Results of the 2013 STAR Model Analysis

Introduction

The flight Safety And Risk (STAR) model requirements and parameters were created by a committee made up of four FHTET personnel including the author of this document, Jeff Mai (Aviation Safety Program Manager), Jim Ellenwood (Remote Sensing Program Manager), Frank Krist (GIS Program Manager). Discussions with this committee were held to examine and define flight safety risk data and the flight safety parameter requirements given an engine out scenario over forested landscapes as well as the selection of an appropriate area to test the efficacy of using satellite data as a surrogate to ADS in areas where it is considered too dangerous or where there are holes in the ADS coverage in forests with pest risk.

STAR Model Data and Requirements

The fact that the aerial survey aircraft typically fly at 2,000 to 3,000 feet above ground level (AGL) is an important constraint on how far an aircraft can glide with no power. This limits the pilot's time to react and find a suitable emergency landing site. The committee's discussion resulted in a list of flight safety-risk constraints:

- Aircraft fly relatively close to the ground; typically at 2,000 to 3,000 feet AGL,
- Aerial survey aircraft typically have a glide-slope ratio of 8:1 to 10:1 (8:1 is the most restrictive with a three mile radius). During an engine out scenario, there is a good possibility of safe landing if the aircraft is within three miles of a landing strip. Beyond the three mile radius to an air filed, the pilot must quickly locate a suitable alternative landing area.
- Because aerial survey aircraft fly lower to the ground, there is far less time to react to the inflight emergency and find suitable landing sites compared to a more typical higher flight altitude(5-10 k agl),
- There are relatively few airports in most of the forested regions as compared to non-forested areas.

Flight Safety Risk Data

The flight safety risk (FSR) model is designed to find and delineate relative flight safety risk across the forested areas of the US. Based on the above FSR constraints, a list of appropriate data sets were agreed upon by the FHTET committee. These dataset are as follows:

- **3-Mile Airport Buffer** – Data Type: point data buffered out three miles and rasterized to 240 meters, Source: Bureau of Transportation Statistics (BTS)
- **Road Density** - Data Type: raster, Resolution: 1 km, Source: FHTET SDL dataset
- **Forest Tree Frequency** - Data Type: raster, Resolution: 240 m, Source: FHTET SDL dataset
- **Percent Slope** – Data Type: raster, Resolution: 240 m, Source: FHTET SDL dataset
- **Drainage Index** (soil wetness) – Data Type: raster, Resolution: 240 m. Source: FHTET SDL

<u>3-Mile Airport Buffer</u>

The 3-mile airport buffer dataset represents a three mile buffer around each airport where a typical aerial survey aircraft has the altitude and distance to glide back (assuming an 8:1 glide-slope ratio) the airport given an engine out scenario. This data is combined with the tree frequency surface as an area of no trees.

Forest Tree Frequency

The tree frequency raster dataset is a 240 meter resolution raster that represents the relative number of trees within each raster cell. Cells with very low or low values have few trees within the cell area and are considered more open and more suitable for emergency landings.

Road Density

Road Density is a 1 kilometer raster layer that represents the amount of linear roadways within the cell. The logic assumes that the higher the road density value, the more potential emergency landing areas available to the pilot. This data does not evaluate the suitability of the roads within any cell for emergency landings (ex., length of straight sections or any adjacent obstructions such as power lines and towers). It is included as a coarse level surrogate for potential suitable sections of roadway for emergency landings.

Drainage Index

Drainage Index (DI) dataset is a 240 meter raster layer developed at FHTET and contains discrete categories of soil drainage. The DI classes range from dry/well drained to very wet and wetland (also includes water and rock outcrops). The dryer or more well drained the soil at any particular raster cell; the more suitable it is as a surface for emergency landings. Poorly drained soils have a greater potential to be muddy and wet (including wetlands and bogs) that would have a tendency to flip an aircraft. Rock and rock outcrops are also considered undesirable for safe landing sites.

The above five data layers form the basis of modeling a coarse level surface of relative FSR across the US. The first step in the FSR model was to preprocess each surface layer to 960 meter spatial resolution. All preprocessing and subsequent analyses were completed by creating ArcGIS Model Builder models. Preprocessing models included incorporating the appropriate functions to create the required 960 meter data that included the ArcGIS commands Aggregate and Resample. Refer to Table 1 for a synopsis of the input FSR data and preprocessing methods used.

Data Layer	Preprocessing Technique to Create 960m Cell	Logic
% SLOPE Values: 0-130 Orig Res: 240m	AGGREGATE Mean; *4	Flat to mild slopes (0-10%) required for safe landing: High % Slopes are more dangerous
DRAINAGE INDEX Values: 0 - 99 Orig Res: 240m	AGGREGATE Mean; *4	Dryer areas better for safer landings: Wet areas more dangerous. This dataset was reclassed before being aggregated to 960 meters.
ROAD DENSITY Values: 1 - 100 Orig Res: 1km	RESAMPLE Bilinear Interp	The higher the road density, the more potential emergency land areas

TREE FREQ. & 8:1 GLIDE AREA Values: 0 - 64 Orig Res: 240m	AGGREGATE Mean; *4	This dataset is a combination of Tree Freq. and Aircraft Glide (3 mile radius for 8:1 glide/slope ratio). The glide areas were embedded into the TF surface using a CON maximum overlay technique. The fewer trees in the cell, the better for emergency landings.

Table 1. The four Flight Safety Risk data layers showing the original data resolution and data values, the preprocessing used to resample to 960 meter resolution, and the logic of the data set within the model.

The ArcGIS model builder functionality allows for data update and iterative adjustments in data classifications and weighting. All data is required to fit the FHTET Aerial Survey grid system that incorporates a 960 meter grid resolution. An example of the FSR preprocessing is shown in figure 1 that takes the SDL Road Density 1KM data set to a 960 meter resolution using the *Resample* command. The other FSR datasets were preprocessed using the *Aggregate* command due to the fact that the data originated from 240 meter resolution data. This requires the data be increased by a factor of four to create a 960 meter product. Figure 2 shows an example of the Percent Slope raster layer processed using the *Aggregate* command.

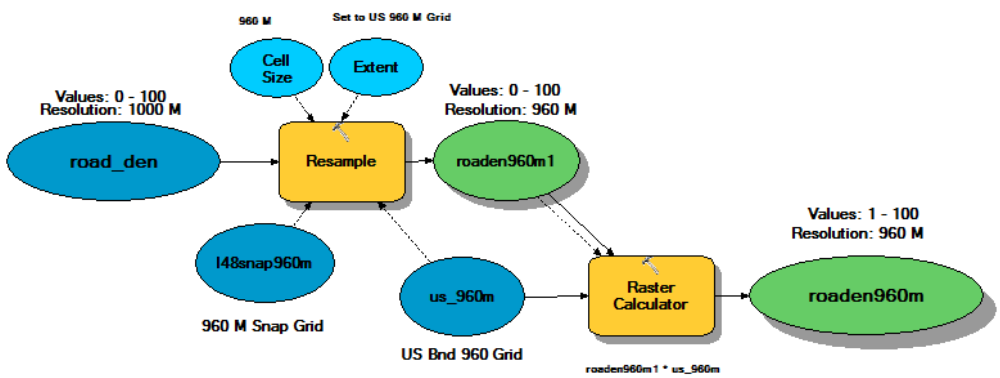

Figure 1. Example ArcGIS Model Builder for preprocessing the Road Density layer from 1KM resolution to 960 meter using the *Resample* command.

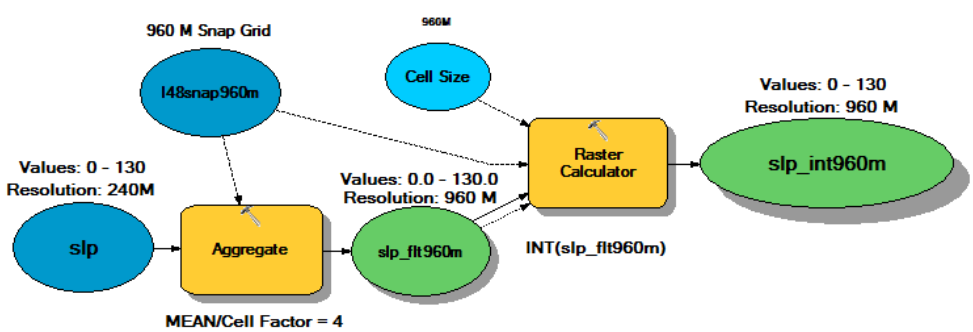

Figure 2. Example ArcGIS Model Builder for preprocessing the Slope layer from 240 meter resolution to 960 meter using the *Aggregate* command.

Preprocessing the five input FSR data layers (Tree Frequency, Glide Area, Slope, Road Density and Drainage Index) resulted in four 960 meter raster Grids: Tree Frequency-Glide Area, Slope, Road Density and Drainage Index (Figure 3). The Tree Frequency and Glide Area data were combined so that all 3-mile glide areas effectively removed pixels that were forested in the Tree Frequency layer.

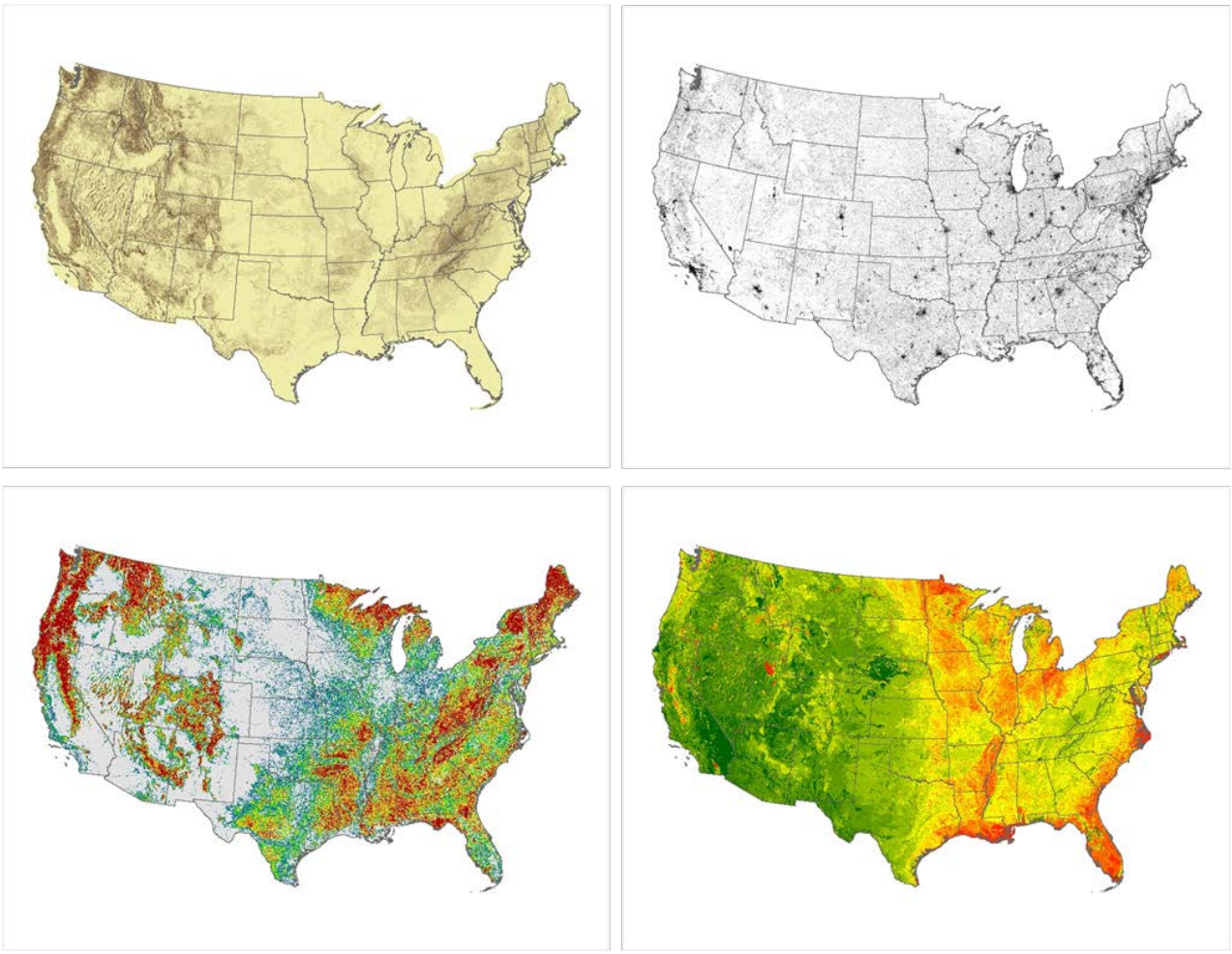

Figure 3. Completed output Grids of the four Flight Risk Data layers including; Top Left: Slope Percentage, Top Right: Road Density, Bottom Left: Tree Frequency with embedded with the 3-MileAircraft Glide Area and, Lower Right: Drainage Index.

The Pest Risk Model

The Pest Risk model requirements and parameters were also created by a committee made up of four FHTET personnel including the author of this document, Jeff Mai (Aviation Safety Program Manager), Jim Ellenwood (Remote Sensing Program Manager), and Frank Krist (GIS Program Manager). The pest-risk surface complements the flight-risk model in that it defines the location and relative intensity of pest/disease activity. Pest-risk, when combined with the flight-risk layer allows managers to spatially determine the relative risk cost/benefit. For example, if an area has high flight safety risk but low pest risk, the aerial survey manager may decide not to fly that area and use other methods to obtain forest health condition information such as high resolution satellite data. The datasets approved for the pest risk model include the NIDRM Percent BA Loss created from the FHTET Risk Map program and the last four years of the Insect and Disease Survey (IDS: 2009 – 2012). The following datasets were agreed upon to incorporate into the pest-risk model:

- **NIDRM Percent BA Loss** – Data Type: raster, Resolution: 1km, Source: FHTET; NIDRM

- **2009-2012 IDS Damage** – Data Type: raster, Resolution: 240 m. Source: FHTET: IDS 2009 – 2012.

NIDRM Percent BA Loss
The NIDRM Percent BA Loss raster layer originated from the National Insect and Disease Risk Map (NIDRM) FHTET program and represents the estimated percent loss by basal area (BA) by insect and disease agents. This dataset represents a predictive estimate of the location and relative severity of all pest and disease activity. The Percent BA Loss dataset is important when prioritizing where to fly based on the predictive pest/disease intensity. For example, if an area is considered in high risk, it becomes more important to fly that area and monitor its condition.

IDS Damage
The raster IDS Damage data used in this model originated as vector IDS polygons. Specifically, these data were selected mortality and defoliation polygons flown between 2009 and 2012. The polygon data was converted to 240 meter resolution raster separately into mortality and defoliation. The mortality and defoliation raster layers were summed in the *Raster Calculator* function that created values from 0 – 4 years (frequency). This dataset was also aggregated up to 960 meter resolution sing the *Aggregate* function.

The two pest-risk data layers listed above were the basis of creating a coarse level surface of relative pest-risk areas across the US. The pest-risk datasets were created by processing each surface layer to 960 meter spatial resolution and a reclass of each raster data layer to best represent categories of risk. **Table 2** defines the original data including data type, the resolution and data values, the preprocessing incorporated to resample or aggregate to 960 meter resolution, and the logic of the data set within the model.

Data Layer	Preprocessing Technique to Create 960m cell	Logic
NIDRM PCT BA LOSS Values: 0-100 Orig Res: 1km	RESAMPLE Bilinear Interp	The more predicted percent BA loss, the more important it is to fly
IDS Damage Type 1 & 2	AGGREGATE Mean: *4 Note: Max Overlay used to resolve spatially coincident pixels	Frequency of areas flown those areas with a frequency of 1 to 2 years given the highest score (newer activity). Frequency of 3 and 4 indicate the event is waning and is the common lifetime of the outbreak. Zero is neutral.

Table 2. The four Flight Safety Risk data layers showing the original data resolution and data values, the preprocessing used to resample to 960 meter resolution, and the logic of the data set within the model.

Figure 4 is an example of preprocessing Model Builder model of the 2009-2012 IDS polygons for defoliation and mortality for the Pest Risk into a 960 meter layer. The two preprocessed Pest Risk data layers are shown in figure 5 and include the Percent BA Loss and the 4-year mortality and defoliation frequency IDS data.

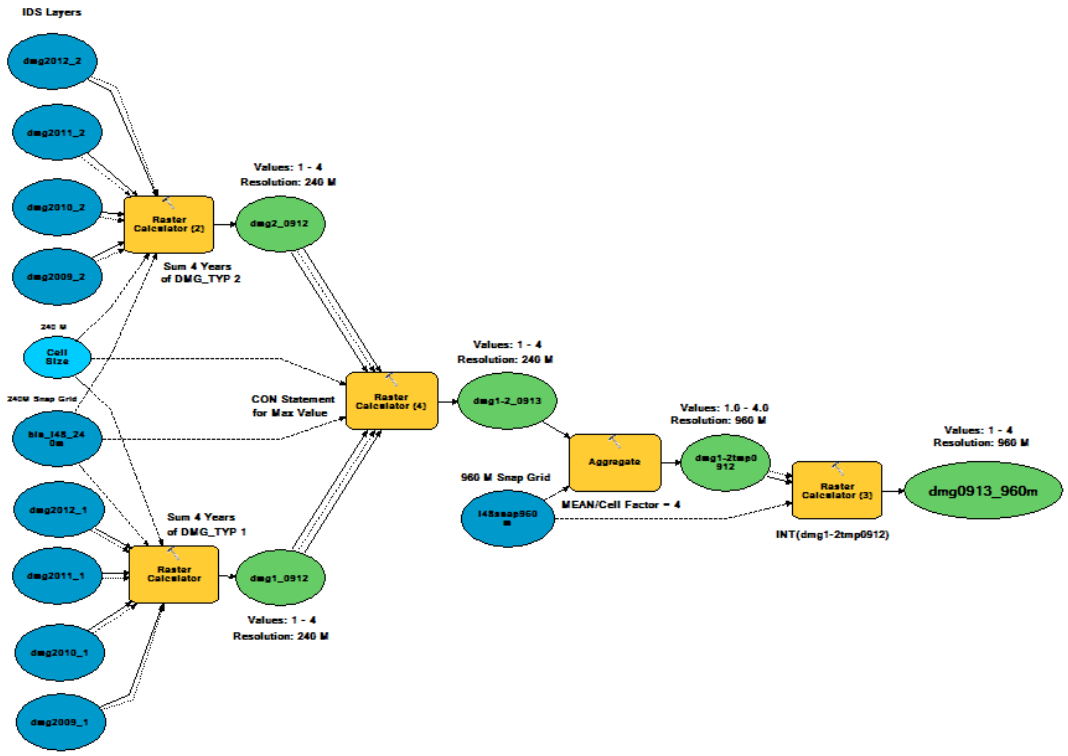

Figure 4. This diagram shows the final steps to preprocess the2009-2012 IDS polygons for defoliation and mortality to a 960 meter layer.

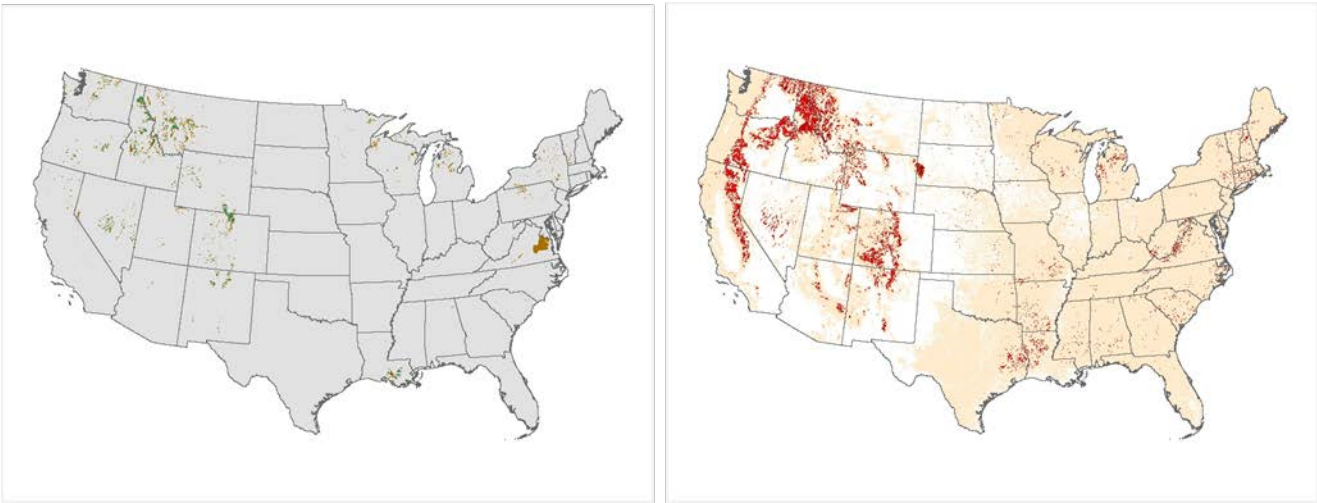

Figure 5. Completed output Grids of the four Flight Risk Data layers including; Top Left: Slope Percentage, Top Right: Road Density, Bottom Left: Tree Frequency with embedded with the 3-MileAircraft Glide Area and, Lower Right: Drainage Index.

Reclass and Weighted Overlay for Flight Safety Risk and Pest Risk Models

Reclass

In order to create a multi-criterion flight safety risk and pest risk models, the data values of each raster layer are reclassed to the same 1-10 range. The process of data reclass is important as it sets relative levels of importance or weight to specific ranges of values for each layer. Model results vary by changing the ranges of values in each layer that are reclassed to 1-10 where 1 is defined as **none** to **very little** risk and 10 represents the **highest** level of risk regarding flight safety or pest risk.

This process specifically defines the level of flight safety or pest risk in relation to the layer's data values and what those data values represent on the 960 meter landscape. All data reclass were completed using the ArcGIS *Reclass* function within a Model Builder model. Figure 6 shows the FSR and Pest Risk reclass models for the four input flight safety data layers (road density, tree frequency (with glide area), slope percent and drainage index) and the two input Pest Risk data layers (IDS and NIDRM BA Loss).

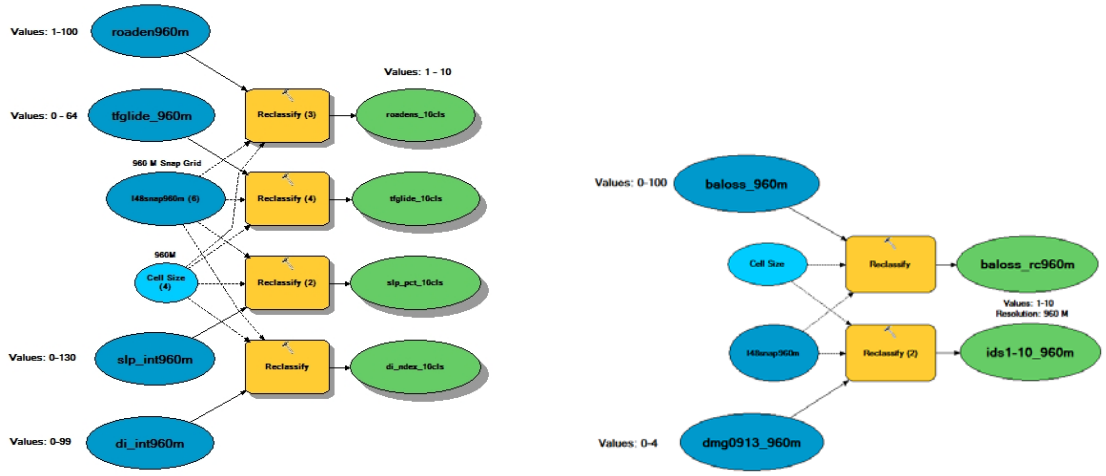

Figure 6. The ArcGIS Model Builder model used to reclass the four data layers for Flight Safety Risk (left) and reclass the two Pest Risk data layers (right). Each dataset was reclassed to values between 1 and 10.

Weighted Overlay

After establishing and reclassing the appropriate values for all the FSR and Pest Risk input datasets to a range of 1-10, these reclassed layers are then analyzed using the ArcGIS *Weighted Overlay* function. The *Weighted Overlay* function is a common analysis methodology used to solve multicriteria problems such as the STAR suitability models. The *Weighted Overlay* function overlays several rasters using a common measurement scale (1-10) and weights each according to importance by the user. The weighted overlay function can be adjusted as needed to create a new FSR weighted overlay product.

In the STAR FSR model, the tree frequency dataset is given the highest weight (40%). The logic behind this in an engine out scenario, the first action, after the pilot sets the aircraft for optimal glide airspeed, is to look for potential openings within the forest canopy for an emergency landing. The next action is to look for areas that are open and as flat as possible. Thus, the slope layer is given the next highest weighting value (25%). Road density and drainage index are given the final weighting values, 20% and 15% respectively.

Using the ArcGIS Model Builder for the STAR model allows the flexibility to adjust values in the both the reclass and the weighted overlay values in order to create the most appropriate output. Table 3 displays the input preprocessed STAR data layers including the original values, the reclass logic and the weighted value for each dataset used in the Flight Safety Risk (light gray) and Pest Risk models (light orange). Figure 7 is the FSR weighted overlay Model Builder model and figure 8 shows the weighted overlay model for Pest Risk.

Data Layer	**RECLASS to 1-10 SCORE** **1 =** most safe **5 =** moderately unsafe **10 =** most unsafe	**Weighted Value (%)**
FLIGHT RISK: ***Percent SLOPE*** Values: 0-130	0-1 = **1**, 1-2 = **2**, 2-3 = **3**, 3-4 = **4**, 4-5 = **5**, 5-6 = **6**, 6-7 = **7**, 7-8 = **8**, 8-9 = **9**, 9-130 = **10**	25%
FLIGHT RISK: ***DRAINAGE INDEX*** Values: 0-99	0 = **10**, 1-56= **1**, 57-60 = **2**, 60=63 = **3**, 63-65 = **4**, 65-67 = **5**, 67-69 = **6**, 69-71 = **7**, 71-73 = **8**, 73-75 = **9**, 75-98 = **10**, 99 = **5**	15%
FLIGHT RISK: ***ROAD DENSITY*** Values: 1-100	0-10 = **10**, 10-20 = **9**, 20-30 = **8**, 30-40 = **7**, 40-50 = **6**, 50-60 = **5**, 60-70 = **4**, 70-80 = **3**, 80-90 = **2**, 90-100= **1**	20%
FLIGHT RISK: ***TREE FREQ-GLIDE AREA*** Values: 0-64	0-2 = **1**, 2-4 = **2**, 4-6 = **3**, 6-10 = **4,** 10-15 = **5**, 15-25 = **6**, 25-35 = **7**, 35-45 = **8**, 45-55 = **9**, 55-64 = **10**	40%
PEST RISK: ***NIDRM PERCENT BA LOSS*** Values: 0-100	0 -2 = **1**, 2-4 = **2**, 4-7 = **3**, 7-10 = **4**, 10-13 = **5**, 13-16 = **6**, 16-19 = **7**, 19-22 = **8**, 22-25 = **9**, 25-65 = **10**, 65-68 = **9**, 68-71 = **8**, 71-74 = **7**, 74-77 = **6**, 77-80 = **5**, 80-83 = **4**, 83-86 = **3**, 86-90 = **2**, >90 = **1**	60%
PEST RISK: ***IDS Damage Type 1 & 2*** Values: 0-4	0 = **1**, 1 = **10**, 2 = **8**, 3 = **6**, 4 = **3**	40%

Table 3. Table 3 displays the input preprocessed STAR data layers including the original values, the reclass logic and the weighted value for each dataset used in the Flight Safety Risk (light gray) and Pest Risk models (light orange).

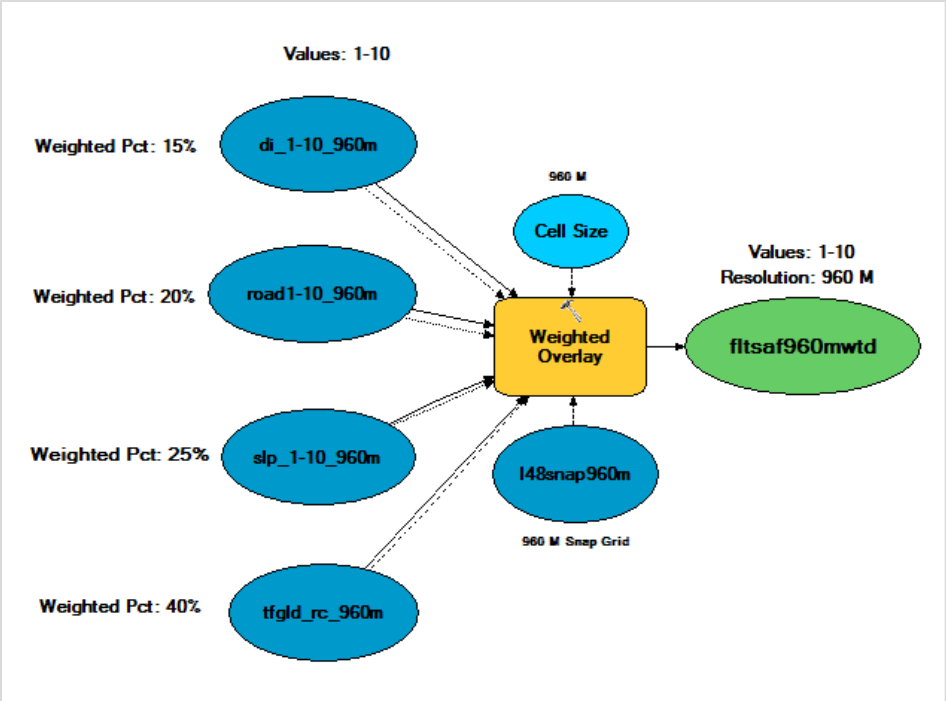

Figure 7. FSR weighted overlay Model Builder model that incorporates the four FSR data sets. The Tree Frequency is weighted the most with 40% with Slope, Road Density and Drainage Index (25%, 20% and 15% respectively).

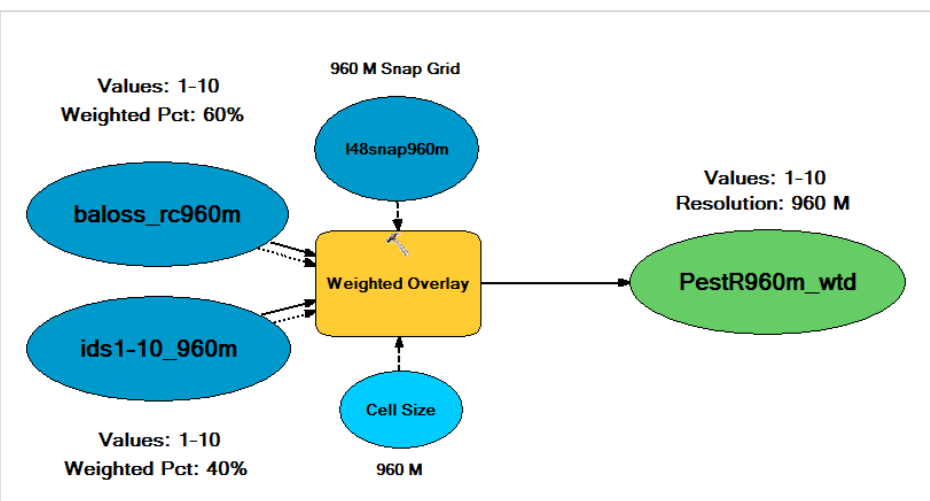

Figure 8. FSR weighted overlay Model Builder model that incorporates the four FSR data sets. The Tree Frequency is weighted the most with 40% with Slope, Road Density and Drainage Index (25%, 20% and 15% respectively).

Results of the Flight Safety Risk Weighted Overlay Analysis

The weighted overlay produces a raster surface with values from 1 – 10. The result of the FSR model show that overall, the US forests flight risk predominately ranges from low to high risk (values 3-8) and is somewhat normally distributed with a slight skew to the higher risk categories (refer to Figure 10 showing the histogram of the 10 class weighted overlay product).

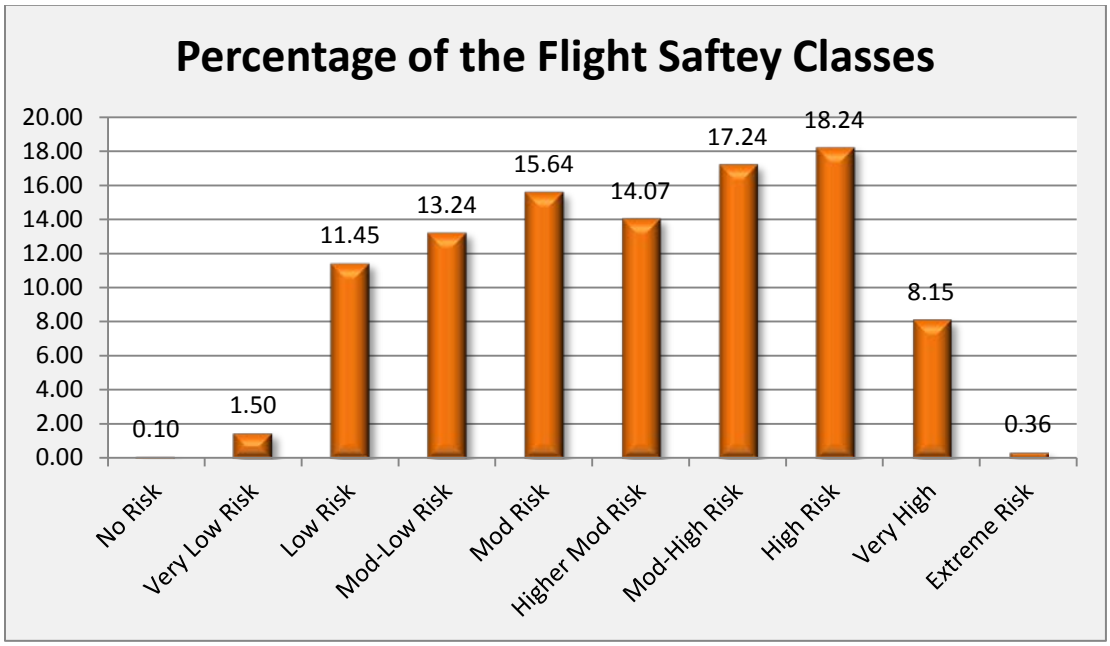

Figure 10. The 10 class histogram of the Flight Safety Weighted Overlay analysis shows a small skew to right towards the moderate and high risk categories. Spatially the west has more classes of higher risk and the eastern forests have more classes of moderate risk.

A qualitative spatial assessment of the flight-risk raster layer shows that there are differences between the Eastern and Western forests (figure 11). Most of the highest flight safety risk fall within the mountains of the western US with the largest areas of highest risk found in the forests of Idaho and Montana and Washington State (figure 9). This appears to be largely influenced by the higher overall slopes in the mountain west and the lower density of roads. The area with the highest lavel of combined flight safety risk is found in the following National Forests: the Nez Perce, Bitterroot, Salmon-Challis, the Flathead and the Mt. Baker-Snoqualmie (figure 10).

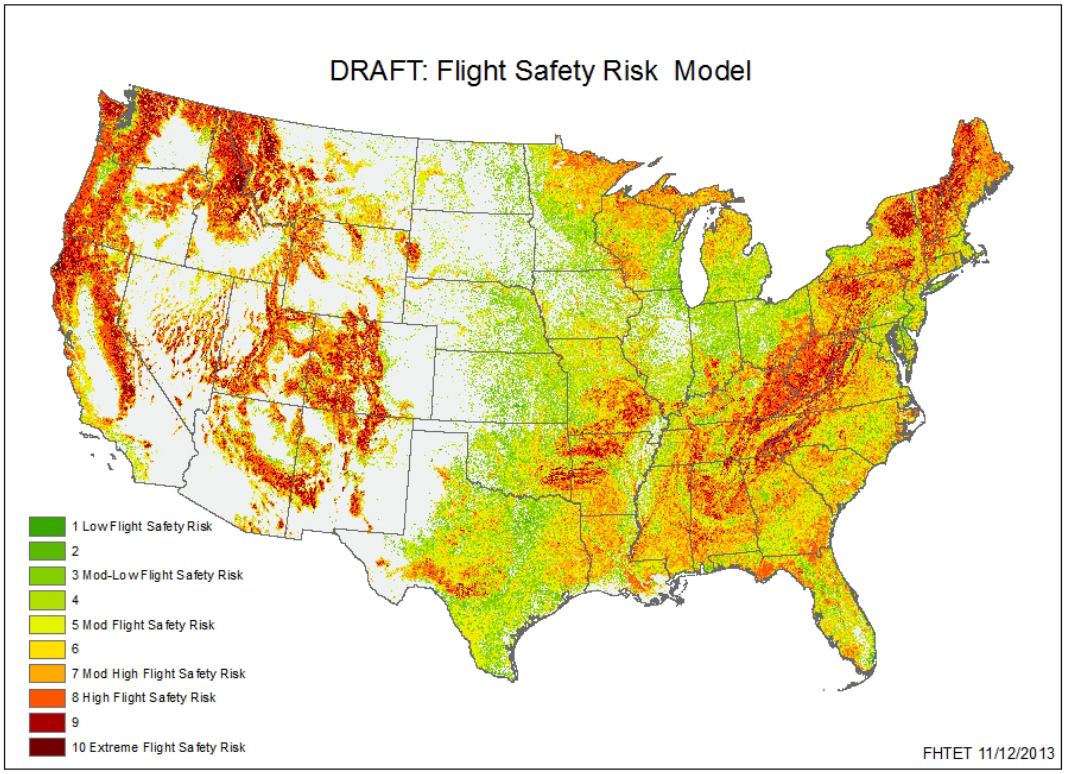

Figure 11. The Flight Safety Risk model show most of the highest flight safety risk falls within the mountains of the western US with the largest areas of highest risk found in the forests of Idaho and Montana and Washington State. In the eastern forests, most of the flight safety risk fall is classified as moderate to moderately low flight safety risk.

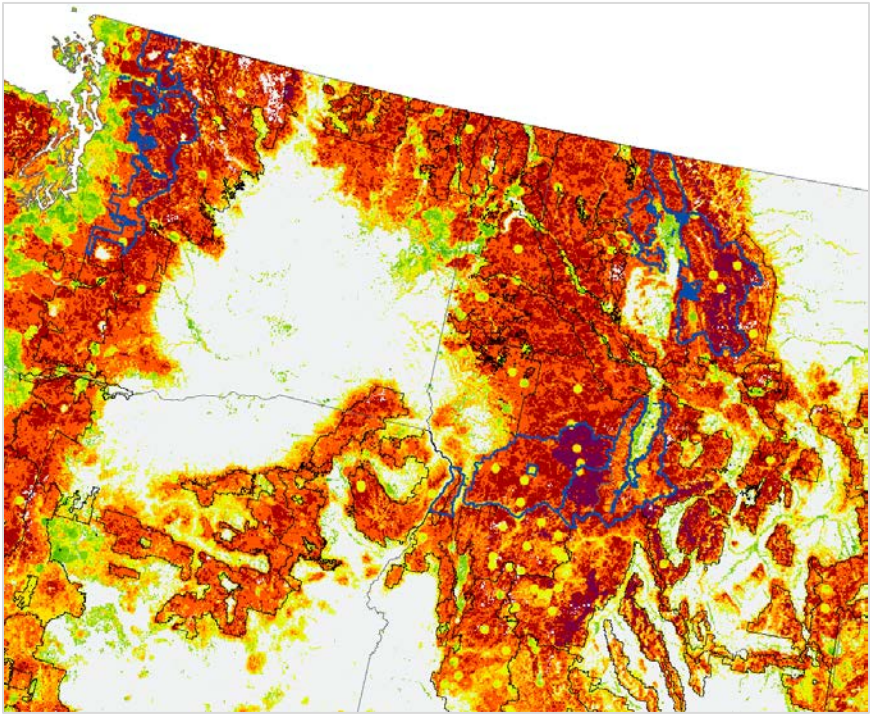

Figure 12. The Flight Safety Risk weighted overlay model results of the forested areas in Washington State, Idaho and Montana where the highest levels of flight safety risk are found.

In the eastern forests, most of the flight safety risk fall is classified as moderate to moderately low flight safety risk (refer to figure 11). However, there are areas in New York, New Hampshire and Maine with higher flight safety risk including the White Mountain NF (NH). In addition, forests in Virginia and West Virginia also contain substantial areas of higher flight risk including the Monongahela National Forest and the George Washington and Jefferson National Forest (Figure 13).

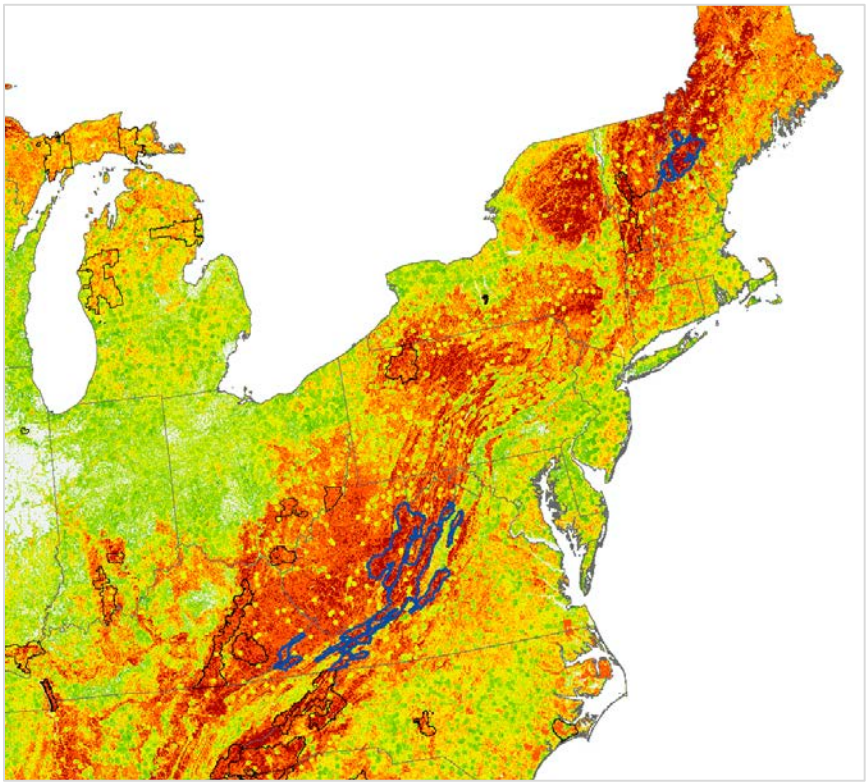

Figure 13. The Flight Safety Risk weighted overlay model results of the forested areas in the Northeast Area. Results show higher degrees of flight risk in the White Mountain NF (NH). In addition, forests in Virginia and West Virginia also contain substantial areas of higher flight risk including the Monongahela NF and the George Washington and Jefferson NF

The flight risk in the Eastern US forests appears to be more evenly split between moderate and high risk classes. The high risk areas in the east fall in the mountainous areas of the Ozarks and Appalachians. There is a large amount of moderate flight risk areas (flatter percent slopes) found in the piedmont of the Southern US states (Virginia, the Carolina's, Georgia and Florida), as well as Alabama, Mississippi, Louisiana, eastern Texas and Oklahoma. This is also true in the northern states of Minnesota, Wisconsin and Michigan where the slopes are generally very flat.

Results of the Pest Risk Weighted Overlay Analysis

The results the pest-risk model reveal that the forested areas of the US are made up of predominantly low to moderate pest risks. The 10-class Pest Risk histogram reveals that the national pest risk model has a strong skew toward the low and moderate risk categories (figure 14). This indicates that most of the US forest does not have higher pest risk.

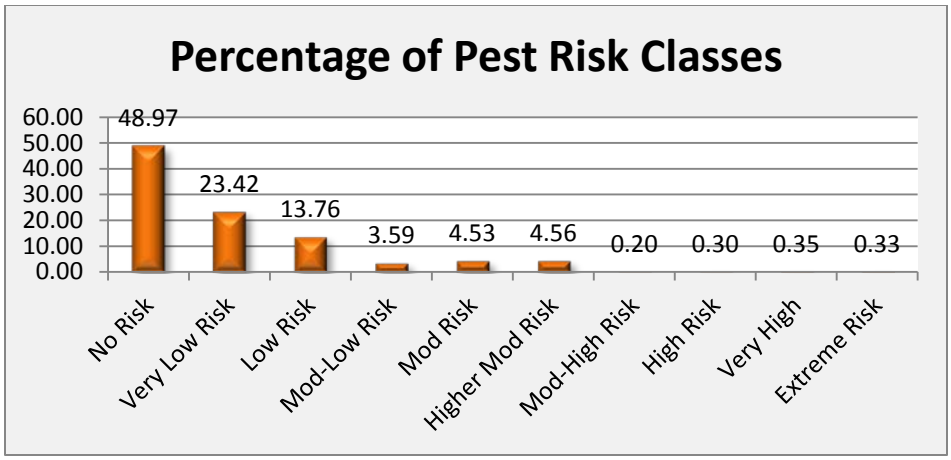

Figure 14. The histogram of the US Pest Risk model reveal a strongly skewed distribution of risk towards low to moderate pest risk categories.

A qualitative spatial assessment of the pest-risk raster layer shows that the eastern US forests are made up of mostly low to moderately low pest risk, with some areas of moderate pest risk in Louisiana and Arkansas. In the Western forests there are significant areas of moderate and to a lesser degree, high pest risk areas. This is especially true in Idaho and Montana and Colorado (figure 15). In addition there are areas of moderate pest risk in the Cascades of the Pacific Northwest and the Sierras in California

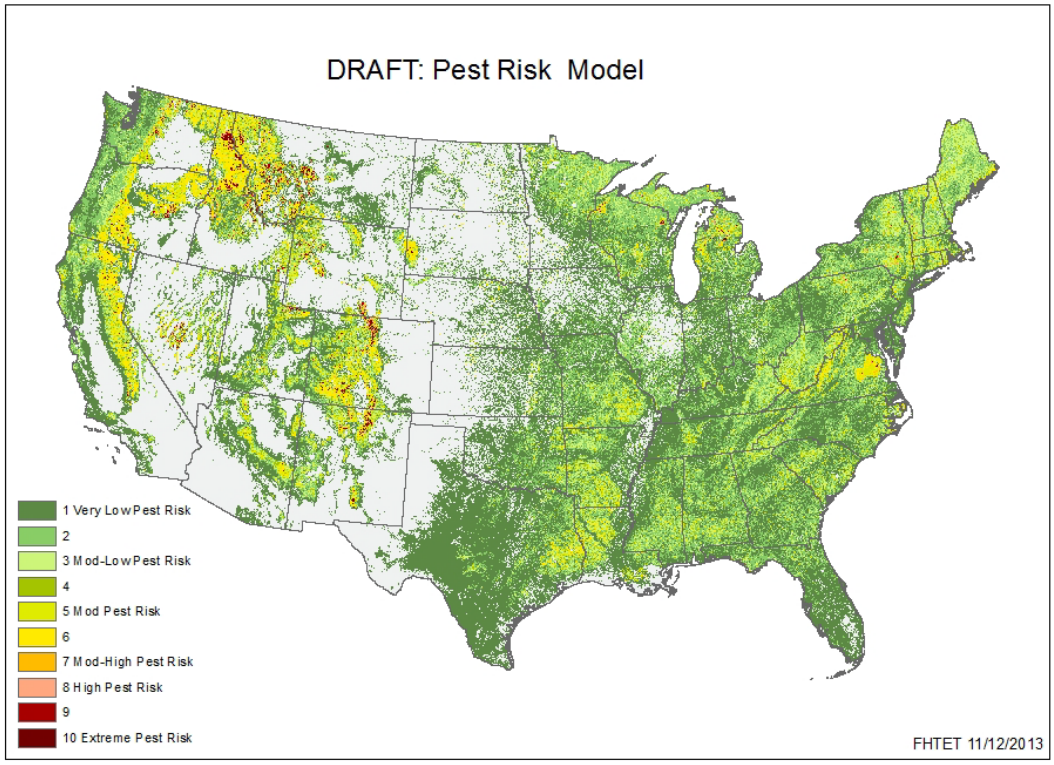

Figure 15. The US 10-class pest-risk model shows the spatial extent of the different levels of pest risk. Most of the moderate to high pest risk is in the western US forests especially in Idaho, Montana and Colorado. In the Eastern forests, the low and moderate pest risk areas are generally intermixed with some concentrated areas of moderate pest risk in Louisiana and Arkansas.

Flight-Risk and Pest-Risk Combined Analysis

The Flight Safety-Risk modeling effort was designed to give the aerial survey community more information regarding the safety and risk of flying in their regions. It is meant as a guide that may aid in decision making regarding flight plans and risk assessment as well as a guide to appropriate areas for use of high resolution satellite data as a surrogate to aerial survey in high risk areas.

Assessing the flight risk and pest risk surfaces independently can give a good idea of the relative risk, but it does not give the aerial survey personnel enough information to determine if the risk of flying a certain area is worth the data collected. For example, a logical way to use these risk surfaces is to find those areas where flight risk is moderate or low and where pest risk is moderate or high. This would represent those areas where is it safest and most productive to fly aerial survey. Areas where pest risk is low and flight risk is high may be candidate areas for alternative methods of forest condition mapping such as high resolution satellite data.

As a result, an additional model was created that combines the flight-risk and pest-risk 3-class raster layers. This was done by reclassing the flight risk 3-class raster into values of 10 (low), 20 (moderate) and 30 (high) to differentiate flight risk from pest risk when the two are combined. The pest risk raster values of 1, 2 and 3 remained unchanged. Using a Model Builder model, the two risk layers were combined by summing the two rasters together in a *Raster Calculator* function (figure 16). The resulting flight-pest raster layer had values of 11, 12, 13, 21, 22, 23, 31, 32, and 33 that represent different combinations of flight risk and pest risk as define below:

11: Low Flight Risk – Low Pest Risk
12: Low Flight Risk – Moderate Pest Risk
13: Low Flight Risk – High Pest Risk
21: Moderate Flight Risk – Low Pest Risk
22: Moderate Flight Risk – Moderate Pest Risk
23: Moderate Flight Risk – High Pest Risk
31: High Flight Risk – Low Pest Risk
32: High Flight Risk – Moderate Pest Risk
33: High Flight Risk – High Pest Risk

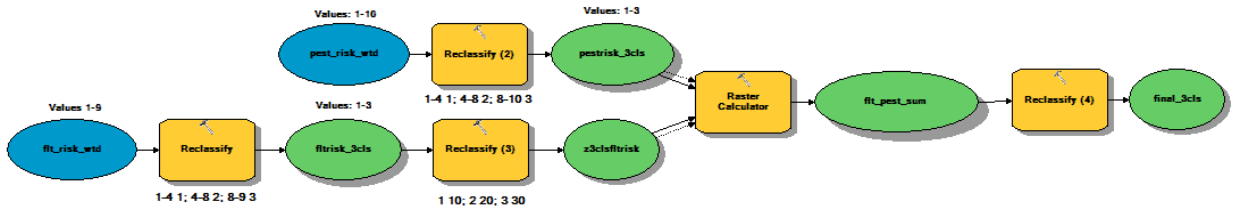

Figure 16 The ArcGIS10 Model Builder model used to create the flight risk/pest risk surface. This dataset can delineate potential areas where pest risk is low and flight risk is high. These areas may be appropriate candidate areas for alternative methods of forest condition mapping such as high resolution satellite data.

The classes that would represent logical areas for "safe" aerial survey include classes 11, 12, 13, 21, 22, and 33. Class 33 is included in the list of adequate safety because it represents a very small area when compared to the other risk areas, and the area is at high risk and the information is important to record Classes 31 and 32 represent those classes where alternative methods to capture forest condition might be best served.

The results of the flight-pest risk combination surface show the most prevalent Flight-Pest Risk class, with 58.6% of the total pixels in the raster surface, was class **21: Moderate Flight Safety Risk/Low Pest Risk** (figure 17). The other flight-pest classes had substantially less area compared to this class. The next most prevalent class, with 25.8% of the total pixels in the raster surface, was class **11: Low Flight Safety Risk/Low Pest Risk**. The third most prevalent class, with 6.3% of the total pixels, was class **22: Moderate Flight Safety Risk/Moderate Pest Risk**. These three classes make up 90.7% of the total pixels in the Flight-Pest Risk surface where both are low pest risk areas falling within low and moderate flight risk areas. This figure increases to 91.5% when including classes 12: Low Flight Safety Risk/Moderate Pest Risk (0.5%), 13: Low Flight Safety Risk/High Pest Risk (0.01%), and 23: Moderate Flight Safety Risk/High Pest Risk (0.3%). All of these classes are made up of low and moderate flight safety risk values with low, moderate and high pest risk values. The logic of these classes is that these are good candidate areas for aerial survey, especially those areas of moderate and high pest risk.

The remaining three classes make up 8.5% of the forested area and include classes **31: High Flight Safety Risk/Low Pest Risk** (6.3%), **32: High Flight Safety Risk/Moderate Pest Risk** (2.8%) and **33: High Flight Risk/High Pest Risk** (figure 17). *This 8.5% of the forested areas are important in term of aerial survey safety and as potential areas to incorporate satellite disturbance delineation as a surrogate to aerial survey.* Classes 31 and 32 are considered the focus classes for where the flight risk is too great for the return on areas of low and moderate pest risk. It could be argued the class 33 should also be included since it is also high flight risk, but the return value of flying a high pest risk area may give credence to flying the area.

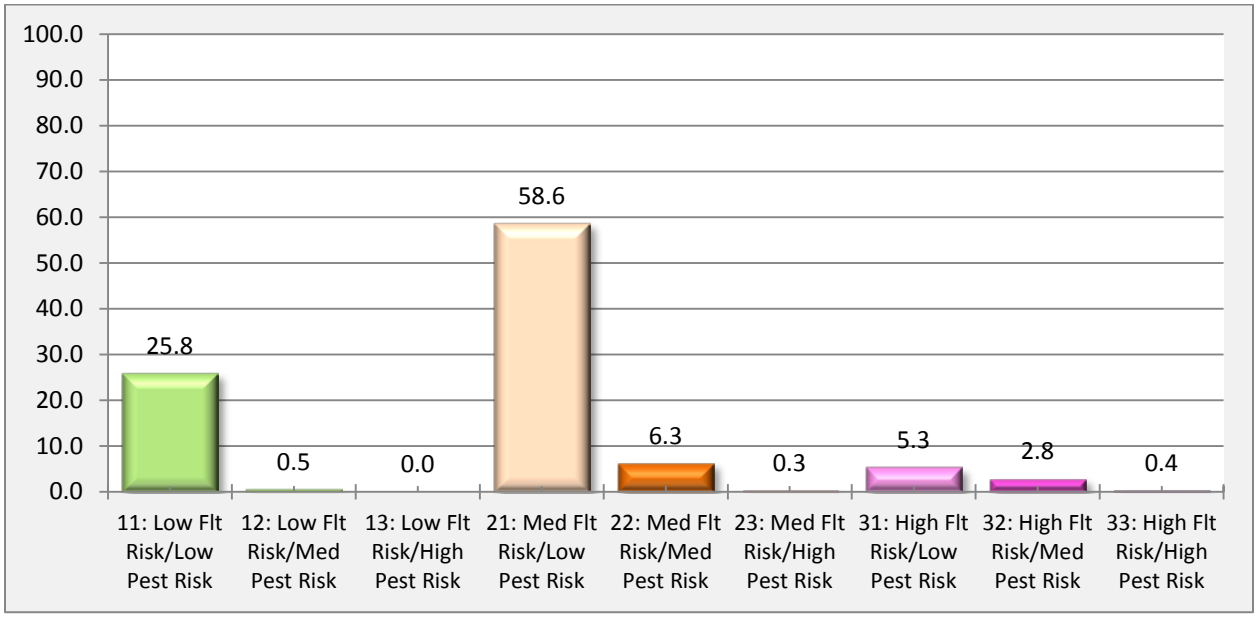

Figure 17. Histogram of the Flight Risk- Pest Risk combination surface. A vast majority (58.6%) of the cells fall within a single class; class 21 (moderate flight-risk/low pest-risk). Classes 11-13, 21-23 constitute 91.5% of the forested area and are defined as low to moderate flight risk. The remaining classes (31.32. and 33) make up 8.5% of the forested areas and are good candidate areas for alternative methods to record forest condition (ex., high resolution satellite classifications).

Finding the areas where there are substantial areas of high flight risk and low to moderate pest classes will aid in locating those areas most suitable for satellite or other methods of spatially collecting forest condition data. Results of the Flight Risk/Pest Risk surface (figure 18)shows that most of the eastern states, specifically Regions 8 and 9 and the eastern half of Region 2 (Kansas, Nebraska, and most of the eastern sides of the Dakotas) are modeled as low-medium flight risk and low pest risk (classes 11 and 21). There are some areas of high flight risk and low- medium pest risk in the eastern forests including the following areas: 1) in and around the Mark Twain NF in southwest Missouri and the Ouachita NF in Arkansas(figure 19), 2) in and around the Chattahoochee and Cherokee NFs (located in GA, TN and NC) and the George Washington NF in Virginia (figure 20), 3) north central Pennsylvania , southeastern and northeastern New York state, and the White Mountain NF in New Hampshire (figure 21).

There are far more high flight risk areas in at least parts of all regions in the western US (regions 1-6). The areas with the a great deal of contiguous high flight risk with low to medium pest risk are found in the following areas: 1) Northern Idaho/western Montana (Nez Perce, Bitterroot, Lolo and Flathead NFs; figure 22), 2) California (Inyo, Sequoia and Sierra NFs; figure 23) 3) New Mexico (Santa Fe and Carson NFs)and Colorado (Arapaho –Roosevelt and San Juan NFs; figure 24)

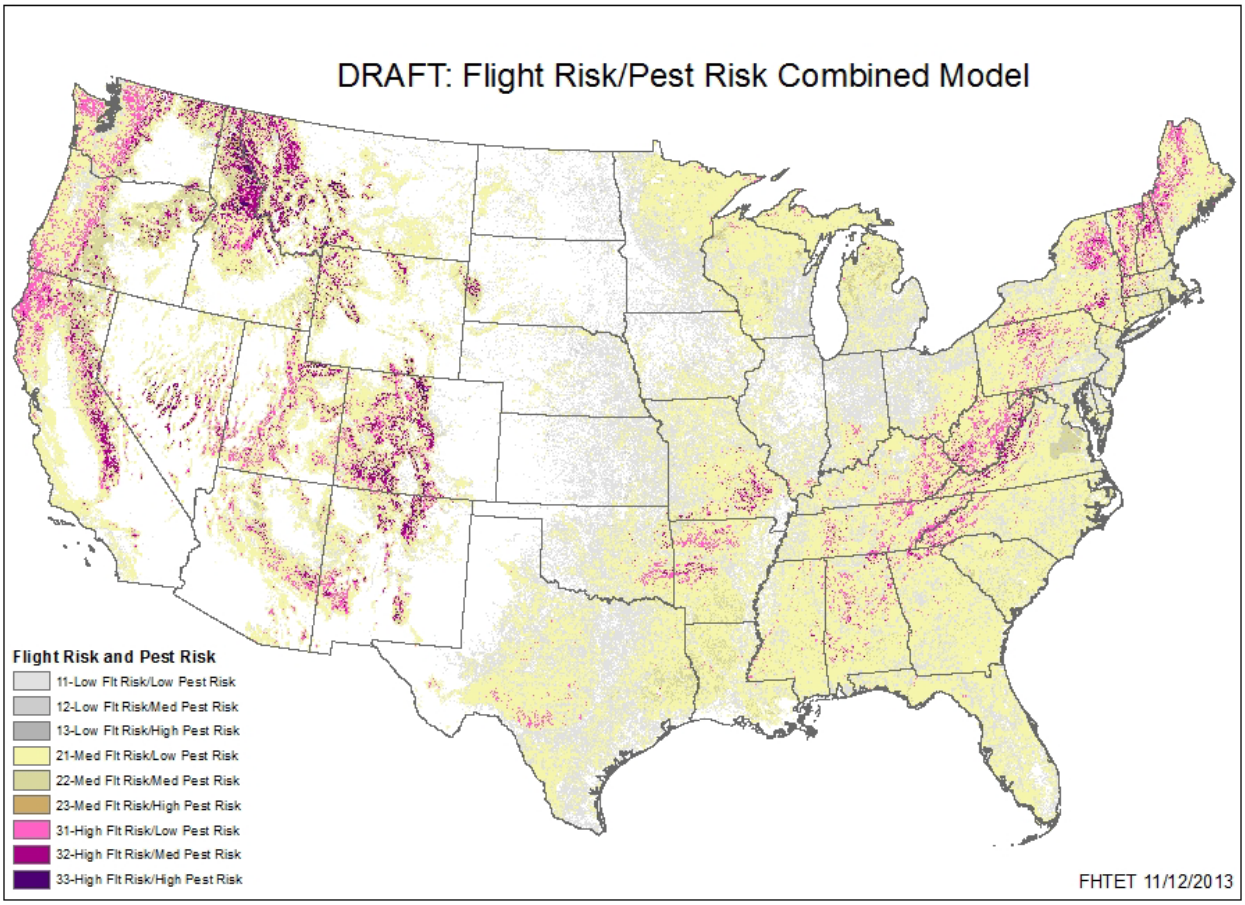

Figure 18. Flight and pest combined risk map showing where the different combinations of flight-risk and pest-risk are found. Classes 31 and 32 (magenta classes) may be good candidates for alternative methods of forest condition recording such as satellite data.

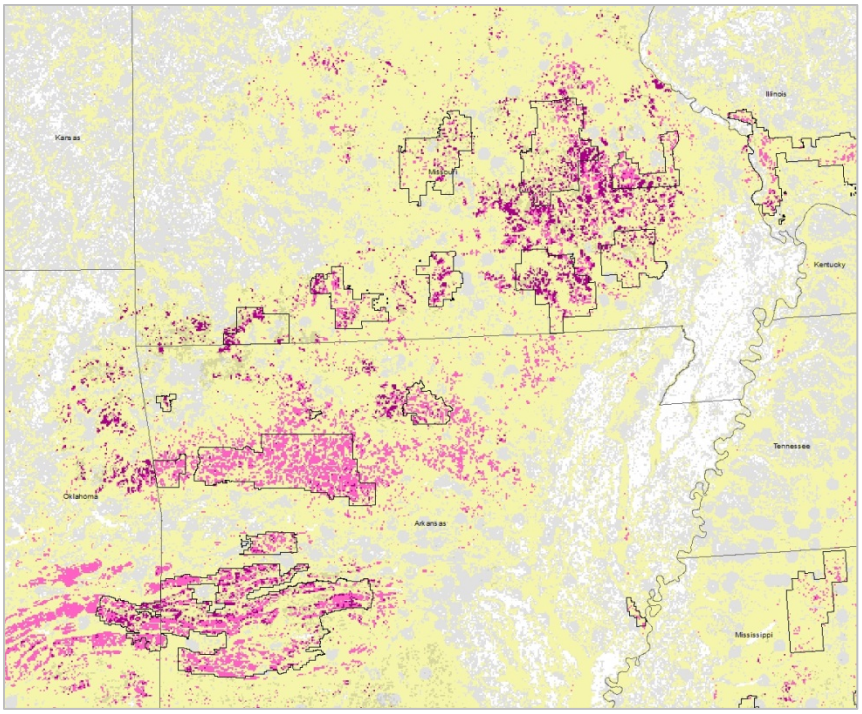

Figure 19. Modeled Flight Risk-Pest Risk results shows areas of high flight risk and low-medium pest risk in southeast Missouri (Mark Twain National Forest) and west central Arkansas (Ouachita National Forest).

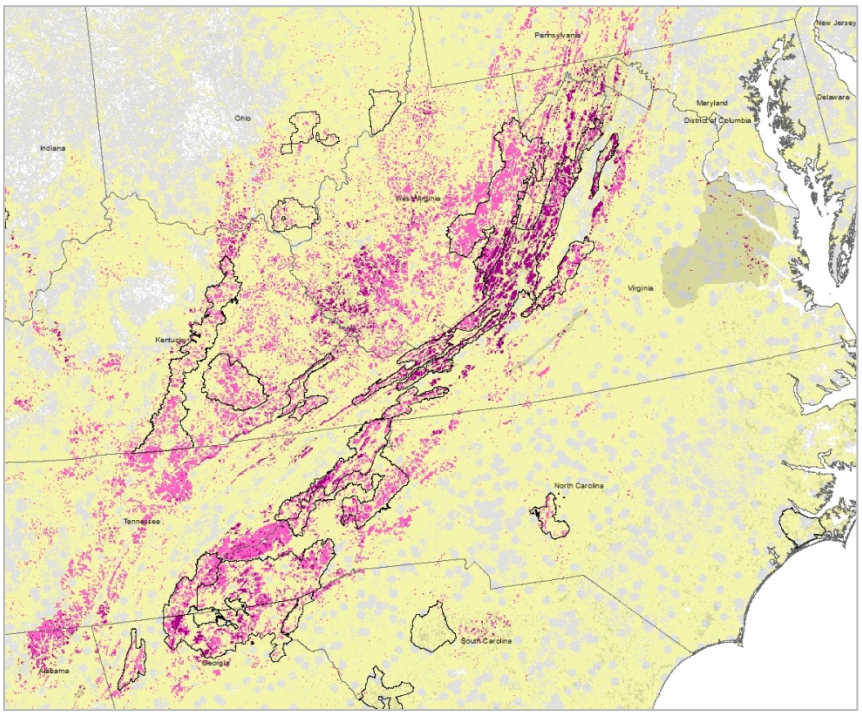

Figure 20. Modeled Flight Risk-Pest Risk shows areas of high flight risk and low-medium pest risk in Georgia, West Virginia and North Carolina including the Chattahoochee, Cherokee and the George Washington-Jefferson National Forests.

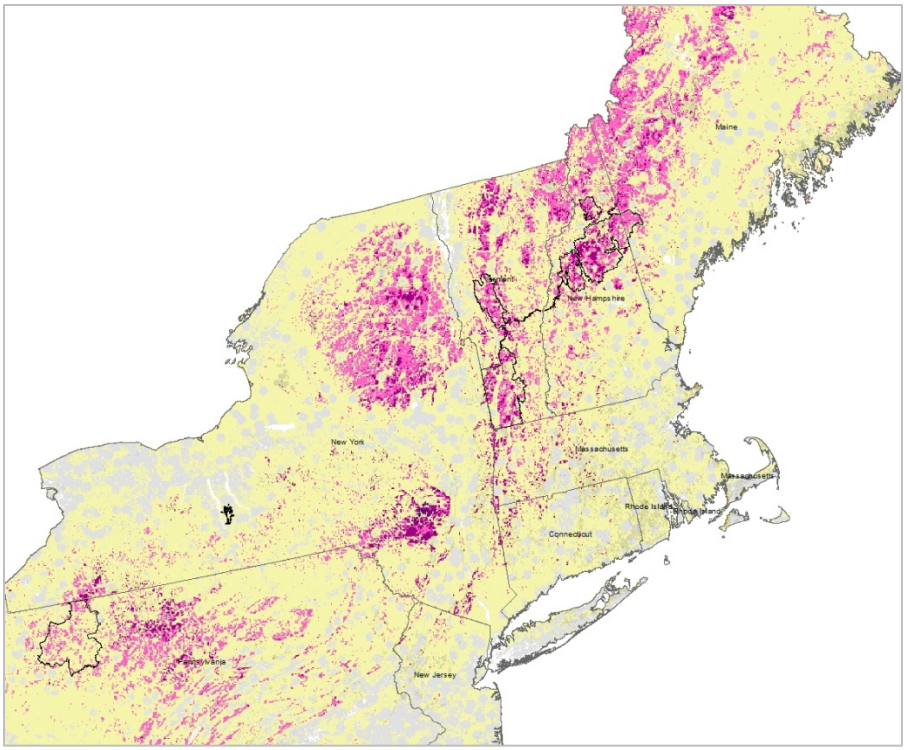

Figure 21. Modeled Flight Risk-Pest Risk shows areas of high flight risk and low-medium pest risk in north central Pennsylvania , southeastern and northeastern New York state, and the White Mountain National Forest in New Hampshire

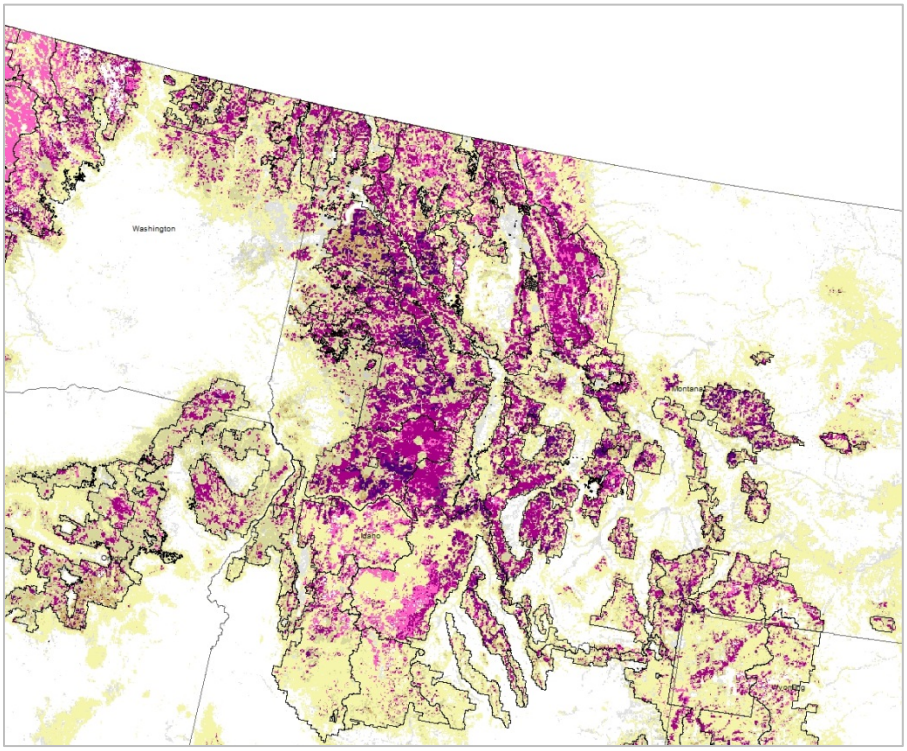

Figure 22. Modeled Flight Risk-Pest Risk shows areas of high flight risk and medium-high pest risk in the Nez Perce, Bitterroot, Lolo and Flathead National Forests of northern Idaho and western Montana.

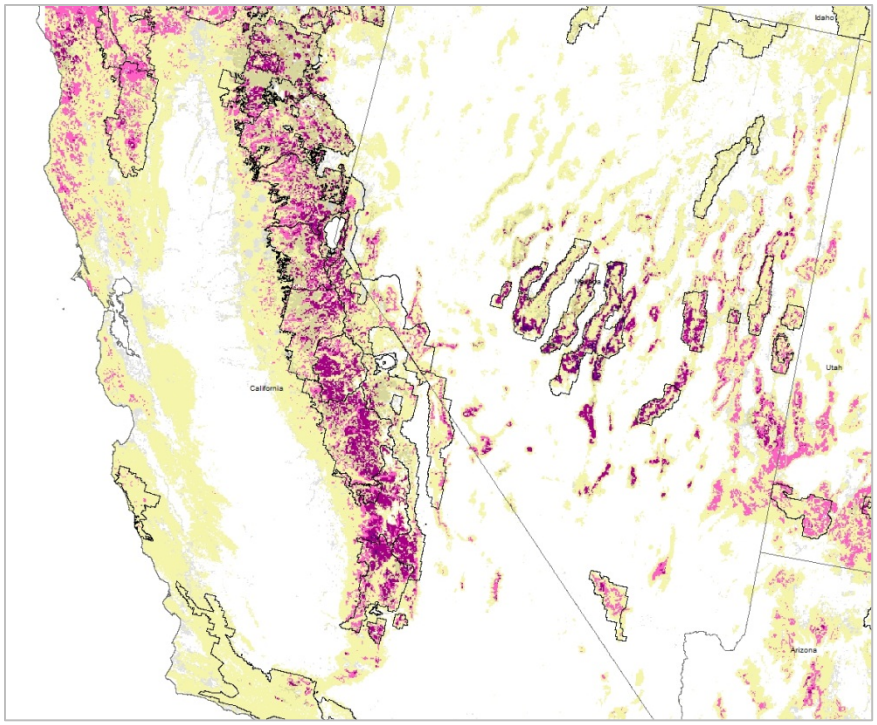

Figure 23. Modeled Flight Risk-Pest Risk shows areas of high flight risk and low-medium pest risk in the Inyo, Sequoia and Sierra National Forests in California.

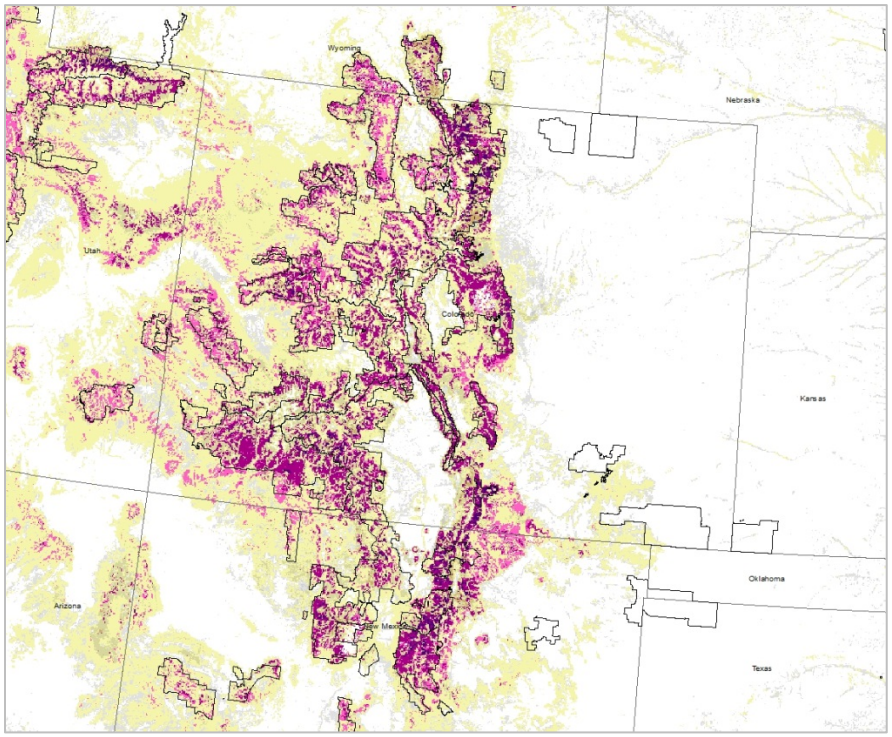

Figure 24. Modeled Flight Risk-Pest Risk shows areas of high flight risk and low-medium-high pest risk in the Santa Fe and Carson National Forests (New Mexico) and the Arapaho –Roosevelt and San Juan National Forests in Colorado.

Selecting Sites for Satellite Analysis

The next step in this process is the selection of an appropriate area to test the efficacy of using satellite data as a surrogate to ADS in areas where it is considered too dangerous or where there are holes in the ADS coverage in forests with pest risk. One way to select an area is by county or National Forest boundary using the *Zonal Statistics* function in ArcGIS. This function creates a table of statistical values (min, max, mean, majority, and median) identify those county or national forest polygons with the greatest amount of high flight- risk and low-high pest risk. The Zonal Statistics method was run on two different polygon dataset; US counties and National Forests.

US Counties Selection

The results of the zonal statistics using the US counties were created by running the **Zonal Statistics** as a Table function based on the ***ObjectID*** attribute. This was then joined to the US Counties layer (Join . Using the following SQL query; *"cntys_fltpest_zonal:MEAN" >=26 AND "cntys_fltpest_zonal:MAJORITY" >=31*; ten counties were selected that contain the highest amount of high flight-risk pixels. The selection was then reduced to three counties by selecting those counties whose majority class was 32 (High Flight Risk and Medium Pest Risk) that included the following sorted my highest Mean value:

1. Alleghany County, Virginia
2. Mineral County, Montana, and
3. Idaho County, Idaho

Refer to figure 25 that show the three selected counties (dark blue lines) in Virginia, Montana and Idaho. These three counties represent the most appropriate areas for satellite disturbance analysis.

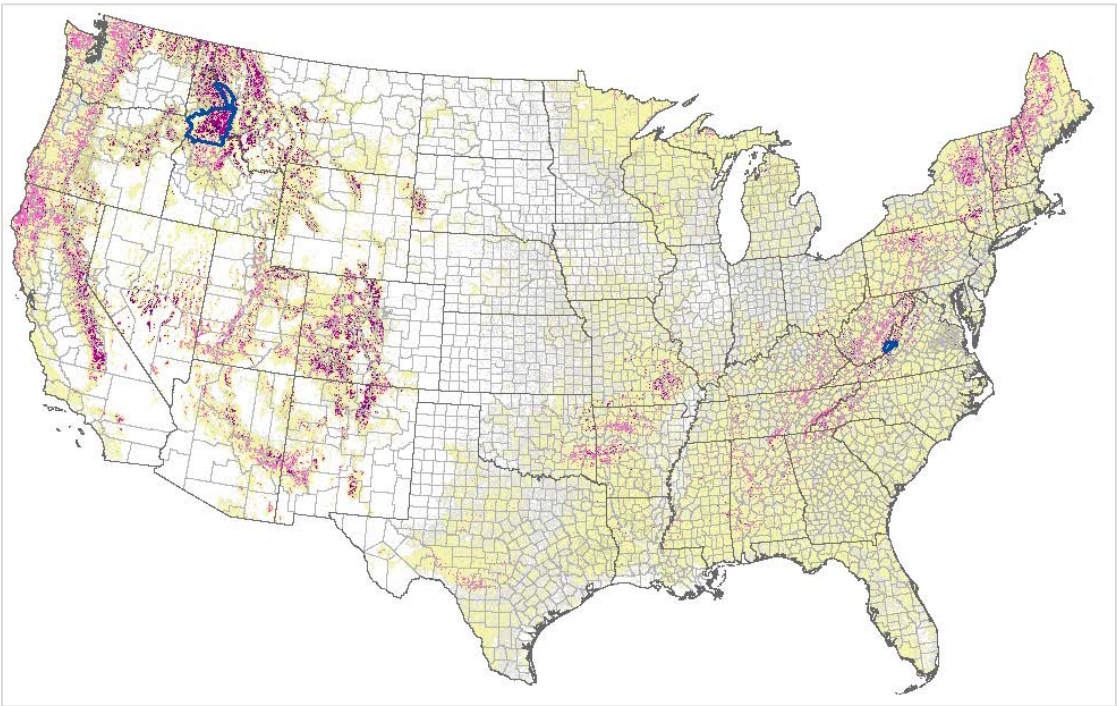

Figure 25. The three selected US counties that contained the highest amount of high Flight-Pest Risk classes using the Zonal Statistics function in ArcGIS. Two of the three selected US counties are found in the Western US forests of Region 1 (Idaho County, ID and Mineral County, MT) and one county in the Eastern US forests of Region 8 (Alleghany County, VA).

National Forest Selection

The results of the zonal statistics using the US counties were created by running the **Zonal Statistics** as a Table function based on the ***ObjectID*** attribute. This was then joined to the US Counties layer (Join . Using the following SQL query; *"nationalforest_fltpest_zonal:MAJORITY" = 32 AND "nationalforest_fltpest_zonal:MEAN" >=26*; eleven national forests were selected that contain the highest amount of high flight-risk pixels. The selection was then reduced to eight national forests by selecting those national forests whose majority class was 32 (High Flight Risk and Medium Pest Risk) that included the following sorted my highest Mean value:

1. Nez Perce National Forest
2. Clearwater National Forest
3. Flathead National Forest
4. San Juan National Forest
5. Lolo National Forest
6. Kootenai National Forest
7. Santa Fe National Forest
8. Sierra National Forest

Note: The Green Mountain National Forest was selected as part of the original eleven national forests. The fact that there are more national forests selected than there were US counties is due to the fact that the counties are much more variable in cover type and topography than is found within the national forest boundaries. Most of the national forests selected are found in the northern Rockies (figure 26).

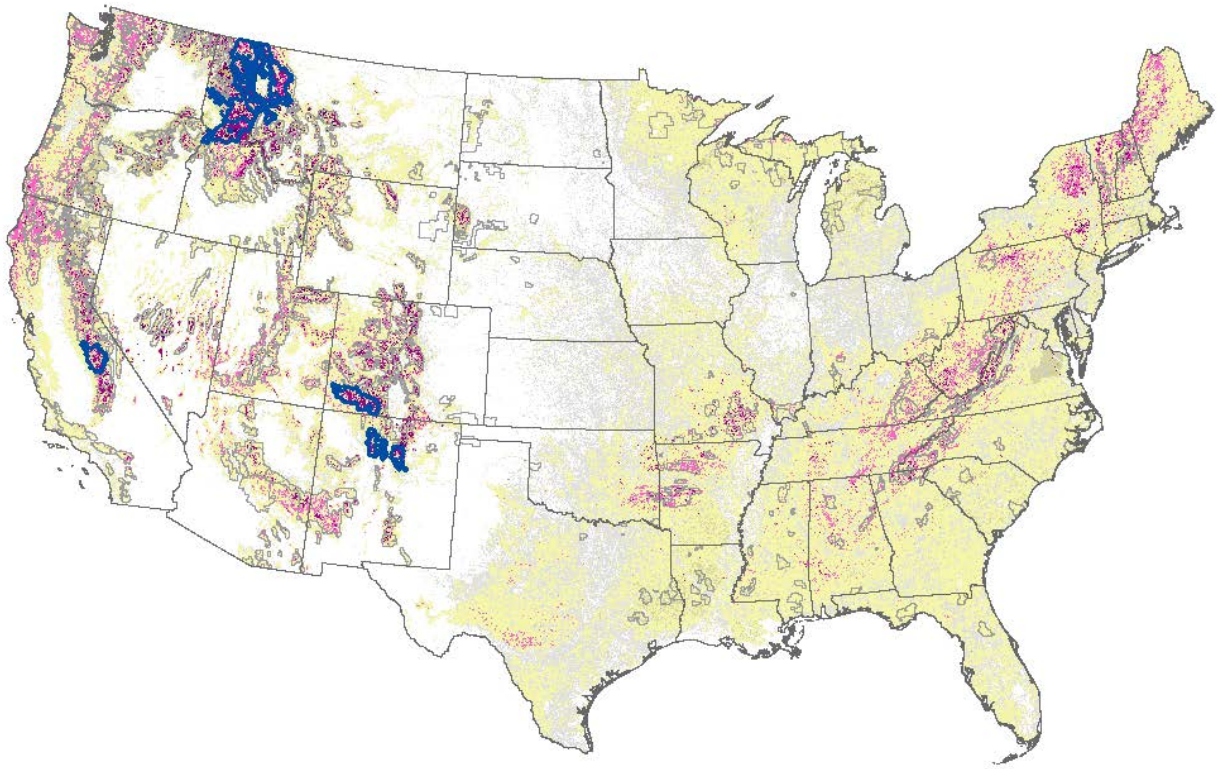

Figure 26. The eight selected National Forests that contained the high amount of high Flight-Pest Risk classes using the Zonal Statistics function in ArcGIS. All selected National Forests are found in the Western US forests with the top three found in Region 1.

Selecting by Identifying Coverage Holes in the Proposed ADS Coverage Area

Another method to locate the optimum area for satellite analysis is by spatially identifying areas where there is no planned future ADS coverage but there is substantial flight and pest risk (also known as "holes" in the ADS coverage). This method may have the most credibility because it incorporates a much more likely scenario for the implementation of satellite forest disturbance analysis as a surrogate to ADS. It fills a specific need where there is no ADS coverage, or no planned coverage, in areas identified as important in the NIDRM pest risk model and would not be considered as threatening to the aerial survey community.

The process involves using the proposed *Category One: Proposed Full ADS Coverage* layer and overlaying it onto the 9-class Flight-Risk/Pest Risk surface in order to locate areas where aerial survey is not planned but there are substantial contiguous areas of high flight safety and pest risk (classes 31, 32, 33). This is done by setting the *Category One: Proposed Full ADS Coverage* layer 30% transparent and overlaying that onto the nine-class Flight-Pest Risk surface. This is then qualitatively assessed spatially to identify areas of high flight-risk and low-medium-high pest risk (classes 31, 32, 33). Refer to figure 27 for the results of this qualitative overlay assessment. (NOTE: the *Category One: Full ADS* coverage relates to all Regions of the US except Region 5 and Region 8. These two regions fall under the *Category 5: Annual Full IDS* which is a combination of ADS and ground survey and, for this assessment, will not be used to locate potential areas for satellite analysis of forest disturbance.)

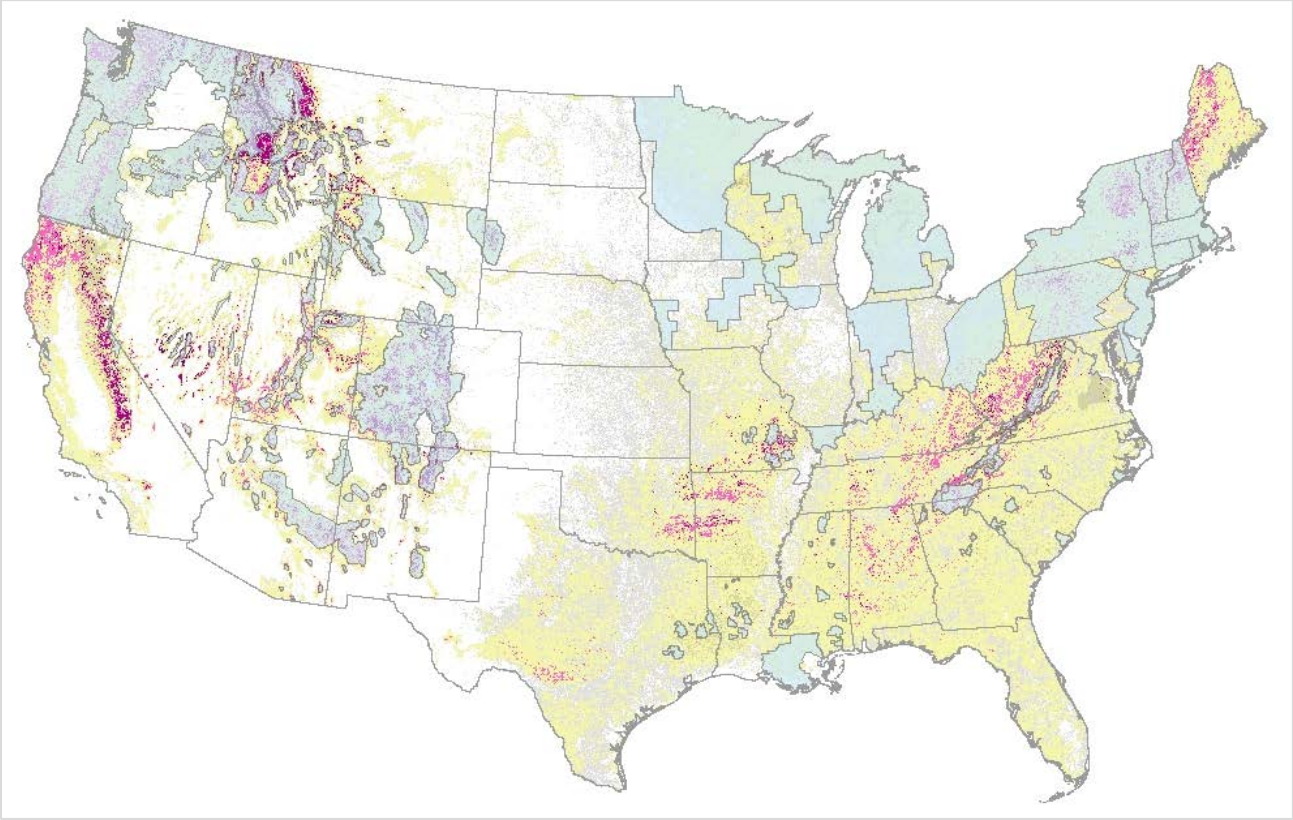

Figure 27. Results of setting the *Category One: Proposed Full ADS Coverage* layer to a 30% transparency and overlaying onto the nine-class Flight-Pest Risk surface in order to identify areas where ADS coverage is missing and there is substantial flight and pest risk, also known as "holes" in the ADS coverage. For this assessment, Regions 5 and 8 are not included because they fall under the *Category 5: Annual Full IDS* which is a combination of ADS and ground survey.

An assessment of the *Category One: Full ADS* overlay indicates that there are extensive holes in the proposed ADS coverage in the northern Rockies, namely in Idaho and Montana, that have a great deal of high flight-risk and moderate to high pest risk (classes 31, 32, 33). This indicates that this is an ideal area for the satellite analysis (figure 28). There are two main areas where there are holes in the ADS coverage and has medium and high pest risk and is classified as high flight safety risk. These areas are delineated by the blue rectangles and covers areas of the Nez Perce, Bitterroot and Flathead National Forests. Satellite analysis of these areas serve two purposes; 1) it serves the purpose of completing areas not covered by ADS and demonstrates that satellite analysis can become part of the operational procedures of the forest health survey community, and 2) this selection serves the more immediate requirement to find an appropriate area to prototype the use of high resolution satellite data to identify and delineate forest disturbance as a surrogate to ADS.

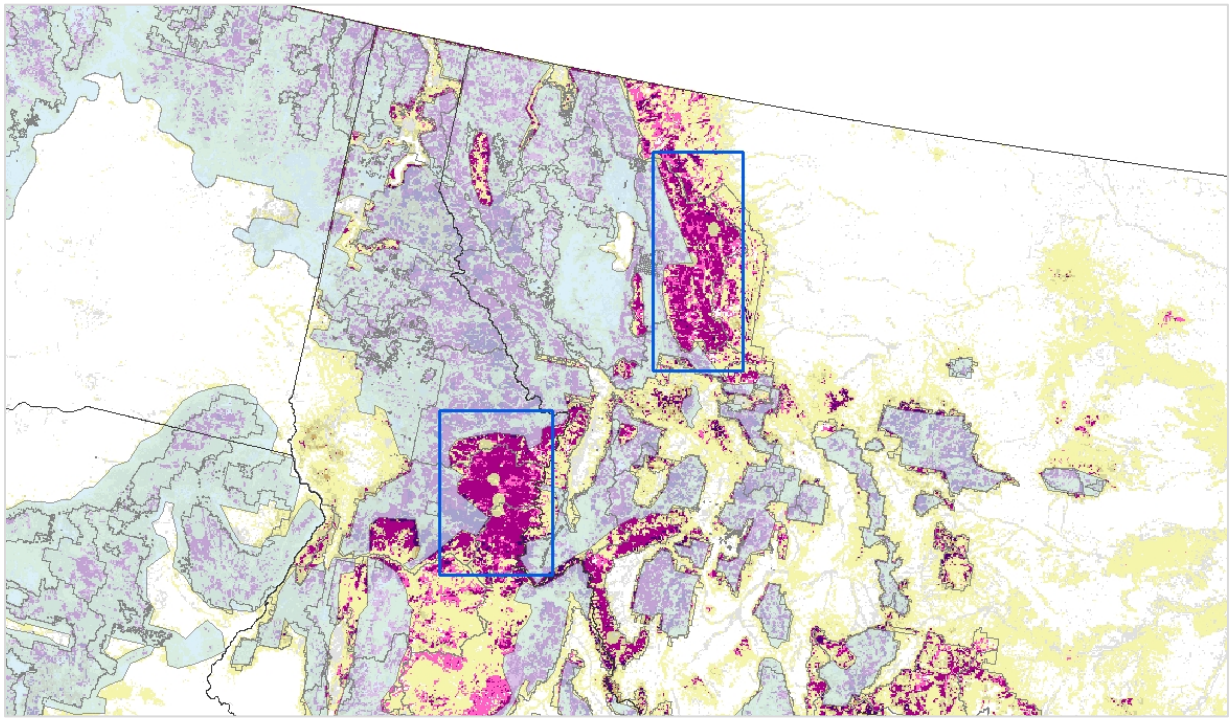

Figure 28. The process to locate areas to prototype the use satellite data as a surrogate to ADS in areas high flight risk and/or where there are holes in the ADS coverage was accomplished by using the proposed Category One: Proposed Full ADS coverage layer and overlaying it onto the 9-class Flight-Pest Risk surface. A qualitative assessment of the overlay located the holes in the planned ADS coverage and there are substantial contiguous areas of high flight-pest risk (classes 31, 32, 33). This qualitative process resulted in the identification of two specific rectangular areas (blue rectangle) located in Region 1 and includes parts of the Nez Perce, Bitterroot and Flathead National Forests.

Conclusion: STAR Model

The STAR model was tasked in order to spatially model a CONUS surface of relative risk in regards to flight risk parameters and degree of pest risk over US forested areas. The flight risk parameter requirements were designed based on the relative risk given an engine out scenario over forested landscapes and assessing that with the relative risk of pest and disease in the forest itself. This was also a method to spatially identify and select an appropriate area to test the efficacy of utilizing satellite data

as a surrogate to ADS in areas where modeled at relatively high flight risk and/or where there are holes in the ADS coverage in forests with relatively high pest risk.

The STAR model was built using a series of ArcGIS Model Builder models that are designed to be adaptable to new data and parameter adjustments. The Flight Risk was modeled separately from the Pest Risk surface. The two models were then combine to create a surface that shows where there is differing levels of flight risk within differing levels of pest risk. STAR was designed and is recommended to be used during national or local program and project aviation risk assessments as a tool to aid mitigation of aviation risk. It is meant as a guide that may aid in decision making in flight planning.

The results of the STAR model's relative risk classification reveal that 8.5% of the forested areas of the US are categorized as high Flight Risk with low, medium and high Pest Risk (Flight-Pest Risk Grid classes 31, 32, and 33). This percentage may be considered the base line to compare past and future STAR model output. This value will change each year because it is dependent on future IDS and NIDRM pest risk data. Equally important is the fact that 91.5% of the US forests are classified as relatively low to moderate flight risk within areas of varying pest risk and can be considered acceptable risk for aerial survey.

Using the results of the Flight-Pest Risk surface created in the STAR model, two specific areas were identified as optimum areas to prototype the use of high resolution satellite data to identify and delineate forest disturbance. This was completed by using the proposed *Category One: Proposed Full ADS Coverage* layer and overlaying it onto the 9-class Flight-Pest Risk surface in order to qualitatively locate areas where aerial survey is not planned but there are substantial contiguous areas of high flight-pest (classes 31, 32, 33) exist. This process resulted in the identification of two specific areas located in Region 1 and includes parts of the Nez Perce, Bitterroot and Flathead National Forests. The advantage of these areas is that it also serves the purpose of potentially completing areas not covered by ADS and demonstrates that satellite analysis can become part of the operational procedures of the forest health survey community.