Saint Mary's University of Minnesota

GeoSpatial Services

Analyzing Urban Change from 1984 to 2021 on the Kenai Peninsula: Researching a Semi-automated Approach to Impervious Surface Mapping

ON THE COVER
City of Kenai - near the Kenai Airport
Photograph by: ilovekenai.com - December 15, 2020

Analyzing Urban Change from 1984 to 2021 on the Kenai Peninsula: Researching a Semi-Automated Approach to Impervious Surface Mapping

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Executive Summary

The Kenai Watershed Forum (KWF) was interested in having Saint Mary's University of Minnesota GeoSpatial Services (SMUMN GSS) conduct the delineation of urban (impervious surface) change in the Kenai River sub-watershed (hydrologic unit code: 190203021806) on the Kenai Peninsula, Alaska for the years of 1984 and 2021. There is a need to understand the correlation between increased urbanization and impacts on the natural landscape. Although urban growth is advantageous for the local economy, impacts on natural features must be understood and monitored to ensure the health of the environment. Climate, vegetation and hydrology are all effected to some degree by urbanization. Derived datasets from this project will help the KWF and stakeholders increase their understanding of how changes in the urban landscape have impacted the natural condition of the watershed and will further assist with conservation and restoration decision support.

Acknowledgments

We want to express our gratitude to Branden Bornemann, Executive Director of the Kenai Watershed Form, for his assistance in making this project possible. We also want to thank the U.S. Fish and Wildlife Service for their support and funding of this project. Thank you to Eagleview Technologies, Inc. and the Kenai Peninsula Borough for the use of the high resolution 2021 Pictometry imagery.

Acronyms and Abbreviations

AHAP - Alaska High-Altitude Aerial Photography

AK – Alaska

AKDNR – Alaska Department of Natural Resources

AKDOT – Alaska Department of Transportation

DNR – Department of Natural Resources

DRG – Digital Raster Graphic

GIS – Geographic Information System

HU - Hydrologic unit code

KWF - Kenai Watershed Forum

NHD – National Hydrography Dataset

SMUMN GSS – Saint Mary's University of Minnesota, GeoSpatial Services

USGS – United States Geological Survey

Introduction

The creation of impervious surface mapping is essential for future environmental planning and water quality improvement. The population on the Kenai Peninsula has grown 6.1% over the last 10 years according the Census Bureau (U.S. Census Bureau 2020). With the increase in population, the development of impervious surfaces has increased significantly within the last 40 years. Increasing amounts of impervious surfaces comes at the reduction of natural areas. Per the Environmental Protection Agency (EPA 2003), impervious surfaces produce in excess of five times the amount of runoff that a similar sized natural landscape does, which is a direct correlation with increased pollutant loading into hydrologic systems.

Runoff from impervious surfaces washes not only sediment and nutrients into streams, but pollutants such as bacteria, automotive fluids, heavy metals and other chemicals as well. Erosion caused by runoff can pose a serious threat to streams as increases in sedimentation reduces the oxygen content of water. Nutrient loading, algae blooms, and changes in water clarity, quality or temperature can negatively impact the fish populations, causing a reduced ability for the affected fish species to thrive. Increased runoff can also lead to higher flood peaks and increased flooding frequency which, in turn, can lead to an escalation in stream bed erosion. This erosion can cause the rerouting of streams, which can adversely affect spawning pathways that are critical for anadromous fish reproduction. Draining of wetlands for urbanization adds further stress to the hydrologic system, as this process can cause a decrease in water filtration and a reduction in groundwater recharge.

The Kenai Watershed Forum (KWF) requested Saint Mary's University GeoSpatial Services (SMUMN GSS) to map the impervious surfaces in the sub-watershed (hydrologic unit code: 190203021806). By the time the initial contract was awarded, the U.S. Geological Survey (USGS) had updated the HU12 boundaries for the Kenai Peninsula, which produced a change in the project area. After consultation with the KWF, it was agreed that both Outlet Kenai River and Sports Lake-Kenai River watersheds would be mapped, as they were the best equivalent to the originally proposed mapping sub-watershed (hydrologic unit code: 190203021806) (Figure 1).

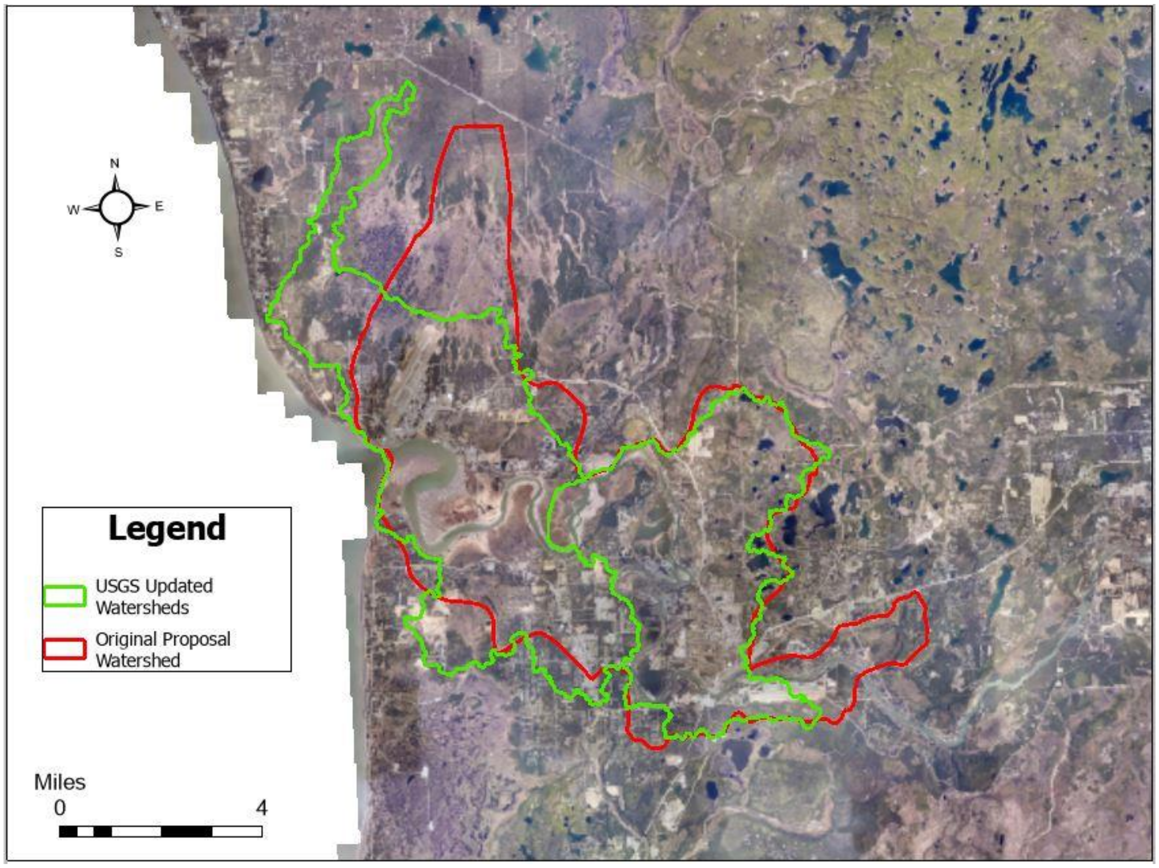

Figure 1. Original versus new sub-watershed project boundary.

There is an existing parcel feature dataset that had been captured by the Kenai Peninsula Borough which reflects parcel locations; however, it must be pared down and reshaped to reflect the urbanized landscape of the project area. Current parcel data from the Kenai Borough does not provide an accurate representation of actual urbanized footprints because there are parcels that are still in natural land cover (tree, shrub meadow, grass, etc.).

SMUMN GSS and the KWF have also identified a need to map roads as polygon features versus the existing linear network that runs down the center line of the roads on the Kenai Peninsula. Roads represent an impervious surface, which change the mechanics of water transportation across the landscape and contribute nutrients and heavy metals to streams and rivers. Roads not only display urban expansion, but give insight to the increase in vehicle traffic.

The base imagery used for the delineation of impervious surfaces and the change analysis was 1984 Alaska High-Altitude Aerial Photography (AHAP) infrared imagery downloaded from the USGS Earth Explorer website. To identify the current state of urbanization, the KWF was able to locate high resolution 2021 true color imagery acquired by Eagleview Technologies, Inc. for the Kenai Peninsula Borough.

Automated feature delineation was investigated during this project as an alternative to the traditional manual creation of features. GIS technological advancements have increased the capabilities of automated image delineation. The standard pixel-based image classification algorithms used in the past have been enhanced with artificial intelligence, neural networking and deep learning. A few of these approaches were examined and it was found that deep learning produced the best results. Although not flawless in detecting all features of interest, the deep learning processing did reduce the need for manual delineation. Where needed due to inaccuracies or errors of commission, manual editing was required to create or reshape polygon features.

Methods

Two different years of imagery were used to identify the changes in impervious surfaces; 2021 high resolution true color imagery and 1984 infrared imagery. The 2021 high resolution imagery was acquired by Eagleview Technologies, Inc. for the Kenai Peninsula Borough. SMUMN GSS and the KWF were able to acquire the 2021 imagery for the defined mapping area from Eagleview Technologies, Inc. through the assistance of the Kenai Peninsula Borough.

The 2021 high resolution imagery came post-processed and readily loaded into the geographic information system (GIS) ArcGIS Pro version 2.9.1. The 1984 infrared images required processing to prepare each scanned photo for use. They were first downloaded from the USGS Earth Explorer website as scanned photos. They are simply scans and lack the coordinate information required for alignment with the 2021 imagery, so georeferencing of each scan to the 2021 imagery was completed to create alignment between the two years of imagery. Additionally, because the 1984 imagery is scanned from hard copy photos, the low resolution of the scanned images made it difficult to locate good control points for registration with the 2021 imagery. As a result, the 1984 images did not align perfectly with the 2021 high resolution images. Several iterations of moving control points were conducted to establish the best registration with the 2021 imagery.

In the past, impervious surface data has been created through heads up digitizing which involves GIS analysts manually drawing the impervious surfaces from imagery. This process can be extremely time consuming, tedious and prone to error in data creation. Over the past few years, Esri has developed pre-trained machine learning models to help automate the impervious surface mapping process. This project used the Building Footprint Extraction model and the Road Extract – North America model to help semi-automate the impervious surface mapping process.

The Building Footprint Extraction model was downloaded from Esri's Living Atlas (Building Footprint Extraction - USA - Overview (arcgis.com)) and used in ArcGIS Pro's Detect Objects Using Deep Learning tool. This model requires an 8-bit, 3-band high resolution (10-40 cm) image. The 2021 imagery, which has a resolution of .75 feet or 22.86 centimeters, was used to extract building footprints for the Sports Lake-Kenai River watershed. Although the tool picked up the majority of the roofs in the study area, there were areas in which roofs were of irregular shape (i.e. fishing huts, storage shacks) that the tool did not include. These roofs were manually digitized and used for training data in a new deep learning model in order to better inform the deep learning tools. This enhanced deep learning model was created using Jupyter Notebooks and the ArcGIS.Learn deep learning module. The new model was input into the Detect Objects using the Deep Learning tool and used to extract roofs over Sports Lake-Kenai River and Outlet Kenai River watersheds (Figure 2).

Figure 2. Example of Output of Detect Objects Using Deep Learning Module Using the Extract Building Footprints Model.

The roads were extracted using a combination of Esri's Road Extraction – North America tool and a roads layer that was downloaded from the Kenai Peninsula Borough's Website. The roads layer was used as an input into the Roads Extraction tool along with the Roads extraction model that was downloaded from Esri's Living Atlas of the World (Road Extraction - North America - Overview [arcgis.com]). The road extraction tool was run multiple times on the 2021 high resolution imagery to create a polyline road network. The output of the road extraction tool was then buffered to the width of the roads as identified in the imagery to create polygons and reshaped, if deemed necessary (**Figure 3**).

Figure 3. Snippet of Output of Roads Extraction Tool Buffered.

Features classified as impervious surfaces that were not derived through the deep learning automated processing were digitized manually from the imagery. These features included parking lots, driveways, quarries, and sidewalks. The roads and roofs layers that were developed with deep learning models were combined into a single feature class called Impervious. A Type field was created and symbolized for three different types of impervious surfaces; roof, road and lots (**Figure 4**).

Figure 4. Example of Completed Impervious Surface Mapping.

Due to the high quality of the imagery and required parameters for image inputs into the deep learning tools, the 2021 imagery was delineated first. From the outputs of the 2021 automated processing and needed manual delineation, the 1984 delineation was then completed. This was done by comparing the mapped impervious surfaces from the 2021 images that were digitized earlier and removing, reshaping or adding areas of imperviousness in the 1984 images (**Figure 5**). The deep learning tools and models would not extract impervious features from the 1984 images because of the low resolution of the images. Additionally, the low resolution of the 1984 images made it difficult to determine through visual inspection if some roofs, roads and lots should be mapped. In these cases, Google Earth and other collateral datasets were used to help verify the mapping.

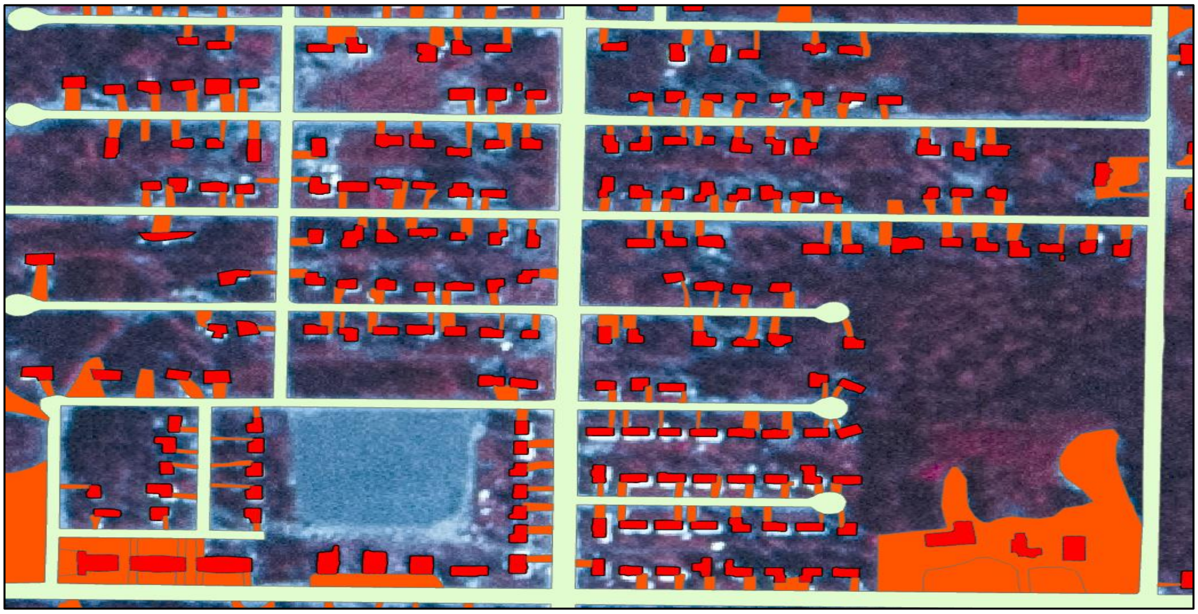

Figure 5. Example of completed 1984 Derived Impervious Surfaces

To find the amount of impervious surfaces per parcel, a parcel layer was added to the map and the Tabulate Area tool was used to generate a table showing the square footage of impervious surfaces per parcel. The table generated from the Tabulate Area tool was then joined to the parcel layer and symbolized to show areas of high impervious vs low impervious. This process was done for both 2021 and 1984 data (**Figure 6**).

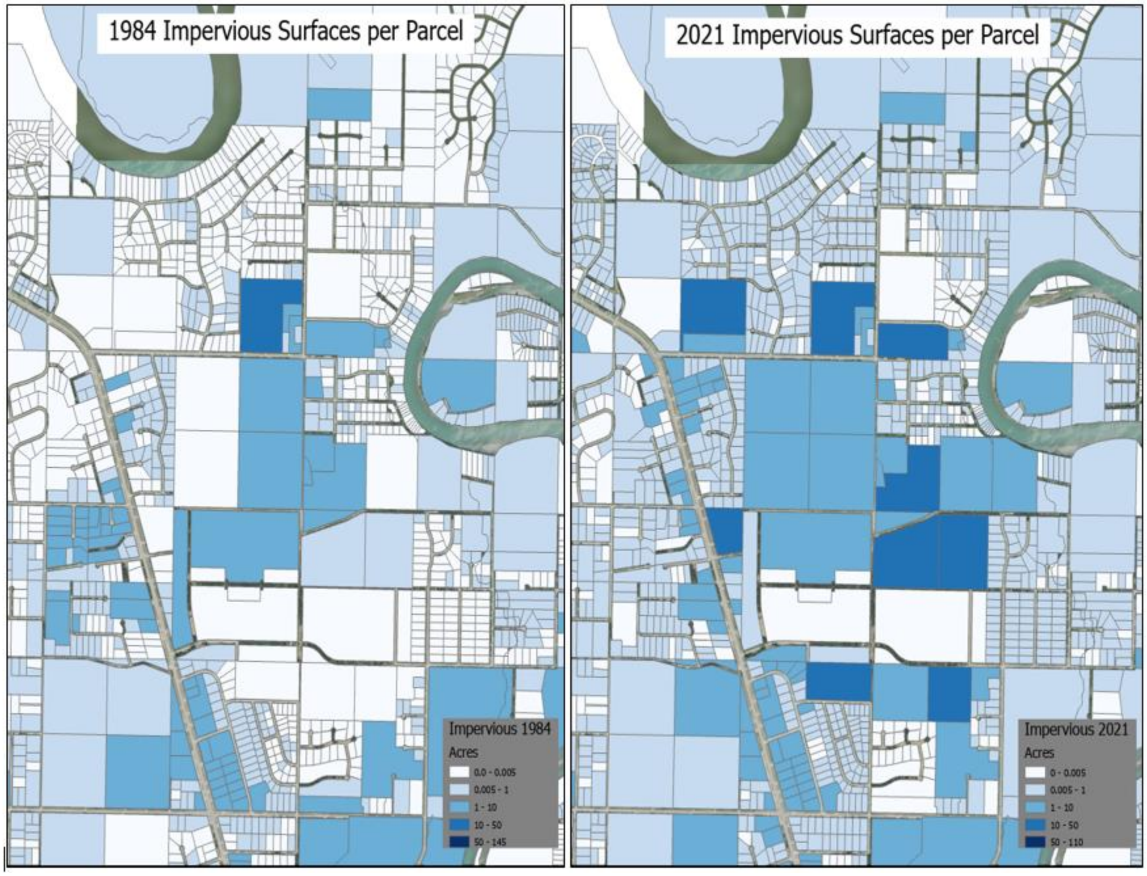

Figure 6. Sample Showing Impervious Surfaces per Parcel in 1984 and 2021.

The delineated impervious surface data for each year was classified into three different types of impervious surfaces; roofs, roads and lots. Using the select by attribute tool, each surface type was selected individually and exported into its own feature class. From these three individual feature classes, a statistics table was generated and a further table was created to compare the statistics of each type of impervious from each year. To visually show the contrast between the amount of 1984 impervious surfaces and the 2021 impervious surfaces, the Erase tool was used to remove all the digitized areas from the 1984 data that overlapped the 2021 data.

The image in **Figure 7** shows a sample of the output from the Erase tool. The green polygons, overlaid on the 1984 imagery, highlight impervious surfaces from 2021 that are not present in 1984. The image indicates that there has been a large increase in impervious surfaces though housing developments and commercial lots.

Figure 7. Sample of Erase Tool Output.

Results

Population on the Kenai Peninsula has been growing steadily since the 1980's. Between 1980 and 2020 the population has grown by 132% over that time period (**Figure 8**). With the influx of people moving into the Kenai Peninsula, impervious surfaces have increased by 22% in that same time frame. With the increase in impervious surfaces, runoff increases threatening the water quality of the rivers, lakes, ponds and other natural resources.

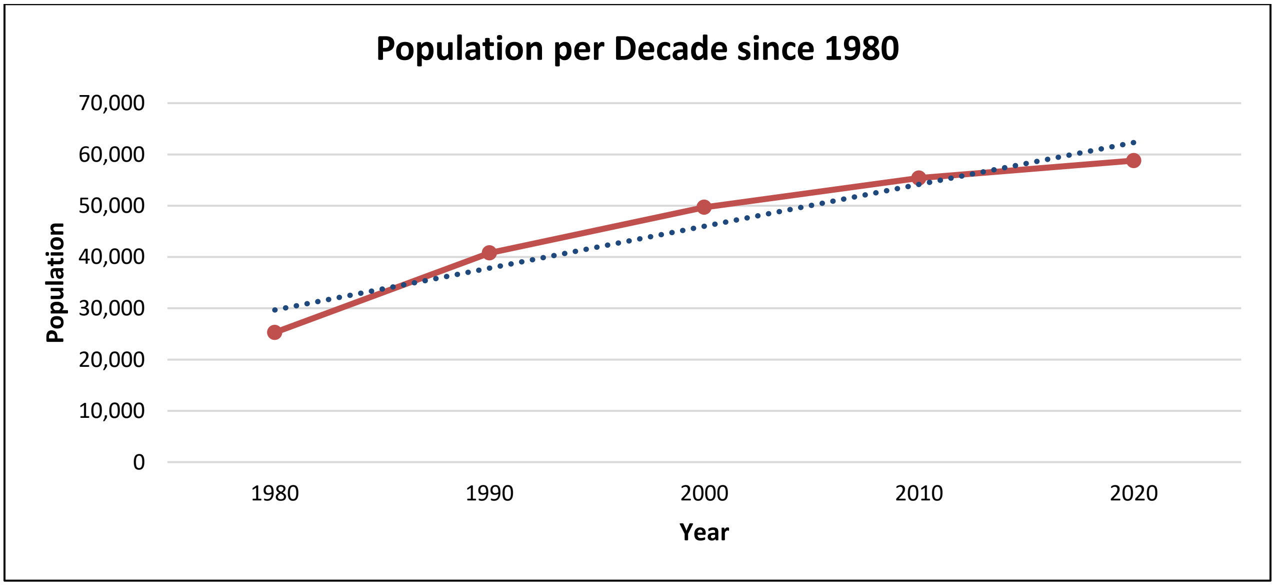

Figure 8. Graph showing the Increase in Population from 1980 – 2020.

Table 1 shows the percent increase of impervious surfaces between 1984 and 2021. The data shows an increase in impervious surface acreage of 22% between the years 1984 and 2021. Between that time the number of impervious surfaces increased by 98% while the average size of impervious surfaces decreased by 40% showing that even though the number of impervious surfaces has increased significantly, the size of impervious areas has reduced by a large margin. This indicates that a large amount of smaller development happened over the timeframe such as the building of houses and cabins. With the population of the Kenai Peninsula growing by 33,517 people or 132% since 1980, the need for housing has increased.

Table 1. Percent Change of Impervious Surfaces (1984-2021)

Year	Mean (Acres)	Median (Acres)	Sum (Acres)	Count
1984	0.48	0.04	3,333.00	7,005
2021	0.29	0.04	4,044.70	13,820
Percent Change	**-40%**	**4%**	**22%**	**98%**

Table 2 shows the percent change of roofs in the study area. Size of the roofs have decreased by an average of 6.25%, with a 112.74% increase in the number of roofs. With the number of roofs increasing, the total acreage of roofs has increased by 100.29% in the study area.

Table 2. Percent Change of Roofs (1984-2021)

Year	Mean (Acres)	Median (Acres)	Sum (Acres)	Count
1984	0.064	0.042	241.10	3,775.00
2021	0.06	0.041	482.90	8,031.00
Percent Change	**-6.25%**	**-2.38%**	**100.29%**	**112.74%**

Surface area of roads has increased in the study area with a 3% increase in acreage (Table 3). With the increase of housing and housing complexes, more roads were constructed for access. With the increase in roads and more impervious surfaces, runoff could increase, but that is out of the scope of this study. Roads proved difficult to distinguish in the 1984 image because of the low resolution of the image and the tree canopy covering service roads and dirt roads that may be present but could not be identified through collateral data.

Table 3. Percent Change of Roads (1984-2021).

Year	Mean (Acres)	Median (Acres)	Sum (Acres)	Count
1984	27.90	0.74	892.90	32.00
2021	40.00	1.76	919.00	23.00
Percent Change	**43%**	**138%**	**3%**	**-28%**

Figure 9 shows a developed location in the study area where mapped impervious surfaces from 2021 were overlaid on the 1984 image. This area shows a housing development that was built between the years of 1984 and 2021. As shown above, new construction includes new roads, driveways and houses. This type of construction is common across the study area in 2021, as more people are moving to the Kenai Peninsula.

Figure 9. Example of Housing Development Not Present in 1984.

Figure 10 shows impervious surfaces for 1984 (purple) and 2021 (yellow). The two layers were overlapped to show the difference between the two years. The biggest areas of growth took place in the central and eastern part of the study area. This was mostly due to housing developments constructed for the influx of people moving into the study area and the Kenai Peninsula as a whole.

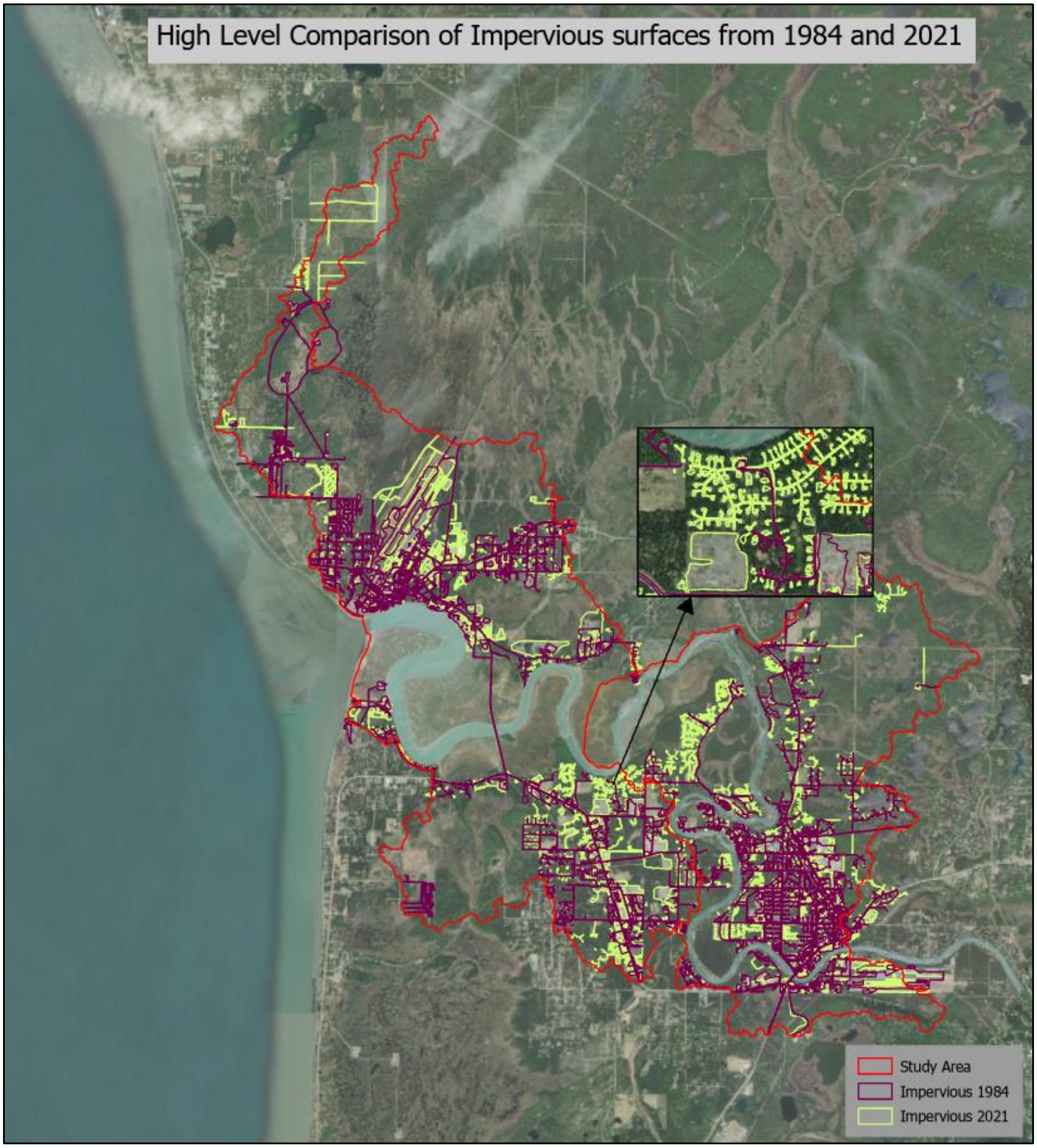

Figure 10. Overview Map of Impervious Surfaces from 1984 (Purple) and 2021 (Yellow)

Conclusion

With the increase of people moving to the Kenai Peninsula, more development was required to accommodate this trend. With the increase in population, impervious surfaces also increased. This study's aim was to map the impervious surfaces from 1984 imagery and 2021 imagery in the defined study area and compare the amount of impervious surface change between those time periods. The study found that impervious surfaces increased by 22%, with the majority of that increase in the form of new housing developments. Roads and lots also increased by a significant margin between the two periods.

With the increase in impervious surfaces, it stands to reason the amount of runoff from non-point pollution sources increased as well. These non-point pollution sources include parking lots, roof runoff, roads, construction sites and residential yards. Chemicals from these non-point pollution sources get washed into rivers, lakes and streams during rain events and can cause damage to the ecology, hydrologic system and the economy if not managed.

There were a few issues encountered when performing this analysis. The low resolution of the 1984 imagery prevented a deep learning model or supervised classification model to be performed. In some locations, the 1984 imagery's low resolution also inhibited manually digitizing the features due to a lack of distinct features and clear boundaries. Another issue that arose during the study was that the processing power of the computer used to do the deep learning analysis would not allow the inclusion of all imagery needed to cover the project area at one time. The study area had to be split at the watershed level to be able to run the deep learning models. The pre-trained detect building footprint model did not pick up irregular-shaped roofs which required them to be manually digitized. These buildings included shopping centers, hospitals and storage sheds. The model was retrained with those irregular building footprints and run again.

Considerations for future studies include the continuation of mapping impervious surfaces throughout the Kenai Peninsula. With the number of people moving to the Kenai Peninsula, mapping impervious surfaces becomes more significant in order to mitigate run off from non-point pollution sources. The impervious surface GIS layers created from this project fill a data gap that can be used for watershed analysis to help identify "problem" areas and management of watersheds.

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