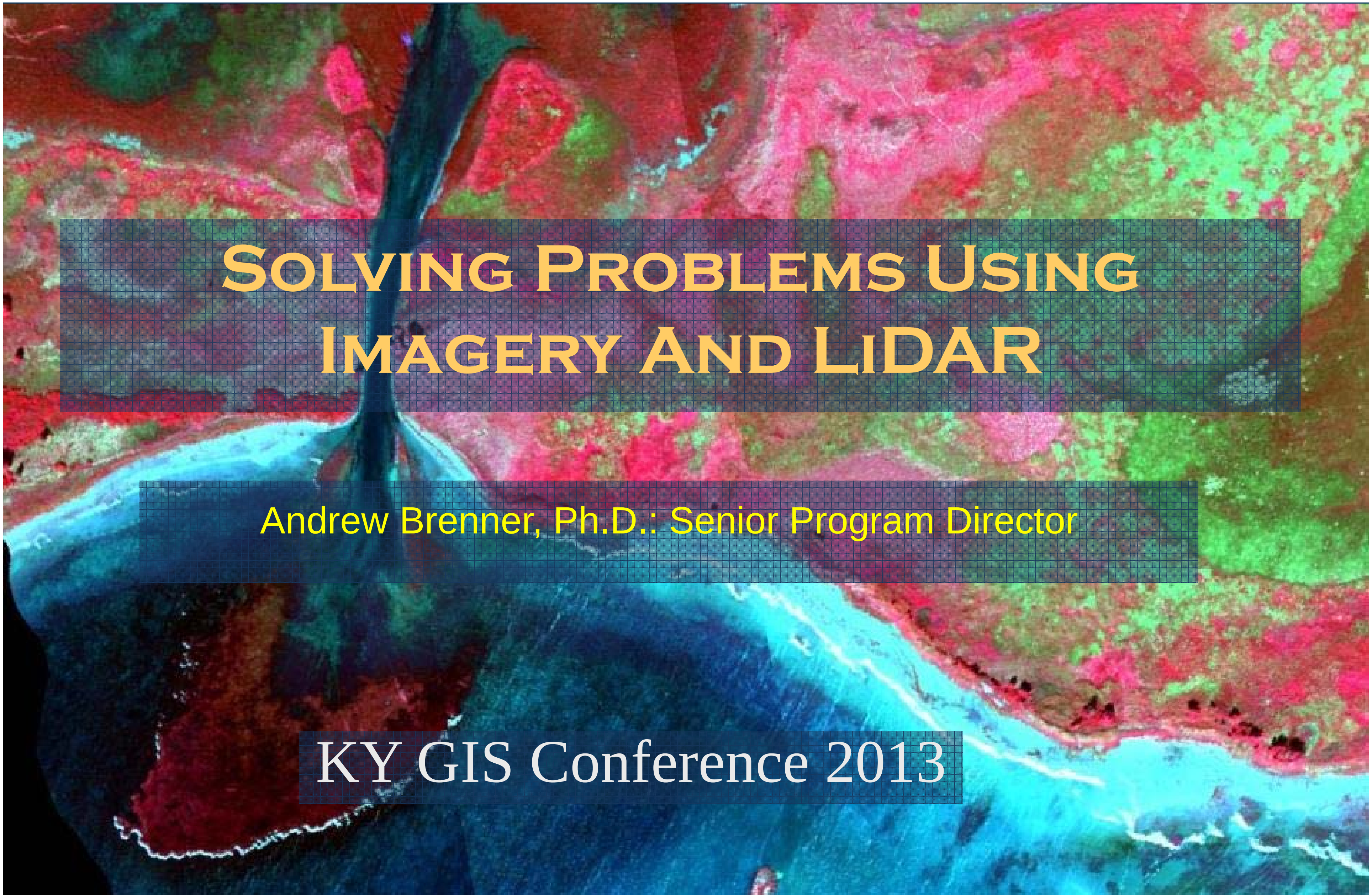

Solving Problems Using Imagery And LiDAR

Andrew Brenner, Ph.D.: Senior Program Director

KY GIS Conference 2013

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Workshop: Part 3

- Principles of classification
  - Resolution of input datasets
  - Classification processes
- Some applications
  - Impervious
  - Green infrastructure
  - Land use
  - Buildings
- Summary

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Remote Sensing Concepts

- Objective of project
- Resolution of imagery and LiDAR
- Classification processes

REMOTE SENSING IS NOT MAGIC

Remote Sensing Concepts

- What are you trying to do with the data
- Source data
  - Resolution
    - Spectral
    - Spatial
    - Temporal
    - Radiometric
  - Spatial Accuracy
- Turn data into information
  - Classification
    - Supervised
    - Unsupervised
    - Pixel based vs. object based

Considerations

- What dataset are you trying to create?
- Do you need imagery and or LiDAR?
- What spectral bands do you need?
- What ground resolution do you need?
- What spatial accuracy do you need?
- What time of the year do you need it?
- What is your timeline for dataset creation?
- What is your budget?

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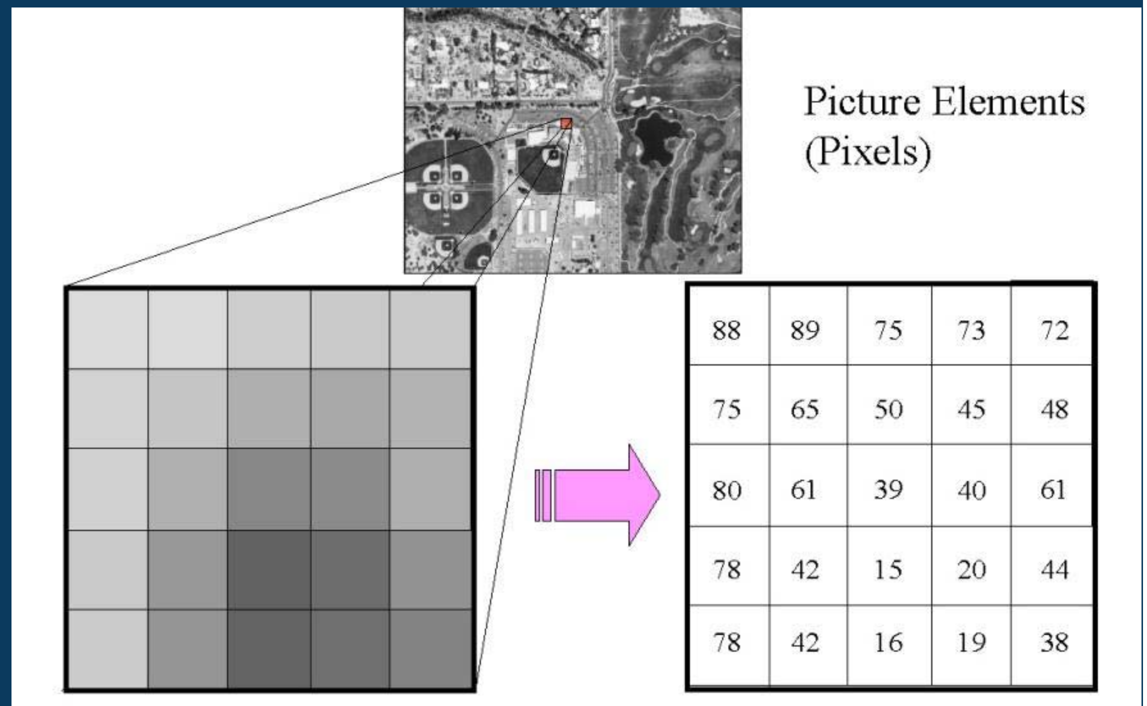
Digital Imagery

- Pixel has a number that relates to photoelectric effect of the reflected light on the detector from an area on the ground.
- 8 bit – 0 – 255
- 11 bit – 0 – 2047
- 12 bit – 0 - 4095



Do you want a picture?

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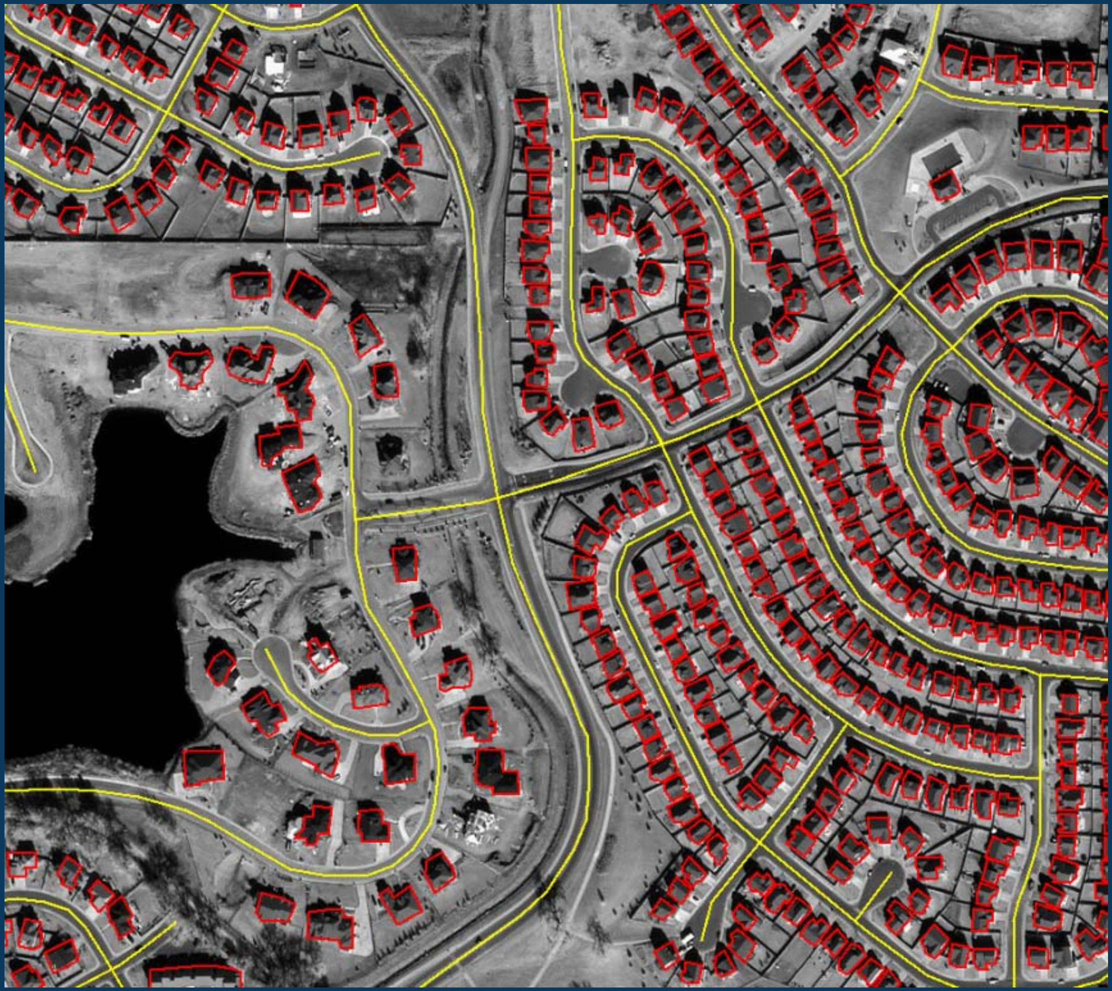
Do you want a basemap?



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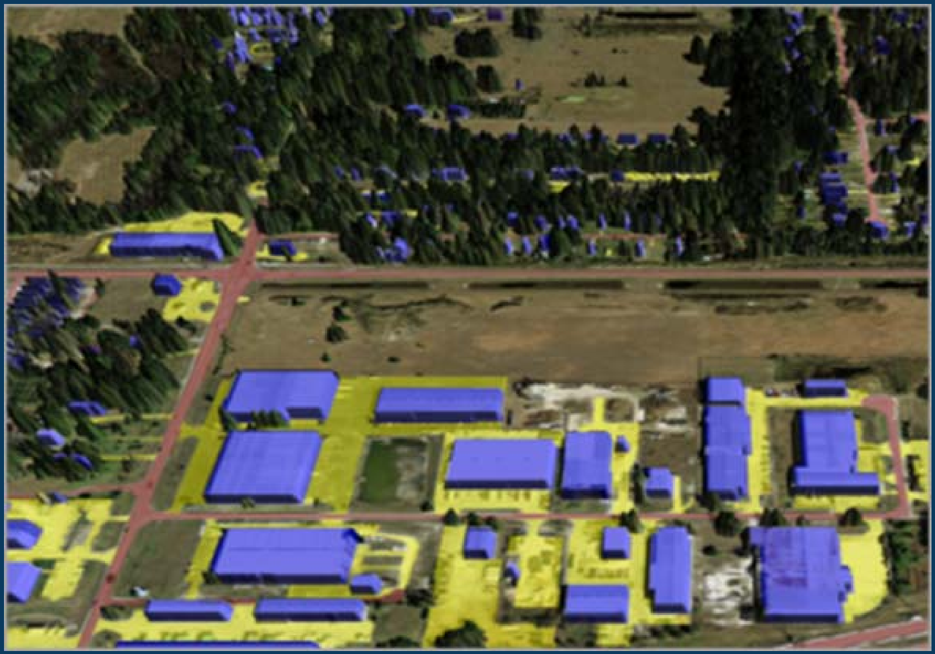
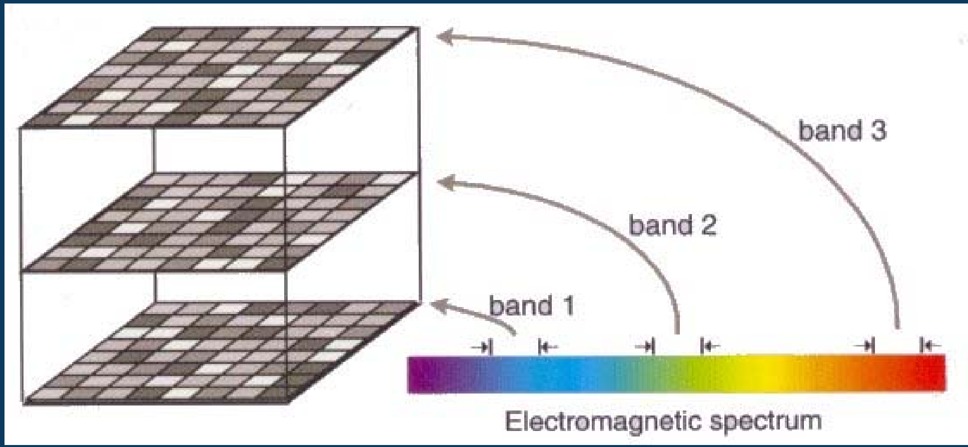
AUTOMATED FEATURE EXTRACTION OR LAND USE CLASSIFICATION?



The Four Resolutions of Imagery

- Spectral
- Spatial
- Temporal
- Data

Spectral



panchromatic

Panchromatic = 1 band

Multispectral ~ 2 - 10

Hyperspectral ~ > 20

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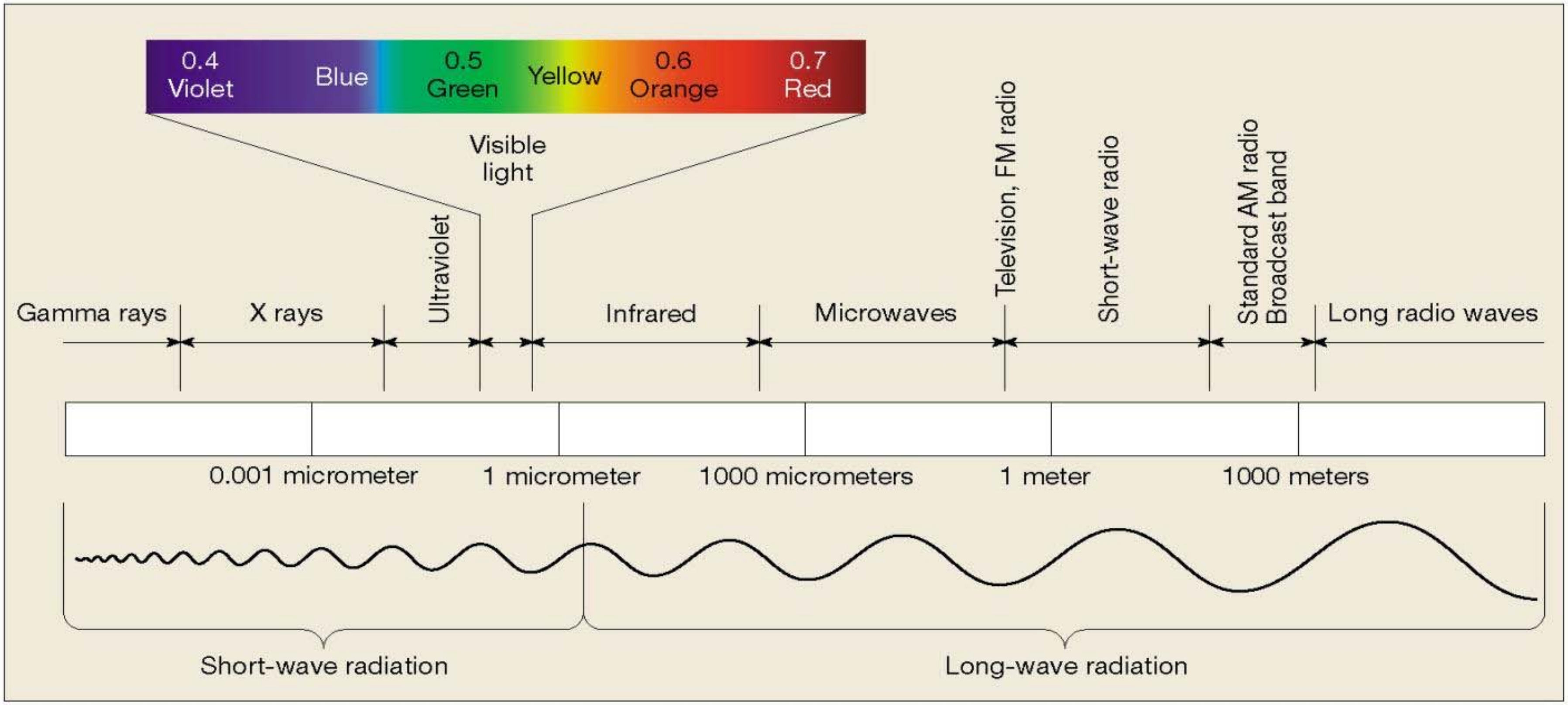
Electro Magnetic Spectrum

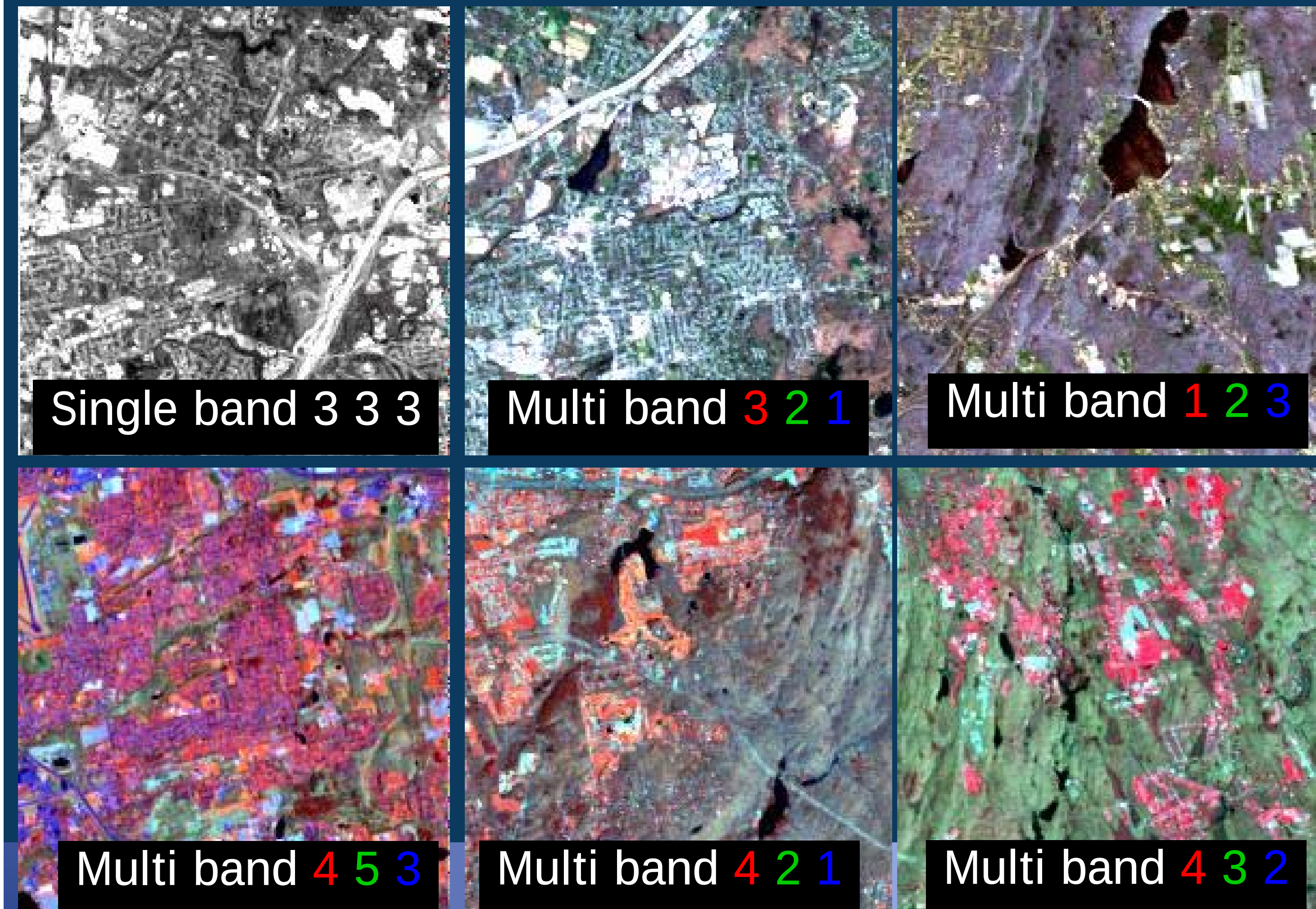


Common units for EMR:

- Micrometers = 1 millionth of a meter (10^{-6} m)
- Nanometer (nm) =1 billionth of a meter (10^{-9} m)

Spectral Resolution

We can view 3 spectral channels from a sensor at a time on a computer screen in red, green, and blue values.



Landsat TM imagery spectral resolution of 7 bands

band 1 = blue
band 2 = green
band 3 = red
band 4 = near-ir
band 5 = mid-ir
band 6 = mid-ir

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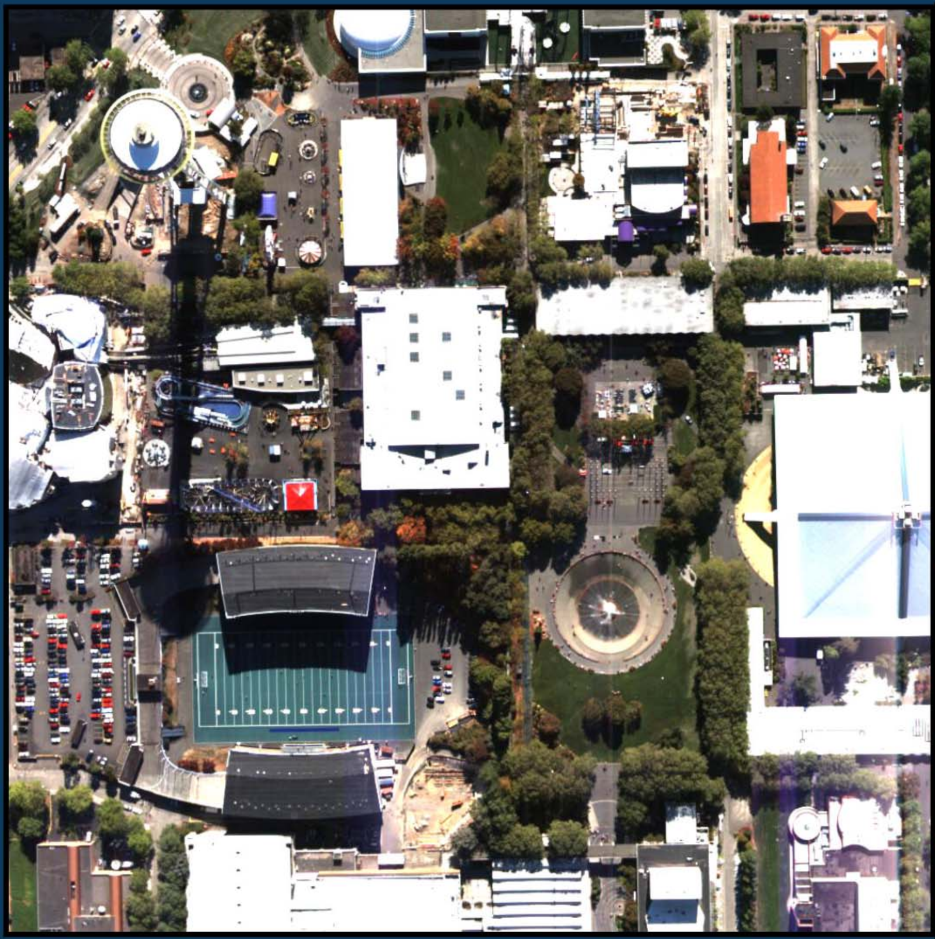
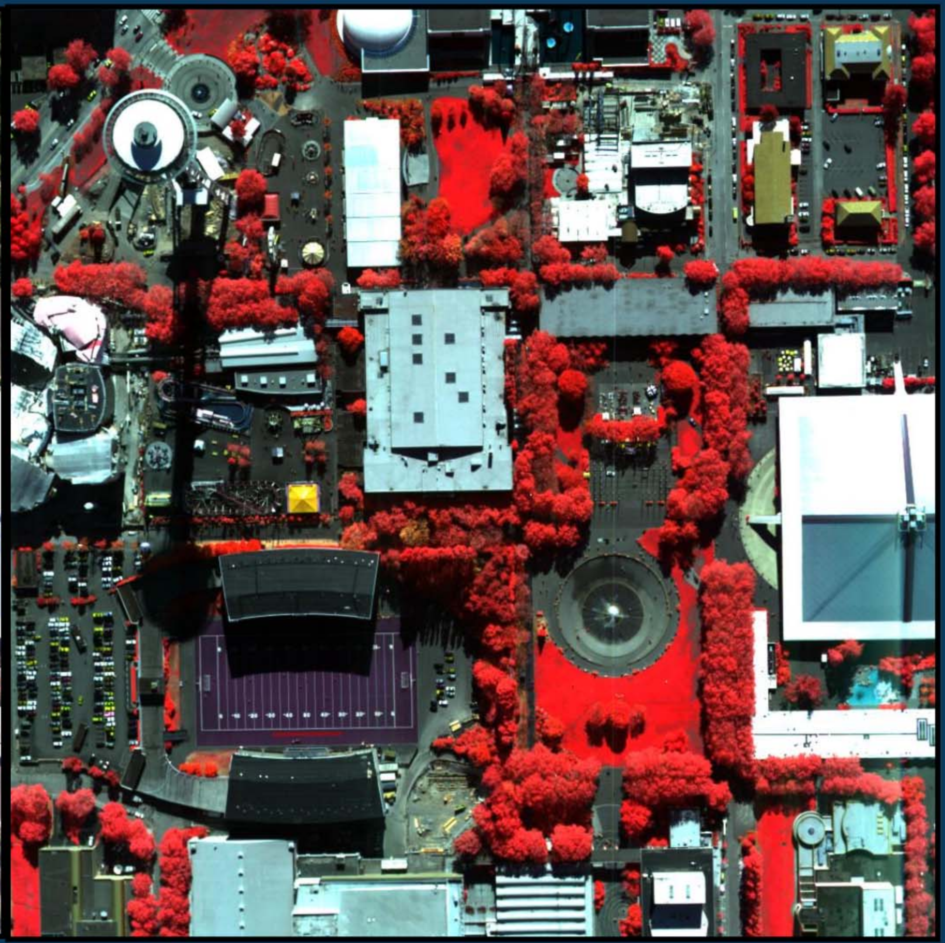
Comparing waveband combinations



True Color



False Color

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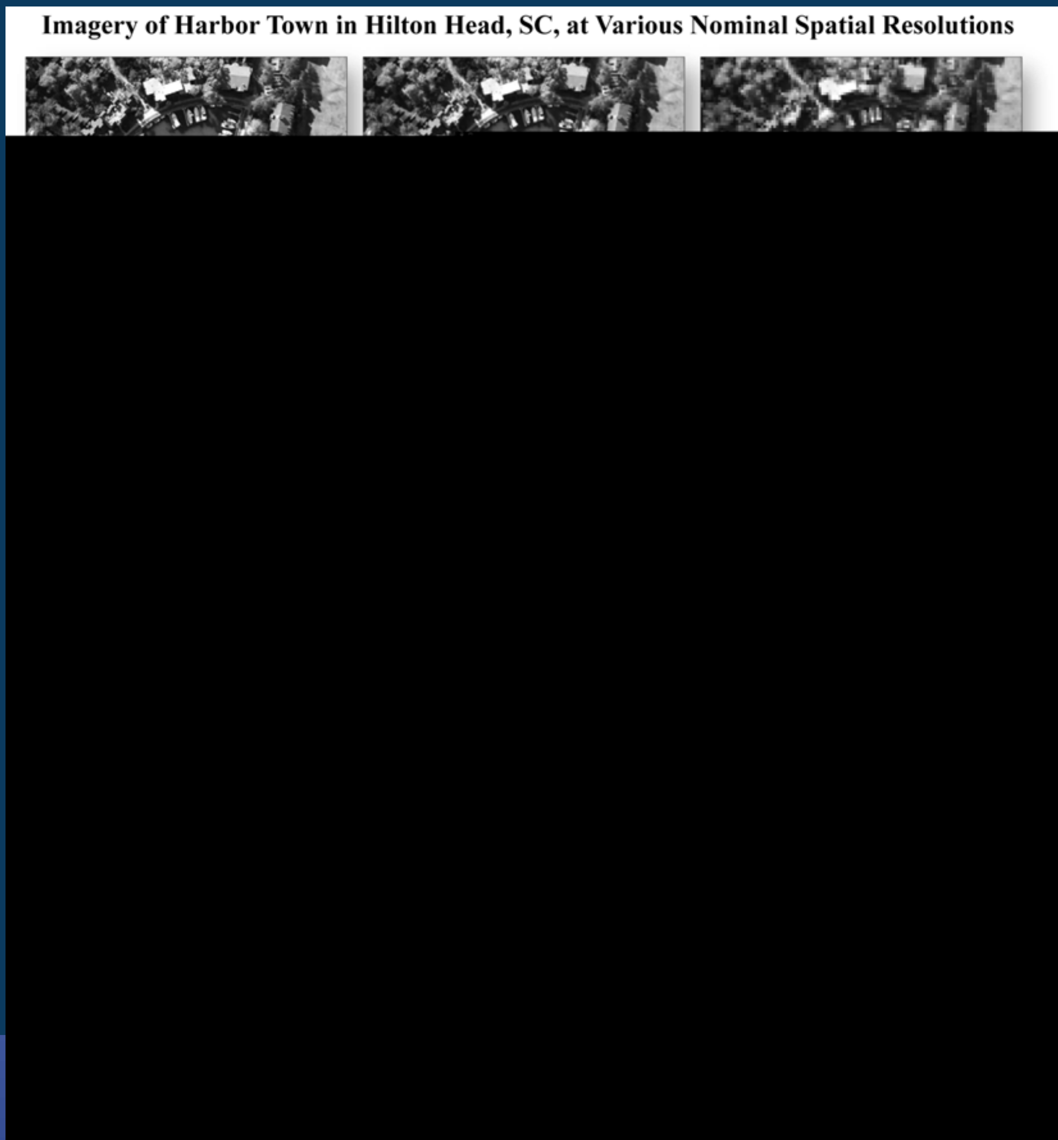
Spatial Resolution

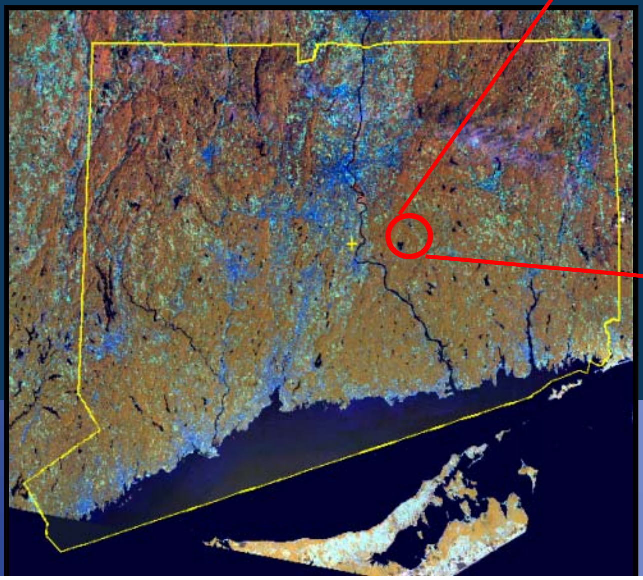


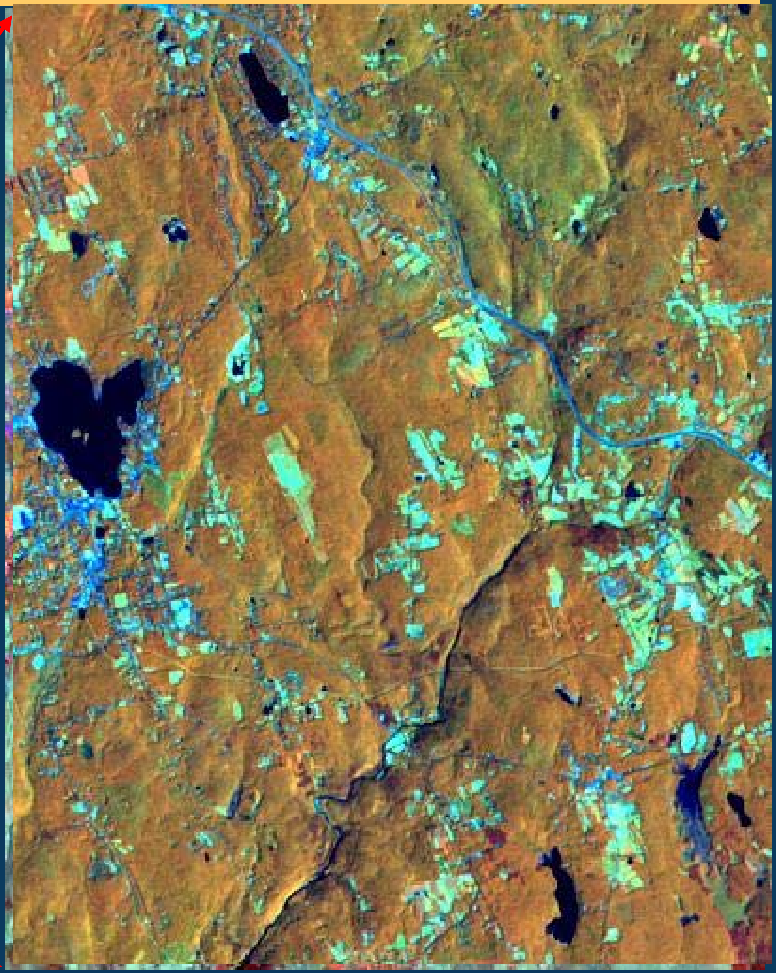
- 6” city aerials
- 1’ state aerials
- 1 m NAIP
- 0.5 m commercial satellite
- 5 m satellite
- 10 – 30 m satellite

Jensen, 2004

Temporal Resolution

Seasonal Changes





Summer

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Temporal Resolution

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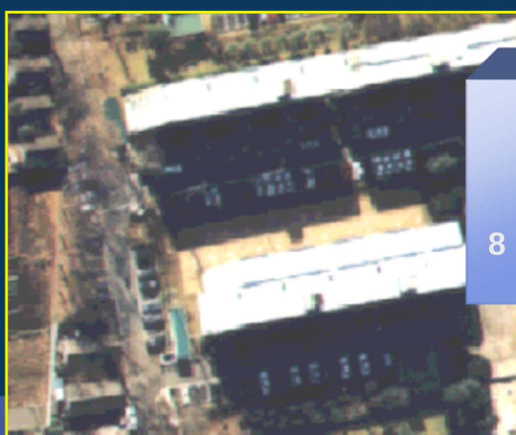
Data Resolution

11 bit image



8 bit image

AREA 1: Bright Areas

11 bit data makes structures distinguishable

8 bit data leaves bright areas overexposed

AREA 2: Dark Areas

11 bit data makes shadowed features distinguishable

8 bit data loses features to shadows

China City, Japan

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The Four Resolutions of LiDAR

- Spectral
- Spatial
- Temporal
- Data

Spectral

Less important for LiDAR

BUT

- Topographic LiDAR (NIR)
- Bathymetric LiDAR (green)
- Methane detecting LiDAR

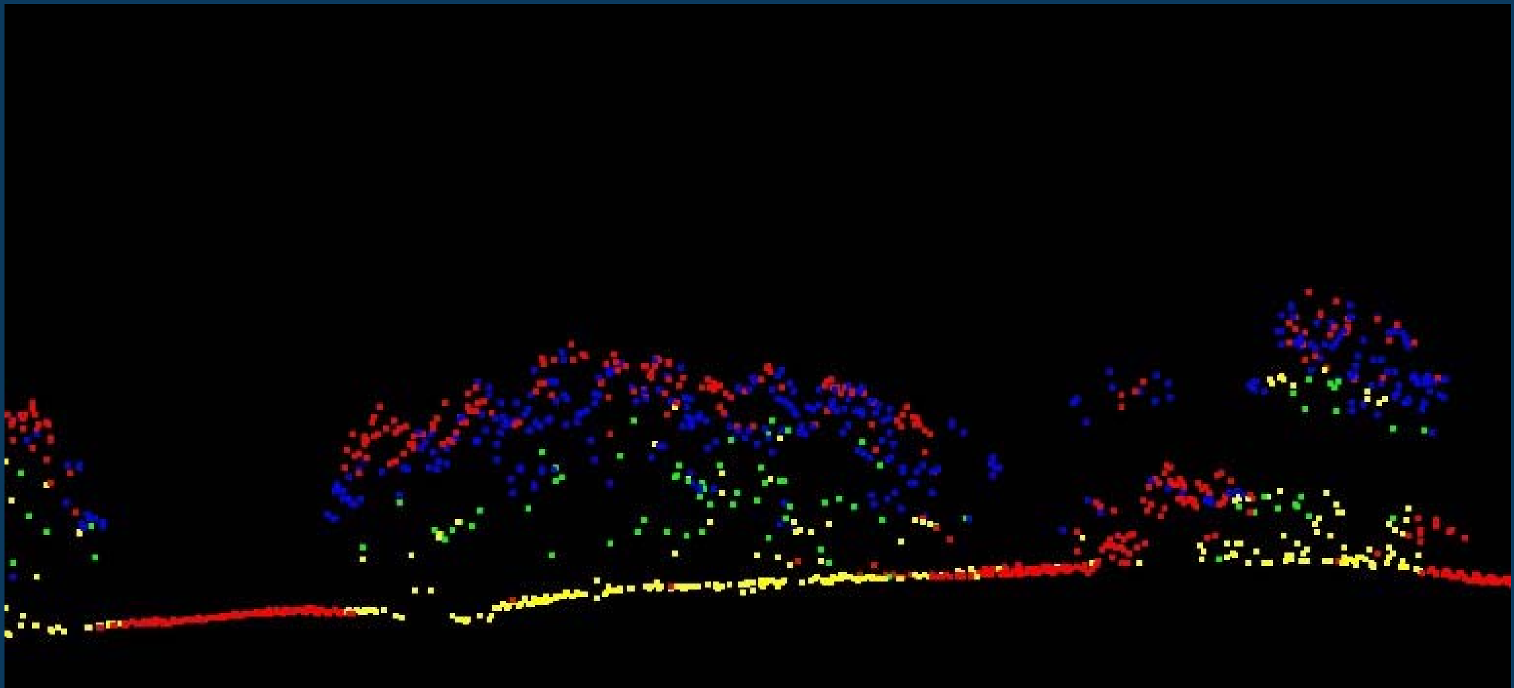
LiDAR Point Density

	Fixed Wing	Rotary Wing	Mobile Mapping
Acquisition Heights	3,000-8,000’ AMT	300-800’ AMT	Ground based
Acquisition Speeds	90-200 knots	20-50 knots	10-60 mph
Vertical Accuracy	9-25 cm	3-15 cm	2-10 cm
Horizontal Accuracy	50 - 100 cm	10-50 cm	3-10 cm
Point Density	0.5-30 ppsm	20-80 ppsm	1,000-8,000 ppsm

Temporal/Data Resolution

- Temporal
  - Collect when features of interest are most pronounced
    - Leaf off – ground features
    - Leaf on – canopy features
- Data
  - Number of returns
  - Intensity values

Multiple Returns



Legend: red – 1st and only,
blue – 1st of many,
green – 2nd or 3rd , yellow - last of many

Image Interpretation

- We are all remote sensors
  - Visual interpretation
    - Color
    - Shape
    - Context
    - Texture
    - Size
  - Tools that can be developed though photo-interpretation
  - Tools developed for the computer

Manual Classification

- Conventional methods for data extraction
  - Techniques have been used for decades
  - Digitize over features and then label features with attributes
  - Reliable, low technical requirement, accurate
  - Requires skill photo interpreters
- However
  - Expensive over large areas
  - Simplifies the landscape
  - Subjective

Automated classification

- Discussed more in this session
  - Using the computer to classify features
  - Can do large areas quickly
  - Captures the variation on the landscape
  - Reduced dependency on subjective analysis
- But trained humans still better at interpretation

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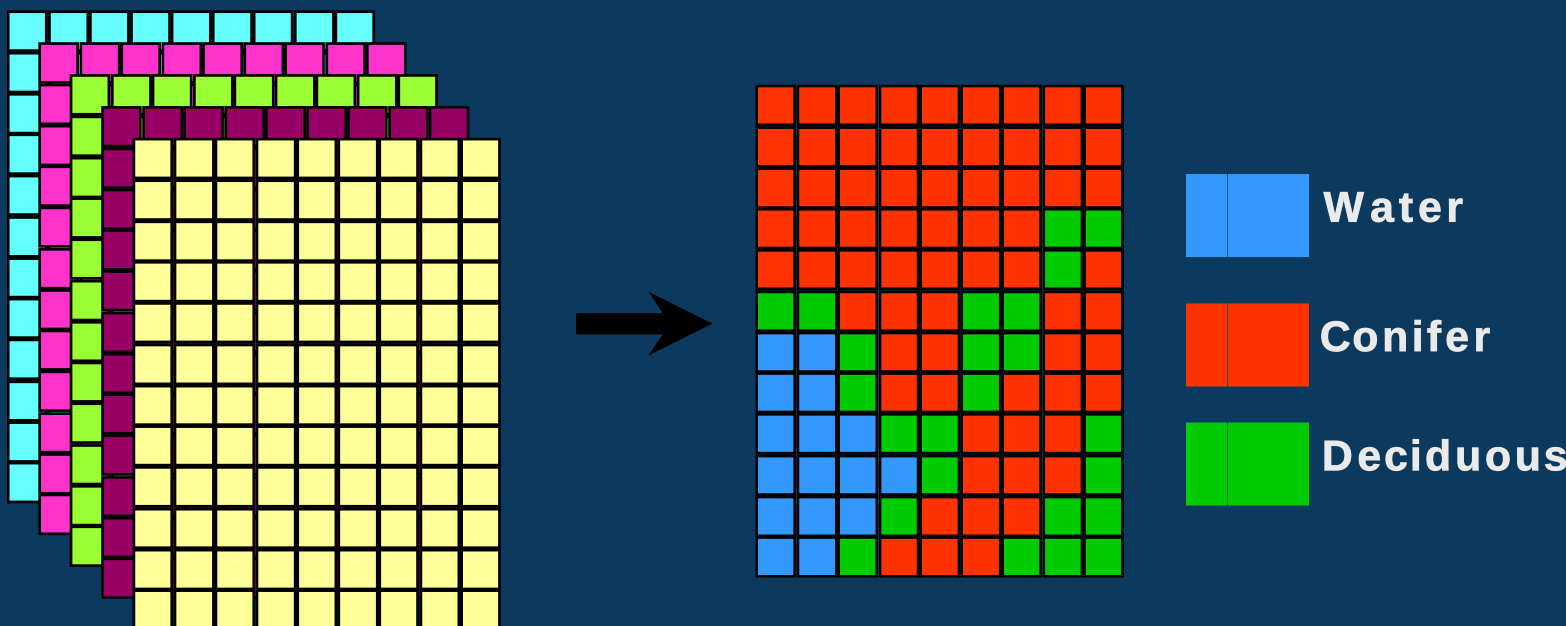
Image Classification is

- Image classification is the process of turning remote sensed data into information

Multi-spectral Raster Image To Land Cover Map



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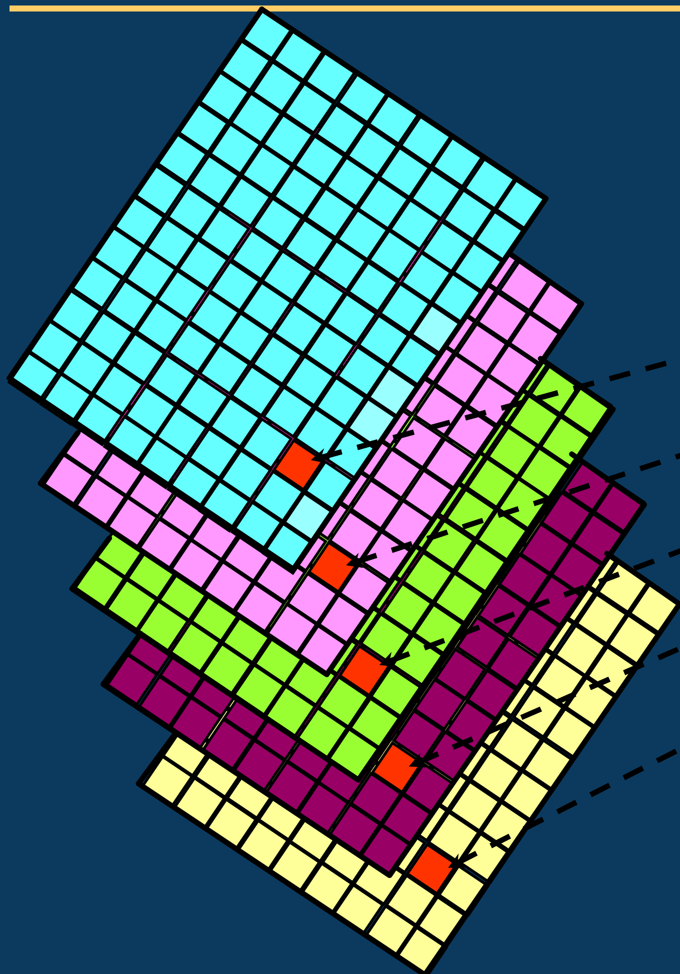
Land Cover - Spectral Data



Pixel Values

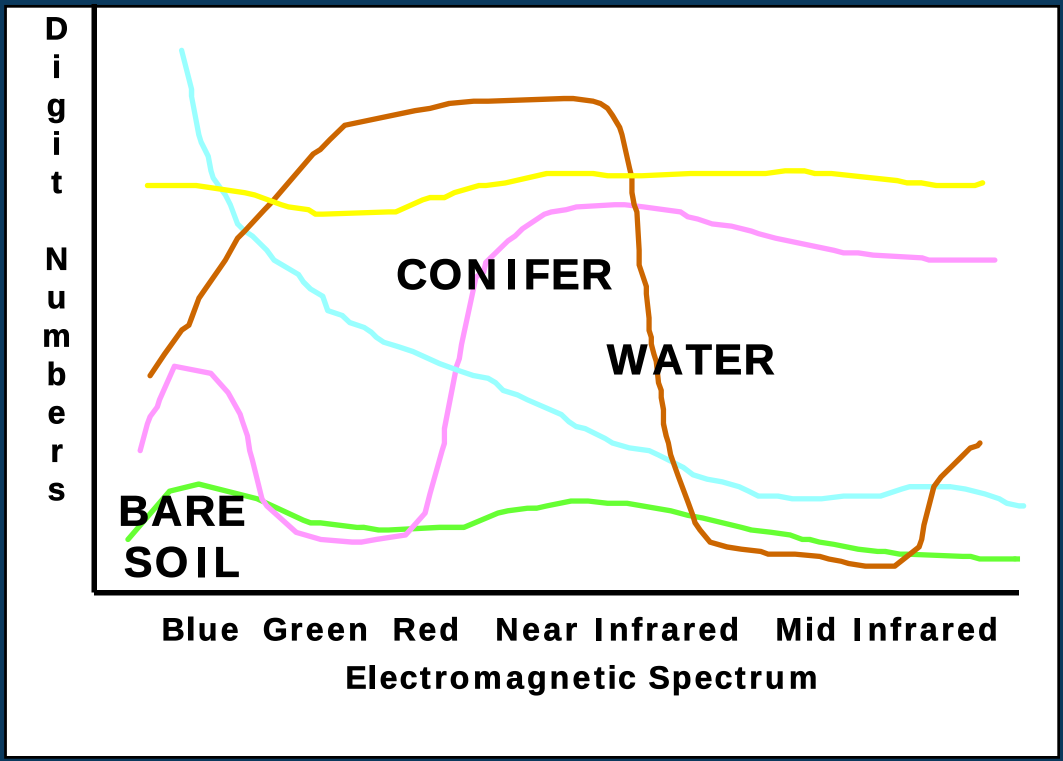
Band	DN
1	12
2	75
3	201
4	4
5	189

Each pixel represents a specific area on the ground

Each digital number is a measure of that area's spectral reflectance

Spectral Response

If you can characterize a land cover based on a distinct spectral response, then you can locate similar area using spectral signatures

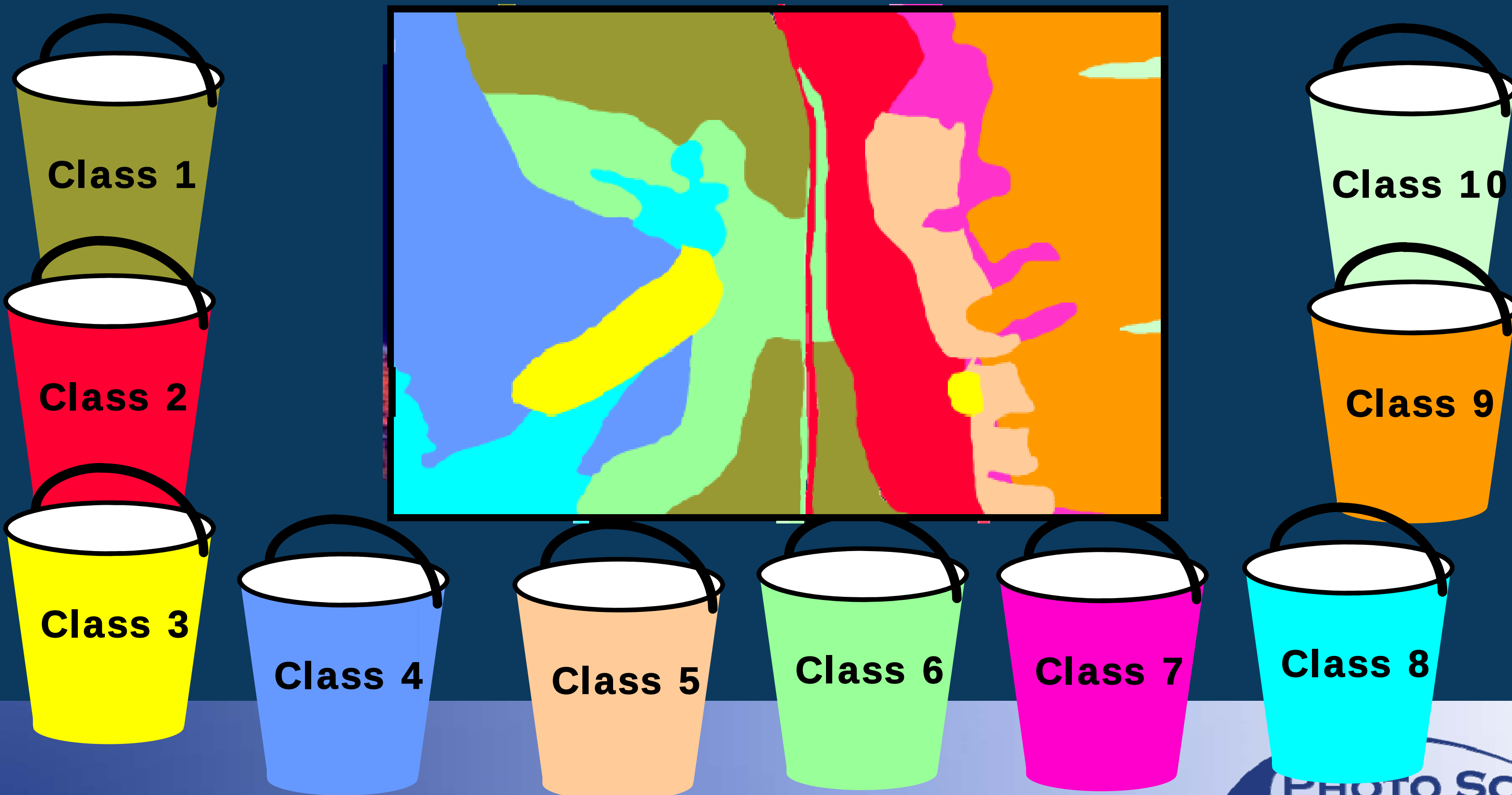


Supervised Classification

- The analyst selects samples of known land cover types, the software calculates spectral signatures for each land cover

Unsupervised Classification

- The software automatically separates the pixels into spectrally similar classes



Object vs. Pixel

- In many cases the pixel has no meaning
- Object is an area that has a uniform property and therefore can be classified the same
- Can include local variability
- Of importance for high resolution imagery

Image objects created in Trimble's eCognition software, image of Ann Arbor, MI from a 2011 leaf-off

Uses of Datasets

- How the imagery and LiDAR can be used for creation of datasets
- How these dataset can be used for decision making
  - Impervious maps
  - Land cover maps
  - Land use maps
  - Building footprints

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Impervious Maps

- Background
  - Impervious - do not allow water to percolate into the soil and refill the ground water
  - Impervious - increase the rate and amount of water runoff
    - Increased flooding
    - Increased water pollution
    - Increased erosion of soils in the river channels
    - Increased stress on the stormwater sewer system
  - Impacts have direct costs
    - flood damage
    - retrofitting stormwater system
    - reduced water quality

Impervious Mapping

- Problem
  - Stormwater fee assessment for City of Ann Arbor
  - Stormwater runoff determined by amount of impervious
  - Need for impervious surface per parcel
  - Need this quickly, at a decent price and easily updatable
- Solution
  - Semi-automated impervious products
  - Based off orthorectified imagery
  - Creates a complete impervious coverage over the whole City
  - Completed quickly and updated manually

Specifications

- What is the input data source
  - Imagery
    - Spectral resolution: red, green, blue, NIR
    - Spatial resolution: 6”
    - Spatial accuracy: < 3.3 ft
    - Data resolution: 12 bit
  - LiDAR – not used
- How was the map made
  - Manual or Automated: Automated with manual clean up
  - Supervised/Unsupervised: Supervised
  - Cluster or CART: CART
  - Pixel of object: Object

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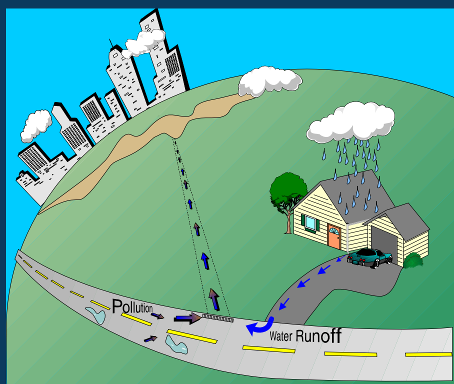
Rate Model Options

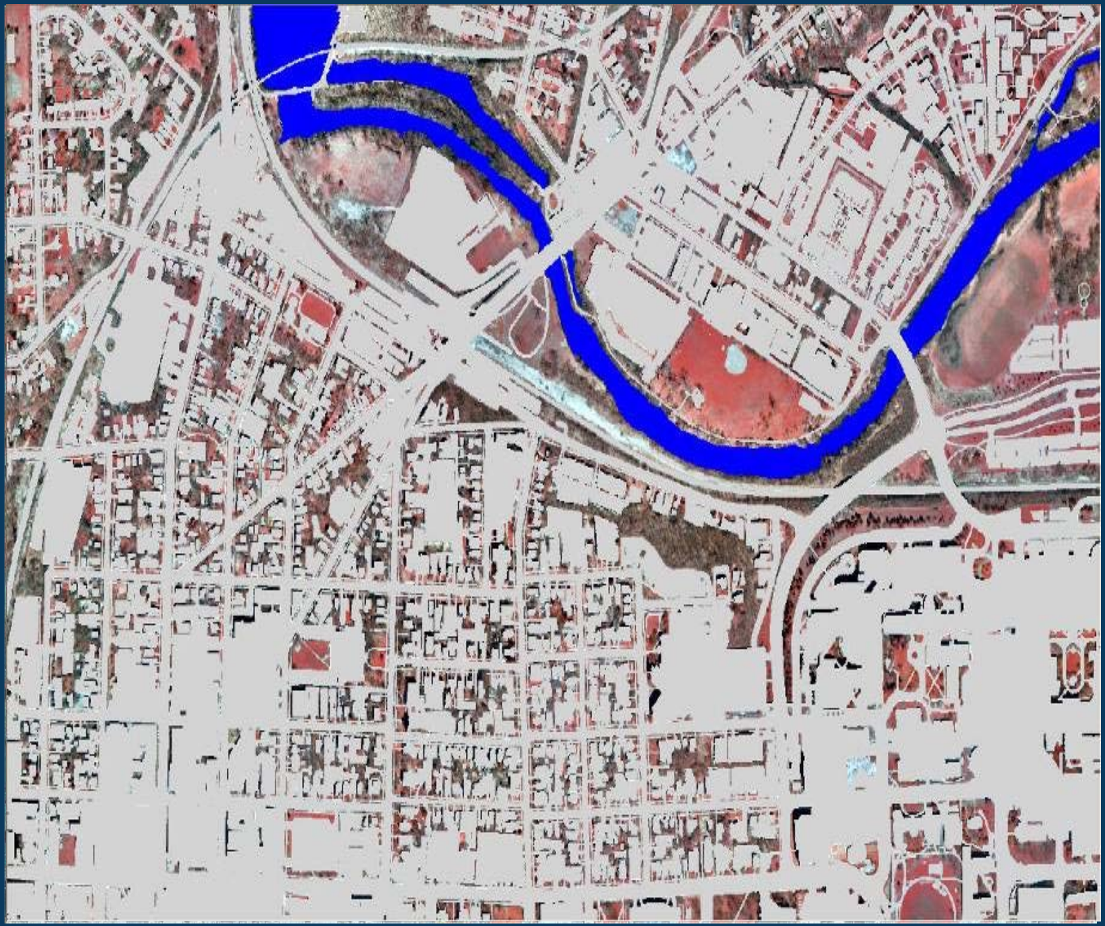


- Impervious Area Measurements
  - Non-SF Residential Properties
  - All Properties
- Level-of-Service / Geography Base
- Runoff Coefficient / Intensity of Development Factor
- Tiered Flat Fee
- Flat Fee
  - All properties
  - All SF residential properties

Level of Effort

Accuracy

MAP



Legend

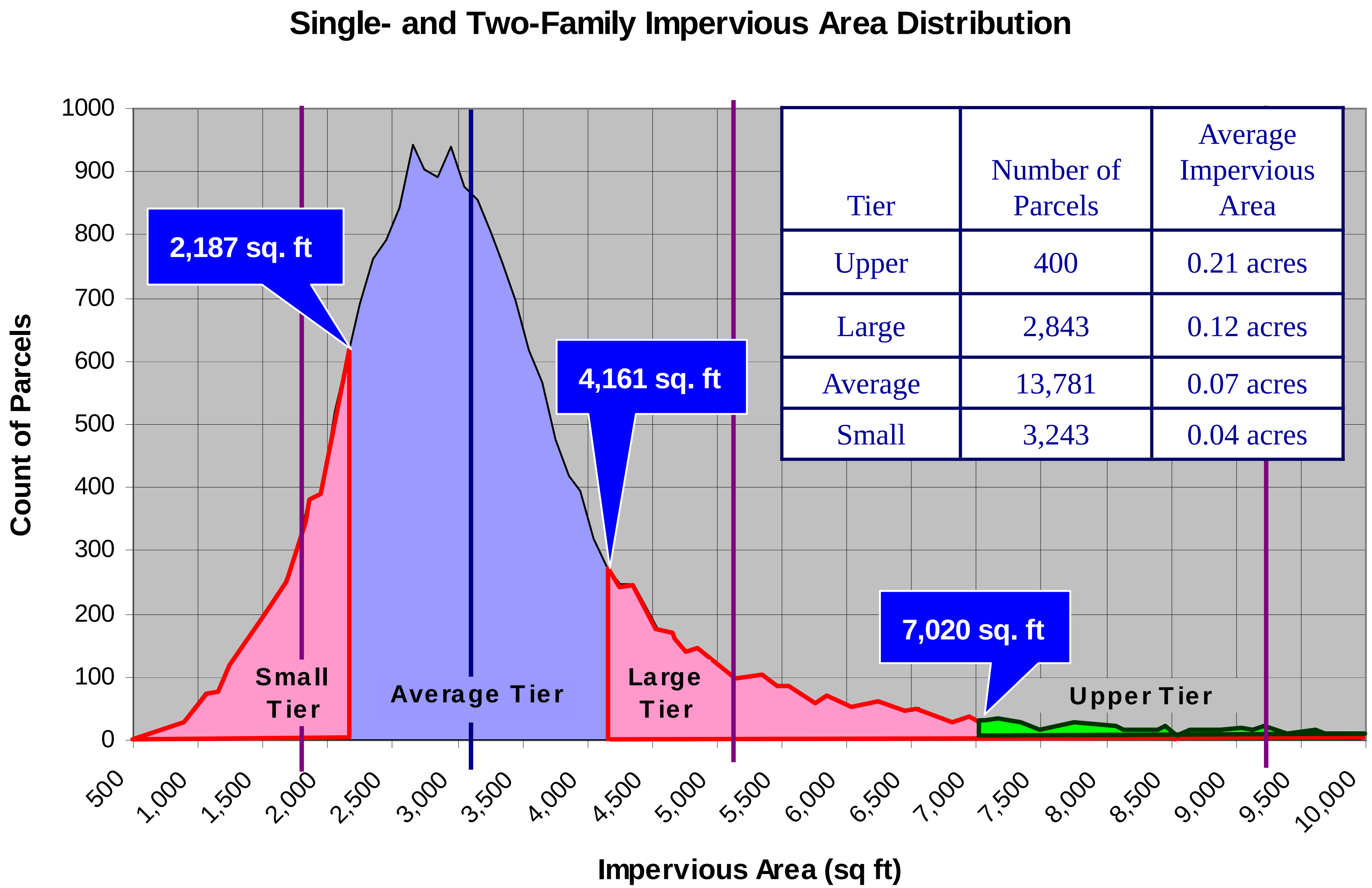
Grey – Impervious

Blue – Water

Transparent - Pervious

Statistical Evaluation

Properties Defines Categories



Tier	Number of Parcels	Average Impervious Area
Upper	400	0.21 acres
Large	2,843	0.12 acres
Average	13,781	0.07 acres
Small	3,243	0.04 acres

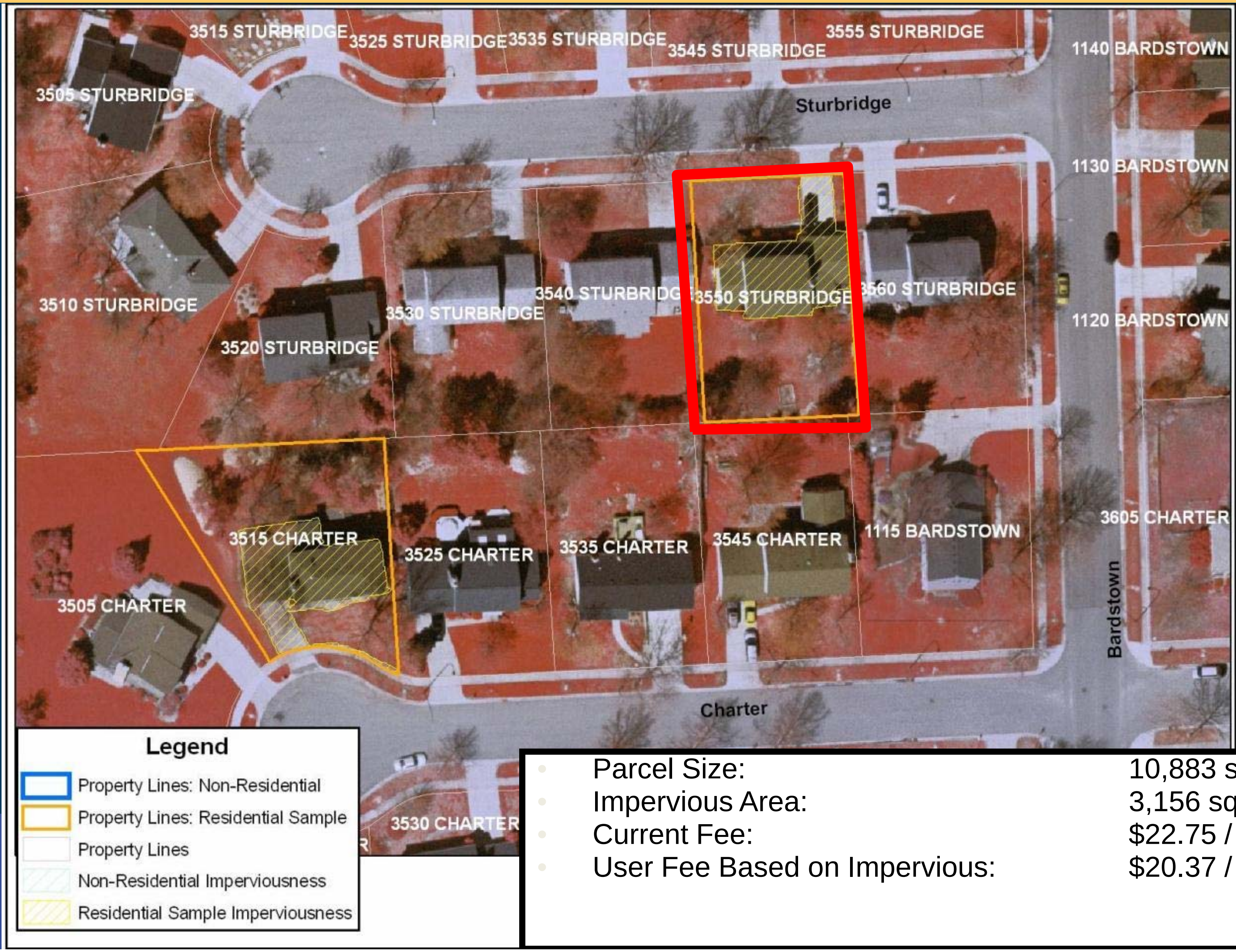
Ann Arbor's Rate Model

- Storm Water Fees:
  - Rates for ALL Residential and Non-Residential Properties
    - $5.92 / quarter / customer PLUS
    - $251.44 / quarter / impervious acre
  - Non-stormwater: $0.27 / quarter / 1000 gal.
  - Reductions for on-time payment
  - Credits recognize on-site stormwater management
- Advantages:
  - Cost recovery proportionate to runoff volume
  - Four residential tiers increase equity and distribution
  - Credit system recognizes stormwater management
  - Allows customers to control use of stormwater service
  - Automates impervious area updates
- Disadvantages:
  - More complex than existing system
  - Additional costs for future updates

Assessment Fees

- Parcel Size: 51820 sq. ft.
- Impervious Area: 9853 sq. ft
- Current Rate Structure: $ 22.75 / quarter
- User Fee Based on Impervious: $ 58.72 / quarter

Single Family Residential



Parcel Size:	10,883 sq. ft.
Impervious Area:	3,156 sq. ft
Current Fee:	$22.75 / quarter
User Fee Based on Impervious:	$20.37 / quarter

Vegetation, Canopy and GI

- Vegetation makes a big difference
  - Fixes carbon
  - Allows percolation of water
  - Evaporates water (transpiration and interception)
  - Filters air and water pollution
  - Impacts microclimate
  - Enhances quality of life
  - Supports urban wildlife
  - Provides recreational opportunities
- Need to monitor, plan and manage urban vegetation
  - Identify opportunities for tree plantings and other GI BMPs
  - Create a return of investment analysis

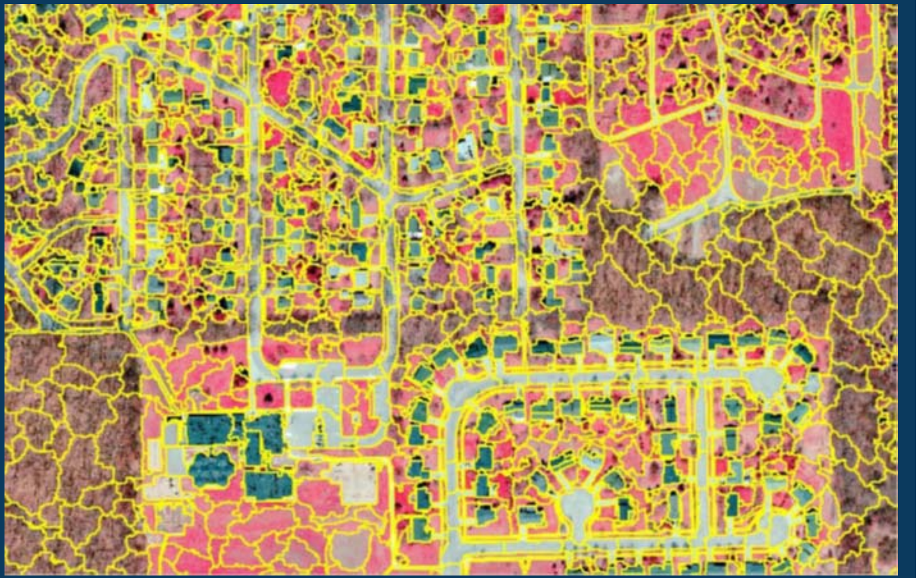
Specifications

- What is the input data source
  - Imagery
    - Leaf off
      - Spectral resolution: red, green, blue, NIR
      - Spatial resolution: 1' resampled to 1 m
      - Spatial accuracy: < 3.3 ft
      - Data resolution: 8 bit
    - Leaf on
      - Spectral resolution: red, green, blue, NIR
      - Spatial resolution: 1 m
      - Spatial accuracy: < 10 ft
      - Data resolution: 8 bit
  - LiDAR – point spacing 1.2 m
- How was the map made
  - Manual or Automated: Automated with manual clean up
  - Supervised/Unsupervised: Supervised
  - Cluster or CART: CART
  - Pixel of object: Object

LiDAR Derivatives

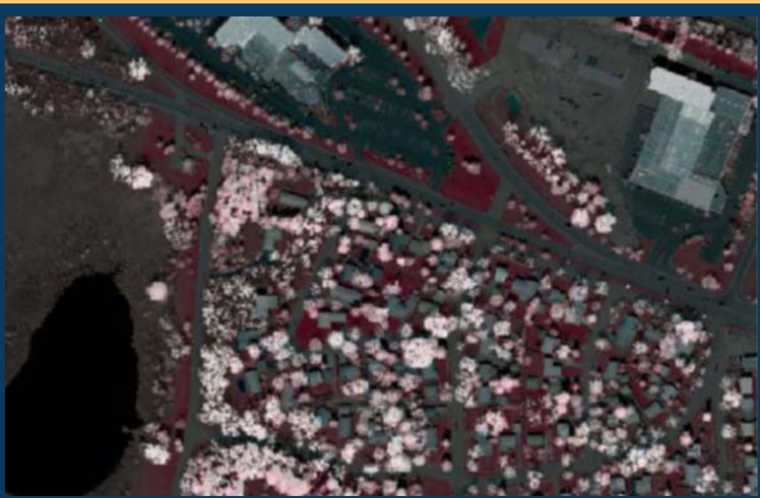
Impervious Data Creation

- Segmentation DSM/ leaf-off imagery
- Classify segments
- QC results
- Modify ruleset
- Manual review and QC
- Deliver
- Finalize



Canopy Creation

- Segment DSM/ leaf-on imagery
- Classify segments using band ratios and texture, derived from leaf-on imagery



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Land Cover Creation

- Merge impervious and canopy
- Segment leaf-off imagery using the impervious and canopy data boundaries
- Segmentation level for rural areas is larger than for urban areas allow for different MMUs
- Classify segments
- Filter and smooth

Data Editing and QC

- Manual editing of errors
- Initial daily meetings with photo interpreters to ensure consistency
- An independent QC team

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Overview map of project area

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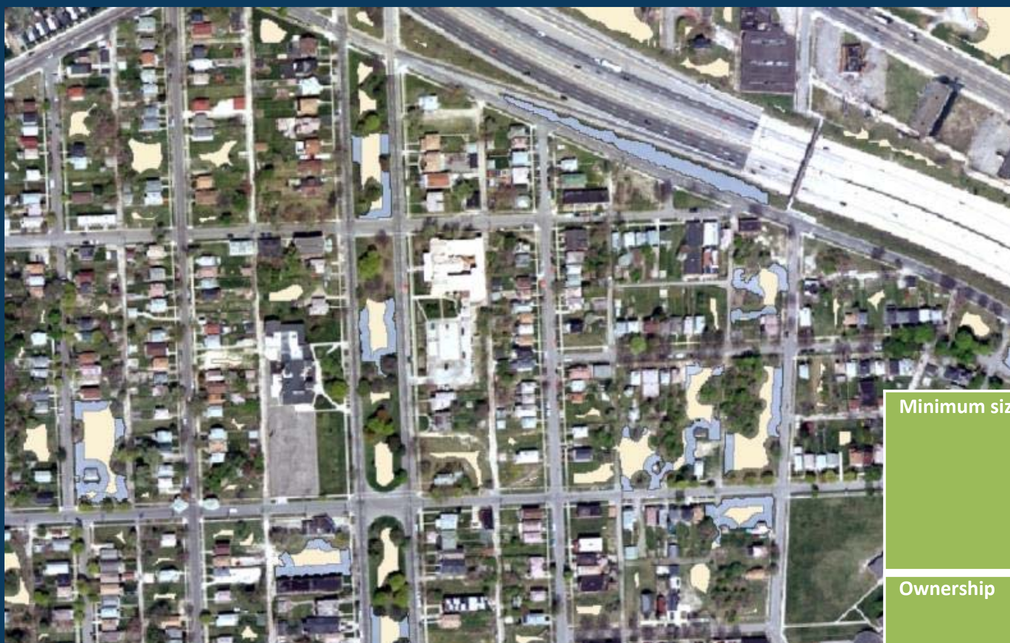
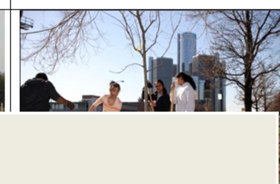
Identifying Locations

- Spatial Models



Tan: Publically owned areas suitable for reforestation

Blue publically owned areas suitable for detention

Photo Example	Description
	**Large Sites:** Establishment of large forested areas in upland sites, areas >= 1 acre and could incorporate an understory comprised of shade tolerant grasses, forbs, and shrubs. Areas of significant size would be included in this practice. These areas are on generally City owned lands. **Medium Sites:** The planting of trees on areas of 0.25 acres – 1 acre. **Small Sites:** 100 square feet – 0.25 acre **Linear Sites:** land wider than 4 feet and longer than 6 feet Species are selected to suit site requirements. Tree material generally ranges from 1.5-2.5" caliper, balled and burlap.
	

Minimum size criteria	• For large sites area >= 1 acre • 0.25 acre <= medium sites < 1 acre • 100 sq. feet < small sites < 0.25 acres • For linear projects, a minimum planting width of 4' is required, length requirement is 6' (space for one tree)
Ownership	• Public lands in short term • Private lands may be considered in longer term
Minimum patch size requirements for tree planting	• 24 ft^2 per tree required to provide enough soil for the root zone to obtain sufficient nutrients/moisture for a mature tree.
Structures	• 25 ft. from ground structures
Utilities	• Should be 10 ft buffer from overground and underground utilities • Information on this is scarce and unreliable
Distance from impervious	• Trees are most effective at a minimum distance of 15 feet from impervious areas.
Soils	• Nothing specific
Slope	• Local slopes should be < 8%
Land cover	• Not on areas of impervious, trees & water

Cost Benefits

- Costs
- Establishment Cost
  - Labor
  - Materials
  - Earth moving
- Maintenance Cost
  - Labor
  - Materials

- Benefits
- Reduced runoff
  - Fewer CSOs
  - Lower annual WWTP costs
- Reduced pollution
  - Lower N, P and heavy metals
  - Less sedimentation
- Reduced infrastructure costs
  - Lower constructions costs
  - Lower maintenance costs
- Lower WWTP costs
- Health
- Community Values

Land Cover – Decision making

- The da
  decisio
  land m
- Suppo
  analys
  infrastr
- Suppo
  decisio
  region

Costs Avoided				
WWTP cost avoidance over 20 years		$ 12,138,447		
Capital costs avoided (does not include maintenance costs)		$ 22,992,308		
Air quality improvements		$ 11,827		
Human Health Impacts			Not included	
Ecological Health Impacts			Not included	
Microclimate Benefits			Not included	
Societal Benefits			Not included	
Total Value Over 20 years		$ 35,142,582		
Costs Incurred				
		Volunteer	Contractor	
Implementation Costs		$ 1,970,059	$ 2,580,076	
Maintenance Costs		$ 421,851	$ 421,851	
Other Costs				User can input
Total Costs over 20 years		$ 2,391,911	$ 3,001,928	
Return on Investment				
Net revenue saved		$ 32,750,671	$ 32,140,654	
Percentage Gain		1369%	1071%	
ROI		13.69	10.71	
Annual Averaged Rate of Return	Averaged over 20 years	68.46%	53.53%	
Internal Rate of Return		14.38%	13.09%	

NCE

Land Use

- Problem:
  - Land use is a fundamental dataset for planning and resource management
  - Land use is constantly changing - needs to be updated at regular intervals
  - Land use is generally created using manual photo-interpreters
    - Expensive
    - Inconsistent
    - Time consuming
  - Creating an easily updated and consistent land use layer - goal
- Solution:
  - Development of a semi-automated land use update process
  - Has defined decision rules
  - Integrates existing GIS data layers into the process
  - Produces an impervious dataset that is extremely useful to most agencies

Specifications

- What is the input data source
  - Imagery
    - Leaf off
      - Spectral resolution: red, green, blue, NIR
      - Spatial resolution: 1’ resampled to 1 m
      - Spatial accuracy: < 3.3 ft
      - Data resolution: 8 bit
- How was the map made
  - Manual or Automated: Automated with manual clean up
  - Supervised/Unsupervised: Supervised
  - Cluster or CART: CART
  - Pixel of object: Object
  - Impervious was created first
  - Impervious was labeled with an urban class
  - Includes a lot of buffering and GIS modeling
  - Manual QC and editing

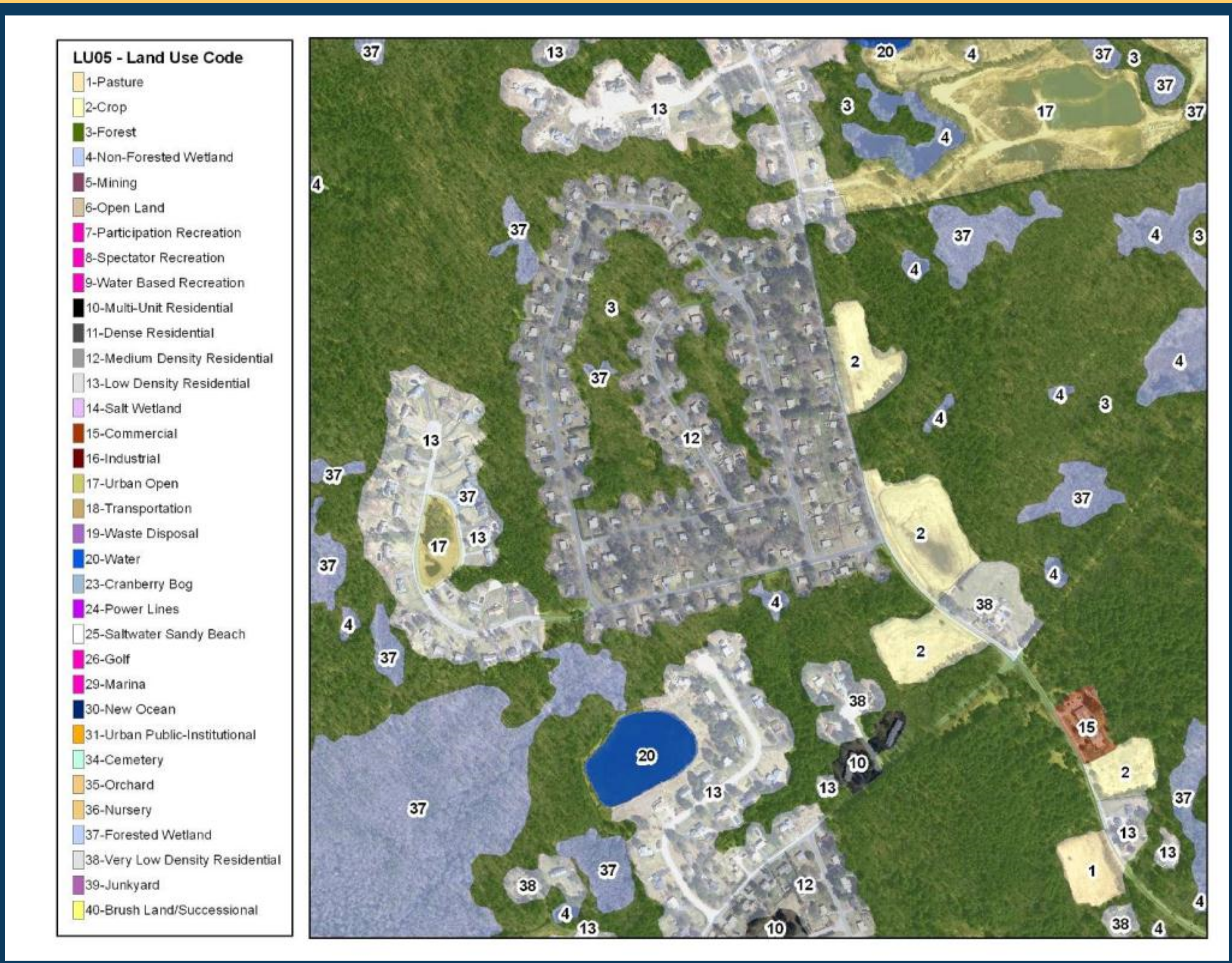
State of Massachusetts

- Massachusetts
  - ½ m 4-band digital imagery
  - 40 class scheme
  - 1 acre minimum mapping unit
  - 7,500 square miles
- Identified new areas of growth
- Corrected errors in the previous manual delineations

Manual vs. Semi-Automated

Manual Delineation

SEMI-AUTOMATION



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True Population Density

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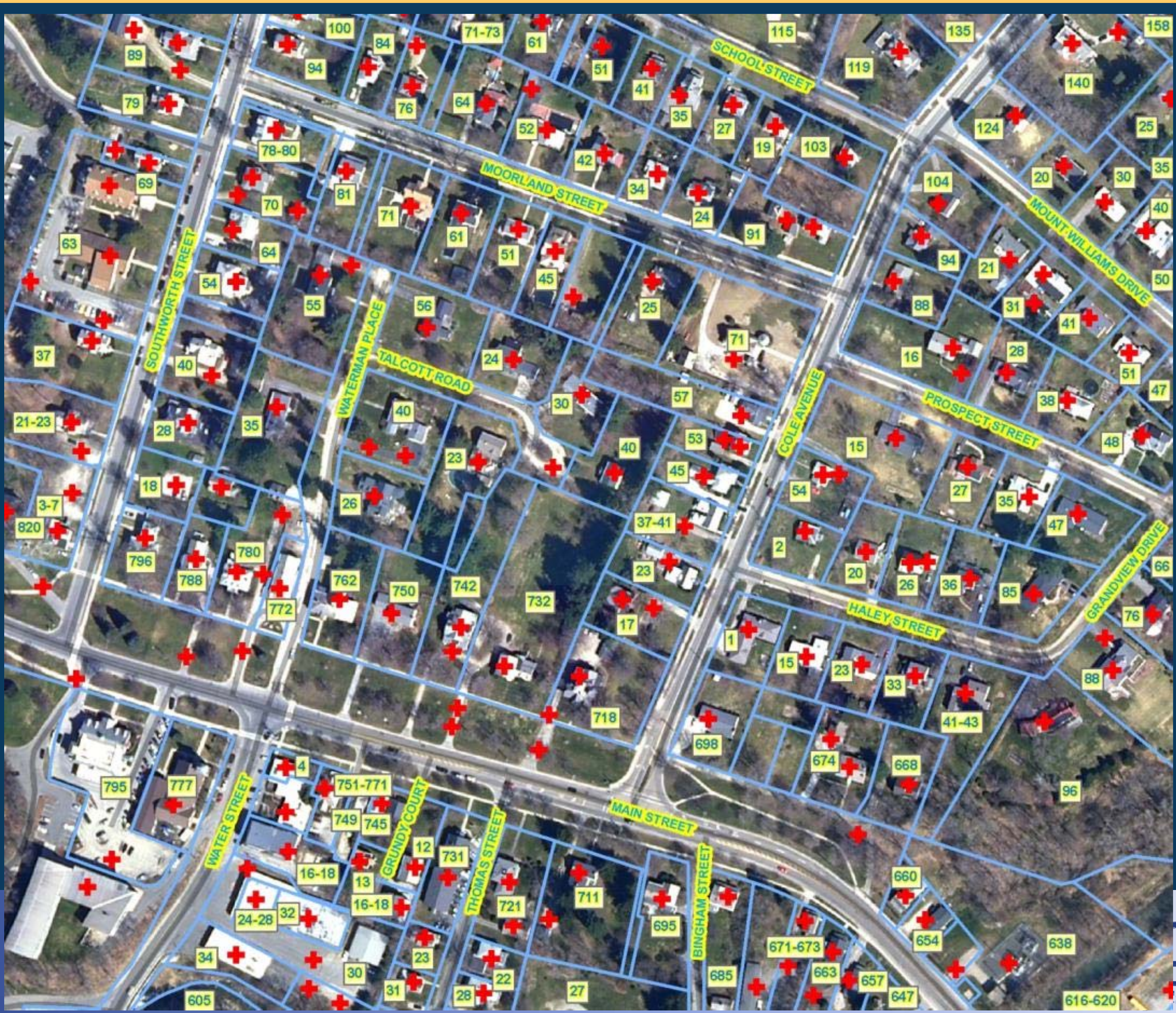
Building points from 4-band images



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Thermal Imagery

- Problem:
  - Municipal Separate Storm Sewer System (MS4) Program
  - MS4 Permit Compliance
  - Need to identify illicit discharges
  - Alternative is walking the streams - costly
- Solution:
  - Use thermal imagery flown during dry periods
  - Where there are thermal anomalies in the water indicate that there are temperature differences
  - Some of these differences will be caused by warmer discharge water entering cooler in-stream temperatures when taken during the winter

Specifications

- What is the input data source
  - Imagery
    - Leaf off
      - Spectral resolution: MW Thermal, LW Thermal
      - Spatial resolution: 2’ resampled
      - Spatial accuracy: < 6 ft
      - Data resolution: 12 bit
    - Detect flow during dry periods
    - At least 72 hours after a storm of > 0.1”
    - When the temperature difference between the dry weather flow and the river flow was greatest
    - Solar heating is minimized creating a more uniform background temperature.
    - Winter - cold but unfrozen ground
    - January 7th and 8th 2013
- How was the map made
  - Imagery orthorectified
  - Converted to 8 bit image
  - Manual interpretation

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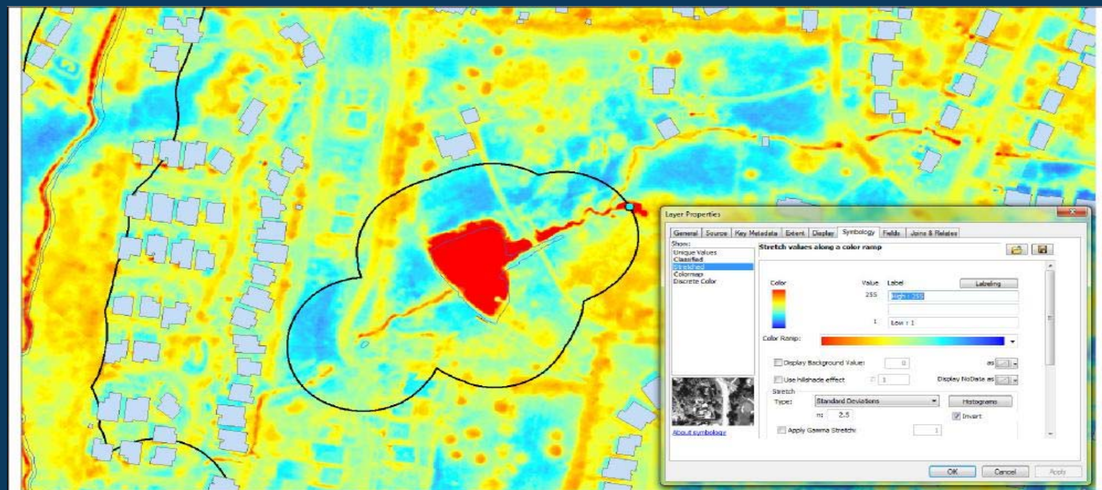
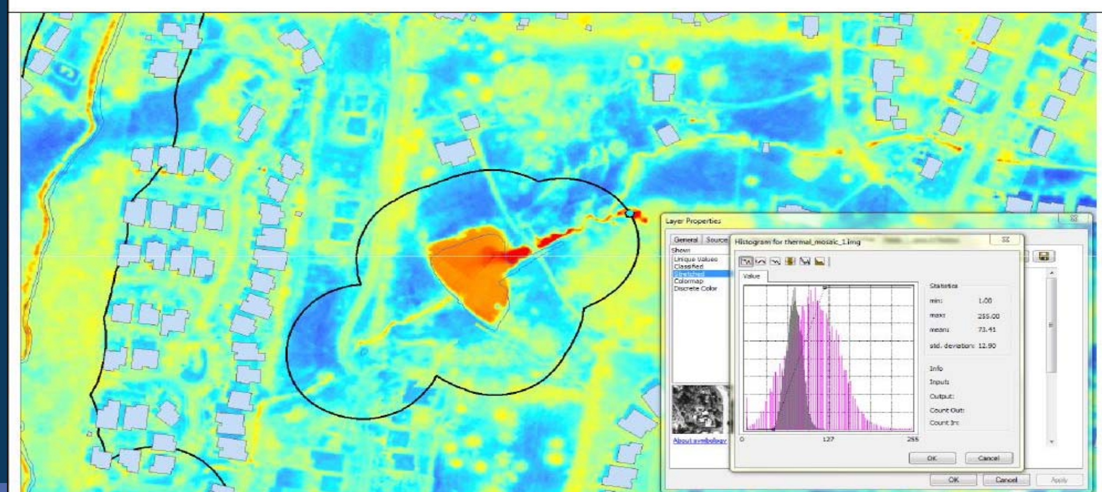
Analysis

- Possible Area of Interest (1) - Warm sections of water bodies; strong plume not visible; infrastructure nearby; depth possible factor; possible discharge from natural springs or streams.
- Probable Area of Interest (2) – Warm plume present with linear tail, elliptical head; infrastructure nearby; other parts of the river or lake is cooler; nearby water bodies have a more uniform temperature.
- Other Area Of Interest (3) – Anomalies that did not fit into probable or possible classification; amorphous warm shapes with center near or under infrastructure; includes a minimal number of reference points annotating commonly encountered thermal signatures around water bodies.

Histogram stretching





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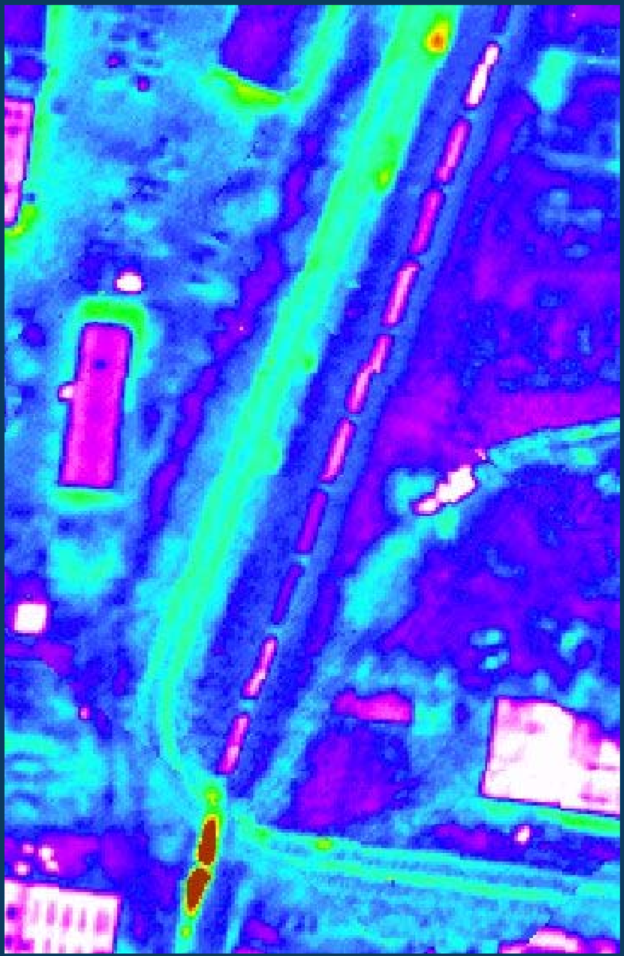
Digital Data Verification

- Digital Screening Effort – Winter & Spring of 2013
- Compared against: Hansen Data, MSD records, & ESRI Software for GIS Analysis
- Review of:
  - LOJIC data
  - MSD Infrastructure
  - Hydrology
  - Land Use
  - Aerial



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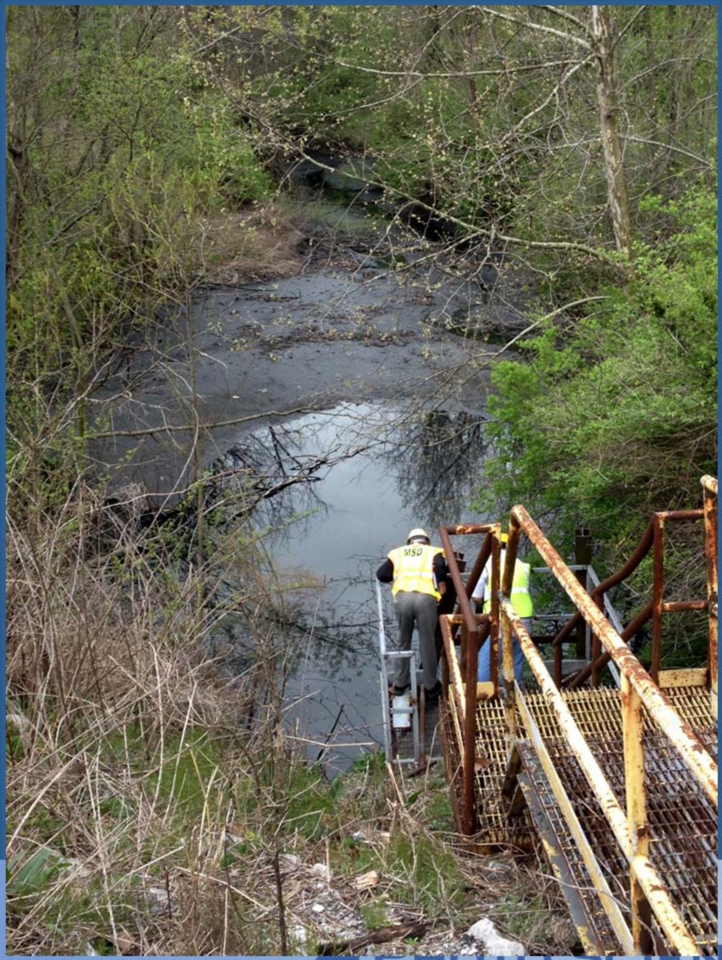
Field Investigation

- Field verification screening began in Spring 2013
- No chemical testing
- Verified 1:1 ratio
- Industrial facilities
- Field observations
- 142 anomalies



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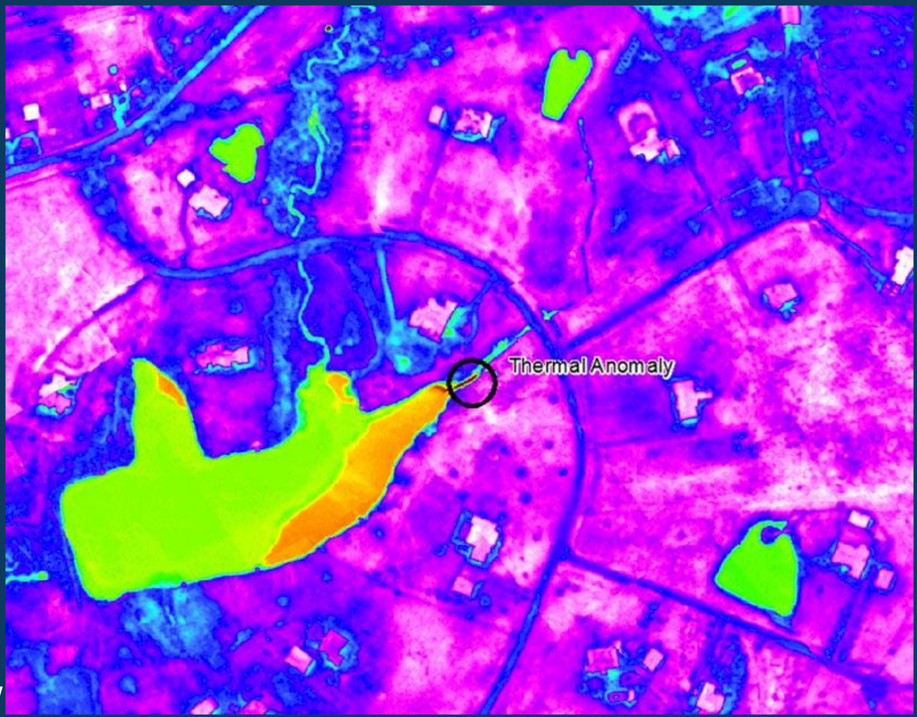
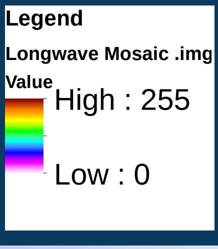
Points Identified

- Signs of Pollution Identified by Crews During Field Inspections
- “False Thermal Signatures” Observed by Shallow Ponding or Specific Slope Conditions





Background

- Building footprints can be used for a large number of purposes
  - Visualizations
  - Emergency response
  - Risk assessments
  - Delivery services
  - Development planning

Building Footprints

- Problem
  - Required identification of building footprints to identify risks associated with gas pipelines.
  - Common for all gas utilities
  - Also valuable to know where houses and trees are relative to power lines
- Solution
  - Utilize LiDAR and imagery to capture the building footprints
  - Use automated processing to identify building footprints

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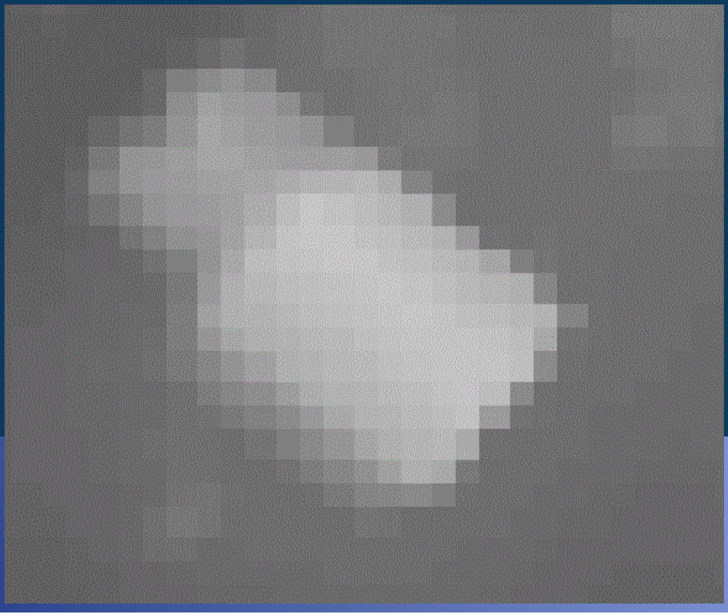
Specifications

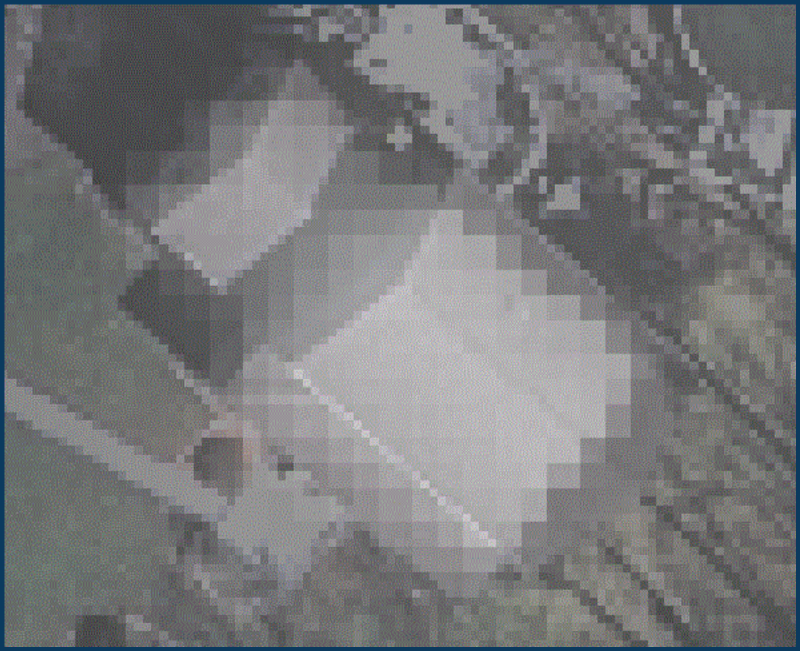
- What is the input data source
  - Imagery
    - Leaf off
      - Spectral resolution: red, green, blue, NIR
      - Spatial resolution: 1’
      - Spatial accuracy: < 3.3 ft
      - Data resolution: 12 bit
    - LiDAR
      - 1 ppsm point spacing
- How was the map made
  - Manual or Automated: Automated with manual clean up
  - Supervised/Unsupervised: Thresholding of LiDAR and unsupervised
  - Cluster or CART: Cluster
  - Pixel of object: Object

Challenges

- Footprint vs. rooftop
- What are the spatial resolutions of your input data sets?
- Co-registration of LiDAR and imagery
- Vintage of imagery and LiDAR
- What is the level of detail needed for the buildings?
- What are the spatial accuracy requirements for the rooftops?

Input Data Sets





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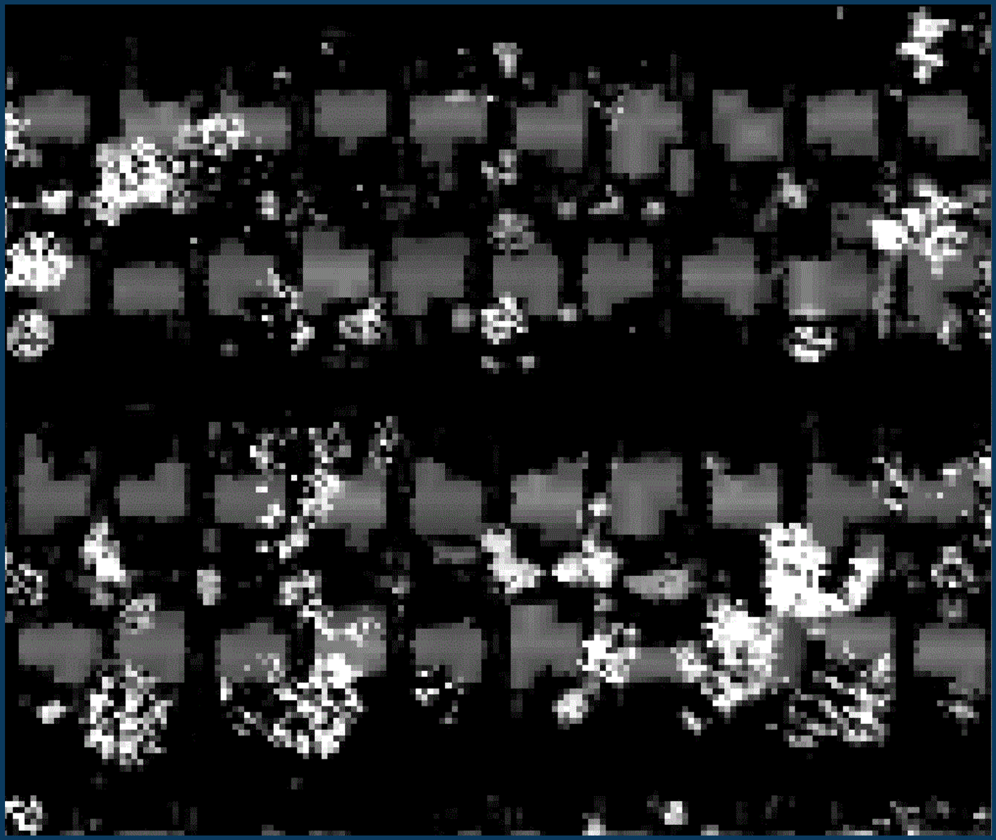
Technical Approach



Preprocessing

- LiDAR into last return surface model
- Slope derived from surface model
- Normalized Vegetation Difference Index (NDVI)
- Stacked into layers and processed together

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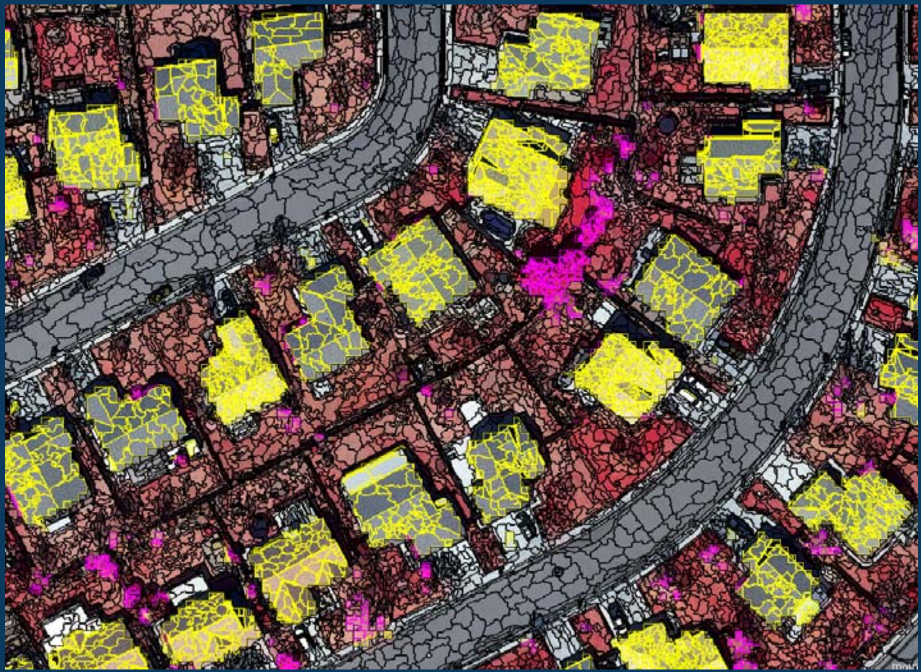
Segmentation & Classification

- Using Trimble eCognition
  - Segmented multi-layer image using small level multi-resolution segmentation
  - Identified elevated features
  - Separated vegetation from urban
  - Classified segments into rooftop and merge segments together



Generalize Edges

- Custom Building Generalization algorithm in eCognition that boosts the uniformity of building edges
- Edges will still have 'stair-step' edge based on raster

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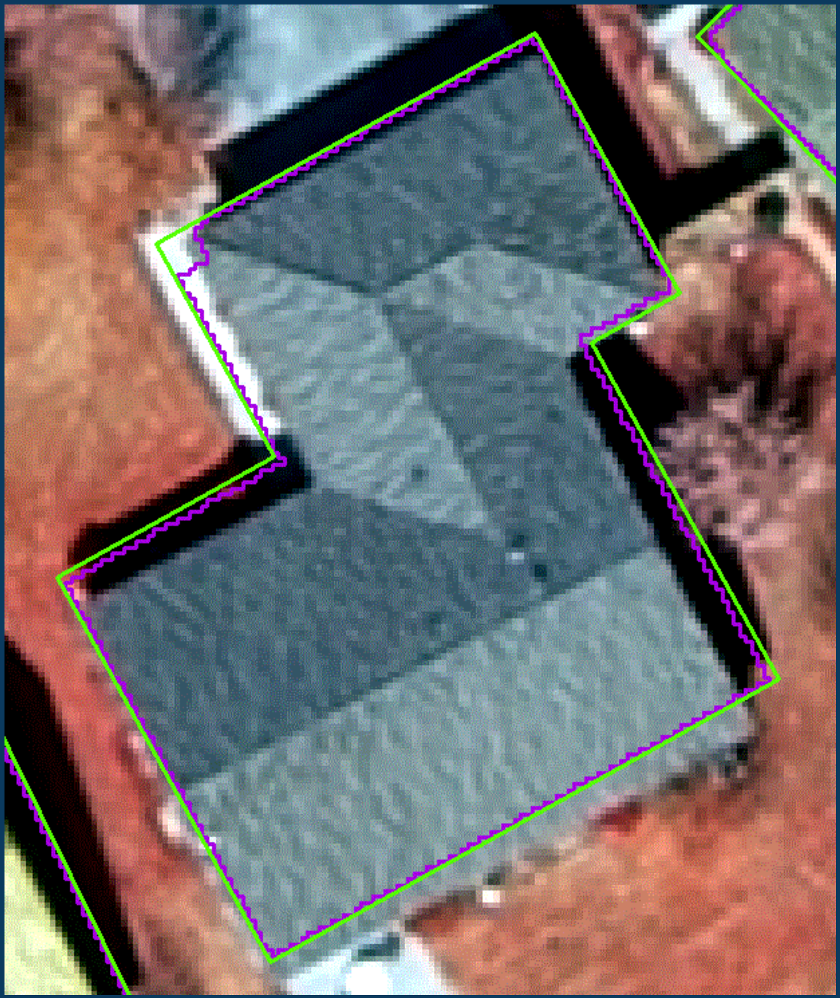
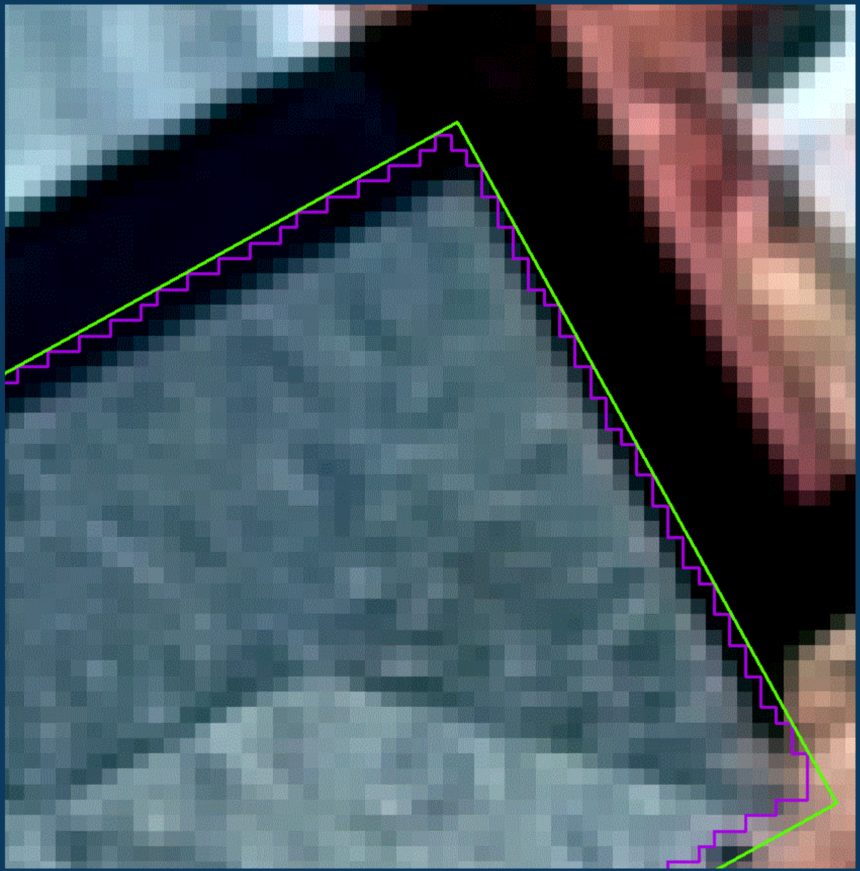
Shape Refinement





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Finalize

- There are going to be errors
- Determine reference dataset – LiDAR or imagery

SUMMARY

- Imagery and LiDAR can be used to generate a large number of different datasets
- Make sure that the imagery and LiDAR specifications support application
- This can
  - Save money
  - Make better decisions
  - Avoid costs
  - Support other operational needs
- Need to document and highlight how people are using land use and cover to demonstrate to decision makers its importance

Questions

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