The application of GIScience to Search and Rescue in Yosemite National Park

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NSF #1031914

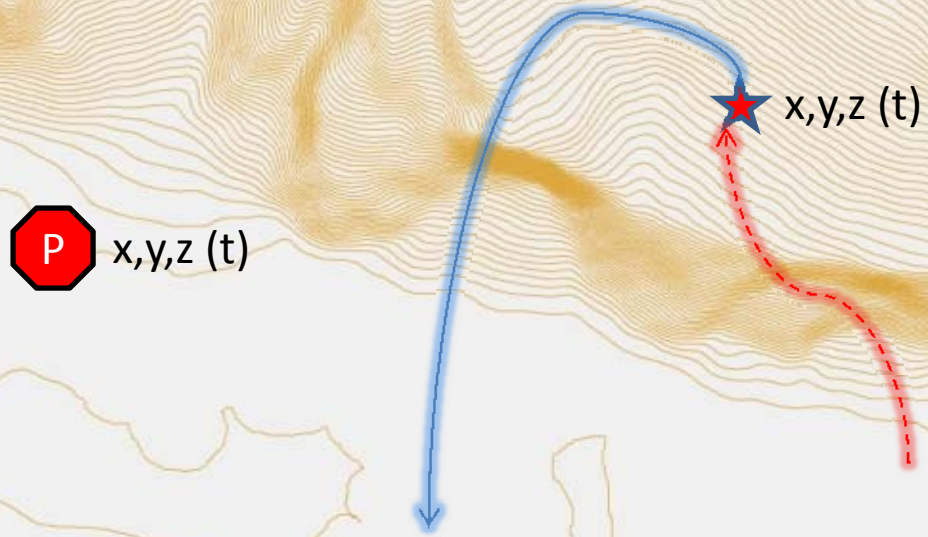
What is a Park Ranger?

- NPS Mission: conserve the scenery, the natural and historic objects, and the wildlife, and to provide for the public's enjoyment of these features in a manner that will leave them unimpaired for the enjoyment of future generations
- Protect: the Park from people, people from the Park, people from each other

Yosemite 2009: 301 arrests, 491 EMS response, 1784 Fire hours, 242 Search and Rescues

What is Search and Rescue? (SAR)

- Locate
- Stabilize
- Extract
- *Prevention*?



Action occurs at a *time* and a *place*

Framework

- If Search and Rescue is an inherently spatial process, then:
  - The application of **GISystems** should enhance the likelihood of desirable outcomes – rescue/prevent
  - The study of SAR in a spatio-temporal context can contribute to **GIScience**

GIScience topics

- Probabilistic time geography
- Dynamic GIS
- Geographic one-class data
- Spatial uncertainty, data quality, and innovative uses of human geography


Yosemite Search and Rescue (YOSAR)
Not me

12,000 sq miles, 95% wilderness, 800 miles of hiking trails

Yosemite National Park

- Annually
  - +3.5 million visitors
  - +200 SARs
- How do we find and rescue them?
- Where and when do they get rescued?

Table 1. Most common injuries and illnesses needing SAR services (n = 2077)

Type of Injury or Illness	N	*Percent*
Fracture	416	20.0
Sprain/strain	290	14.0
Unspecified	253	12.2
Dehydration/hypovolemia/hunger	172	8.3
Contusion	157	7.6
Laceration	143	6.9
Cold injury/hypothermia/frostbite	95	4.6
Abrasion	91	4.4
Nausea/vomiting	63	3.0
Dislocation	50	2.4

Table 2. Most common activities victims were participating in at time of incident (n = 2327)*

Activity	N	*Percent*
Hiking/snowshoeing	1208	52.0
Rock climbing/scrambling	442	19.0
Driving	139	6.0
Skiing	130	5.6
Leisure/working	101	4.3

Hung et al 2007

What is Search and Rescue? (SAR)

- Locate
- Stabilize
- Extract
- *Prevention*?

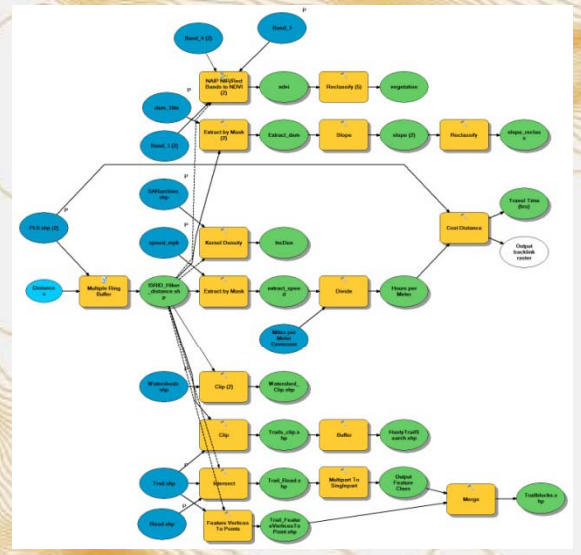
When location is known

Notification:

- In Person
- Radio
- Cell-phone (Enhanced-911)
- S.E.N.D. (SPOT)

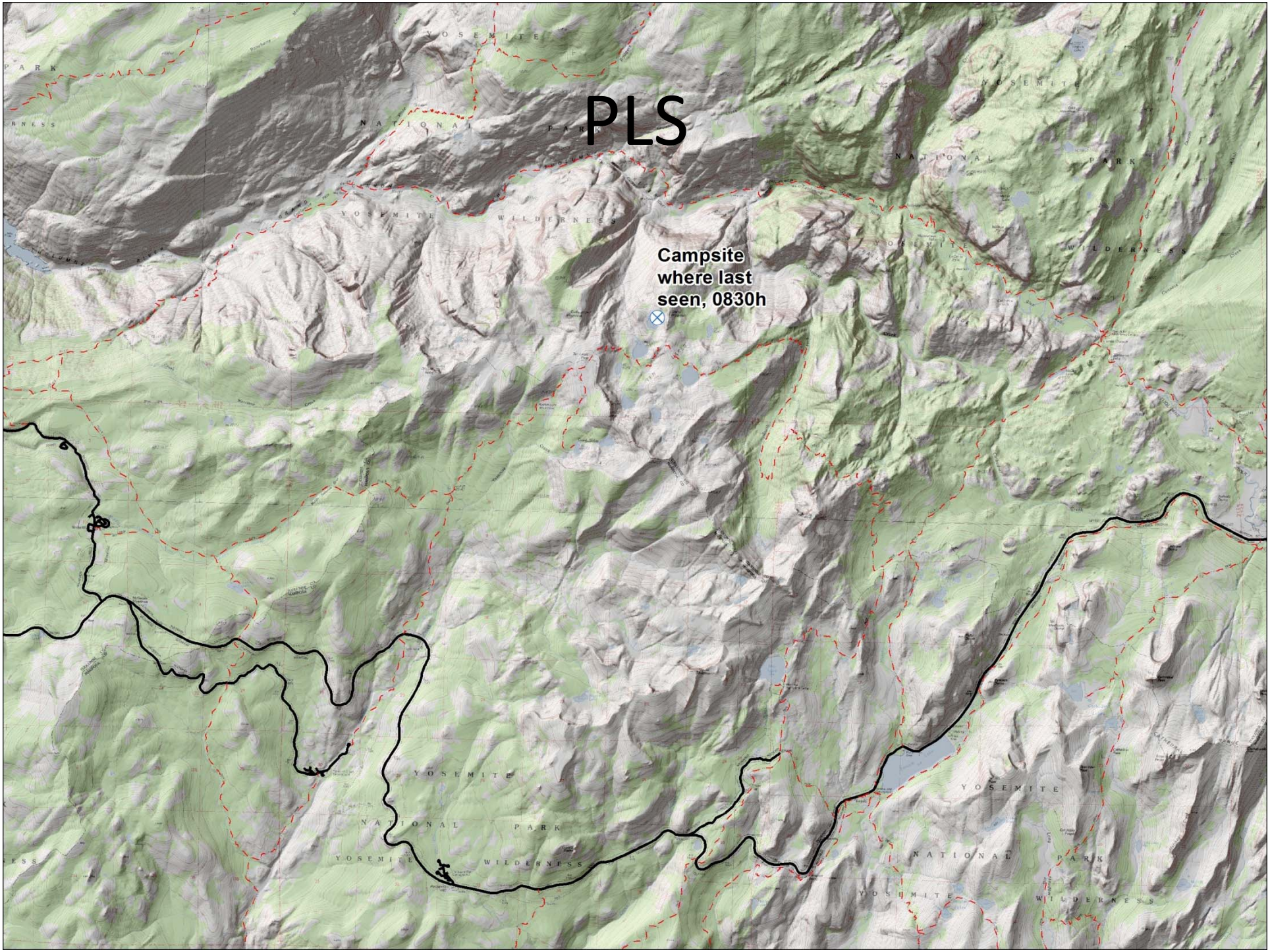
When location is unknown

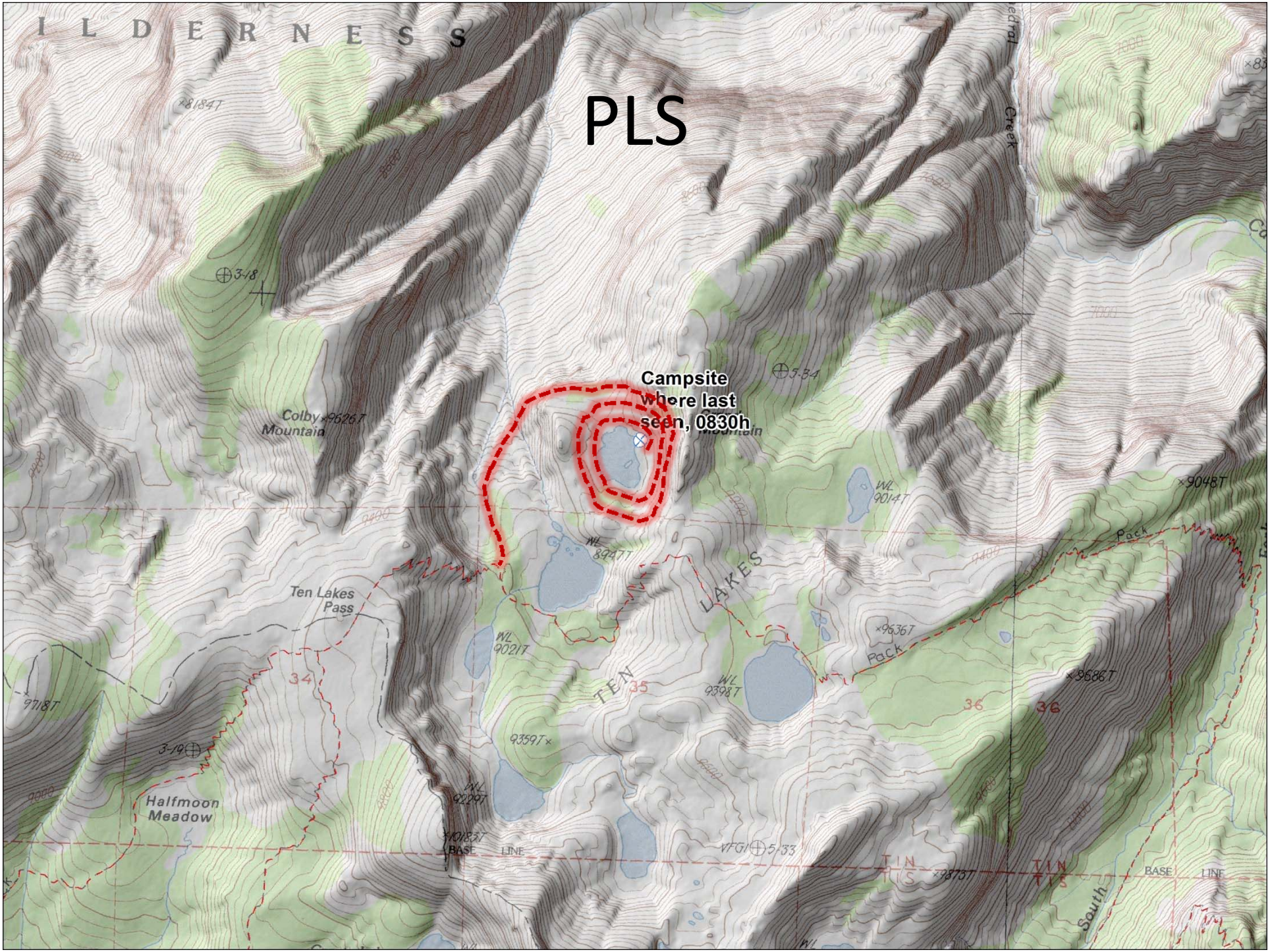
- Point Last Seen (PLS)
- Last Known Point (LKP)
- Witnesses
- Itinerary
- Clues

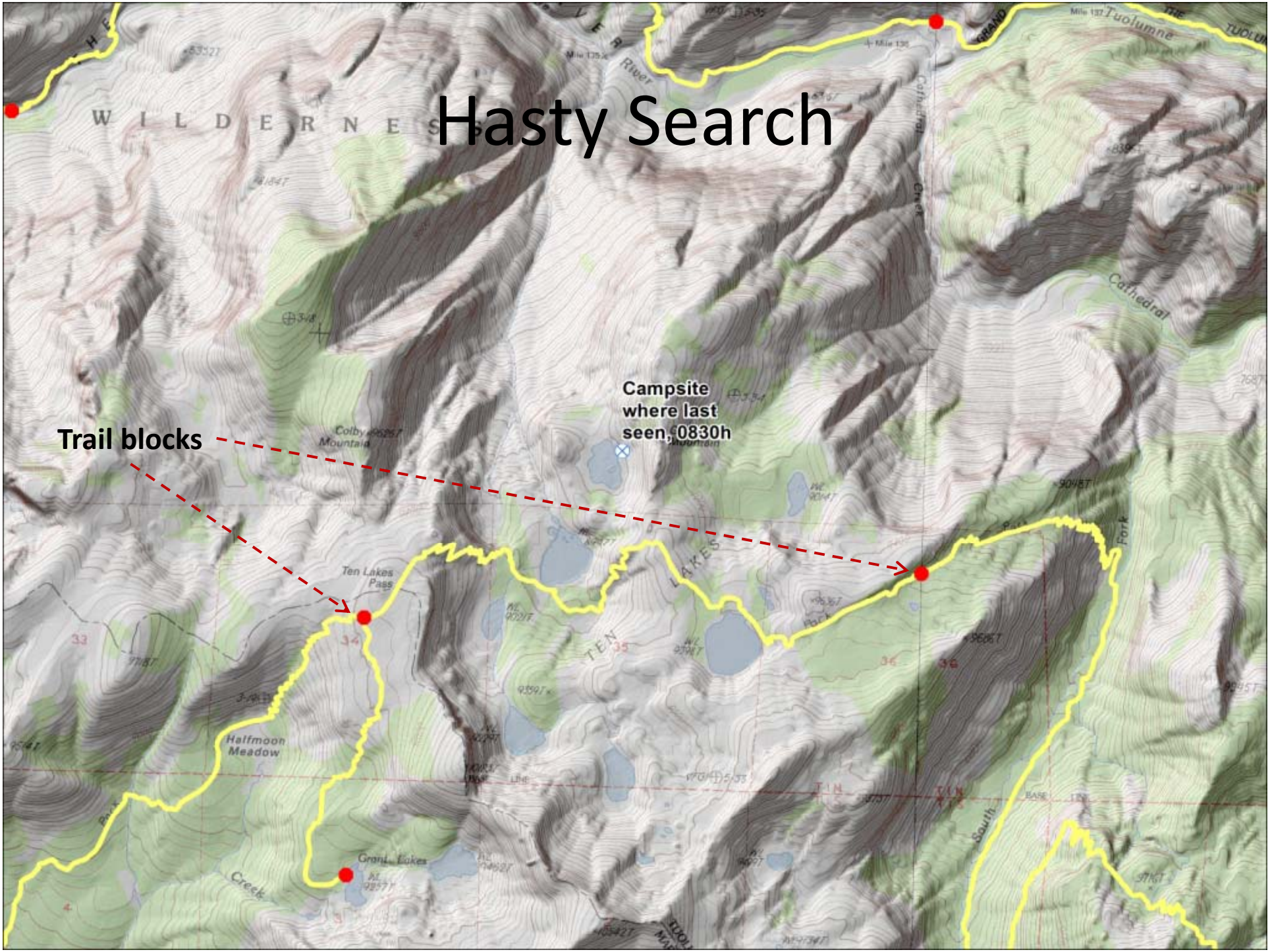


ArcGIS Modelbuilder for custom tools

Are they missing or overdue?


PLS
Campsite where last seen, 0830h


PLS
Campsite where last seen, 0830h
Colby Mountain
Ten Lakes Pass
Halfmoon Meadow
TEN LAKES
Pack
Pack
BASE LINE
BASE LINE
South

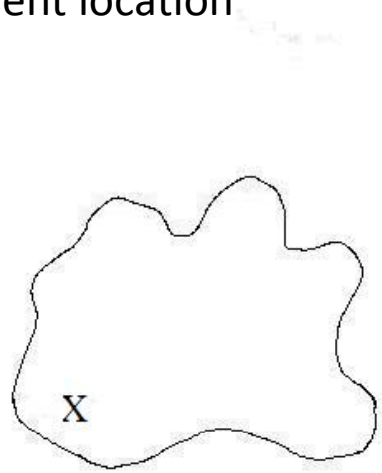

Hasty Search
Campsite where last seen, 0830h
Trail blocks
WILDERNESS
Tuolumne
Cathedral
Ten Lakes Pass
TEN LAKES
Halfmoon Meadow
Grant Lakes
Creek

Planning

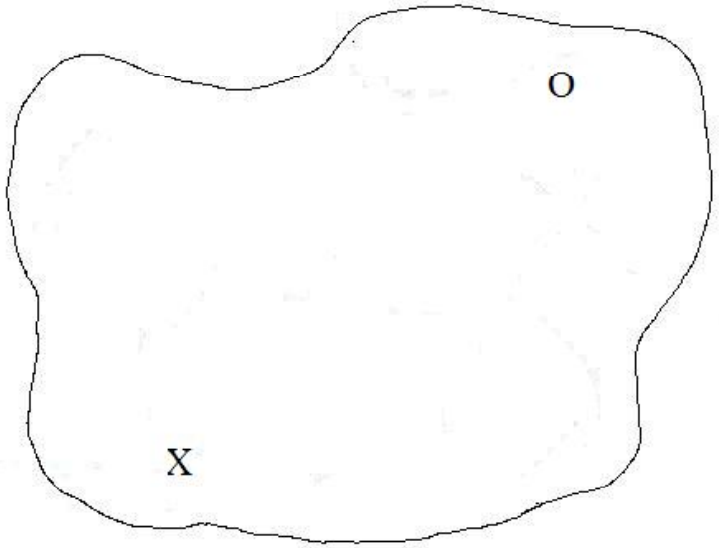
- Probability of Area (POA)
- Probability of Detection (POD)

Small Search Area = Low POA

X = last known point
O = current location



Large Search Area = Low POD



***Probabilistic time geography

Lost Person Behavior Statistics for the Hiker Category (ISRID)

Pages 184-185 in Lost Person Behavior *by Robert Koester (dbS Productions, Charlottesville, VA)*

Hiker

Distance (horizontal) from the IPP (miles)					
	Temperate		Dry		Urban
	Mtn	Flat	Mtn	Flat	
n	**568**	**274**	**221**	**58**	**8**
25%	0.7	0.4	1.0	0.8	
50%	1.9	1.1	2.0	1.3	1.6
75%	3.6	2.0	4.0	4.1	
95%	11.3	6.1	11.9	8.1	

Distance (horizontal) from the IPP (kilometers)					
	Temperate		Dry		Urban
	Mtn	Flat	Mtn	Flat	
n	**568**	**274**	**221**	**58**	**8**
25%	1.1	0.6	1.6	1.3	
50%	3.1	1.8	3.2	2.1	2.6
75%	5.8	3.2	6.5	6.6	
95%	18.3	9.9	19.3	13.1	

Elevation (vertical) Change from the IPP (feet)						
	Temperate			Dry		
	Uphill	Down	Same	Uphill	Down	Same
%	**32%**	**52%**	**16%**	**48%**	**52%**	
25%	182	160		317	500	
50%	480	400		956	975	
75%	1175	1166		1500	2109	
95%	2634	2175		3623	5094	

Horizontal Change from IPP (miles) for Mtn Terrain						
	Temperate			Dry		
	Uphill	Down	Same	Uphill	Down	Same
n	**58**	**131**	**34**	**47**	**57**	**0**
25%	0.5	0.7	0.0	1.8	1.0	
50%	1.4	1.7	0.0	2.2	2.0	
75%	2.6	4.0	1.5	4.0	5.0	
95%	7.2	17.4	12.8	10.7	12.3	

Hiker

Mobility (hours)		
	Temperate	Dry
n	**232**	**112**
25%	0	4
50%	3	8
75%	6	12
95%	14	26

Dispersion Angle (degrees)		
	Temperate	Dry
n	**134**	**28**
25%	2	20
50%	23	47
75%	64	124
95%	132	175

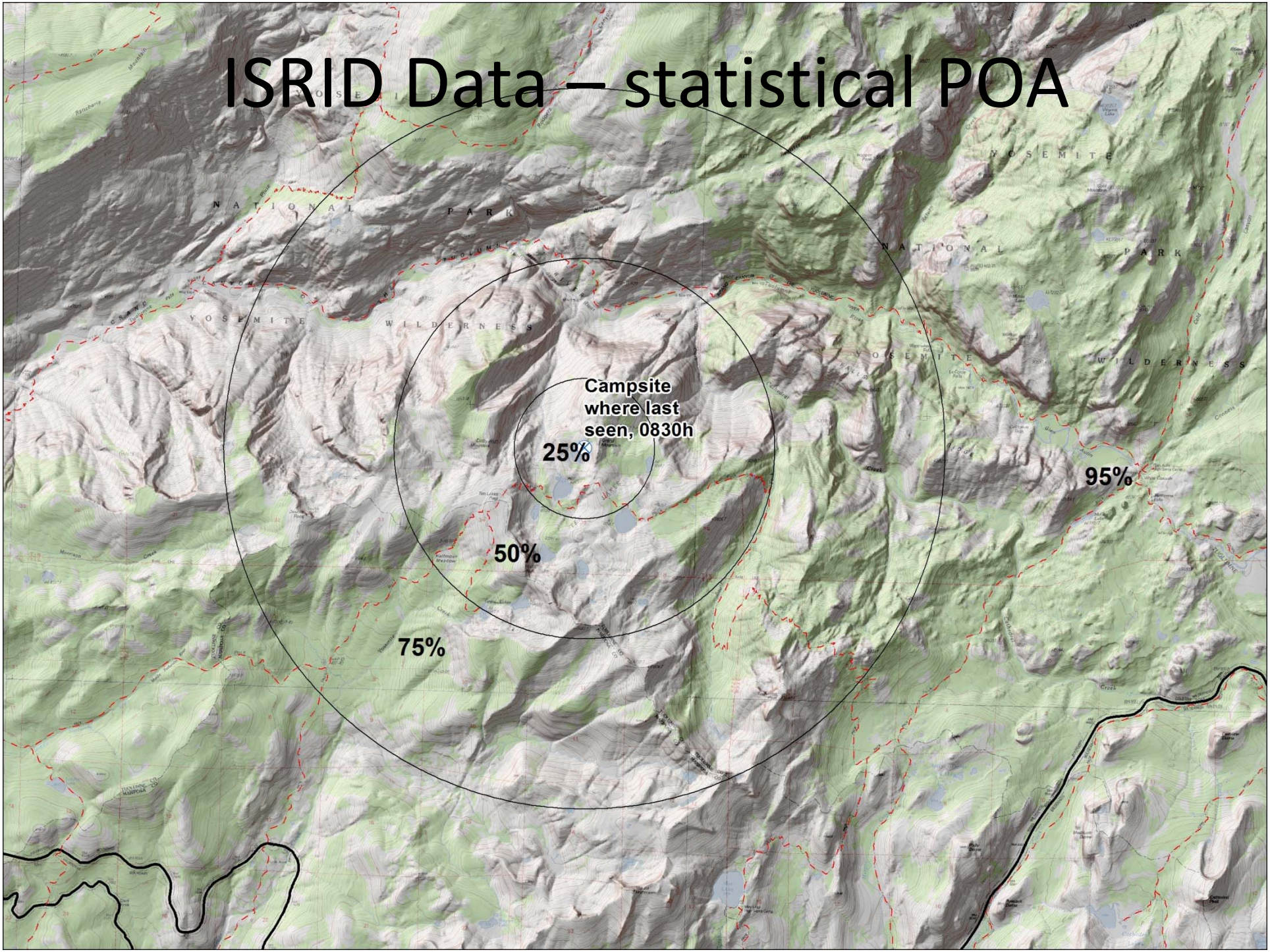
Find Location (%)			
	Temp	Dry	Urban
n	**312**	**196**	**17**
Structure	13%	10%	24%
Road	13%	17%	35%
Linear	25%	31%	18%
Drainage	12%	18%	6%
Water	8%	9%	12%
Brush	2%	2%	
Scrub	3%	3%	
Woods	7%	6%	
Field	14%	1%	6%
Rock	4%	2%	

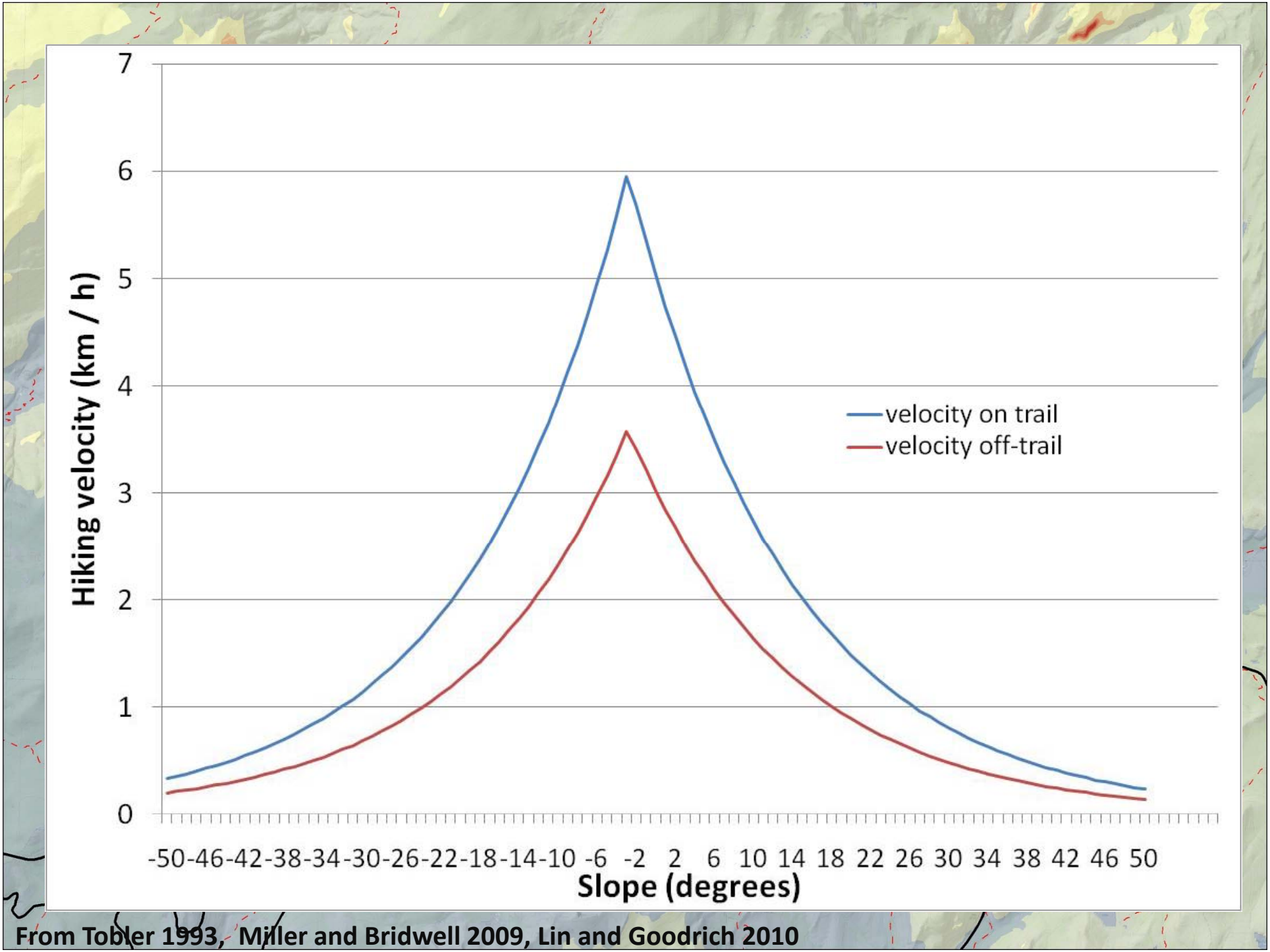
Scenario (%)	
n	**2242**
Avalanche	
Criminal	
Despondent	
Evading	1%
Investigative	1%
Lost	68%
Medical	2%
Drowning	
Overdue	16%
Stranded	4%
Trauma	7%

Survivability		
	Wilderness	Urban
Uninjured	78%	59%
Injured	16%	24%
Fatality	6%	12%
No Trace		6%
Survivability	**Alive**	**n**
<24 hours	97%	2460
>24 hours	76%	361
>48 hours	60%	118
>72 hours	52%	51
>96 hours	49%	23

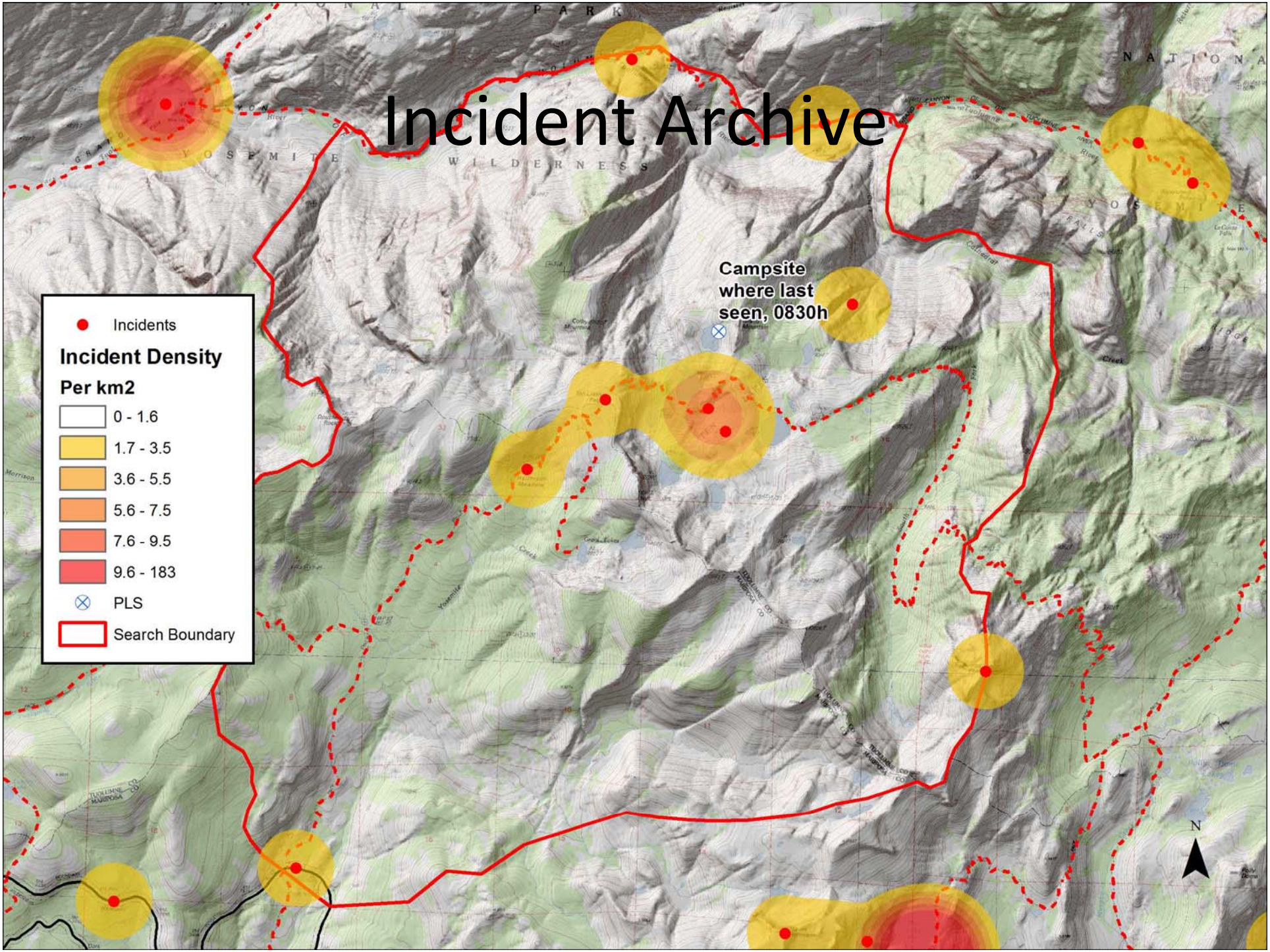
Track Offset (meters)	
n	**40**
25%	50
50%	100
75%	238
95%	424

ISRID Data – statistical POA



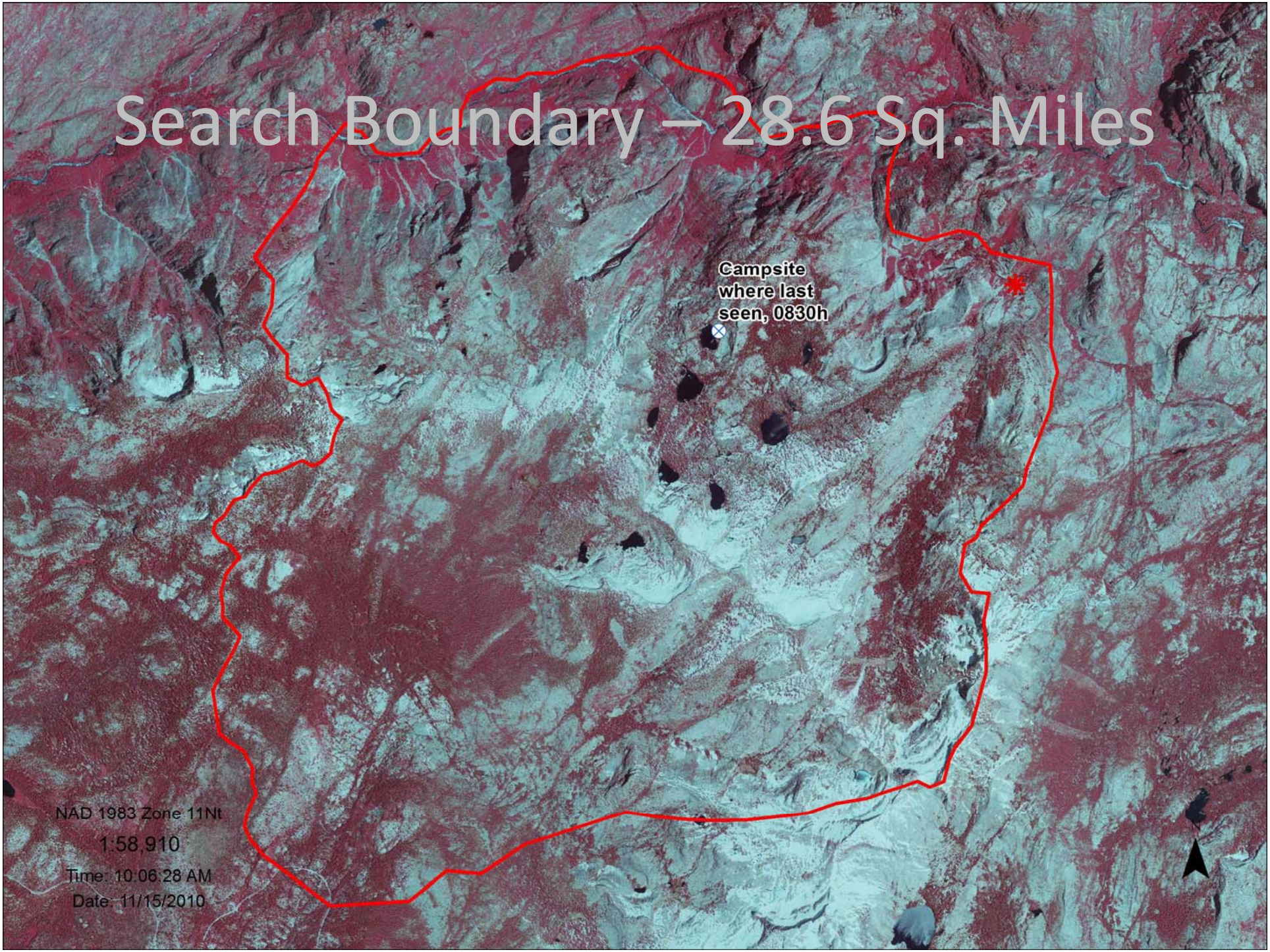


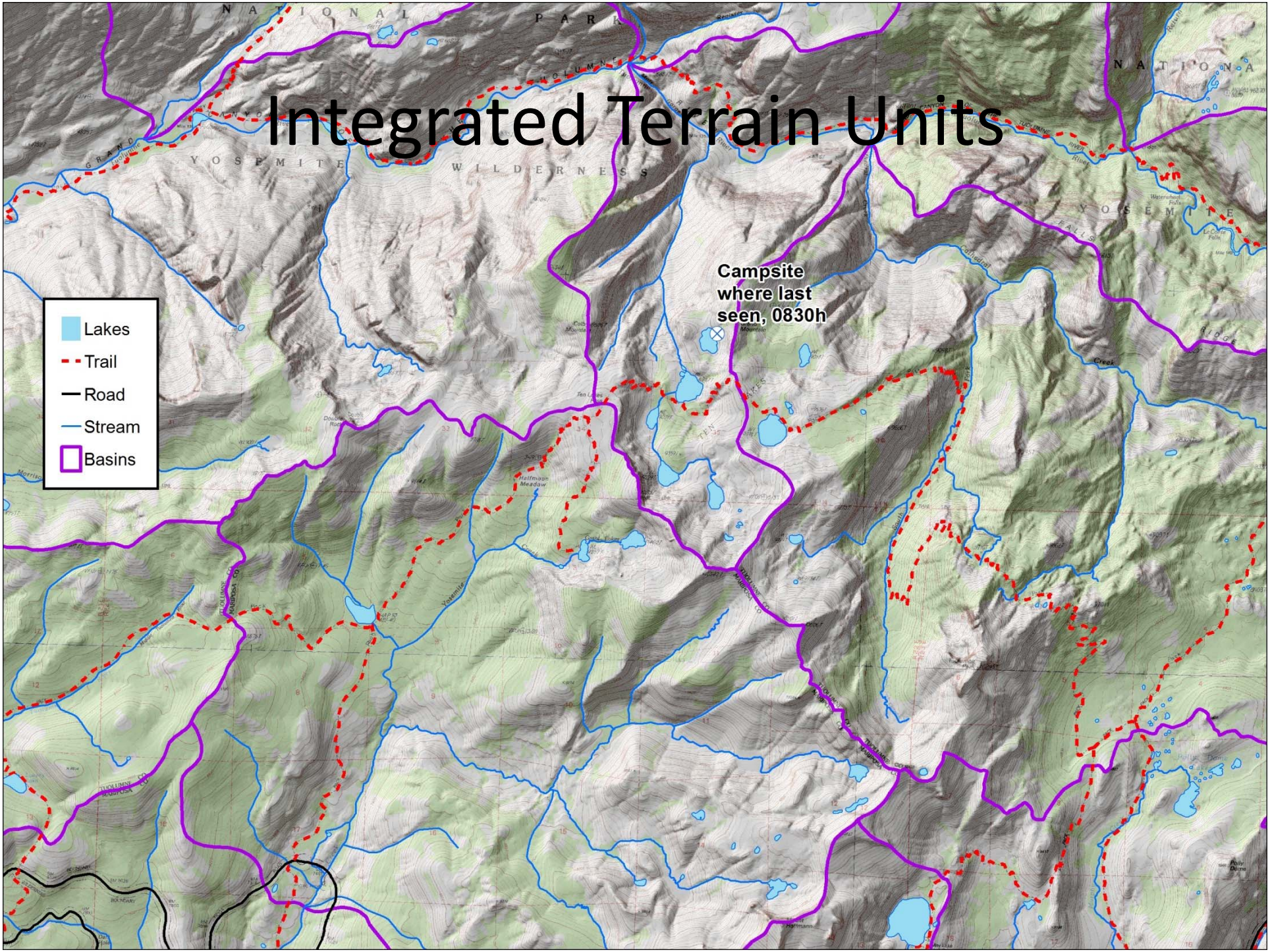
From Tobler 1993, Miller and Bridwell 2009, Lin and Goodrich 2010


Incident Archive
Campsite where last seen, 0830h
Incidents
Incident Density
Per km2
0 - 1.6
1.7 - 3.5
3.6 - 5.5
5.6 - 7.5
7.6 - 9.5
9.6 - 183
PLS
Search Boundary
N

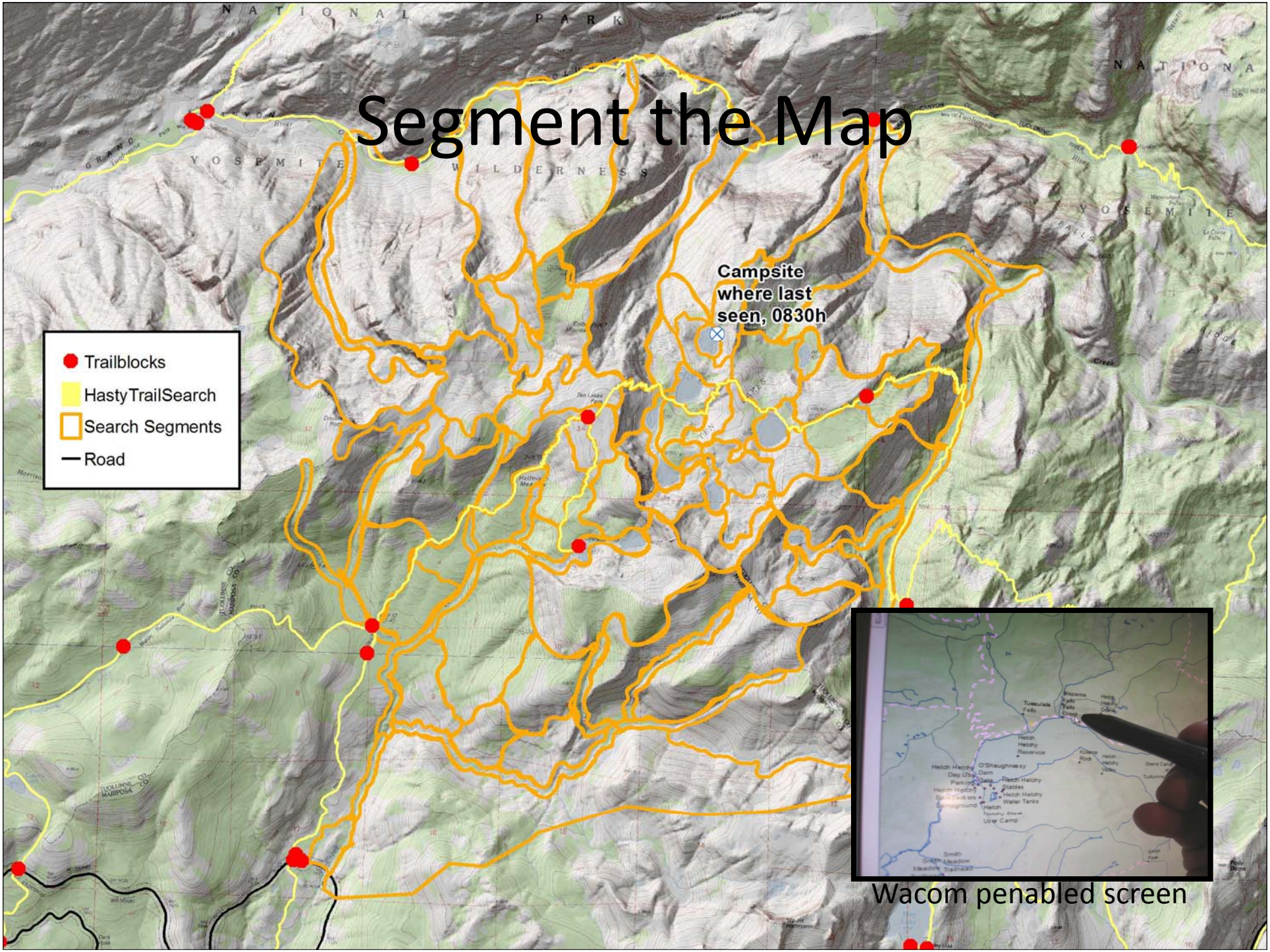
Assignments

- Search Segments
  - Terrain
  - Man-made features
  - Water
- Teams
  - Tracking
  - Ground
  - Dog
  - Helicopter


Search Boundary – 28.6 Sq. Miles
Campsite where last seen, 0830h
NAD 1983 Zone 11Nt
1:58,910
Time: 10:06:28 AM
Date: 11/15/2010

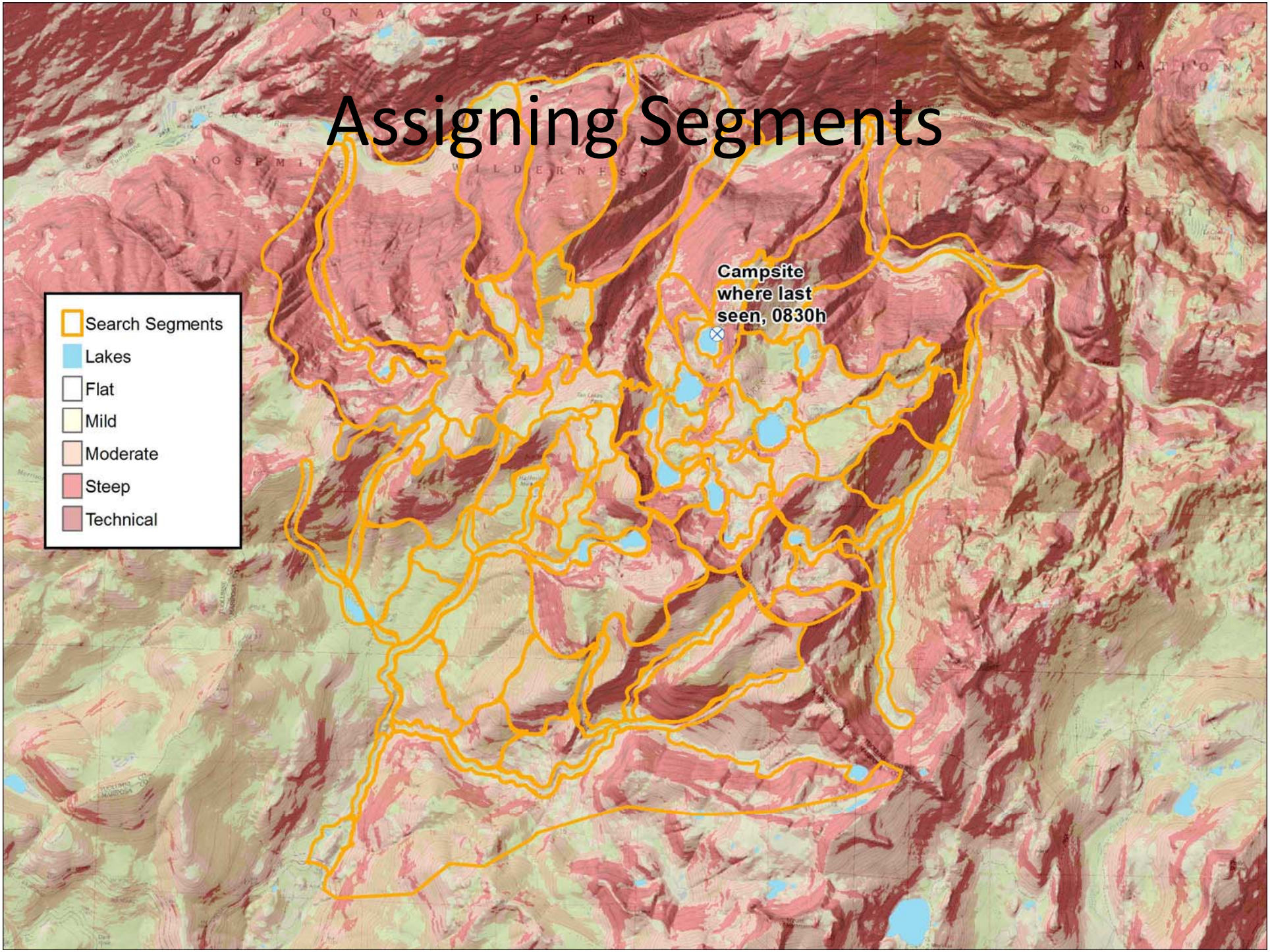

Integrated Terrain Units
Campsite where last seen, 0830h
Lakes
Trail
Road
Stream
Basins

Segment the Map

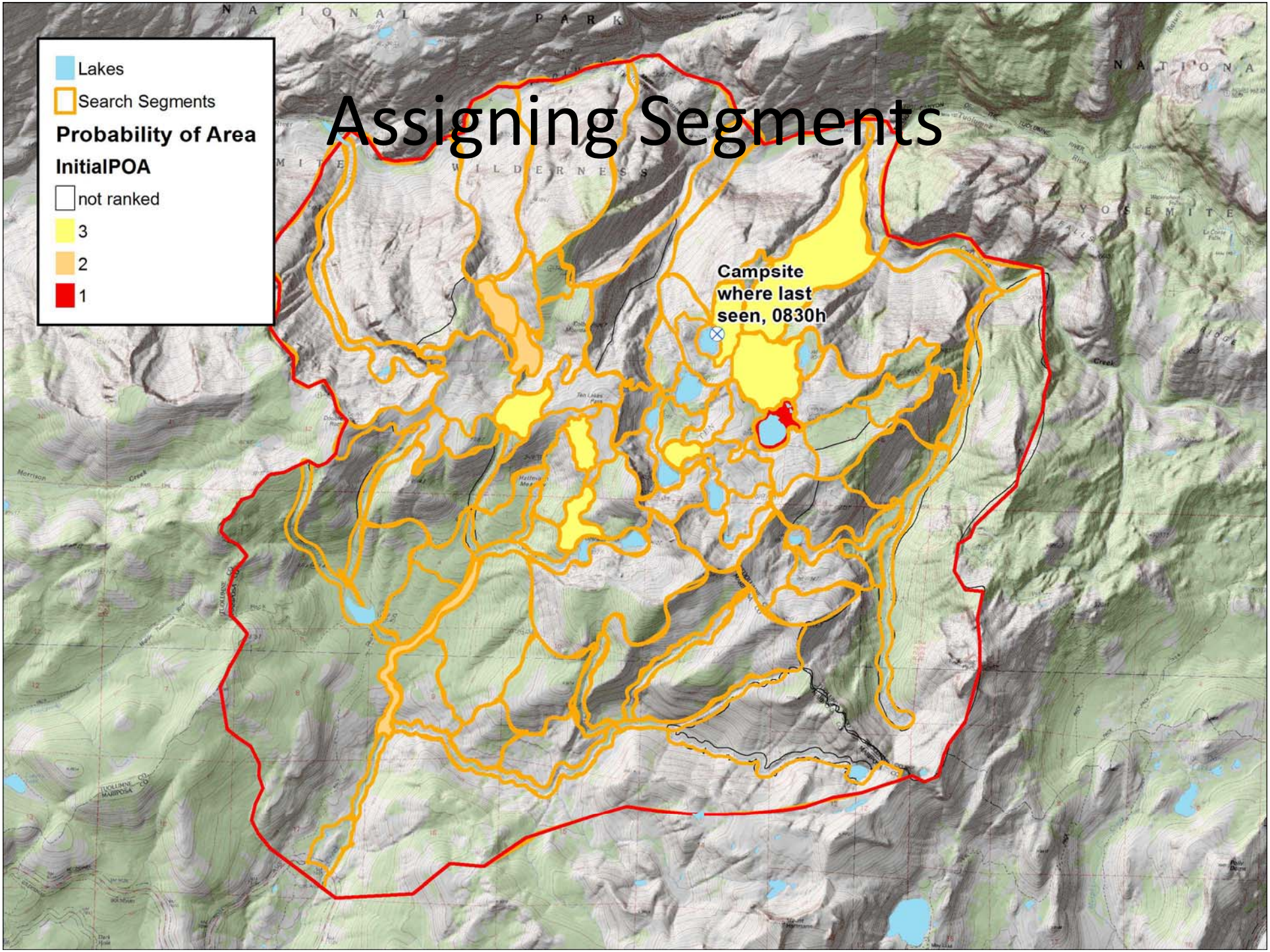


Wacom penabled screen

Assigning Segments



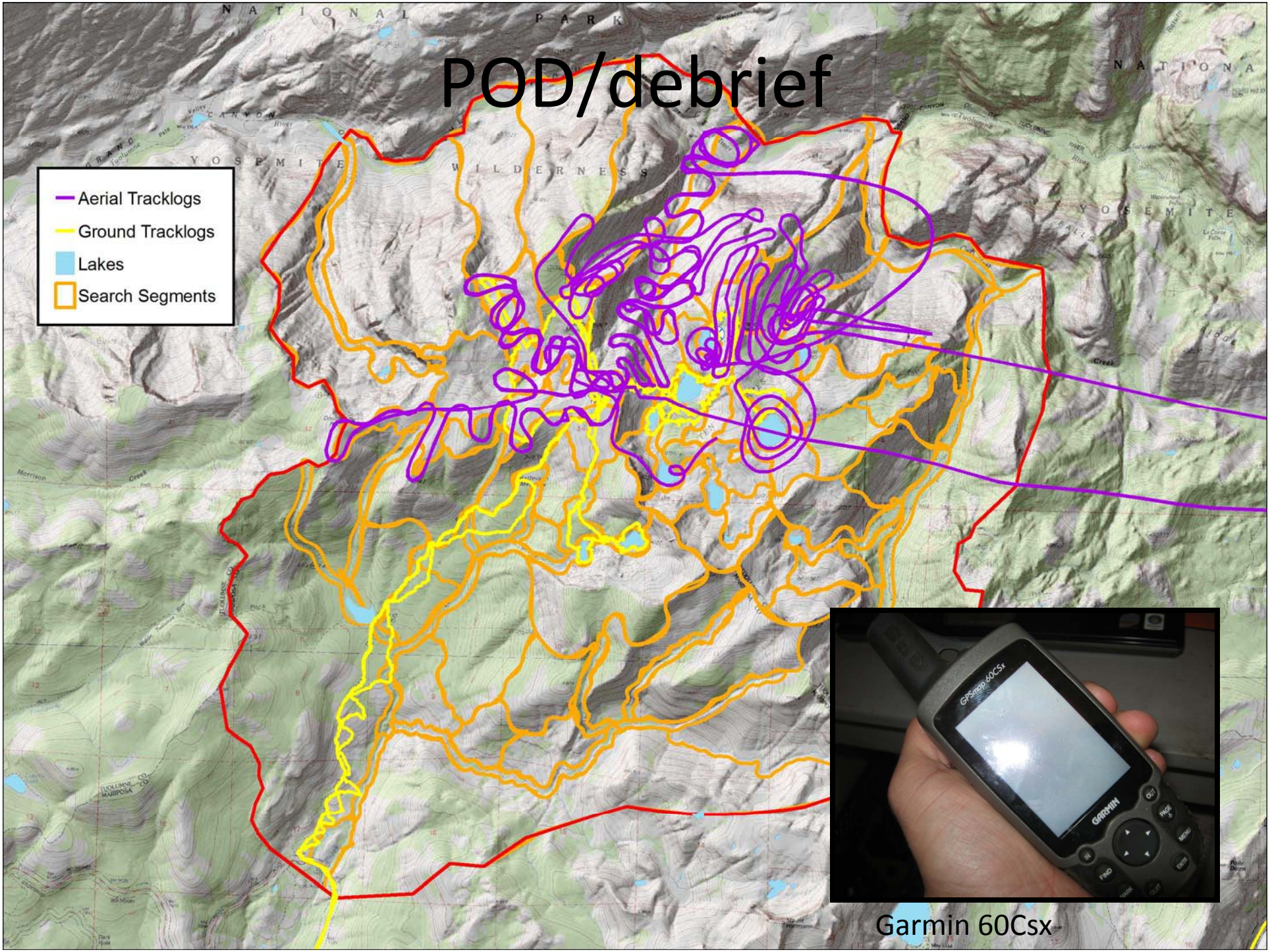
Assigning Segments



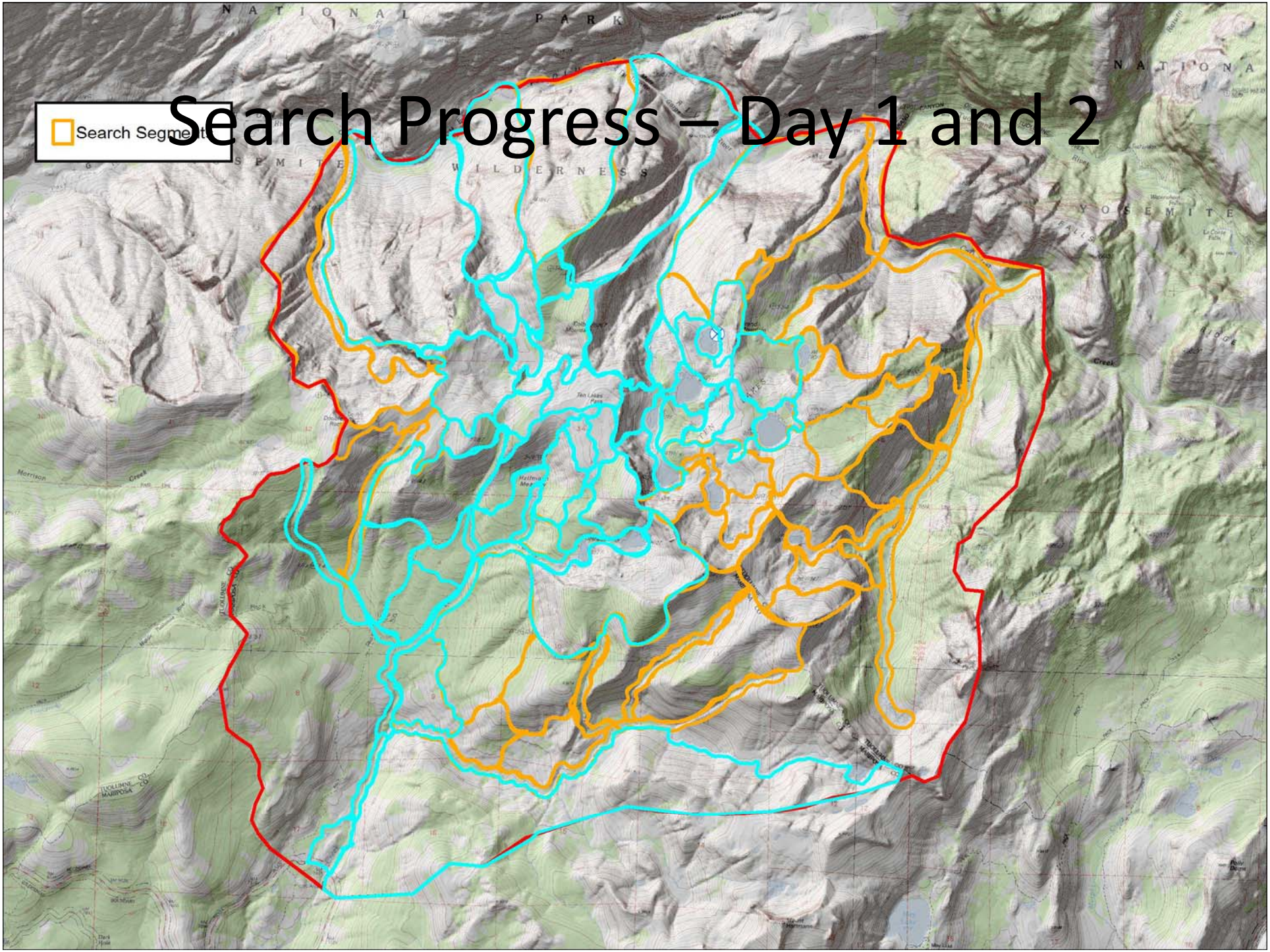
Assignment Maps

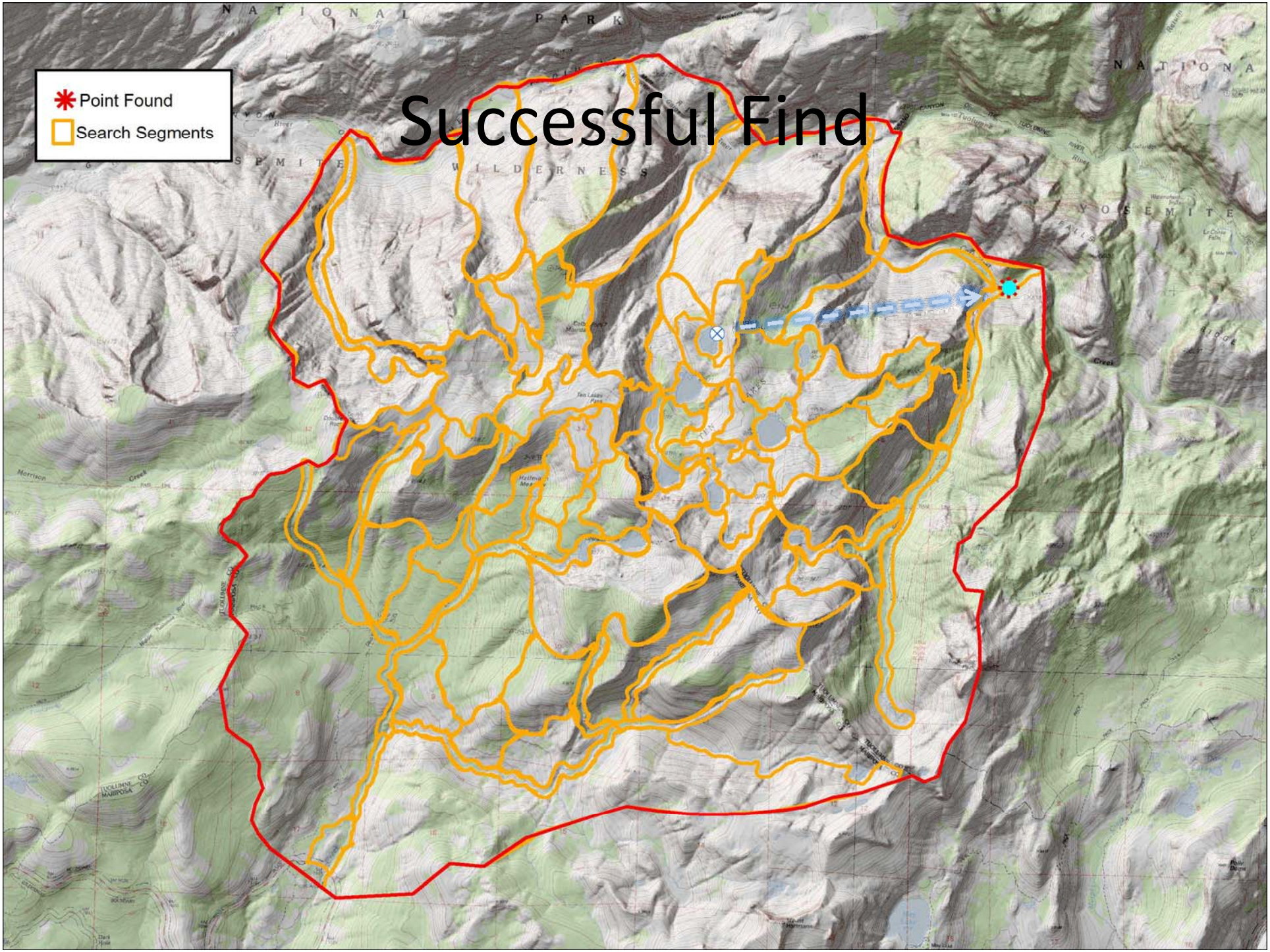
Large format HP plotter

POD/debrief

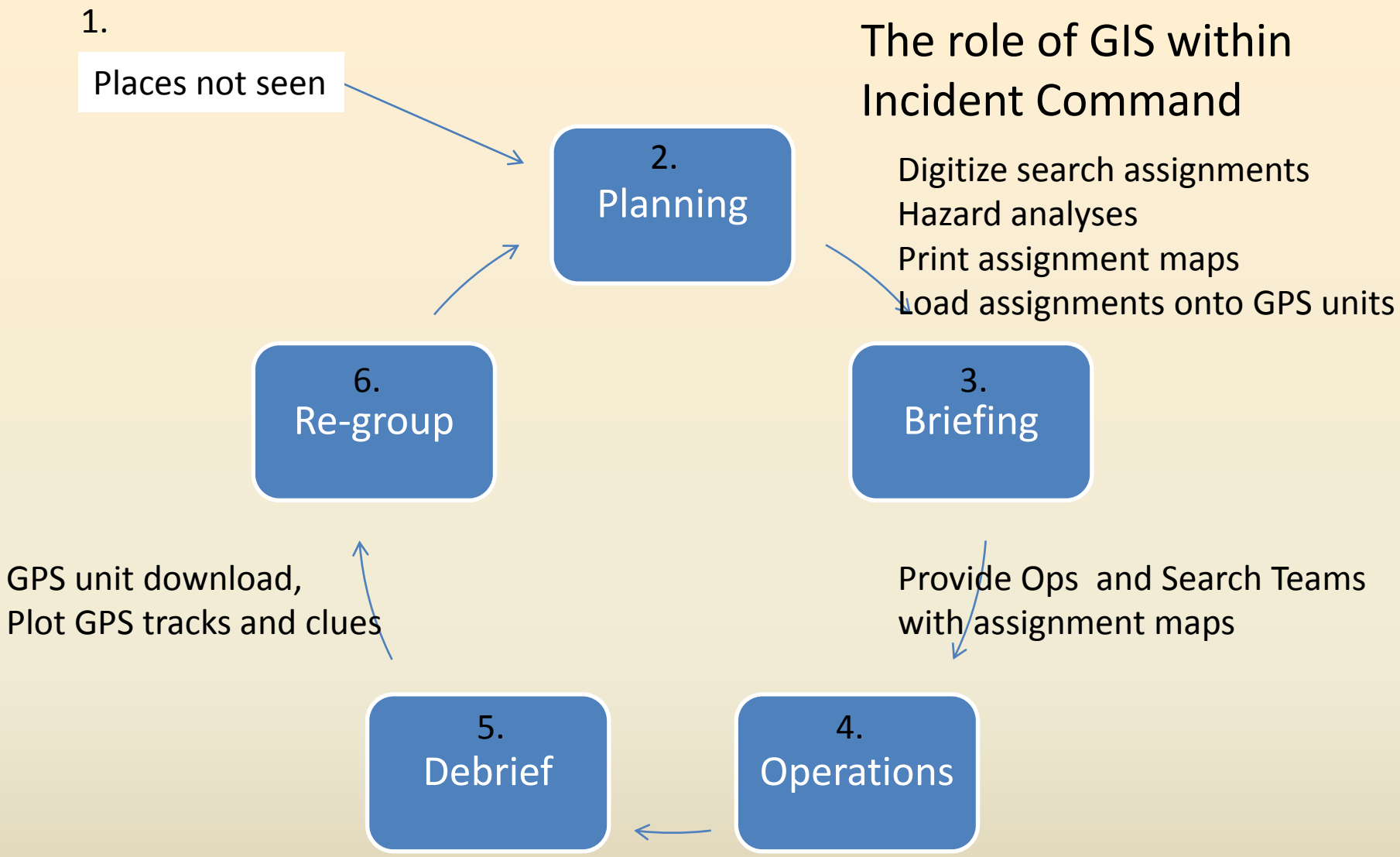


Garmin 60Csx


Search Segment
Search Progress – Day 1 and 2


Point Found
Search Segments
Successful Find

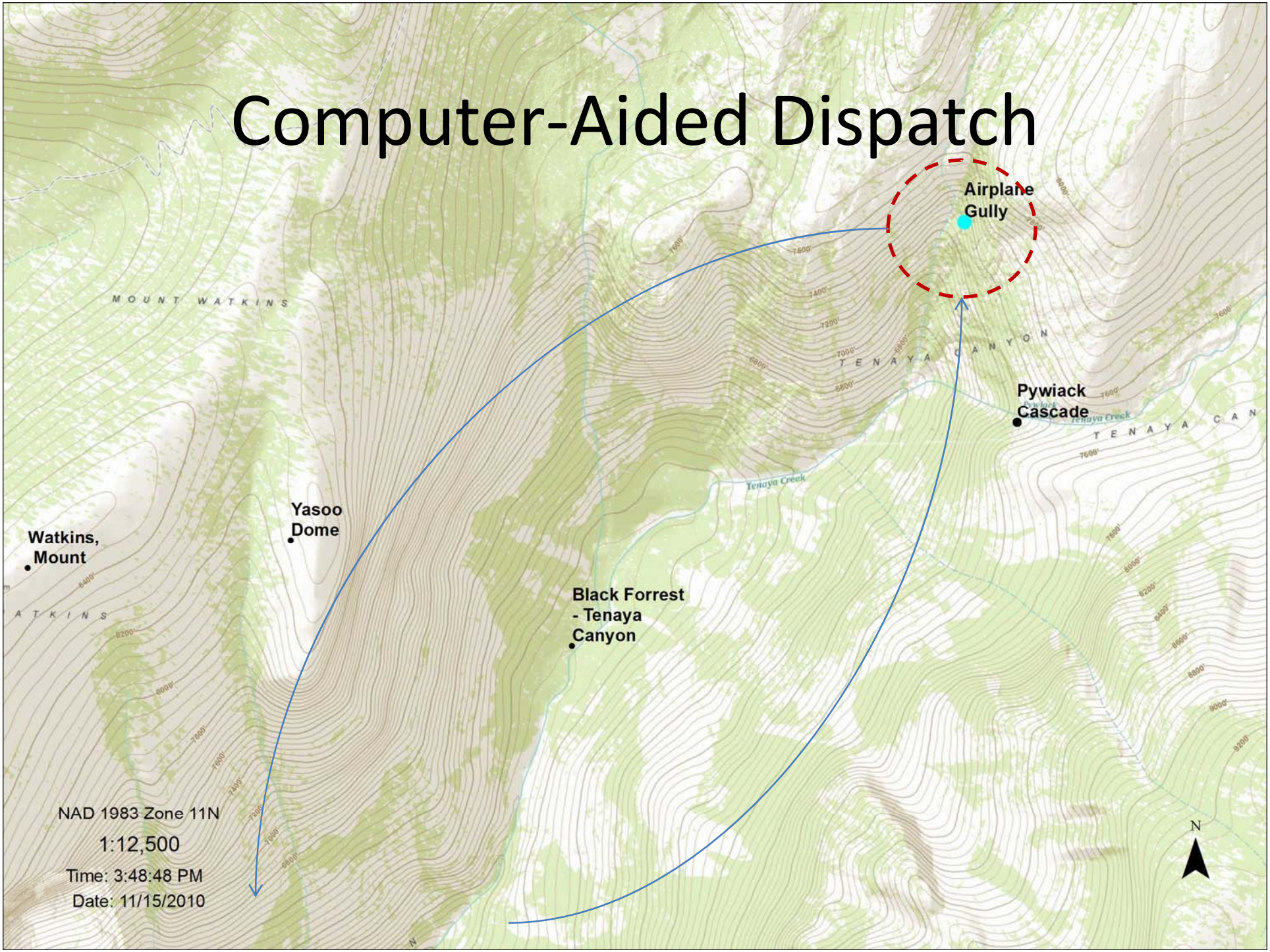
The role of GIS within Incident Command



* The GISS falls under the Planning Section, working directly for the SITL

What is Search and Rescue? (SAR)

- Locate
- Stabilize
- Extract
- *Prevention*?


Computer-Aided Dispatch
Airplane Gully
Pywiack Cascade
Yasoo Dome
Watkins, Mount
Black Forrest - Tenaya Canyon
MOUNT WATKINS
TENAYA CANYON
Tenaya Creek
NAD 1983 Zone 11N
1:12,500
Time: 3:48:48 PM
Date: 11/15/2010
N

Common Operational Picture

- Unified cartography
- Real-time tracking
  - GPS enabled radios
  - Smart phones
  - Automated flight following
- Web-GIS

***Dynamic GIS

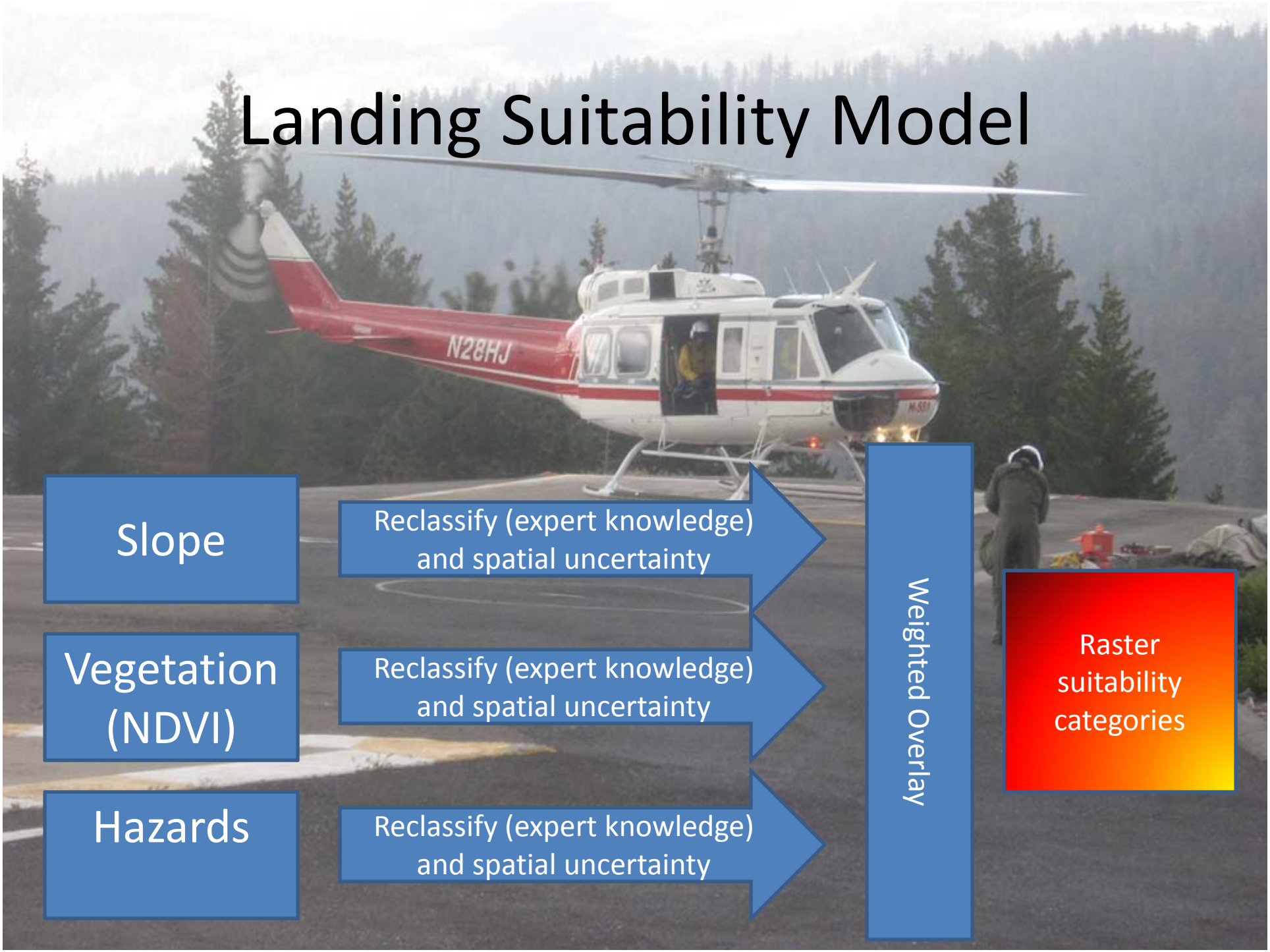
What is Search and Rescue? (SAR)

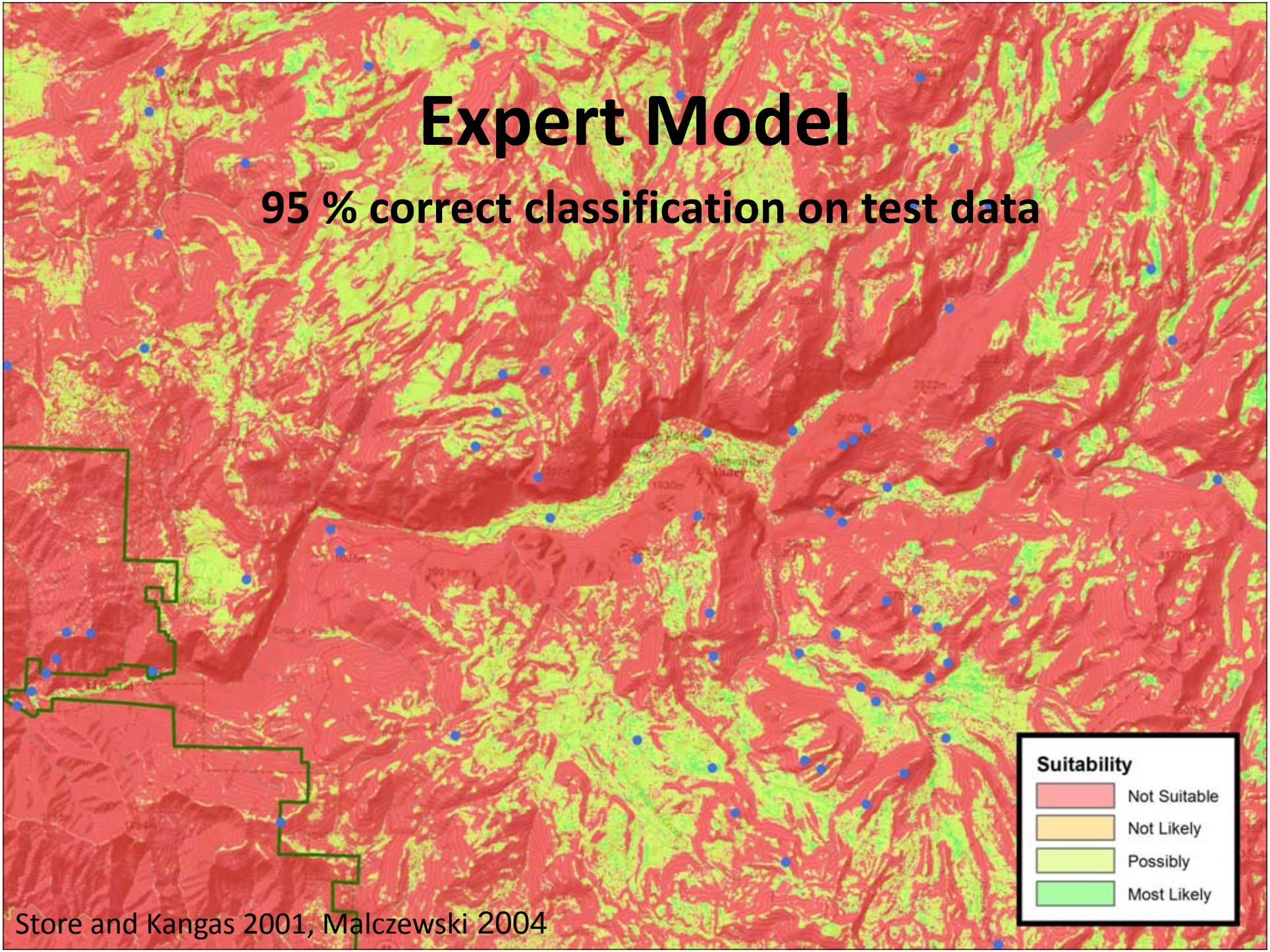
- Locate
- Stabilize
- Extract
- *Prevention*?

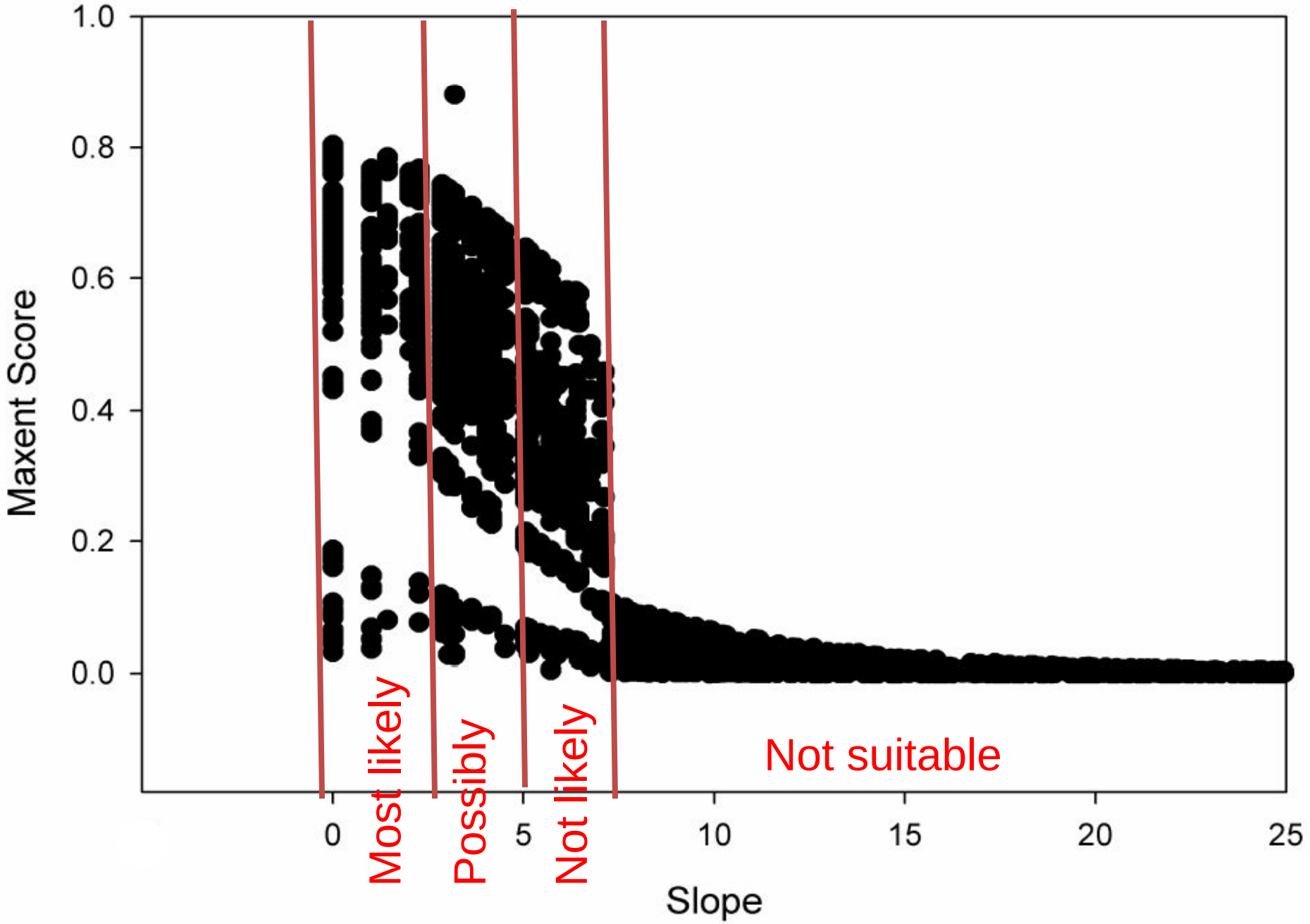
Types of Extraction

- Ground
  - Walk/crutch-out
  - Litter Carryout
  - Technical Rescue
- Water
  - Shore-based
  - Rescue Swimmer/Technical Rescue
- Air
  - Direct
  - Short-haul

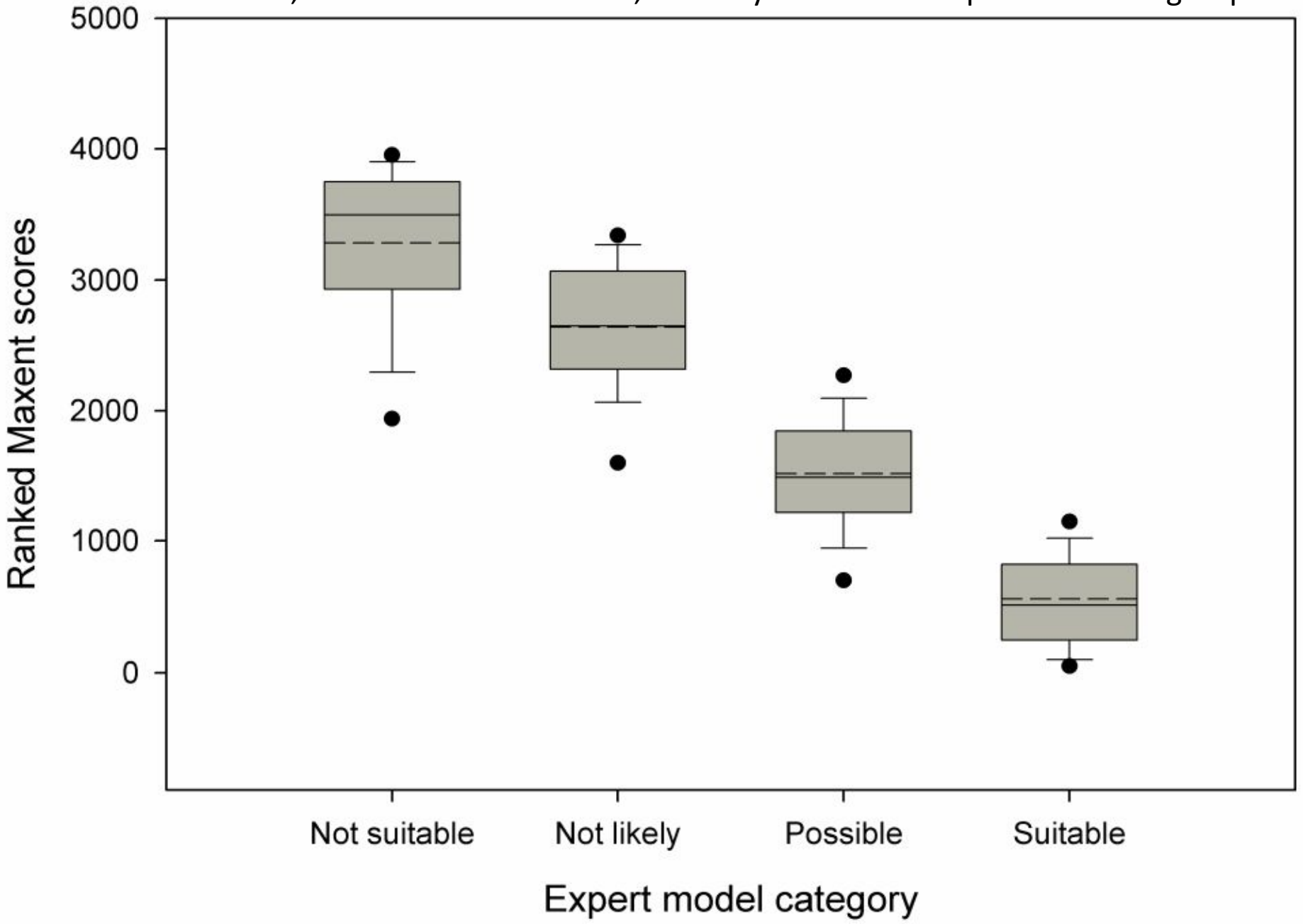
Landing Suitability Model

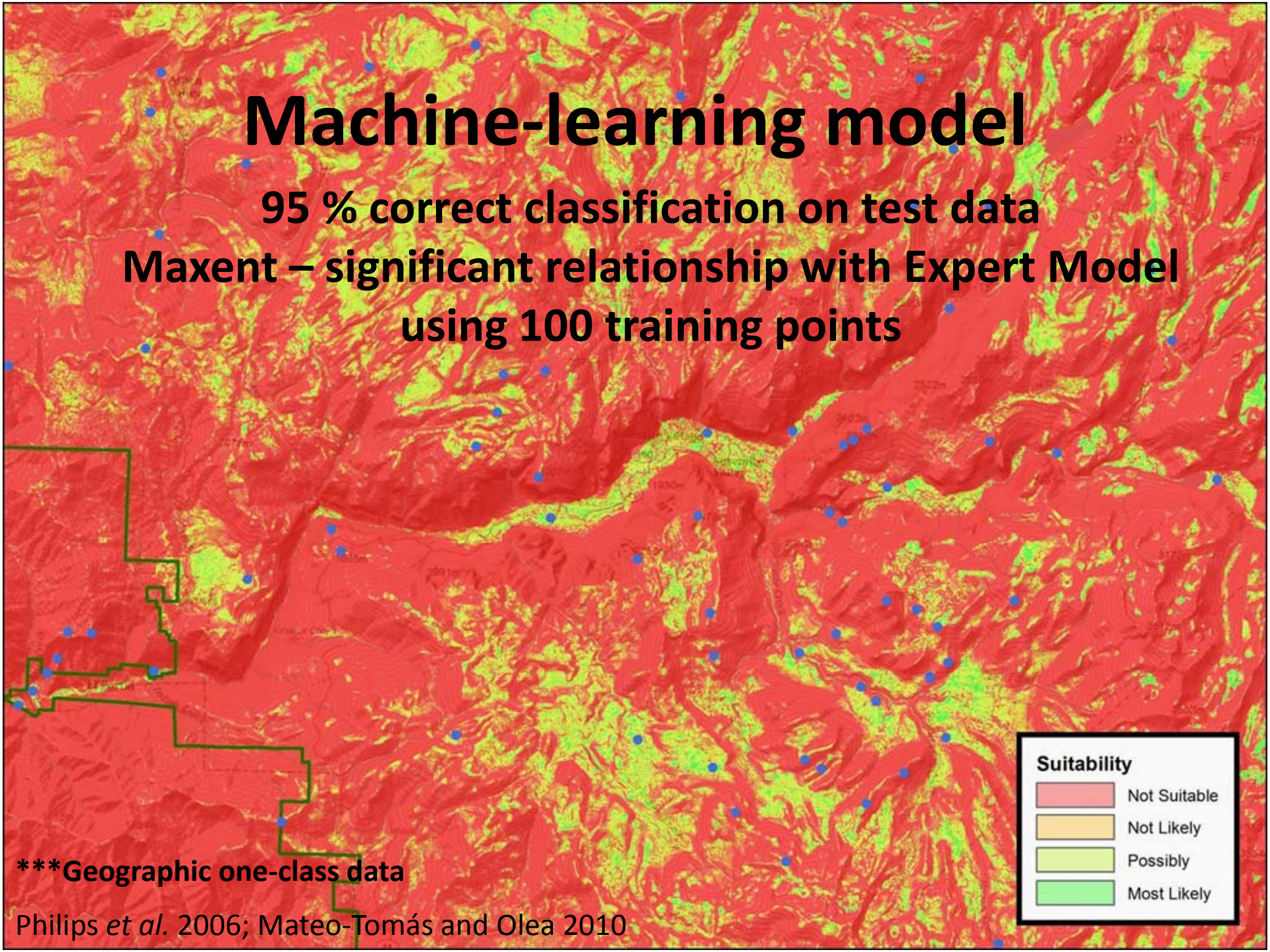



Expert Model
95 % correct classification on test data
Suitability
Not Suitable
Not Likely
Possibly
Most Likely
Store and Kangas 2001, Malczewski 2004


1.0
0.8
0.6
0.4
0.2
0.0
Maxent Score
0
5
10
15
20
25
Slope
Most likely
Possibly
Not likely
Not suitable

N = 4000, Kruskal-Wallis $P < 0.001$, Nemenyi test shows separation of all groups




Machine-learning model
95 % correct classification on test data
Maxent – significant relationship with Expert Model
using 100 training points
***Geographic one-class data
Philips *et al.* 2006; Mateo-Tomás and Olea 2010
Suitability
Not Suitable
Not Likely
Possibly
Most Likely

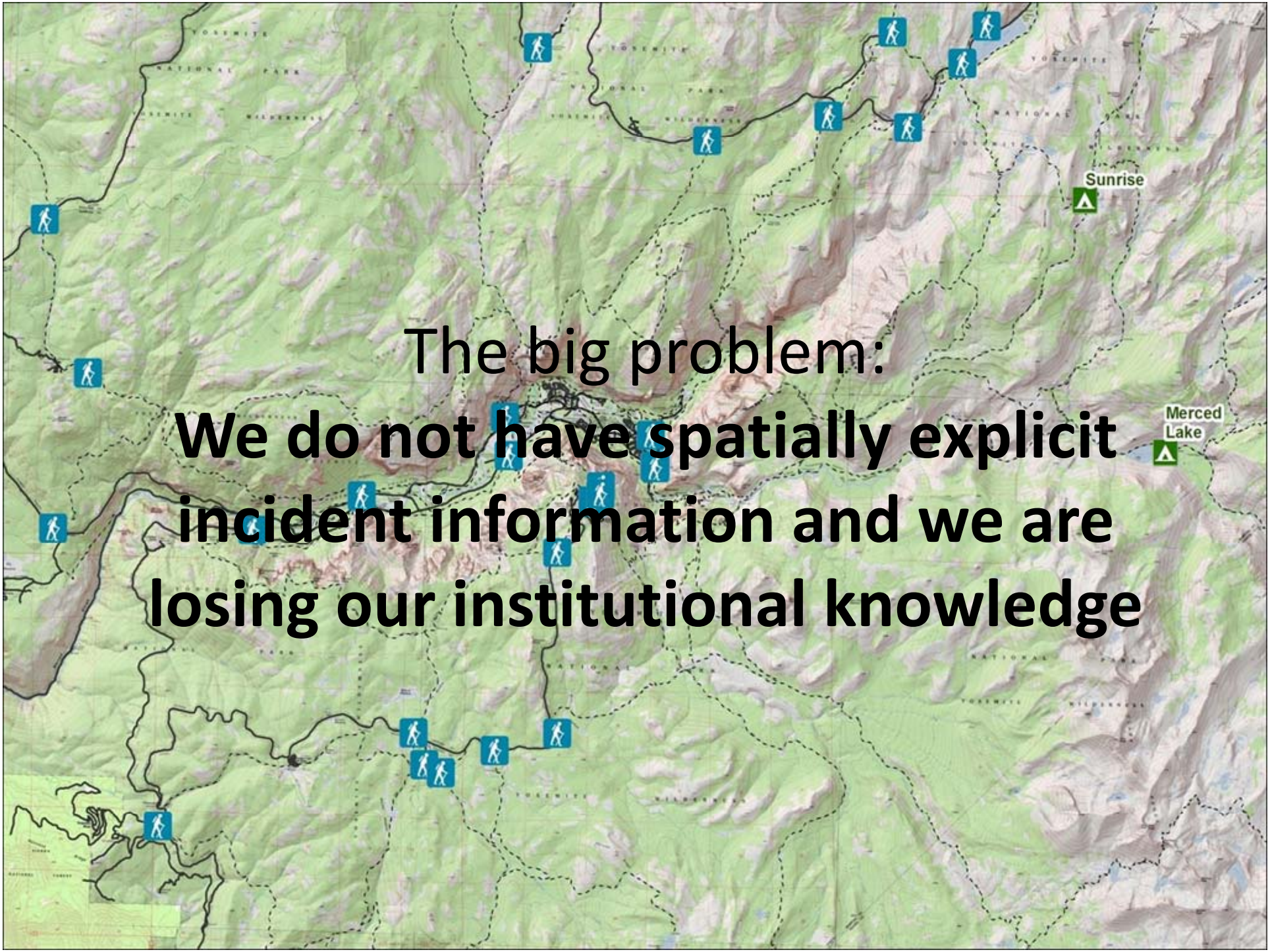
What is Search and Rescue? (SAR)

- Locate
- Stabilize
- Extract
- *Prevention*?

Preventative Search and Rescue

- Use our knowledge of past incidents to inform:
  - The visitors
  - The management
  - The rescuers

*****Spatial uncertainty, data quality, and innovative use**

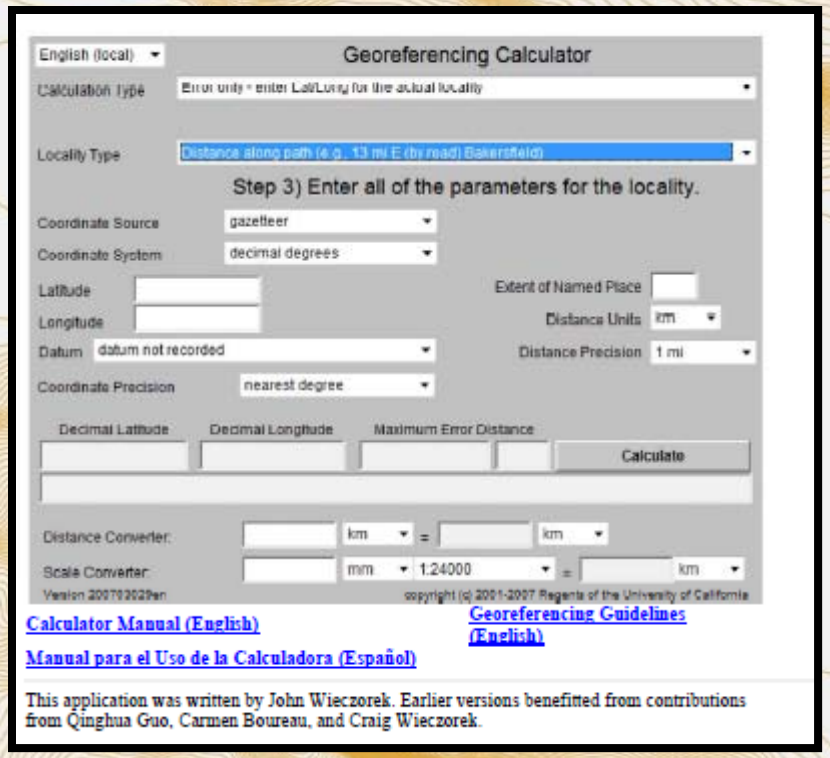


The big problem:

We do not have spatially explicit incident information and we are losing our institutional knowledge

What is an *ideal* georeference?

A numerical description of a place that can be mapped and that describes the spatial extent of a locality and its associated uncertainties as well as possible.



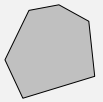
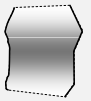
Guide to Best Practices for Georeferencing

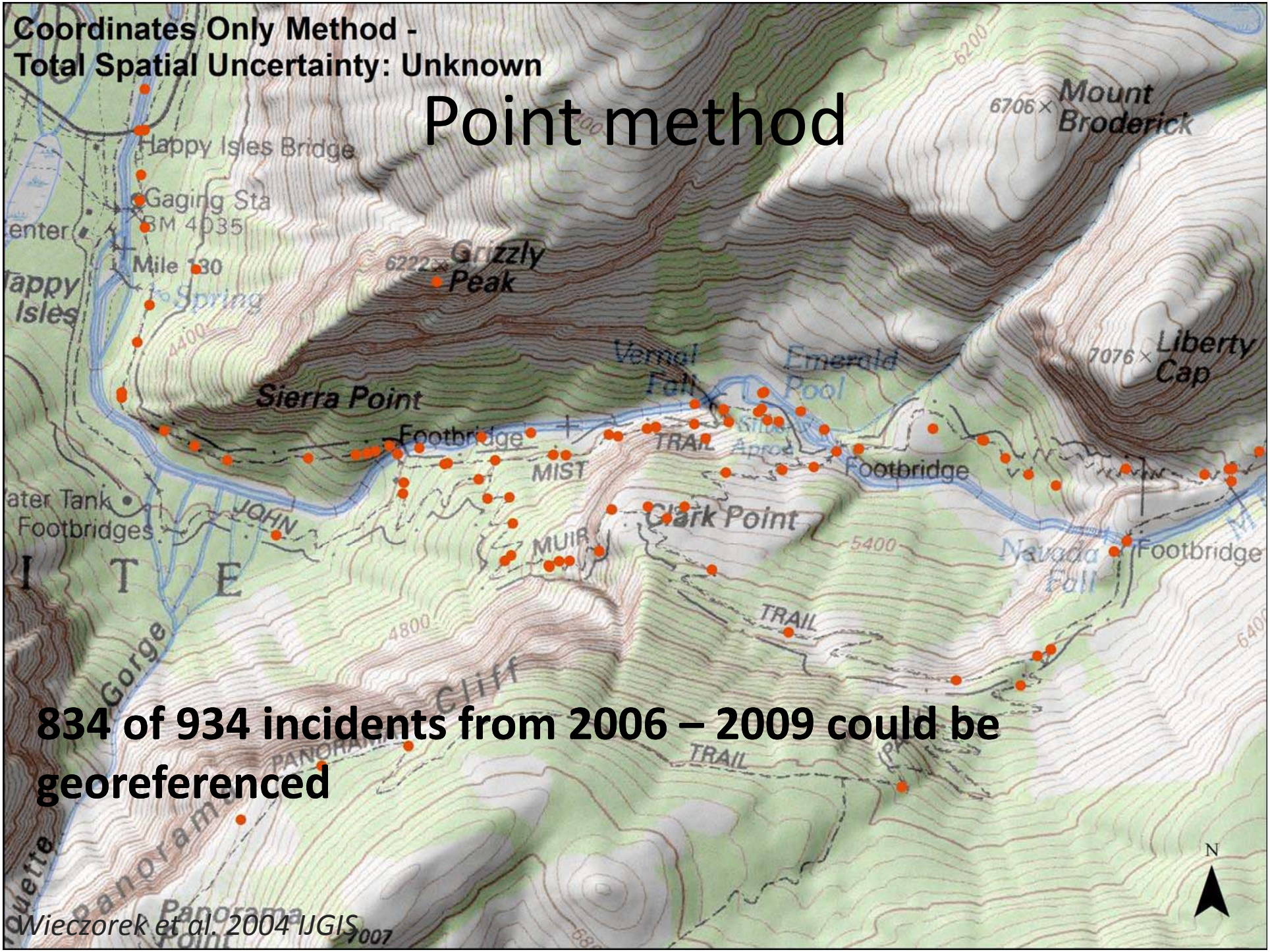
Wieczorek et al 2004; Chapman and Wieczorek 2006, Guo et al 2008; Liu et al 2009

Put it on a map, do it well, and know how confident you should be

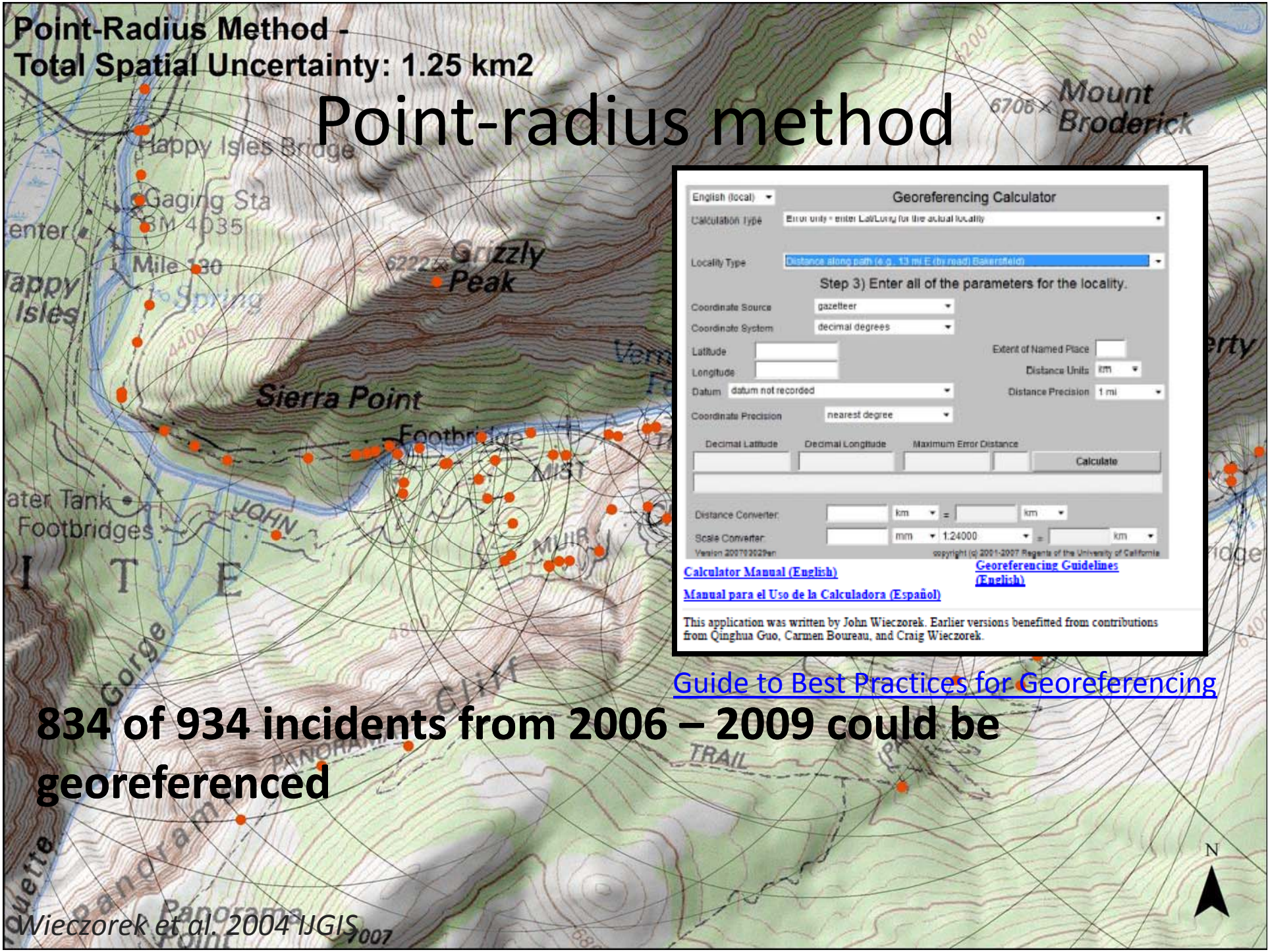
Reference object vs. Target object

Georeferencing SAR

Locality	Description	Example	Figure
F	Feature	"Patient fractured ankle at **Columbia Point**".	
P	Path or linear feature	"Patient twisted knee while on the **Mist Trail** between the **Steps** and the top of **Vernal Falls**".	
J	Junction	"Patient was found unconscious at the **junction of the John Muir and Panorama Trail**".	
BF	Between features or paths	"The missing person's body was located between the **Tioga Road** and **Gaylor Lakes Trail**".	


Coordinates Only Method -
Total Spatial Uncertainty: Unknown
Point method
Happy Isles Bridge
Gaging Sta
BM 4035
Mile 1.30
Spring
Grizzly Peak
6222
Mount Broderick
6706
Liberty Cap
7076
Vernal Fall
Emerald Pool
Sierra Point
Footbridge
TRAIL
MIST
JOHN
MUIR
Clark Point
Nevada Fall
Footbridge
TRAIL
TRAIL
Cliff
Panorama Point
7007
5400
4800
4400
6200
N
834 of 934 incidents from 2006 – 2009 could be georeferenced
Wieczorek et al. 2004 IJGIS

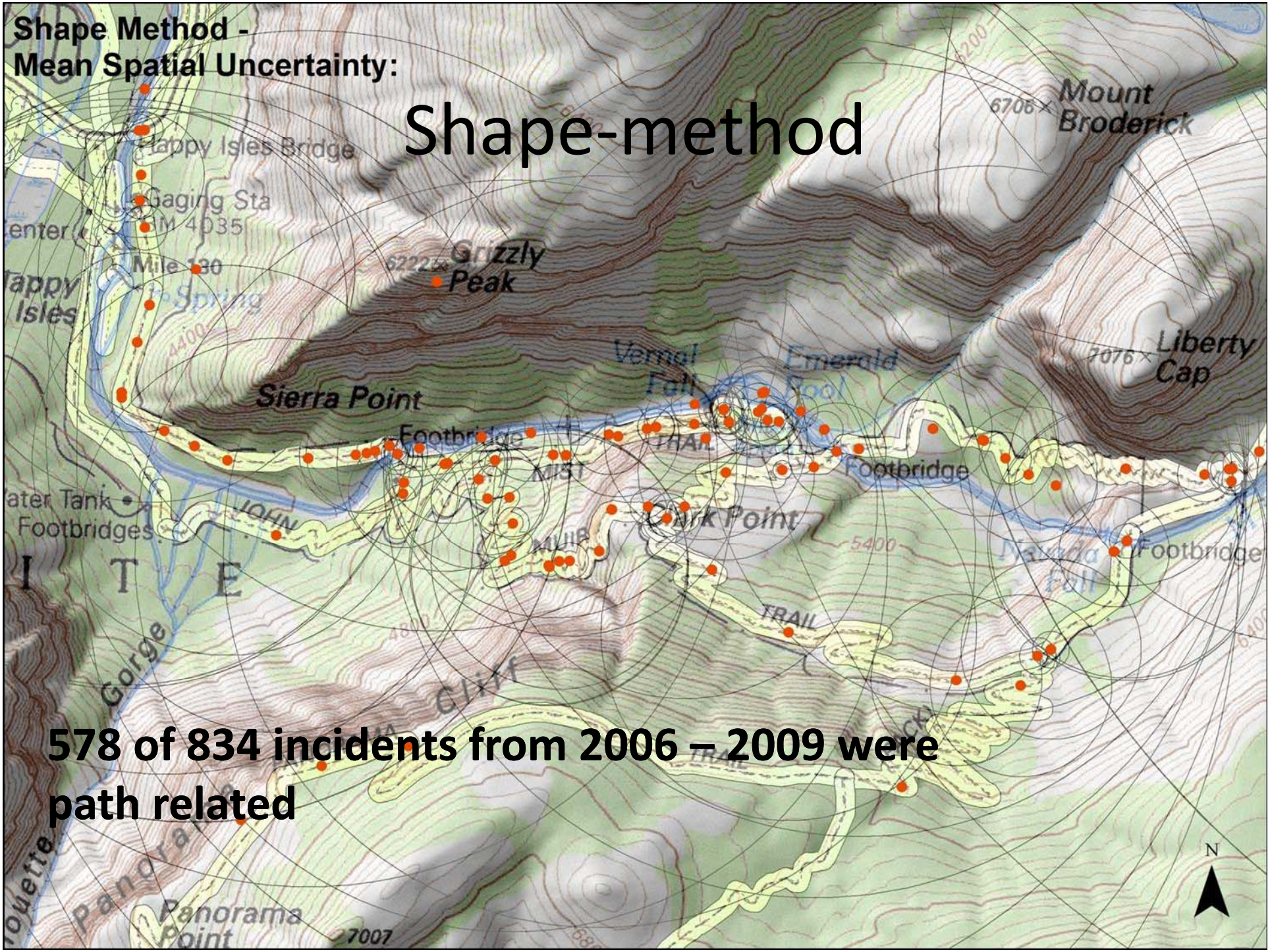
Point-radius method



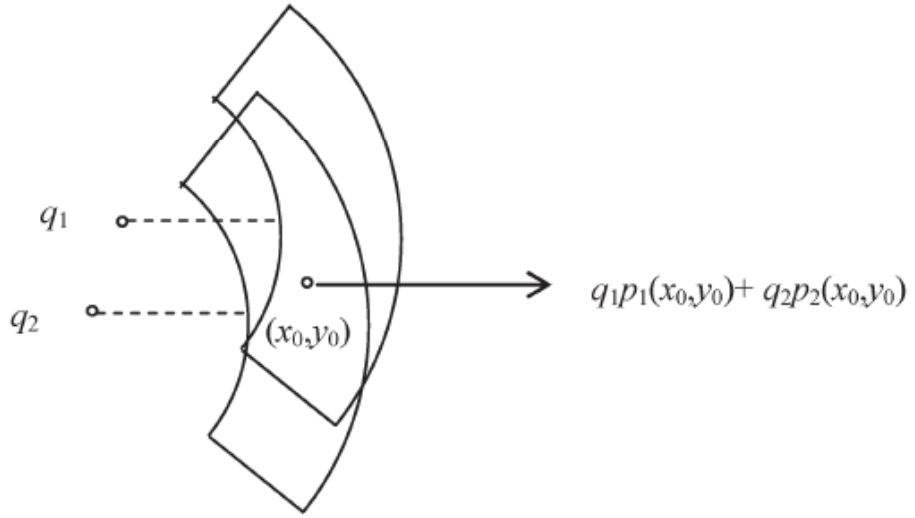
Guide to Best Practices for Georeferencing

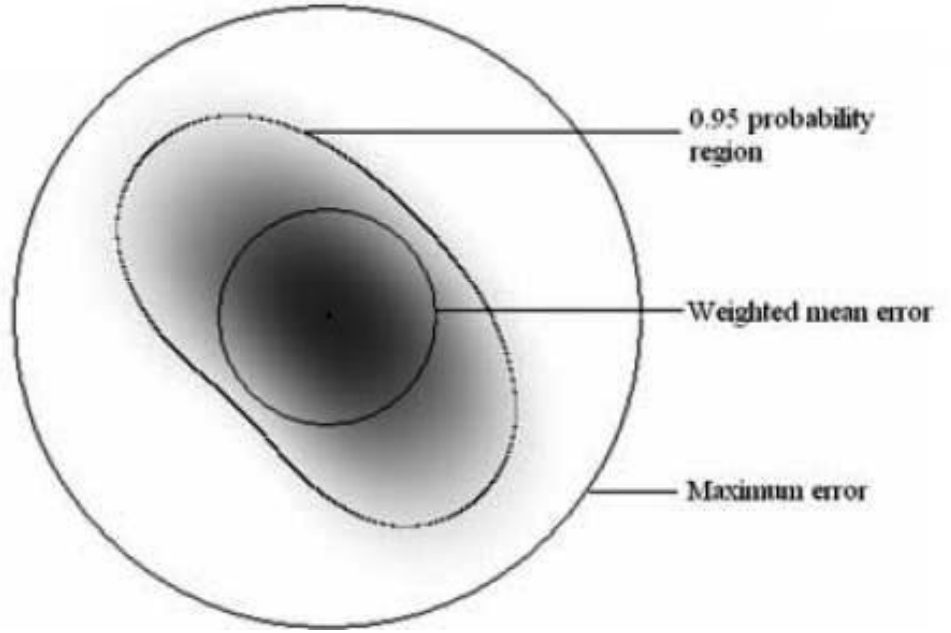
834 of 934 incidents from 2006 – 2009 could be georeferenced

Wieczorek et al. 2004 IJGIS


Shape Method -
Mean Spatial Uncertainty:
Shape-method
Happy Isles Bridge
Gaging Sta
Mile 1.30
Grizzly Peak
Mount Broderick
Liberty Cap
Sierra Point
Vernal Fall
Emerald Pool
Footbridge
Clark Point
Nevada Fall
TRAIL
Panorama Point
N
578 of 834 incidents from 2006 – 2009 were path related

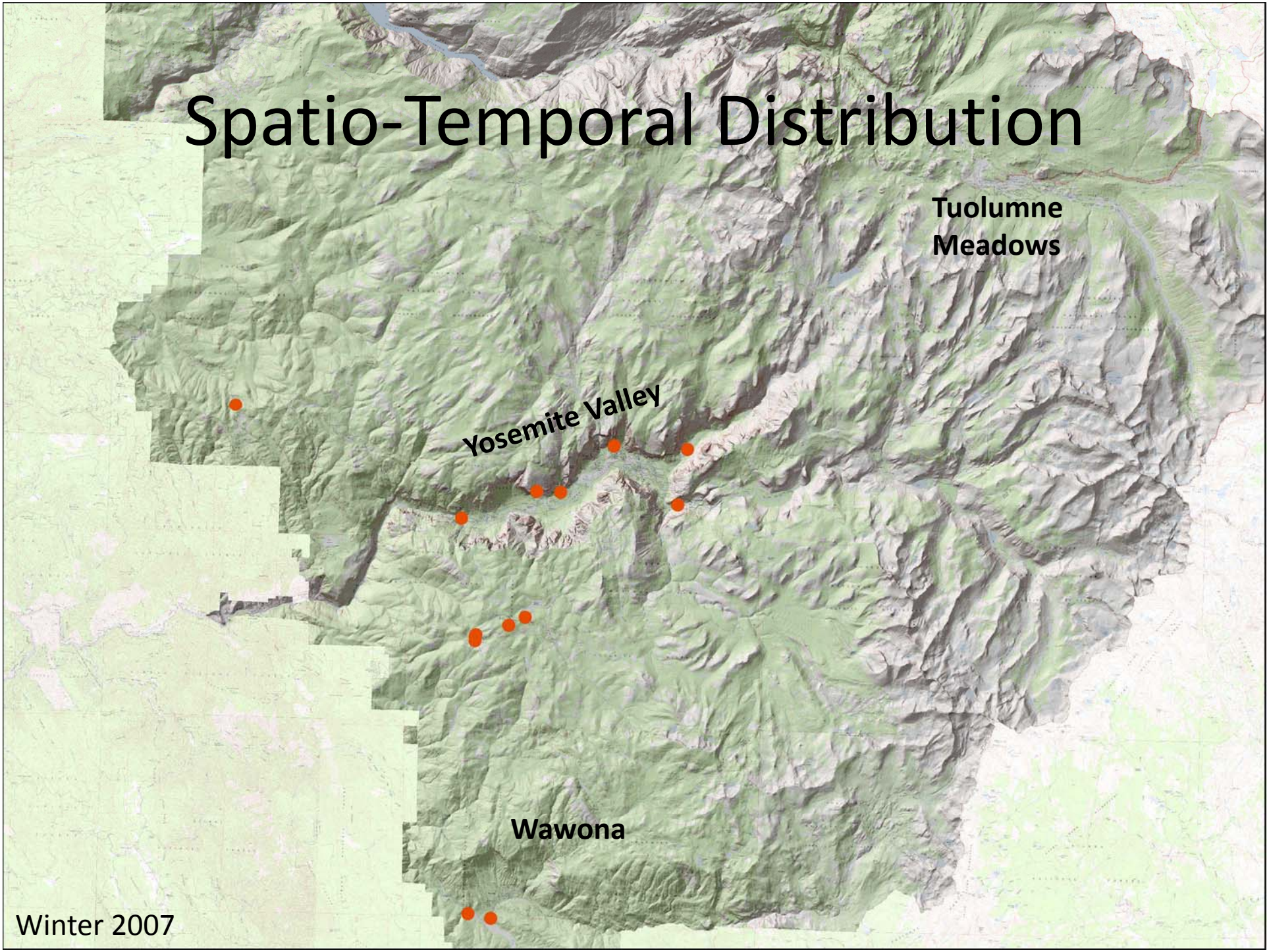
Probability-field method

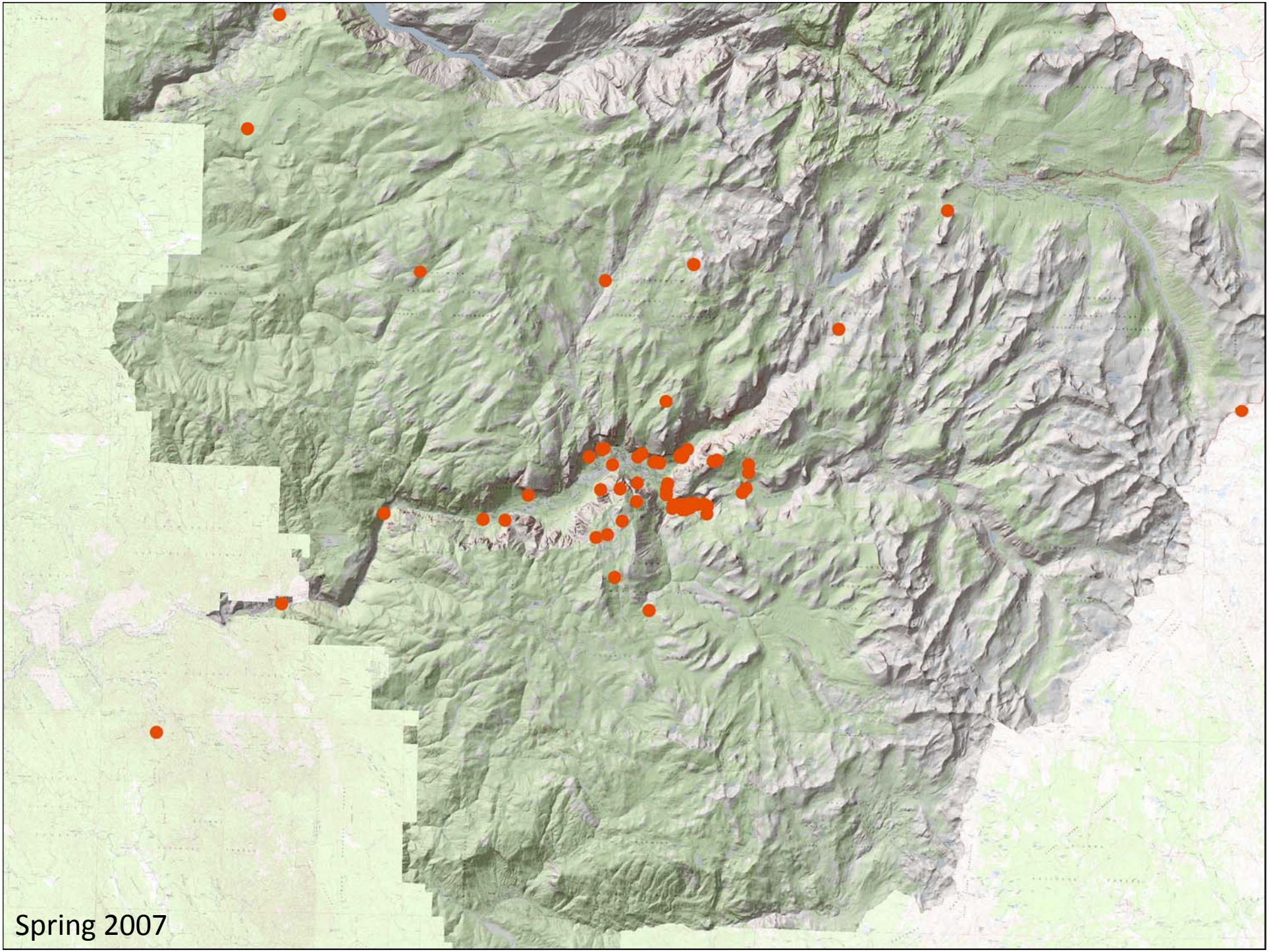


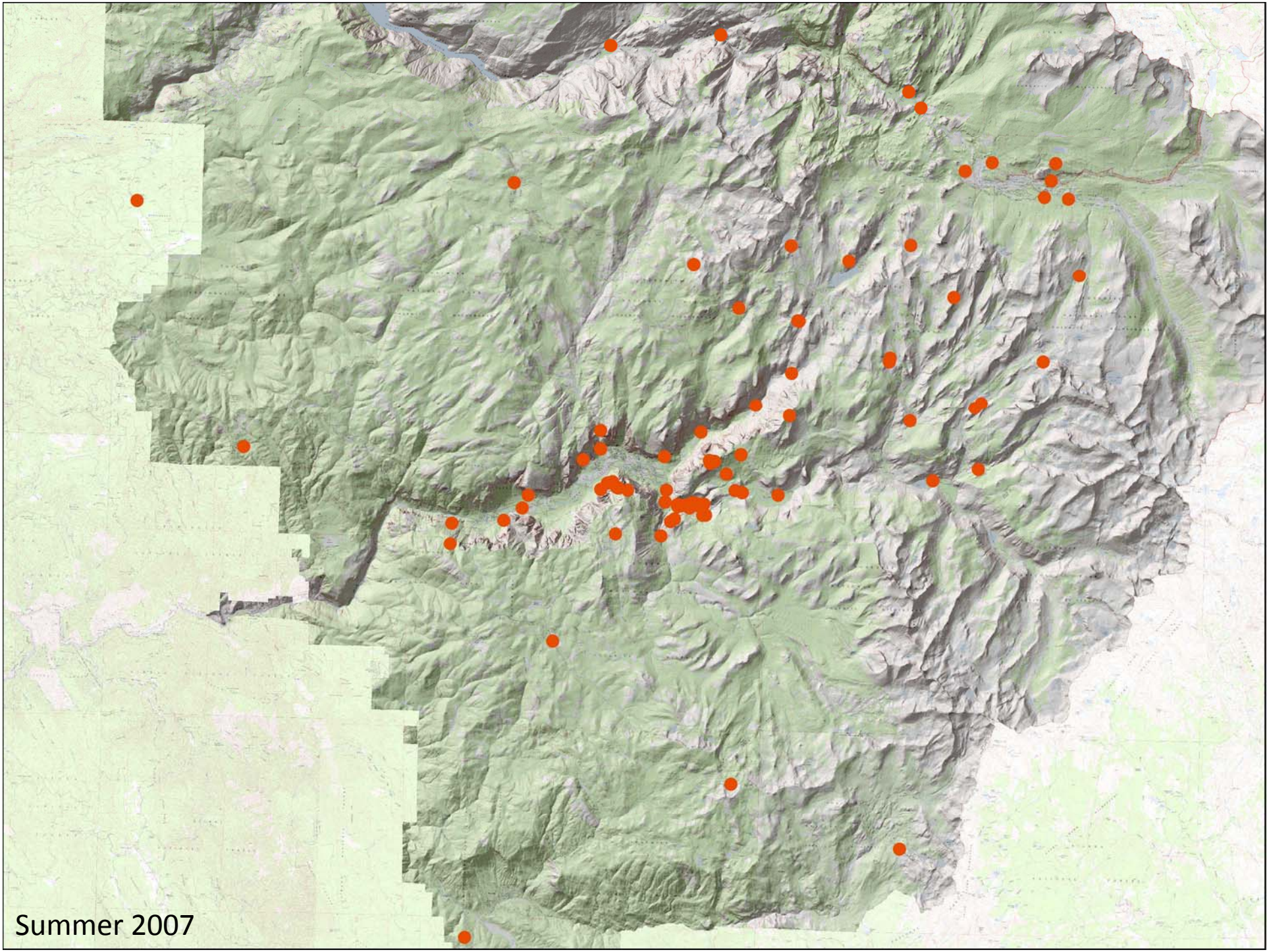


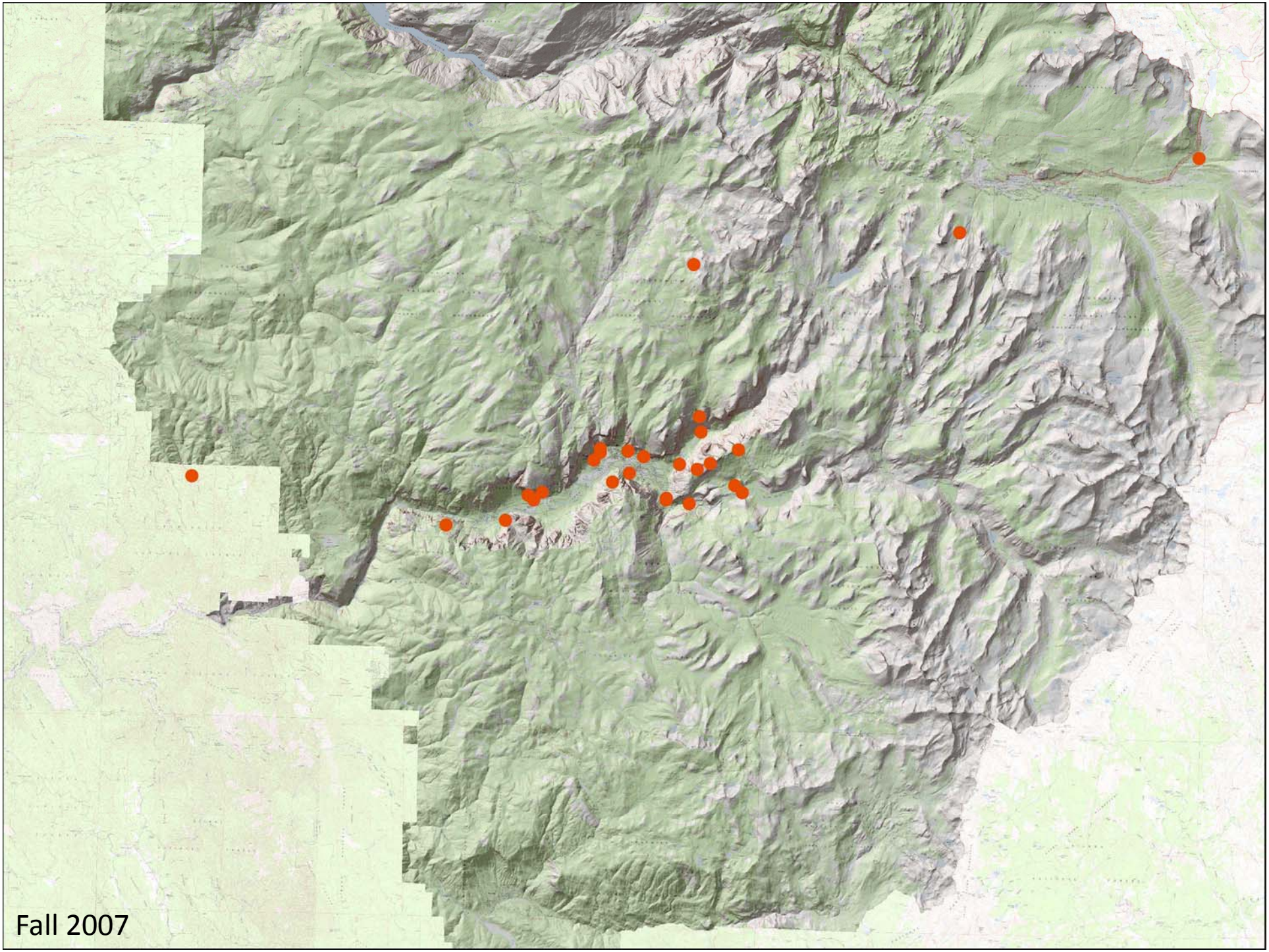
Guo et al. 2008 IJGIS

Spatio-Temporal Distribution




Spring 2007


Summer 2007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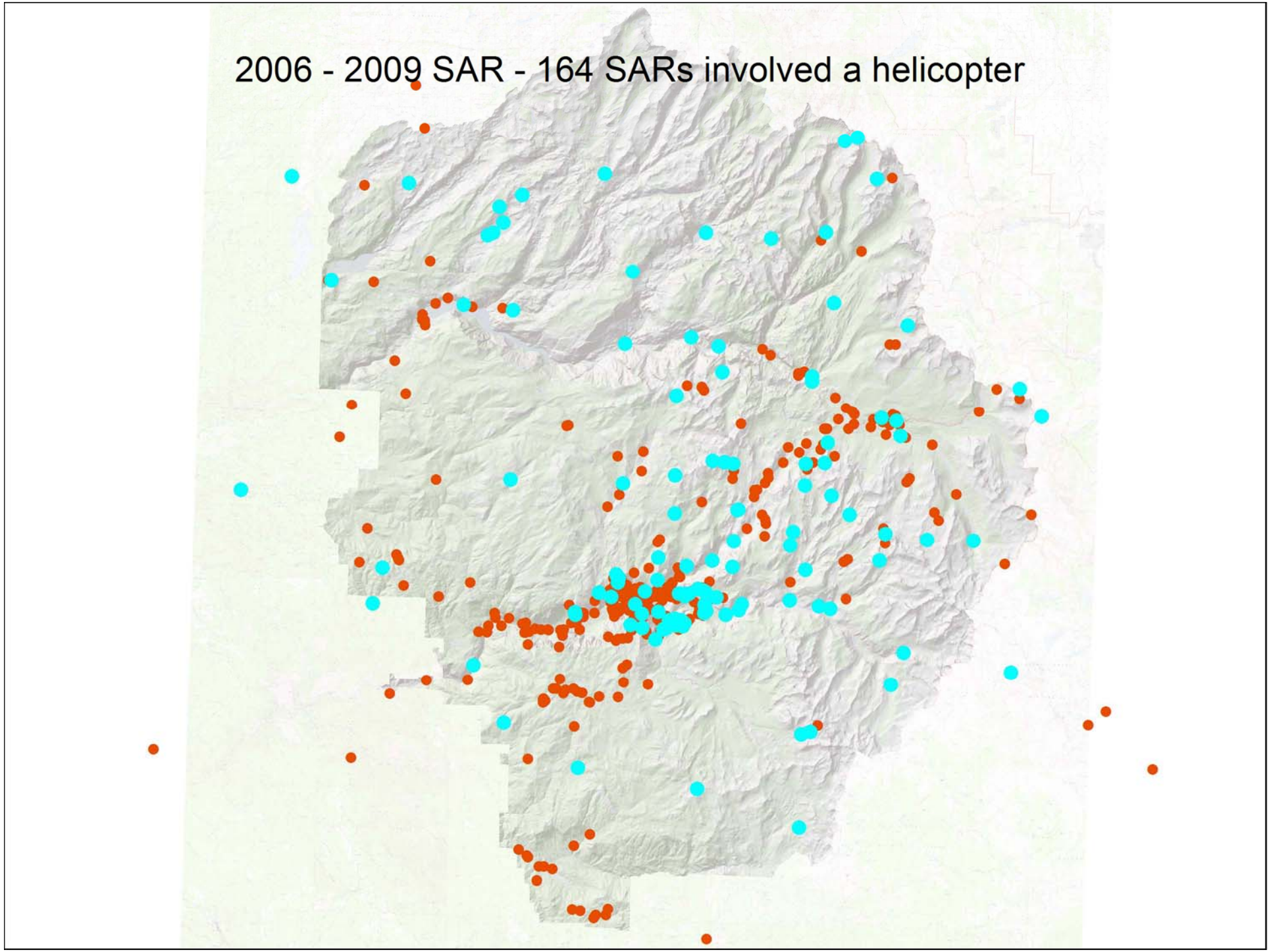
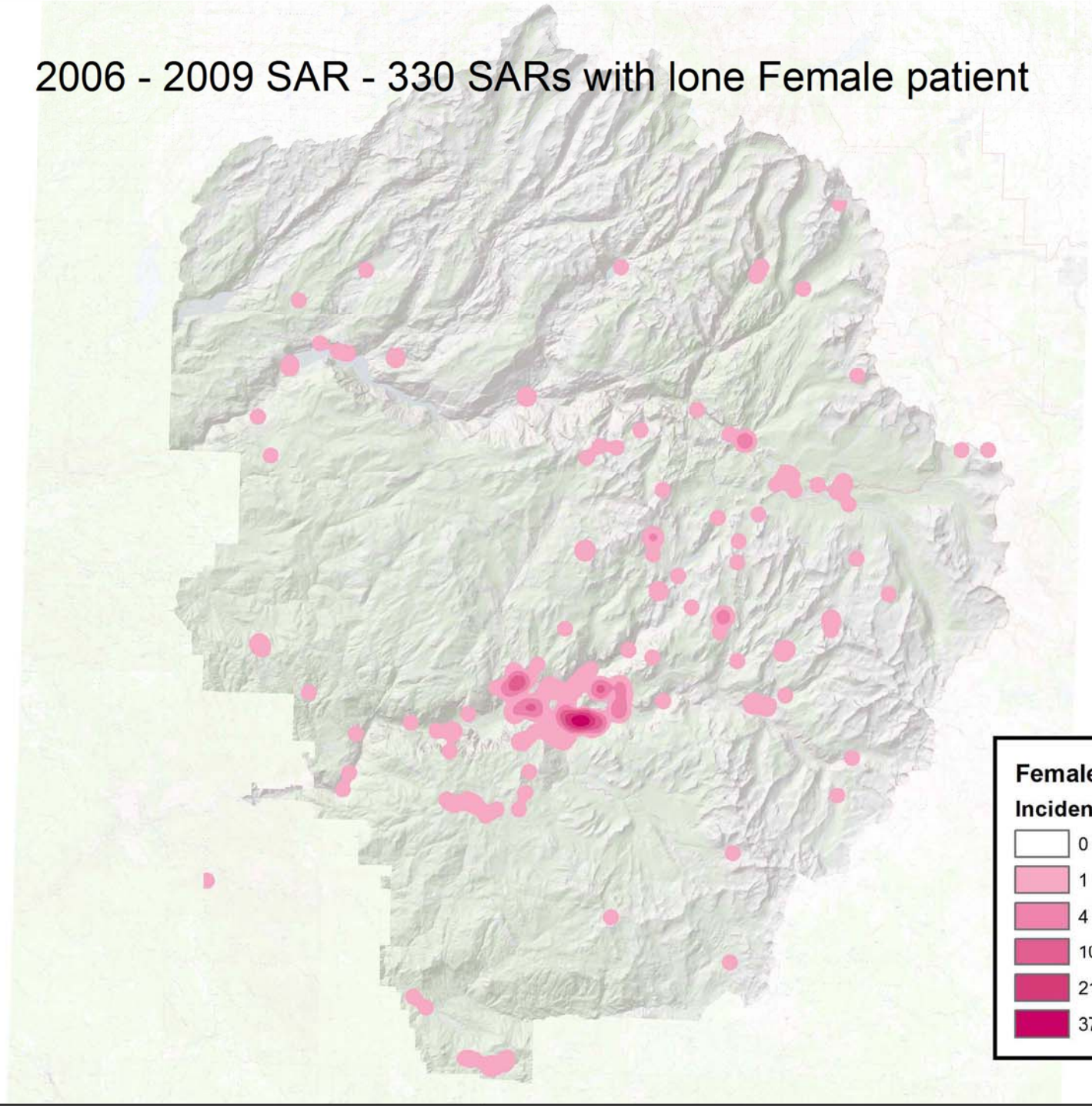
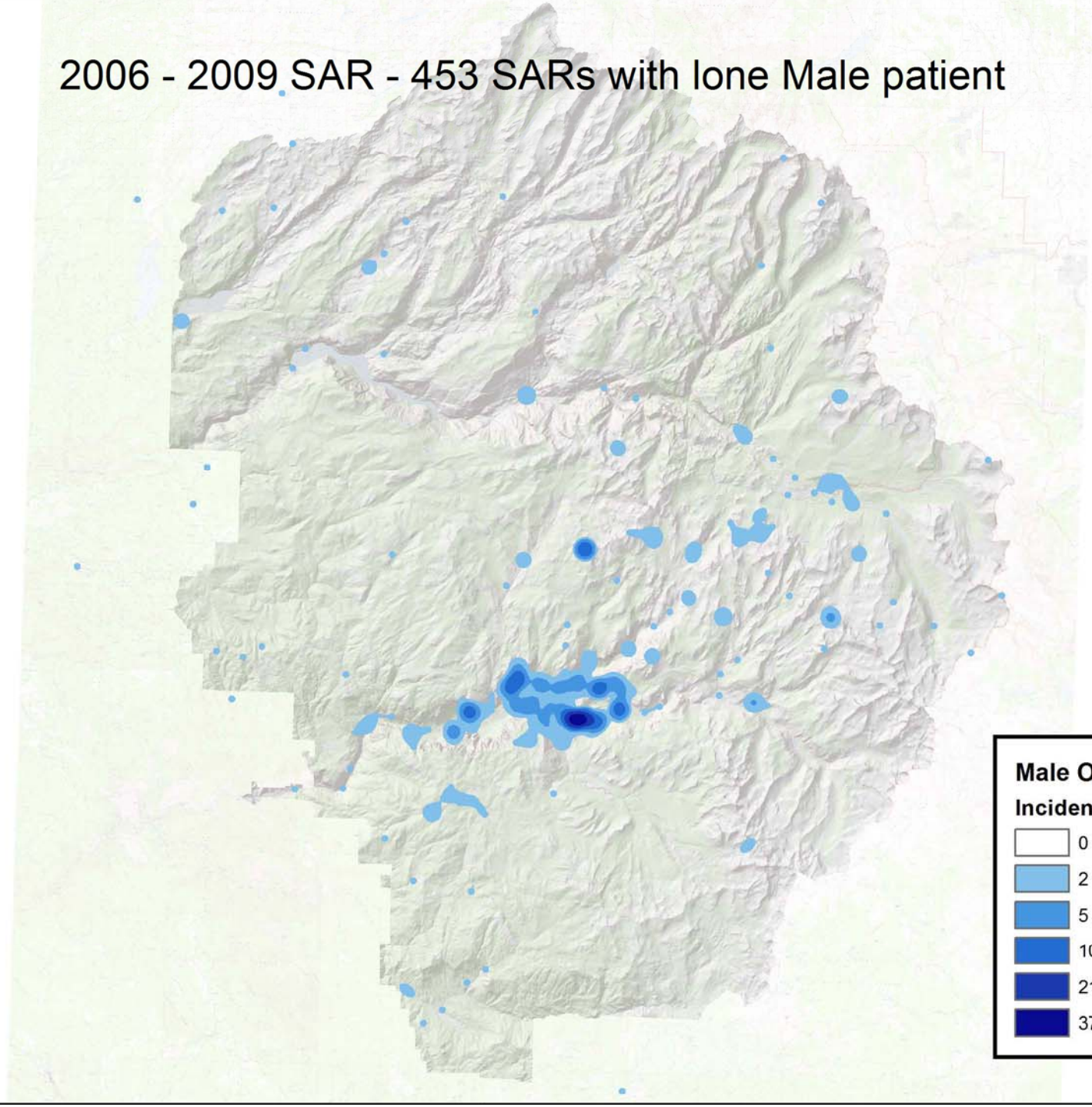
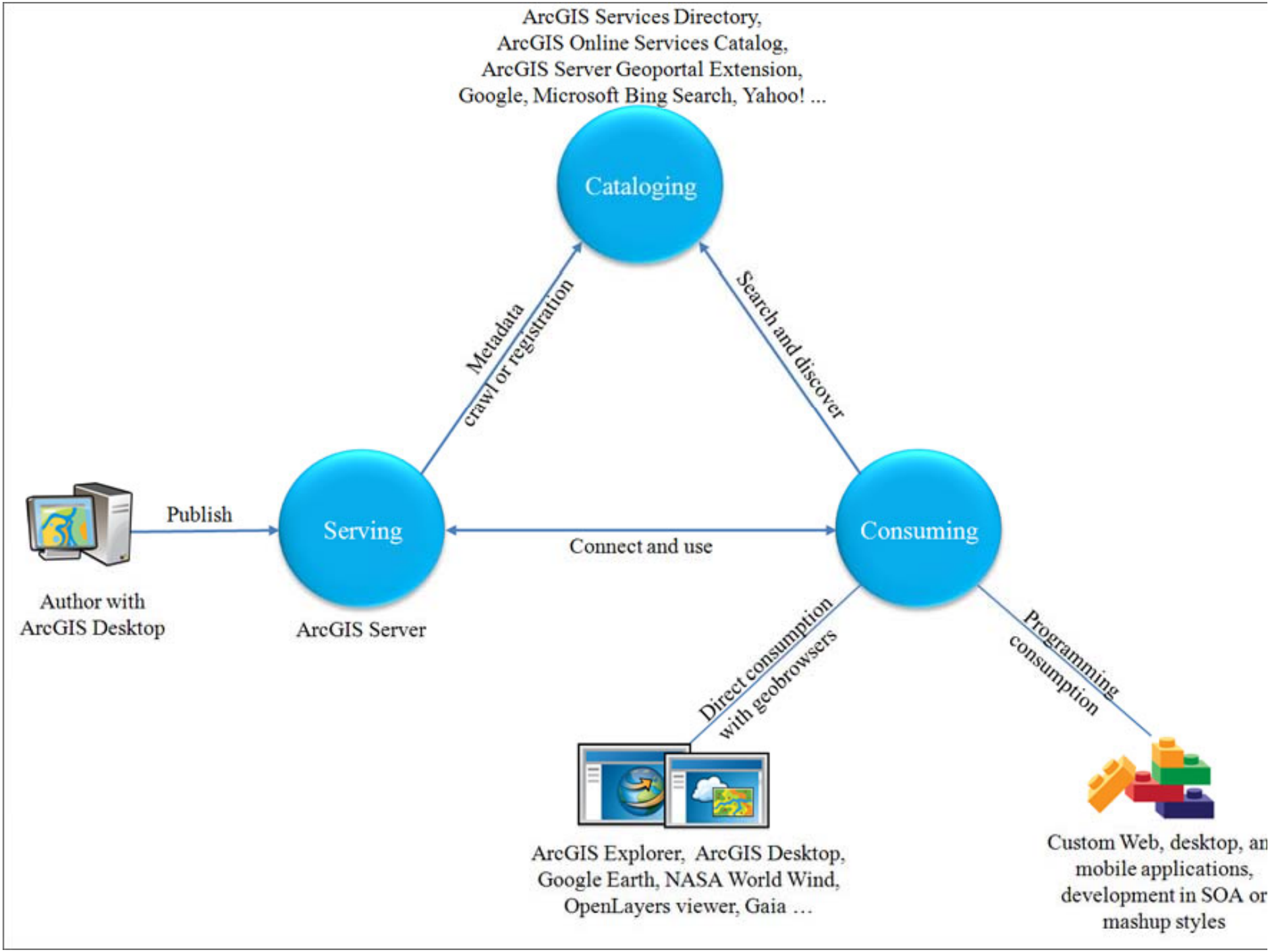

2006 - 2009 SAR - 164 SARs involved a helicopter

2006 - 2009 SAR - 330 SARs with lone Female patient



2006 - 2009 SAR - 453 SARs with lone Male patient




ArcGIS Services Directory,
ArcGIS Online Services Catalog,
ArcGIS Server Geoportal Extension,
Google, Microsoft Bing Search, Yahoo! ...
Cataloging
Metadata
crawl or registration
Search and discover
Publish
Serving
Connect and use
Consuming
Author with
ArcGIS Desktop
ArcGIS Server
Direct consumption
with geobrowsers
Programming
consumption
ArcGIS Explorer, ArcGIS Desktop,
Google Earth, NASA World Wind,
OpenLayers viewer, Gaia …
Custom Web, desktop, an
mobile applications,
development in SOA or
mashup styles

"As a collector, you may have an intended use for the data you collect but data have the potential to be used in unforeseen ways; therefore, the value of your data is directly related to the fitness of those data for a variety of uses".

"As data become more accessible, many more uses become apparent".

Chapman and Wieczorek 2006

GIScience topics

- Probabilistic time geography
- Human geography
- Geographic one-class data
- Machine learning algorithms
- Spatial uncertainty, data quality, and innovative use

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WHERE DISCOVERIES BEGIN

When Every Second Counts

Yosemite uses GIS for coordinating search and rescue operations

By Jesse Theodore, ESRI Writer

GIS has helped the Yosemite Search and Rescue (YOSAR) team improve its methods of operation and has been used successfully in searches for missing persons in Yosemite National Park.

Every year, three million visitors come to Yosemite National Park to enjoy the outdoors. One of the nation's greatest travel destinations, Yosemite provides camping, fishing, hiking, and other activities for guests to enjoy. While most visitors have the time of their lives, a few face the frightening prospect of becoming disoriented or getting injured while hiking the park's many trails.

Each year, Yosemite National Park responds to hundreds of calls reporting missing persons. Most often, a lost hiker or vacationer is found during the first 24 hours. However, when someone is missing for more than 24 hours, multiple search teams are dispatched. Search and rescue operations require a significant, coordinated effort on the ground and in the air. For these incidents, the National Park Service calls on YOSAR, a team of specialists.

Photo by David Pope

A helicopter rescue technician rappels from Yosemite's contract helicopter H-551.

YOSAR is a group of park rangers, technical climbers, helicopter pilots, and incident management staff who are directed by Keith Lober, the emergency services coordinator for Yosemite National Park.

These skilled search and rescue operators are known around the world for their ability to make backcountry extractions of injured hikers; perform climbing rescues off of "big walls," such as El Capitan; search for missing hikers; and respond to multi-casualty incidents. They work primarily in the park, but are requested by mutual aid management teams throughout the country.

Once activated, YOSAR assembles and deploys ground, technical, canine, and air units and manages the entire incident response process. Managing complex emergency situations requires rapid response capability that ensures a comprehensive, coordinated search is carried out in the fastest possible time frame.

Expanding GIS at Yosemite

Paul Doherty, a park ranger and GIS specialist for the National Park Service, was hired in May 2008 to establish GIS support specifically for search and rescue operations.

"Once I settled in and started working, the GIS needs in the Protection Division were evident and the opportunity to get involved was very exciting," said Doherty.

The National Park Service has successfully used GIS in its Resource Management and Science Division, as well as in its response to wildland fires. Protection Division chief Steve Shackelton envisions applying the same technology and services to all branches of emergency response (i.e., search and rescue, law enforcement, disaster management, and structural fire) in the park.

Managing a Complex Operation

Missing person incidents are common in Yosemite. When a hiker is missing or overdue, it requires an initial response known as a "hasty search." These searches are carried out in the first 24 hours in the immediate vicinity where the lost person was last seen. Trail blocks are established to interview possible witnesses and gather information on hiking conditions.

If the person is not found quickly, a large search area of 1–40 square miles is drawn on a map. This area is segmented to create smaller search assignments, and a comprehensive search and rescue case is created.

Finding a missing person in the wilderness is a complex process. Maps are at the core of this process. Incident managers and field teams want to know the coordinates where the person was last seen to determine where they should begin the search. They also want to know about the surrounding landscape so they can safely and efficiently locate, stabilize, and extract victims as quickly as possible.

These search and rescue operations, managed under the Incident Command System, can increase in complexity very quickly. YOSAR members are adept at implementing modern search theory as well as using lessons learned from previous searches.

The Yosemite Search and Rescue team and Chief Ranger Steve Shackelton of Yosemite National Park were selected to receive a Special Achievement in GIS award this year.

YOSAR's skilled search and rescue operators are well-known for their ability to make backcountry extractions of injured hikers and perform climbing rescues off of "big walls," such as El Capitan. In this photo, a rescuer and the partner of a rescued climber are pulled from Big Sandy Ledge on the face of Half Dome.

Photo by David Pope

Any questions?

Special thanks to KU Graduate Student Jared Doke for georeferencing 934 incidents this summer