Analysis of NAIP Contractor Identified Areas Where DEM Errors Occur

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Introduction

The purpose of this report is to determine on a broad scale, based on contractor supplied National Elevation Database (NED) Digital Elevation Model (DEM) error lists, if there are any trends in land cover and elevation characteristics in these areas. The National Digital Elevation Program (NDEP), which is interested in the distribution of accurate elevation information, initiated the project by asking if there were any patterns of features in the imagery, which could help explain why the DEM's accuracy was not sufficient to build an ortho rectified image in the states where contractor error lists were generated.

In the 2009 acquisition of NAIP (National Agriculture Imagery Program), contractors submitted a list of Quarter Quads (QQs) where DEM errors were evident during the image ortho rectification process for 1-meter imagery. The 2009 NAIP contract section 2.6 states, "Any errors identified in the USGS NED during the production of NAIP imagery shall be reported to the Government using a comma delimited ASCII text file with the attribute fields listed below."

ATTRIBUTE	DESCRIPTION
QQName	name of QQ where a DEM error was identified during ortho production
QKey	the QKey identifier associated with the QQName
ErrType	type of error - allowable values: blunder, systematic, random, or unknown
ErrDetail	description of error - allowable values: edgematch, slope, constant_elevation, unknown, measurement, or age_of_dem
ErrMag	magnitude of error (refers to how large the perceived vertical offsets were, relating to the level of need to repair the DEM to make ortho) - allowable values: minor, moderate, or major

Error lists were provided for Colorado, North Carolina, Alabama and Mississippi. The project area with the most contractor identified errors when producing the 1-meter ortho rectified imagery was Colorado, which is characterized by more areas of steep elevation and forest than the other states listed.

To determine land cover type in problem areas it was not practical at this time to classify all the individual NAIP 2009 DOQQs listed in the error reports. There were 6080 individual DOQQs listed by the contractor as having some degree of DEM error with respect to producing 1-meter ground sample distance (GSD) ortho images. Alabama, Mississippi, and North Carolina all had error magnitudes that were indicated by the contractor to be major. Colorado, which had the greatest amount of errors, with 5011, had a variety of error magnitudes.

Land Cover Classification in Areas of Contractor Identified DEM Errors

To determine what types of land cover were in these problem areas, the National Land-Cover Database 2001 (NLCD 2001) dataset was used. (See appendix 1 for a list of definitions of NLCD land cover types) The federal consortium Multi-Resolution Land Characterization 2001 created the NLCD 2001. The information was derived from LANDSAT 5 and 7 imagery. The classification is based on a 30-meter cell resolution. Even though NAIP imagery is 1-meter resolution, the NLCD still provides an overview of the land cover types in problem areas. A land classification project of this size on 1-meter resolution imagery would be a lengthy process requiring the use of many resources. The NLCD 2001 was a good compromise for this project. In comparison, the National Agricultural Statistics Service (NASS) dataset uses a 56-meter cell resolution and several more land classifications. The NLCD 2001 dataset was used because of the higher resolution and land classification structure for this project. The land classification structure of the NLCD 2001 dataset uses a standardized land classification system, which provides enough detail to describe the features on the ground for this project.

The NLCD 2001 dataset was downloaded by mapping zone for the state project areas, then clipped out and mosaicked together using ERDAS Imagine software. The NLCD 2001 classification and color scheme was used throughout the project.

The NAIP contract specifications require contractors to use the NED DEMs. The NAIP specification for using a digital elevation model (DEM) section 6.2 paragraph d, states that, "Digital Elevation Model (DEM) of USGS National Elevation Database (NED) for terrain-correcting the imagery. The NED dataset used by the Contractor during tile production shall be current as of the date of task award. The Government's preference is the use of the highest resolution NED. The Contractor shall **use** the most current/recent version dataset available when producing NAIP imagery. **If the NED does not contain elevation data for the project area, such as in areas in Mexico or Canada, the Contractor shall use the best available DEM and shall document the source in the imagery metadata."** The NED elevation data used to produce the NAIP imagery is likely a finer resolution than was used for this study. The results obtained from this study produce a broad picture of what land cover and elevation characteristics may be more prevalent in contractor defined areas where the DEM used had observed errors.

The elevation data used in the project was downloaded from the National Map Seamless Server. The NED one arc-second (approximately 30 meters) was used because it more closely matches the NLCD data's 30M Ground Sample Distance (GSD). The elevation data was cut out and mosaicked to fit the project area using ERDAS Imagine software. Then the data was reprojected using ERDAS Imagine software into the appropriate UTM zone so that elevation values could be obtained in meters. Where states fell in multiple UTM zones the predominant zone was used in analysis.

Once the land classification data and the elevation data was prepared for each state project area, a zonal statistics operation was performed in ArcMap to determine average slope and elevation for each land cover type in the areas of interest. Analysis was also done at the state level for comparison to determine how the averages in the areas of interest compared to statewide land classification, slope and elevation. All calculations were raster based.

Comparison of State Land Cover Characteristics

Trends that emerged from this analysis: 1. areas of contractor observed errors were characterized by more heavily vegetated areas like forest and scrub; 2. errors were more common in areas of higher elevation. 3. Areas of contractor identified areas of DEM errors often mirror state majority land classification types. The following illustrations depict trends compared between the states. Note that one major or minor error in a QQ could cause the QQ to be identified as a problem area.

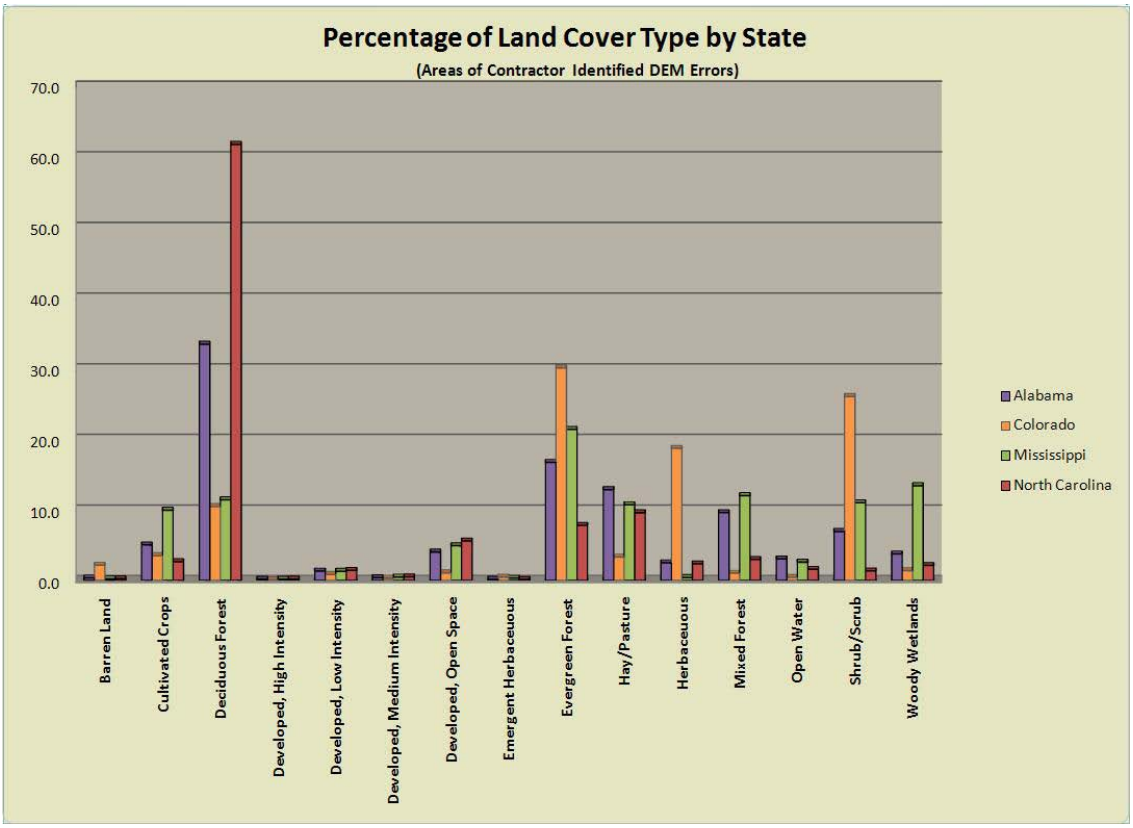
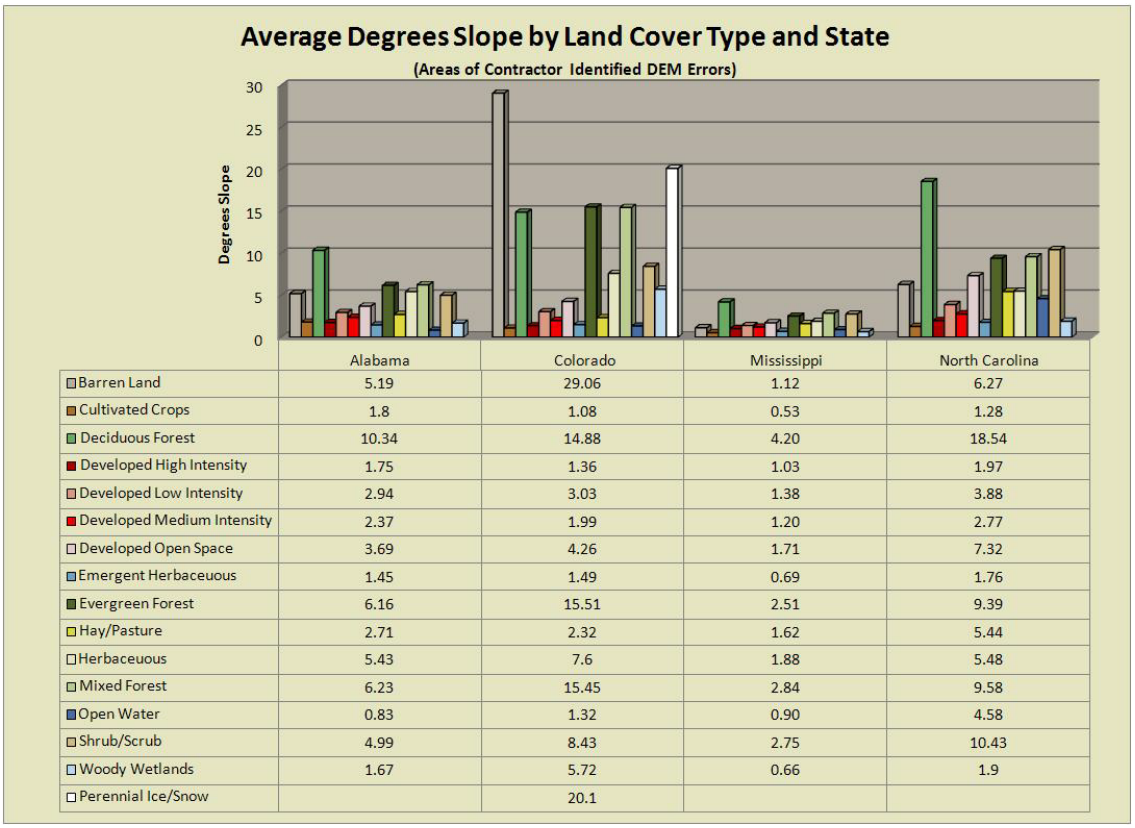


Chart 1: Percentage of Land Cover Type by State



	Alabama	Colorado	Mississippi	North Carolina
Barren Land	5.19	29.06	1.12	6.27
Cultivated Crops	1.8	1.08	0.53	1.28
Deciduous Forest	10.34	14.88	4.20	18.54
Developed High Intensity	1.75	1.36	1.03	1.97
Developed Low Intensity	2.94	3.03	1.38	3.88
Developed Medium Intensity	2.37	1.99	1.20	2.77
Developed Open Space	3.69	4.26	1.71	7.32
Emergent Herbaceuous	1.45	1.49	0.69	1.76
Evergreen Forest	6.16	15.51	2.51	9.39
Hay/Pasture	2.71	2.32	1.62	5.44
Herbaceuous	5.43	7.6	1.88	5.48
Mixed Forest	6.23	15.45	2.84	9.58
Open Water	0.83	1.32	0.90	4.58
Shrub/Scrub	4.99	8.43	2.75	10.43
Woody Wetlands	1.67	5.72	0.66	1.9
Perennial Ice/Snow		20.1		

Chart 2: Average Degrees Slope by Land Cover Type and State

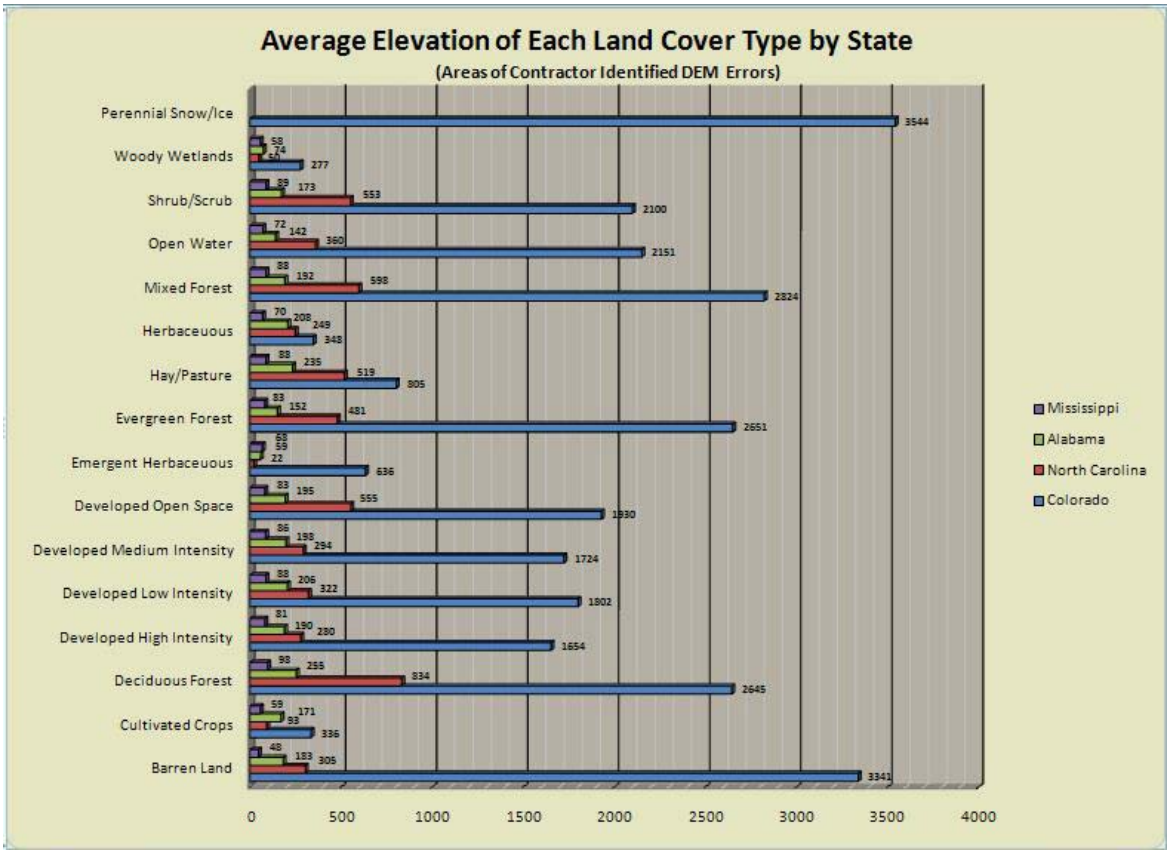
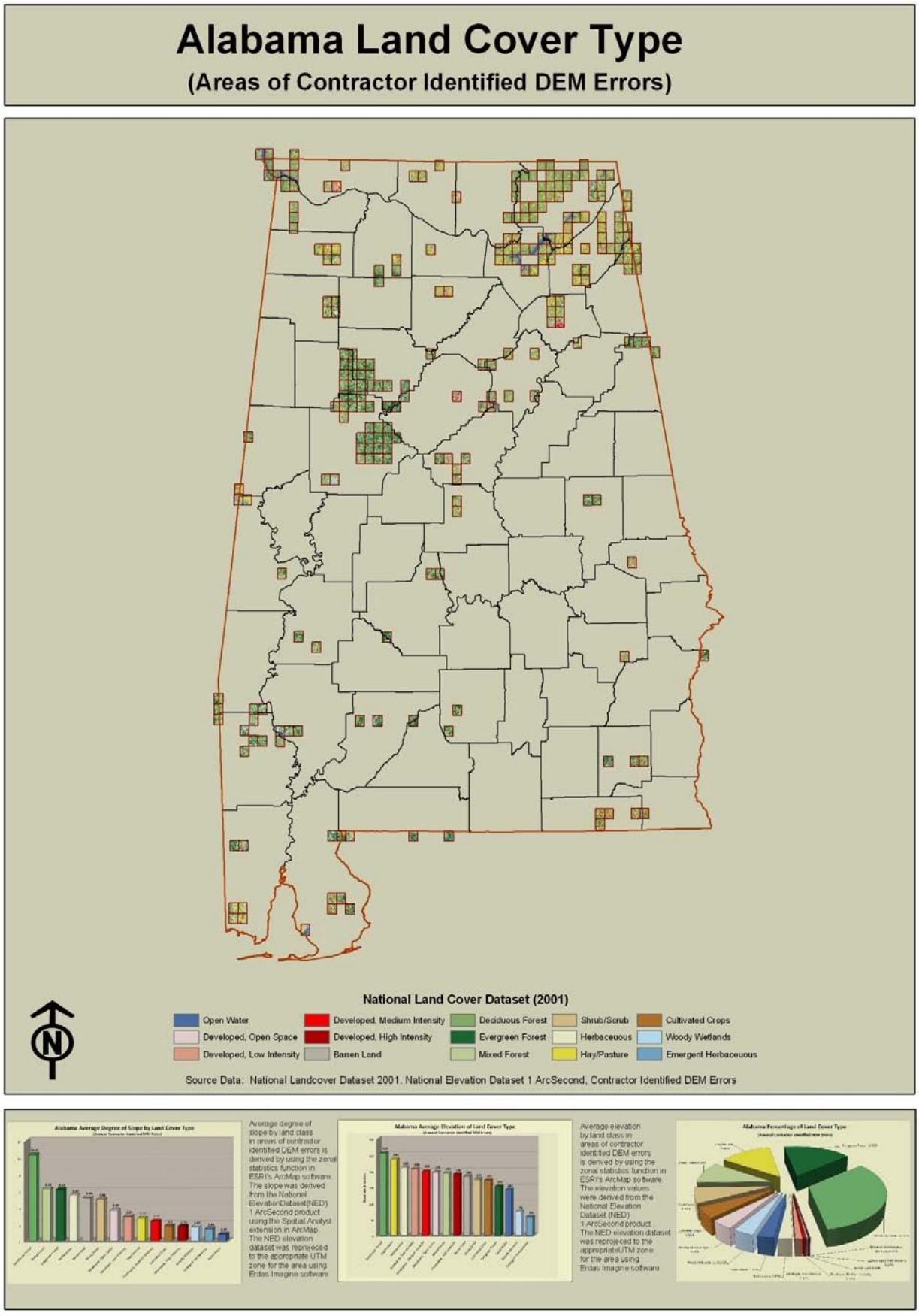


Chart 3: Average Elevation of Each Land Cover Type by State

Individual State Based Analysis of Contractor Identified DEM Errors

The following charts and maps are the individual results for each state where contractors identified DEM errors. The maps indicating land cover types in areas of contractor identified areas of DEM errors show the DOQQ outline for each area of observed errors. Contractors did not specify how many errors were found in these areas or exact locations of observed errors. The slope was derived from the NED 1 Arc Second product using the Spatial Analyst extension in ArcMap. The average degree of slope and elevation by land class in areas of contractor identified DEM errors is derived by using the zonal statistics function in ESRI's ArcMap software. The zonal statistics tool summarizes raster data on a cell by cell basis using another dataset to create the zones. In this study, the NLCD 2001 clipped raster dataset was used as the input and the DOQQ shapefile indicating contractor observed errors was used as the zone data. The results are output to a table.

The first state examined is Alabama. Alabama had 255 out of 3,481 DOQQs that contained contractor identified DEM errors for creating ortho rectified 1-meter imagery. All contractor errors were characterized as major errors. Individual errors were not shown on each DOQQ. The contractor provided only the DOQQ where errors occurred. Most errors occurred in the northern half of the state with a large concentration in the northeast corner of the state. Almost half the errors in Alabama occurred in either deciduous or evergreen forest. The average elevations were highest in the deciduous forest and hay/pasture land cover types. The forest, land cover type had the greatest degree of slope in Alabama within areas of contractor identified DEM errors.



Map 1: Alabama land cover types in areas of contractor identified DEM errors

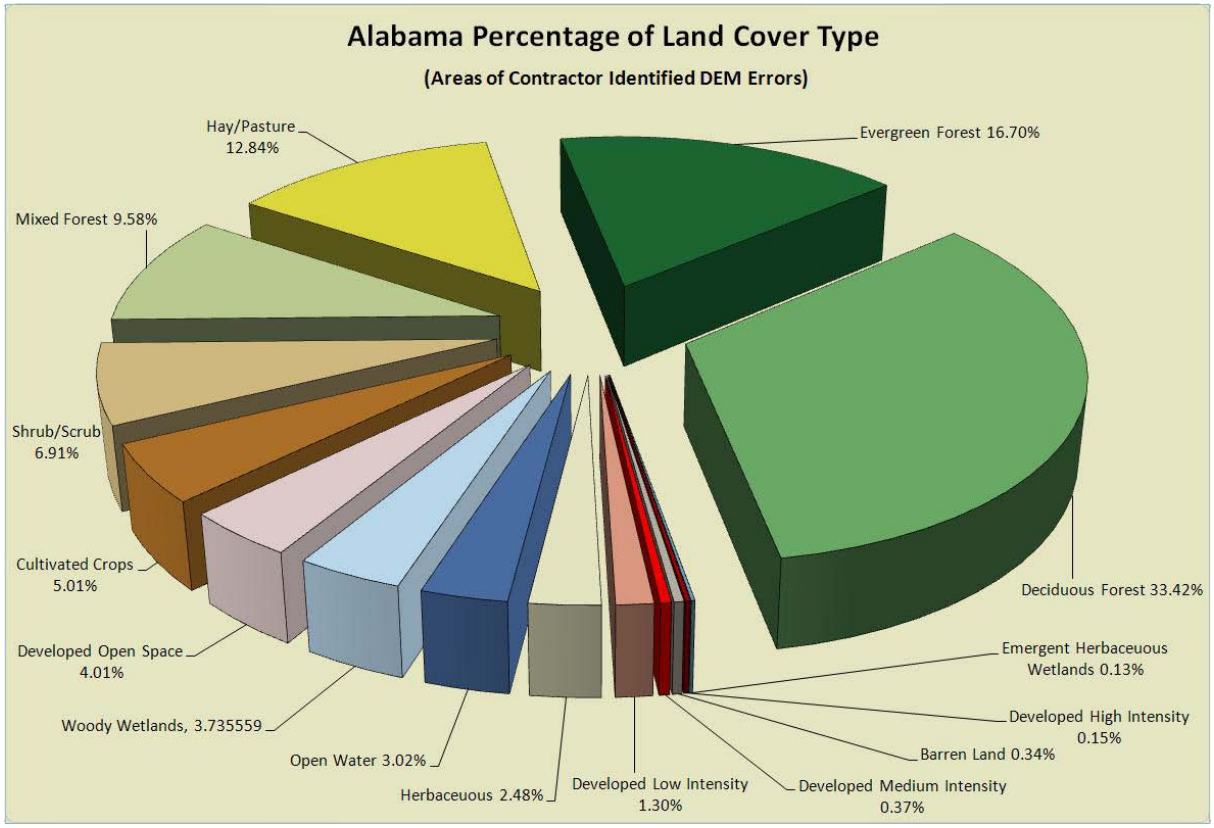


Chart 4: Alabama percentage of land cover types

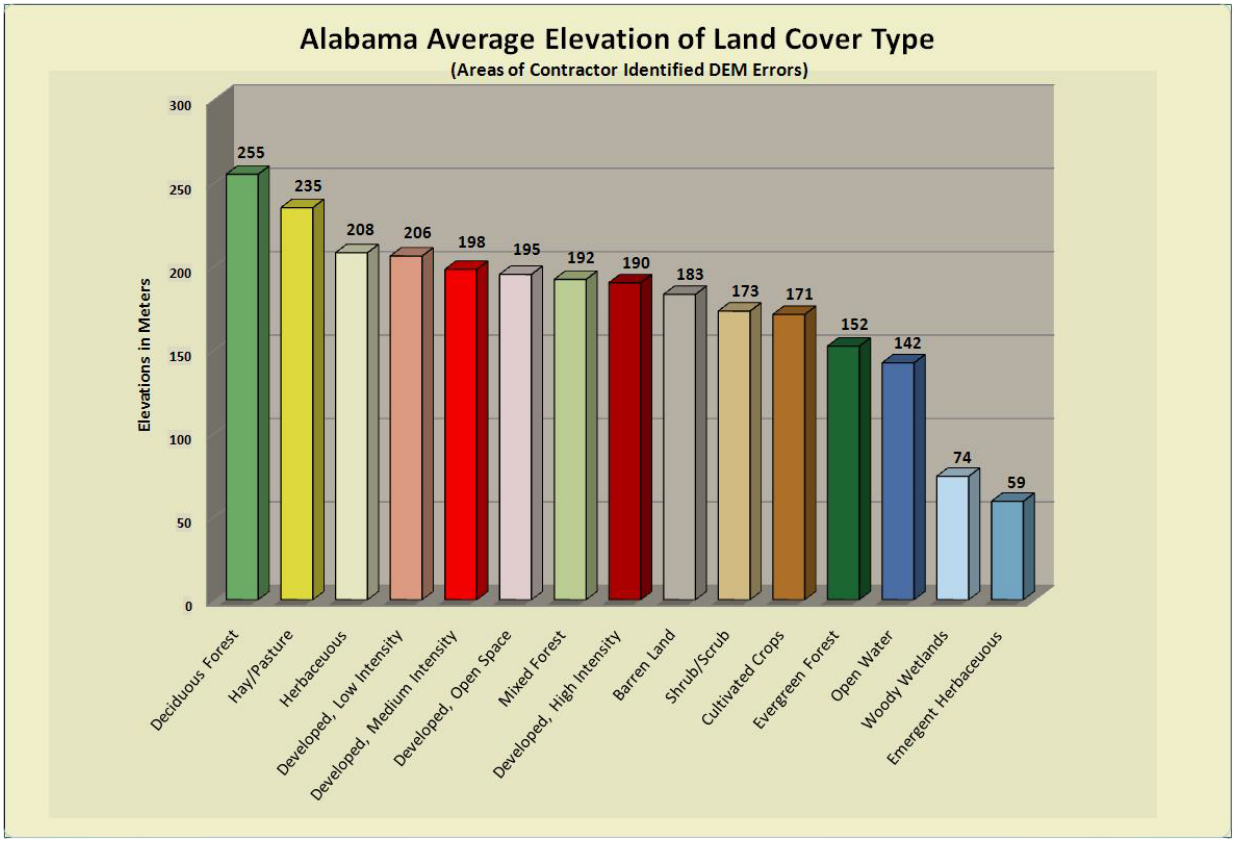


Chart 5: Alabama average elevation of land cover types in areas of contractor identified DEM errors

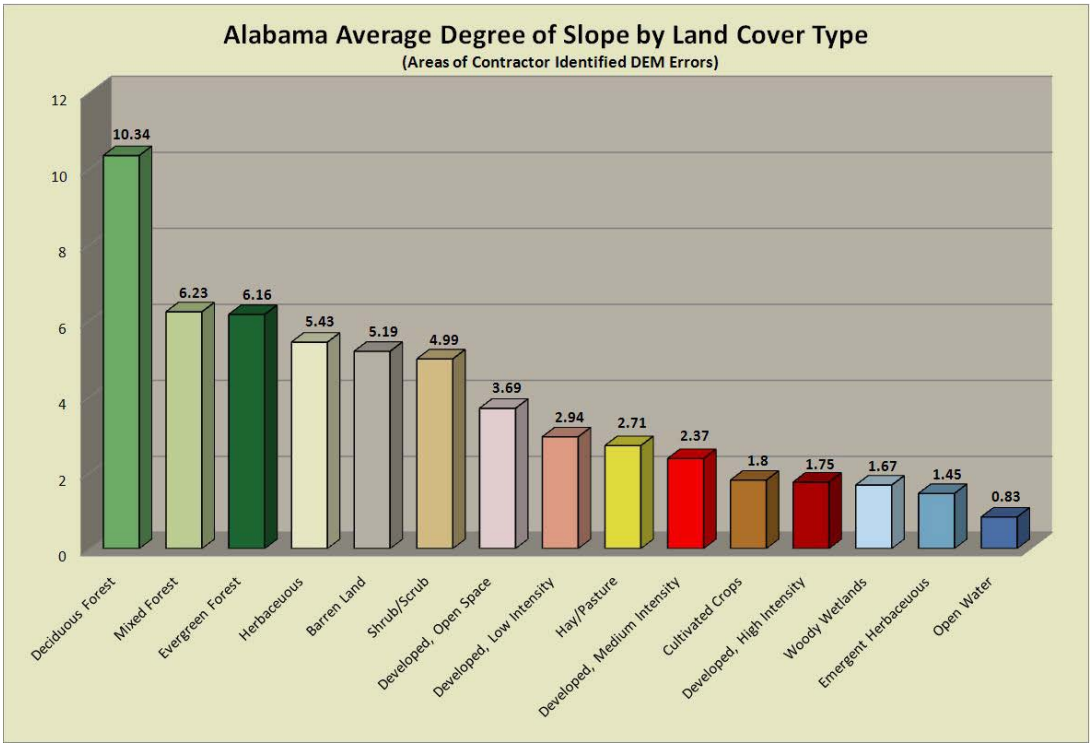
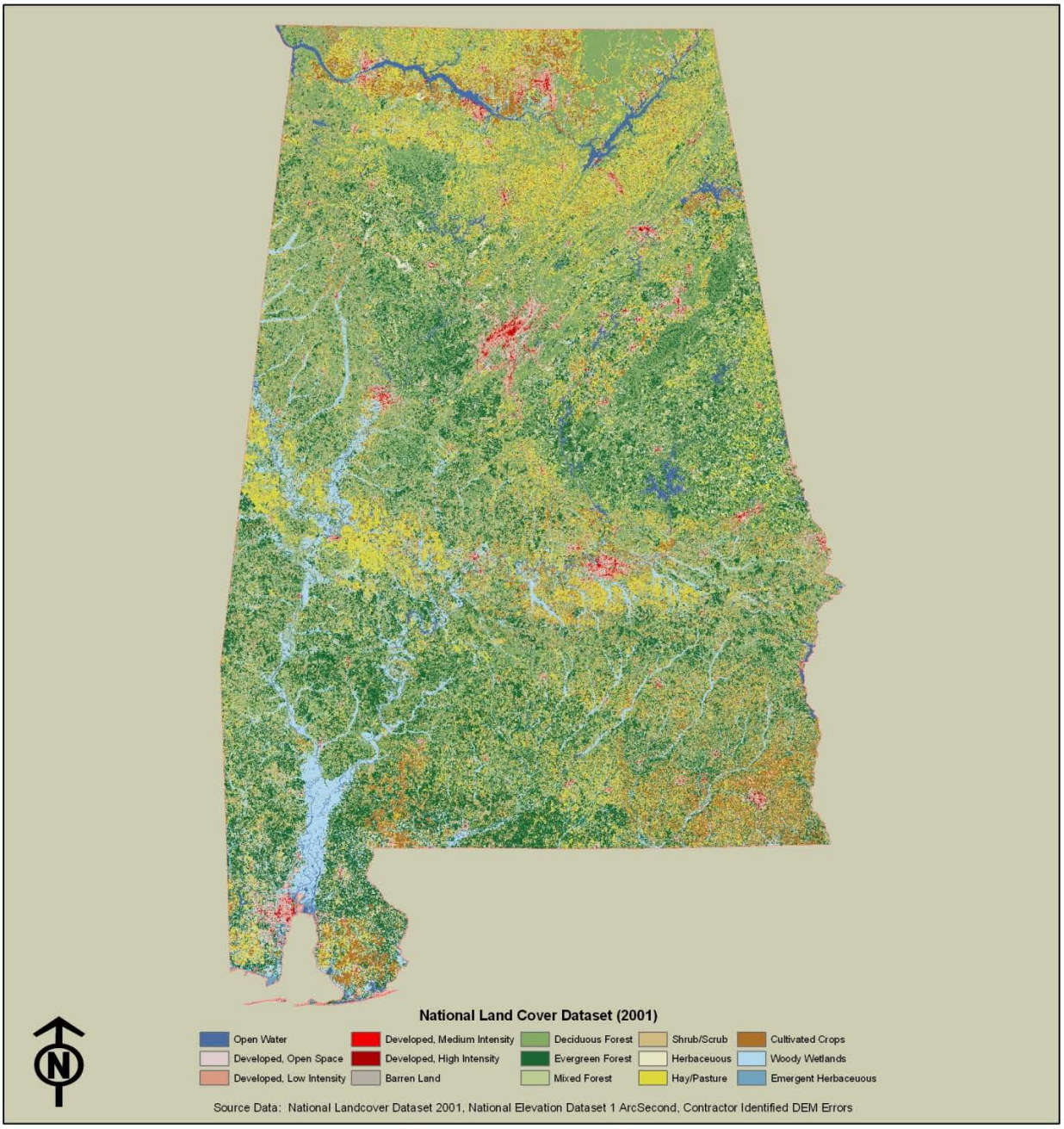


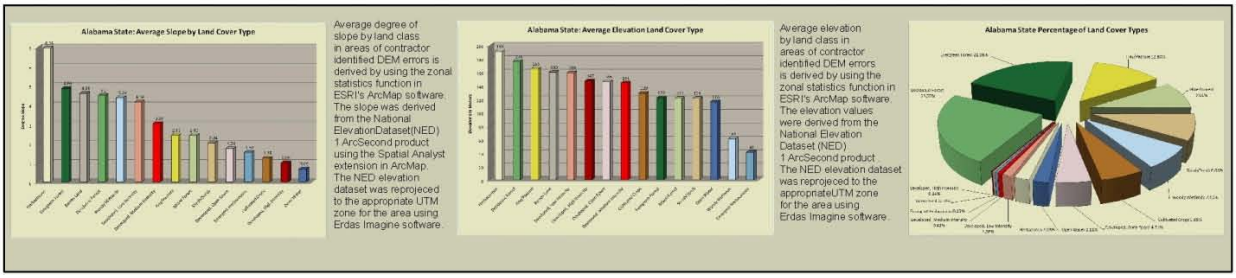
Chart 6: Alabama average degree of slope by land cover type in areas of contractor identified DEM errors

The following charts and maps show the percentage of land cover types according to the NLCD 2001 for the entire state of Alabama. By comparing these results with the results of the contractor identified areas of DEM errors you can get an idea of how this smaller area relates to the whole state. Results will differ depending on how the data is spatially aggregated. For example, as aerial units change, the percentages of land cover types will change across the given area, such as areas of observed errors, state, region etc. For the purpose of this analysis, the area of observed errors has been compared to the state area.

More than fifty percent of the total land cover types for the state as a whole are deciduous forest, evergreen forest and hay/pasture. Compared to the state percentages of land cover, the contractor identified DEM errors occurred mainly in areas of deciduous forest, evergreen forest and hay/pasture. There appears to be a direct correlation between the locations of identified errors and the locations of the most predominant land cover types in the state.

Alabama State Land Cover Classifications





Map 2: Alabama State Land Cover Classifications

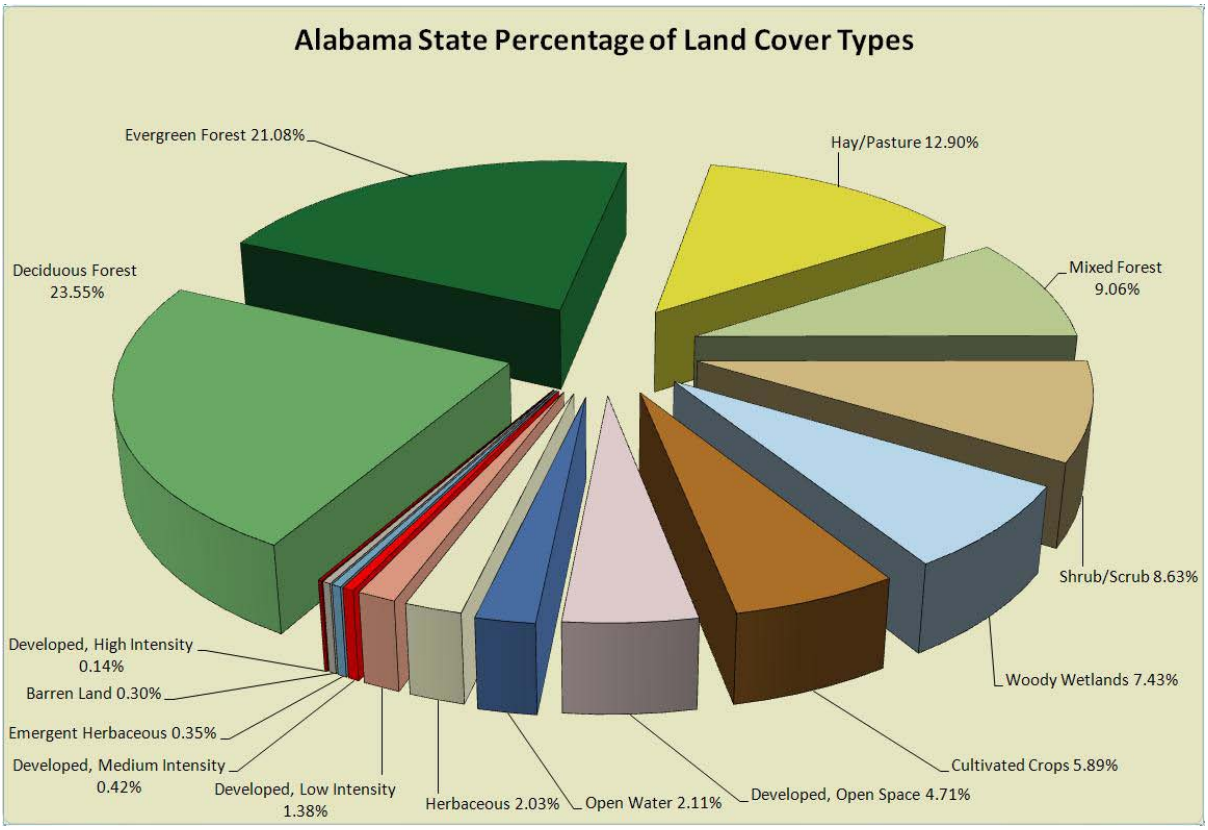


Chart 7: Alabama State Percentage of Land Cover Types

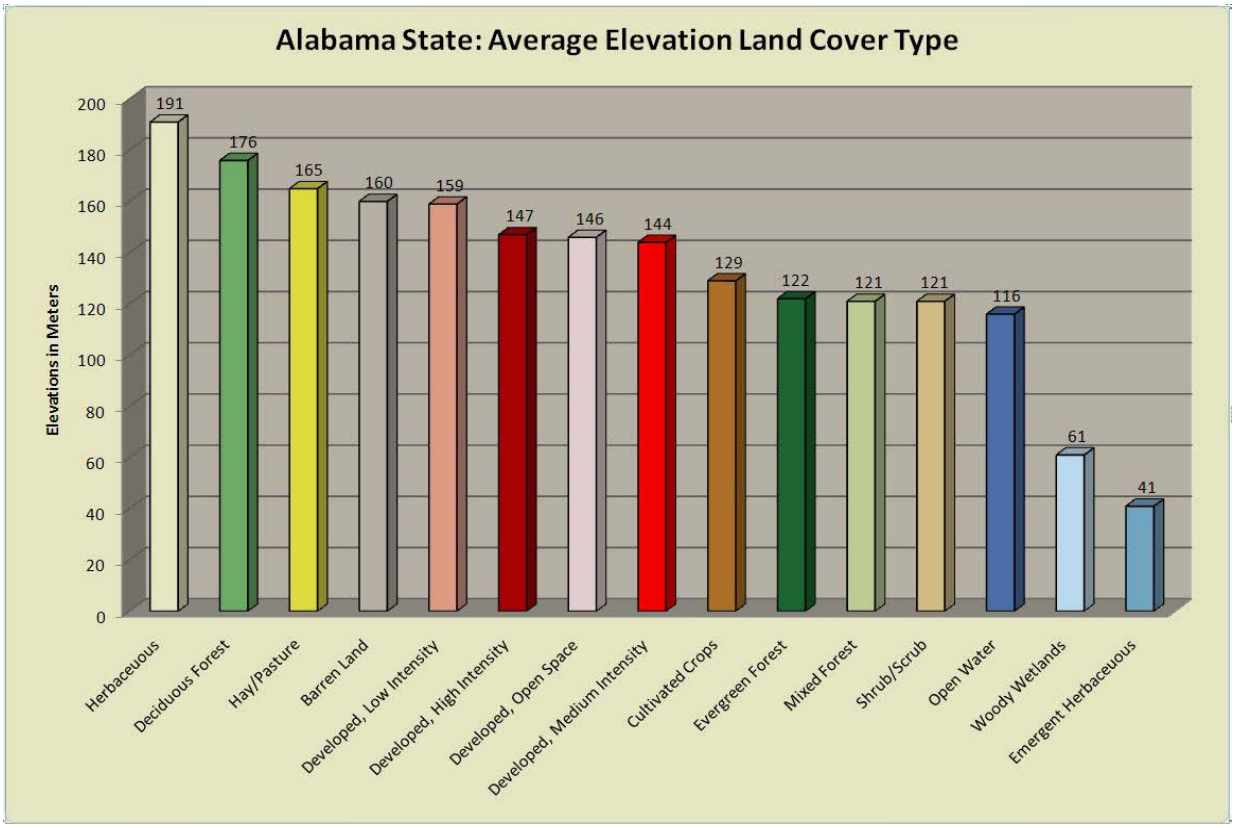


Chart 8: Alabama State Average Elevation of Land Cover Types

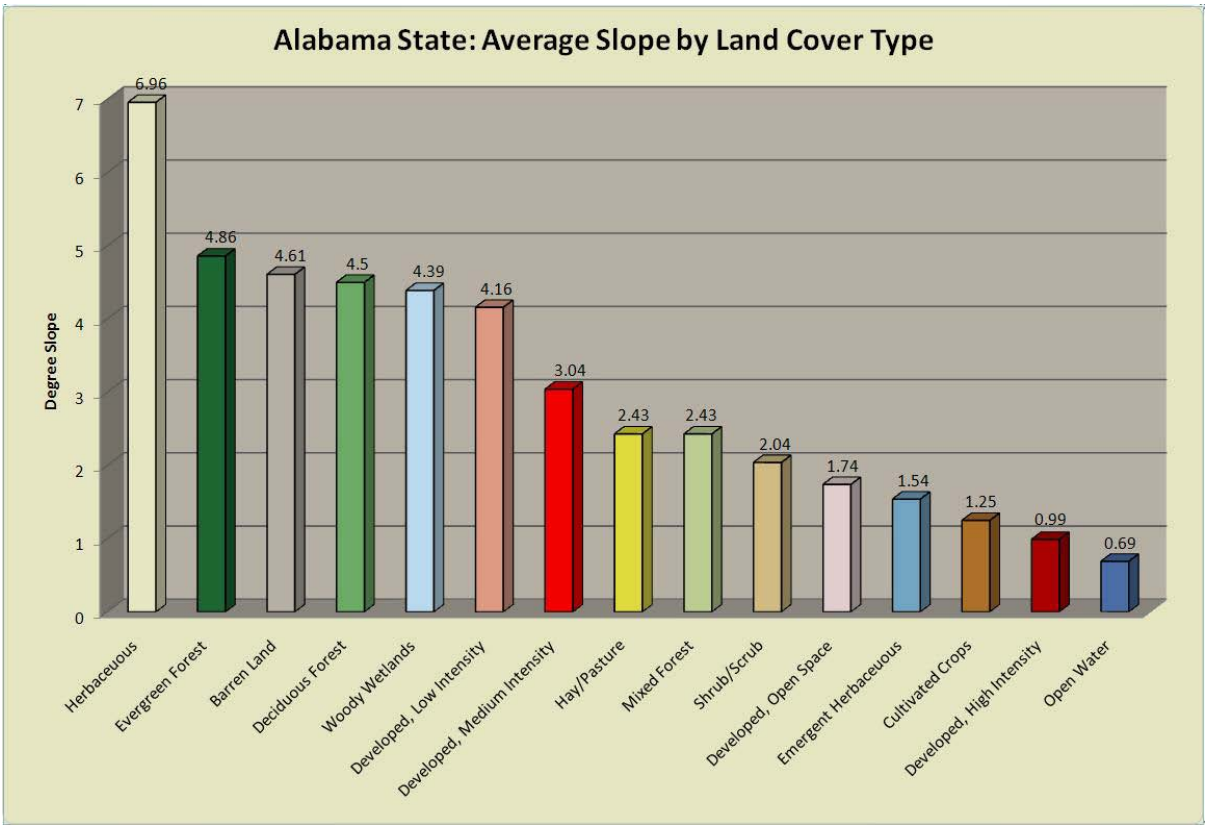


Chart 9: Alabama State Average Slope by Land Cover Type

The following charts show a comparison between the state as a whole and areas of contractor identified DEM errors. Some interesting trends from the comparison are that average elevations of land cover types are higher in areas of identified errors and average slope is greater in forested land cover types in areas of error than in the state as a whole. This observation could imply that due to vegetation cover, the elevation information in some areas could be influenced by treetops rather than elevations on the ground.

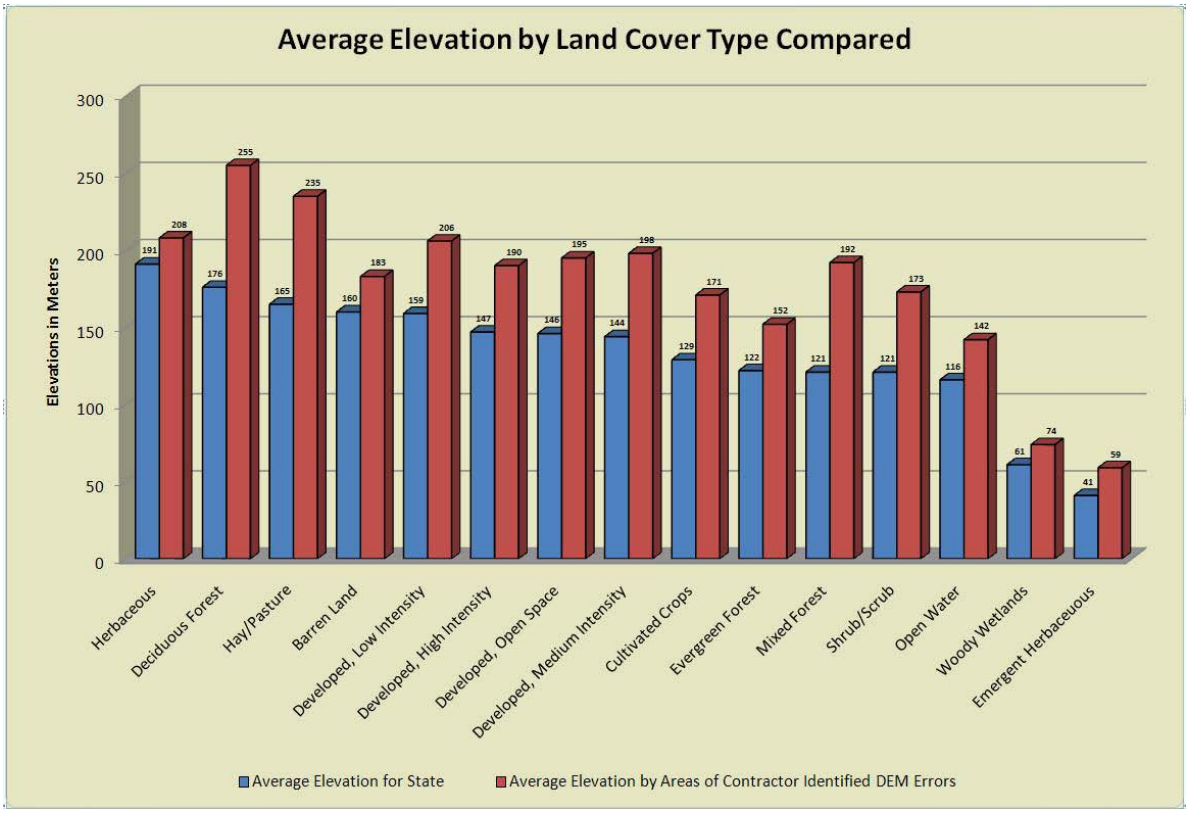


Chart 10: Average Elevation by Land Cover Type Compared by State and Identified Errors

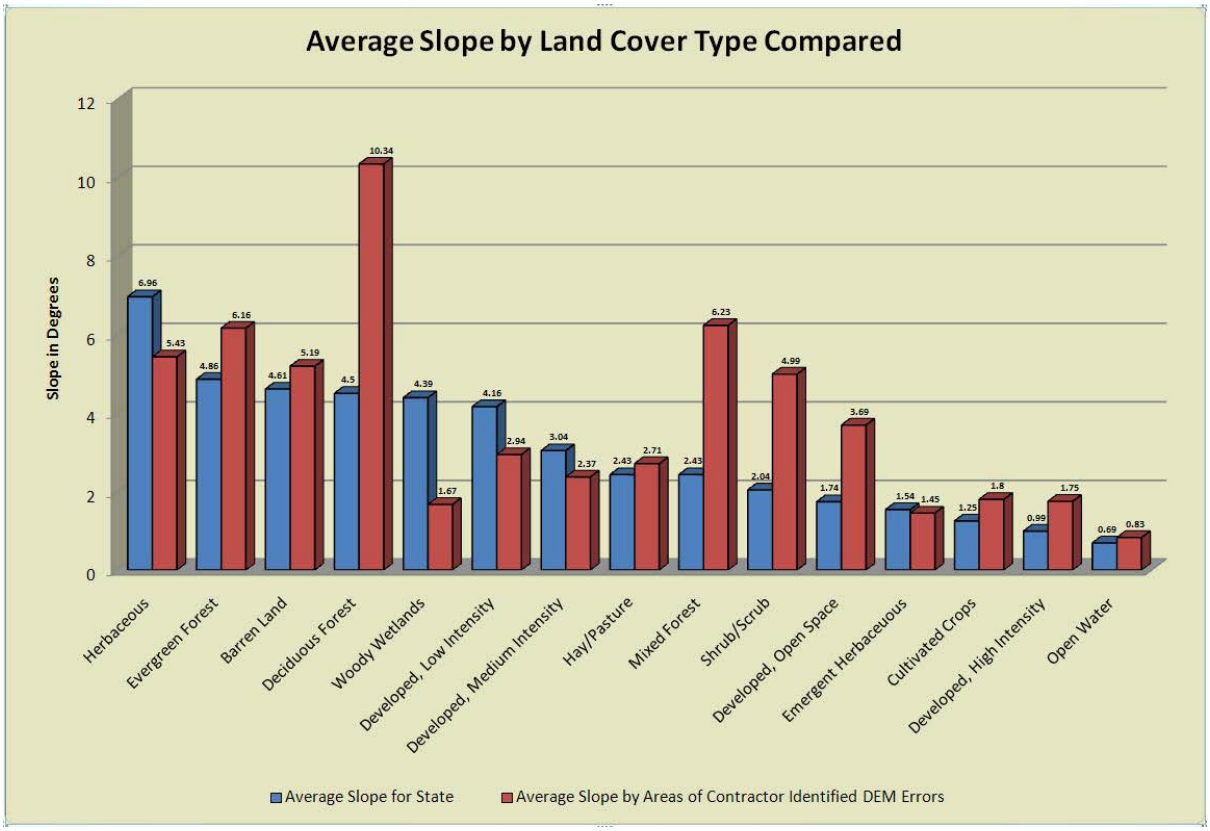


Chart 11: Average Slope by Land Cover Type Compared by State and Identified Errors

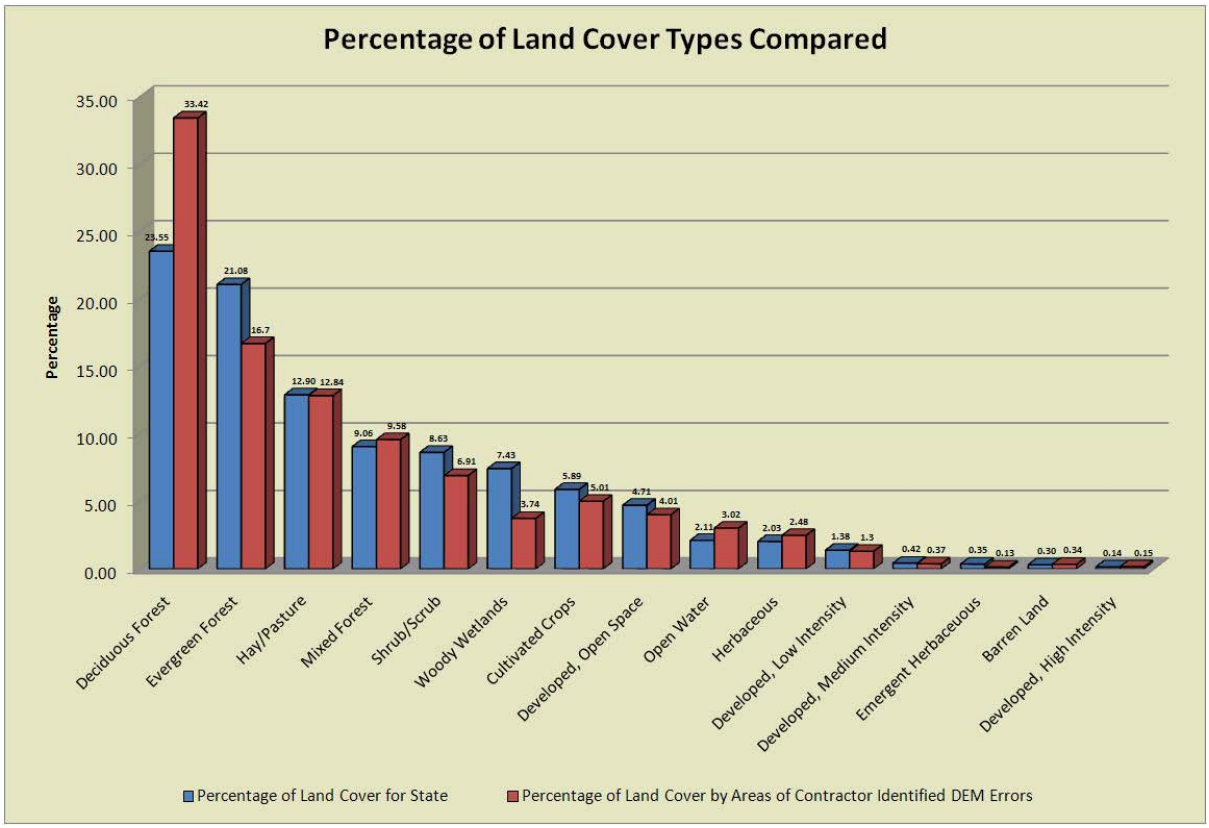


Chart 12: Percentage of Land Cover Types Compared by State and Contractor Identified Errors

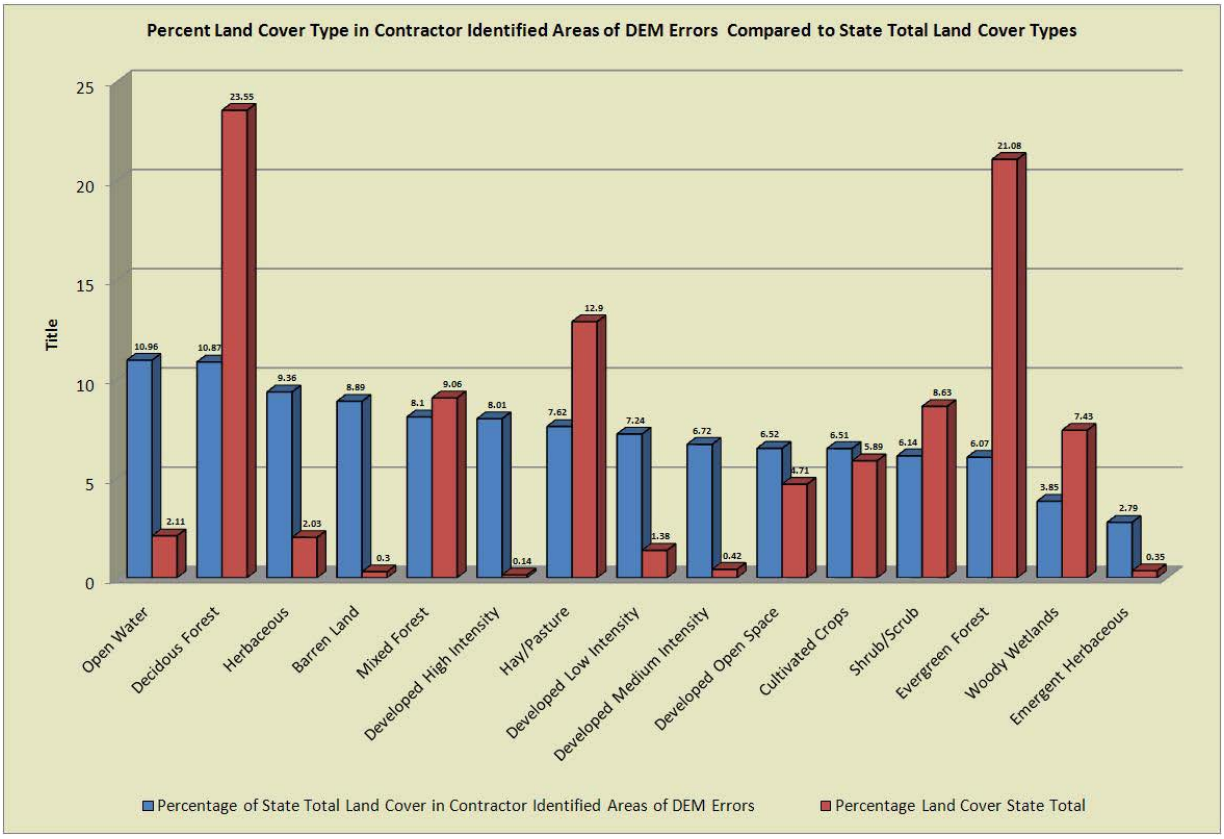
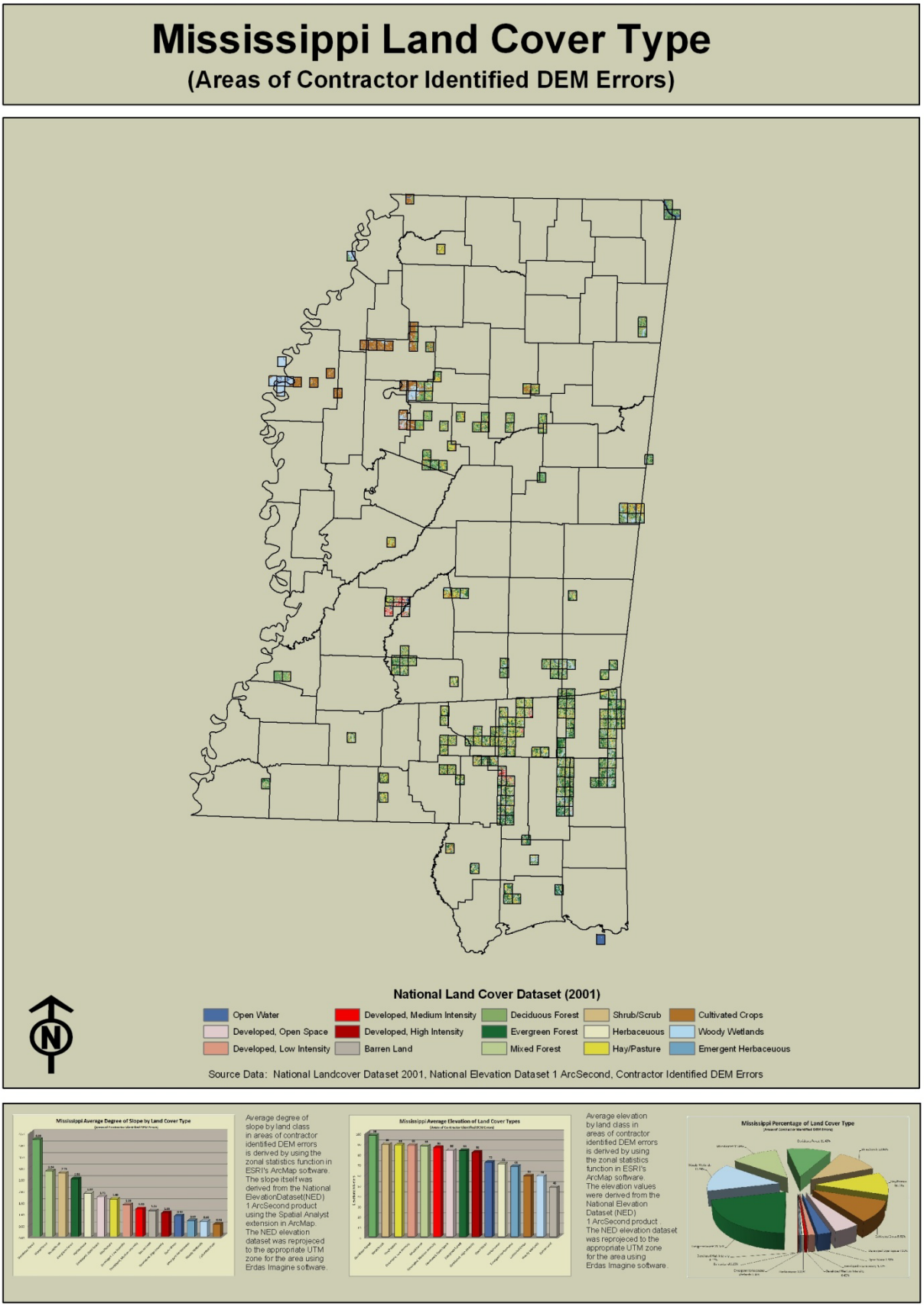


Chart 13: Percentage of State Total Land Cover in Contractor Identified Areas of DEM Errors

The general conclusion could be made that the number of identified DEM errors within an area of primarily deciduous forest land cover correlate to the fact that there is more of this type of land cover in Alabama. On the other hand, land cover areas with a higher percentage of identified DEM errors than the percentage of that land area within the state could take on more importance. This could indicate more problems with these types of land cover areas than areas that make up a larger percentage of the whole state. For example, the herbaceous land cover type makes up 2.03% of the state land cover types, and of this small percentage, 9% was located in contractor identified areas of DEM errors.

Mississippi had 193 out of 3,237 DOQQs, which contained contractor identified DEM errors. The contractor characterized all errors as major errors. Most of the errors were concentrated in the southeast corner of the state. Over fifty percent of the contractor identified DEM errors were in areas of forest and shrub/scrub. There was also some correlation between higher elevation, slope and dense vegetation. Deciduous forest and shrub/scrub were in the highest elevations and deciduous forest and shrub/scrub averaged more degrees of slope than other types of land cover.



Map 3: Mississippi Land Cover Types in Areas of Contractor Identified DEM Errors

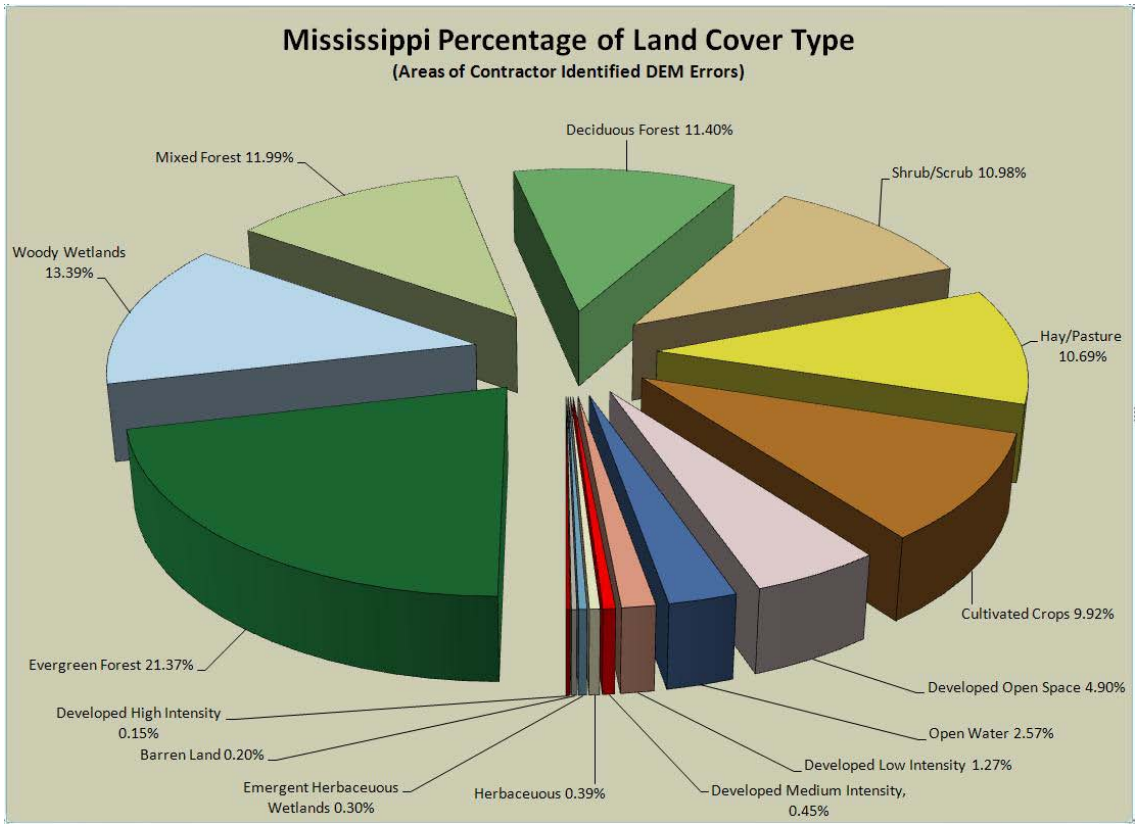


Chart 14: Mississippi Percentage of Land Cover Type in Areas of Contractor Identified DEM Errors

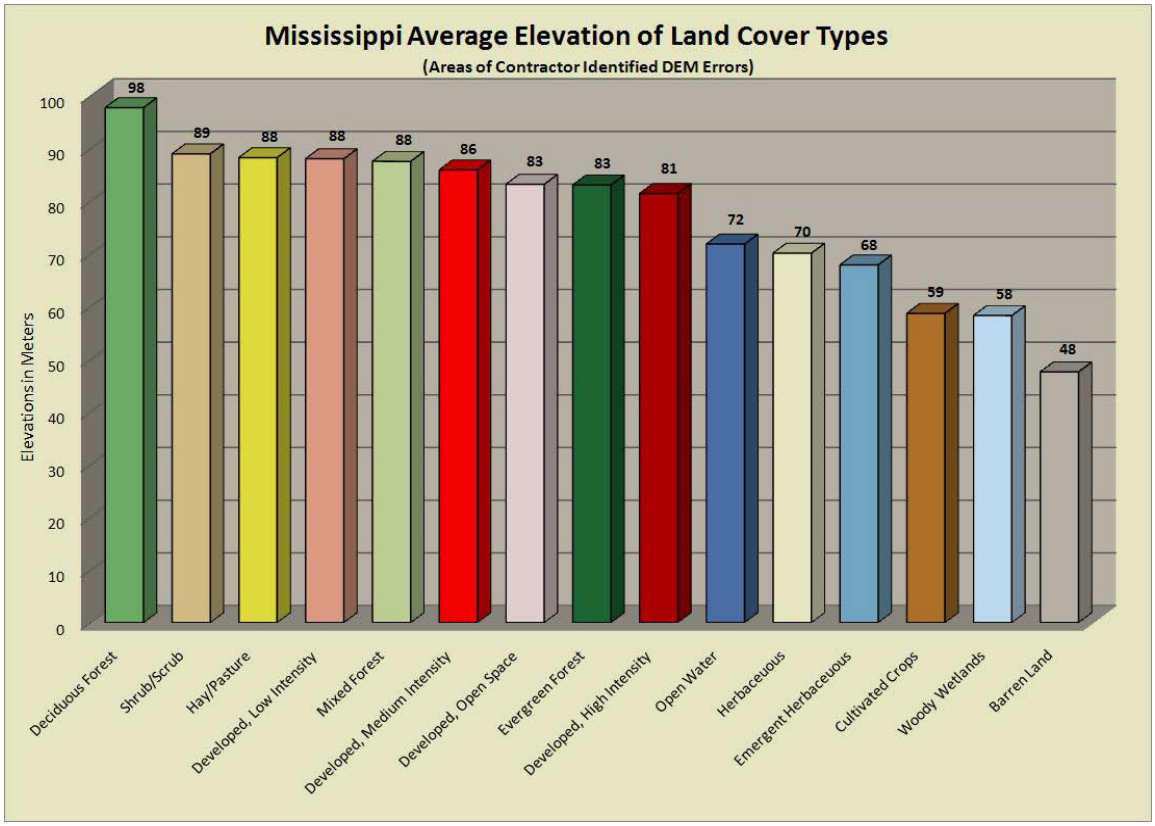


Chart 15: Mississippi Average Elevation of Land Cover Types in Areas of Contractor Identified DEM Errors

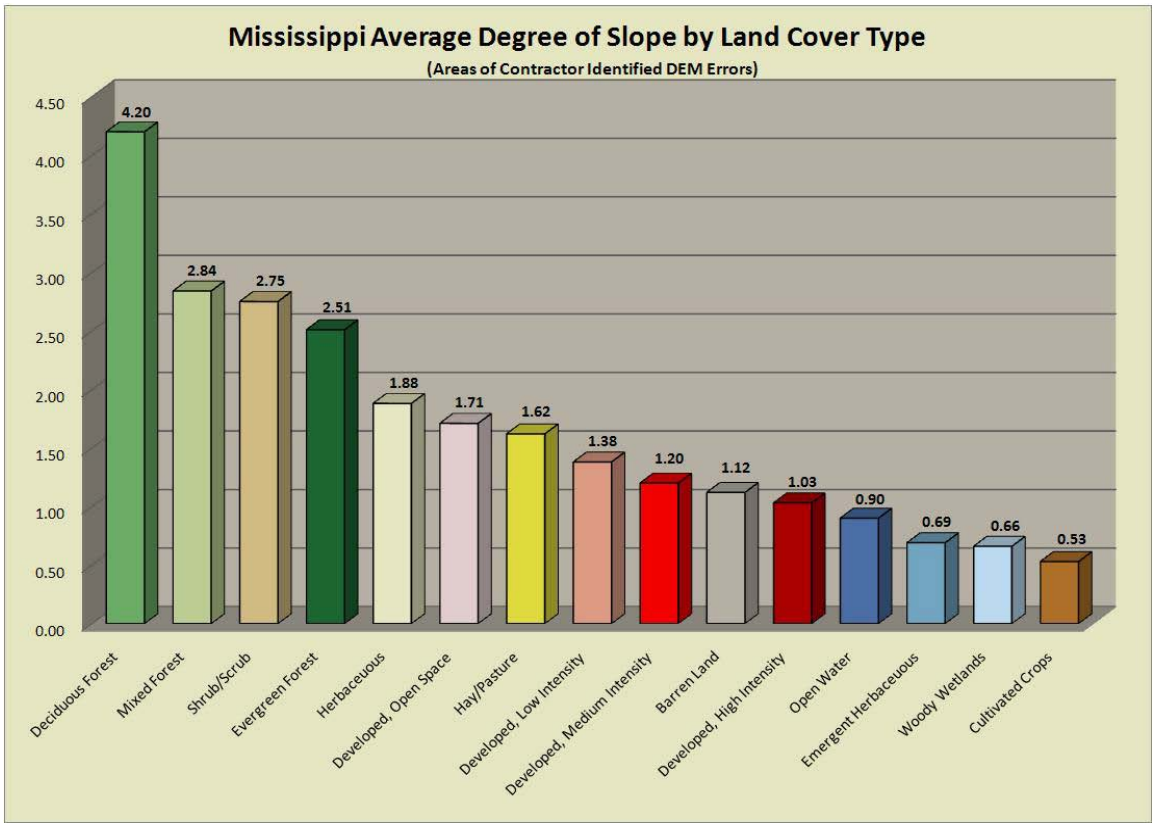
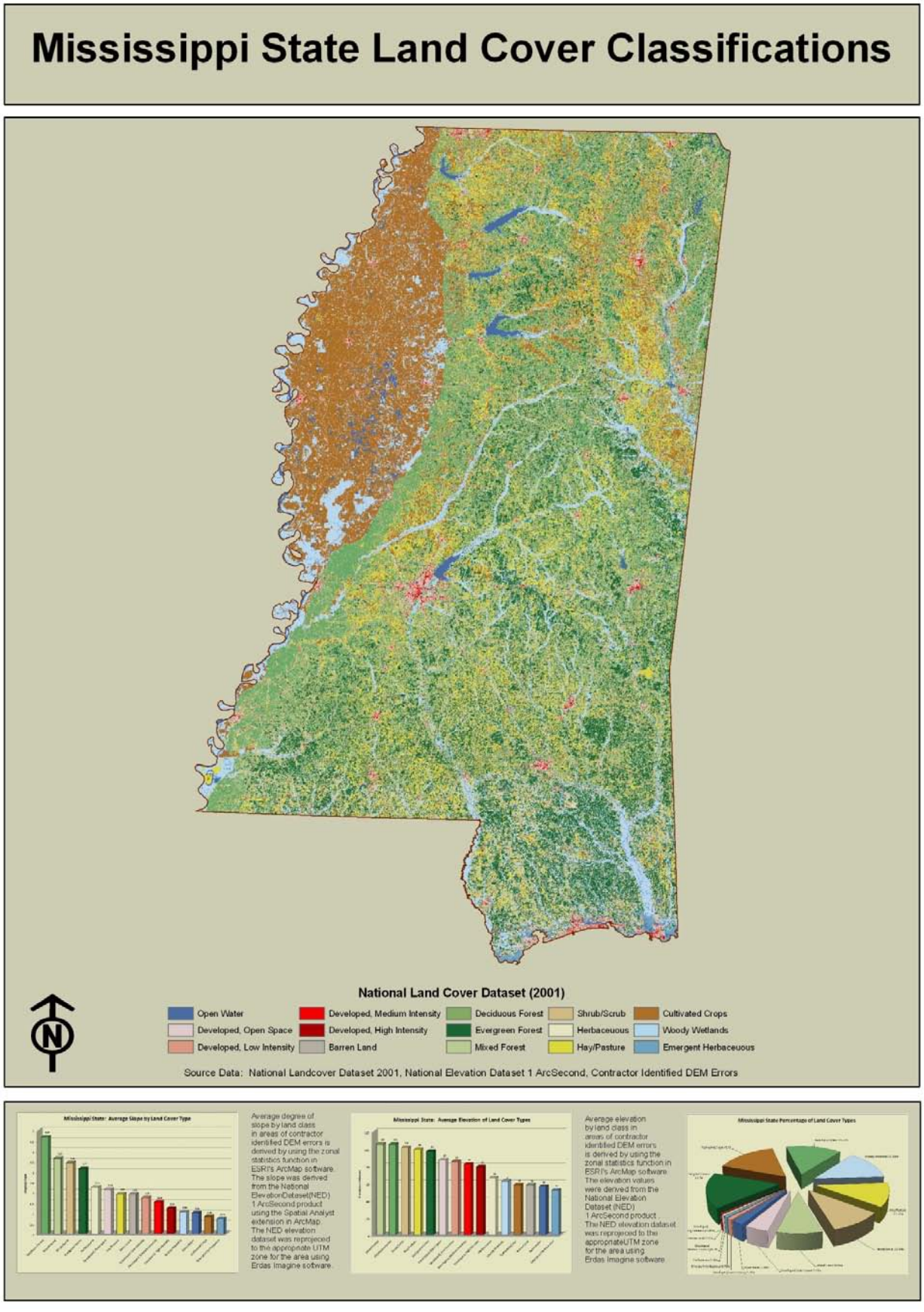


Chart 16: Mississippi Average Degree Slope of Land Cover Types in Areas of Contractor Identified DEM Errors

The following charts and maps show the percentage of land cover types according to the NLCD 2001 for the entire state of Mississippi. By comparing these results with the results of the contractor identified areas of DEM errors you can get an idea of how the area of interest relates to the whole state. For the purpose of this analysis, the area of observed errors has been compared to the state area.

Approximately 30 percent of the total land cover types for the state as a whole are evergreen forest and deciduous forest. Another 28 percent of the state is made up of cultivated crops and hay/pasture land cover types. Compared to the state percentages of land cover the contractor identified DEM errors occurred mainly in areas of evergreen forest, woody wetlands and mixed forest. There appears to be some correlations between where the most numerous identified errors occur and the total land cover types in the state. Average elevation and average slope statewide are greatest in areas of mixed forest, deciduous forest and the shrub/scrub categories.



Map 4: Mississippi State Land Cover Classifications

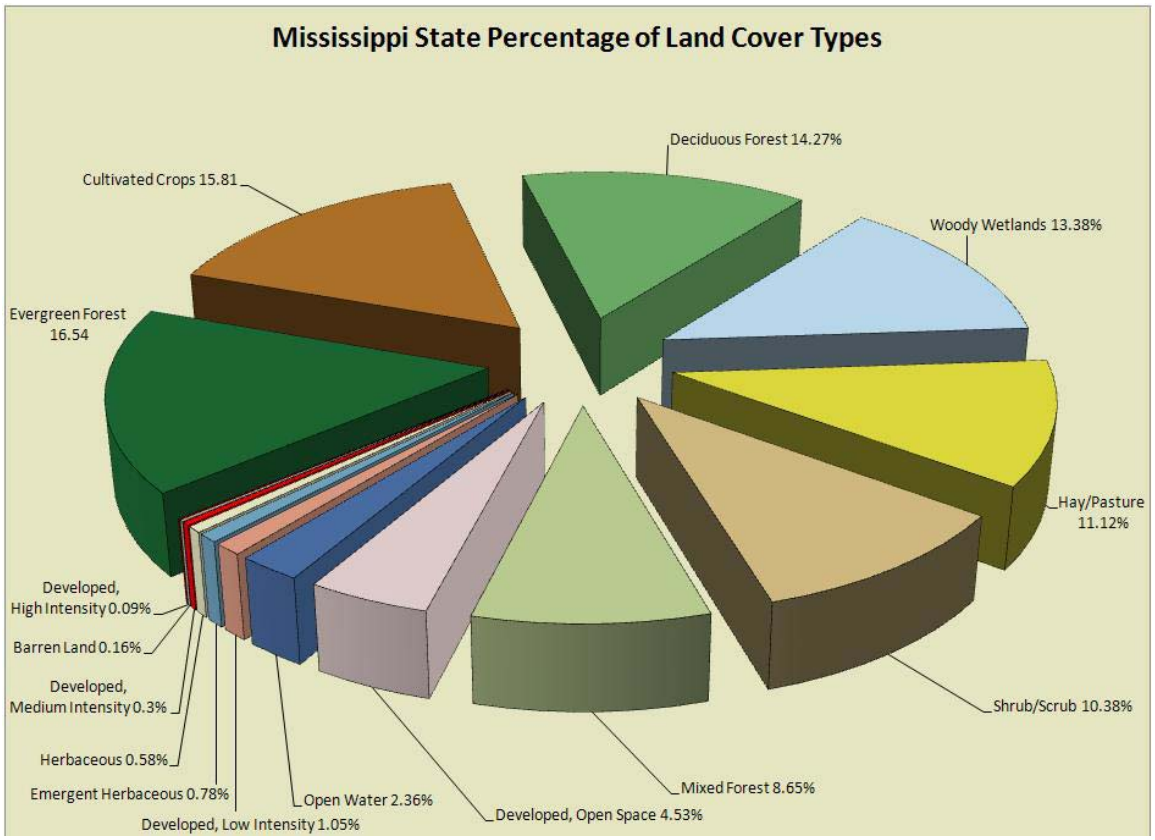


Chart 17: Mississippi State Percentage of Land Cover Types

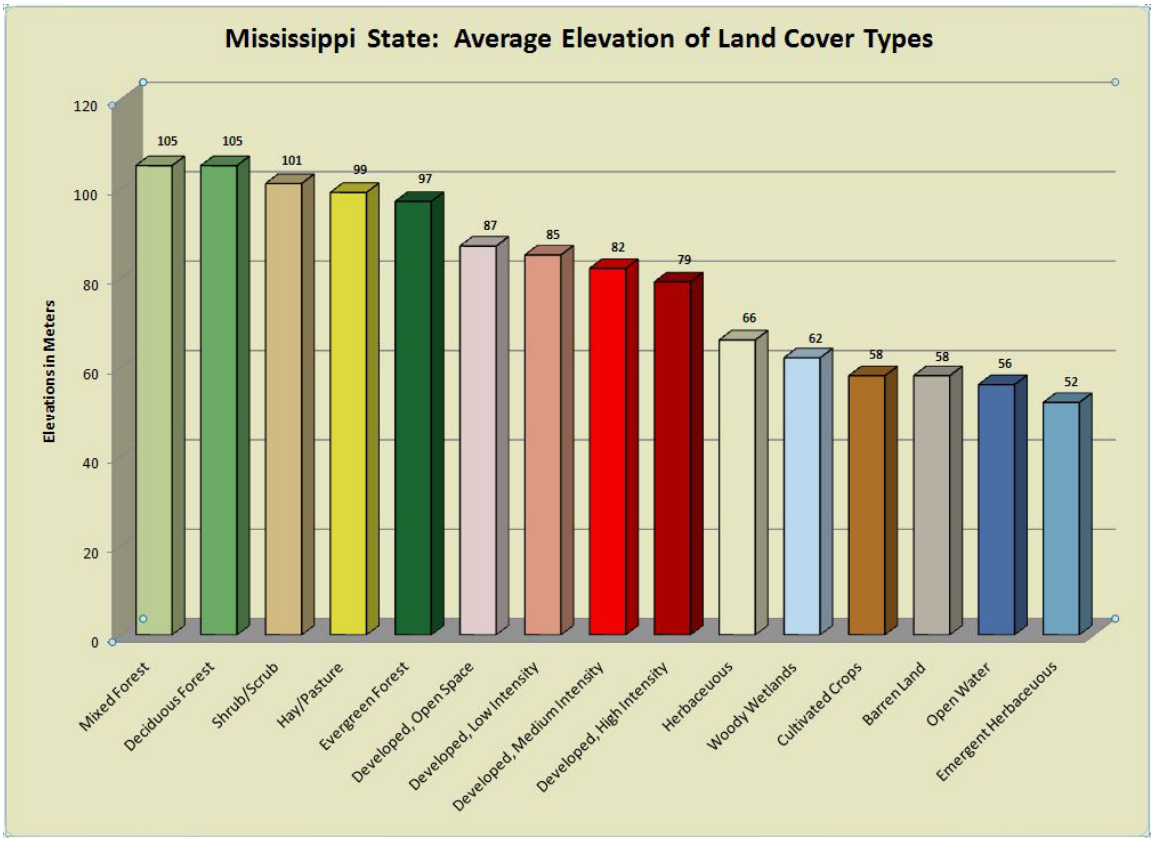


Chart 18: Mississippi State Average Elevation of Land Cover Types

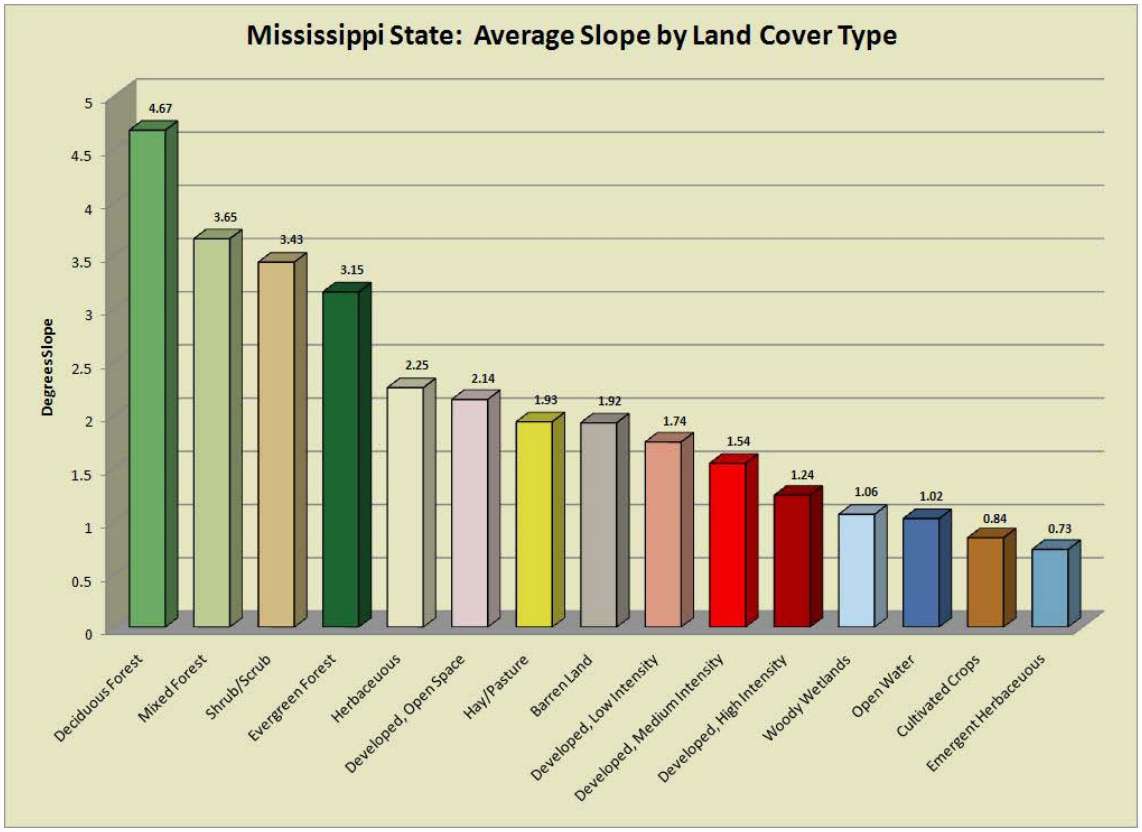


Chart 19: Mississippi State Average Slope by Land Cover Type

The following charts show a comparison between the state as a whole and areas of contractor identified DEM errors. Some interesting trends from the comparison are that average elevations of land cover types are higher in the state as a whole in (or as below with:) mixed forest, deciduous forest, shrub/scrub, evergreen forest, hay/pasture, developed open space, barren land and woody wetlands. On the other hand, the state total is lower than the observed errors total in the following land cover types: developed low intensity, developed medium intensity, developed high intensity, herbaceous, cultivated crops, open water and emergent herbaceous wetlands. Average state slope is higher across all land cover types than in areas of observed errors, and percentages of land cover types are consistent in both groups, with the exception of mixed forest, which makes up a larger percentage of the observed errors group than the state as a whole.

Several land cover types appear to occur frequently in areas of observed DEM errors due to their frequency of occurrence in the state. These land cover types include evergreen forest, mixed forest, deciduous forest, woody wetlands and cultivated crops. The land cover types developed high intensity, developed medium intensity, barren land and herbaceous contain a high percentage of errors, but occupy only a small percentage of the total land area in the state. This may indicate that problems are more serious in these areas.

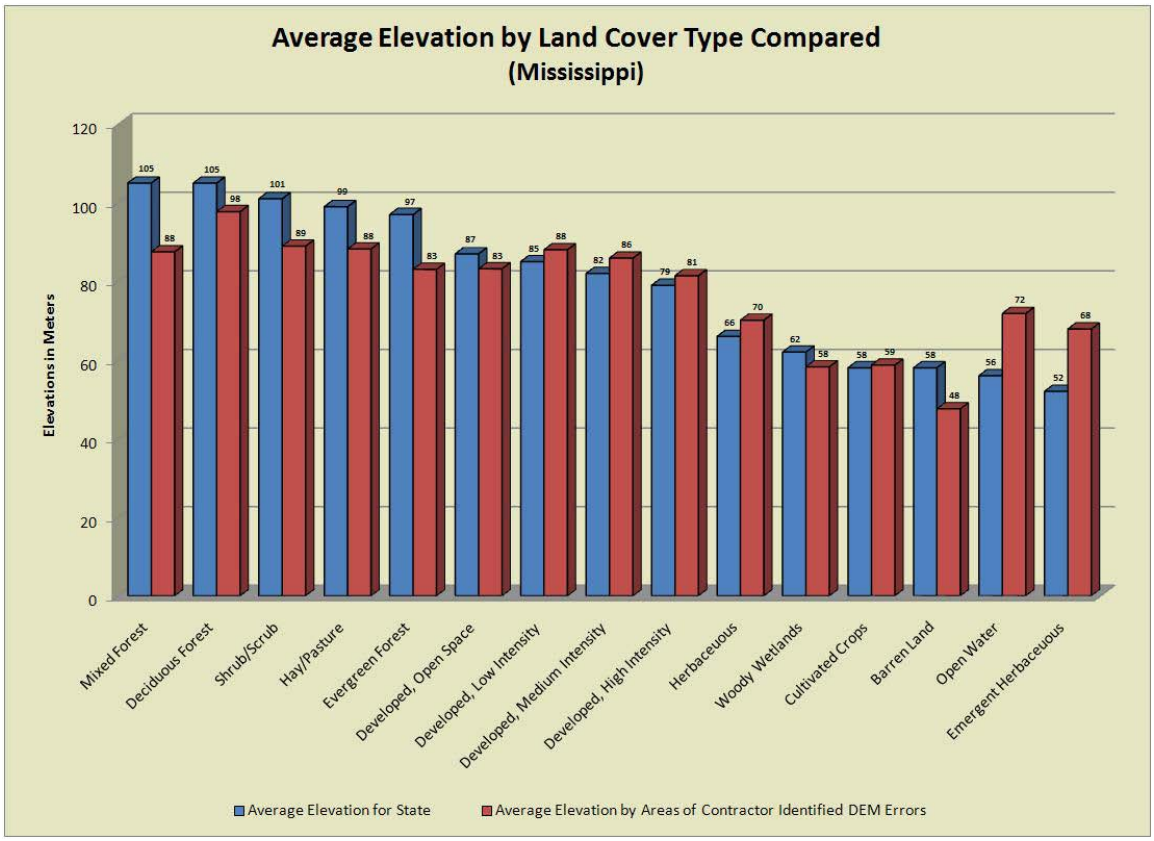


Chart 20: Average Elevation: Entire State Compared to Areas of Contractor Identified DEM Errors

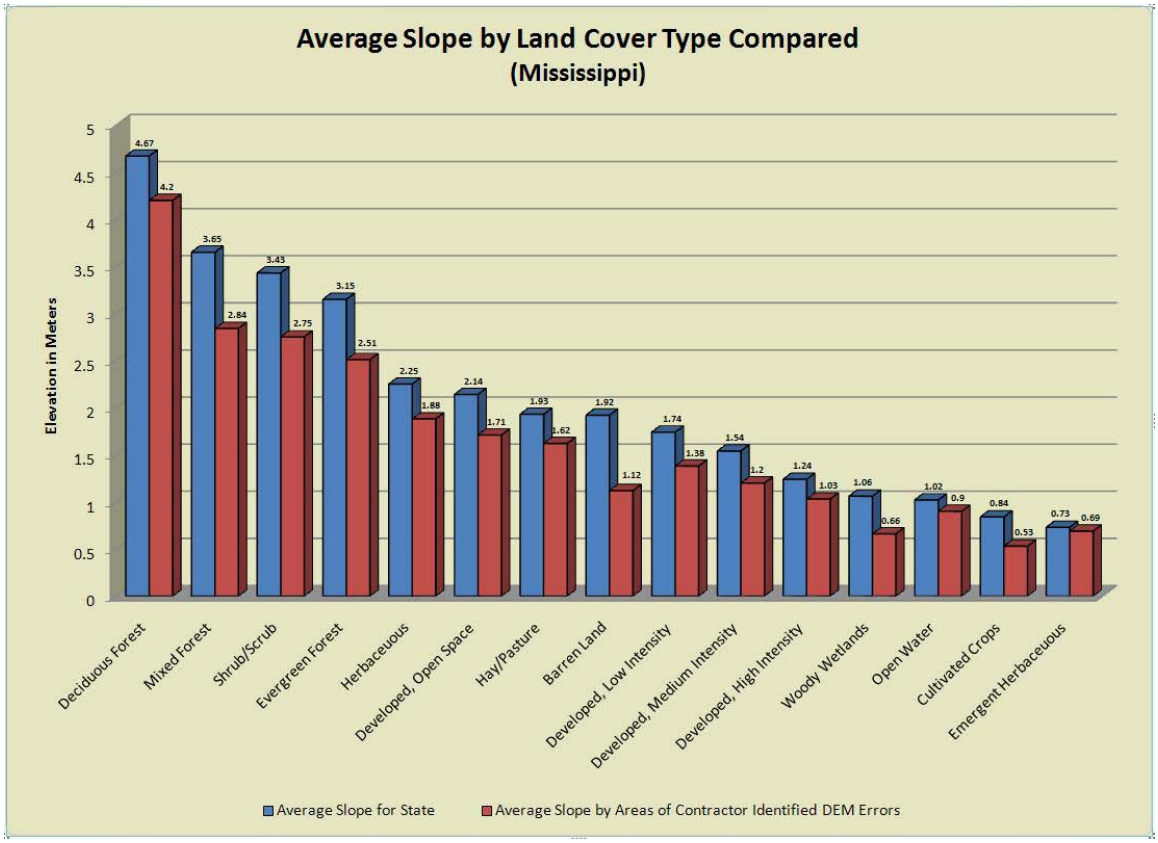


Chart 21: Average Slope: Entire State Compared to Areas of Contractor Identified DEM Errors

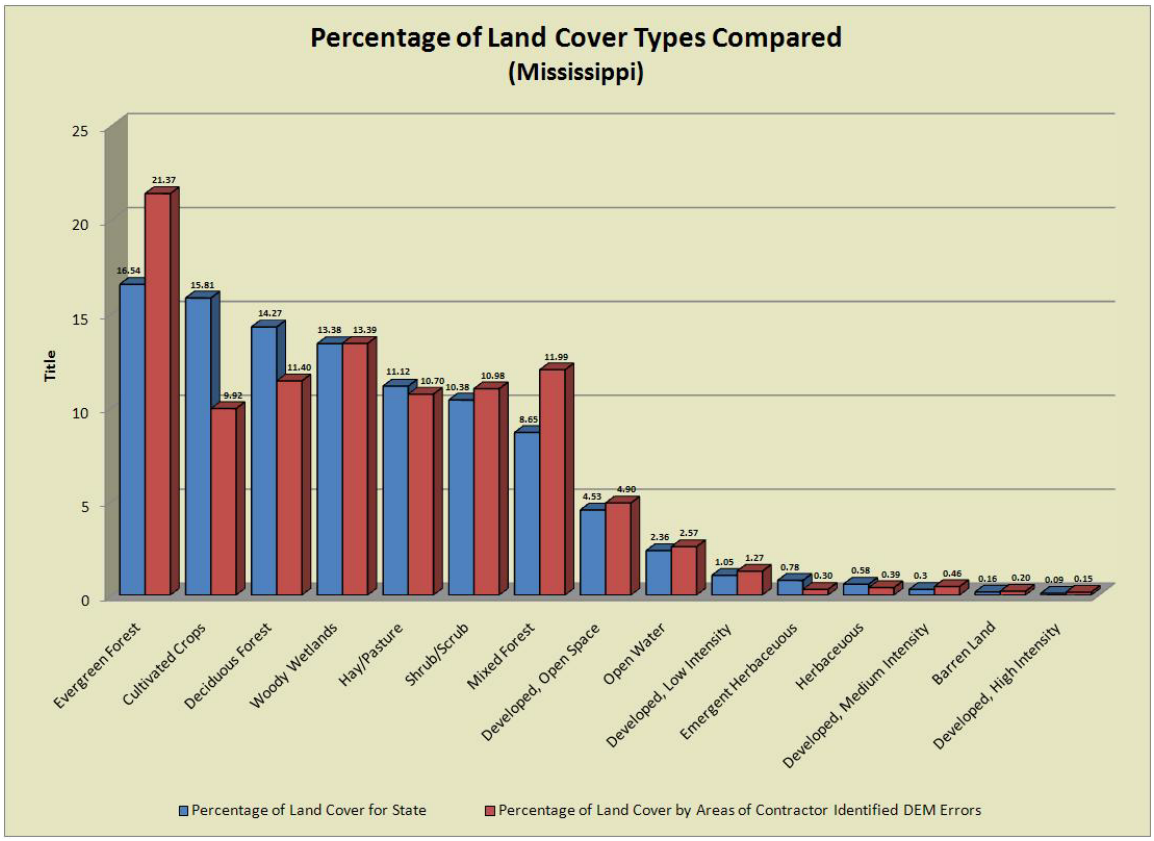


Chart 22: State Total Percentage of Land Cover Types Compared to Areas of Contractor Identified DEM Errors

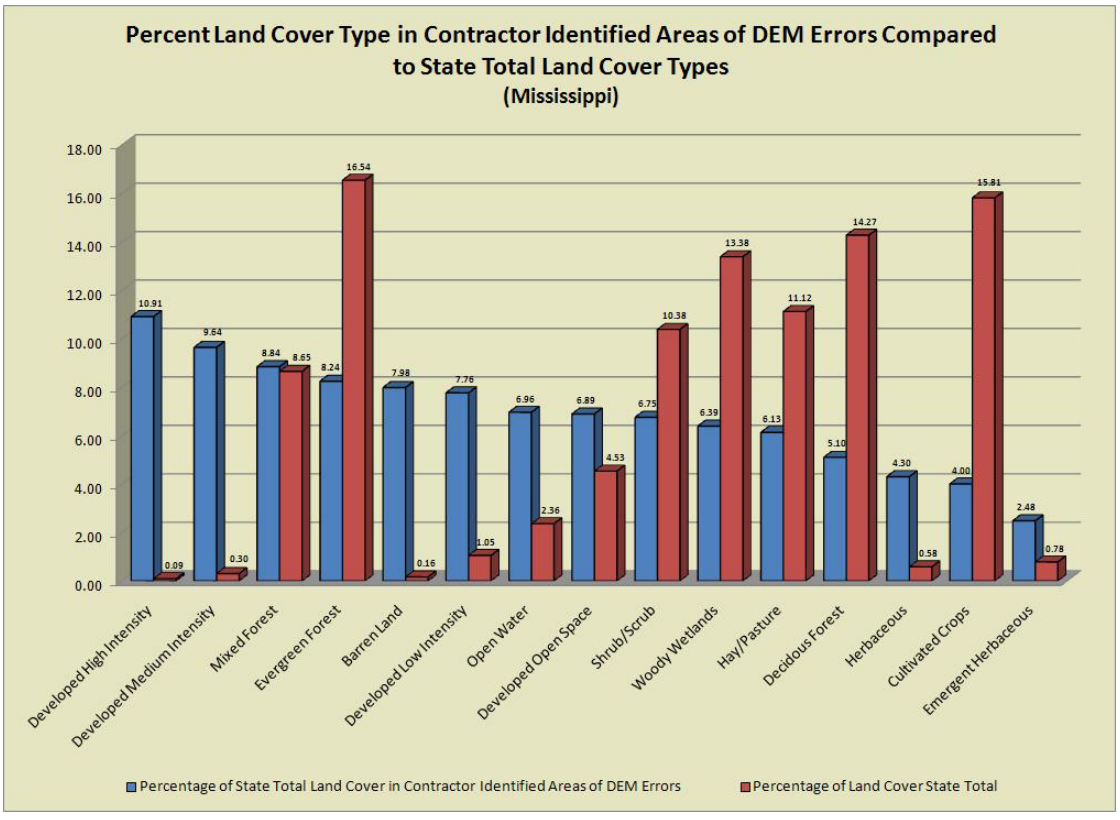
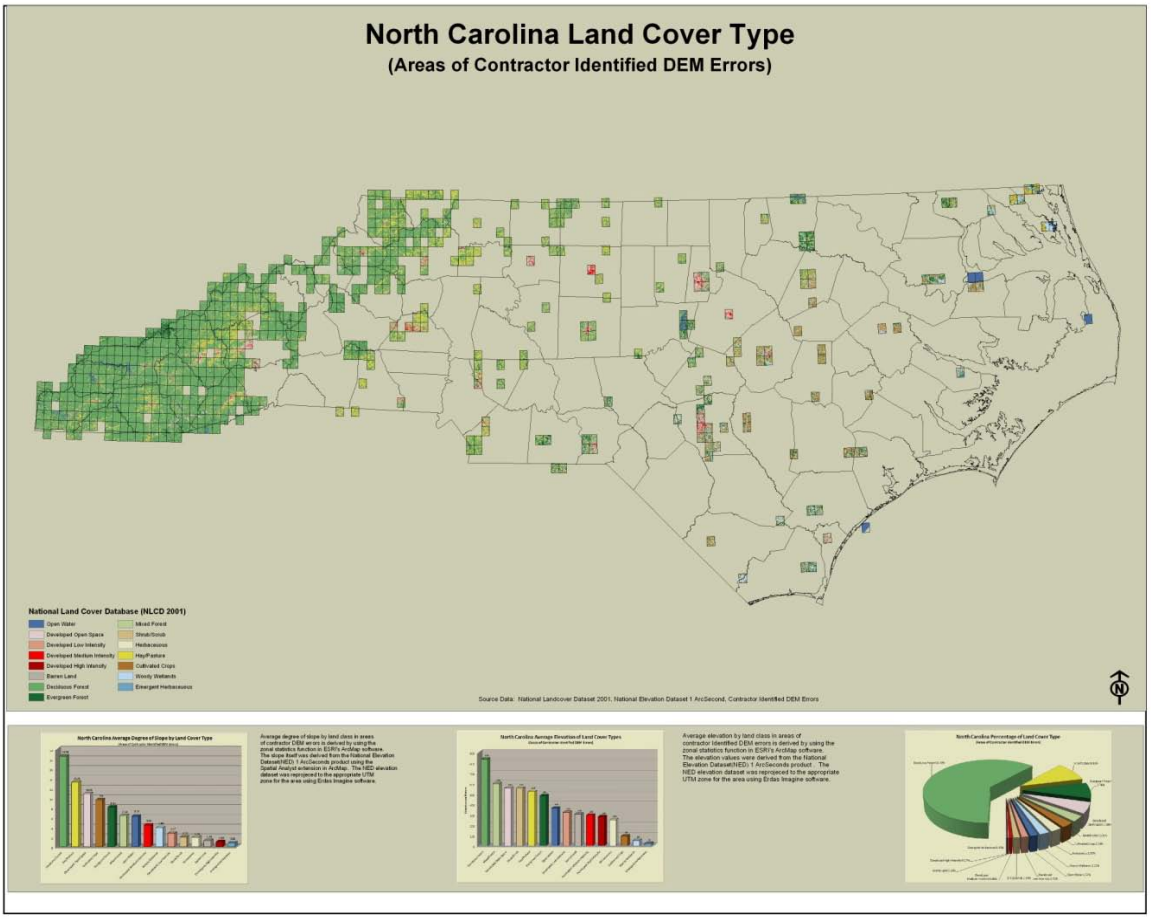


Chart 23: Percentage of State Total Land Cover Types of Contractor Identified Areas of DEM Errors Compared to State Total

In North Carolina, 621 out of 3,581 DOQQs, contained contractor identified DEM errors. All errors were characterized as major errors. Most errors occurred in the western tip of the state. Over 75 percent of the errors in North Carolina were in areas of forest or hay/pasture land. Average elevation in deciduous forest areas was also higher than in other land cover types. Average degree of slope was highest in the deciduous forest areas, with hay/pasture land second. There appears to be some correlation between higher degrees of slope and land cover types that were observed in areas of contractor identified DEM errors.



Map 5: North Carolina Land Cover Type in Areas of Contractor Identified DEM Errors

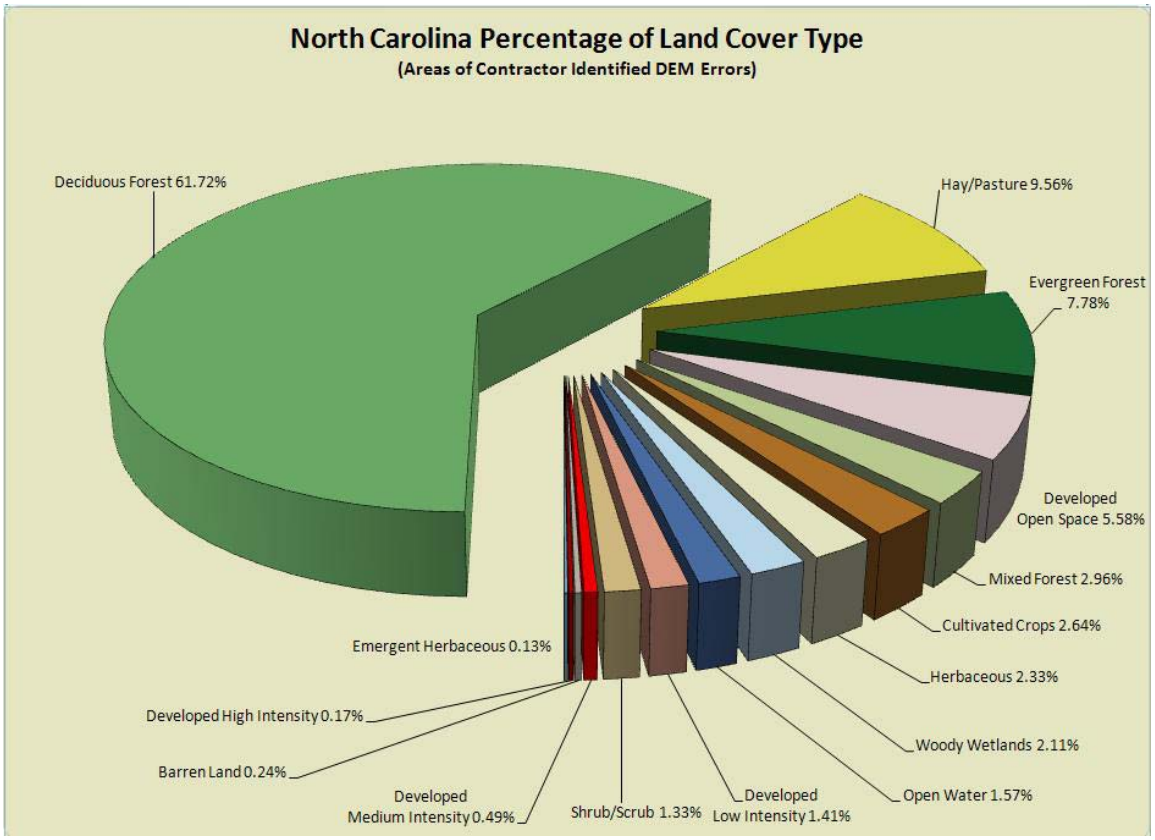


Chart 24: North Carolina Percentage of Land Cover Types in Areas of Contractor Identified DEM Errors

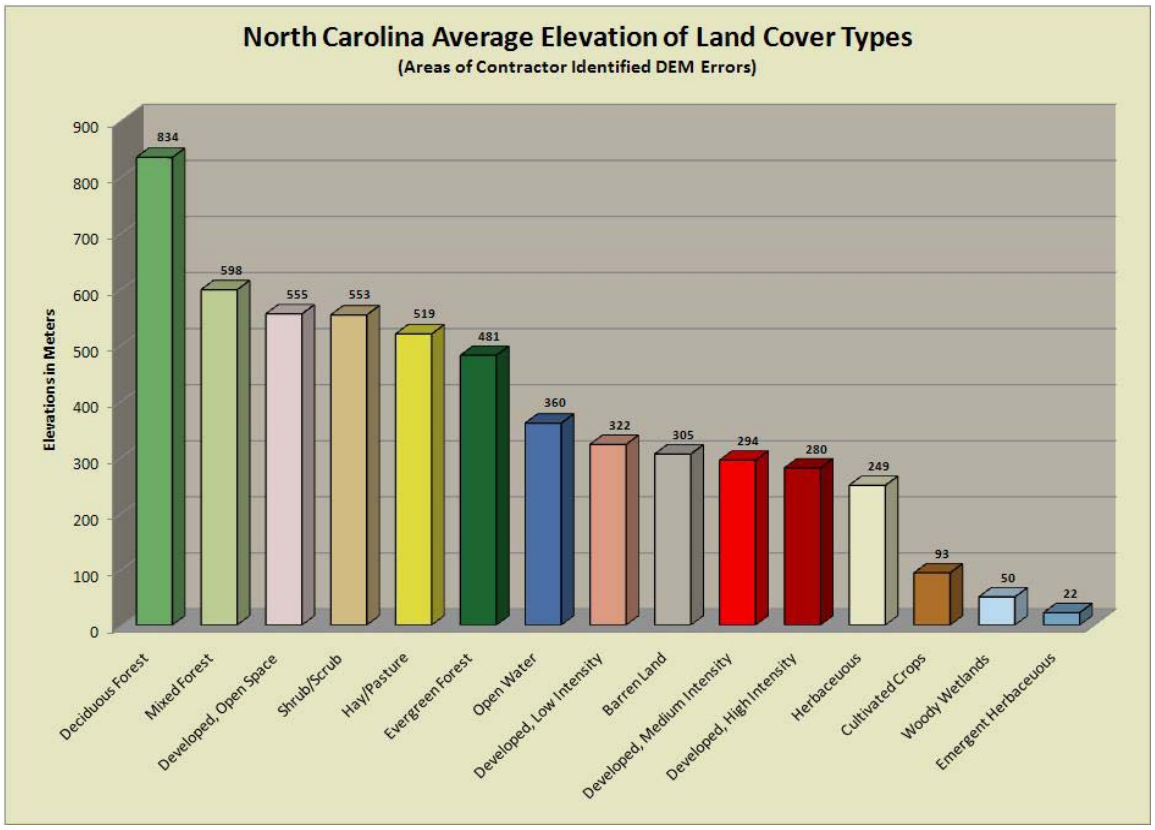


Chart 25: North Carolina Average Elevation of Land Cover Types in Areas of Contractor Identified DEM Errors

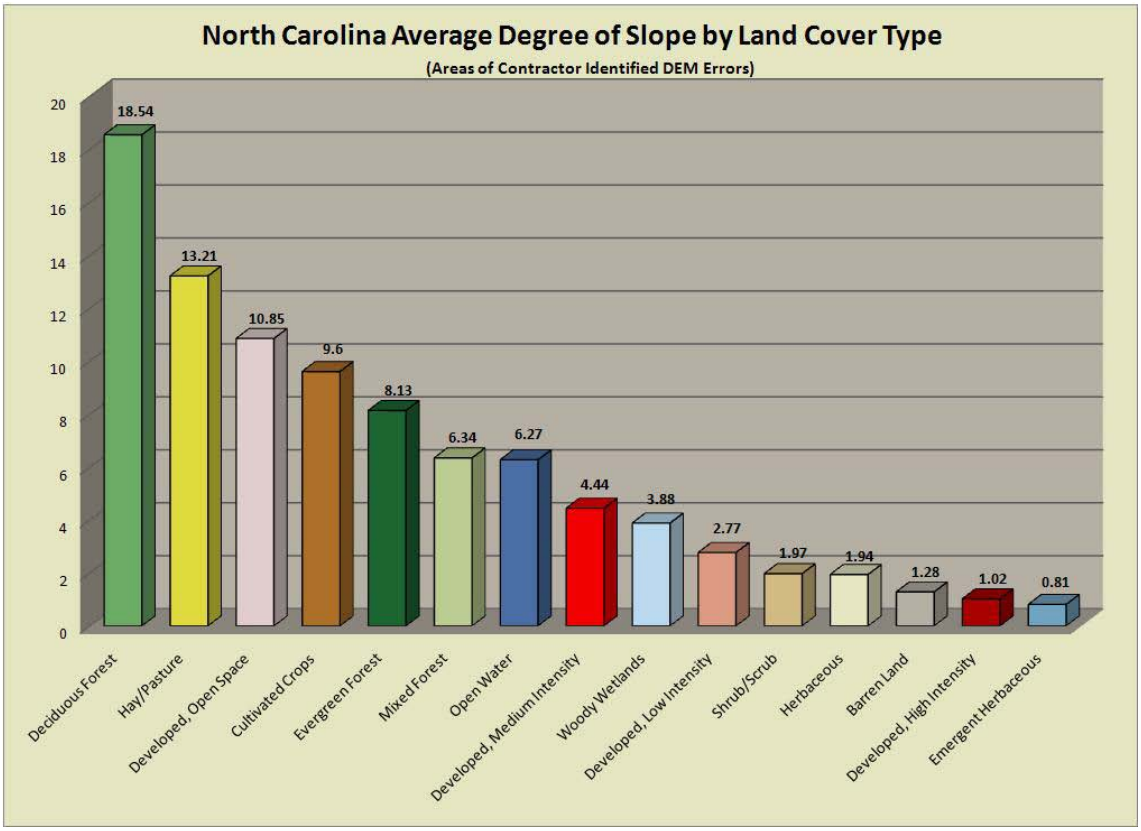
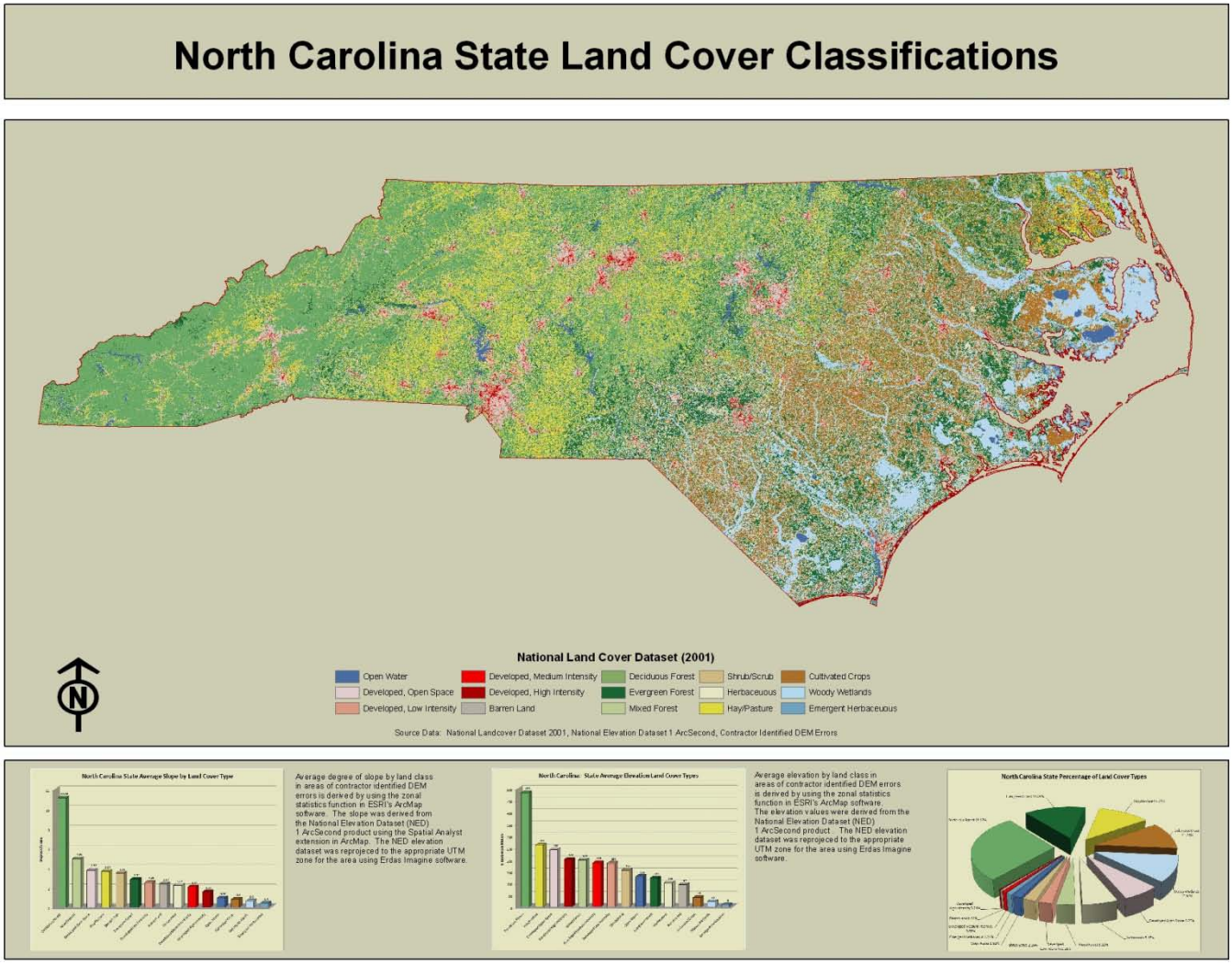


Chart 26: North Carolina Average Degree of Slope by Land Cover Type in Areas of Contractor Identified DEM Errors

The following charts and maps show the percentage of land cover types according to the NLCD 2001 for the entire state of North Carolina. By comparing these results with the results of the contractor identified areas of DEM errors you can get an idea of how the contractor identified areas of DEM errors relates to the whole state. Again, North Carolina has been studied by comparing the area of observed errors to what average land cover types, slope, and elevation are found at the state level.

Approximately 42 percent of the total land cover types for the state as a whole are deciduous forest and evergreen forest. Another 23 percent of the state contains hay/pasture and cultivated crops land cover types. Compared to the state percentages of land cover, the contractor identified DEM errors occurred mainly in areas of deciduous forest and hay/pasture. There appears to be some correlation between where the most numerous identified errors occur and the total land cover types in the state. Average elevation and average slope statewide are greatest in areas of deciduous forest.



Map 6: North Carolina State Land Cover Classifications

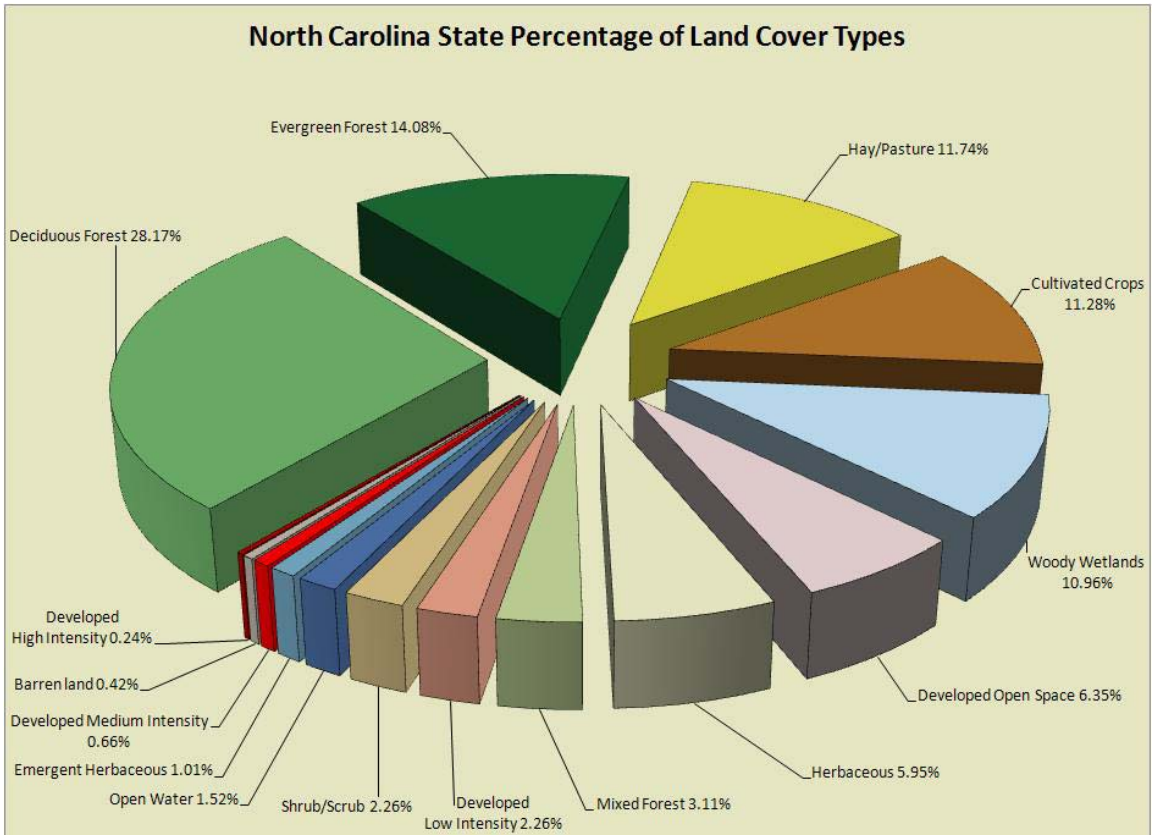


Chart 27: North Carolina State Percentage of Land Cover Types

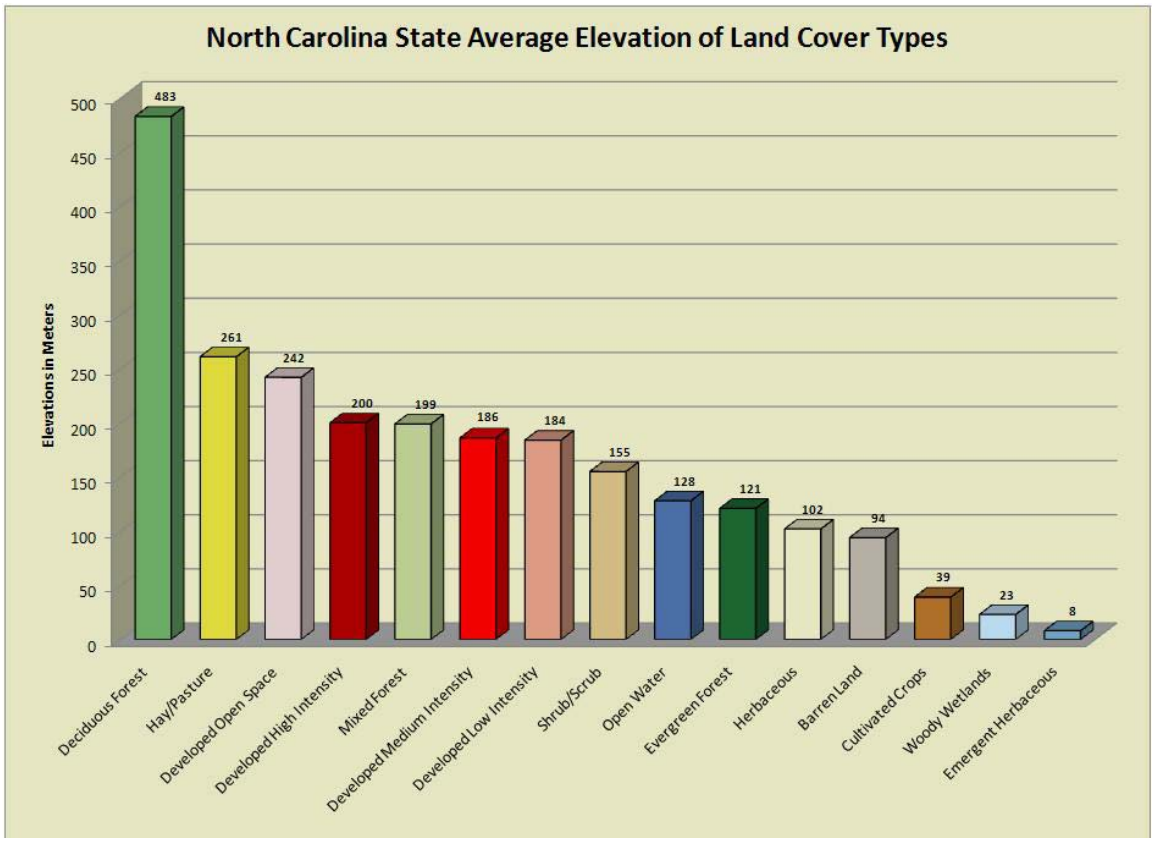


Chart 28: North Carolina State Average Elevation of Land Cover Types

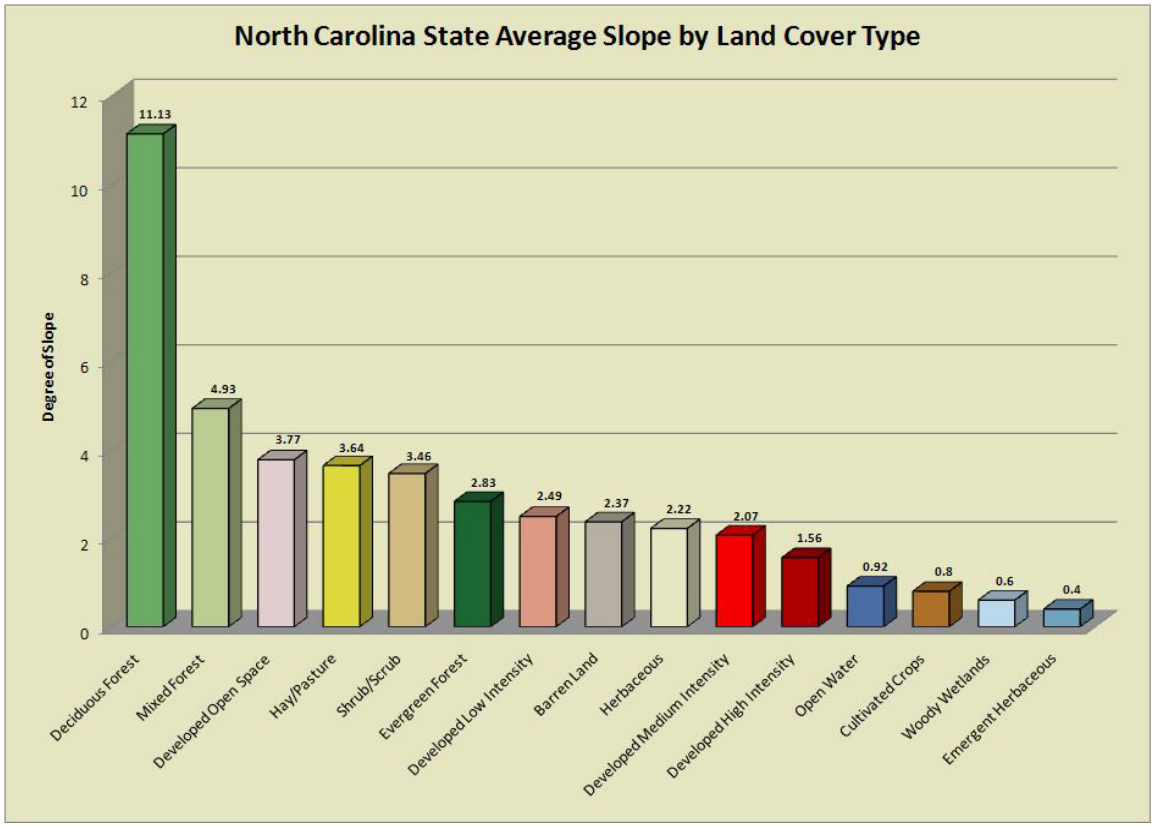


Chart 29: North Carolina State Average Slope by Land Cover Type

The following charts show a comparison between the state as a whole and areas of contractor identified DEM errors. Some interesting trends from the comparison are that average elevations of land cover types are lower in the state across all land cover types. Average state slope is higher than the slope in areas of contractor observed errors in the following land cover types: shrub/scrub, barren land, herbaceous, and developed high intensity. This could indicate that errors in these areas may not have a strong correlation to slope. Contractor observed areas of DEM errors that have higher average slope than the state average could indicate that these errors may have some correlation with higher slope. The land cover types that display this trend in North Carolina are deciduous forest, developed open space, hay/pasture, evergreen forest, open water, mixed forest, and cultivated crops.

Deciduous forest had a higher percentage of observed errors (61.72%) than any other land cover type. Deciduous forest is also the most predominant land cover type in the state. There is a strong correlation between contractor observed DEM errors and predominant land cover type in North Carolina. The percentage of state deciduous forest, and land cover type where errors were observed was also high, at 41.77%. Land cover types that make up a very small percentage of the state total but have a high percentage of observed error may indicate that these land cover types may present more serious error than deciduous forest. An example of this phenomenon is the developed high intensity land cover type, which only makes up 0.24% of the state total and has a percentage of contractor observed error of 13.52%.

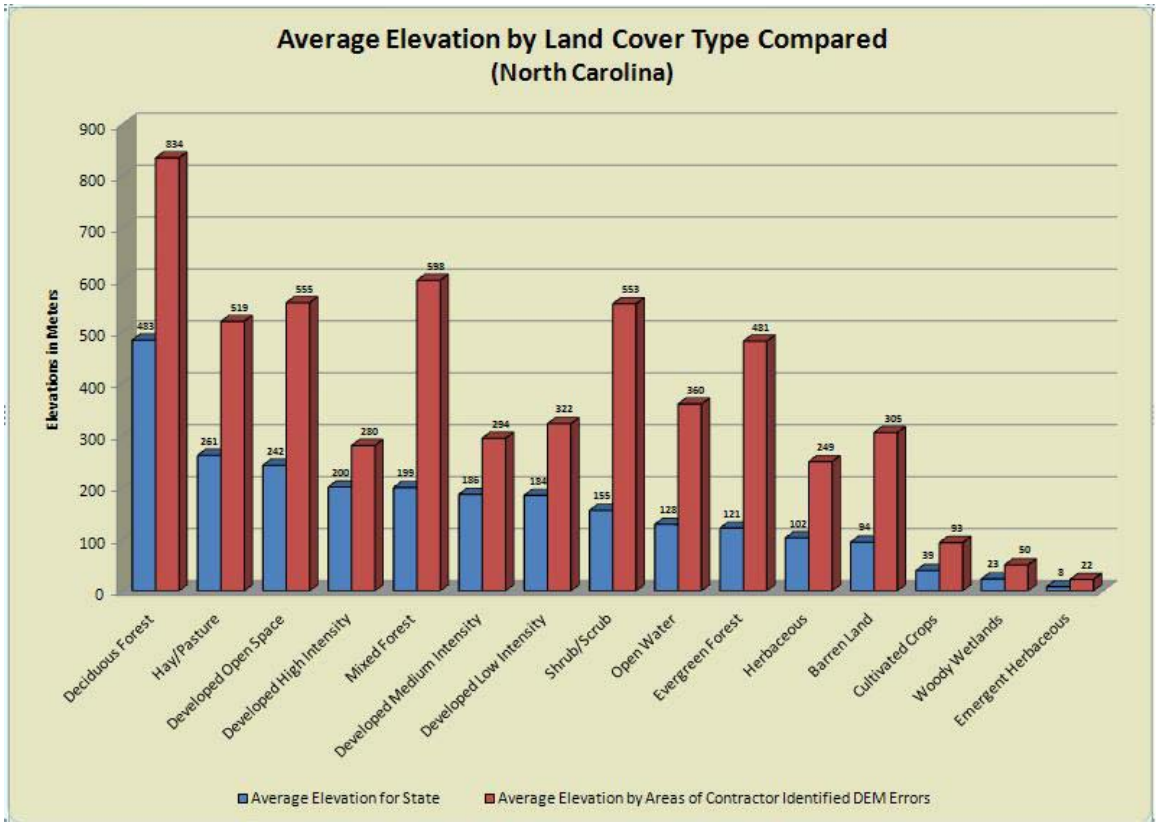


Chart 30: Average Elevation State Total Compared to Areas of Contractor Identified DEM Errors

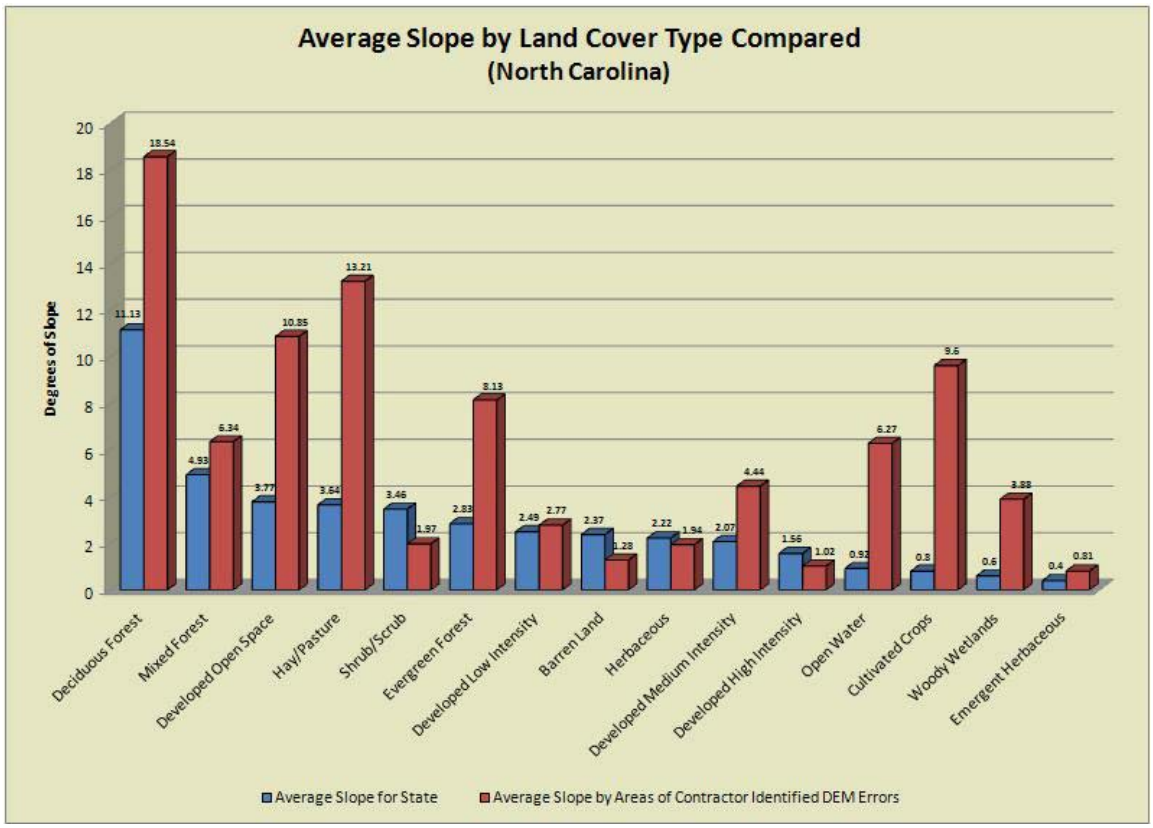


Chart 31: Average Slope State Total Compared to Areas of Contractor Identified DEM Errors

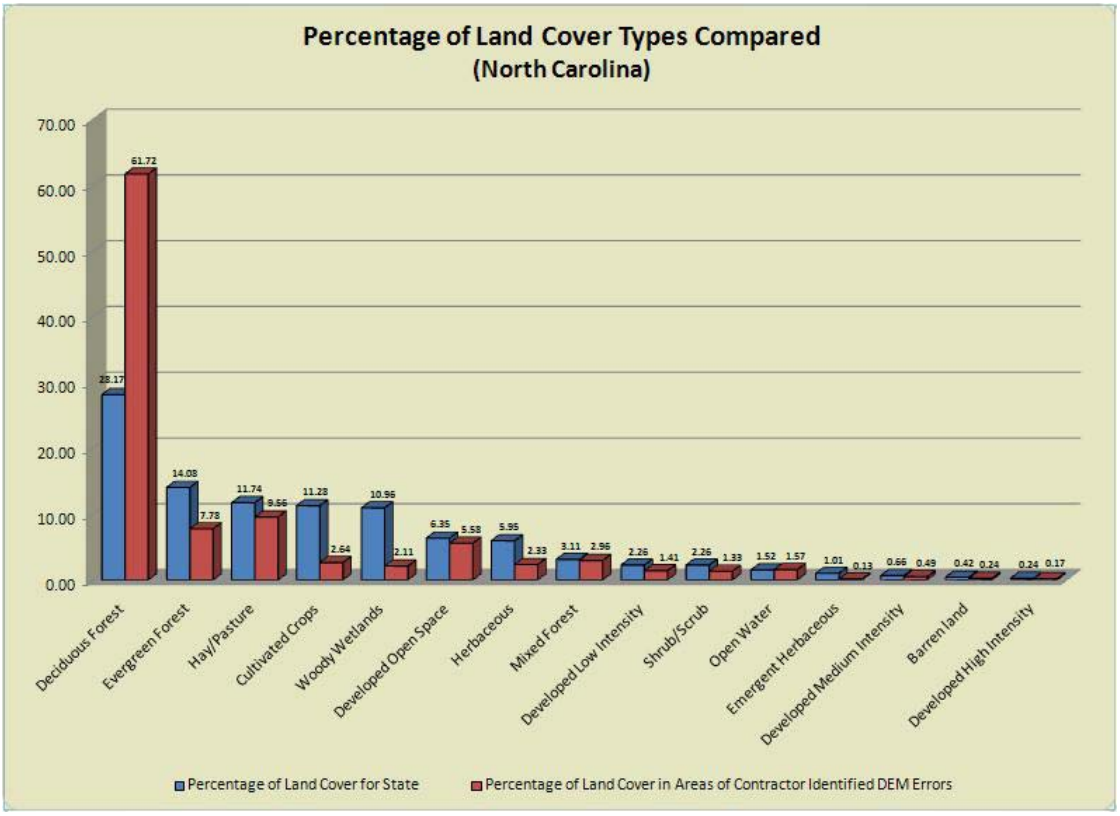


Chart 32: State Total Percentage of Land Cover Types Compared to Areas of Contractor Identified DEM Errors

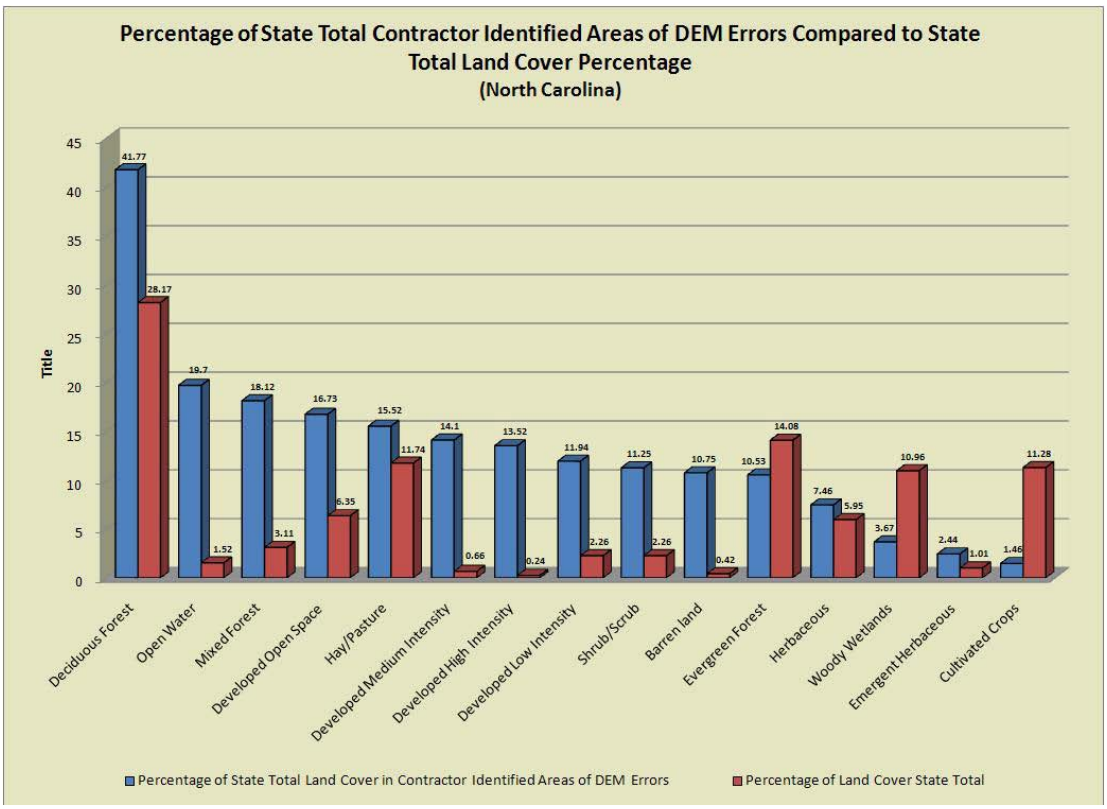
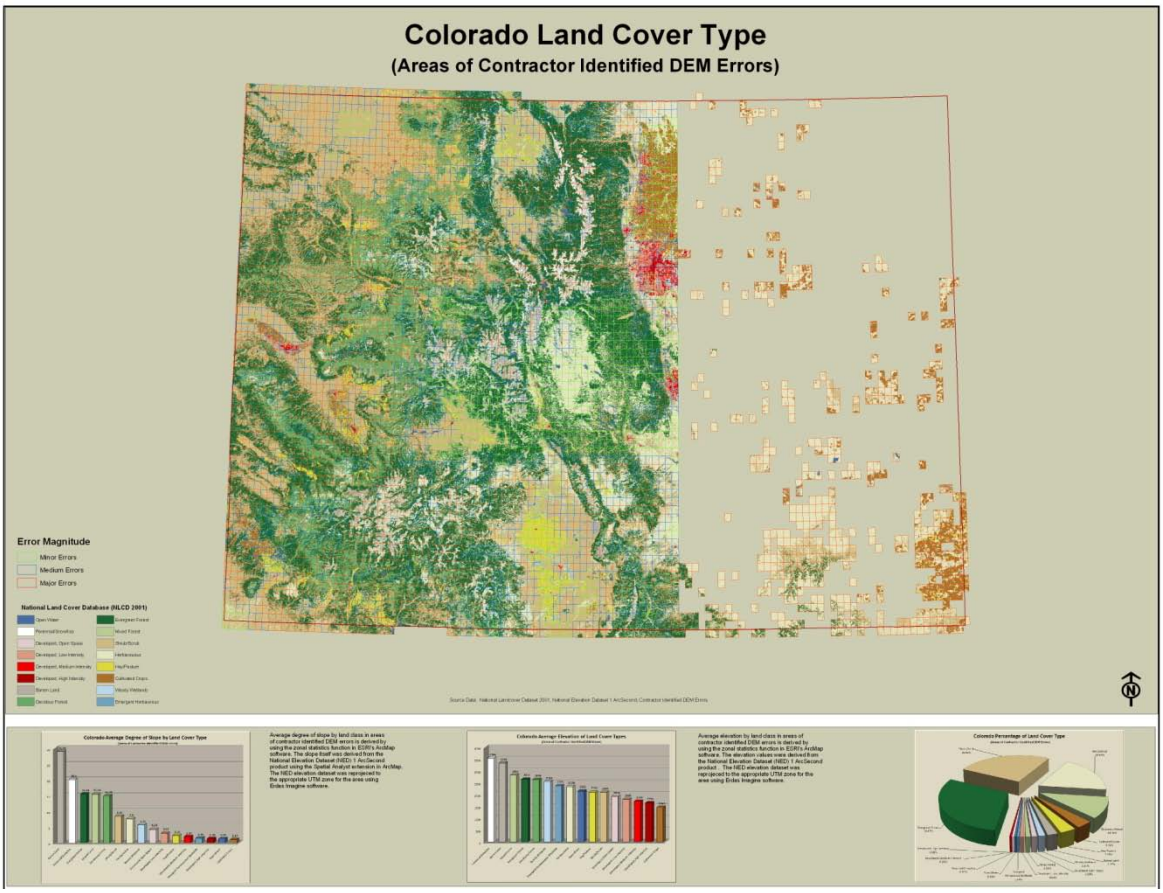


Chart 33: Percentage of Land Cover Types within Contractor Identified Areas of DEM Errors Compared to percentage of Land Cover Types within the Entire State

In Colorado, 5,011 of 7,424 DOQQs, contained contractor identified DEM errors. The errors were characterized as minor, moderate and major errors. Of these types of errors 2794 were characterized as major errors, 1462 were moderate and 755 were minor errors. Most of the errors were concentrated in the western two thirds of the state. Over forty percent of the DEM errors were in areas of forest and another forty percent consisted of shrub/scrub and herbaceous or grassy areas. The highest average elevations of land cover types occurred in the perennial snow/ice, barren land and evergreen, deciduous and mixed forest areas. These same trends were seen with the average degree of slope for these land cover types.



Map 7: Colorado Land Cover Types in Areas of Contractor Identified DEM Errors

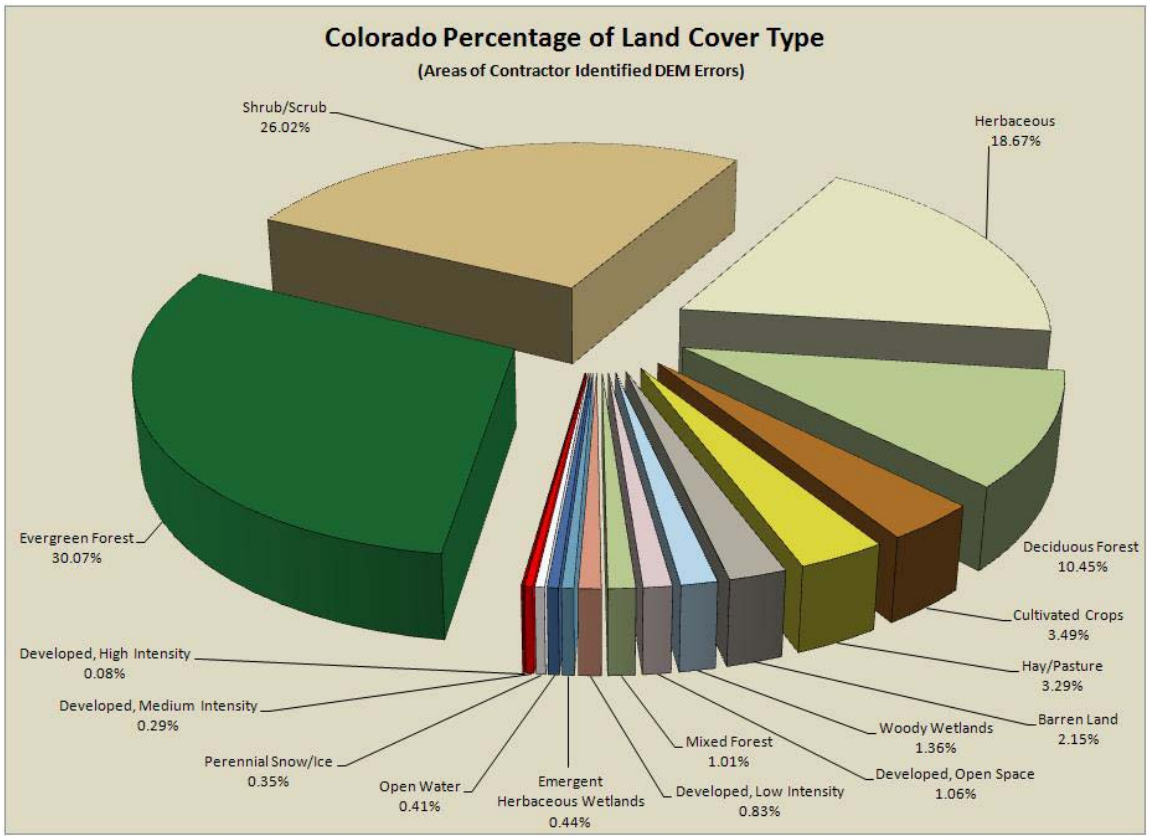


Chart 34: Colorado Percentage of Land Cover Type in Areas of Contractor Identified DEM Errors

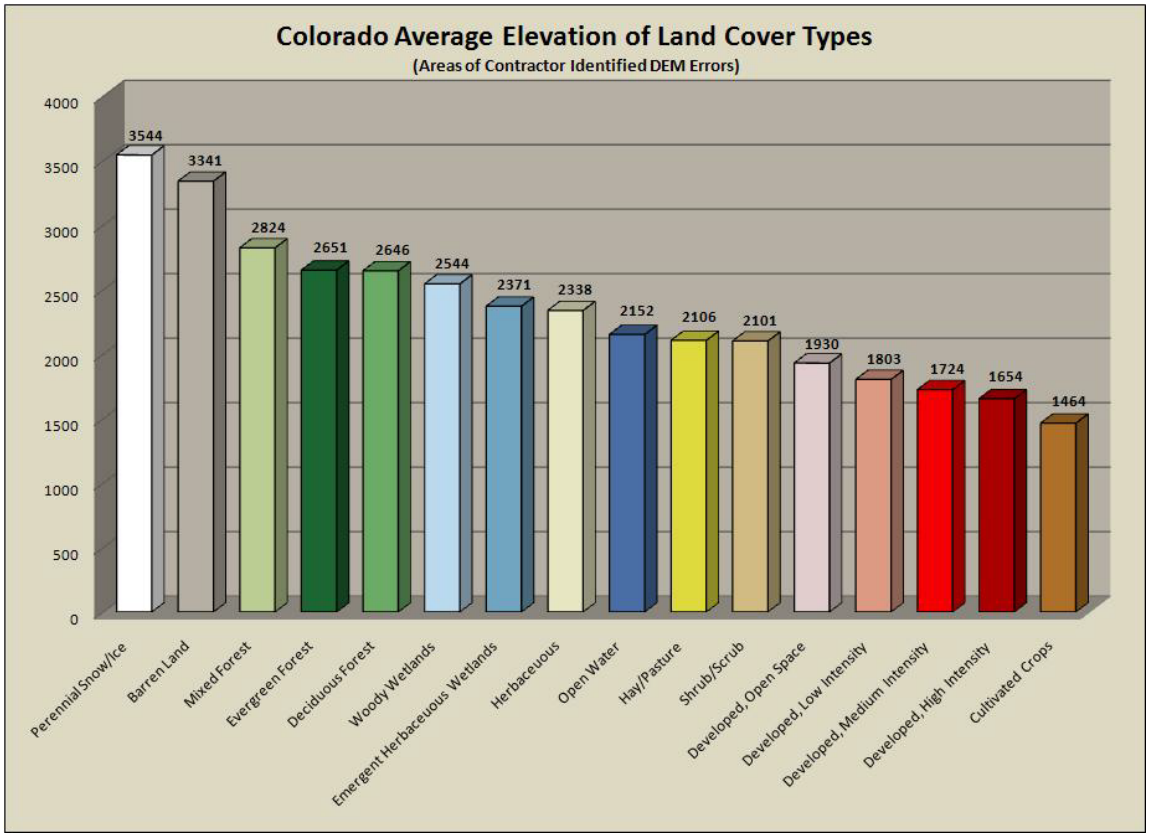


Chart 35: Colorado Average Elevation of Land Cover Types in Areas of Contractor Identified DEM Errors

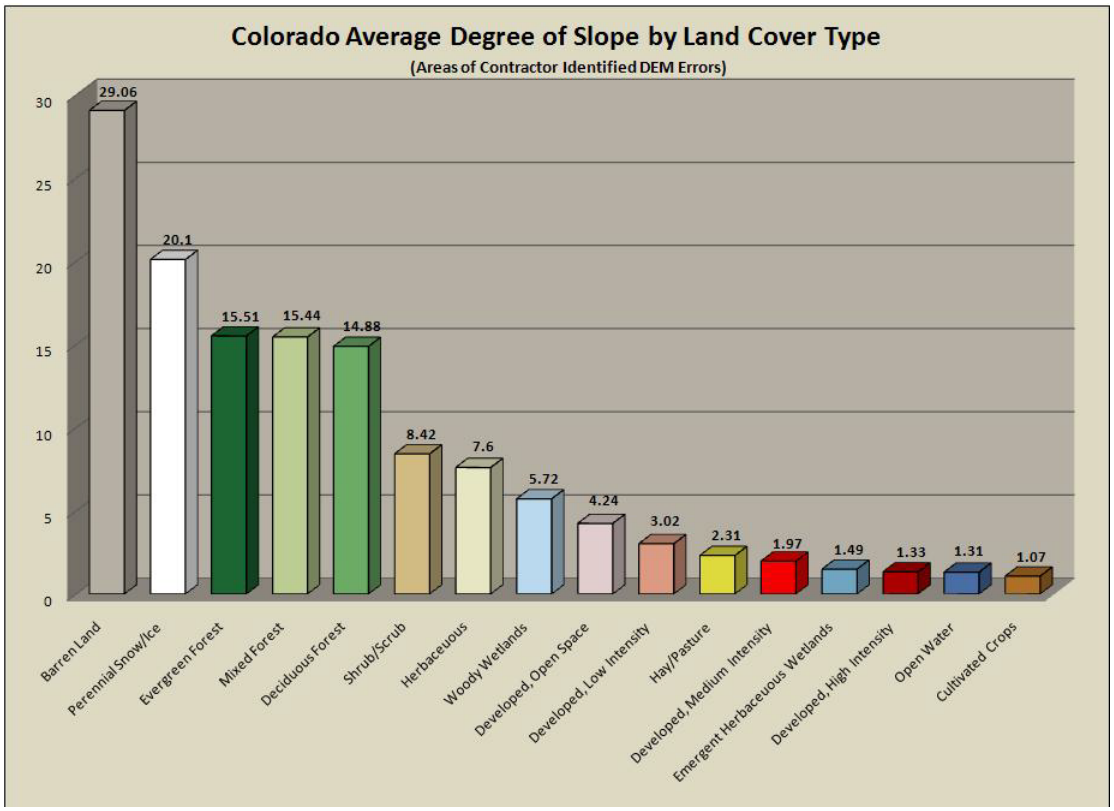


Chart 36: Colorado Average Degree of Slope by Land Cover Type in Areas of Contractor Identified DEM Errors

The following charts indicate the percentage of land cover type according to contractor identified error magnitude in Colorado. Colorado was the only state that had a variety of error magnitudes. All other states had only major observed errors while Colorado had minor and moderate errors as well as major observed errors. Evergreen forest, herbaceous, and shrub/scrub land cover types show the highest percentage of errors in all error magnitude types.

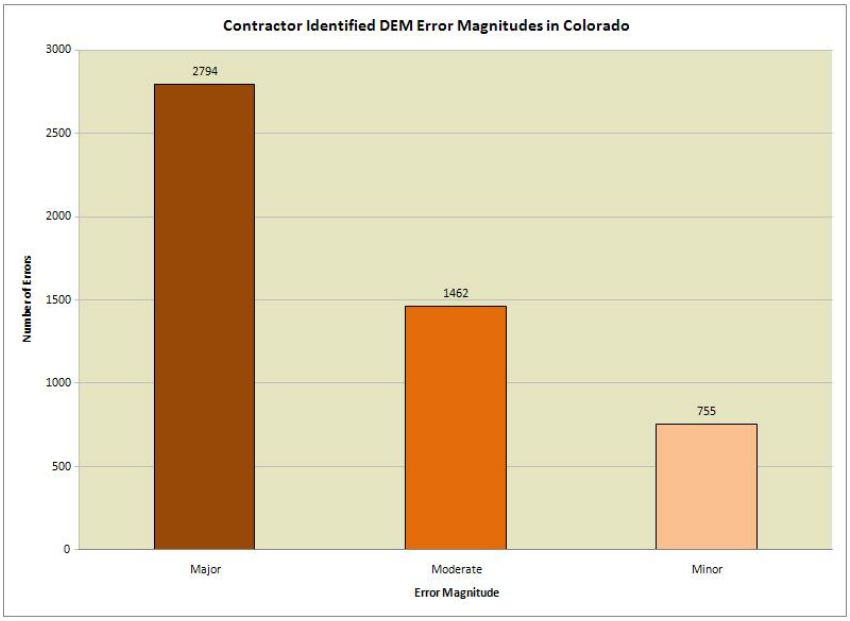


Chart 37: Contractor Identified DEM Error Magnitudes in Colorado

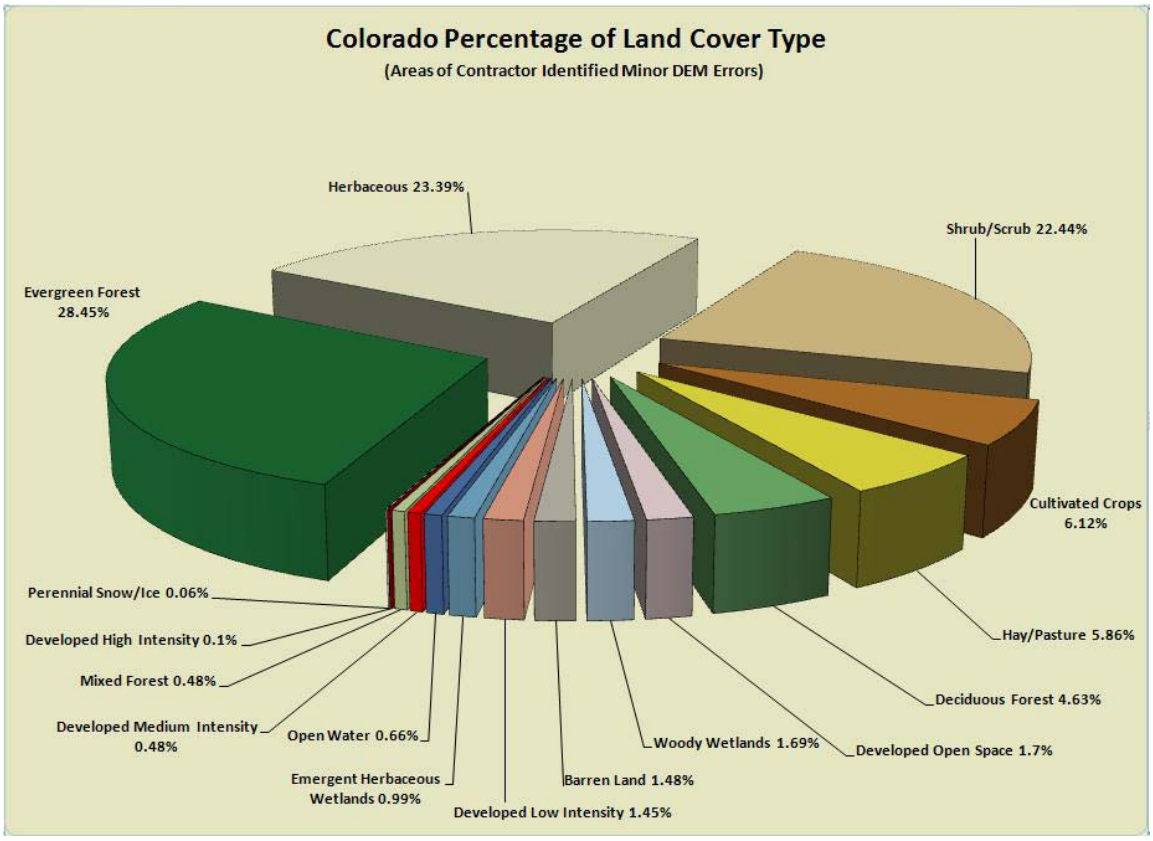


Chart 38: Colorado Percentage of Land Cover Type in Areas of Contractor Identified Minor DEM Errors

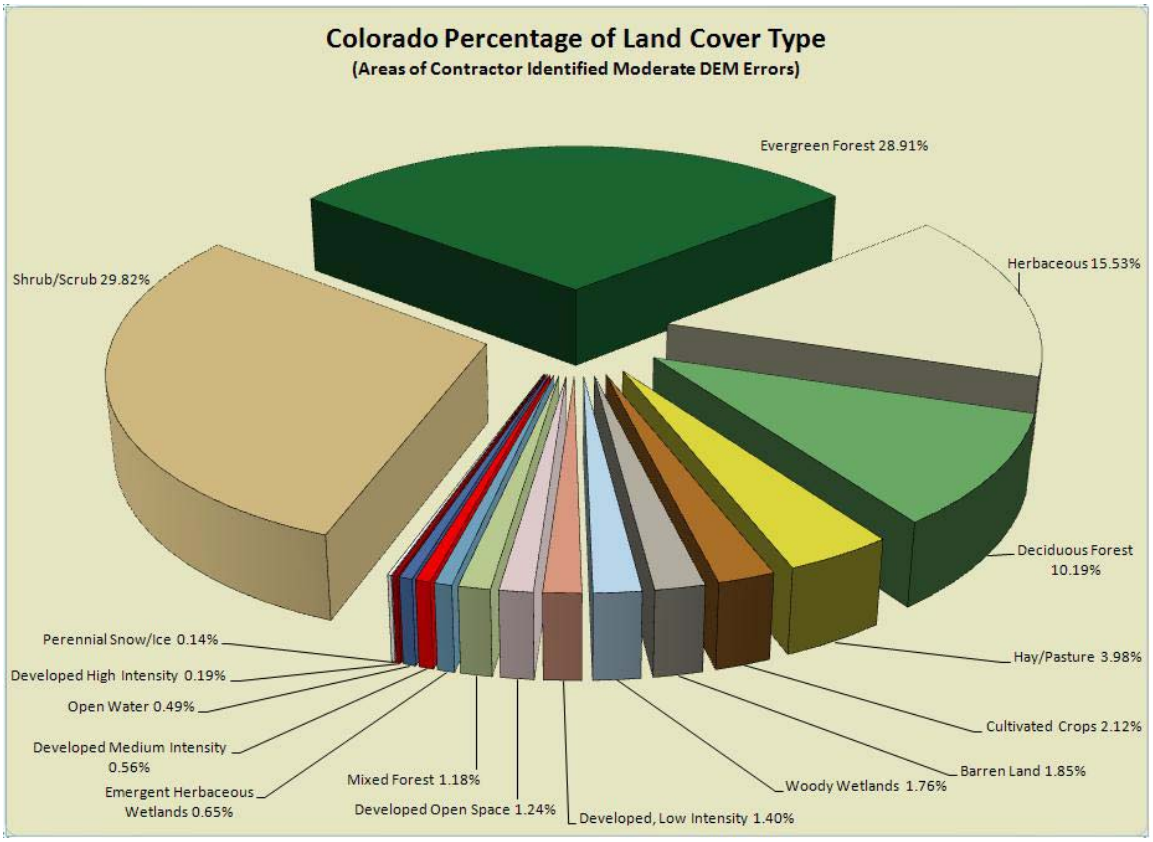


Chart 39: Colorado Percentage of Land Cover Type in Areas of Contractor Identified Moderate DEM Errors

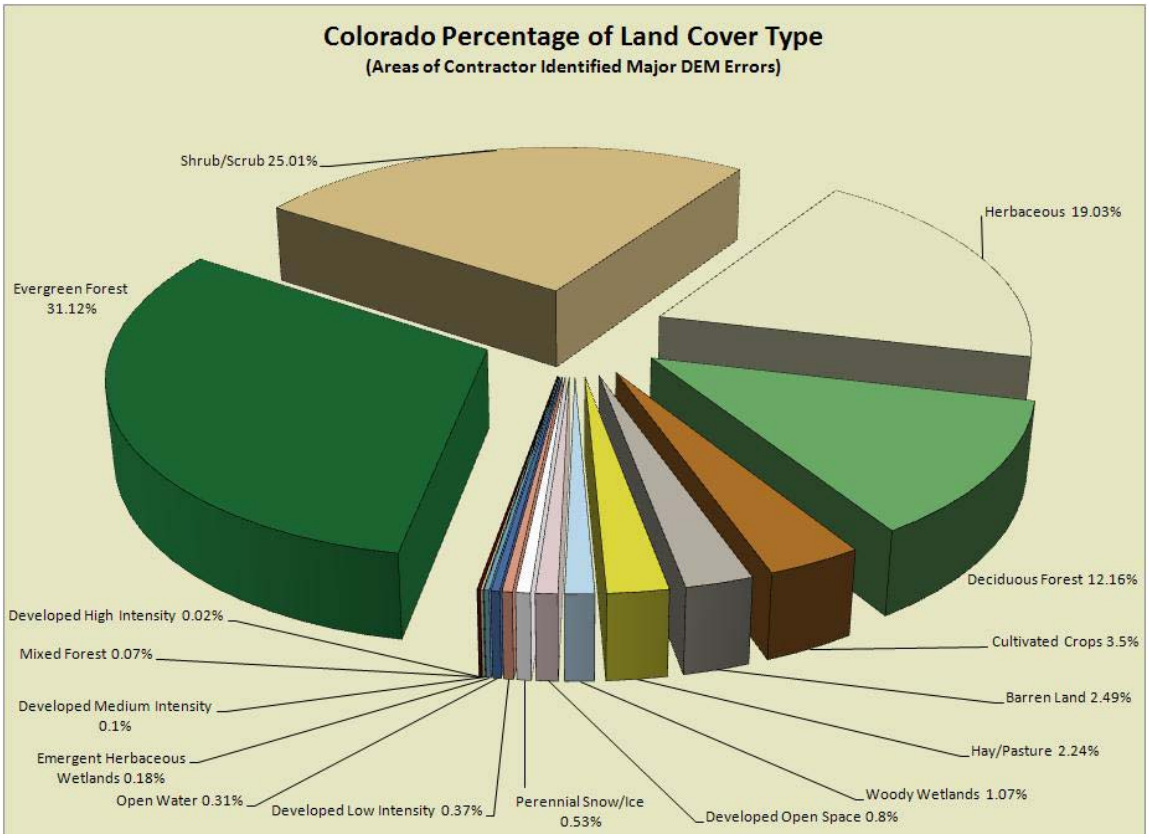
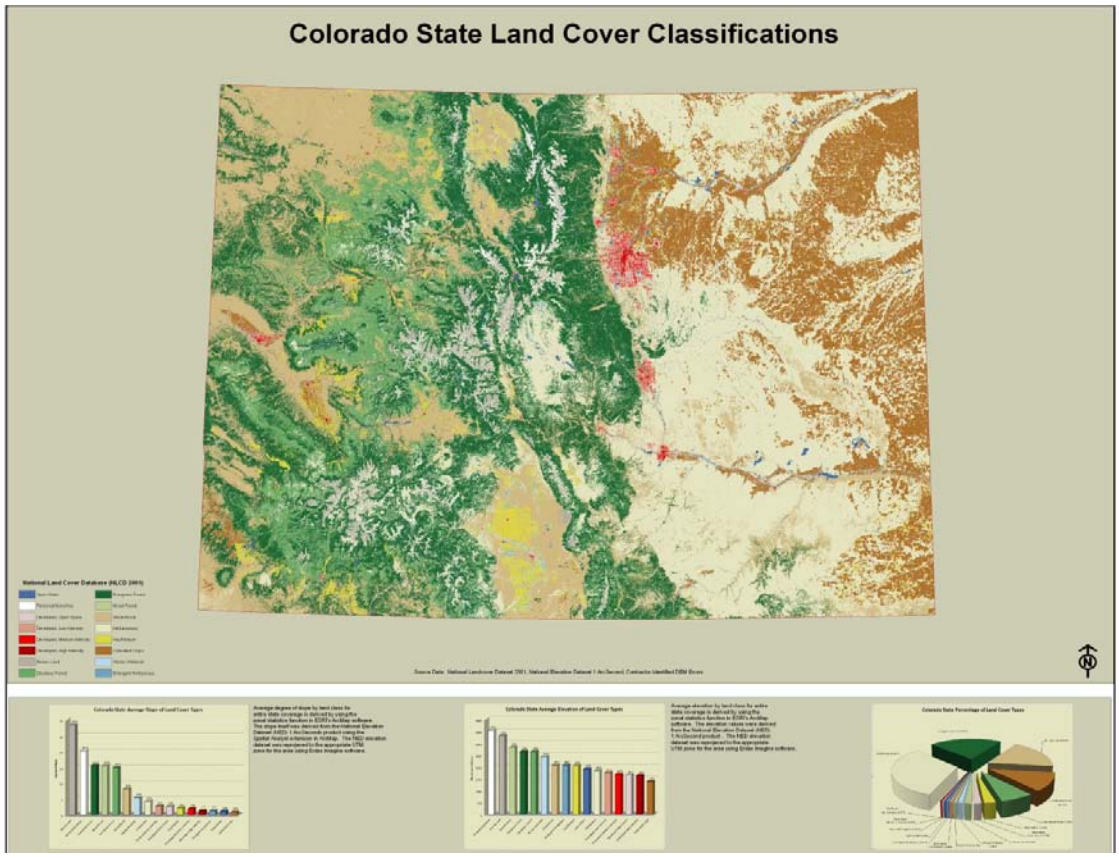


Chart 40: Colorado Percentage of Land Cover Type in Areas of Contractor Identified Major DEM Errors

The following charts and maps show the percentage of land cover types according to the NLCD 2001 statewide for Colorado. By comparing these results with the results of the contractor identified areas of DEM errors you can get an idea of how the contractor identified areas of DEM errors relate to the whole state. Colorado was studied by comparing the area of observed errors to the state as a whole.

State land cover percentages mirror contractor identified areas of DEM errors. Herbaceous makes up approximately 32% of the state total, evergreen forest 21% and shrub/scrub 19%. There appears to be some correlations between where the most numerous identified errors occur and the total land cover types in Colorado.

Average elevation and average slope statewide are greatest in areas of perennial snow/ice and barren land. These two land cover types are a very small percentage of the state total, 0.24% and 1.54% respectively.



Map 8: Colorado State Land Cover Classifications

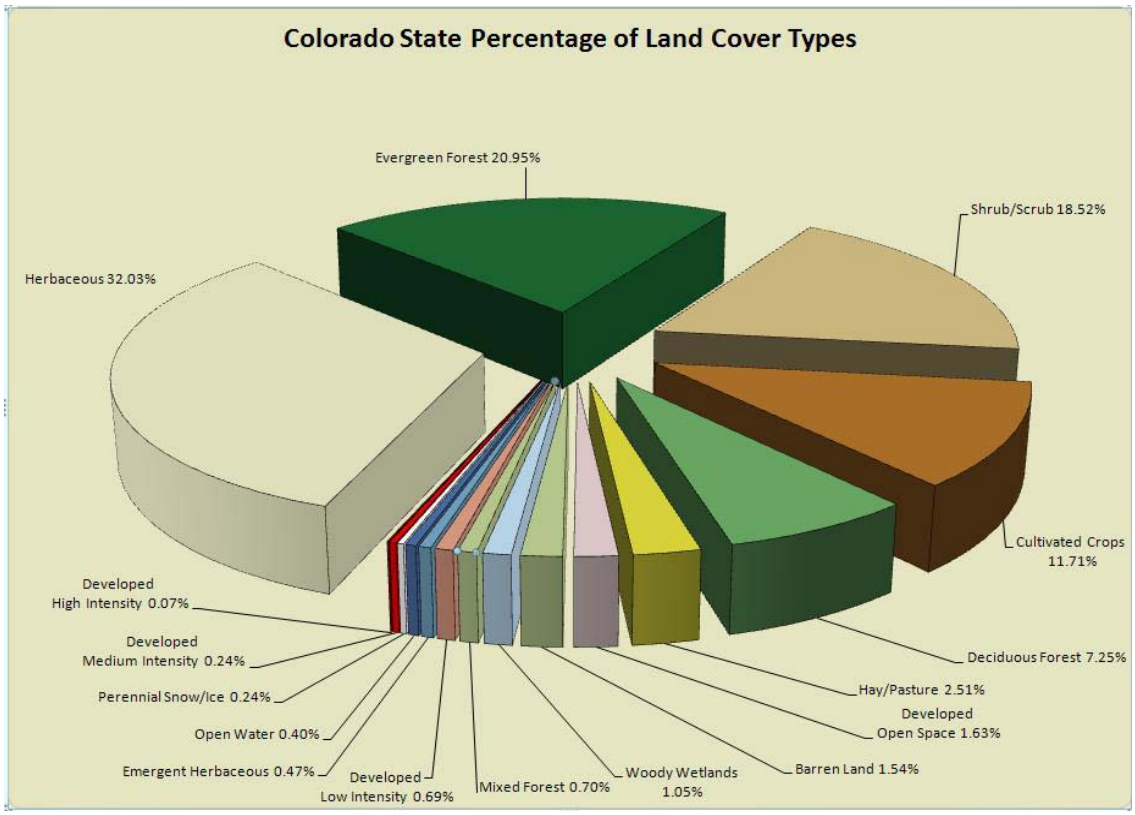


Chart 41: Colorado State Percentage of Land Cover Types

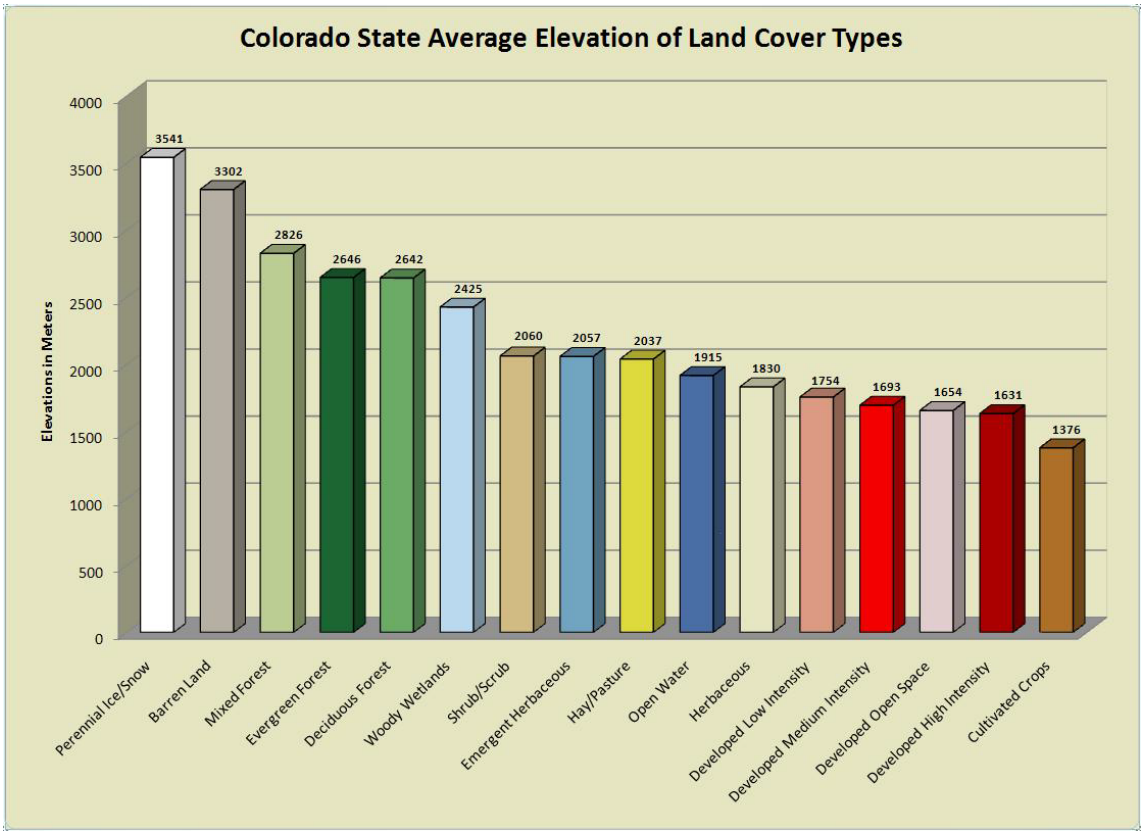


Chart 42: Colorado State Average Elevation of Land Cover Types

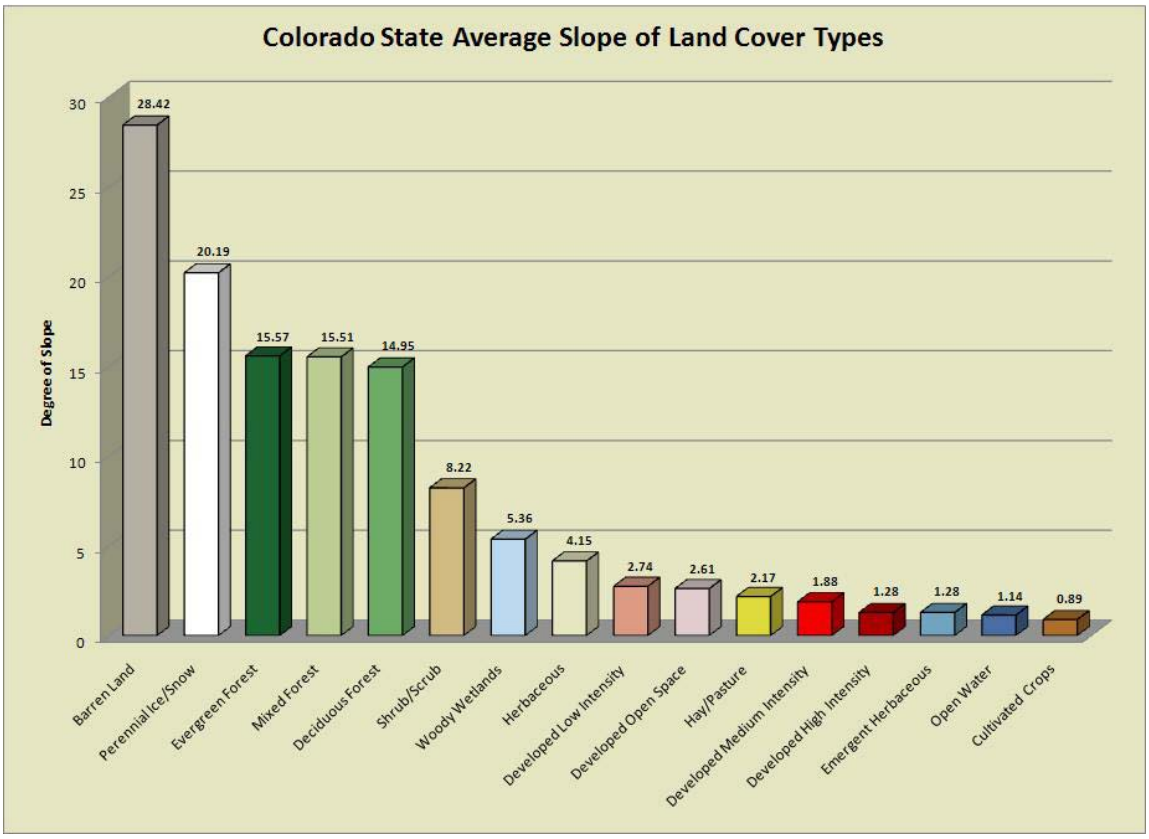


Chart 43: Colorado State Average Slope of Land Cover Types

The following charts show a comparison between the state as a whole and areas of contractor identified DEM errors. Colorado is somewhat different from the previous states in that there is a much higher percentage of contractor observed DEM errors here. Contractor observed DEM errors identified were present on 68% of the DOQQs which make up the state.

Some interesting trends from the comparison are that average elevations of land cover types are higher in the state as a whole in the following land cover types: perennial ice/snow, mixed forest, evergreen forest, deciduous forest, woody wetlands and developed open space. On the other hand, the state total is lower than the observed errors total in the following land cover types: barren land, shrub/scrub, emergent herbaceous wetlands, hay/pasture, open water, herbaceous, developed low intensity, developed medium intensity, developed high intensity and cultivated crops. Average state slope is very similar across all land cover types with the exception of herbaceous and developed open space, which are higher in areas of observed errors. Percentages of land cover types in the state as a whole are higher than percentage of observed errors in the land cover types in areas of herbaceous, cultivated land, developed open space, emergent herbaceous wetlands and open water.

Several land cover types appear to occur frequently in areas of contractor observed DEM errors due to their frequency of occurrence in the state. These land cover types include herbaceous, shrub/scrub, evergreen forest and deciduous forest. Observed DEM areas that have a high percentage of land cover types but do not make up a large percentage of the state total land area may indicate that there is more of a problem in these areas. Land cover types that have a high percentage of errors but make up only a small portion of the state land area are perennial ice/snow, mixed forest, barren land, developed high intensity, developed medium intensity, developed low intensity, open water, emergent herbaceous wetlands, and developed open space. It is likely that these percentages are so much higher in Colorado because a large portion of the state as a whole was identified by the contractor as having DEM errors. Perennial ice/snow had virtually 100% of the state area total having observed contractor errors. Other land cover types covering very high percentages of the state total land area, and also containing contractor observed errors were mixed forest (99.52%), deciduous forest (99.46%), evergreen forest (98.44%), barren land (97.49%) and shrub/scrub (93.09%).

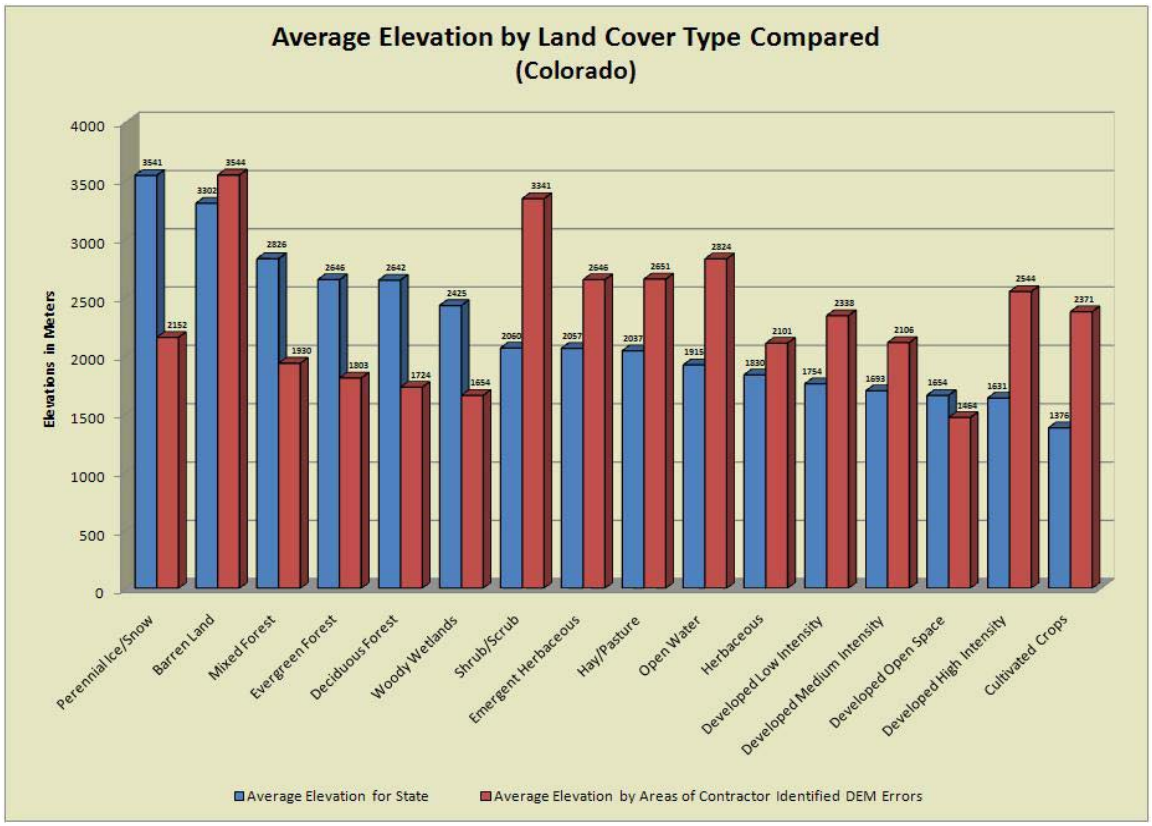


Chart 44: Average Elevation State Total Compared to Areas of Contractor Identified DEM Errors

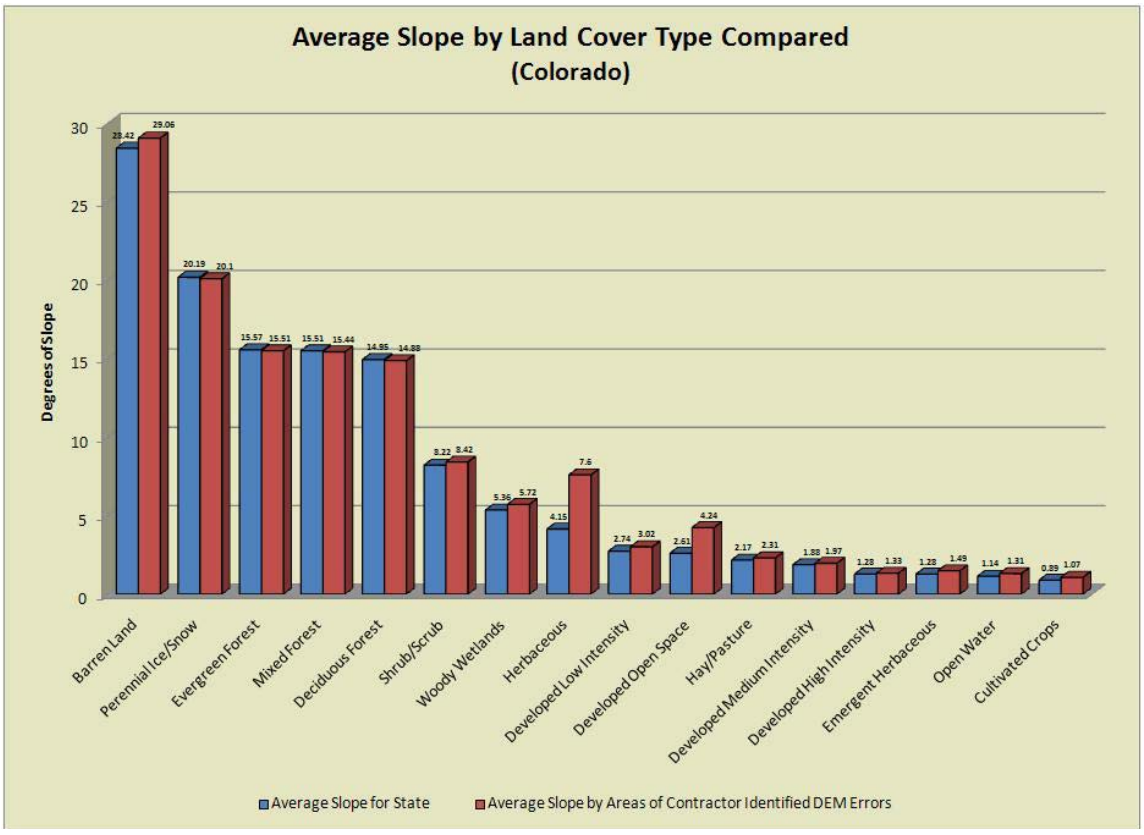


Chart 45: Average Slope State Total Compared to Areas of Contractor Identified DEM Errors

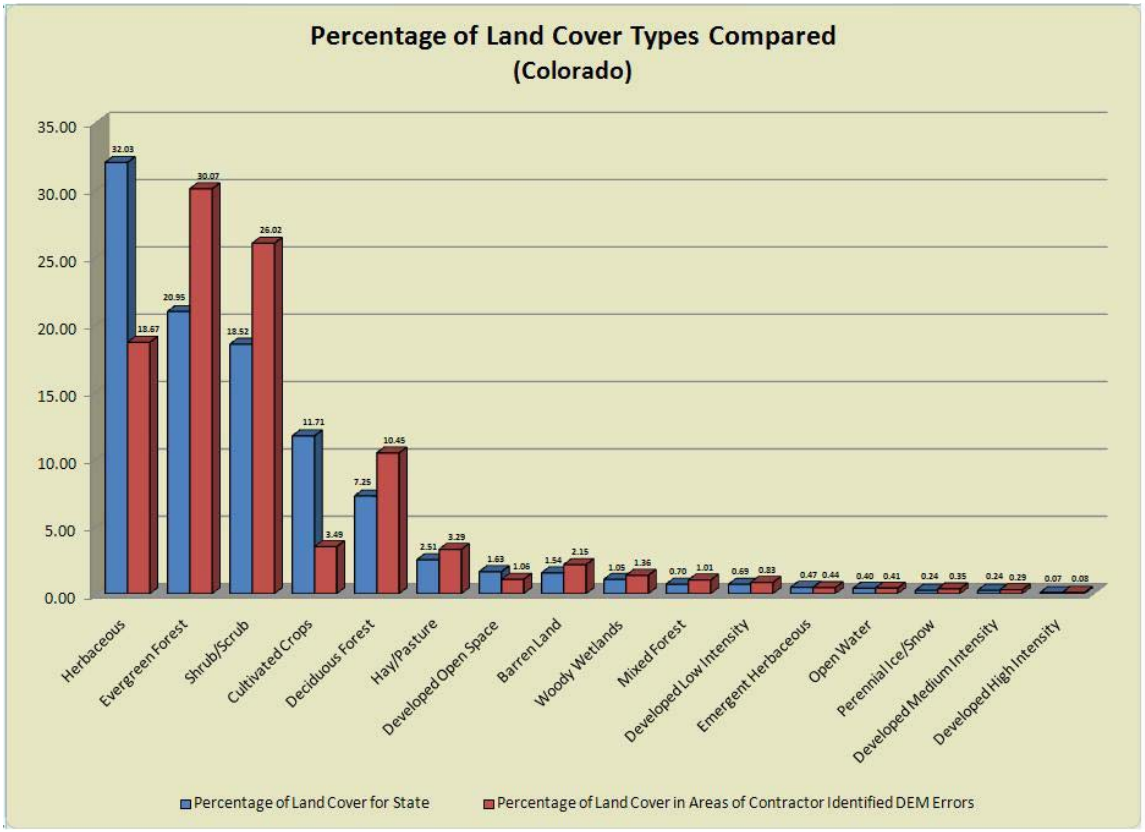


Chart 46: Percentage of State Land Cover Types Compared to Areas of Contractor Identified DEM Errors

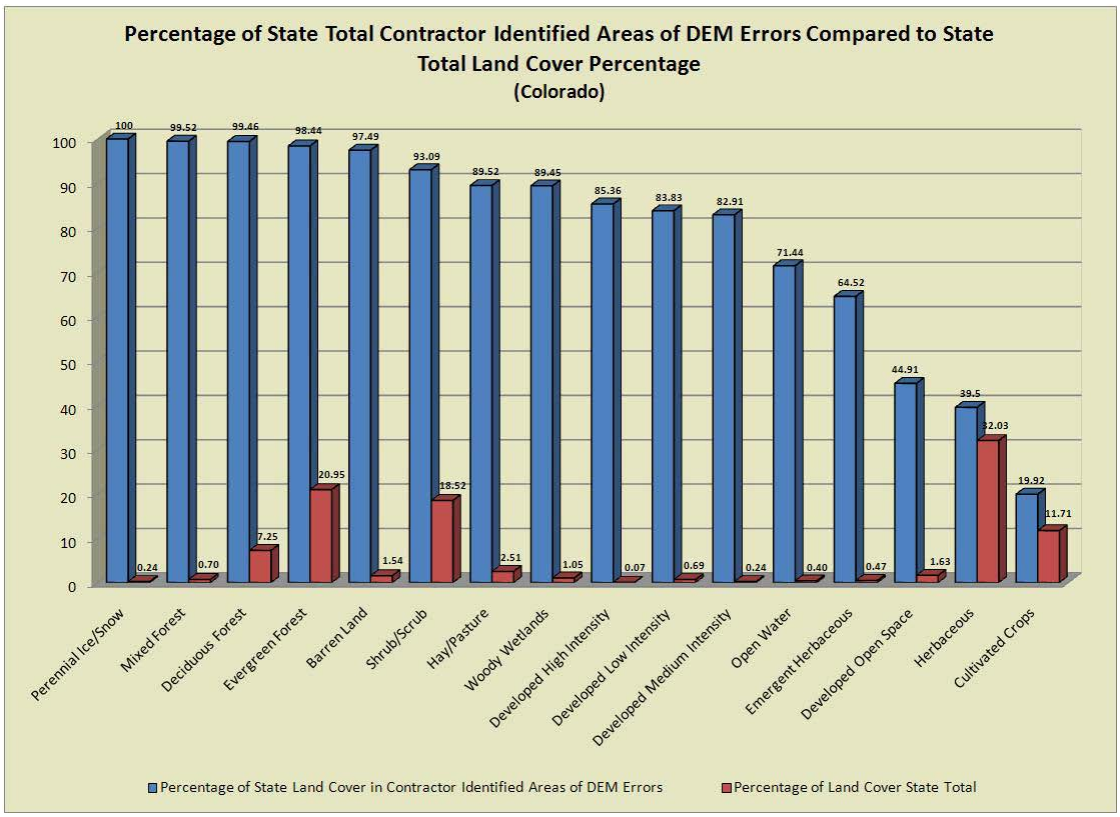


Chart 47: Percentage of State Total Land Cover Types of Contractor Identified Areas of DEM Errors Compared to State Total

Land Classification Accuracy Assessment for Contractor Identified Areas of DEM Errors

In addition to the spatial analysis of the area using the NLCD 2001 dataset and the NED dataset an accuracy assessment was performed on the land cover classifications as they compare to the NAIP 2009 imagery. The accuracy assessment was done in ArcMap using the Create Random Points tool with the state boundary as the envelope. After an initial set of random points was generated, the Extract Values to Points tool was run to identify which points actually fell in the area of interest. The final number of points was obtained by a random systematic deletion of points until 150 were left for the accuracy assessment. Each state's accuracy assessment used the preceding methods except Colorado and North Carolina, which used a set of 200 points, as their error count was much higher.

An accuracy assessment is often done using ground observations or higher resolution imagery. In this case the NAIP 2009 imagery is 1-meter compared to the 30 meter resolution of the NLCD 2001 dataset. The NLCD 2001 dataset was visually assessed using the random points to determine if the land cover class at the point was accurate to the NAIP imagery.

The error or confusion matrix generated from the accuracy assessment gives the analyst some idea of how accurate the classification using the NLCD 2001 dataset is compared to what is present on the NAIP 2009 imagery. The values listed on the diagonal of the matrix are those that have been classified correctly. By adding up these values, the percentage of correctly classified values (PCC) is obtained. The PCC gives a basic summary of the matrix but does not take into account how many of the classifications may have occurred by chance. At the bottom of each matrix is the Kappa index, which is a statistic that shows the percentage of correctly classified values minus those that could be accounted for by chance. The Kappa index removes the classifications that can be equated to chance from the equation. Also listed on the matrix is the producer's accuracy and the user's accuracy. The producer's accuracy measures how accurately the analyst (producer of the NLCD 2001 dataset) classified the image data by category. Producer's accuracy also refers to errors of omission or the probability that the land cover type indicated is correctly mapped. An error of omission results when a pixel is omitted from its correct class. The user's accuracy refers to errors of commission or the probability that the land cover type sampled really matches the reference data, in this case the NAIP 2009 imagery. An error of commission results when pixels are assigned to an incorrect class.

North Carolina had the greatest percentage of correctly classified values at 89% while Mississippi had the smallest percentage of correctly classified values at 78.7%. Some error encountered is likely due to some misregistration between the two data sets. Some land cover types are more accurate than others across all areas. Open Water, Woody Wetlands, Deciduous Forest, Developed Low Intensity and Evergreen Forest had a user's accuracy of at least 50% percent in all states. Herbaceous and Developed, Open Space were less consistently accurate across states. Herbaceous had a user's accuracy of 60% in Alabama, 0% in Mississippi, 44% in North Carolina and 82% in Colorado. In general, the accuracy was reasonable enough to ensure that the trends in the data are representative of what would occur on the ground.

Land use codes from the NLCD 2001 dataset:

11- Open Water
12-Perennial Snow/Ice
21-Developed, Open Space
22-Developed, Low Intensity
23-Developed, Medium Intensity
24-Developed, High Intensity
31-Barren Land
41-Decidous Forest
42-Evergreen Forest
43-Mixed Forest
52-Shrub/Scrub
71-Herbaceuous
81-Hay/Pasture
82-Cultivated Crops
90-Woody Wetlands
95-Emergent Herbaceous Wetlands

Table 1: Alabama Accuracy Assessment

	11	21	22	23	31	41	42	43	52	71	81	82	90	Total	User's
11	**10**													**10**	**100%**
21		**5**				**1**								**6**	**83%**
22			**5**											**5**	**100%**
23				**1**										**1**	**100%**
31				**1**										**1**	**100%**
41		**1**				**20**								**21**	**95%**
42		**1**			**1**		**9**	**1**						**12**	**75%**
43			**1**			**1**		**20**						**22**	**91%**
52						**3**			**16**					**19**	**84%**
71			**1**			**1**			**2**	**6**				**10**	**60%**
81		**1**				**1**			**3**		**19**	**1**		**25**	**76%**
82												**10**		**10**	**100%**
90						**2**							**6**	**8**	**75%**
Total	**10**	**8**	**7**	**2**	**1**	**29**	**9**	**21**	**21**	**6**	**19**	**11**	**6**	**150**	
Producer's	**100%**	**63%**	**71%**	**50%**	**0%**	**69%**	**100%**	**95%**	**76%**	**100%**	**100%**	**91%**	**100%**		

Total accuracy (PCC) = 85%
Kappa coefficient = 82.78%

Table 2: Mississippi Accuracy Assessment

	11	21	22	24	41	42	43	52	71	81	82	90	95	Total	User's
11	3													3	100%
21		3			2						1			6	50%
22			2											2	100%
24				2										2	100%
41					4			2						6	67%
42		1				29		5						35	83%
43		1					19	1						21	90%
52		1					6	7			1			15	47%
71						1	1	1						3	0%
81								1		13				14	93%
82					2						14			16	88%
90		1			1			1				21	1	25	84%
95	1												1	2	50%
Total	4	7	2	2	9	30	26	18	0	13	16	21	2	150	
Producer's	75%	43%	100%	100%	44%	97%	73%	39%	0%	100%	88%	100%	50%		

Total accuracy (PCC) = 78.7%
Kappa coefficient = 75.45%

Table 3: North Carolina Accuracy Assessment

	11	21	22	23	24	31	41	42	43	52	71	81	82	90	Total	User's
11	5														5	100%
21		9					4			1					14	64%
22			5												5	100%
23				3											3	100%
24					1										1	100%
31						3	1								4	75%
41						1	85								86	99%
42								13							13	100%
43									8			1			9	89%
52							1			5			1		7	71%
71							1		1	2	4	1			9	44%
81		2					4			1		24			31	77%
82							1						8		9	89%
90														4	4	100%
Total	5	11	5	3	1	4	97	13	9	9	4	26	9	4	200	
Producer's	100%	82%	100%	100%	100%	75%	88%	100%	89%	56%	100%	92%	89%	100%		

Total accuracy (PCC) = 89%
Kappa coefficient = 84.76%

Table 4: Colorado Accuracy Assessment

	11	12	21	22	23	31	41	42	43	52	71	81	82	90	95	Total	User's
11	**1**															**1**	**100%**
12						**1**										**1**	**0%**
21			**1**													**1**	**100%**
22				**1**	**1**											**2**	**50%**
23					**2**											**2**	**100%**
31						**4**										**4**	**100%**
41							**9**			**2**						**11**	**82%**
42							**6**	**44**	**1**	**2**	**2**					**55**	**80%**
43							**1**		**2**							**3**	**67%**
52				**2**		**1**	**1**	**1**		**53**			**3**			**61**	**87%**
71										**8**	**36**					**44**	**82%**
81										**1**		**6**				**7**	**86%**
82													**5**			**5**	**100%**
90														**2**		**2**	**100%**
95															**1**	**1**	**100%**
Total	**1**	**0**	**1**	**3**	**3**	**6**	**17**	**45**	**3**	**66**	**38**	**6**	**8**	**2**	**1**	**200**	
Producer's	**100%**	**0%**	**100%**	**67%**	**33%**	**67%**	**53%**	**98%**	**67%**	**80%**	**95%**	**100%**	**63%**	**100%**	**100%**		

Total accuracy (PCC) = 84%
Kappa coefficient = 79.05%

Summary

Several conclusions can be drawn from looking at the reports provided by the contractors indicating the locations of observed DEM errors encountered while creating 1-meter orthorectified NAIP imagery. The first conclusion is that there were large differences in the numbers of errors observed between the four states studied. In Alabama approximately 7% of DOQQs contained areas of contractor observed DEM errors. Mississippi had approximately 6%, North Carolina approximately 17% and Colorado approximately 68%. The second conclusion is that errors were more prevalent in heavily vegetated areas such as forest, shrub/scrub and herbaceous. These land cover types in general had higher degrees of slope and elevation than most other types.

Another conclusion that can be made is that the contractor observed errors were more predominant in the land classes that were more predominant across the state. It could be concluded that these findings exhibit some degree of positive spatial autocorrelation. It would make sense that errors would be more numerous in predominant land cover types. This trend is illustrated particularly well in North Carolina where deciduous forest is the most predominant land cover class with 28.17% of the state total and deciduous forest makes up 61.72% of the land cover types where the contractor observed DEM errors in creating 1-meter ortho imagery. This is twice the amount of the next nearest land cover type where errors were observed.

It could also be concluded that land cover types which make up very little of a state's overall land classification, but have a high percentage of contractor observed DEM errors, may indicate a greater degree of error for that type of land class because the land class is so sparse. A good example of this phenomenon is developed high intensity land class type in Mississippi, where the observed errors were found in 10.91% of this land class type even though it only made up 0.09% of the state total land area. This particular example is strengthened by the findings of the accuracy assessment, with 100% accuracy for both the user's and producer's accuracy. In general, the NLCD 2001 land classification dataset provided a good overview of what land cover types exist in contractor identified areas of DEM errors.

Observed errors can also be complicated by slope, elevation and accuracy assessment. A good example of this is perennial snow/ice in Colorado, where the observed errors were found in 100% of this land class type even though it only made up 0.24% of the state total land area. The perennial snow/ice land cover type also has the highest average elevation at 3544 meters and the second highest average degree of slope at 20.1. The assumption here is that higher elevation and slope may contribute to the difficulty of producing the ortho imagery. This example is also complicated by the accuracy assessment. Both the user's and producer's accuracies are 0% due to the fact that only one point fell in this land class and it was identified as barren land. Because there was only one point in the sample, there was only one chance to make sure this was classified correctly.

This study was worthwhile in attempting to discover some trends in what types of features and characteristics exist on NAIP 2009 imagery in areas where contractors identified DEM errors in ortho production of the imagery. The study could be improved in several areas. The first area of improvement is the contractor provided list of observed errors. A more detailed list that included error types and locations rather than just the DOQQ location of the error could give a more detailed view of

what occurs on the ground in specific error locations. The second area of improvement is the land cover classification layer. It would be more accurate to have a land cover layer that is specific to more current NAIP imagery. It may not be feasible to have such a layer but it would be of great benefit to this study and could potentially be used in other types of analysis. This type of layer would add more accuracy to the study by reducing data shifts due to the differing data sources and resolutions of the raster data. A land classification layer created specifically for NAIP imagery would reduce data shifts and provide a more detailed land classification due to the 1 meter resolution of the imagery. At this time, it is not feasible to perform such an analysis due to constraints on time and resources.

The information gained from this study is still valuable, but there is room for improvement and refinement in the level of detail. Analysis could be improved in the future if contractual requirements for contractor reporting of observed DEM errors included more detail and specific locations of the observed errors. Analysis could be directed more towards specific errors rather than the general areas currently provided by the contractors.

References

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McGrew, Chapman, & Monroe, Charles B. (2000). An Introduction to Statistical Problem Solving in Geography. (pp. 84-100). United States: McGraw-Hill.

Multi Resolution Land Characteristics Consortium (MRLC) URL:
http://www.mrlc.gov/nlcd_definitions.php

National Map Seamless Server URL:
http://seamless.usgs.gov/

Appendix 1: NLCD 2001 Land Class Definitions

11. Open Water - All areas of open water, generally with less than 25% cover of vegetation or soil.

12. Perennial Ice/Snow - All areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.

21. Developed, Open Space - Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes

22. Developed, Low Intensity - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of total cover. These areas most commonly include single-family housing units.

23. Developed, Medium Intensity - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79 percent of the total cover. These areas most commonly include single-family housing units.

24. Developed, High Intensity - Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to100 percent of the total cover.

31. Barren Land (Rock/Sand/Clay) - Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.

32. Unconsolidated Shore* - Unconsolidated material such as silt, sand, or gravel that is subject to inundation and redistribution due to the action of water. Characterized by substrates lacking vegetation except for pioneering plants that become established during brief periods when growing conditions are favorable. Erosion and deposition by waves and currents produce a number of landforms representing this class.

41. Deciduous Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.

42. Evergreen Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.

43. Mixed Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover.

51. Dwarf Scrub - Alaska only areas dominated by shrubs less than 20 centimeters tall with shrub canopy typically greater than 20% of total vegetation. This type is often co-associated with grasses, sedges, herbs, and non-vascular vegetation.

52. Shrub/Scrub - Areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.

71. Grassland/Herbaceous - Areas dominated by grammanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.

72. Sedge/Herbaceous - Alaska only areas dominated by sedges and forbs, generally greater than 80% of total vegetation. This type can occur with significant other grasses or other grass like plants, and includes sedge tundra, and sedge tussock tundra.

73. Lichens - Alaska only areas dominated by fruticose or foliose lichens generally greater than 80% of total vegetation.

74. Moss - Alaska only areas dominated by mosses, generally greater than 80% of total vegetation.

81. Pasture/Hay - Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.

82. Cultivated Crops - Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.

90. Woody Wetlands - Areas where forest or shrubland vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

91. Palustrine Forested Wetland* -Includes all tidal and non-tidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation coverage is greater than 20 percent.

92. Palustrine Scrub/Shrub Wetland* - Includes all tidal and non-tidal wetlands dominated by woody vegetation less than 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation coverage is greater than 20 percent. The species present could be true shrubs, young trees and shrubs or trees that are small or stunted due to environmental conditions.

93. Estuarine Forested Wetland* - Includes all tidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent. Total vegetation coverage is greater than 20 percent.

94. Estuarine Scrub/Shrub Wetland* - Includes all tidal wetlands dominated by woody vegetation less than 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent. Total vegetation coverage is greater than 20 percent.

95. Emergent Herbaceous Wetlands - Areas where perennial herbaceous vegetation accounts for greater than 80 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

96. Palustrine Emergent Wetland (Persistent)* - Includes all tidal and non-tidal wetlands dominated by persistent emergent vascular plants, emergent mosses or lichens, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Plants generally remain standing until the next growing season.

97. Estuarine Emergent Wetland* - Includes all tidal wetlands dominated by erect, rooted, herbaceous hydrophytes (excluding mosses and lichens) and all such wetlands that occur in tidal areas

in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent and that are present for most of the growing season in most years. Perennial plants usually dominate these wetlands.

98. Palustrine Aquatic Bed* - The Palustrine Aquatic Bed class includes tidal and nontidal wetlands and deepwater habitats in which salinity due to ocean-derived salts is below 0.5 percent and which are dominated by plants that grow and form a continuous cover principally on or at the surface of the water. These include algal mats, detached floating mats, and rooted vascular plant assemblages.

99. Estuarine Aquatic Bed* - Includes tidal wetlands and deepwater habitats in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent and which are dominated by plants that grow and form a continuous cover principally on or at the surface of the water. These include algal mats, kelp beds, and rooted vascular plant assemblages.

* Coastal NLCD class only

Source: Multi Resolution Land Characteristics Consortium (MRLC) URL:
http://www.mrlc.gov/nlcd_definitions.php