USAID|WINNER

Land Use/Land Cover Classification 2010

Summary Report

CJ Hendrix
hendrix.cj@gmail.com
20-Aug-2010

CONTENTS

INTRODUCTION

The WINNER project required land use/land cover (LULC) data more detailed than the available datasets to support operational planning and land use management planning in WINNER's zones of intervention. An earlier project, DEED, had developed a classification system oriented toward land use management and assessment of erosion risk. To ensure cross-project interoperability of these datasets, WINNER employed the prior land cover classification scheme. This report details the classification taxonomy, and summarizes the data and methods used to produce WINNER's 2010 LULC dataset. A discussion of the types of class confusion seen in the resulting map is also made.

The project covers two regions: the watershed of the La Quinte River in the north (referred to as the northern zone of intervention (North ZI) and the watersheds of the Rivière Blanche and Rivière Grise combined with portions of Archaie/Cabaret, Saut d'eau, and Mirebalais (collectively referred to as the South ZI).

True color display of WorldView2 2.0m multispectral imagery.

Classified LULC data

DATA INPUTS, OUTPUTS, AND ALGORITHMS

INPUTS

- WorldView2 2 m multispectral and 0.5 m panchromatic imagery were acquired for the project in the months of January to March, 2010. All or almost all of the imagery was acquired after the January 12, 2010 earthquake.
- 20 m resolution SPOT DEM was used in orthrectification of the satellite imagery. It should be noted that this data exhibits significant 'terracing' in areas of steep slopes, limiting its usefulness for slop analysis. However, this data was used for watershed boundary delineation and the resulting delineations agree well with the watershed boundaries visible in the imagery or extracted from the SRTM DEM download from CGIAR
- Significant use was made of high resolution imagery acquired after the January 12, 2010 earthquake (January 25, 2010) and posted on Google Earth. Estimated resolution of this imagery is 10cm This was used as a resource for photointerpretation.
- Project boundary was determined by combining the WorldView2 image order area with the limits of the SPOT DEM. Adjustments were made in the Archaie area to compensate as much as possible for areas added to the project after the imagery was ordered. However, there remains a small area in the NE corner of the Southern ZI that is not covered by the WorldView2 imagery and therefore not mapped.
- The roads and paths layer compiled from many sources by the OpenStreetMap community was used.
- The rivers layer maintained by CNIGS (with some edits in the La Quinte plain) was used.
- Two additional layers were used to track each tile of imagery and data that was processed as a unit (roughly 6000m x 6000m). These have been retained for reference.

Data Source	File Location
WorldView2 Satellite imagery, 2m and 0.5m	…\WINNER\Data\Imagery\WorldView2010\[various file names]
SPOT DEM, 20m	…\WINNER\Data\Terrain\SPOT20m\ccg_DEM20m_SPOT.img
LULC Mapping Boundary	…\WINNER\Data\LandUseLandCover\WorldView2010\Documentation\MappingArea_DEM_Intersect.shp
Snapshot of OpenStreetMap roads/paths data	…\NationalData\Haiti\Transportation\Roads\ht_Roads_OSM.shp
Hydrology	…\GIS_Work\NationalData\Haiti\Hydrology\ht_PrimaryAndSecondaryRivers_WINNER.shp
Processing Tiles	…\WINNER\Data\LandUseLandCover\WorldView2010\Documentation\ccm_DicedImageBounds.shp and gv_DicedImageBounds.shp

OUTPUTS

Final data files are in raster format; one for the northern ZI and one for the southern ZI. The locations of these files are shown below.

Data Source	File Location
Southern ZI	…\WINNER\Data\LandUseLandCover\WorldView2010\ccm_LandUseLandCover2010_WINNER.img
Northern ZI	…\WINNER\Data\LandUseLandCover\WorldView2010\gv_LandUseLandCover2010_WINNER.img

PROCESSING ALGORITHMS

A key part of the development of the LULC dataset was executed in eCognition 8.0, using algorithms developed in that software. Although these algorithms can only be executed in eCognition, for which WINNER does not have a license, the algorithms are included in the delivery in case they should be needed in the future. These files are located at …\WINNER\Data\LandUseLandCover\WorldView2010\Documentation\eCognitionRulesets

MINIMUM MAPPNIG UNIT, SCALE, AND CLASSIFICATION ACCURACY

Previous land use land cover mapping projects with similar classification systems have used the MMUs as shown in the following table. The difference in the MMU seen below was driven largely by the data sources available for the mapping projects.

Project	Mapping Scale	MMU	Size of a square, MMU-sized feature at map scale
US National Land Cover Dataset	1:24,000	1 to 2 ha	4 to 6 mm on a side
US Geological Survey/National Park Service Vegetation Mapping Project	1:24,000	0.5 ha	3 mm on a side

The target MMU for the WINNER LULC data was 1 ha, though smaller features were often identified due to the much finer resolution of the source imagery. Intended mapping scale was 1:24,000, though the final product supports map scales as large as 1:12,000.

Based on the budget available for this task a typical LULC classification accuracy of 80-85% was targeted. Although no formal accuracy assessment was budgeted, visual inspection of the map indicates that overall accuracy meets or exceeds this specification. Some confusion between difficult to distinguish classes, in particular the distinction between Sparse Canopy Agroforestry and Medium Canopy Agroforestry and the distinction between Medium Canopy Agroforestry and Dense Canopy Agroforestry may show lower accuracies.

Detailed discussion of the types of class confusion seen in the map (as assessed against the high resolution imagery available as noted above as well as a limited number of field samples that were available) is made in a following section.

CLASSIFICATION SYSTEM

GOALS OF THE CLASSIFICATION SYSTEM

SUPPORT WATERSHED MANAGEMENT AND SERVE AS AN INPUT TO FURTHER ANALYSIS

First and foremost, the classification system must serve as a basis for land use planning decisions in the project's watersheds. Thus, the system must contain the categories of land use relevant to the goals of the land use planning in these areas. Sustainable natural resource management in this context largely, though not exclusively refers to the need to retain soil and soil moisture to promote sustainable cultivation, surface water, and subsurface water.

Thus, the classification system focuses on separating those land use classes in terms of their potential for soil erosion and water retention. The use of the word 'potential' in this context is indicative of the fact that a given

land use class may be very erosive on steep slopes but not at all on flat ground. The land use map is only an input to an analysis of erosion risk which would combine other data layers (such as slope, soil type, and/or rainfall) with the land use classification for a comprehensive analysis of soil erosion risk or flood risk under different rainfall scenarios.

PROVIDE EXTENSIBILITY

In hopes that the classification system can be applied to areas beyond the WINNER and DEED project areas, perhaps using different methodologies or data to produce the maps, the land use classification system has been left somewhat open to the addition of further classes to provide more detail. Conversely, if only the coarsest data were available for a given project area, a more general set of classes should be available which could be extracted from the less data rich information (Congalton and Green, 2008).

EXHAUSTIVE COVERAGE

All areas included in the project must fall within one of the classes. This is not to say that all areas in the project need to be classified to the same level of detail, but that all areas must be classified. Due to the need for extensibility described above, potentially all forms of land use/land cover in Haiti should be covered in the system. This has been achieved through the use of the Anderson Classification System (Anderson et al, 1976), which provides an exhaustive set of more general categories but retains the flexibility to add more detail as needed. The Anderson system has become the de facto standard for land use classification worldwide.

MUTUAL EXCLUSIVITY

No area can fit more than one class. Combined with the requirement of exhaustive coverage described above, it can be said that every area in the project must fit one and only one class. This is achieved by careful construction of a rule based classifier composed of both class labels and rules describing criteria that the area must meet to become a member of a class (Congalton and Green, 2008). These rules should account for any land use configuration found in the project area.

ACHIEVABLE USING AVAILABLE DATA SOURCES AND METHODS

Although the contents of the classification system are primarily driven by the intended use of the land use map that results, consideration must be made for how practical it is to map the set of classes defined by the system. Although the imagery data for this project are very detailed, the single season image makes differentiation of the agricultural classes difficult in some cases.

CLASSIFICATION SYSTEM DEFINITION

BASIS FOR THE LAND USE CLASSIFICATION SYSTEM

The Land Use Classification System defined here is based on the Anderson Classification System (Anderson et al, 1976). This system has been in use for many years and has proven itself to be a sound and flexible basis for developing classification systems in highly varied environments. This system is the basis for the US Geological Survey's National Land Cover Dataset, which was originally developed in 1991 and updated in 2002 and 2006.

The Anderson System was developed primarily to take advantage of the then newly available remote sensing satellite datasets. However, when better data are available, such as field surveys or the current generation of high resolution imagery, the Anderson system retains the flexibility to add more classification detail which can be derived from these richer data sources.

The classification system used in the 2002 land use map of Haiti appears to be based on the Anderson system, with significant modification. The commentary for each class in this document provided useful input to the development of the classification system used in this project. As a basis for the current project, however, this system has two key issues:

- This system is designed for small scale mapping (1:100,000), and does not provide enough detail in the agricultural classes to meet the WINNER project's needs.
- Agroforestry is partially grouped with other forms of agriculture, which would require significant changes to the Level II classes in order to be applicable to the work in Haiti.

Due to the extent of the changes that would be needed, it was decided to use the original Anderson Classification System as the basis for the land use/land cover classification system.

The Food and Agriculture Organization's (FAO) Land Cover Classification System (LCCS) was also considered as a basis for this project. LCCS is not so much a classification system as a rigorous methodology for defining a classification system. This rigor has made it somewhat cumbersome to use, and the system has not found widespread use outside of FAO's Africover project. To address this, the next version (version 3), which is currently under development, will change to a Unified Modeling Language based approach. Should LCCS version 3 prove to be a useful global standard, it will be possible to translate the classification system used here to LCCS terminology.

CLASS LABELS

The classification system is hierarchical which allows for different levels of detail to be represented depending on the purpose of the map or the limitations of available data.

The class hierarchy is shown below. The dichotomous key is presented in the next section, and the definitions follow that.

As discussed previously, not all classes were mapped, but are included here for possible future use of the system for other land management projects in Haiti. The definitions of each class and the dichotomous key follow. Classes mapped in this project are shown in blue. Others are in black.

LEVEL I	LEVEL II	LEVEL III
1. Urban or Built-Up Land		
2. Agricultural Land	21. Cropland and Pasture	211. Inundation Agriculture
		212. Terraced Agriculture
		213. Cultivated Non-Woody Perennials
		214. Cultivated Annuals
	22. Orchards and Groves	221. Sparse Canopy Agroforestry
		222. Medium Canopy Agroforestry
		223. Dense Canopy Agroforestry
3. Rangeland	31. Herbaceous Rangeland	311. Grazed Herbaceous Rangeland
		312. Ungrazed Herbaceous Rangeland
	32. Shrub and Brush Rangeland	321. Grazed Shrub and Brush Rangeland
		322. Ungrazed Shrub and Brush Rangeland
4. Forest Land		
5. Water	51. Near-Shore Marine	511. Coral
		512. Marine Vegetation
		513. Sand, Rocks, or Mud
6. Wetland	61. Forested Wetland	611. Mangroves
	62. Non-Forested Wetland	
7. Barren Land	72. Beaches	
	74. Bare Exposed Rock	
	75. Stripmines, Quarries, and Gravel Pits	
91. Unclassified (cloud or cloud shadow)		

[1]Gaps in the level II numbering system in the Barren Land class indicate that some existing Anderson classes have been left out of this system for simplification. These can be added later if future projects need those details.

DICHOTOMOUS KEY

The dichotomous key provides a mechanism through which a given area is assigned to a class. The priorities of a given land use classification project are often more clearly expressed in the ordering of items in the dichotomous key than can be captured in the wording of the class definitions. Adjustments to the thresholds in each key or in their ordering are the first place to try and make adjustments to the classification system if test results are unsatisfactory.

The dichotomous key is also an essential tool for carrying out the classification work. It is difficult to rigorously apply a classification system to a given area without a dichotomous key. Class distinctions that seem simple and intuitive prove not to be when faced with real field situations. Different individuals will classify the same area differently. The dichotomous key provides a more rigorous mechanism for the task of classification.

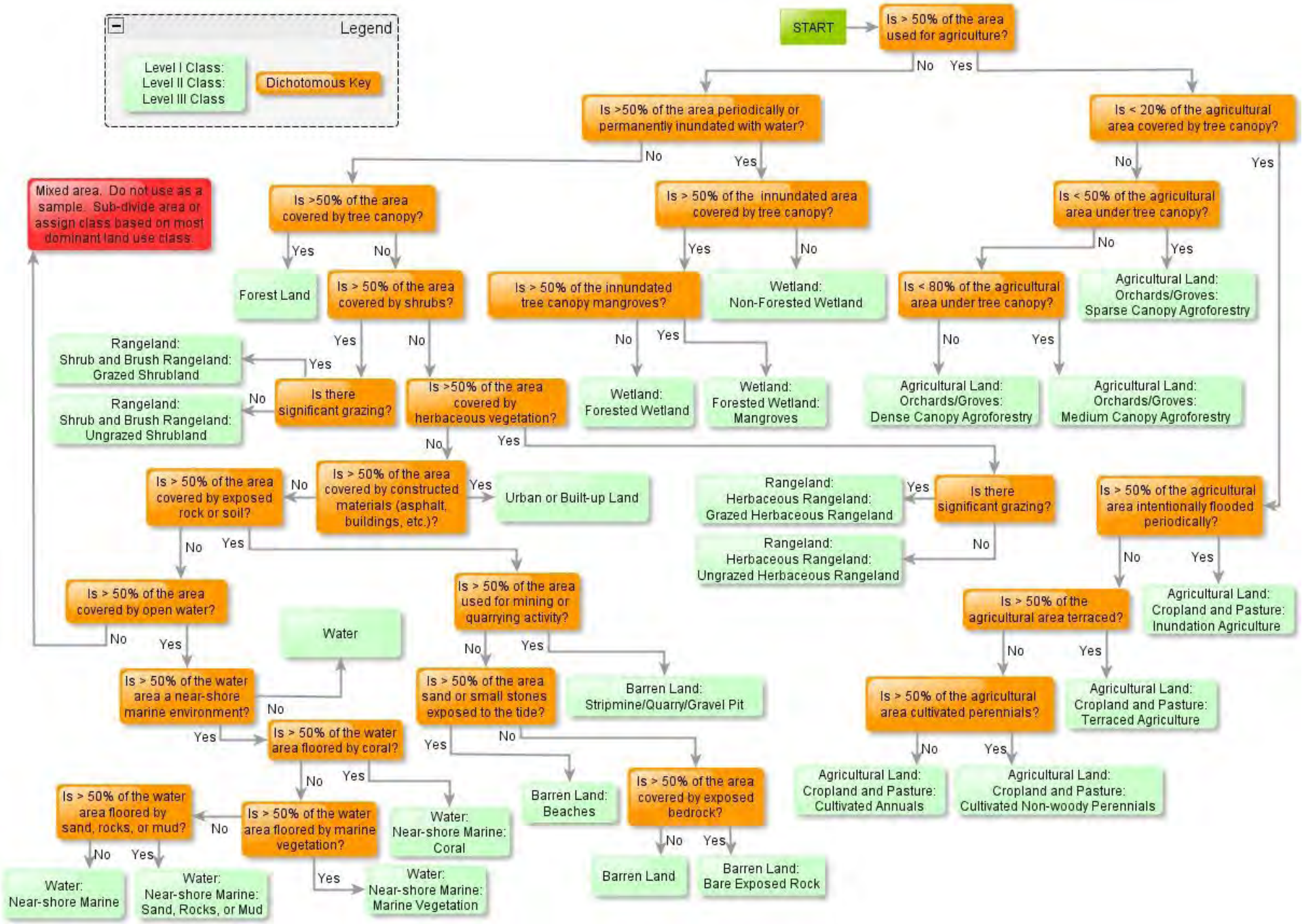
Figure 1 below presents the dichotomous key for this project. Some rules should be kept in mind when using the key:

- *Area*, when used in the key, refers to a delineated, contiguous unit of land or water. The delineation may be made by software, by someone looking at the landscape, or by someone delineating areas on an image. The degree of variation acceptable in a delineated area is dependent on the scale of map that is being produced. Generally speaking an *area* will be dominated by the same land use class, with potentially some small areas of other land use classes included (these should be too small in area to be

delineated as separate areas). If it is frequently found that areas contain different land use classes of a size large enough to be mapped at the desired scale, the delineation parameters should be reconsidered.

- All delineated areas must receive some class. However, not all areas must be classified to Level III. For example open water areas that are not classified into Coral, Marine Vegetation, or Sand/Rock/Mud are simply labeled with the Level I class Water.
- Note that frequently the questions in the dichotomous keys use percentages applied to only a portion of an area. For example, "Is < 20% of the agricultural area covered by tree canopy?" is only concerned with that portion of a delineated area that is agricultural, not the whole area.
- The goal of any map using this classification system is to identify how the land is used, rather than its state at a given moment. For example, a recently cleared plot of land used for cultivation of corn should be classed as Annual Agriculture, not Barren Land even though its land cover technically meets the definition of barren land.

Figure 1: Dichotomous key



CLASS DEFINITIONS

The definitions of each class follow. As indicated above, this classification system is based on the Anderson Land Use/Land Cover Classification System (Anderson et al, 1976). The definitions given by Anderson have been modified to better reflect the context of the Haitian landscape and the goals of the WINNER project.

1. URBAN OR BUILT-UP LAND

Urban or Built-up Land is comprised of areas of intensive use with much of the land covered by structures. Included in this category are cities, towns, and villages; transportation and industrial facilities; and institutions that may, in some instances, be isolated from urban areas. Recreational areas, such as playing fields may have few structures, but should be included in this class.

This class is not sub-divided into finer detail because the goals of the project do not call for fine-grained detail in urban environments. However, the Anderson classification system offers additional detail in this class should it be needed in future projects. Note that dirt roads in urban areas often are classified as urban, however similar roads in rural areas are (more correctly) classified as barren land. This is due to the context sensitive classification algorithm. Although a consistent classification of barren land would be preferred, it was decided that the editing effort to correct this problem was better spent on more critical class distinctions.

2. AGRICULTURAL LAND

Agricultural Land may be defined broadly as land used primarily for production of food, fiber, or fuel. The interface of Agricultural Land with other categories of land use may sometimes be a transition zone in which there is an intermixture of land uses at the first and second levels of categorization. Where farming activities are limited by wetness, the exact boundary also may be difficult to locate, and Agricultural Land may grade into Wetland. When the production of agricultural crops is not hindered by wetland conditions, such cropland should be included in the Agricultural class. This latter stipulation also includes those cases in which agricultural crop production depends on wetland conditions, such as the flooding of rice or sugar cane fields.

21. CROPLAND AND PASTURE

The WINNER project requires significant detail in this category to meet project goals. Therefore, several level III classes have been added. No detail has been added for Pastureland, as this is not a significant class in the current project (note that this class does not include Rangeland, described below). However, should areas of Haiti mapped in future LULC efforts show significant amounts of pasture, this class can be easily added to the classification system. For the current project, any examples of pasture have been classified as annual agriculture, as they are frequently cultivated during some parts of the year.

211. INUNDATION AGRICULTURE

This class describes cultivation with less than 20 percent tree canopy cover which is periodically or constantly intentionally inundated with water. Typical examples include jonc and rice. Technically, however, even areas that might fit into classes 212, 213, or 214 below should be in the Inundation Agriculture class if they are inundated. The dichotomous key reflects this prioritization of Inundation Agriculture above the other Cropland and Pasture classes. In practice, classification of inundation agriculture relies on visible evidence of inundation in the satellite imagery (evidence of rice threshing, banking, inundated fields). Areas without this evidence and that were fairly dry at the moment of imaging are likely to be mapped as annual or perennial agriculture.

212. TERRACED AGRICULTURE

This class describes cultivation taking place on slopes that have been reinforced in some way to make level steps on which the cultivation takes place. If the terraces are intentionally inundated, they should be included in class 211. Tree canopy cover is less than 20%. Note that even areas that might fit into classes 213 or 214 below should be in the Terraced Agriculture class if they are on terraced slopes. The dichotomous key reflects this prioritization of Terraced Agriculture. Because there is little terracing in the project area, this class was not mapped.

213. CULTIVATED NON-WOODY PERENNIALS

This class indicates the production of cultivated perennials excluding trees. Tree cover is less than 20 percent, and the land is neither terraced nor intentionally inundated. Sugar cane is a typical example of this class. Bananas, when planted as a monoculture are also an example; however when bananas are mixed with other tree crops, they should be classified as agroforestry. It is difficult to separate young sugarcane from annual crops using only a single date of imagery as in this project. It is likely that sugarcane is often misclassified as Annual Agriculture.

214. CULTIVATED ANNUALS

This class indicates the production of cultivated annuals with less than 20 percent tree canopy cover. The land is not terraced or intentionally inundated. In the project areas, this is commonly beans, corn, sorghum, and some types of root vegetables. However, many other types of annuals would also be included in this category. Not included in this class are those crops which are cut after more than one year, such as sugar cane.

22. ORCHARDS AND GROVES

Orchards, groves, and vineyards produce the various fruit and nut crops. Nurseries and horticultural areas are used perennially for those purposes. Note that areas where the trees are used to shade underlying crops and not directly for the production of any product are also included in this class. Tree nurseries which provide seedlings for plantation forestry also are included here. Of particular importance to the WINNER project, this class includes detail about agroforestry. Excluded from this class is natural forest which may be used as a source for some products (medicinal substances, fuel, wild edibles, etc.) without significant management. Such forests should be included in the Forest Land class.

221. SPARSE CANOPY AGROFORESTRY

This class describes any one of many possible combinations of tree crops with other types of agriculture or no agriculture taking place underneath. For this class, at least 20 percent and less than 50 percent of the area must be covered by tree canopy.

222. MEDIUM CANOPY AGROFORESTRY

This class describes any one of many possible combinations of tree crops with other types of agriculture or no agriculture taking place underneath. For this class, at least 50 percent and less than 80 percent of the area is covered by tree canopy.

223. DENSE CANOPY AGROFORESTRY

This class describes any one of many possible combinations of tree crops with other types of agriculture or no agriculture taking place underneath. For this class, 80 percent or more of the area is covered by tree canopy.

3. RANGELAND

Rangeland historically has been defined as land where the potential natural vegetation is predominantly grasses, forbs, or shrubs and where herbivory is an important influence in its state.

31. HERBACEOUS RANGELAND

The Herbaceous Rangeland category encompasses lands dominated by naturally occurring grasses and forbs as well as those areas of actual rangeland which have been modified to include grasses and forbs as their principal cover, when the land is managed for rangeland purposes and not managed using practices typical of pastureland. Although there may be few areas in Haiti where rangelands are not grazed, it was considered important to make the distinction between grazed and ungrazed rangeland to allow for land use planning activities to perhaps assign some areas to the ungrazed category. Thus some Level III categories were added to capture this detail.

311. GRAZED HERBACEOUS RANGELAND

This class includes herbaceous rangeland where grazing has impacted the density of the vegetative land cover.

312. UNGRAZED HERBACEOUS RANGELAND

This class describes herbaceous rangeland where no significant grazing has taken place.

32. SHRUB AND BRUSH RANGELAND

The landscape in these classes is dominated by shrubs, defined here as woody vegetation generally less than 3 m tall. Over 3 m, and the area is better classified in the Forest Land class. Left alone long enough, many areas of shrub and brush rangeland may become Forest Land. Although there may be few areas in Haiti where rangelands are not grazed, it was considered important to make the distinction between grazed and ungrazed rangeland to allow for land use planning activities to perhaps assign some areas to the ungrazed category. Thus some Level III categories were added to capture this detail.

321. GRAZED SHRUB AND BRUSH RANGELAND

This class includes shrub and brush rangeland where grazing has impacted the density of the vegetative land cover. Agricultural fields left fallow for multiple years will generally become Shrub and Brush Rangeland. Also included are large areas of mesquite trees that dominate some of the project area, though these areas can become tall enough to be considered agroforestry. The line between Shrub and Brush and the Agroforestry classes is a blurry one, basically dependent on height, which is impossible to determine precisely from satellite imagery alone.

322. UNGRAZED HERBACEOUS RANGELAND

This class describes herbaceous rangeland where no significant grazing has taken place. All herbaceous rangeland in the project area was considered to be grazed, but the class is included here for future projects in other parts of Haiti.

4. FOREST LAND

Forest Lands have tree canopy covering more than 50 percent of the area. The Forest Lands class excludes those areas where the trees are cultivated or provide shade for cultivated plants. In those cases, the area should be classified into Orchards/Groves or one of its sub-classes. Also those areas which would otherwise be classified as Wetland if not for the forest cover should be classified as Forested Wetland.

Although the Anderson Classification System does provide more detail in this class, it is not critical to the WINNER project. However, if applying this system to other areas of Haiti, additional detail may need to be added to this class. The only occurrence of forest in the project area is in the pine forests of the Parc La Visite area. Much of these pine forests (especially east of Parc La Visite) appear to have been thinned, presumably for charcoal production. These thinned areas have been mapped as Agroforestry. Denser stands have been mapped as Forest.

5. WATER

The Anderson Classification System does not provide much detail about marine environments. Thus, this class is probably the most modified from the original Anderson Classification System. Any open water not included in the Level II and Level III classes below should be simply be labeled with the Level I class. This would include lakes and rivers large enough to be included in the scale of mapping to which this classification system is applied. The current project maps water only to Level 1. However, additional classes are included if more detail is needed by future projects.

51. NEAR-SHORE MARINE

This group of classes contains the details necessary for managing fishing and other activities in the coast zone should future projects have some activities where such classes are relevant.

511. CORAL

The sea floor is dominated by any of the various forms of coral, including coral rubble.

512. MARINE VEGETATION

The sea floor is dominated by marine vegetation.

513. SAND, ROCKS, OR MUD

The sea floor is dominated by unconsolidated sediments (sand or mud), loose stones, bedrock, or some combination of these.

6. WETLAND

Wetlands are those areas where the water table is at, near, or above the land surface for a significant part of most years. The hydrologic regime is such that aquatic or hydrophytic vegetation usually is established, although alluvial and tidal flats may be nonvegetated. Wetlands frequently are associated with topographic lows, even in mountainous regions. Examples of wetlands include marshes, mudflats, and swamps situated on the shallow margins of bays, lakes, ponds, streams, and manmade impoundments such as reservoirs. They include wet meadows or perched bogs in mountain valleys and seasonally wet or flooded basins, or playas with no surface-water outflow. Shallow water areas where aquatic vegetation is submerged are classed as open water and are not included in the Wetland category. Areas in which soil wetness or flooding is so short-lived that no typical wetlands vegetation is developed properly belong in other categories.

Cultivated wetlands, such as the flooded fields associated with rice production, are classified as Agricultural Land. Uncultivated wetlands from which wild rice, cattails, wood products, and so forth are harvested, or wetlands

grazed by livestock, are retained in the Wetland category. Wetland areas drained for any purpose belong to other land use and land cover categories such as Agricultural Land, Rangeland, Forest Land, or Urban or Built-up Land. When the drainage is discontinued and such use ceases, classification may revert to Wetland.

61. FORESTED WETLANDS

Forested Wetlands are wetlands dominated by woody vegetation. Unlike the distinction between Forest Land and Shrubland, the height of the woody vegetation is not important.

611. MANGROVES

This class describes a forested wetland dominated by Mangroves.

62. NON-FORESTED WETLAND

Non-forested Wetlands are dominated by wetland herbaceous vegetation or are non-vegetated. These wetlands include tidal and non-tidal fresh, brackish, and salt marshes and non-vegetated flats and also freshwater meadows, wet prairies, and open bogs.

7. BARREN LAND

Barren Land is land in which less than 50 percent of the area has vegetation or other cover. In general, it is an area of thin soil, sand, or rocks. Vegetation, if present, is more widely spaced and scrubby than that in the Shrub and Brush category of Rangeland. Unusual conditions, such as a heavy rainfall, occasionally result in growth of a short-lived, more luxuriant plant cover. Wet, non-vegetated barren lands are included in the Non-Forested Wetland class. Agricultural Land may be temporarily without vegetative cover because of cropping season or tillage practices, but should not be included in this category.

Note that because some categories from the Anderson System are not relevant to this project and have been dropped, there are some gaps in the numbering of the Level II classes in this category. Although more detail in this class is provided in Level II (below), the current project maps only to Level 1.

72. BEACHES

Beaches are the smooth sloping accumulations of sand and gravel along shorelines. The surface is stable inland, but the shoreward part is subject to erosion by wind and water and to deposition in protected areas.

74. BARE EXPOSED ROCK

The Bare Exposed Rock category includes areas of bedrock exposure or other areas of consolidated stable stone. Areas dominated by loose rock mixed with soil or other unconsolidated material should be classed as Barren Land. This difference is due to the different erosion potential between bedrock or consolidated rock and loose rock found on overgrazed slopes.

75. STRIPMINES, QUARRIES, AND GRAVEL PITS

Those extractive mining activities that have significant surface expression are included in this category. Vegetative cover and overburden are removed to expose deposits. Quarrying of building materials and recovery of sand and gravel deposits also result in large open surface pits and should be included here.

IMAGE CLASSIFICATION

The general approach to this project was to use an expert systems-based approach. Most of the data preparation steps took place in ERDAS Imagine 9.1 and ArcGIS 9.2. The expert system was built within eCognition 8. Final data editing was done in ArcGIS 9.2.

Construction of the rule-based expert systems classifier relied on analyst knowledge of the landscape from previous field-based classification. The intention was to conduct some field sampling missions during the satellite imagery campaign, however the aftermath of the January 12 earthquake made that impossible. However the high resolution nature of the imagery combined with previous experience of the analyst in the project area offset this lack of field samples at the time of image collection.

An unexpected additional resource was very high resolution imagery (estimated at 10-15cm) made available through Google Earth after the earthquake. It is very unusual to have such high resolution imagery acquired during the same time frame as the satellite imagery. Although this data did not cover the entire project area, it was consulted frequently in the areas of coverage.

SPECIFIC TYPES OF CONFUSION SEEN IN THE FINAL LAND USE DATASET

1. **Shrub and Brush Rangeland/Cultivated Annuals Confusion:** This is probably the single largest problem in the map. This results from the fact that on steep slopes which have been cleared for agriculture, there are many gradations between a hillside that has been allowed to recover somewhat, eventually returning to Shrub/Brush Rangeland, and a hillside that has some cultivated annuals mixed with shrubby regrowth. It should be noted that Shrub and Brush Rangeland in this context can be considered as part of the annual agriculture cycle and therefore closely related to this class for purposes of land use planning.
2. **Bare Ground/Agriculture Confusion:** It is impossible to distinguish spectrally between a hillside that is bare because it has been prepared for cultivation and a hillside that is bare due to erosion which will no longer support cultivation. In practice, areas that had a bare ground spectral signature were generally classified as Cultivated Annuals unless on slopes greater than 15 degrees, in which case they were more likely to be classified as Bare Ground. However, the reality is that factors other than steepness of slope, such as rainfall and soil type, impact locally on the likelihood that a barren slope is used or not used for agriculture, and these additional factors were not captured in the available data used for classification. During photointerpretation, however, the presence of other signs of agricultural use (hedges, clearly defined field borders, etc) also pushed a given bare area toward classification as Annual Agriculture.
3. **Inundation Agriculture/Cultivated Perennials Confusion:** According to the classification system, Inundation Agriculture is the preferred agricultural class, regardless if the crops are annual or perennial. However, it is difficult to sample these classes which change dramatically throughout the year. The result is that obviously wet areas in the imagery were mapped as Inundation Agriculture (which is correct), but areas that may be subjected to inundation but were fairly dry or had very mature stands of crops obscuring the wet ground were classified as either Cultivated Annuals or Cultivated Perennials. These classifications are not incorrect, but do not exactly reflect the priorities of the classification system.
4. **Confusion among the Agroforestry Classes:** The difficulty in determining canopy closure in the field or from overhead imagery is notoriously difficult, and the difficulty in determining distinctions in the WINNER LULC project comes as no surprise. Every attempt has been made to identify the relatively rare areas of medium and dense agroforestry, but these were only mapped using manual photointerpretation.

APPROACHES FOR FURTHER IMPROVEMENT TO THE LAND USE MAP

The LULC data represents almost all of the land use information that can be determined from the contents of the WorldView2 imagery and other data inputs. Further photointerpretation of the imagery could be used to improve the accuracy, but probably not without significant fieldwork comparing the imagery to the actual ground situation. It is therefore recommended that further map editing be based on field reconnaissance in areas of particular interest or on discussion with people having expert local knowledge of an area.

REFERENCES

Congalton, R. and K. Green. 2008. Assessing the Accuracy of Remotely Sensed Data: Principles and Practices, Second Edition. CRC/Lewis Press, Boca Raton, FL. 137 p.

Anderson, James R., et al. 1976. A Land Use And Land Cover Classification System For Use with Remote Sensor Data: Geological Survey Professional Paper 964. Edited by NJDEP, OIRM, BGIA, 1998, 2000, 2001, 2002, 2005.

APPENDIX 1 – SIMPLIFIED WORKFLOW