APPENDIX B
AWUDP PORTION – STATEWIDE FRAMEWORK FOR UPDATING THE HAWAI'I WATER PLAN

Department of Agriculture

Pursuant to Act 101, Session Laws of Hawaii (SLH) 1998, the Department of Agriculture (DOA) shall be responsible for preparation and regular updating of a State Agricultural Water Use and Development Plan (AWUDP). The initial plan shall be prepared and submitted to the legislature no later than twenty days prior to the convening of the regular session of 2000. Preparation of the AWUDP by DOA shall be coordinated with the CWRM for future incorporation into the SWPP.

Agricultural Water Use and Development Plan (AWUDP)

The major objective of the AWUDP is to develop a long-range management plan that assesses state and private agricultural water use, supply and irrigation water systems.

The plan shall address projected water demands and prioritized rehabilitation of existing agricultural water systems.

Legal Mandate and Specific Statutory Requirements - AWUDP

Based on the provisions of Act 101, SLH 1998, the AWUDP shall provide for:

- *A master inventory of irrigation water systems;*
- *Identification of system rehabilitation needs, costs and sources of funding for repair and maintenance;*
- *Development of prioritization criteria and a 5-year program for system repairs;*
- *Set up of a long range plan to manage the systems; and*
- *Incorporation of the above findings into the SWPP.*

Recommended Plan Elements

The effort described above is identified in the Act as a "master irrigation inventory plan" and should therefore be considered as an initial step in the development of a comprehensive Agricultural Water Use and Development Plan. The additional steps that would need to be taken to complete a comprehensive AWUDP should include the following:

1) *Based on existing statewide agricultural land uses, assess the existing agricultural water irrigation needs of each of the counties.*
2) *Based on long-term agricultural crop development plans, develop a range of future agricultural irrigation water needs for each of the counties, including projected agricultural water demands of the DHHL.*
3) *Based on the information from the WRPP and the "master irrigation inventory plan," identify existing sources for irrigation water and assess any shortfalls or excess capacities in existing irrigation systems.*
4) *Identify options for development of additional and alternative irrigation water sources.*
5) *Identify options for conserving irrigation water and/or managing the uses to reduce the total irrigation water demand.*
6) *Develop strategies encompassing both demand management and resource development options.*

In order for the AWUDP to be consistent with the SWPP, the WRPP and WQP, it should include the following elements:

1) *Consistency with the WRPP – The AWUDP shall comport with the provisions of the Water Resource Protection Plan and should utilize the ground-water hydrologic units and surface-water hydrographic units designated statewide by the CWRM for the presentation of data and analyses.*
2) *Current and Future Demand Forecasts – The AWUDP should evaluate current and future water demands for agricultural programs and projects statewide to insure orderly authorization and development of existing water resources. The AWUDP shall consider a twenty-year projection period for analysis purposes.*

   The review of all existing and contemplated agricultural projects shall be based upon water consumption guidelines and water demand unit rates used by the CWRM for the purposes of its water permit application review process. All

projects should indicate the following information, at a minimum:

a) Type of project;
b) Source of water;
c) Existing uses;
d) Contemplated uses;
e) System capacity;
f) Location/Tax Map Key (TMK);
g) Project schedule;
h) Quality of water needed;
i) Basis for water demand projections (e.g. area, units, etc.); and
j) Primary source development plan for the project(s).

3) Water demand-forecasting techniques – The forecasts developed by the DOA should identify the significant demand determinants used by the agency which may include but are not limited to:

- *The data, the sources of data, the assumptions, and the analysis upon which the forecast is based;*
- *The relative sensitivity of the forecasts to changes in assumptions and varying conditions; and*
- *The procedures, methodologies, and models used in the forecast, together with the rationale underlying the use of such procedures, methodologies, and models.*

The approach used by the DOA in their forecasts should be based on sufficient historical data and at a minimum should result in high, medium, and low forecasts of average day demands. Additional forecasts of annual, seasonal, and peak-day system demands, as may be necessary should be based upon forecasted average day demands. The validity and reliability of the approach used by the DOA must be demonstrated and the agency must be prepared to discuss unexplained variation in demand.

4) *Integrated Resource Planning Elements – To provide consistency and coordination between the State Water Projects Plan and the County Water Use and Development Plan, the following elements of the IRP approach should be followed in the preparation of the AWUDP:*

   a) *Demand Forecast – The AWUDP shall include a range of forecasts of the amount of water required over the planning horizon. The DOA shall develop forecasts for multiple scenarios that are necessary or appropriate in the development of the SWPP and the County WUDP. Among the scenarios are the base case scenario (a scenario based on the most likely assumptions), a high-growth scenario, and a low-growth scenario.*

      Forecasts shall be based on yearly increments for the first 5 years. Thereafter, forecasts shall be based on 5-year increments to the year 2020. The DOA is encouraged to extend their forecasts beyond the year 2020, particularly when the forecasts for the initial 20-year period indicates that the limits of particular resources are within reach.

   b) *Water System Profiles - The AWUDP shall include a thorough description of current supplies, major conveyance facilities and storage reservoirs, re-use programs, and conservation programs that are currently in operation. This description shall also include resources, if any, to which the State, county, or private agricultural entities have made commitments. The ability of the current (and, if applicable, committed) system to meet future demands should be explored.*

   c) *Resource Development Options – As applicable, the AWUDP shall address the following types of resource options:*

      - ***Supply sources**, including both surface-water and ground-water supplies and various combined uses of the two. The issue of inter-basin transfers should be*

examined, with due regard to the environmental and cultural impacts in the basin of origin.

- ***Transmission and other infrastructure**, including, but not limited to, major conveyance, treatment, and pumping facilities to relieve existing or anticipated constraints on effectively utilizing existing supplies.*
- ***Storage facilities,** to take advantage of annual, seasonal, daily, or diurnal variations in demands and/or available supplies.*
- ***Conservation programs** for agricultural water users. Conservation options should be considered as carefully as supply and facility options as to their ability to achieve objectives. In particular, the estimates for future program participation, costs, and savings should be enumerated and explained. As used here, the term "conservation programs" also includes conservation-oriented rate designs.*
- ***Direct and indirect use of reclaimed wastewater** for irrigation uses. Such options must be consistent with federal, state, and county laws and regulations.*

- *Source Development Plan – The AWUDP must include a source development plan based upon selected resource options. The plan shall be divided into three periods as follows:*
  - ***Near-term (initial 5 years)**: For this period, the source development plan must detail all of the actions that need to take place to accommodate the projected agricultural water demands anticipated for the initial 5-year time frame. A near-term implementation schedule and a detailed description of each action shall be presented. This schedule shall reflect the anticipated timing and sequencing of all near-term actions. The schedule shall also include expected supply-side capacity additions and demand-side program penetration levels by year. Near-term actions may include, but are not limited to pre-design, design, construction, obtaining financing, information gathering, staff hiring, execution of initial*

conservation program phases, and additional stakeholder and public involvement activities. The 5-year plan should also include estimates of incremental annual capital and operating costs.

- ***Medium-term (subsequent 5 years)**: The source development plan for the medium-term will require less detail, and should focus on major decision points and actions such as plan reassessments, and other actions that may require substantial advance preparation. Precise scheduling and sequencing of events is not critical. However, such information will need to be developed as part of subsequent updates to the AWUDP.*
- ***Long-term (final 10 years)**: The long-term source development plan should serve to highlight major events that are anticipated in the final portion of the planning period. It is expected that detailed information may not be available for long-term plans, however, available data should be identified and sufficiently described.*

5) *Resource Strategies - The resource and facility options that are identified by the DOA in the AWUDP must be combined into resource strategies and integrated with the county strategies. A resource strategy is defined as:*

   A flexible sequence of supply, infrastructure, storage, and conservation program additions intended to meet agricultural water needs over the planning period.

   The DOA must be prepared to develop alternative strategies and to evaluate each strategy against the other. During the update of each county's WUDP, the DOA's strategies should be re-evaluated based upon county specific objectives and measurable criteria developed under the prescribed IRP process. The final product of this step should result in a manageable

number of strategies within the WUDP from which a final recommendation will be selected.

6) *Uncertainties - The DOA should consider future uncertainties in the development of resource strategies. Source development strategies should provide for future contingencies that may arise in the face of particular outcomes. Sensitivity analysis of strategies developed by the DOA should be performed to evaluate the sensitivity of forecasts and outcomes to various future scenarios.*

7) *Updating – The responsibility for maintaining, monitoring, and updating the AWUDP document resides with the DOA. However, it is recommended that agricultural stakeholders annually update project information in order to monitor demand forecasts and implementation of water development strategies. The DOA should establish a mechanism for regular review of existing, planned, and proposed water resources to meet projected agricultural requirements.*

APPENDIX C
FARMER SURVEY FORM

APPENDIX

Appendix 1: Survey Instrument

ID#_____

IRRIGATION SURVEY INSTRUMENT

By SMS Research on behalf of the Department of Agriculture

SMS Research on behalf of the Department of Agriculture is surveying to find an accurate interpretation of water usage from the farmers of Hawaii. Please answer the following questions as honest as possible. If you are uncomfortable answering any question or feel you cannot answer it honestly skip the question.
Your answers are completely confidential. All questionnaires will be anonymous. This survey will help us and our community to understand Hawaii's water usage better.

Q1. What Agricultural Park are you apart of?

_____

Q2. What is the name of your farm?

_____

Q2a. Is this your only property or do you farm at other properties as well?

Only ..... O
Farm at others ..... O

Q2b. (IF MULTIPLE) Can you please list the where these other properties are?

_____
_____
_____

Please answer the following questions for this property only.

Q3. What is your role for farming at this farming operation?

Owner ..... O
Overseer ..... O
Farm hand ..... O
Other (Specify) ..... O
_____

Q4. How long have you been farming?

1-5 Years ..... O
5-10 Years ..... O
10-15 Years ..... O
15-20 Years ..... O
20 or more Years ..... O

Q5. How long have you been farming at this site?

1-5 Years ..... O
5-10 Years ..... O
10-15 Years ..... O
15-20 Years ..... O
20 or more Years ..... O

Q6. What method(s) of water distribution do you currently use to water your cops? Select all that apply.

Center-Pivot ..... O
Drip ..... O
Flood ..... O
Furrow ..... O
Gravity ..... O
Rotation ..... O
Sprinkler ..... O
What type of head? _____
How many? _____
Subirrigations ..... O
Traveling Gun ..... O
Supplemental ..... O
Surface ..... O
Catchment System ..... O
Other (Specify) ..... O
_____

Q7. Is this irrigation system metered or non-metered.

Metered ..... O
Non-Metered ..... O

Q8. On an average month during the dry season about how many gallons of water do you use for irrigation?

_____Gallons per month

If you do not know can you explain what type of irrigation you use each month and how long you use it?

Q9. On an average month during the wet season about how many gallons of water do you use for irrigation?

_____Gallons per month

If you do not know can you explain what type of irrigation you use each month and how long you use it?

Irrigation Survey Instrument — Page 1
© SMS — March 2014

ID#_____

Q10a. (HAND RESPONDENT ANSWER SHEET) Now if you could go through this table and select the crops you grow and answer the following questions for each crop. For each crop you grow, please write the estimated number of crops you have, the number of times you harvest this crop, the number of acres you use for that crop, the type of irrigation used to water that crop (drip, flood, sprinkler, etc.), as well as how many gallons of water per month you use for both dry and wet season.

Q10b. Please select which plant you grow and answer the following questions for each plant. Please write the estimated number of plants you have, the number of times you harvest this plant, the number of acres you use for that plant, the type of irrigation used to water that plant (drip, flood, sprinkler, etc.), as well as how many gallons of water per month you use for both dry and wet seasons.

Q10c. Please specify the type of livestock you raise, if any, in the table below. Please write the amount of livestock as well as the gallons of water you use for their care each month.

Q10d. What is your total acreage for all your crops? _____

Q11. Do you keep these crops for the whole year, or do you change crops in different seasons?

_____

_____

Q12. How do you determine how often you irrigate and how much water you add during the dry season?

Plants look wilted ..... O
On a schedule basis ..... O
Other (Specify) ..... O

_____

Q13. How do you determine how often you irrigate and how much water you add during the wet season?

Plants look wilted ..... O
On a schedule basis ..... O
Other (Specify) ..... O

_____

Q14. Please specify any crops that you rotate throughout the year.

Q15. What other agricultural activities (preparation, packaging, processing) do you do at this location?	Q15a. How much water do you use with each activity?

Q16. How many residential units are on this property? _____
Q17. How many people per unit? _____
Q18. How many gallons of water per unit is used a month? _____
Q19. How many months of the year are these units in use? _____

ID#_____

Q20. Do you have any issues with usage/availability that you think are important to discuss?

_____

_____

_____

Q21. How would you rate your water service on a scale of 1 to 5, 1 being the worst and 5 being the best? _____

Q22. And why do you say that?

_____

_____

Q23. Where is your farm located?

Oahu ..... O
Maui ..... O
Hawaii ..... O
Kauai ..... O
Molokai ..... O

Q23a. What is your farm location zipcode?

96☐☐☐

Interviewer:	
Date:	
Time of day:	
Respondent name:	
Respondent Contact information	
Can you provide documentation of water usage?	
GPS Location :	

Thank you and have a nice morning/afternoon/evening.

If you have any questions please contact Jim Dannemiller at 808-440-0701 or jdannemiller@smshawaii.com

ID#_____

Respondent Copy

Q10a. Now if you could go through this table and select the crops you grow and answer the following questions for each crop. For each crop you grow, please write the estimated number of crops you have, the number of times you harvest this crop, the number of acres you use for that crop, the type of irrigation used to water that crop (drip, flood, sprinkler, etc.), as well as how many gallons of water per month you use for both dry and wet season.

Produce

Crop	Number of harvests per year	*Number of Acres	Type of Irrigation used to water crop	Gallons of water per month Dry Season	Gallons of water per month Wet Season
Alfalfa Initial					
*If less than .25 acres, please describe amount of land devoted to crop:					
Alfalfa Ratoon					
*If less than .25 acres, please describe amount of land devoted to crop:					
Banana Initial					
*If less than .25 acres, please describe amount of land devoted to crop:					
Banana Ratoon					
*If less than .25 acres, please describe amount of land devoted to crop:					
Cabbage					
*If less than .25 acres, please describe amount of land devoted to crop:					
Cantaloupe					
*If less than .25 acres, please describe amount of land devoted to crop:					
Coffee					
*If less than .25 acres, please describe amount of land devoted to crop:					
Dry Onion					
*If less than .25 acres, please describe amount of land devoted to crop:					
Eggplant					
*If less than .25 acres, please describe amount of land devoted to crop:					
Eucalyptus					
*If less than .25 acres, please describe amount of land devoted to crop:					

ID#_____

Crop	Number of harvests per year	*Number of Acres	Type of irrigation used to water crop	Gallons of water per month Dry Season	Gallons of water per month Wet Season
Ginger					
*If less than .25 acres, please describe amount of land devoted to crop:					
Guava					
*If less than .25 acres, please describe amount of land devoted to crop:					
Heliconia					
*If less than .25 acres, please describe amount of land devoted to crop:					
Herbs (Basil, Rosemary, Thyme)					
*If less than .25 acres, please describe amount of land devoted to crop:					
Kikuyu Grass					
*If less than .25 acres, please describe amount of land devoted to crop:					
Lettuce					
*If less than .25 acres, please describe amount of land devoted to crop:					
Lychee					
*If less than .25 acres, please describe amount of land devoted to crop:					
Macadamia nut					
*If less than .25 acres, please describe amount of land devoted to crop:					
Other Melon					
*If less than .25 acres, please describe amount of land devoted to crop:					
Pineapple					
*If less than .25 acres, please describe amount of land devoted to crop:					
Pumpkin					
*If less than .25 acres, please describe amount of land devoted to crop:					
Seed, Corn					
*If less than .25 acres, please describe amount of land devoted to crop:					
Sugarcane Year 1					

ID#_____

Crop	Number of harvests per year	*Number of Acres	Type of Irrigation used to water crop	Gallons of water per month Dry Season	Gallons of water per month Wet Season
*If less than .25 acres, please describe amount of land devoted to crop:					
Sugarcane Year 2					
*If less than .25 acres, please describe amount of land devoted to crop:					
Sugarcane Ratoon					
*If less than .25 acres, please describe amount of land devoted to crop:					
Sweet Potatoes					
*If less than .25 acres, please describe amount of land devoted to crop:					
Taro					
*If less than .25 acres, please describe amount of land devoted to crop:					
Ti					
*If less than .25 acres, please describe amount of land devoted to crop:					
Watermelon					
*If less than .25 acres, please describe amount of land devoted to crop:					
Herbs (Basil, Rosemary, Thyme)					
*If less than .25 acres, please describe amount of land devoted to crop:					
Biofuel Crops (specify)					
*If less than .25 acres, please describe amount of land devoted to crop:					
Other (specify)					
*If less than .25 acres, please describe amount of land devoted to crop:					
Other (specify)					
*If less than .25 acres, please describe amount of land devoted to crop:					

ID#_____

Q10b. Please select which plant you grow and answer the following questions for each plant. Please write the estimated number of plants you have, the number of times you harvest this plant, the number of acres you use for that plant, the type of irrigation used to water that plant (drip, flood, sprinkler, etc.), as well as how many gallons of water per month you use for both dry and wet seasons.

Plants/Botanicals

Crop	Number of harvests per year	*Number of Acres	Type of irrigation used to water crop	Gallons of water per month Dry Season	Gallons of water per month Wet Season
Bromeliad					
*If less than .25 acres, please describe amount of land devoted to crop:					
Ferns					
*If less than .25 acres, please describe amount of land devoted to crop:					
Dendrobium, Pot micro-sprink					
*If less than .25 acres, please describe amount of land devoted to crop:					
Draceana, pot micro-sprink					
*If less than .25 acres, please describe amount of land devoted to crop:					
Orchids					
*If less than .25 acres, please describe amount of land devoted to crop:					
Xanthiums					
*If less than .25 acres, please describe amount of land devoted to crop:					
Other (specify)					
*If less than .25 acres, please describe amount of land devoted to crop:					
Other (specify)					
*If less than .25 acres, please describe amount of land devoted to crop:					
*Other (specify)					
If less than .25 acres, please describe amount of land devoted to crop:					

ID#_____

Q10c. Please specify the type of livestock you raise, if any, in the table below. Please write the amount of livestock as well as the gallons of water you use for their care each month.

Livestock

Livestock (Please specify)	Number of animals	Gallons of water used for care per month	Water usage for pasturage

APPENDIX D
HISTORICAL WATER FLOW DATA

WATER FLOW DATA - KAUAI COUNTY

Irrigation System	Hist. Ave. Flow (2) (mgd)	USGS(1) Location Date Range	USGS (1) Old HI Datum (Latitude Longitude)	USGS (1) Est. Mean Monthly Discharge (low) (mgd)	USGS (1) Est. Mean Monthly Discharge (high) (mgd)	Transmission Capacity (2)
East Kauai Irrigation System						[473]
Hanamaulu	[21]	Near Lihue 1910-1919	22°02'05" 159°25'36	9.7	23.9	
Stable Storm	[17]	Near Lihue 1937-2002	22°04'09" 159°26'46"	2.6	9.0	
Kapahi	[10]	Nr. Kealia 1917-2002	22°06'09" 159°22'28"	2.9	5.4	
Makaleha		Nr. Kealia 1936-1998	2°07'06" 159°22'04"	2.1	5.4	
Wailua	[10]	nr. Kapaa 1936-2002	22°04'34" 159°24'04"	6.0	14.2	
Aahoaka		nr. Kapaa 1966-1972	22°03'30" 159°23'49"	0.6	1.1	
Iliiliula-N. Wailua	[12]					
Kekaha Ditch Irrigation System	[56] 30	Camp 1 1908-1968	22°02'35" 159°38'29	33.6	40.7	[104] 40
Kokee Ditch Irrigation System	15	nr. Waimea 1926-1982	22°06'42" 159°40'43"	8.4	22.6	[105] 55
Kaloko and Puu Ka Ele Ditches						
Kahiliwai - (Porter)		nr. Kilauea 1934-1967	22°11'07" 159°25'58	1.3	3.1	
Kahiliwai - (Mill Ditch)						

WATER FLOW DATA - KAUAI COUNTY
(continued)

Irrigation System	Hist. Ave. Flow (2) (mgd)	USGS(1) Location Date Range	USGS (1) Old HI Datum (Latitude Longitude)	USGS (1) Est. Mean Monthly Discharge (low) (mgd)	USGS (1) Est. Mean Monthly Discharge (high) (mgd)	Transmission Capacity (2)
Puu Ka Ele		Near Kilauea 1932-1967	22°11'10" 159°24'17"	1.7	3.2	
Koloko		Near Kilauea 1932-1968	22°10'43" 159°22'59"	2.5	4.0	
• Anahola Ditch						
• Anahola Ditch		abv. Wasteway nr. Kealia 1915-1921	22°08'15" 159°22'31"	3.9	6.5	
• Lower • Anahola		nr. Kealia 1937-1995	22°08'14" 159°19'31"	0.8	2.1	
• Upper and Lower Lihue Ditches and por. Waiahi-Iliiliula Ditch						
• Lihue Ditch		nr. Lihue 1910-1919	22°01'45" 159°25'52"	3.7	7.8	
• North Wailua		blw. Waikoko Str. nr. Lihue 1965-2002	22°03'34" 159°28'00"	12.9	14.9	
• Waiahi-Iliiliula						
• Upper and Lower Haiku Ditches						
• Lower Haiku		nr. Puhi 1963-1971	21°58'20" 159°26'55"	2.2	8.4	
• Upper Haiku		nr. Puhi 1963-1971	21°58'48" 159°27'13"	2.1	10.3	

WATER FLOW DATA - KAUAI COUNTY
(continued)

Irrigation System	Hist. Ave. Flow (2) (mgd)	USGS(1) Location Date Range	USGS (1) Old HI Datum (Latitude Longitude)	USGS (1) Est. Mean Monthly Discharge (low) (mgd)	USGS (1) Est. Mean Monthly Discharge (high) (mgd)	Transmission Capacity (2)
Kauai Coffee Irrigation System						
Kamooloa						
Wainiha Power Plant	50					
Pump 3	[35] 34					
Alexander Reservoir	10					
Waiaha-Kuia Aqueduct, por. Waiahi-Iliiliula Ditch, and Koloa-Wilcox Ditch						
Waiaha-Kuia		nr. Puhi 1964-1971	21°58'36" 159°28'28"	1.6	7.8	60-90
Koloa Ditch		nr. Koloa 1964-1971	21°57'06" 159°28'11"	7.1	18.1	
Olokele Ditch						
Olokele Ditch	66	Makaweli Weir 1912-1917	22°00'06" 159°36'45"	30.4	49.8	
Hanapepe	35	blw. intake nr. Eleele 1930-1938	21°58'06" 159°32'05"	21.3	31.0	

1 USGS Surface –Water Monthly Statistics for the Nation (http://waterdata.usgs.gov/nwis)

2 Source: Wilcox, Carol, 1977

Hist. Ave. Flow - Historical Average Flows, based on the historical record

WATER FLOW DATA - MAUI COUNTY

Irrigation System	Hist. Ave. Flow (2) (mgd)	USGS(1) Location Date range	USGS (1) Old HI Datum (Latitude Longitude)	USGS (1) Est. Mean Monthly Discharge (low) (mgd)	USGS (1) Est. Mean Monthly Discharge (high) (mgd)	Transmission Capacity (2)
East Maui Irrigation System						440
(old) Hamakua	[65]	Honopou nr. Huelo 1918-1965	20°53'32" 156°15'17"	0.8	4.2	
Spreckels (old Haiku)	[30]	below Kaaiea nr Huelo 1918-1929	20°52'38" 156°12'05"	2.9	8.4	
Lowrie	[45]	Honopou nr. Huelo 1910-1985	20°54'45.2" 156°14'57.4" NAD83	18.1	30.3	60
New Hamakua	[54]	Honopou nr. Huelo 1918-1985	20°53'17.0" 156°15'11.8" NAD83	14.9	36.8	
Koolau	[55]	Wahinepee nr. Huelo por. 1922	20°51'35" 156°11'30"	21.3	98.2	85
New Haiku	[45] 25	Honopou nr. Kailua 1910-1985	20°54'56.1" 156°14'49.1" NAD83	11.0	25.9	100
Kauhikoa	[71]	Opana Weir 1910-1928	20°53'26" 156°16'33"	9.0	22.0	110
Wailoa	[110]	Honopou nr. Huelo 1922-1987	20°53'10.3" 156°15'08.7" NAD83	88.5	135.1	160-195

1 USGS Surface –Water Monthly Statistics for the Nation (http://waterdata.usgs.gov/nwis)

2 Source: Wilcox, Carol, 1977
Hist. Ave. Flow - Historical Average Flows, based on the historical record

WATER FLOW DATA - MAUI COUNTY
(continued)

Irrigation System	Hist. Ave. Flow (2) (mgd)	USGS(1) Location Date range	USGS (1) Old HI Datum (Latitude Longitude)	USGS (1) Est. Mean Monthly Discharge (low) (mgd)	USGS (1) Est. Mean Monthly Discharge (high) (mgd)	Transmission Capacity (2)
Maui Land And Pineapple/Pioneer Mill Irrigation System						
Honokohau	[35] 20	At Intake nr. Honokohau 1907-1913	20°57'50" 156°35'25"	19.4	22.6	[18] 35
Kauaula	4.5	nr. Lahaina 1912-1917	20°52'40.4" 156°37'21.9"	5.1	6.5	25.5
Olowalu	4	nr. Olowalu 1911-1967	20°49'33" 156°36'50"	3.8	5.5	11
Honolua (Honokohau_	[50] 30-18					
Honokowai	6					
Kahoma	3					
Kanaha	3.8					
Launiupoko	0.8					
Ukumehame	3					
Wahikuli	[5]					
Upcountry Maui Irrigation System	[3]					
West Maui Irrigation System						
Waihee Ditch (Sprekels)	[10] 10-2					
Waihee Canal (Ditch)	[27] 27					
Nine smaller ditches						
Molokai Irrigation System	[8]	Tunnel W. Portal 1965-2004	21°07'27" 156°59'50"	3.8	5.4	[36]

WATER FLOW DATA - HAWAII COUNTY

Irrigation System	Hist. Ave. Flow (2) (mgd)	USGS(1) Location Date range	USGS (1) Old HI Datum (Latitude Longitude)	USGS (1) Est. Mean Monthly Discharge (low) (mg)	USGS (1) Est. Mean Monthly Discharge (high) (mg)	Transmission Capacity
Waimea Irrigation System	[10] 8	Abv. Waimea Res. 1974 - 2004	20°03'35" 155°37'44"	3.6	8.4	
Lower Hamakua Ditch Irrigation System	[66] 30	Main Weir Kukuihaile 1964-1973	20°07'07" 155°35'09"	25.9	33.0	[tbd]
Kohala Ditch		Pololu 1927-1972	20°10'19" 155°44'20"	22.0	30.4	
Kehena Ditch		Kehena Ditch 1918-1966	20°07'25" 155°45'05"	4.2	9.7	

1. USGS Surface –Water Monthly Statistics for the Nation (http://waterdata.usgs.gov/nwis)
2. Source: Wilcox, 1977
   Hist. Ave. Flow - Historical Average Flows, based on the historical record

WATER FLOW DATA - HONOLULU COUNTY

Irrigation System	Hist. Ave. Flow (2) (mgd)	USGS(1) Location Date range	USGS (1) Old HI Datum (Latitude Longitude)	USGS (1) Est. Mean Monthly Discharge (low) (mgd)	USGS (1) Est. Mean Monthly Discharge (high) (mgd)	Transmission Capacity
Oahu Ditch (Wahiawa, Helemano, and Tanaka)						
Oahu		Mauka Ditch nr. Wahiawa 1947-1968	21°30'48" 157°59'17"	2.3	3.0	
Wahiawa		At Wahiawa 2012-2013	21°30'02.0"1 58°03'03.7" (NAD 83)	6.5	12.3	
Opaeula, Kamananui						
Waiahole Ditch Irrigation System	42-27	Adit 8 1956-1969	21°157°57' 157°57'30"	22.6	35.3	100
Waiahole Ditch (continued)	[28]	Adit 8 2001-2003	21°157°57' 157°57'30"	6.5	9.5	[193]
Waimanalo Irrigation System						
		Nr. Waimanalo 1954-2002	21°20'45 157°45'11"	0.9	1.7	
		Ainoni Spring 1991-2002	21°21'03" 157°46'03"	0.5	0.8	
		Abv. Anianinui Tunnel 1991-2000	21°20'50" 157°45'26"	0.8	1.2	

1. USGS Surface –Water Monthly Statistics for the Nation, (http://waterdata.usgs.gov/nwis)
2. Source: Wilcox, Carol, 1977
   Hist. Ave. Flow - Historical Average Flows, based on the historical record

APPENDIX E
SATELLITE AND AERIAL IMAGERY ANALYSIS

Crop Mapping for Ag Ditch Assessment, Methods Report
Hawaii: Kauai, Oahu, and Big Island
June 2015

Prepared by:
Resource Mapping Hawaii LLC
Stephen Ambagis

EXECUTIVE SUMMARY

This mapping project covered the agriculture areas of 3 Hawaii islands where existing ditch irrigation systems are in place (Kauai, Oahu, and Big Island). The product is a series of land cover maps indicating the distribution of different types of agriculture across the areas of interest. Each island was analyzed separately using a combination of satellite image analysis and aerial image interpretation. The data used were provided by Digital Globe and Resource Mapping Hawaii (RMH). The initial mapping was done on the 2 meter resolution satellite data acquired from 2011 using automated image analysis, an object based analysis using eCognition. A subsequent visual analysis was performed using a 4cm image data set collected by RMH in 2014. The final land cover maps were produced by manually assessing the entire initial satellite classification result in conjunction with the recent aerial data collected as "ground truth". A 100% visual review was performed and manual corrections applied where required. The islands of Kauai and Oahu were both mapped in the above described manner while Hawaii Island was only assessed using the automated analysis with the available satellite data. The agriculture classes that were defined were generally vague given the level of complexity associated with mapping specific species and or types of agriculture. A considerable amount of effort dedicated to determining the difference between active ranching lands and fallow tilled lands. Often these two states of use were confused and frequently overlapped given farming practices in the state of Hawaii. Each island had a different suit of dominant agriculture products and therefore required extensive review and refinement. All species of produce were lumped into one group as were all species of fruit and nut trees. Agroforestry species were also all lumped into a single class. In some cases individual species could be distinguished using the 4cm data but not consistently enough to warrant separate classes for this study. The maps produced are only a snapshot in time. From the evaluation of multiple data sets its clear that many of the common agriculture areas rotate crop covers and use from year to year.

It should be noted here that this analysis was done independently of information produced by either land owners or the state. The resulting data therefore has a level of objective observation different from most classical agriculture assessments that rely heavily on information gained from interviews or tax assessment based information.

TABLE OF CONTENTS

Contents

Methods REPORT

1 Introduction

Mapping crop types has been a perennially difficult process over the years. Recent improvements in satellite, aerial imaging, and image analysis technologies have brought this process into a more manageable state. Resource Mapping Hawaii (RMH) was hired to produce maps of the current crop types being produced in specific areas around the state. Previous mapping efforts involved the use of satellite imagery and object based analysis along with visual evaluation and refinement. In this most recent iteration RMH incorporated the use of high resolution aerial imagery into the process to help inform the satellite based mapping. This process was both instructive and successful.

2 Mapping Methods

2.1 Preliminary mapping products

The first phase of this mapping process was to do an initial evaluation of the available satellite data to determine both extents of the areas of interest as well as the feasibility to map the crop types of interest.

2.1.1 Available satellite data

An assessment was done for all of the available satellite data at that time. Of the data sets available one set was considered to be the most applicable as well as consistent across the entire state. In 2009/2010 NOAA and affiliates contracted Digital Globe to use its World View II (WV2) sensor to collect imagery for all the main Hawaii Islands. Once collected that data was made publicly available.

The WV2 sensor is capable of producing 7 bands of multispectral data at 2m resolution including deep blue, blue, green, yellow, red, red edge, near infrared1 and near infrared2. An 8th panchromatic band is also collected at 50cm resolution (Figure 1).

The WV2 data set that was collected and available covered the state with approximately 20% cloud cover and spanned approximately 2 years. The images were color balanced and mosaicked by NOAA personnel and made available. Due to the new capacity of that sensor in

both spacial resolution, number of available bands, and geographic coverage it was determined to be the best data available for mapping crop type.

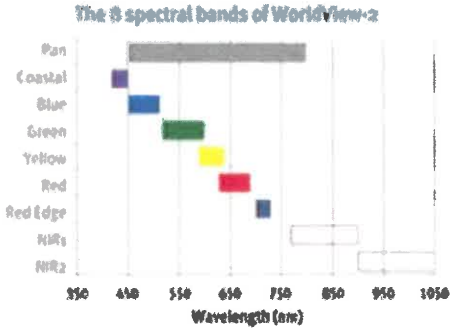


Figure 1 – 8 bands collected by the WV2 satellite sensor

2.1.2 Initial evaluation of satellite data products

An initial assessment was performed using the satellite data to determine its effectiveness for use in crop mapping. The data were imported into an object based classification software call eCognition, developed by Definiens and owed by Trimble Inc. It was determined from early mapping efforts that data with this level of resolution are better analyzed using object based approaches rather than pixel based classification approaches.

Preliminary assessments indicated that a number of crops were spectrally independent but positive identification of those crops was unclear without considerable ground assessment.

It was also determined that the areas under agricultural use of some kind were generally evident and definable in the satellite data using the object based classification approach.

2.2 Aerial imaging for crop determination

2.2.1 Initial flying and data collection

Data collection flights started at the beginning of 2014 and continued through September of that year. The aerial imagery collection was initially contracted to be at ground sampling distance (GSD) of 8cm. An initial assessment flight was done on the island of Kauai to determine the relative usefulness of the imagery to identify crop cover types. After initial evaluation it was determined that the requirements of this project required at least a doubling of resolution so the data was collected at an average of 4cm (GSD) for the remainder of the project. Due to the required doubling of the resolution it was determined that a strategic approach to the flying would be taken that would focus on areas of difficulty where crop type and or land use was unclear. All image data were post processed into fully ortho-recitified image mosaics ready for GIS analysis and interpretation alongside the satellite data being used for the mapping

production. Maps of the actual area covered are in contained in figures **3** and **5**. A total of 21,795 acres were collected on the island of Kauai, 9114 on Oahu and 1500 on Big Island.

Data collection was generally straight forward with a few exceptions common to aerial imaging.

- The presence of clouds above the aircraft creating inconsistent shadows on the ground.
- Periodic high winds that created excessive turbulence and periodic "smearing" in the imagery.
- Variable lighting from time of day differences within a given area of interest.

2.2.2 Image processing of ortho-mosaics

All of the image data underwent the same processing workflow. The original TIFF data was converted from the PhaseOne proprietary format using their custom software CaptureOne. During this process the images were corrected for lens distortion, variable lighting, and systematic noise reduction or image sharpening.

The data were then imported in the IPS 3.4 (Icaros Inc. Image Processing Software) where the GPS and INS data were synced with the imagery data and then run through a standard photogrammetric aerial triangulation routine. Each block of data was systematically cleaned until a within model RMSE of >1.0m was obtained. Then a series of ground control points (GCP) were chosen from the World View 2 satellite data and the block then run again. By incorporating GCPs from the WV2 data we ensured that the aerial data would line up with the satellite data that was being used for the actual mapping portion of the process. Final RMSE for each block was brought to >1.5m with ground control.

The image data was then individually processed out into ortho images using the USGS 10M as elevation control. The resulting ortho-imagery was run through a stitching algorithm also part of the IPS 3.2 platform. During the stitching phase the imagery is color balanced and dodged to create a seamless mosaic ready for analysis. The data were exported into 2GB tiles in an uncompressed GeoTIFF format in the NAD 1983 UTM Zone 4 projection system to correspond with the WV2 satellite data.

2.2.3 Visual assessment of the aerial imagery for crop determination

From the initial test flight it seemed as though 4cm would be resolute enough to determine most crop types. In many instances this was the case. Crops such as coffee, corn, taro, and others 4cm data was sufficient for the positive determination. However, a number of other crops, primarily ones not grown at large scale such as most of the produce based crops were impossible to separate at this resolution. This is very similar to what RMH found when trying to identify and map invasive plant species in conservation units. It was found that most species level mapping within forest communities required 1cm level aerial imaging to successfully identify individual species. While this did come to be a limitation for the analysis the overall result was generally successful.

The basic approach to analysis consisted of a preliminary draft classification of the satellite data and then using the aerial imagery as ground truth information each cover class was evaluated to determine cover type. In the case of most crop species this approach worked well. In some cases such as determining the difference between fallow crop agriculture fields and either active or inactive grazing pastures this approach was only mildly helpful. Within the 4cm data certain characteristics such as obvious animal trails or variable grazing patters were evident. However this was not often the case. These classes tended to be difficult to distinguish from one another throughout the process.

2.3 Mapping of the satellite data

2.3.1 Object based image analysis

The primary analysis approach utilized during this mapping effort was an object based approach. This differs from traditional land cover mapping with imagery that usually employs a pixel based approach. Pixel level analysis evaluates each pixel based on its spectral components and their relative severability. This type of automated image analysis has long been used when the data available tended to be large pixels covering multiple cover types. With the technological development of higher resolution imaging systems, both satellite and aerial, analysis approaches have become more varied. With the WV2 data used in this project the pixel size was small enough that grouping pixels by their relative similarity can be more effective for defining certain cover types. Object based approaches tend to give the user the ability to incorporate another level of information that of object shape, size, and relative position. This is especially helpful when looking at cover types such as man produced crops that while often spectrally overlap with other plant species are usually planted with some level of consistency and geometric pattern easily recognizable to the human eye but not identifiable in a pixel based analysis.

The software eCognition Developer 9.0 was chosen to do this object based analysis and was developed by Definiens Inc and now owned and distributed by Trimble. It is the industry standard for object based mapping and has by far the most encompassing tool sets available for managing high resolution imagery.

For each site / island, the WV2 satellite data was imported into eCognition and then subset into a small representative area for initial mapping methods development. This significantly reduces the time to determine the best approach to mapping each area and it specific cover types. In some cases if the islands or areas of interest (AOI) are similar enough then the methods used for one site can be applied to the others. In the case of this analysis each of the sites posed their unique challenges and variable cover types that required a slightly different set of variables be applied to produce a reasonable outcome.

2.3.2 Kauai Island

The Island of Kauai was the first Island to be analyzed and coincidentally also contained the largest amount of area under agriculture production as well as the highest diversity of cover types. The total number of agriculture classes defined on this island was 13. Of those 13, 2 of the classes represented fallow crops or ranch lands.

The majority of cover classes used were fairly straight forward however a few presented challenges given the available data. For example the crops containing the common "produce crops" such as tomatoes, lettuces, and other smaller scaled crops were difficult to impossible to tell apart from either the satellite data or the aerial imagery. In such cases an overarching class was created to include all of those types of crop termed mixed produce. The same could be said for many of the fruit and nut tree varieties. The classes termed grazing, fallow grazing, and fallow agriculture were also quite difficult to separate consistently. These cover types are often intermixed and change from year to year.

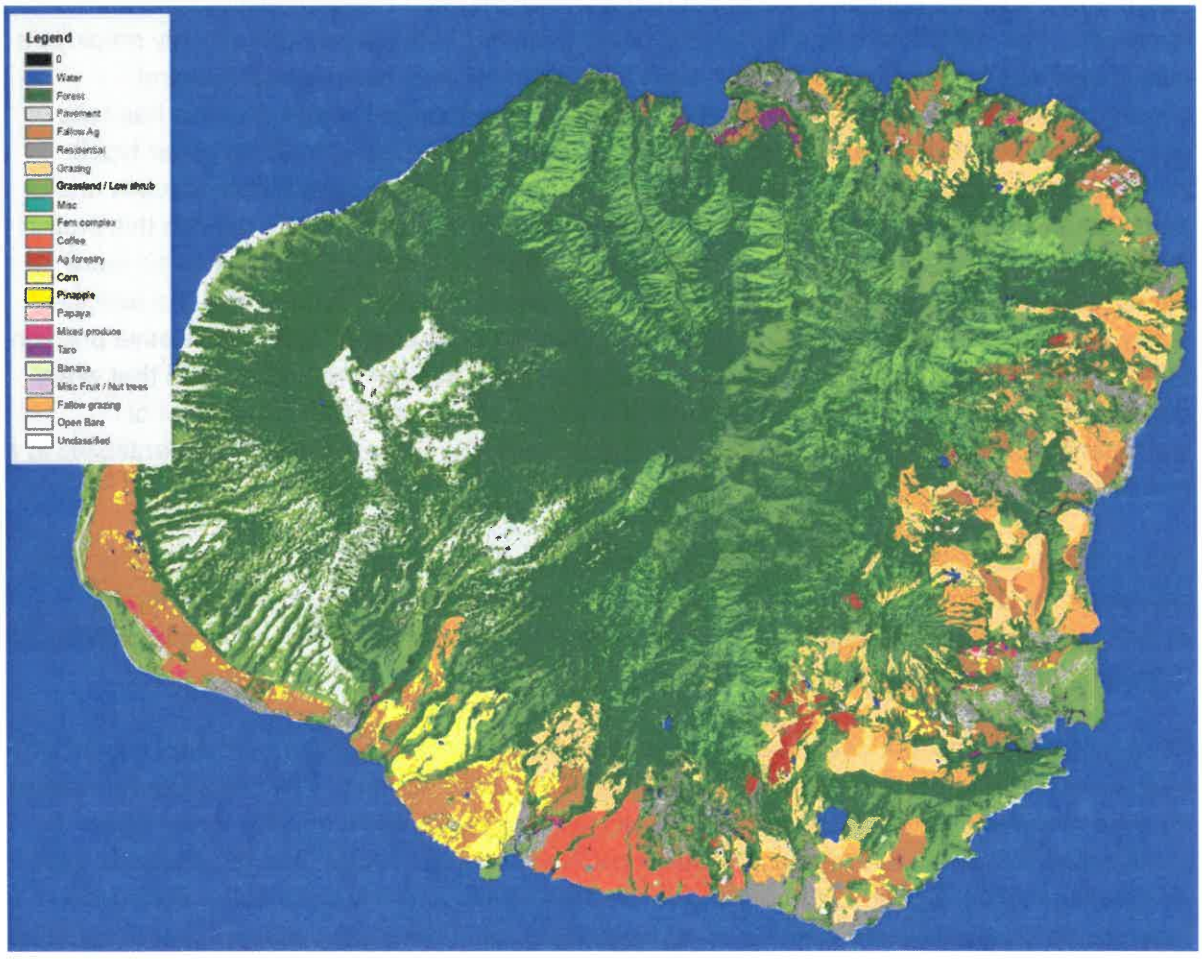


Figure 2 – Kauai Island agricultural land use classification

Figure 3 – Sites were 4cm aerial imagery was collected for visual referencing.

2.3.3 Oahu Island

For the island of Oahu the same number of agricultural classes was used totaling 13 in all. The amount of area under apparent agricultural use was less than Kauai with more emphasis on the larger crops of corn and pineapple. There was also a considerable amount of likely fallow agriculture with either some cover crop or bare ground. In this case it was clear that there were probably fallow agriculture lands that were not identified give their relative age of regrowth back

to a more natural looking mix of plant species.

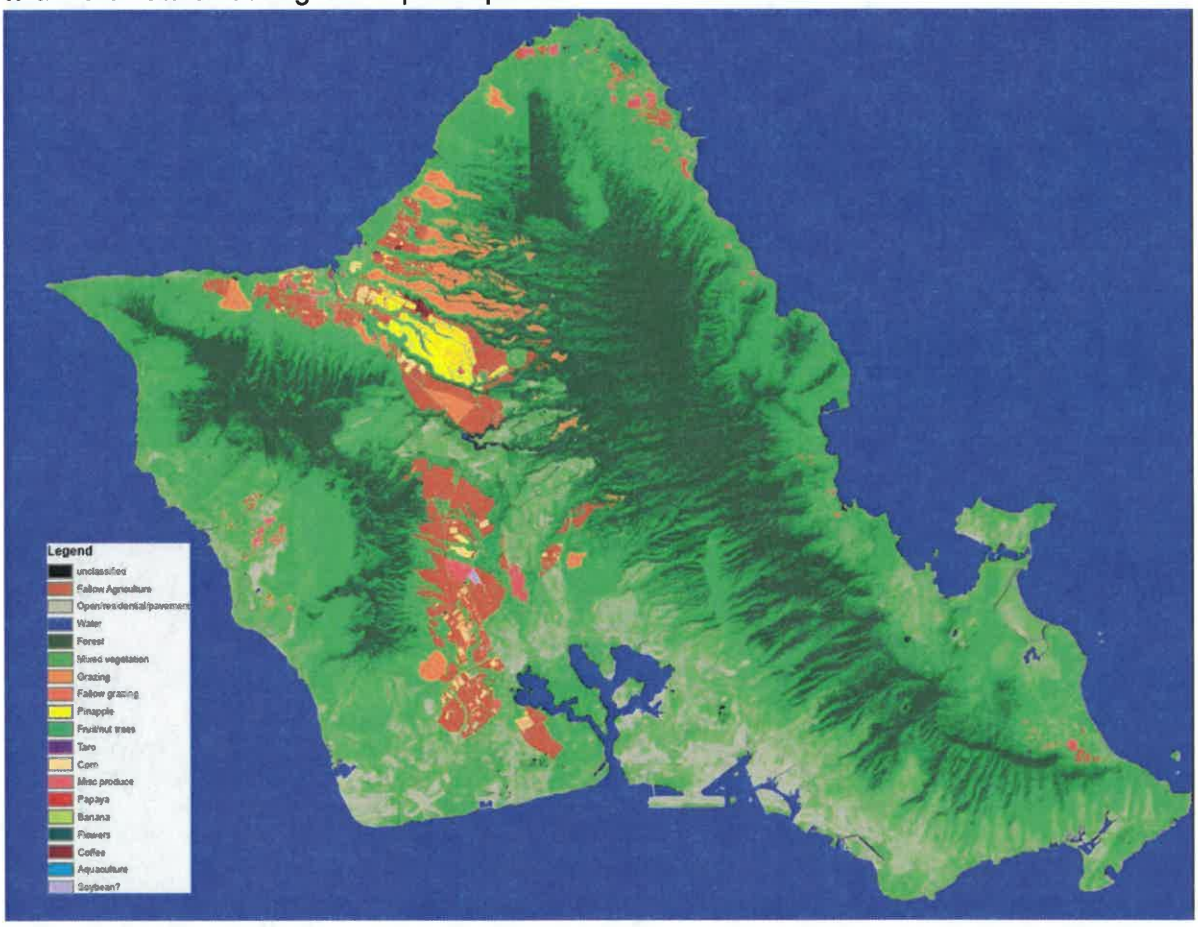


Figure 4 – Oahu Island agricultural land use classification

Figure 5 – Sites were 4cm aerial imagery was collected for visual referencing.

2.3.4 Hawaii Island

The Big Island of Hawaii was not evaluated in total in the same manner as the other islands given its size. The areas of interest were limited to the northern most section and southern most sections of the island. The other difference between this island and the others was related to the available satellite data at that time. The same world view 2 data was collected and distributed for this island as the others notable in that it was limited to 3 bands of information corresponding to the blue, green, and red bands. In the case of the other islands the full 8 multispectral bands were available to use. The limited amount of data did impact the final products but not in a considerable way given the predominant features that were used to map the agricultural classes.

In the case of the northern section of the island only 5 agriculture classes were deemed required and or identifiable. Such was not the case for the southern section of the island where more active classes were clearly evident.

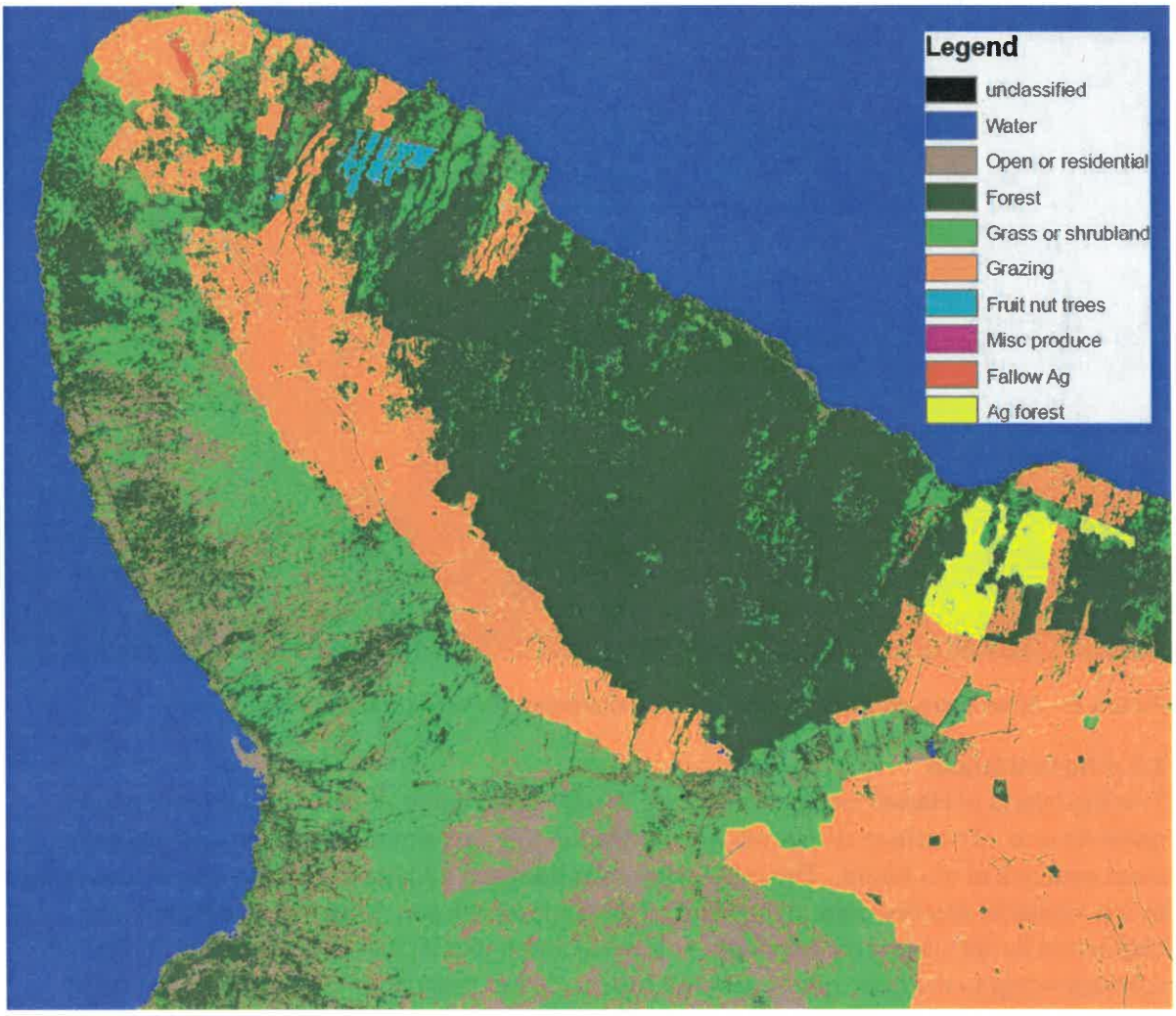


Figure 6 – Hawaii Island agricultural land use classification

2.3.5 Evaluation and clean up

After the preliminary object based semi-automated mapping process a visual assessment was done of all the agricultural areas comparing the results from the machine classified satellite data to what could be seen in the aerial imagery. If differences were detected, a manual reclassification was performed to the classified image. This process was done on each island where aerial data was collected or other available high resolution imagery could be incorporated. In some cases such as the south side of Hawaii Island, very little aerial imagery was available and so the classification relied primarily upon the machine classification and the interpreters local knowledge of the crops and land cover.

Visual examples of some of the different cover classes and the corresponding satellite data are provided in Appendix A below.

Appendix A

Figure 7 – Banana from the aerial imagery at 4cm.

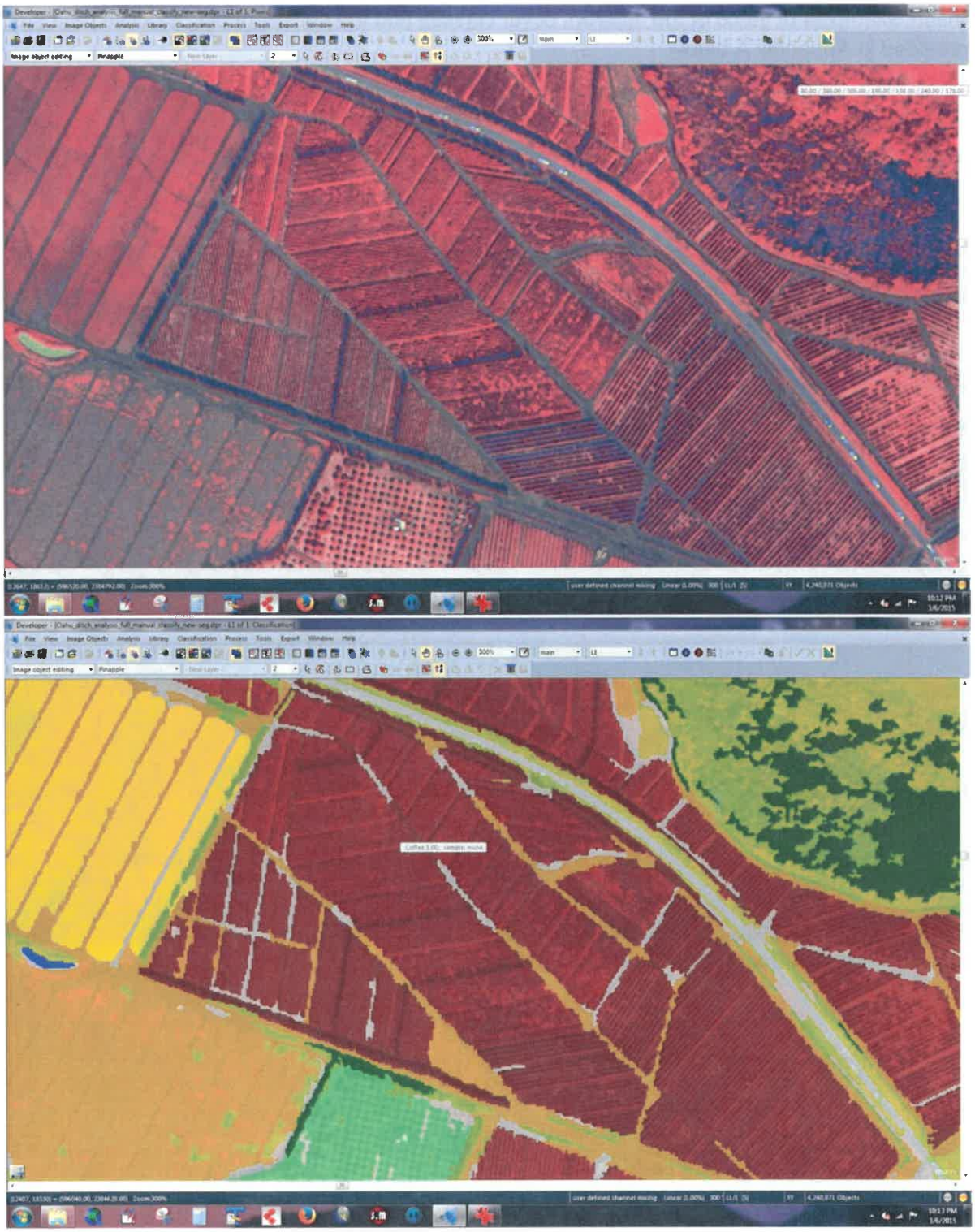


Figure 8 – Top: WV2 image. Bottom: Classified image with coffee identified in brown.

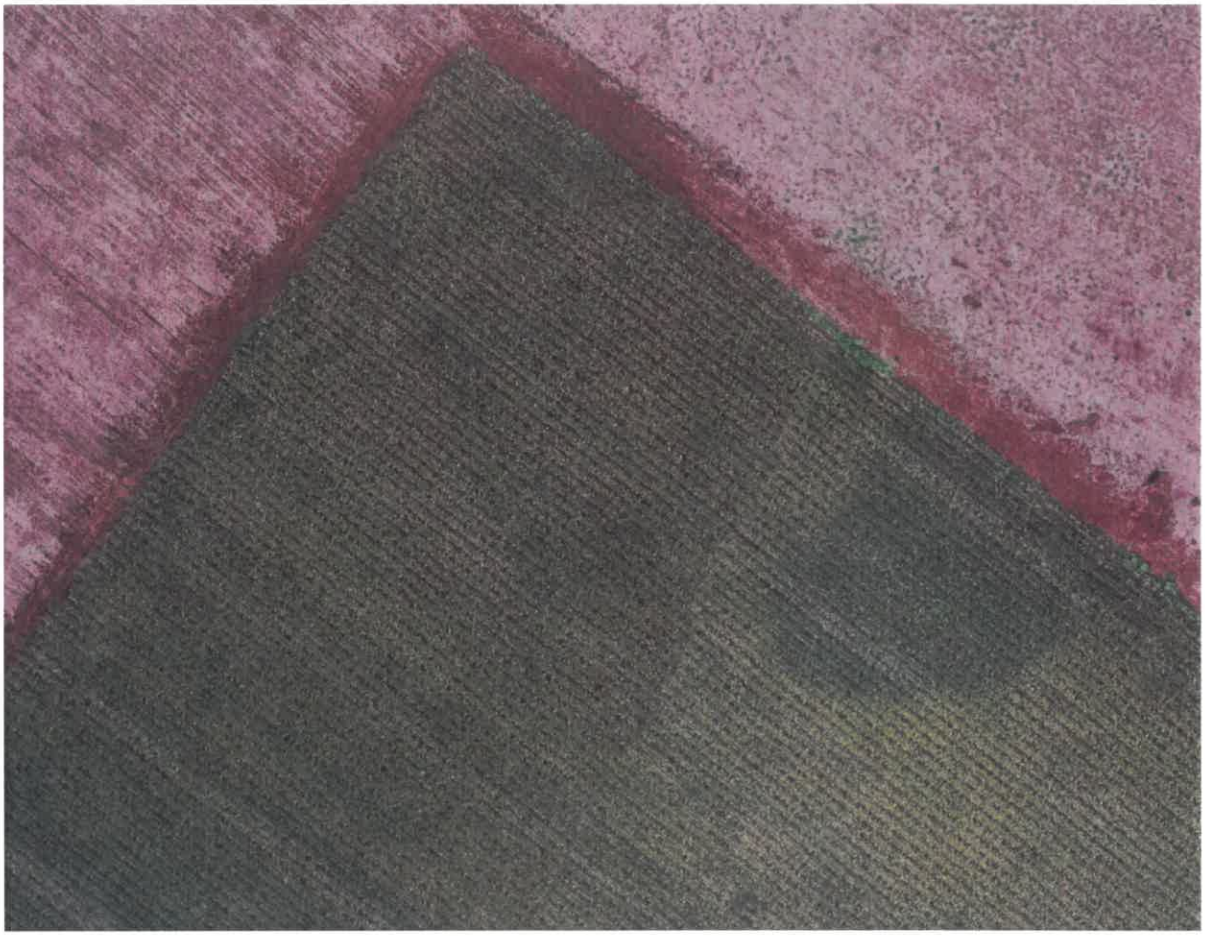
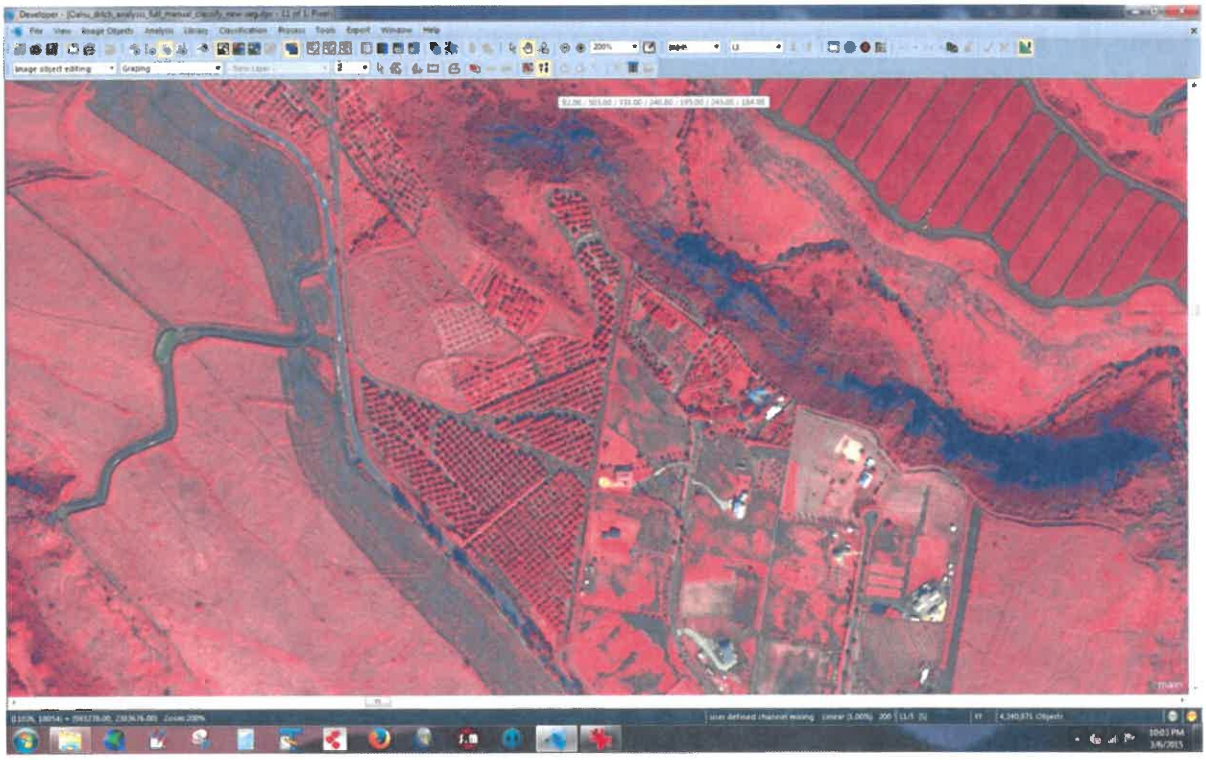


Figure 9 – Corn from the aerial imagery at 4cm.

Figure 10 – Top: WV2 image. Bottom: Classified image with corn identified in yellow.

Figure 11 – mixed fruit and nut trees from the aerial imagery at 4cm.



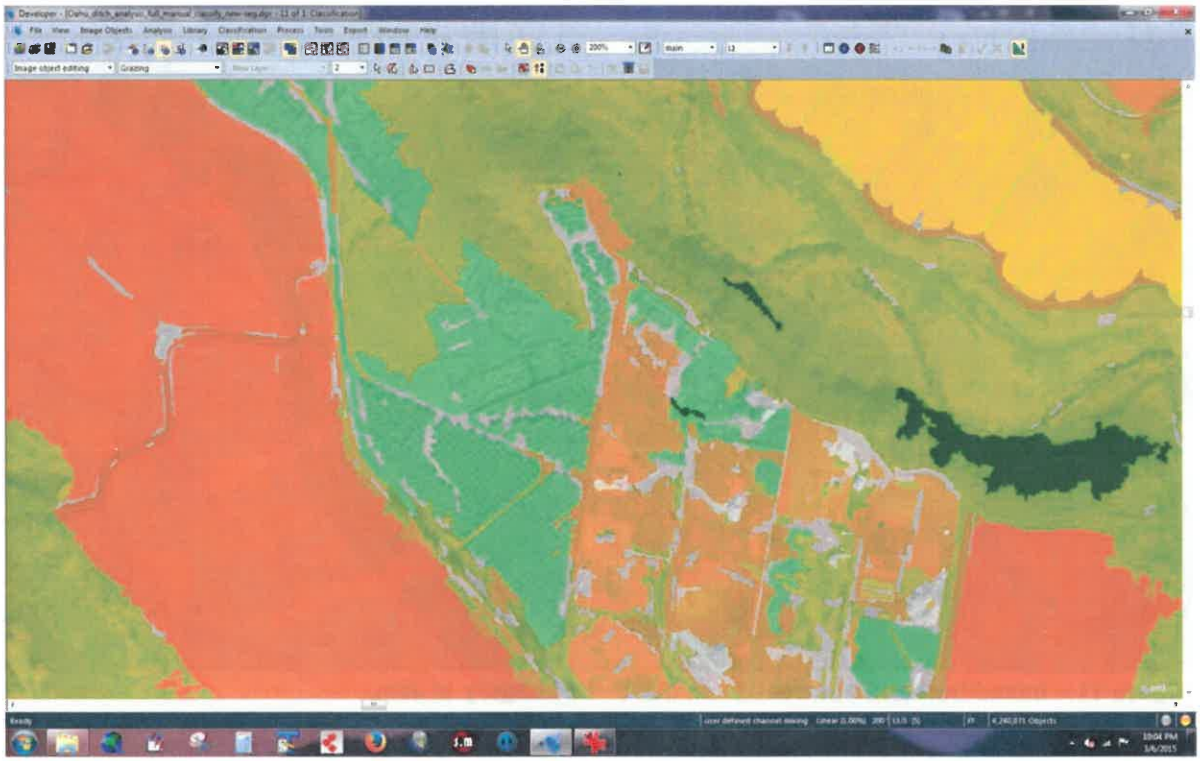


Figure 12 – Top: WV2 image. Bottom: Classified image with fruit trees identified in light green.

Figure 13 – mixed produce from the aerial imagery at 4cm.

Figure 14 – Top: WV2 image. Bottom: Classified image with mixed produce identified in purple.

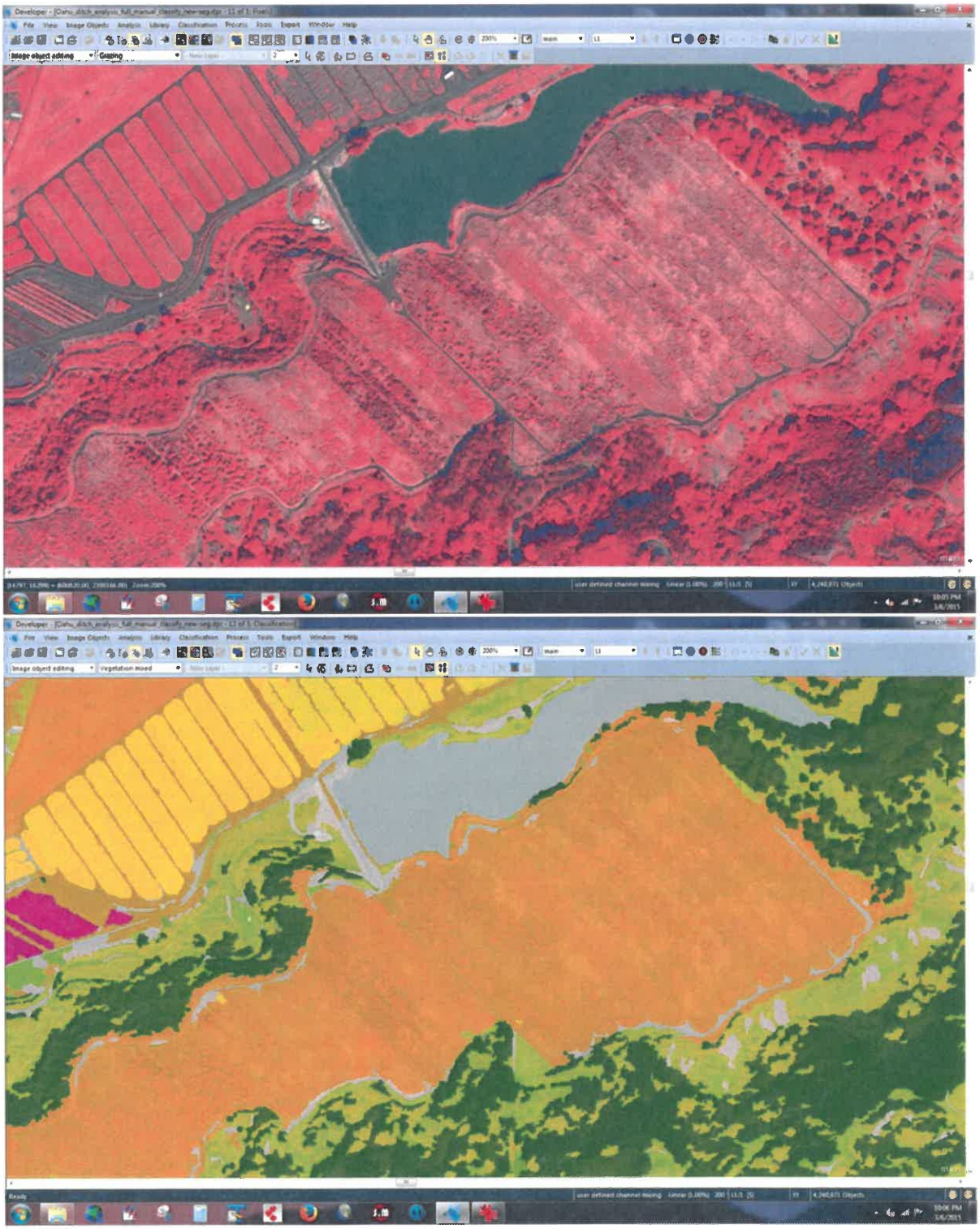


Figure 15 – Top: WV2 image. Bottom: Classified image with fallow agriculture identified in light brown.

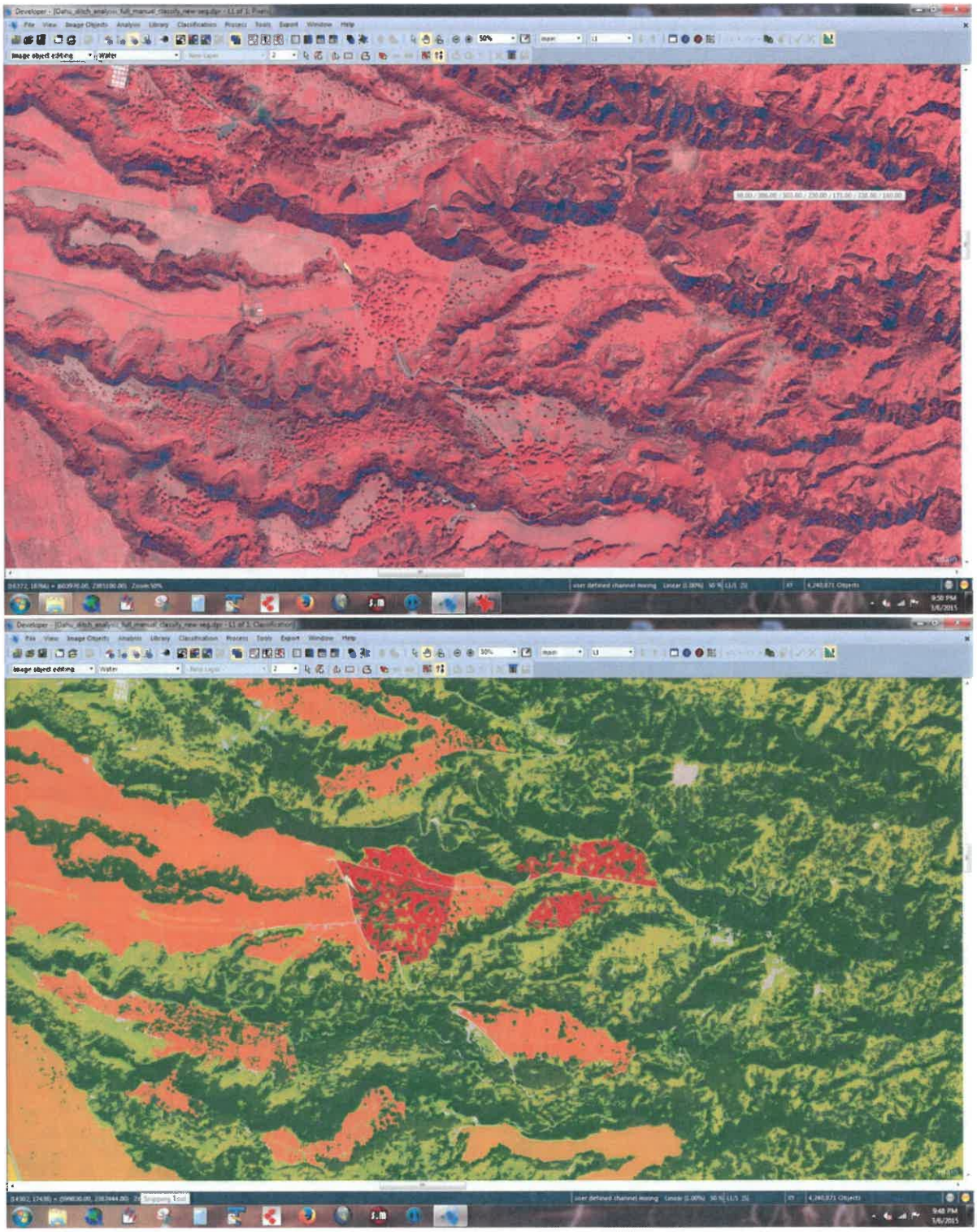


Figure 16 – Top: WV2 image. Bottom: Classified image with grazing identified in orange and fallow grazing in reddish brown.