



# West Nile Virus Outbreak Prediction **Chicago**

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# Table of contents

**01**

Background

**02**

Methodology

**03**

Exploratory Data  
Analysis

**04**

Modelling

**05**

Cost Benefit  
Analysis

**06**

Recommendations



# 01

# Background



# Background

The Chicago Department of Public Health (CDPH) runs a surveillance program annually to keep mosquito count low and to protect its residents from the West Nile virus (WNV).




# Challenges faced

- Chicago ranked in the Top 5 US cities, with highest no. mosquitoes in 2021
- Priority shifted towards fighting COVID-19
- Tightening of funds due to looming economic recession






# Problem statement



Build a model with **more than 70% recall** to predict the **period and location where mosquitoes will test positive for WNV**, enabling CDPH to preemptively allocate the city's spraying resources to curb the virus transmission.



# Transmission of West Nile virus

- West Nile virus (WNV) is a vector-borne pathogen, carried and spread by *Culex Pipiens* mosquito species
- WNV passed through a transmission cycle between infected birds and mosquitoes
- Eventual spread to their incidental hosts through the mosquitoes

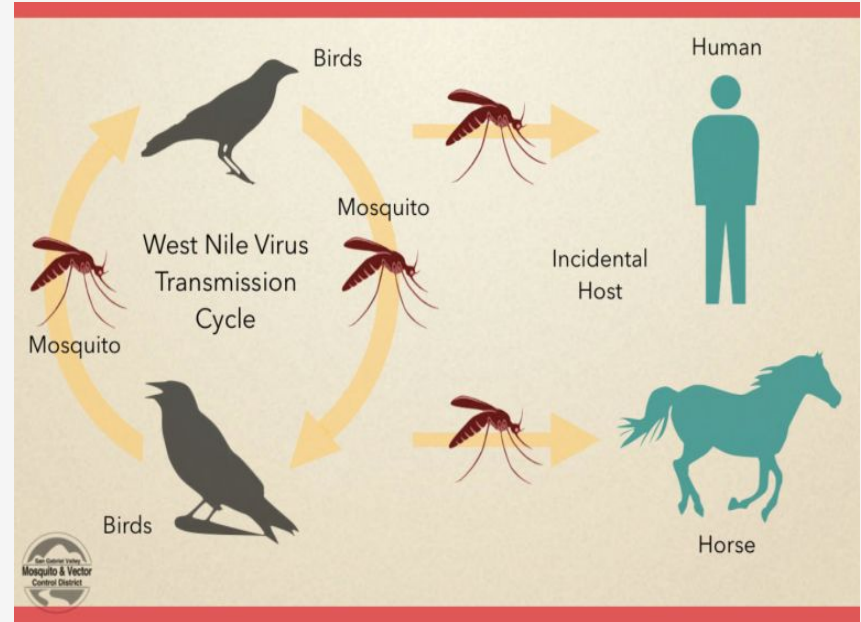
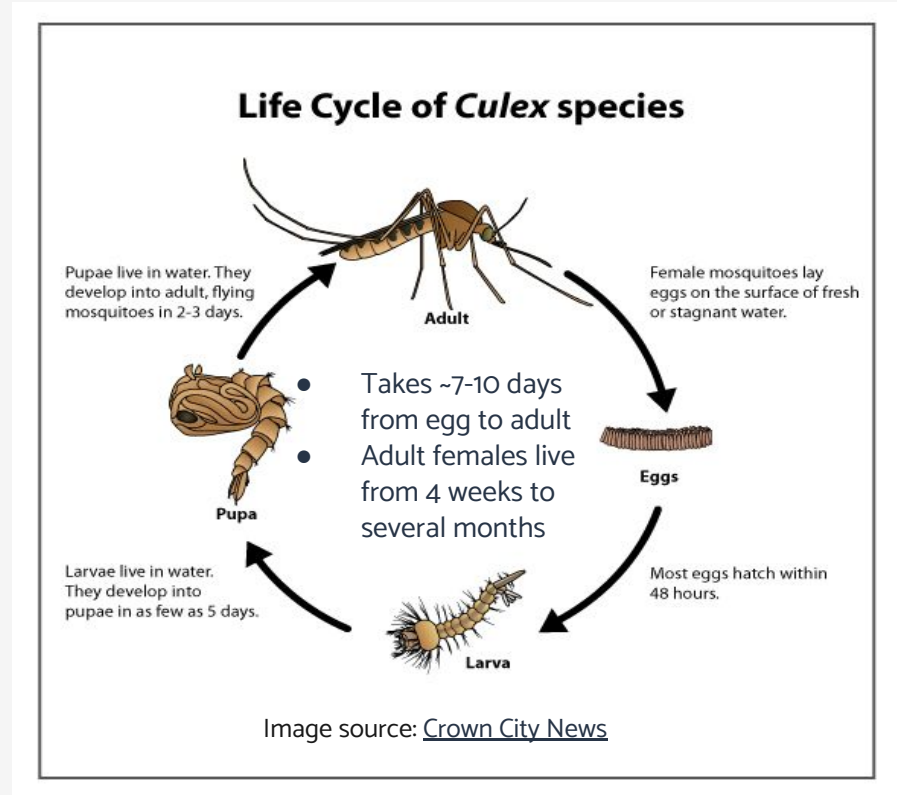


Image source: [Crown City News](#)

# Life cycle of Culex Pipiens







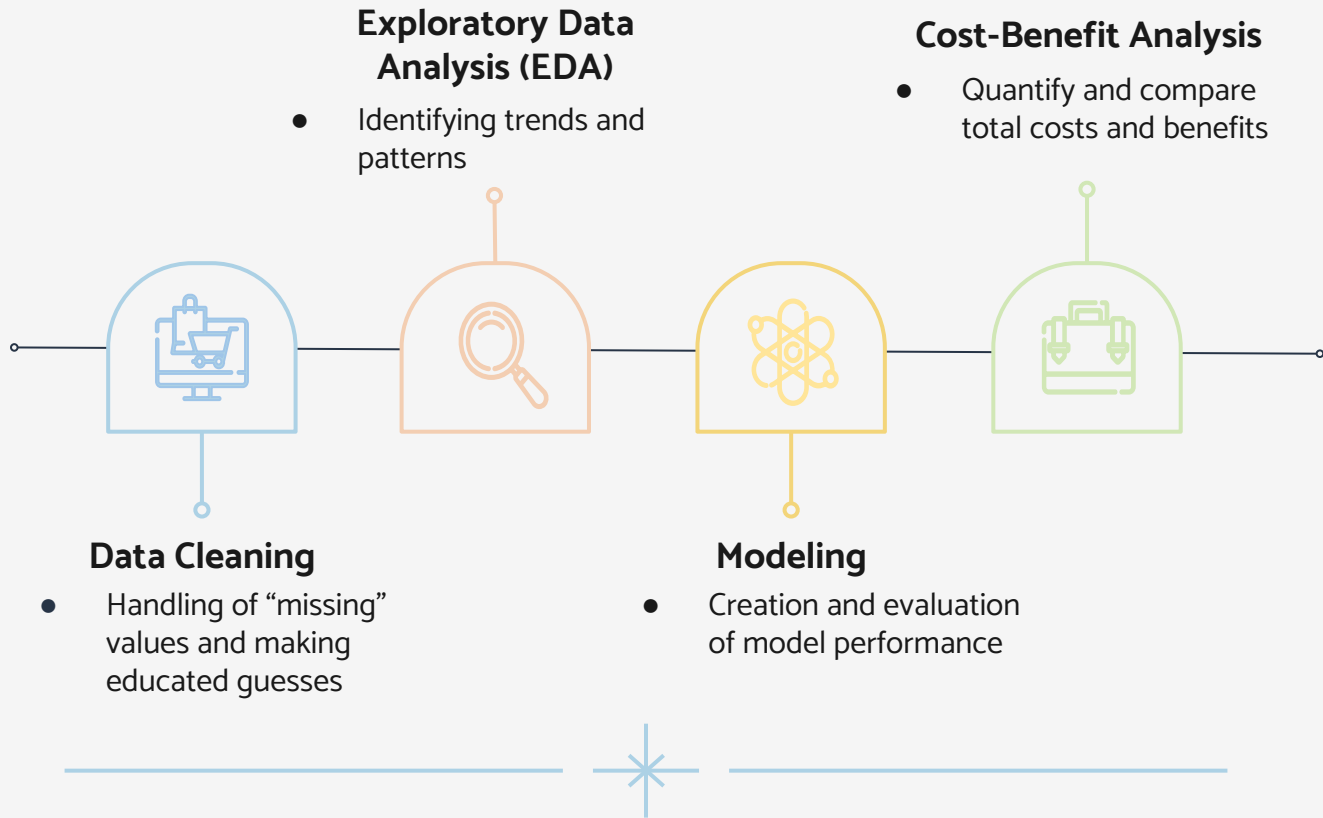
# 02

## Methodology





# Overview of workflow





03

# Exploratory Data Analysis



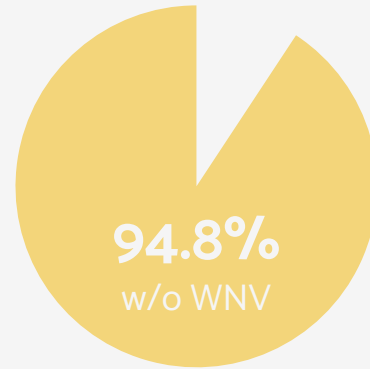
# Overview of the datasets

Data period (May - Oct):

- Information of mosquito traps (Year 2007, 2009, 2011, 2013)
- Spray records (Year 2011, 2013)
- Weather readings (Year 2007 - 2014)

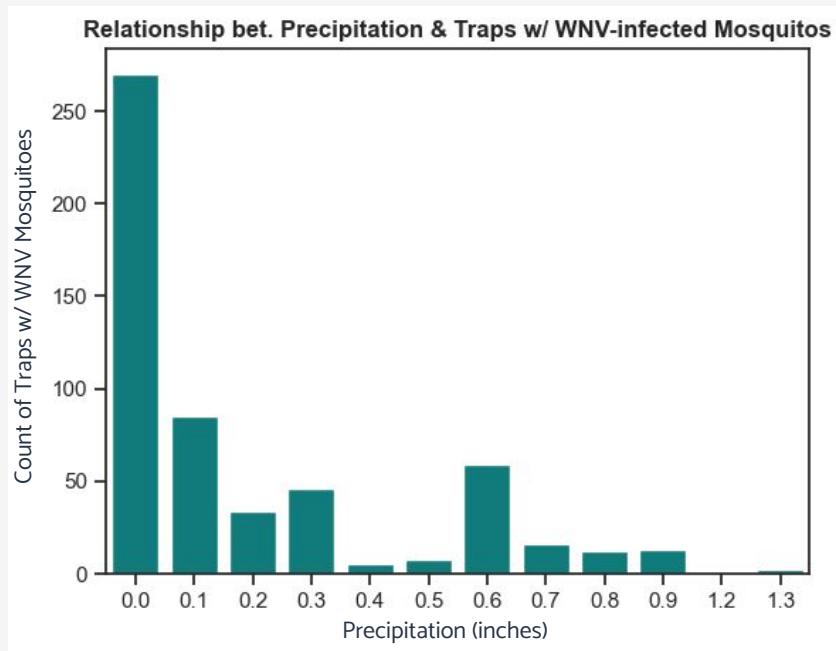
Processing of weather dataset:

- 7-day rolling average (to align with mosquito life cycle)



Class imbalance with 94.8% of data points (105,06) classified as negative case

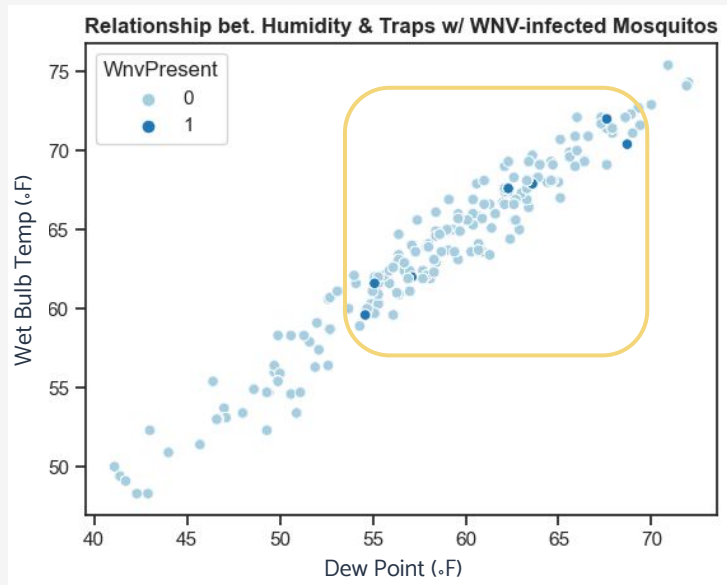
# Presence of WNV-infected mosquitoes in low precipitation during the warmer seasons



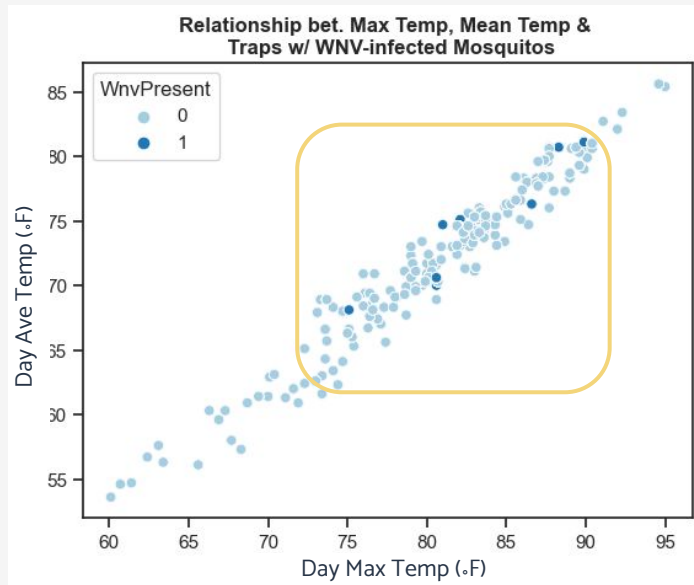
Data information: (1) Period: 2007, 2009, 2011, 2013; (2) 7-day rolling average was applied to Precipitation

- Precipitation (0 inch) accounted for 50% of the data points
- Average precipitation recorded: 0.1-0.2 inches
- Precipitation may not play a key role in facilitating the breeding of mosquitoes in Chicago

# More WNV-infected mosquitoes in higher humidity and temperature



High humidity is optimal for mosquitoes to breed

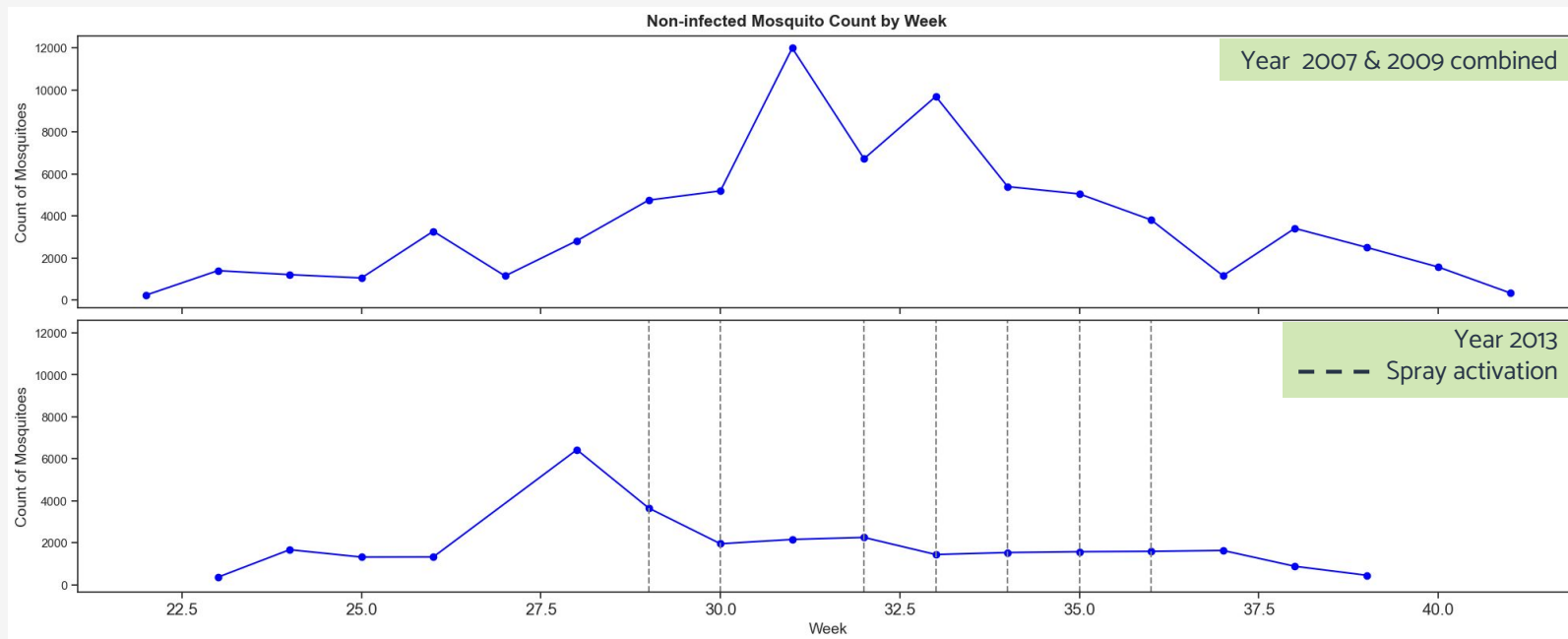


Higher temperature (from 16°C to 32°C)\* accelerated mosquito population growth

- High humidity leads to increased Dew Point and Wet Bulb temperatures.
- Data information: (1) Period: 2007, 2009, 2011, 2013; (2) 7-day rolling average was applied to the variables

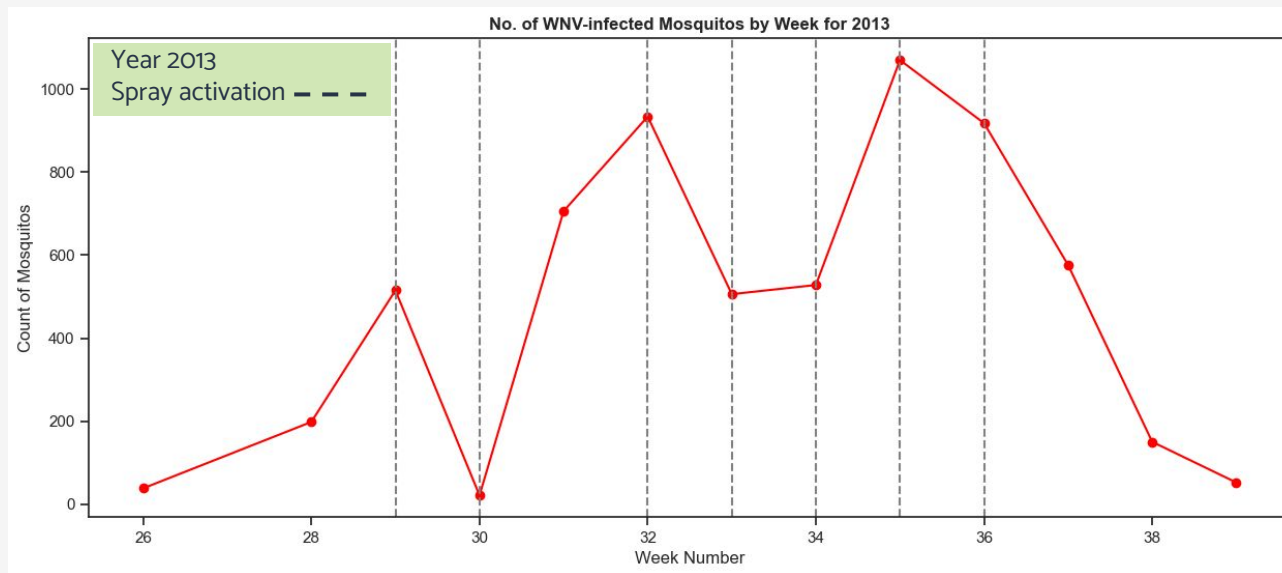
\*Source: Goutam Chandra, Devaleena Mukherjee, in *Advances in Animal Experimentation and Modeling*, 2022

# Spraying helped reduce mosquito population



- Without spraying, mosquito population peaked around Week 31
- After spraying around Week 30 period, there was a decline followed by a plateau in the mosquito population

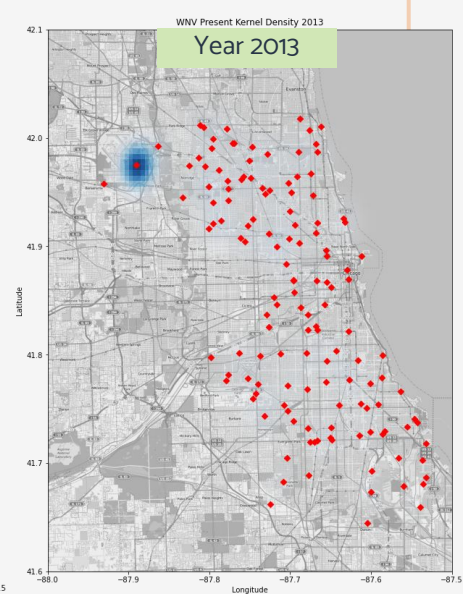
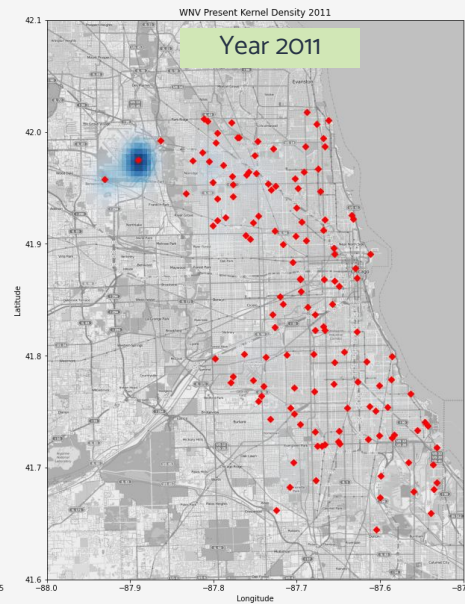
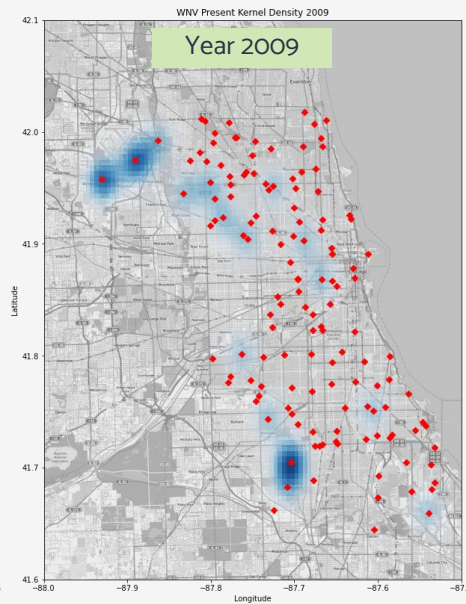
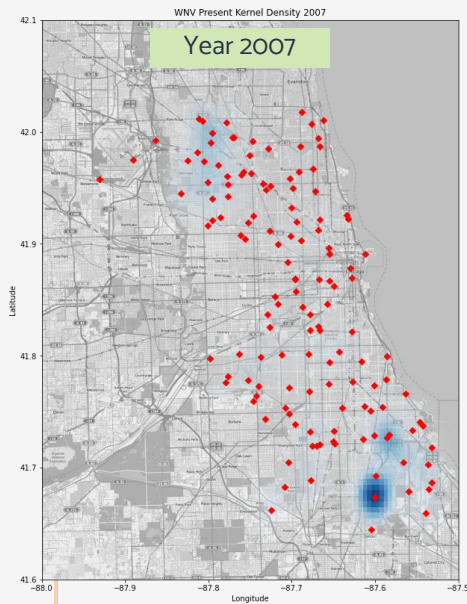
# Spraying was not consistently effective in managing WNV-infected mosquitoes



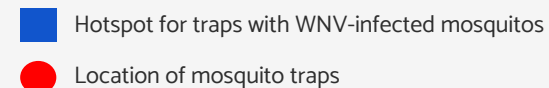
- There was no significant effect on the number of infected mosquitos after each spray
- Takes a while for spray to work; may need to look at spraying earlier and more frequently



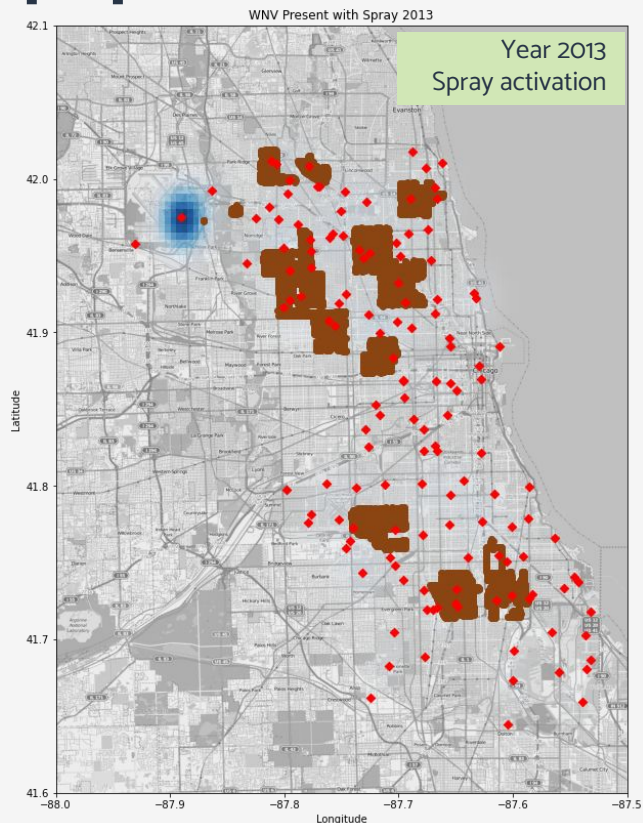
# Hotspots for WNV over the years



- Hotspots occurred at different locations - important to identify them ahead of time to deploy timely interventions



# Targeted spraying is needed to help control population of WNV-infected mosquitoes



- In 2013, spraying was conducted in various areas with mosquito traps. This could have prevented them from being WNV hotspots
- The WNV hotspot area is situated within the O'Hare International Airport compound where it was not covered by the spraying efforts

- Hotspot for traps with WNV-infected mosquitos
- Areas with spray conducted in 2013
- Location of mosquito traps

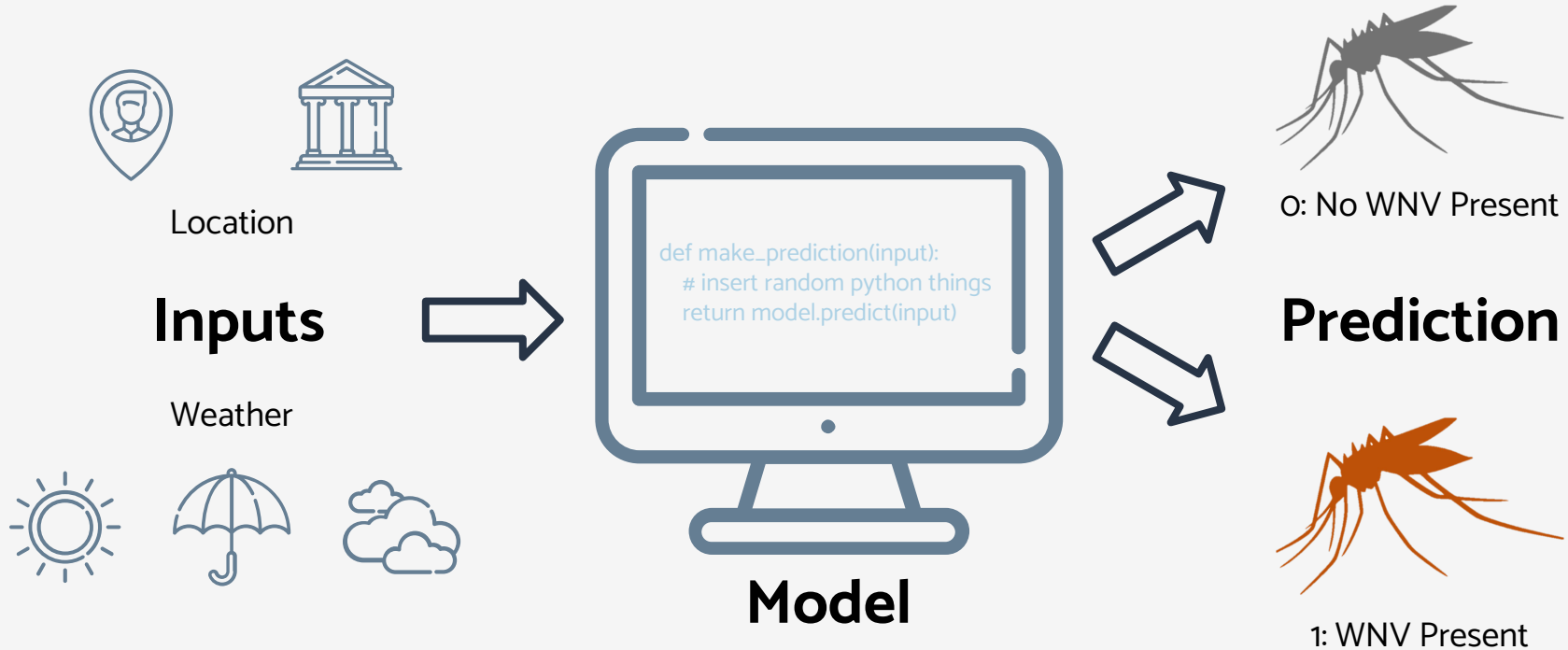


# 04

## Modelling & Evaluation



# Classification model



# Features

## 40 Features

Weather, Location, Time Period



## Binary Target

1: WNV Present

0: No WNV



## Train-Validation Split

Stratified by target due to imbalance



# GridSearchCV pipeline



## 1. Vectorisation

OneHotEncoder to vectorise categorical features

## 2. Scaling

MinMaxScaler to scale our features between (0, 1)

## 3. PCA

Principal Component Analysis to reduce dimensionality and collinearity

## 4. Sampling

SMOTE Tomek to address class imbalance

## 5. Classification

Train classification model to predict the binary outcome

# Model selection

## Class Imbalance

Accuracy is not an ideal metric  
Compare performance using ROC AUC

## ROC AUC

Measures the ability of model to distinguish between classes

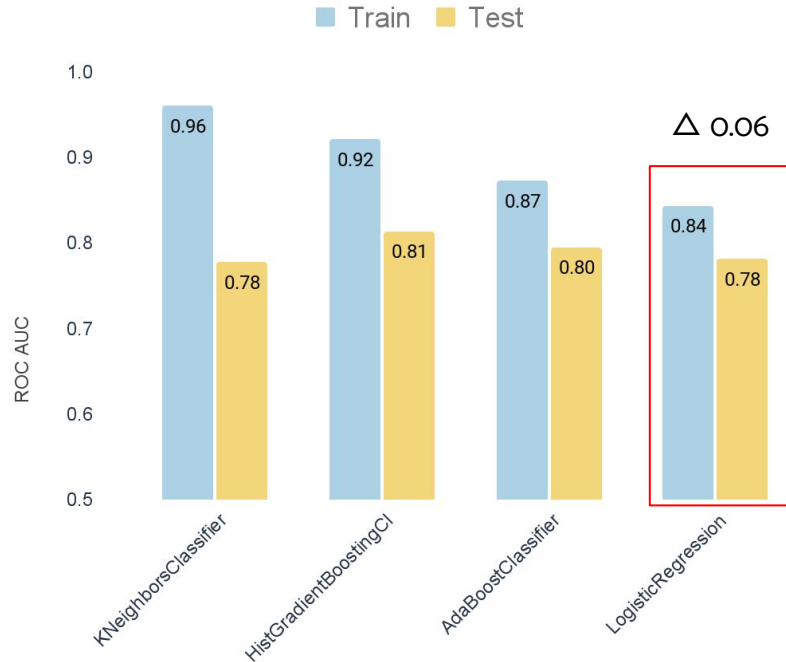
✗ 0.5 = model with random guesses

✓ 1.0 = model which is 100% correct

## Generalizability

Minimise the variance between our Train and Test scores

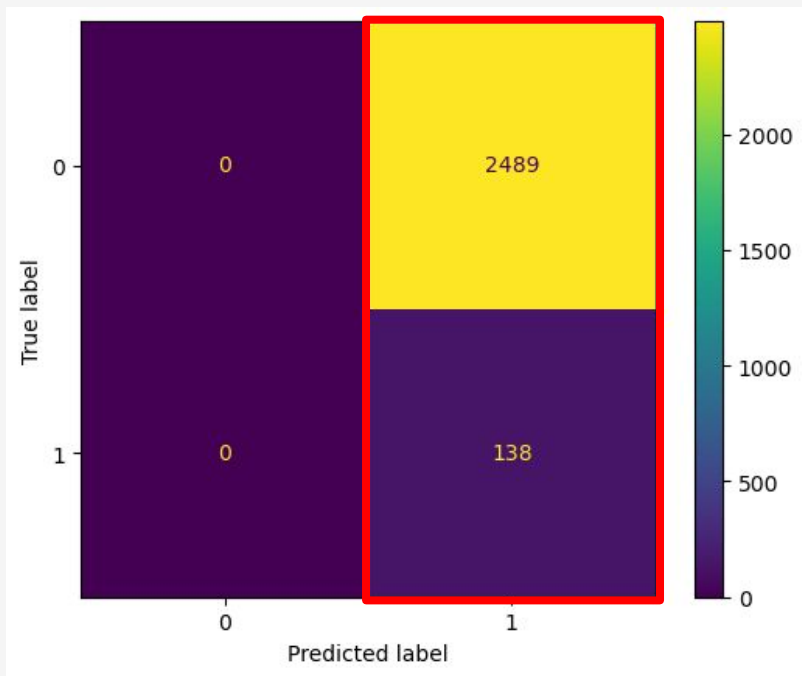
Model Performance (ROC AUC)





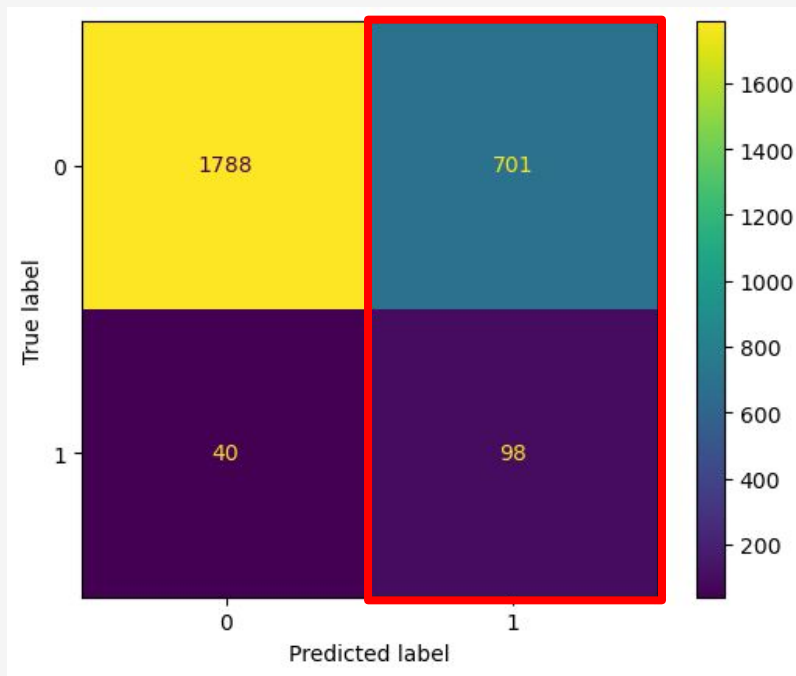
Perfect Metric : 1.0

Baseline (All Predictions 1)



ROC AUC : 0.50  
Precision : 0.05  
Recall : 1.00

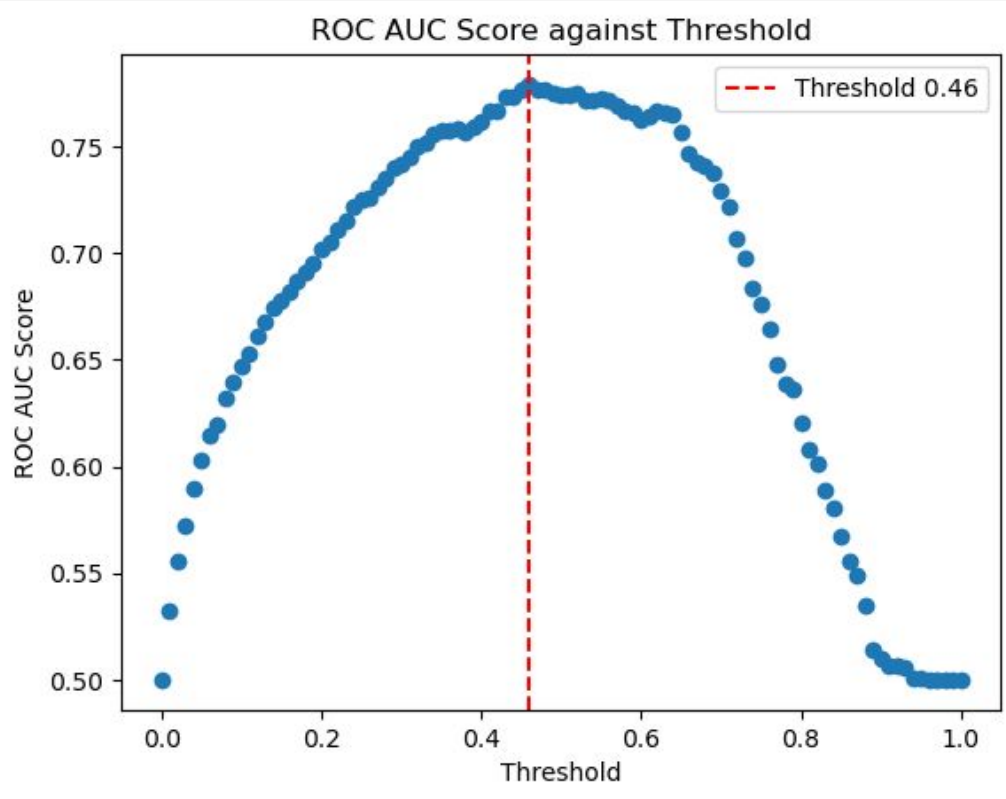
Logistic Regression Model



ROC AUC : 0.78  
Precision : 0.12  
Recall : 0.71



# Model optimisation



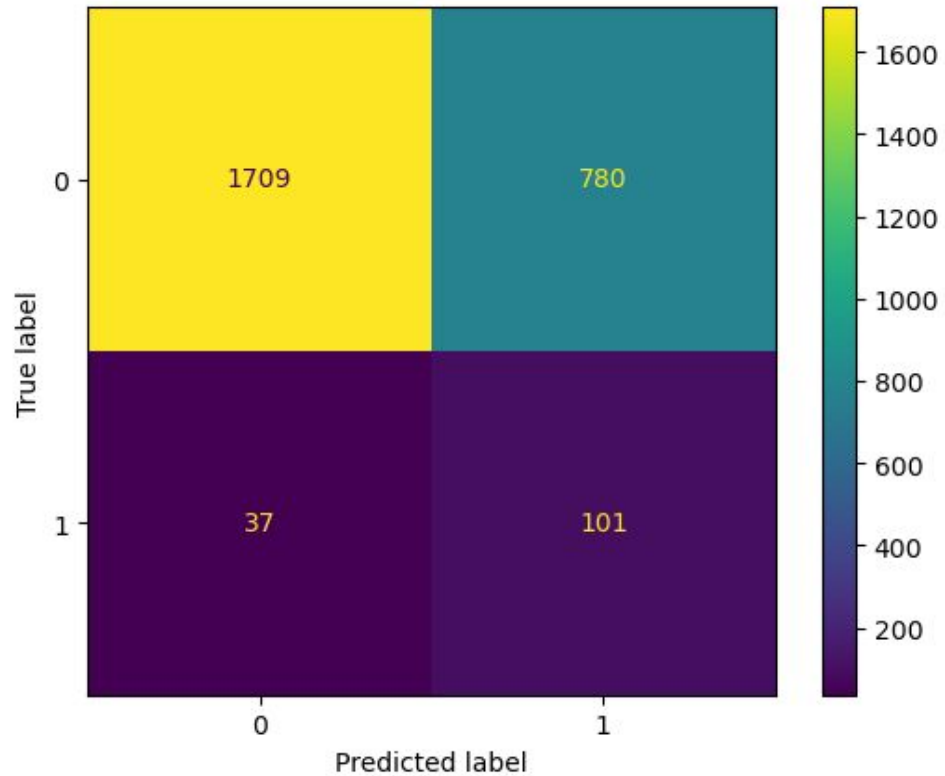
## Prediction Threshold

Checked for ROC AUC across various prediction thresholds

Optimal ROC AUC when threshold is set at 0.46



# Optimised model



## Recall score of 0.73

Adjusting the threshold allows us to maintain a Recall of 0.73, while reducing the number of false positives compared to a blanket prediction



**05**

# **Cost-Benefit Analysis**



# Existing surveillance program



## Location

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- Areas where WNV-infected mosquitoes have been detected
- 



## Time

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- At night when most mosquitoes are active
- 



## Material

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- Utilizes Zenivex E4
  - Effective in killing adult mosquitoes
-

# Costs for consideration

## Spray

67 cents per acre\*, leading to:

- \$100k for entire Chicago city limits
- \$4-5k for up to 4 neighborhoods



## Productivity loss

\$2,136 median^ loss initially  
\$6,771 median^ long-term loss



## Initial medical costs

Median \$4,617^ for less severe cases  
Median \$25,117^ for more severe cases



## Long-term medical costs

Up to an average of \$49,163^ in follow-up consultations and medical fees



*\*Taken from Zenivex flyer*

*^ Taken from Initial and Long-Term Costs of Patients Hospitalized with West Nile Virus Disease*

# West Nile virus human cases

These figures include Chicago, Cook and DuPage counties. Approximately 66% of the positive human cases are in Chicago.

Year	Number of human cases	Number of pools tested	Number of positive pools	Total number of mosquitoes tested
2005	181	7,165	1,939	271,235
2006	129	9,428	1,984	318,386
2007	43	12,131	1,259	375,520
2008	10	9,024	587	298,995
2009	1	9,450	298	311,220
2010	47	11,491	2,086	393,279
2011	24	8,911	939	287,774
2012	229	10,162	3,182	323,497
2013	66	11,078	1,967	407,326
2014	31	9,273	990	333,489
2015	36	7,725	1,046	314,363
2016	108	6,144	1,687	219,909

Maximum number of human cases in Chicago is 66% of 181: **119\***

*\* Average figure omitted because of lower no. pools tested*

Average human cases with spraying efforts is 66% of 82: **54**

# Option 1: Spray entire city area

**0**

Approximate no. positive human cases

**USD 1,206,740**

To spray the entire city once a week,  
from July to September

**USD 0**

Estimated initial and long-term  
medical cost and productivity loss



**USD 1,206,740**

Total cost & expenditure

- Costly spraying approach
- Likely harmful for the environment with the frequent spraying
- May harm residents with sensitive skin and sense of smell
- Limitation in identifying hot spots
- No guarantees that this will eliminate positive human cases

# Option 2: No spray at all



**119**

Approximate no. positive human cases

**USD 0**

To spray the entire city once a month,  
from July to September


**USD 5,681,655**

Estimated initial and long-term  
medical cost and productivity loss



**USD 5,681,655**

Total cost & expenditure

- Most costly approach
  - Higher risk of contracting WNV
  - Puts more lives at risk
- 



# Option 3: Targeted spraying

**15\***

Approximate no. positive human cases

**USD 50,105**

To spray 3-4 targeted locations once a week, from July to September

**USD 696,122**

Estimated initial and long-term medical cost and productivity loss

**+USD 460,512**

Cost savings from spraying every area of the city



**USD 746,227**

Total cost & expenditure

- Lowest cost approach
- Minimize environmental impact from spraying
- Minimize harm to residents

*\*Calculated using recall score 73% of the 54  
(average no. cases when there's spraying)*

# Cost-benefit evaluation

Recommended

	Option 1 (Spray all)	Option 2 (No spray)	Option 3 (Targeted spray)
No. cases	0	119	15
Weekly spray cost	USD 1,206,740	USD 0	USD 50,105
Medical & productivity cost	USD 0	USD 5,681,655	USD 696,122
Total cost	USD 1,206,740	USD 5,681,655	USD 746,227
Cost savings	-	-	USD 460,512*

\*Cost savings compared to spraying every area of the city



# 06

## Conclusions & Recommendations



# In a nutshell

**Problem statement recap:** Build a model with **more than 70% recall** to predict the **period and location where mosquitoes will test positive for WNV**, enabling CDPH to preemptively allocate spraying resources to curb the virus transmission.



## Model selected:

Logistic Regression Classifier

Train ROC AUC: **0.84**

Test ROC AUC: **0.78**

Recall: **0.73**



## Solution:

Optimise through targeted spraying approach in forecasted WNV present areas

Projected savings: **USD 460,512**

# Taking preventive measures



## Optimizing Insecticide Spray

- Strategically optimise frequency of spraying and target areas



## Insect Repellants & Pesticides

- Install mosquito repellent screens
- Distribute insect repellants and pesticides to each home



## Mosquito Control & Raise Awareness

- Campaigns to educate the public to prevent vector breeding
- More frequent trash collection (especially disposables)
- Alert neighborhoods with recorded WNV presence

# Moving forward



## Data collection

- Keep track of spray data
- Include other external factors, e.g. human cases and bird cases
- Control vs Spray areas



## Weather conditions

- Current weather data is localised to airports
- Central city areas and neighborhoods could have differing conditions

# Thank you!

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Do you have any questions?

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# 07

## Appendix





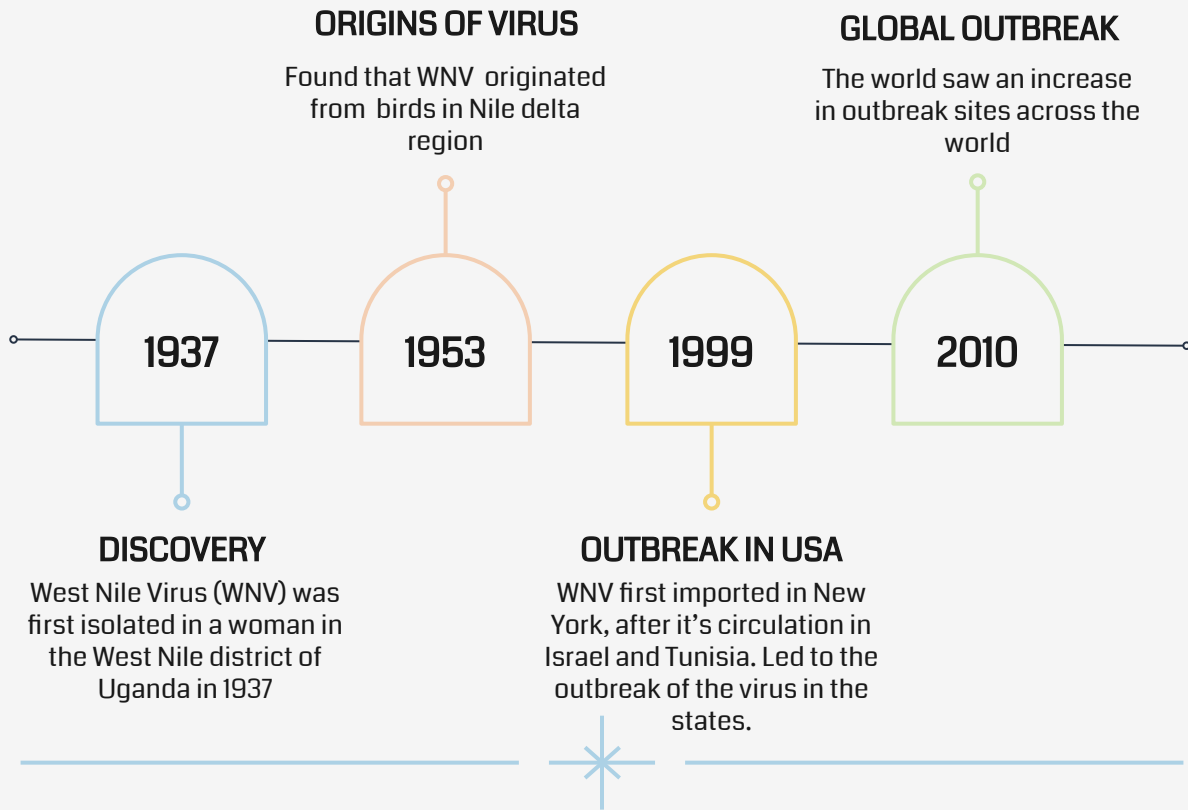
# Our tasks at hand

As part of the Disease and Treatment Agency hired by CDPH, we're tasked to:

1. Analyze the years with more severe WNV outbreak
2. Devise a plan to identify locations which are potential WNV hotspots
3. Optimize the use of the city's funds to curb the mosquito population and subsequently, WNV transmission



# TIMELINE OF WEST NILE VIRUS (WNV)



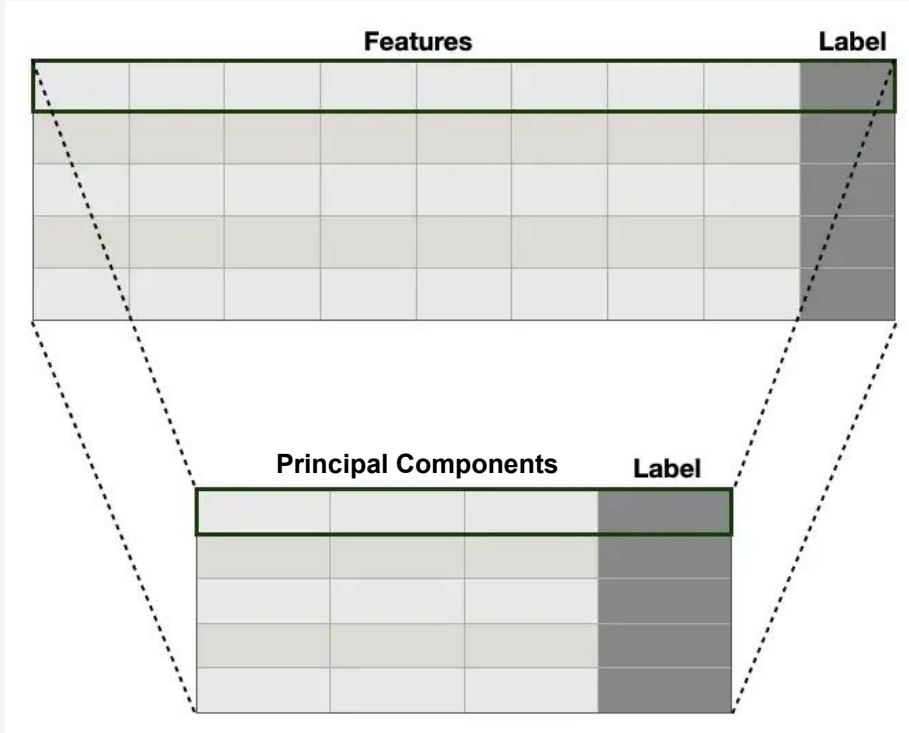


# DATA CLEANING

“Null” Values Replacement	Values Calculation	Dropping columns
<ul style="list-style-type: none"><li>- Replacement with station 1 values. Not expecting too much difference across the stations which were only ~20 km apart, e.g. snowfall</li><li>- Replacement with forward fill method. Not expecting major day to day differences, e.g. Preciptotal.</li></ul>	<ul style="list-style-type: none"><li>- Imputation of station 2 Depart values, by finding 30 year normal temperature for station 1.</li></ul>	<ul style="list-style-type: none"><li>- Dropping columns with only null or 0 values, e.g. depth, water1.</li></ul>



# Principal component analysis



## Reduce Dimensionality

Transforms features into principal components

## Reduce Collinearity

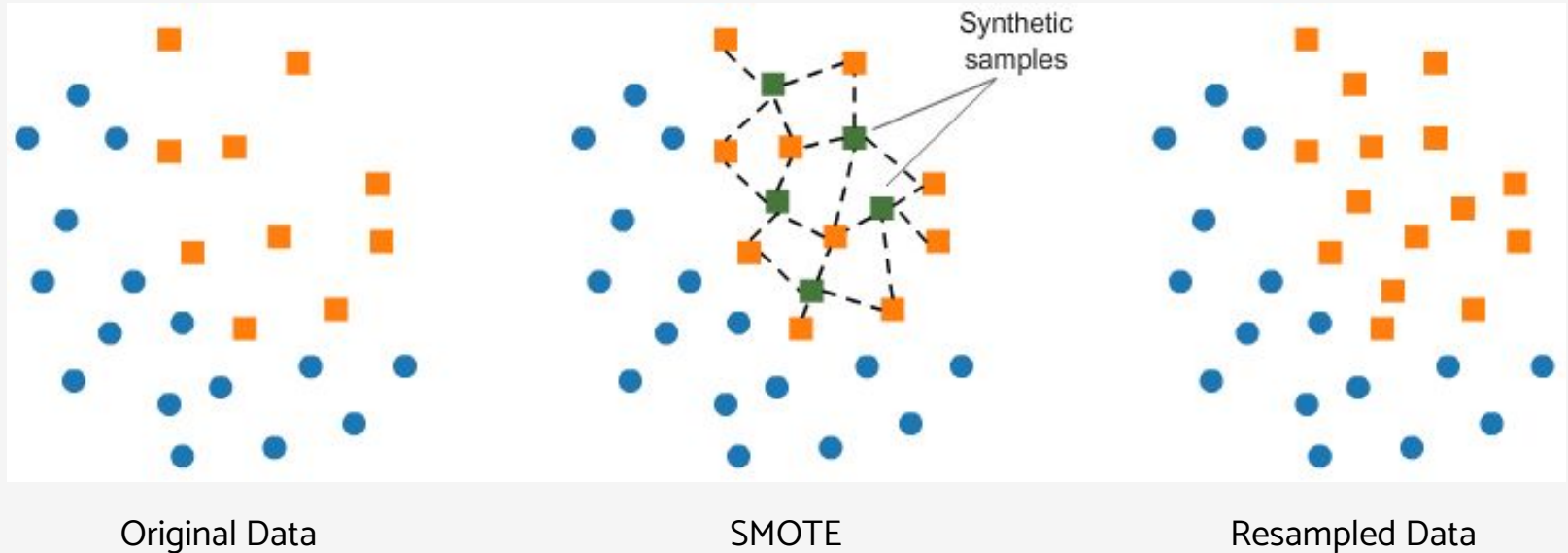
Removes features that are highly correlated

## Reduce Overfitting

Removes unnecessary features

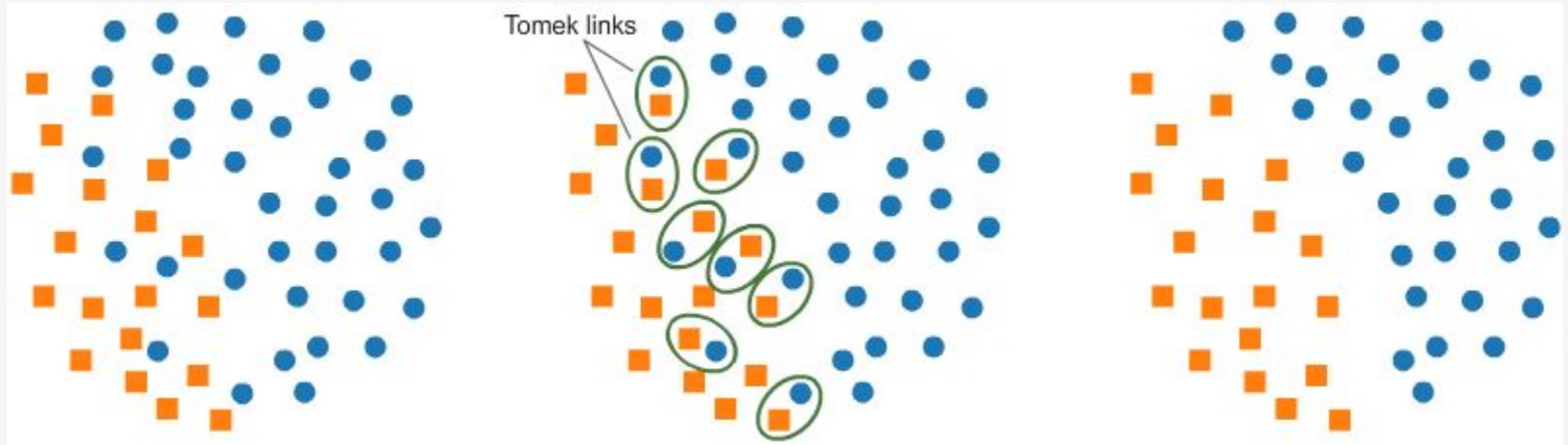
# Over-sampling with SMOTE

- Oversample by creating new synthetic samples for the minority class



# Under-sampling with Tomek

- Tomek links are close pairs of instances of the opposite class
- Removing the majority instance of each pair increases the space between the two classes



Original Data

Tomek

Resampled Data

# ROC

An **ROC curve (receiver operating characteristic curve)** is a graph showing the performance of a classification model at all classification thresholds. This curve plots two parameters:

- True Positive Rate (Recall)
- False Positive Rate

**True Positive Rate (TPR)** is the proportion of the positive class that is correctly classified and is therefore defined as follows:

$$\text{TPR} = \text{TP} / (\text{TP} + \text{FN})$$

**False Positive Rate (FPR)** is the proportion of the negative class that is incorrectly classified by the classifier and is defined as follows:

$$\text{FPR} = \text{FP} / (\text{FP} + \text{TN})$$

A higher TPR and a lower FPR is desirable since we want to correctly classify both classes.

