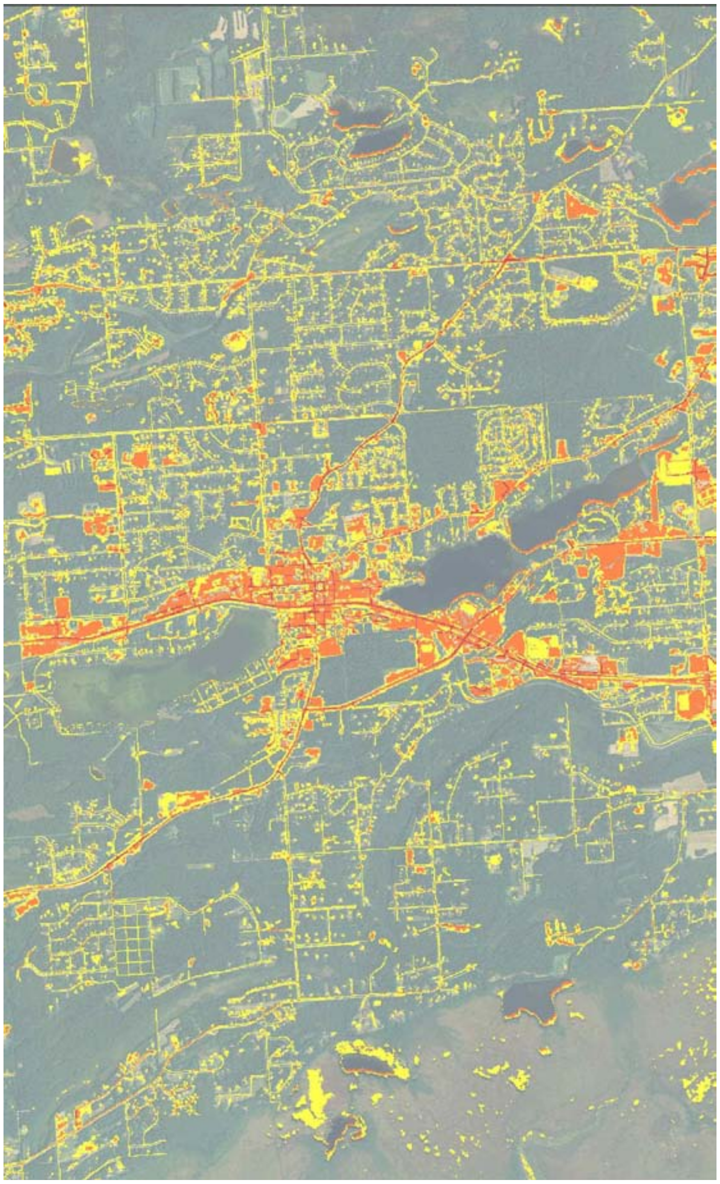

# Mapping Impervious Surfaces in the Mat-Su

## Measuring Development at the Subwatershed Scale

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November 2011

**QUESTION:** How has impervious surface changed across the Matanuska-Susitna basin during the past decade of rapid population growth?

Research has shown that increased impervious cover levels can negatively impact water quality and flows leading to degraded stream health for fish (Schueler, R.,et.al; 2009). The Matanuska-Susitna Salmon Partnership identified minimizing impervious surfaces and their resultant storm water runoff as an objective in the Partnership's Strategic Action Plan (MatSu Salmon, 2008). Additionally, the release of 2010 Census data confirmed the Mat-Su Borough as Alaska's fastest growing region which further strengthened the need for a study of impervious surfaces (US Census, 2011).

**METHODS:** What are the most appropriate means to generate an updated impervious surface dataset of the highest accuracy and precision using existing source data and within the project budget?

Prior to this project, the US Geological Survey's (USGS) National Land Cover Dataset (NLCD) imperviousness layer functioned as the only basin wide baseline. The USGS generated this layer using LANDSAT satellite imagery from the years 1999-2001. While this dataset is of a relatively coarse nature with 30 meter pixels, it does characterize the relative extent of development within the region approximately one decade ago. This current project seeks to improve the level of spatial detail by more accurately delineating smaller impervious features. Additionally, by using more recent source data this new layer will reflect development over the past 8-10 years.

1) Which Method and What Source Data?

These two elements, method and source data, are linked as one determines the other. This necessitated an inventory of available source data with a particular focus on currentness and spatial resolution. By knowing which data can be used, we can develop a list of project options. A summary of data is charted on Appendix 1 (Source Imagery Considered for Impervious Surface Project).

*Land Cover – Land Use Data*

Impervious surface estimations elsewhere have employed land use/cover classifications which are then assigned an impervious surface coefficient based upon previous study results. Total impervious surface can then be calculated by multiplying the individual landcover areas by the coefficients which are expressed as a percentage and then summing each cover type's impervious area. This method is employed in highly developed areas which have detailed municipal land use data; however, neither of these conditions exists in the Mat-Su basin making it susceptible to significant errors and therefore unsuitable for this project. Another reason for dismissing this approach is that the most recent and perhaps only comprehensive land cover dataset for the Mat-Su region is the USGS's National Land Cover Dataset of 2001 which is the baseline dataset for this project to measure change. The overall thematic accuracy of the Alaska NLCD was calculated to be 76% with lower values for less abundant landcover types. Due to the relative scarcity of the developed area classes (less than 0.1%) across the entire state, these land cover types were not considered by this study. (Selkowitz, Stehman, 2011).

*Aerial Photograph or Natural Color Satellite Image Delineation*

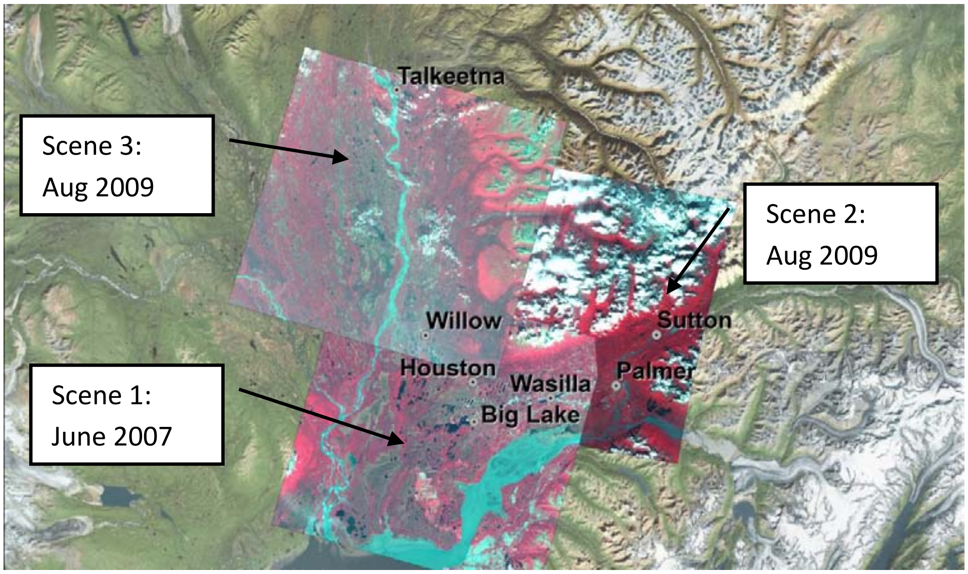
Other studies have utilized high resolution aerial photography to generate impervious surface layers. Manual plannimetric delineation methods were succeeded by computerized interpretation using a series of multiple training sites of known impervious surfaces to "train" the software to identify impervious areas. The Natural Resource Conservation Service (NRCS) of the US Department of Agriculture acquired orthrorectified color photography of much of the Mat-Su's developed lands in 2004-05. While these images offer excellent spatial resolution and an ability to finely demarcate smaller suburban features such as driveways and rooftops, the acquisition dates only provide an additional three to four years beyond the baseline dataset from 2001. The Nature Conservancy investigated purchasing commercial high resolution (0.5m-5m) imagery from the Quickbird, GeoEye, or RapidEye satellites. We were unable to find scenes that met our criteria of: cloud-free and snow-free images, sufficient spatial coverage, and within our project budget. Although we were unable to consider this methodology for the current study, the acquisition of high resolution orthophotography by the Mat-Su Borough during the summer of 2011 could lead to the development of a very fine scale impervious surface dataset in the future (Appendix 1:Source Imagery Considered for Impervious Surface Project).

*NDVI – Normalized Difference Vegetation Index with Medium Resolution Satellite Data*

The demand for remote sensing information has led to numerous satellites generating data of varying resolution and multiple bands. Much of these data are accessible via either commercial vendors or through academic research institutions. The University of Alaska's Alaska Satellite Facility (ASF) functions as a download and distribution center for the Japanese ALOS (Advanced Land Observation Satellite) data. The ALOS data are finer resolution than the baseline NLCD data (10meter vs. 30meter pixels) and offer four bands of information which permits standard remote sensing calculations such as the normalized difference vegetation index (NDVI). The NDVI is frequently referenced as a measure of greenness and is generated through the following equation where NIR = near infrared light wavelengths and VIS = visible light wavelengths.(NASA, 2011)

$$NDVI = (NIR-VIS)/ (NIR+VIS)$$

The NDVI value provides a simple and easily computed measure of vegetated landcover. Values can range from +1 (completely vegetated, vigorous growth) to -1 (devoid of vegetation). Pixels with negative NDVI values are interpreted as impervious surfaces. The ALOS data inventory includes relatively clear, summer scenes from the later part of the decade (2007, 2008, and 2009) which capture the more recent regional growth. The Alaska Satellite Facility's ability to acquire and process these scenes quickly and inexpensively met the final criteria for project data selection. The three ALOS scenes that were ultimately chosen and processed covered nearly 4,000,000 million acres, almost 16,000 square kilometers, or over 6,100 square miles. This area covers the entire Mat-Su core area of Palmer/Wasilla/Big Lake and runs north along the Parks Highway to Talkeetna.



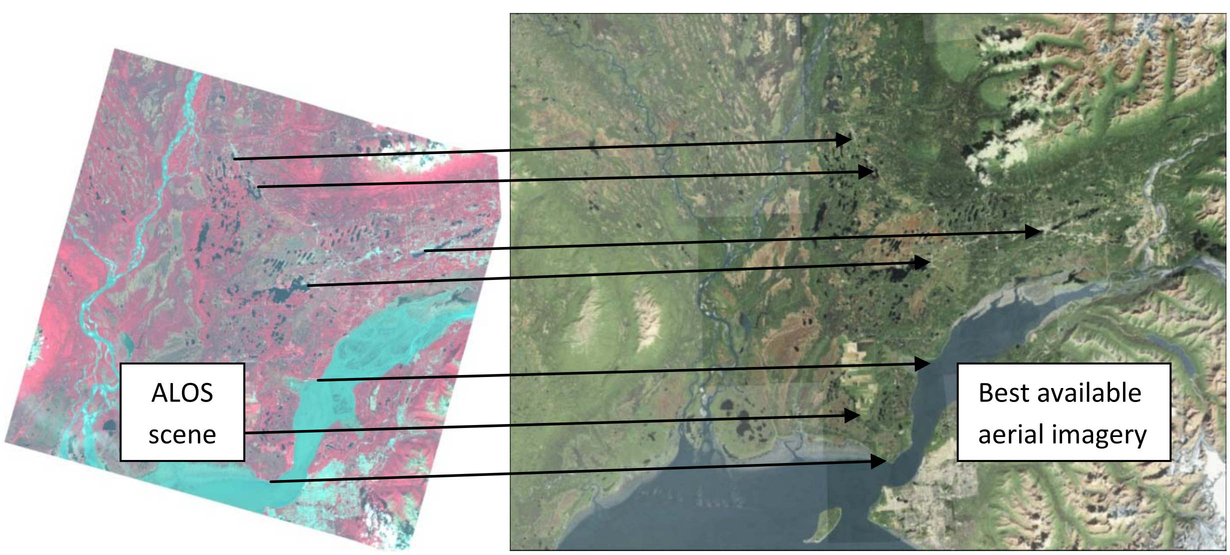

False color images of the ALOS scenes analyzed for this data layer. Note core developed areas and highway corridors are primarily clear and cloud free.

2) How to Process the Data:

This section will explain the basic processing steps used to generate the impervious surface through plain language and example graphics to illustrate the techniques as they were applied in this landscape. A more detailed accounting of the specific parameters and settings used for the data preparation can be found in the dataset's metadata available in multiple formats (html, pdf, xml)

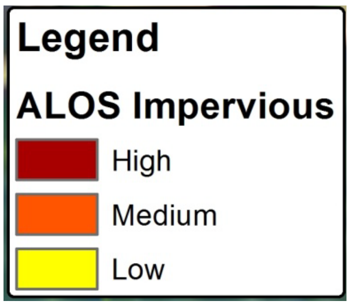
*a) Georeferencing*

Following the NDVI computation, the images were referenced to the best available aerial imagery for the area which was typically the 2004-2005 NRCS imagery. ASF staff used a rubbersheeting technique by selecting 70-90 control points on each ALOS image of easily identifiable locations (road intersections or lakes in remote areas) and then matched them to corresponding spots on the aerial photos.



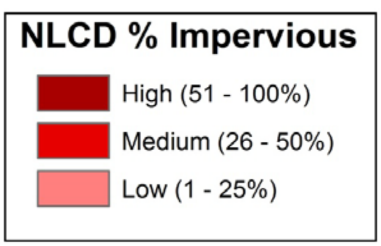
*b) Converting NDVI to Impervious Surface Levels (high, medium, low thresholds)*

The project's objective of comparing the more recent ALOS imagery to the 2001 NLCD imperviousness layer required a conversion from NDVI values ranging from +1 to -1 to values similar to the NLCD's percent impervious cover. Remote sensing experts at the Alaska Satellite Facility developed thresholds to delineate high, medium, and levels of impervious cover to facilitate analysis and comparison between watersheds and wit h the year 2001 impervious surface dataset. The exact threshold specifications for each ALOS satellite scene can be found in the final metadata file (impervious.html).



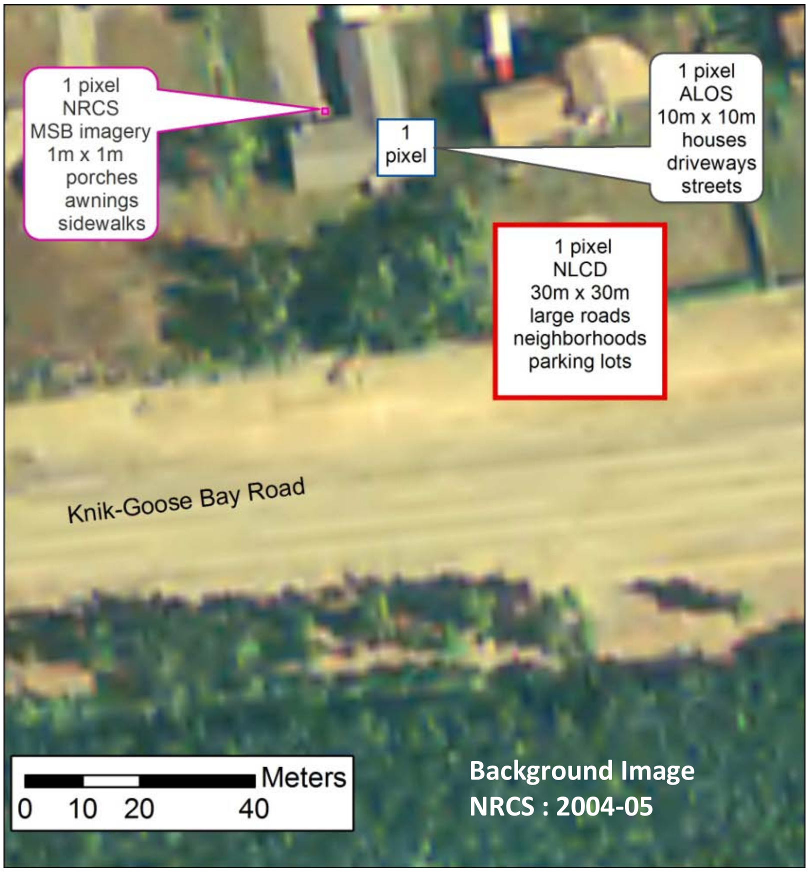

HIGH – large, contiguous areas of completely impervious surfaces: highways, expansive roofs and buildings, large parking lots, and heavily compacted lands within gravel pits

MEDIUM – most roads, moderately sized parking lots, and many residential and commercial structures




LOW – smaller roads including dirt and gravel roads, many smaller buildings and houses, some driveways

The coarse resolution of the NLCD imagery translates to pixels which are larger than most discrete impervious features that are to be measured in a rural/suburban environment (houses, small roads). On the ground this means that the NLCD pixels are often spanning areas that are not homogenous and therefore the pixel measures a percentage of impervious surface from 0-100%.



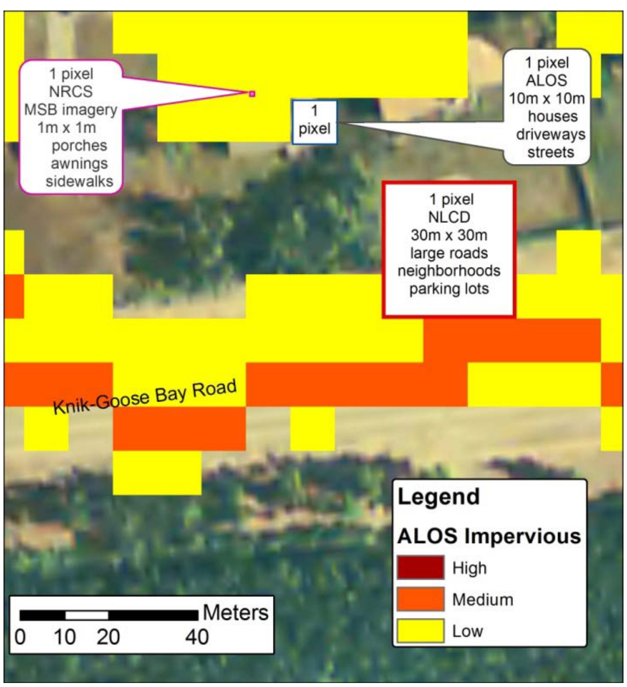

Example of various imagery sources' pixel sizes and how these varying dimensions represent different land cover types and their respective impervious surface levels

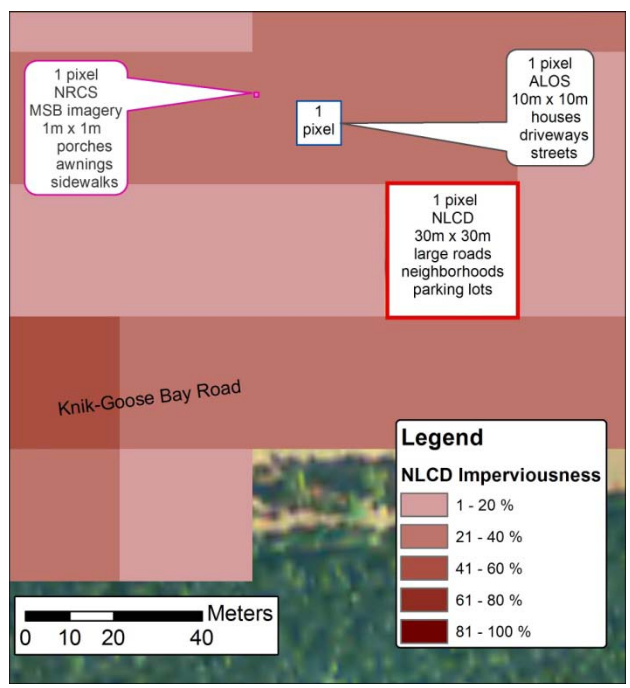
NLCD pixel = 900m$^2$ or 0.22 acres

ALOS pixel = 100m$^2$ or 1075 sq ft

(Below) The base NLCD pixels can only represent large features such as the road, most of the other pixels are a mix of impervious (houses) and vegetation (trees).

(Below) The ALOS pixel resolution delineates the road as well as the houses while not misclassifying the vegetation.

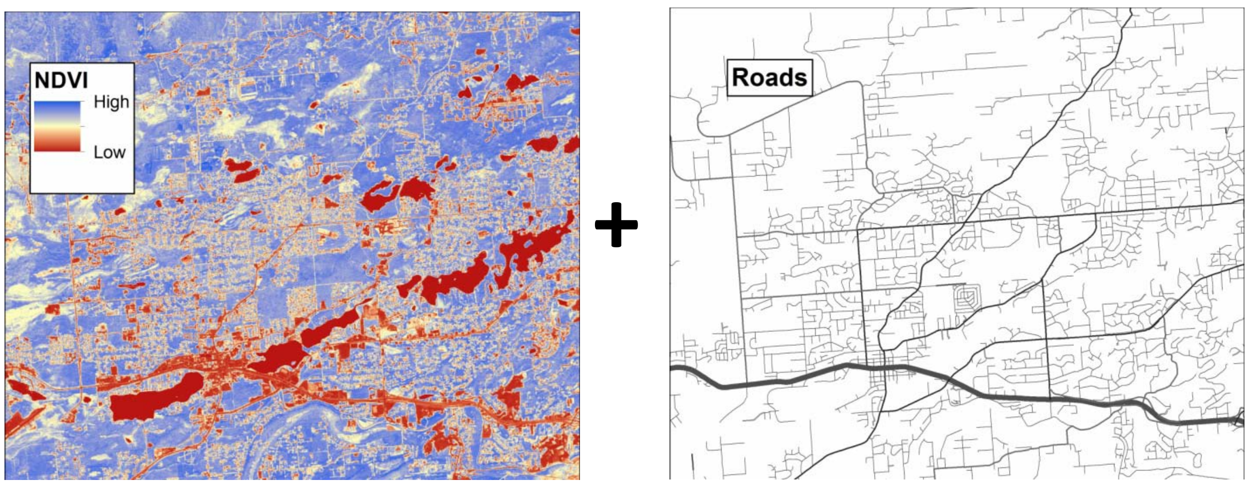


*c) Roads*

The unvegetated areas identified by the NDVI method required additional processing to develop a more accurate impervious surface layer to insure that known impervious surfaces were included. Numerous existing geographic information system (GIS) datasets were used to edit the raw NDVI. Alaska Satellite Facility staff converted the Matanuska-Susitna Borough's roads GIS layer into a raster layer and combined this data with the existing impervious layer to incorporate the roads. The current roads GIS layer does not include attributes such as road width or surface type (paved, gravel, dirt) so the roads raster layer was assigned a width of 10 meters and a moderate level of imperviousness. Future impervious surface datasets would benefit from such detailed road attributes.

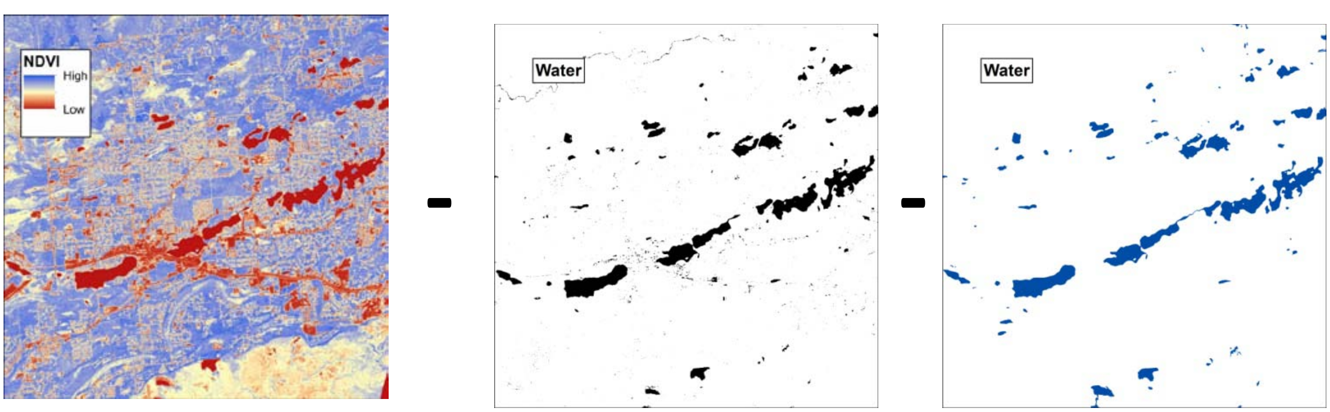
Base NDVI                Vector Roads converted to 10m pixels




*d) Water Mask*

The NDVI calculation yields areas which are unvegetated yet it does not differentiate between human conversion and lands which are naturally devoid of vegetation. Using the ArcGIS Iso Cluster tool, ASF staff applied an initial water mask derived from the ALOS imagery to remove large water bodies from the impervious dataset. TNC staff then edited the data even further by converting the USGS' National Hydrographic Dataset of lakes and large rivers into a raster dataset to remove these areas.

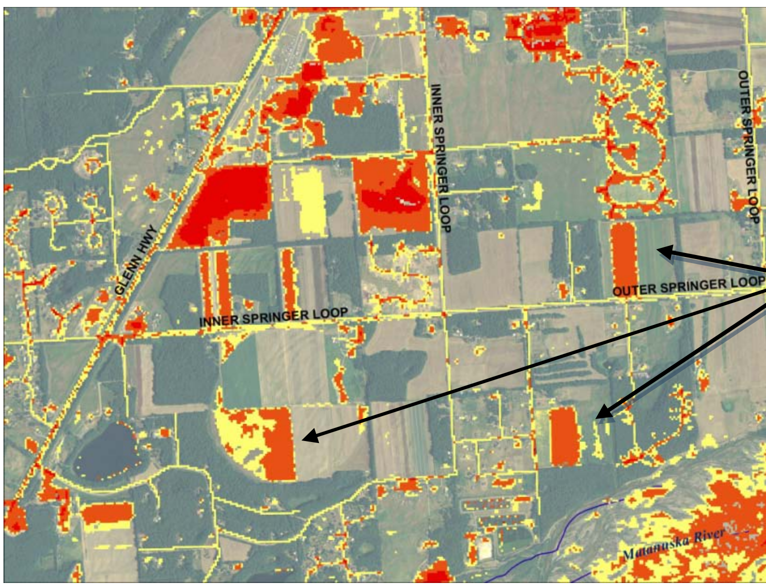
NDVI                subtract ASF water mask                subtract TNC water mask



*e) Manual Edits*

TNC continued editing the data by manually removing pixels via onscreen editing at approximately 1:12,000 scale, using the most recent regional aerial photography for spot verification (NRCS, 2004, BING, 2010, ALOS – 2007-09). In cases where determining land cover (impervious or permeable) was difficult using the background imagery, Conservancy staff used Mat-Su Borough parcel level data to discern recent building construction activity (i.e. impervious surface development). The parcel data with taxable building values were selected and then symbolized to reflect the most recent construction which is not reflected in the 2004 NRCS imagery (Borough document date greater than 2004). Land uses with negative NDVI values that were most frequently removed from the impervious layers included: large gravel bars along major rivers, agricultural fields with differing NDVI values depending on cropping seasons, wetland complexes which had sufficient water content to decrease the NDVI, clouds, and lake shorelines and large rivers that extended beyond the NDVI and GIS derived water masks.

EXAMPLES (agricultural lands, gravel bars, and rivers)

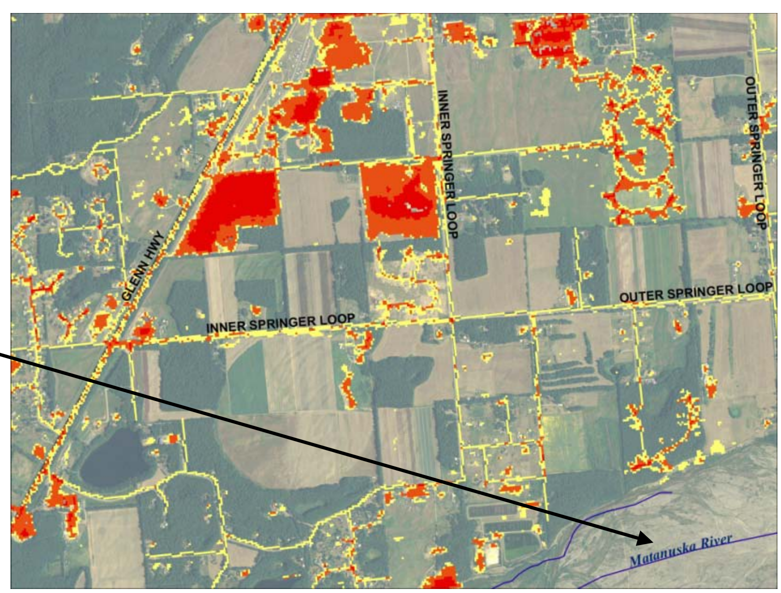



2004 NRCS imagery background with raw (unedited) impervious surface overlay – Glenn Highway, Palmer – State Fairgrounds area.

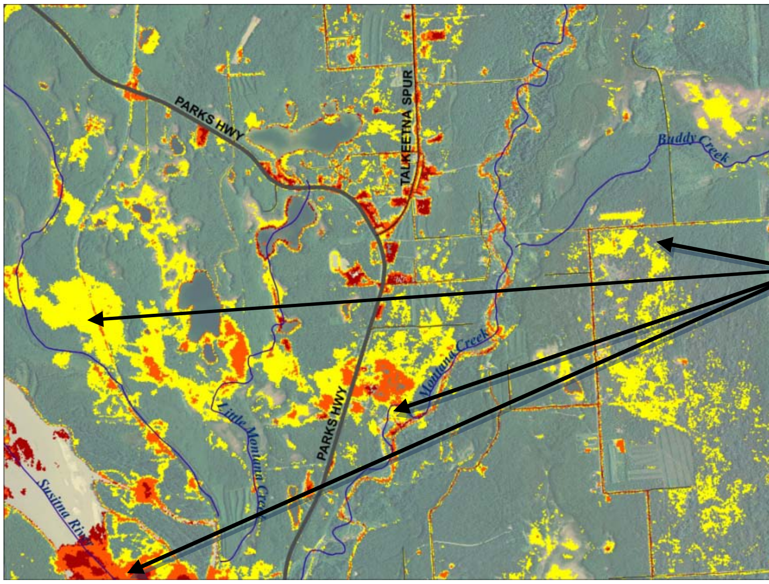
Agricultural lands miscoded in raw dataset, removed during editing

2004 NRCS imagery background with edited impervious surface overlay – Glenn Highway, Palmer State Fairgrounds area.

Matanuska River gravel bars removed from impervious dataset



EDIT EXAMPLES continued (cloud removal, lakeshore edges)

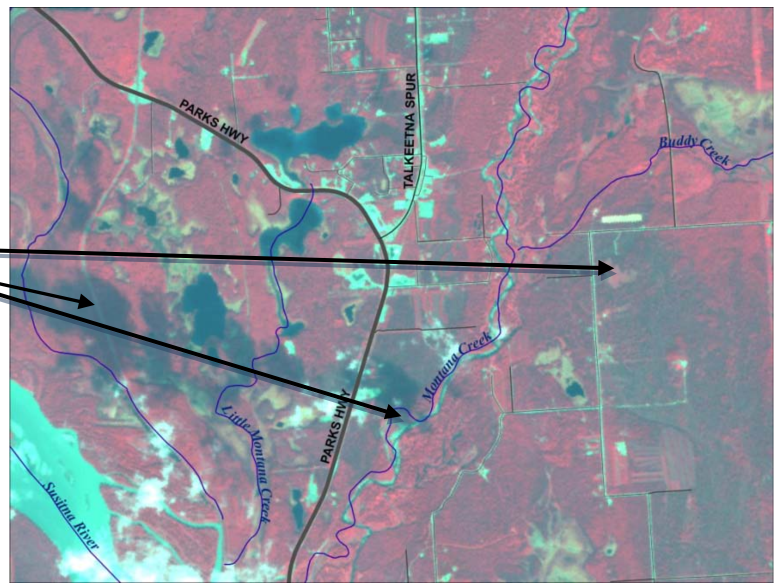


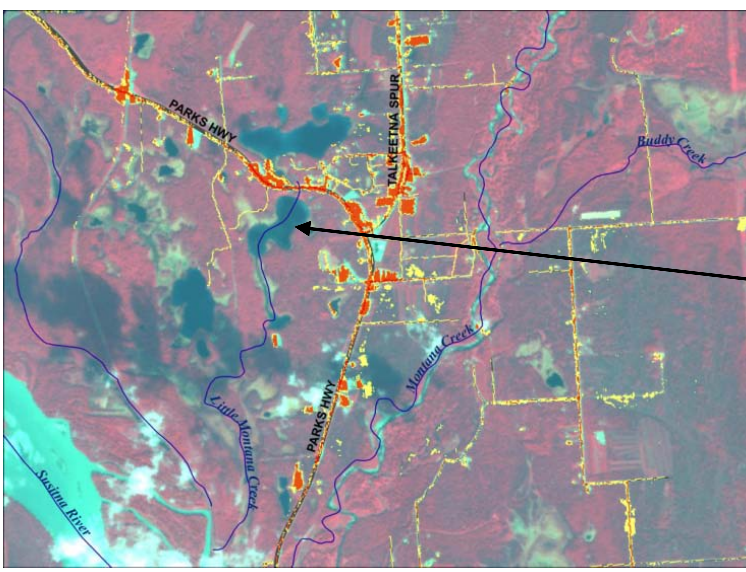

2004 NRCS imagery background with raw (unedited) impervious surface overlay – Parks Highway, Talkeetna "Y" area

Large impervious signal in region in a lightly developed area needs investigation

2009 ALOS false color imagery – Parks Highway, Talkeetna "Y" area.

"Impervious signal" created by clouds and their shadows over the landscape

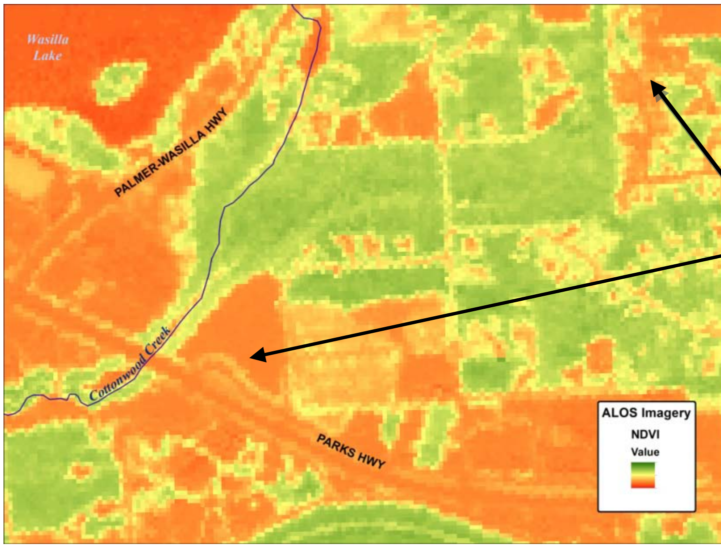



2009 ALOS false color imagery with final (edited) impervious surface dataset – Parks Highway, Talkeetna "Y" area.

Edits included removing clouds as well as this lakeshore rim effect created by misaligned water masks

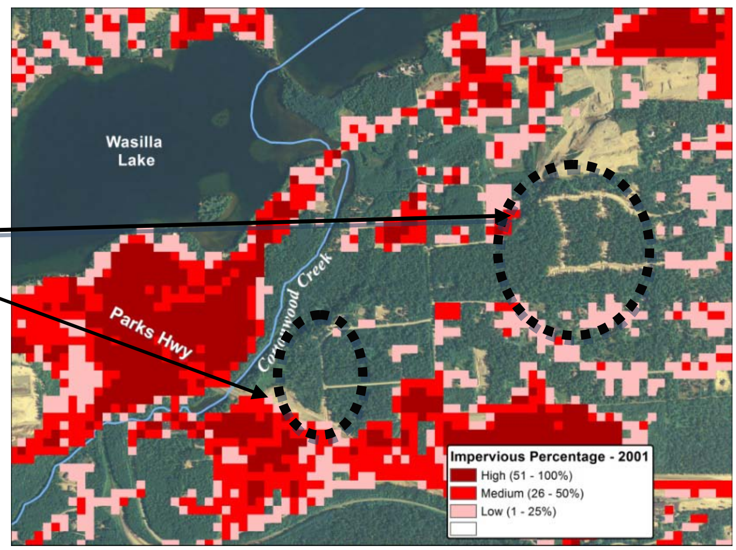
EDIT EXAMPLES continued (verification with parcel data)



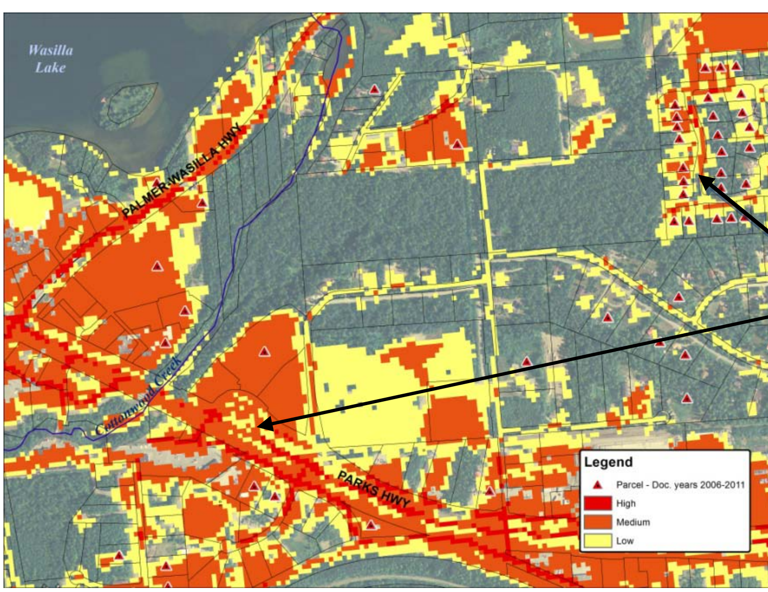

2007 ALOS NDVI imagery – Parks Highway, Cottonwood Creek area

Significant negative NDVI signal in areas not present in the 2001 NLCD data, warrants further investigation

2004 NRCS imagery with 2001 NLCD impervious surface data – Parks Highway, Cottonwood Creek area



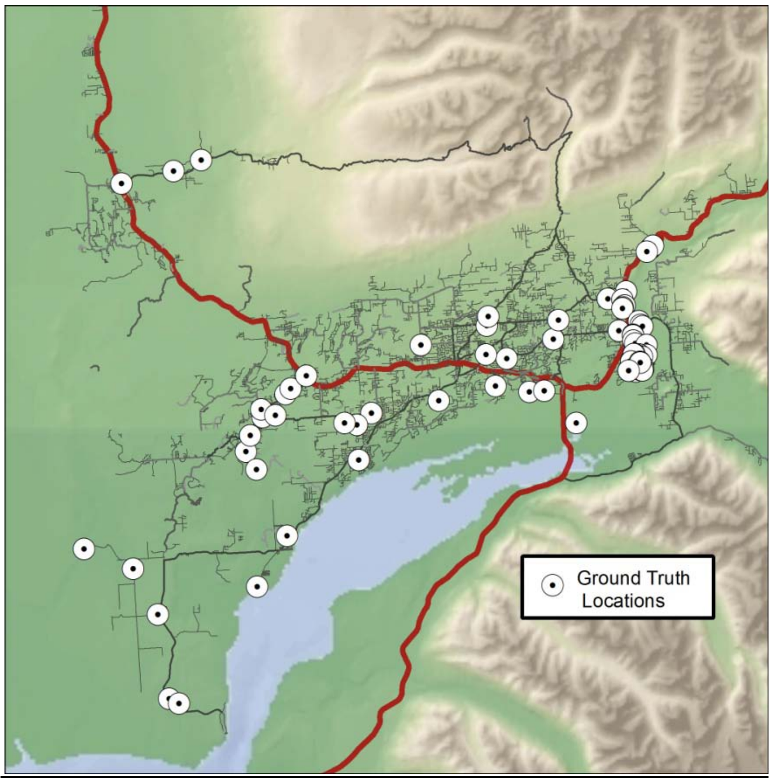

Impervious surfaces not present in the 2001 NLCD, but with negative NDVI values shown




2004 NRCS imagery with TNC generated impervious surface dataset and MatSu Borough parcel data – Parks Highway, Cottonwood Creek area

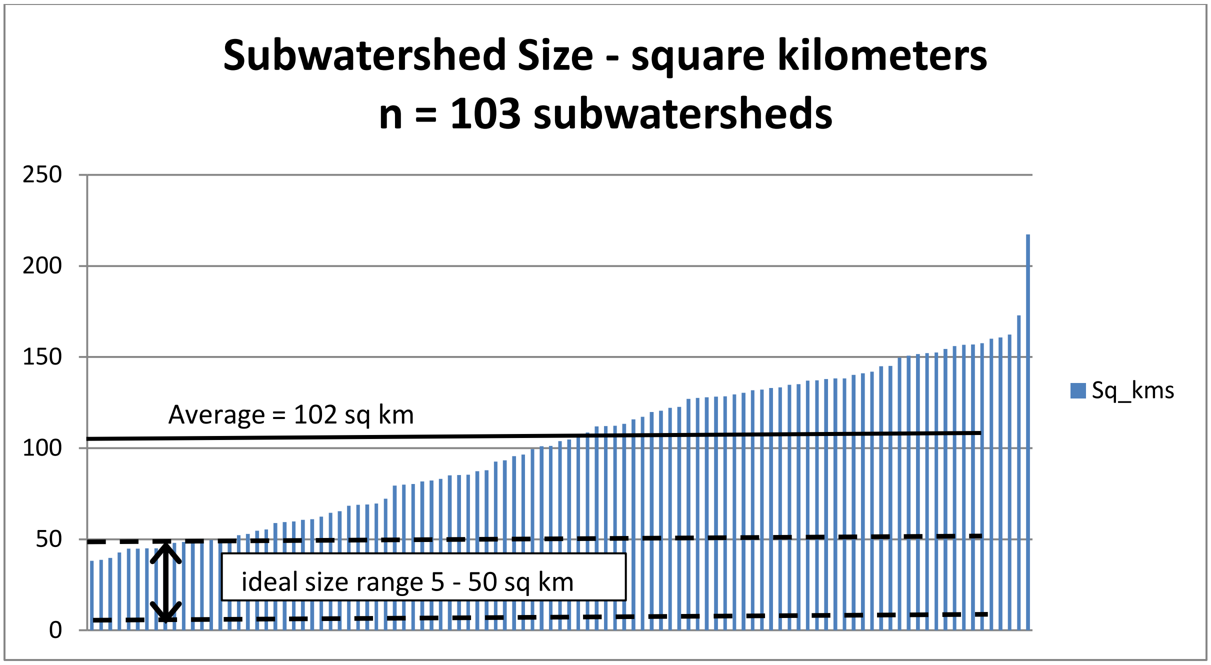
Red triangles represent parcels developed between 2006-2011 (MatSu Borough), confirming impervious growth as shown by NDVI *f) Ground truthing (field verification)*

Four separate field trips to the study region were conducted to visually verify actual land cover types across a wide range of settings. TNC staff selected ground truthing sites that captured locations where the NDVI derived impervious surface layer seemed to generate false positives (e.g. agricultural lands, riverine gravel bars, confirm cloud shadows, etc.). Additional sites included development in salmon watersheds of the Matanuska-Susitna core area.




## ANALYSIS:

A recent meta-analysis of 65 impervious surface studies identified an ideal subwatershed size range of 5 to 50 square kilometers for accurately measuring impervious cover levels and their relative impact to water quality (Schueler, 2009). The three ALOS satellite scenes chosen for the study provided NDVI derived impervious values for 103 subwatersheds, also known as 12 digit hydrologic units, or HUC12s. They are defined by the US Department of Agriculture's Natural Resource Conservation Service Watershed Boundary Dataset (NRCS, 201 ). Although these subwatersheds are the finest resolution drainages available for the region, the average subwatershed size is 102 $km^2$ and over twice the recommended maximum area. These relatively large analysis areas can translate into relatively low measures of impervious surface coverage by diluting developed regions across larger landscapes. A further delineation of finer scale drainages in the future may be warranted to more accurately characterize more meaningful impervious surface measures.




Using the ArcGIS Tabulate Area command, the ALOS/NDVI impervious raster layer from years 2007 - 2009 was combined with the 103 subwatersheds yielding a tabular summary of impervious surface area by subwatershed (high, medium, and low square meters). These values were summed and divided by the watershed area to generate an overall percent impervious surface for each of the 103 subwatersheds.

Impervious Surface Percentage for year 2008 =

$$\frac{(\text{Low Impervious Area}*0.75) + \text{Medium Impervious} + \text{High}}{\text{Subwatershed Area}}$$

Considering the 2001 impervious surface dataset's relatively coarse pixel size and its values of percent imperviousness ranging from 1 to 100%, a proportional method of calculating overall percent impervious by watershed was implemented. After using a similar tabulate area method in ArcGIS with the NLCD impervious raster layer and the subwatersheds, TNC staff weighted the areas for each increment of impervious surface by multiplying the area for each of the values by its inverse and then summing across all categories from 1% through 100%.

Impervious Surface Percentage for year 2001 (n=100) =

$$\frac{(\text{square meters of 1\% impervious} * (1/100)) + (m^2 \text{ of 2\% impervious} * (2/100)) + \ldots}{\text{Subwatershed Area}}$$

*Impervious Growth Calculations:*

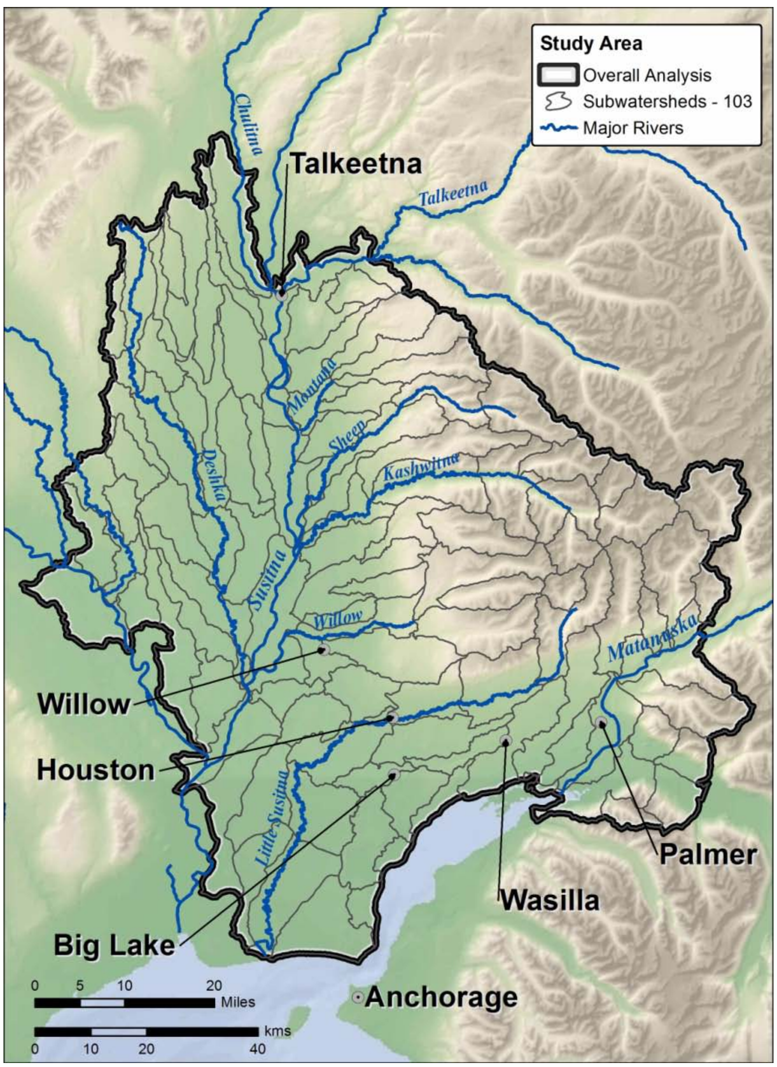
After computing values from the ALOS data and the NLCD data, the 2001 percentages were compared to the composite data from 2007-2009 to calculate impervious surface growth rates, both cumulative growth and an average annual growth rate over the approximately 7 years between source data.

$$\text{Cumulative Growth} = \frac{\text{2008(ALOS) Impervious Area} - \text{2001 (NLCD) Impervious Area}}{\text{2001 (NLCD) Impervious Area}}$$

$$\text{Annual Growth Rate} = \frac{\text{Cumulative Growth}}{\text{7 (years)}}$$

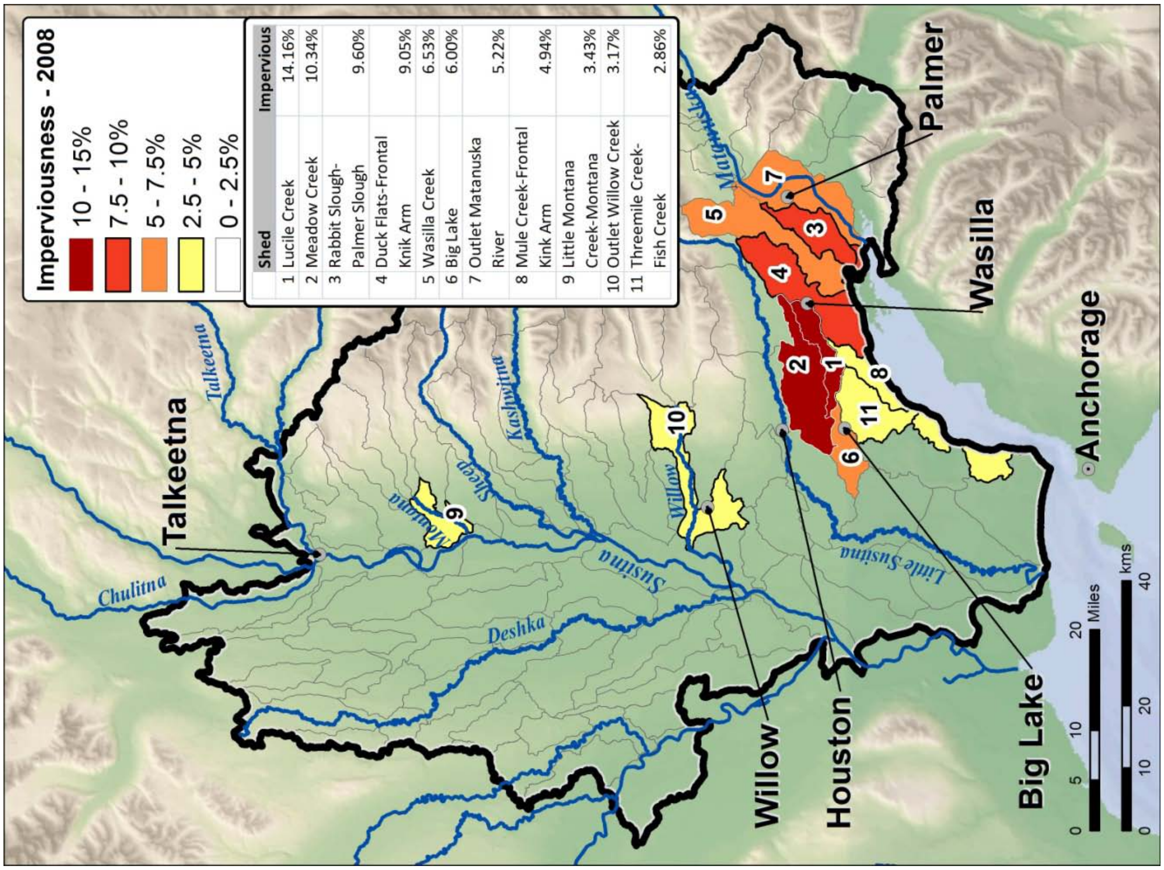
**RESULTS:**

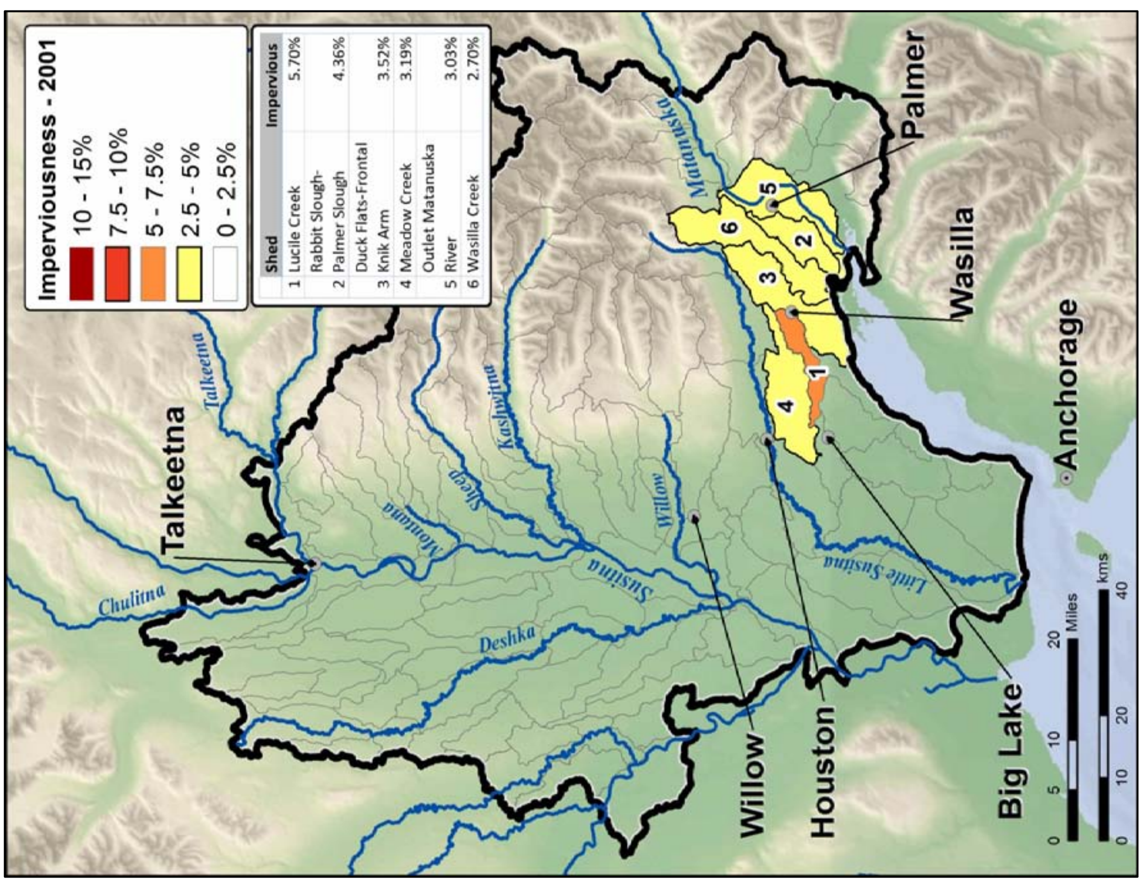
The study's results can be viewed as tables, as maps summarized by watershed, or in GIS formats suitable for numerous mapping software. Impervious cover values from the baseline, year 2001, NLCD derived dataset ranged from 5.7% (Lucile Creek subwatershed) to 0% (numerous subwatersheds). The updated ALOS generated impervious surface values ranged from a high 14.16% (Lucile Creek) to 0%. The subwatersheds with the highest impervious surface values can be found on the maps shown on the following page.



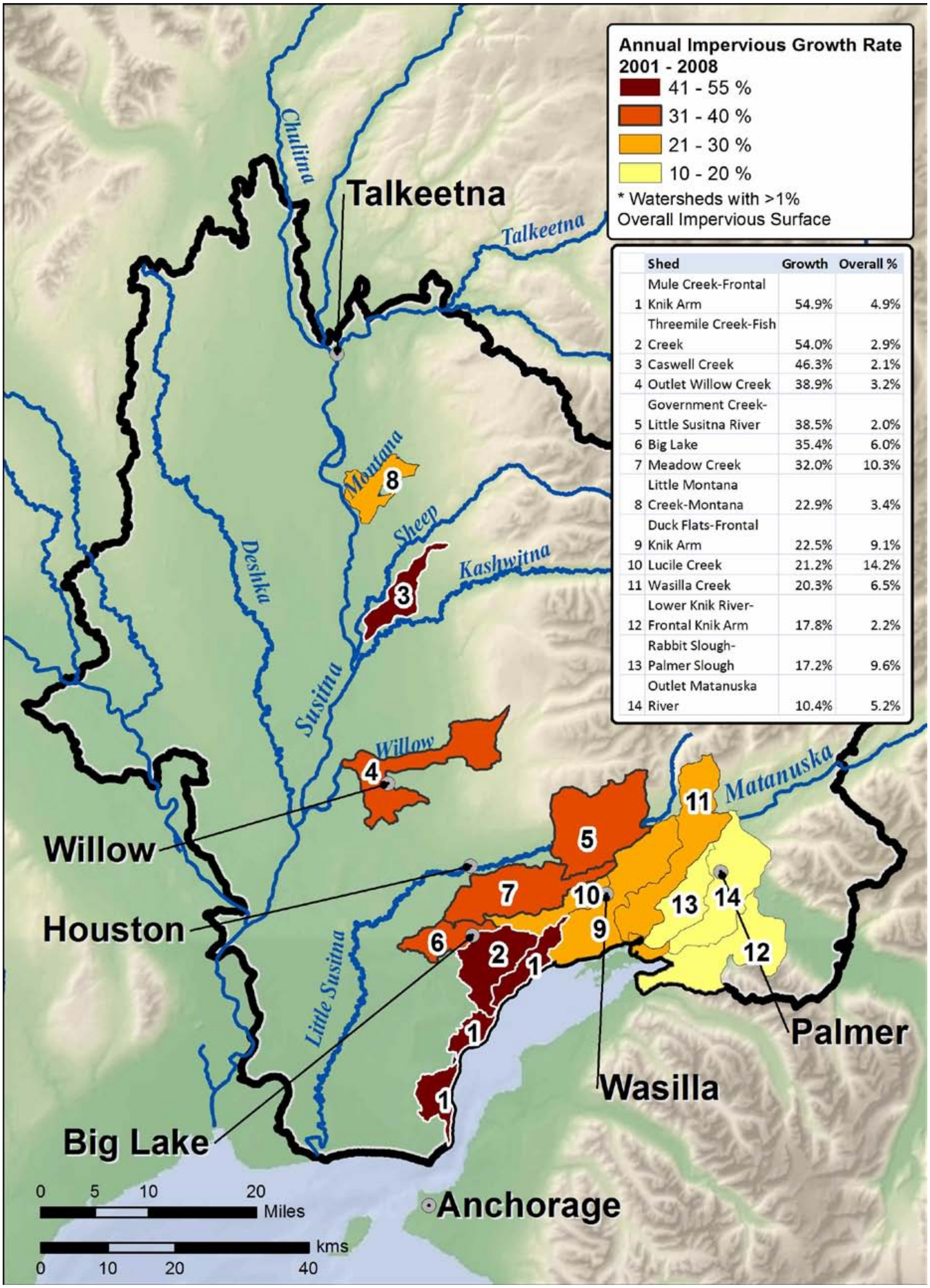

Study area encompasses 10,500 square kilometers, or 4048 square miles and includes the Mat-Su's core developed area stretching from Palmer west through Wasilla and Big Lake and then following the Parks Highway corridor north to Talkeetna.

## Impervious Surface Percentages by Subwatershed: 2001 and 2008

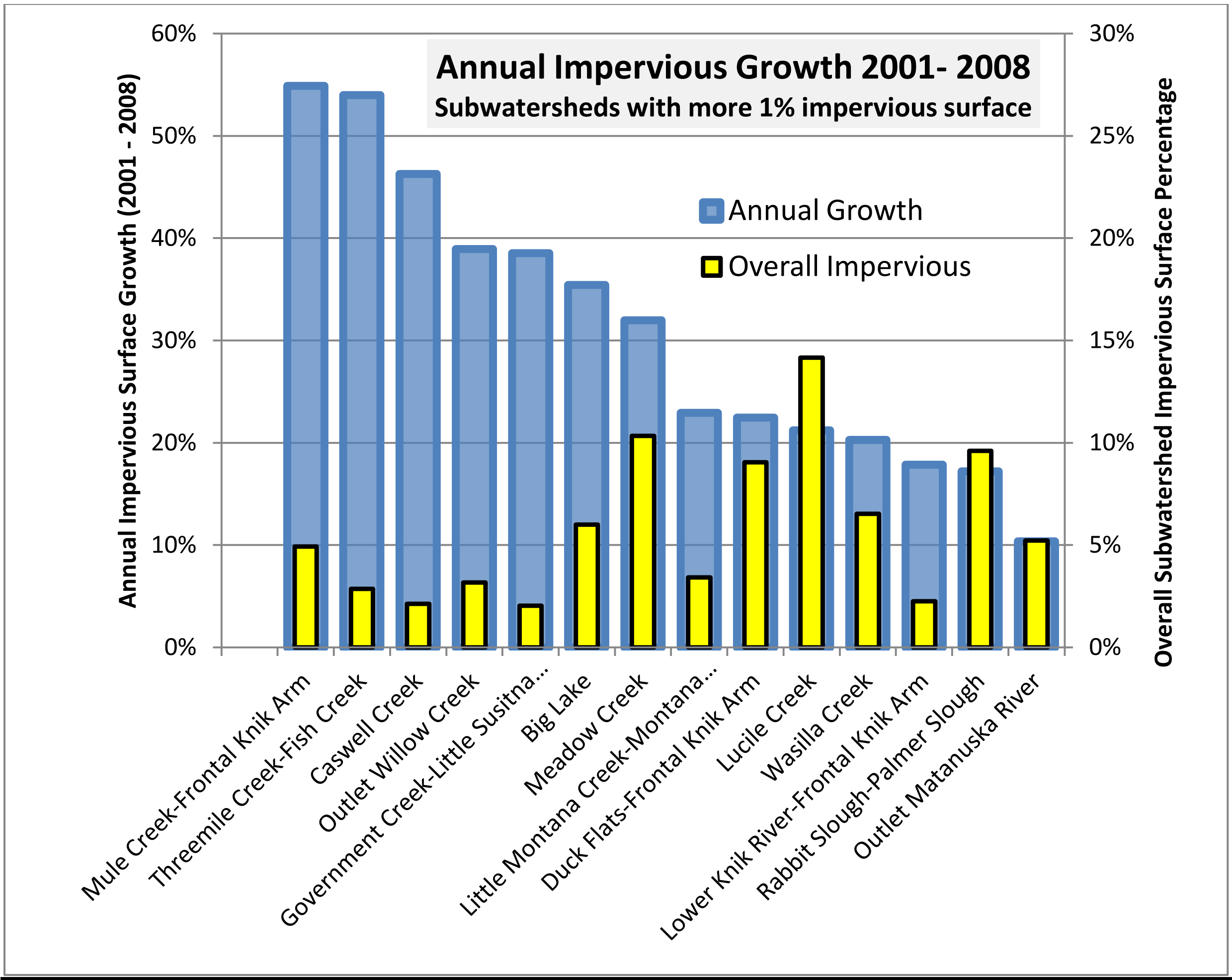


**Watersheds with fastest impervious surface growth over the past seven years.**




| | Shed | Growth | Overall % |
|---|---|---|---|
| 1 | Mule Creek-Frontal Knik Arm | 54.9% | 4.9% |
| 2 | Threemile Creek-Fish Creek | 54.0% | 2.9% |
| 3 | Caswell Creek | 46.3% | 2.1% |
| 4 | Outlet Willow Creek | 38.9% | 3.2% |
| 5 | Government Creek-Little Susitna River | 38.5% | 2.0% |
| 6 | Big Lake | 35.4% | 6.0% |
| 7 | Meadow Creek | 32.0% | 10.3% |
| 8 | Little Montana Creek-Montana | 22.9% | 3.4% |
| 9 | Duck Flats-Frontal Knik Arm | 22.5% | 9.1% |
| 10 | Lucile Creek | 21.2% | 14.2% |
| 11 | Wasilla Creek | 20.3% | 6.5% |
| 12 | Lower Knik River-Frontal Knik Arm | 17.8% | 2.2% |
| 13 | Rabbit Slough-Palmer Slough | 17.2% | 9.6% |
| 14 | Outlet Matanuska River | 10.4% | 5.2% |




## DISCUSSION AND RECOMMENDATIONS:

- Future work should focus on most developed and fastest growing regions
- Use LiDAR data to delineate finer scale drainages
    - The higher resolution digital elevation data would permit creation of detailed drainage networks and watersheds
- Examine hydrologic connectivity of impervious surfaces to salmon streams
    - Inventory regional stormwater management systems, map areas implementing best management practices such as rain gardens and vegetated drains.
- 2011 aerial imagery to study impervious growth in sensitive riparian areas
    - Create a fine scale (one meter) impervious layer within important habitat such as a riparian buffer along streams.

## ACKNOWLEDGEMENTS:

This dataset was created with financial support from the US Fish and Wildlife Service's Coastal Program in the Anchorage (Alaska) Field Office, Wallace Research Foundation, and Conoco Phillips Alaska, Inc. and through a partnership with Dr. Don Atwood and Moritz Wurth at the Alaska Satellite Facility at the University of Alaska Fairbanks.

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**APPENDIX 1: Source Imagery considered for Impervious Surface Project**