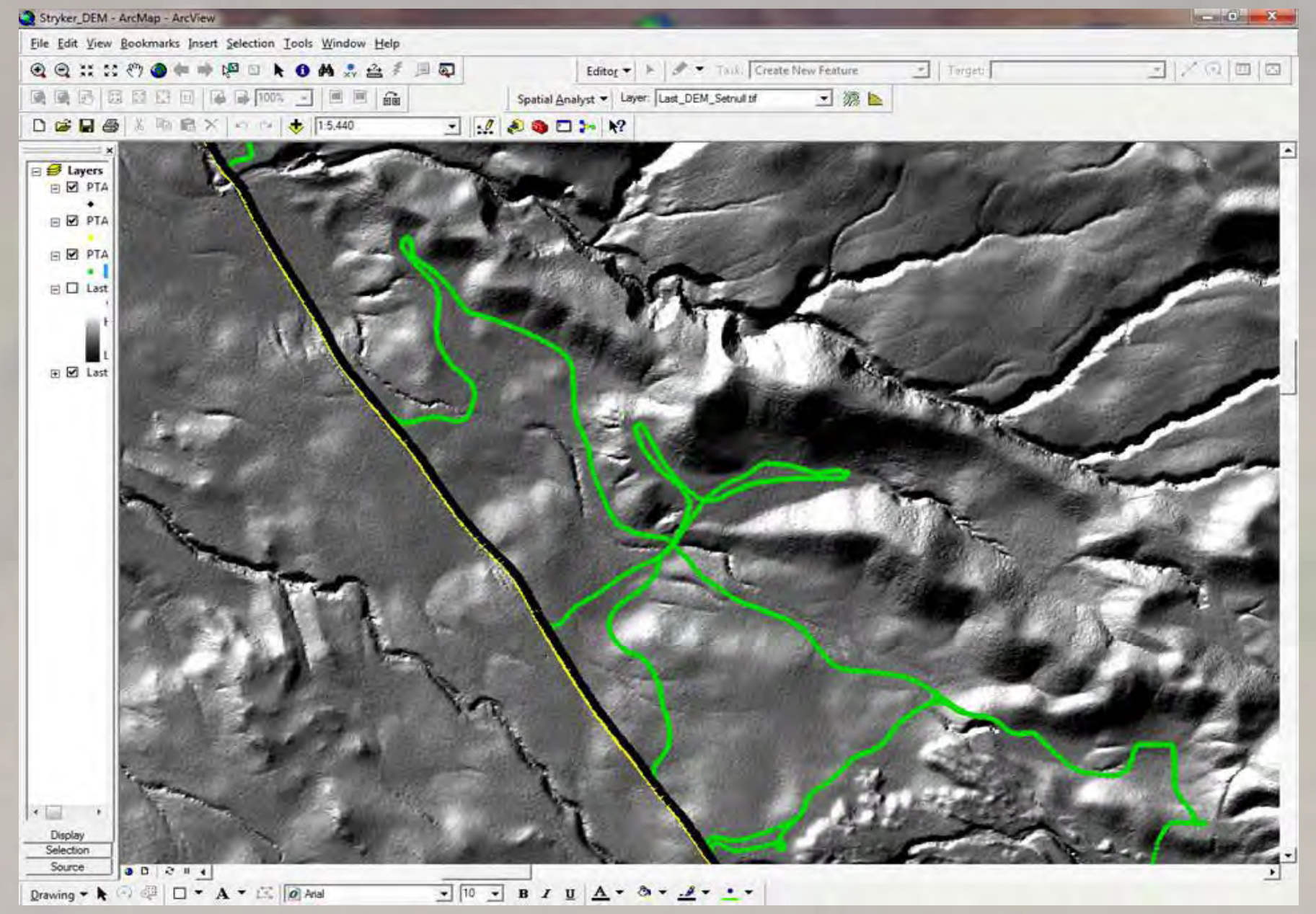
RESULTS (cont).

The Table below summarizes the vehicle movement patterns for the 3 Strykers during the proofing maneuvers. Most of the movement was on-road (over 90%). For the off-road travel, an average of 9.1 km of off-road travel distance was measured, with an average speed of 3.69 m/s. For the 3 vehicles, an average of 1,251 meter square of vegetation removed per vehicle during the proofing maneuver was estimated.

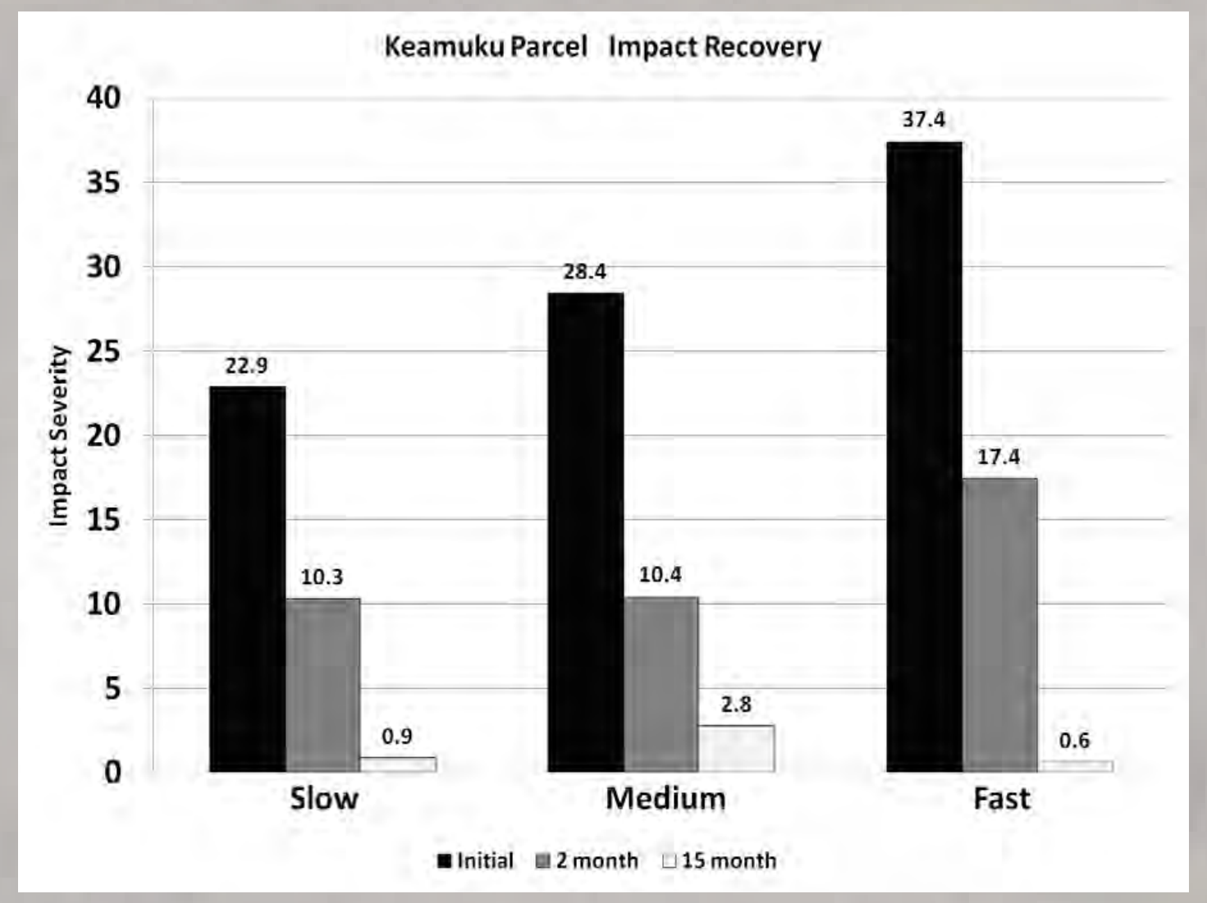
Stryker vehicle movement patterns during proofing maneuver.

Vehicle	Total Distance (km)	Total Avg. Speed (m/s)	Off-Road Distance (km)	Off-Road Avg. Speed (m/s)	Vegetation Removed Area (sq m)
PTA 08	65.27	4.86	5.90	3.33	722
PTA 17	118.30	5.00	11.85	4.00	1642
PTA 19	117.32	5.15	9.65	3.75	1388

An analysis of vehicle movement showed the travel was in the lower elevations of the area. Figure 5 show the vehicle tracks as related to the training area topography. Mostly the valleys and plateaus are traversed, as the vehicles stayed off the steep slopes where possible.


Off-road vehicle movement related to topography.

Vegetative recovery is important in understanding the sustainability of training maneuvers at an installation. The Stryker spirals were reevaluated one month and 13 months after the initial impacts. Substantial vegetative recovery (re-growth) occurred after the first month. Over 90% of the vegetation had recovered after 15 months of the initial impact.



Vegetative recovery from the Stryker spirals conducted at PTA.

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