PREDICTION OF OPTICAL AND NON-OPTICAL WATER QUALITY PARAMETERS IN OLIGOTROPHIC AND EUTROPHIC SYSTEMS USING A SMALL UNMANNED AERIAL SYSTEM

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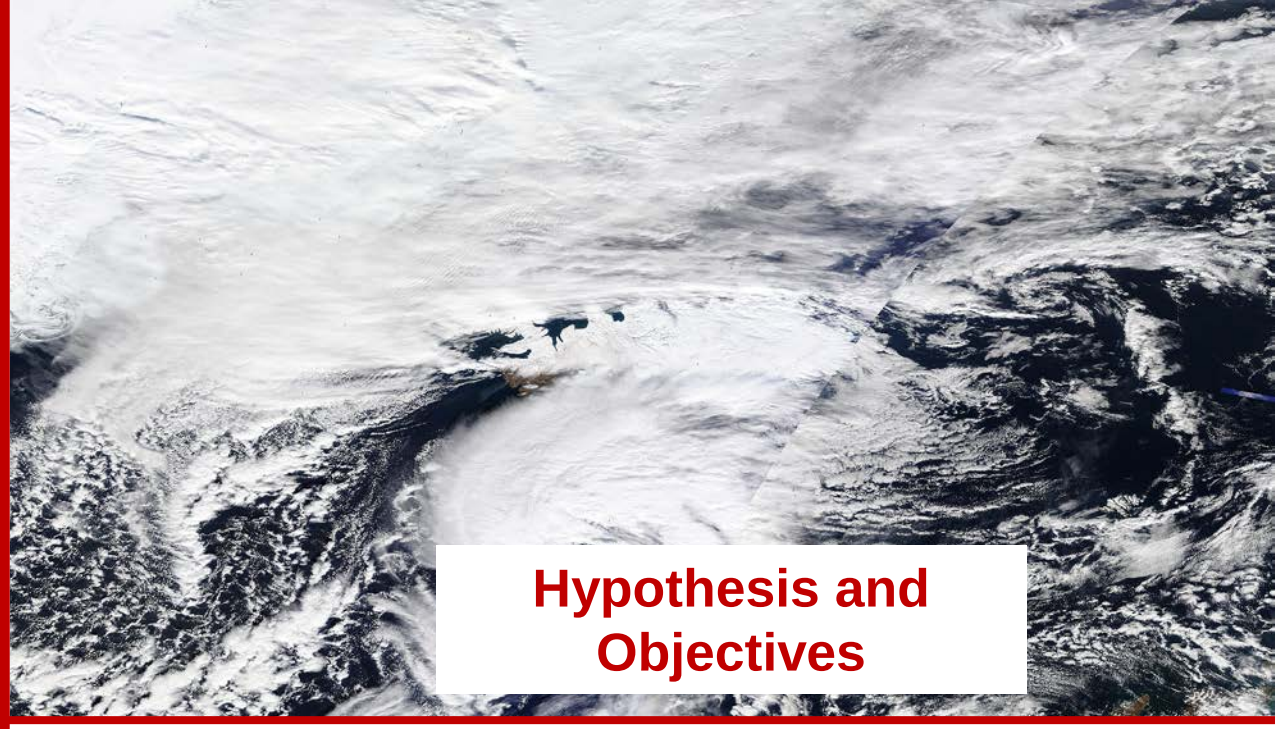
CREW

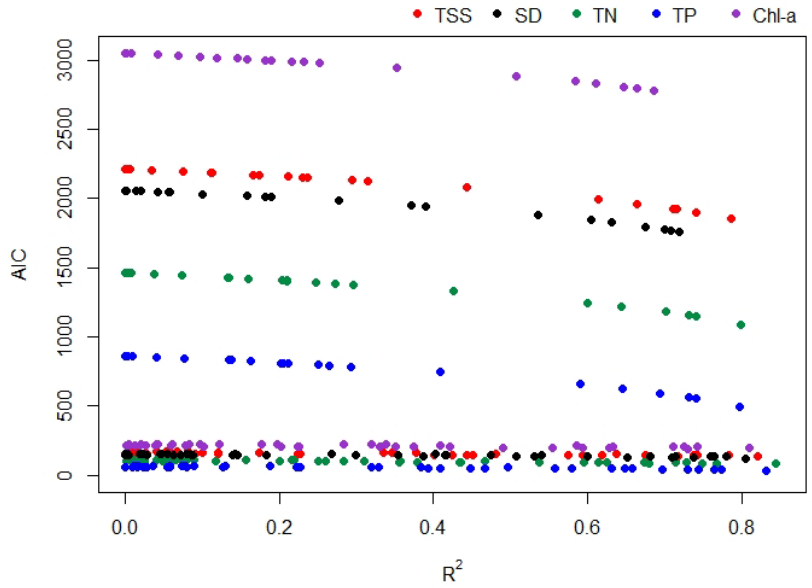
Center for Restoration of Ecosystems and Watersheds
University of Oklahoma

Introduction



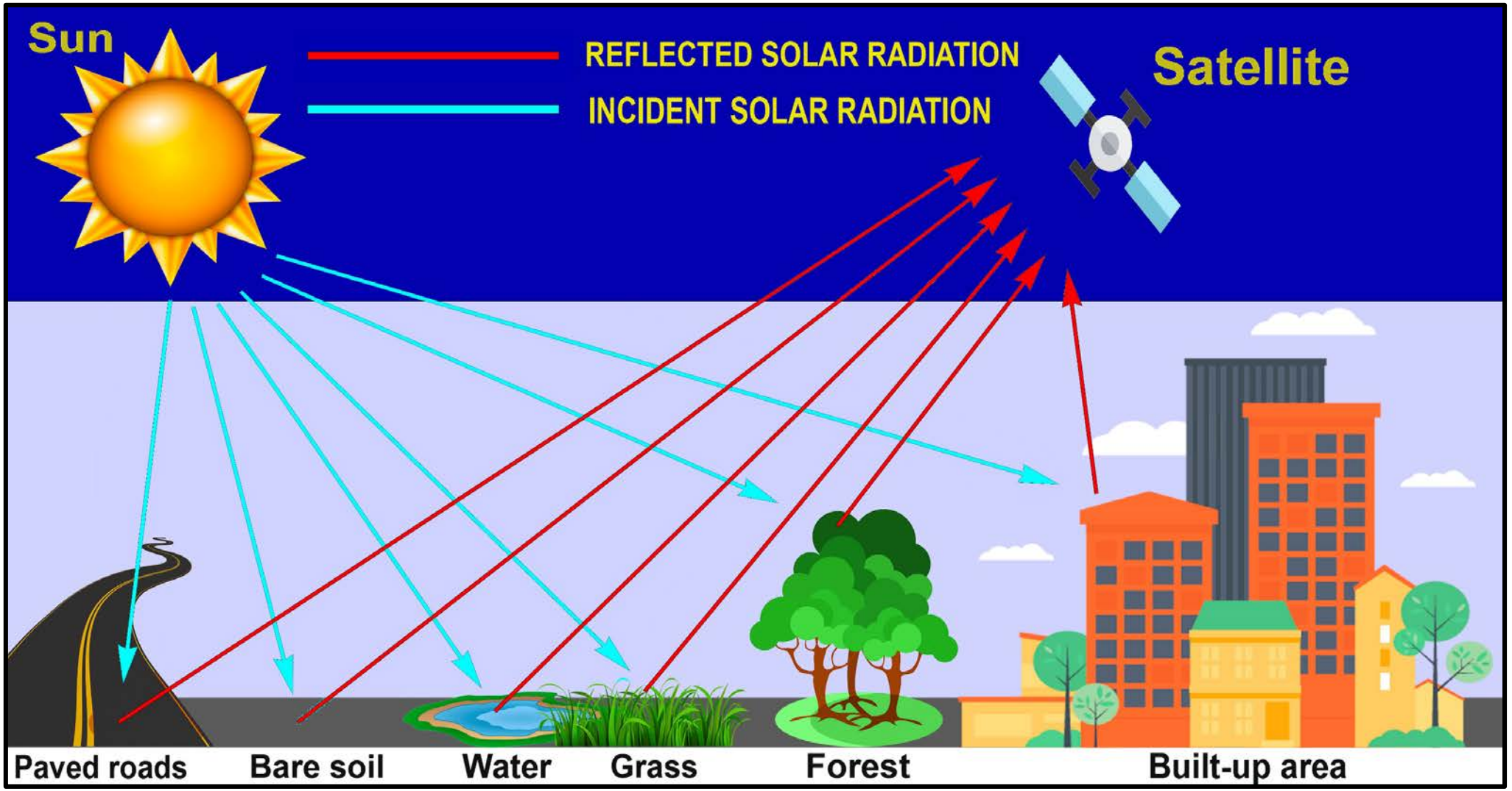
Hypothesis and Objectives

Methodology

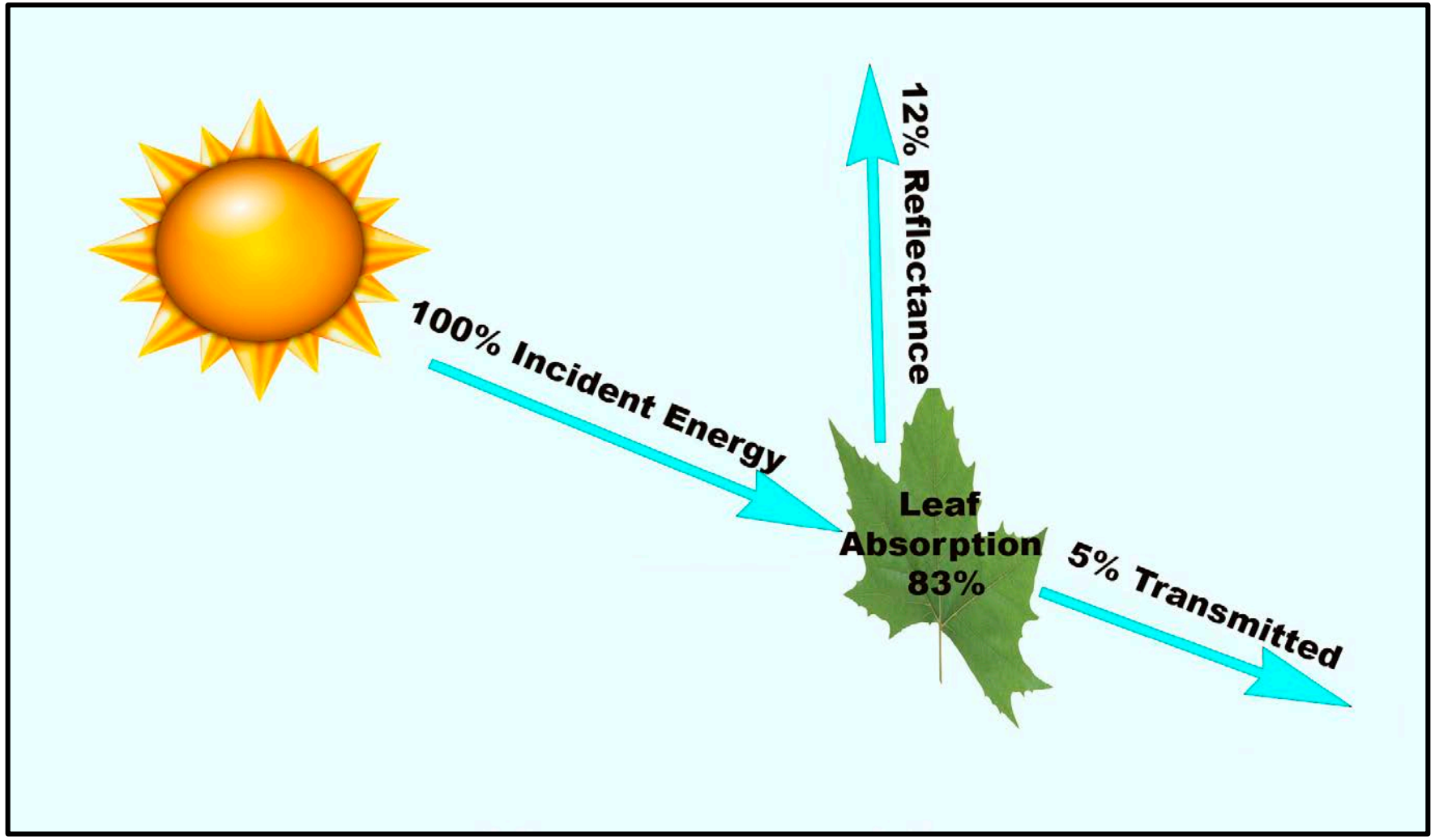


Results

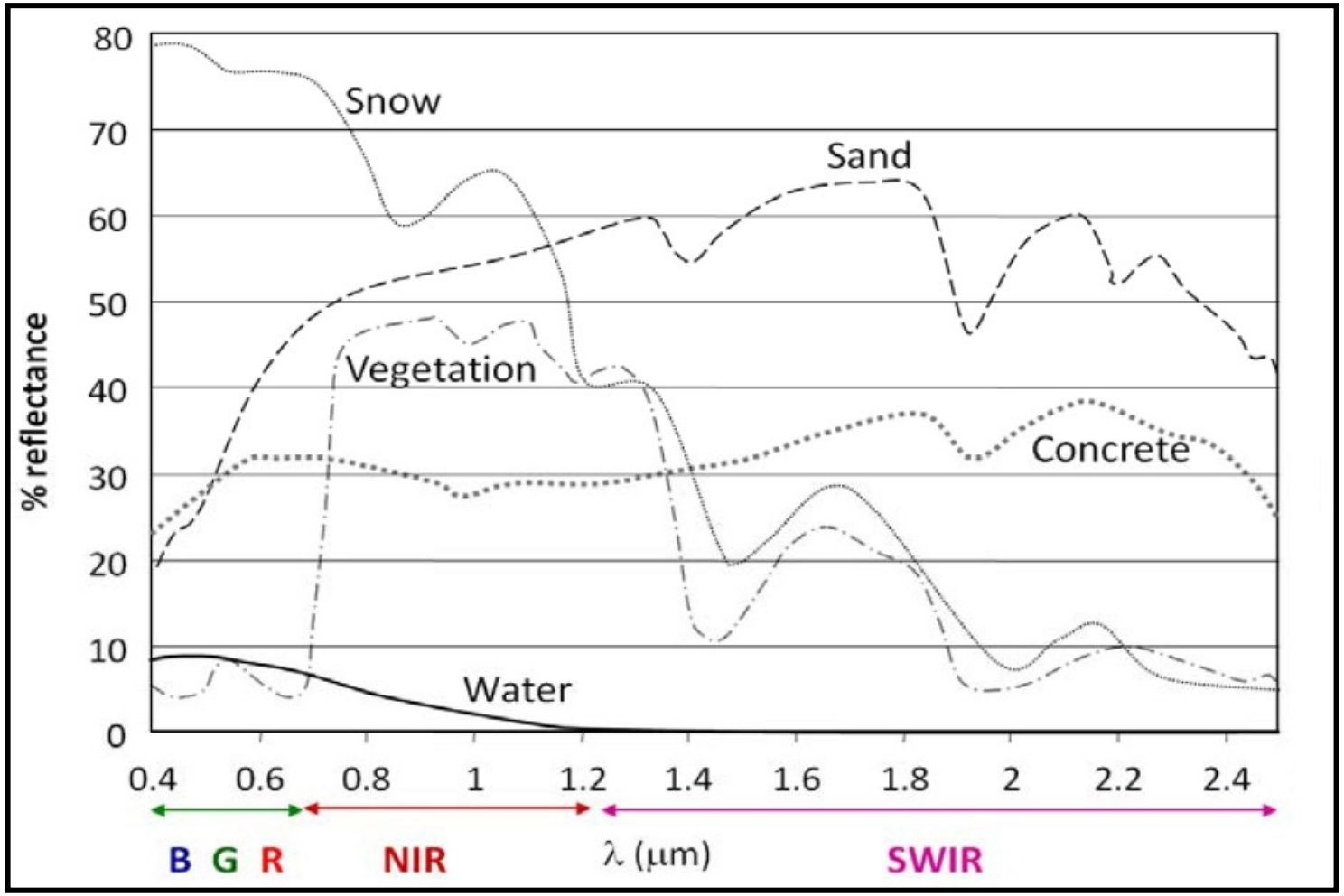
REMOTE SENSING



ENERGY INTERACTIONS WITH TARGETS



SPECTRAL SIGNATURES

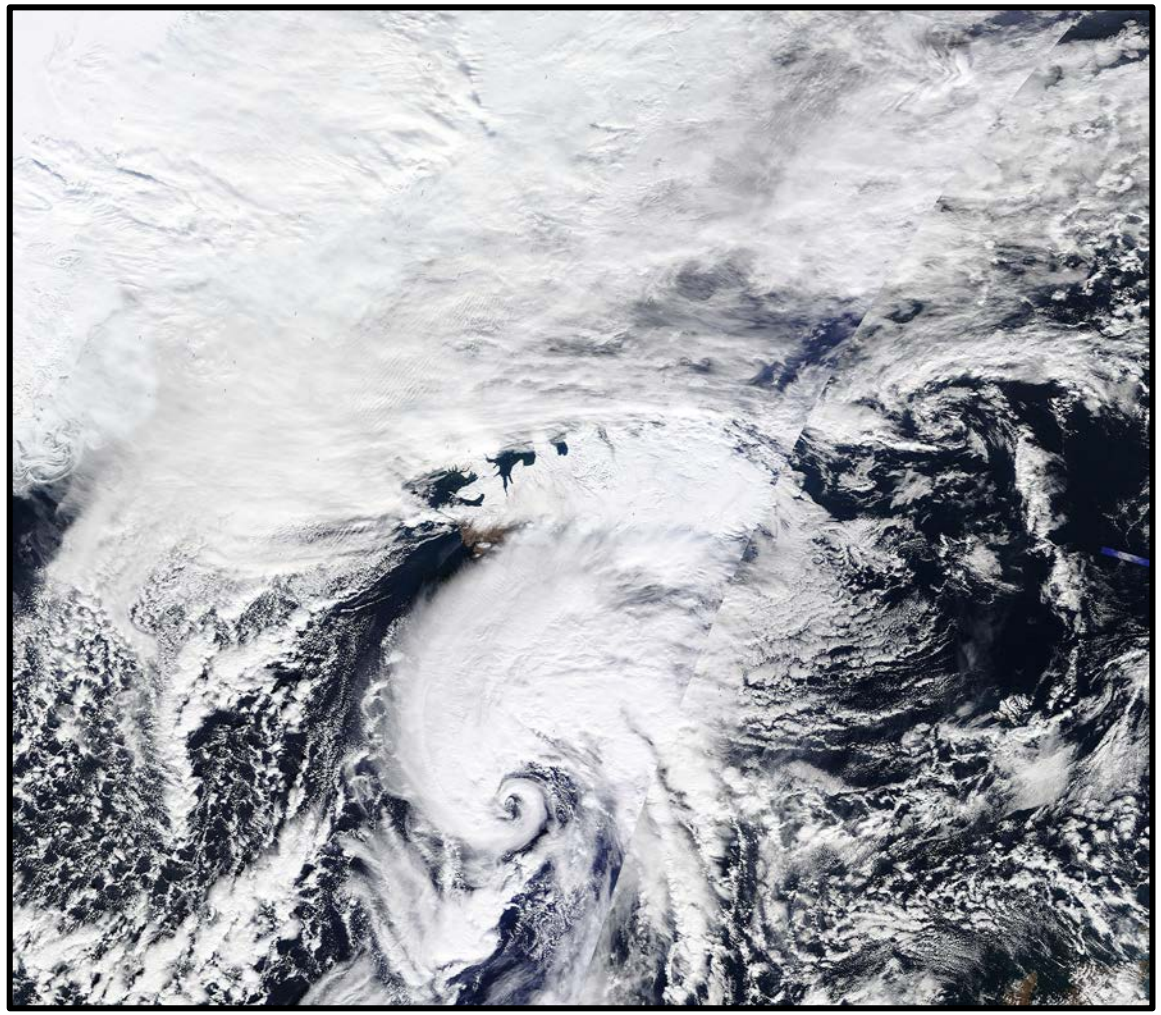


EARTH OBSERVATION SATELLITES

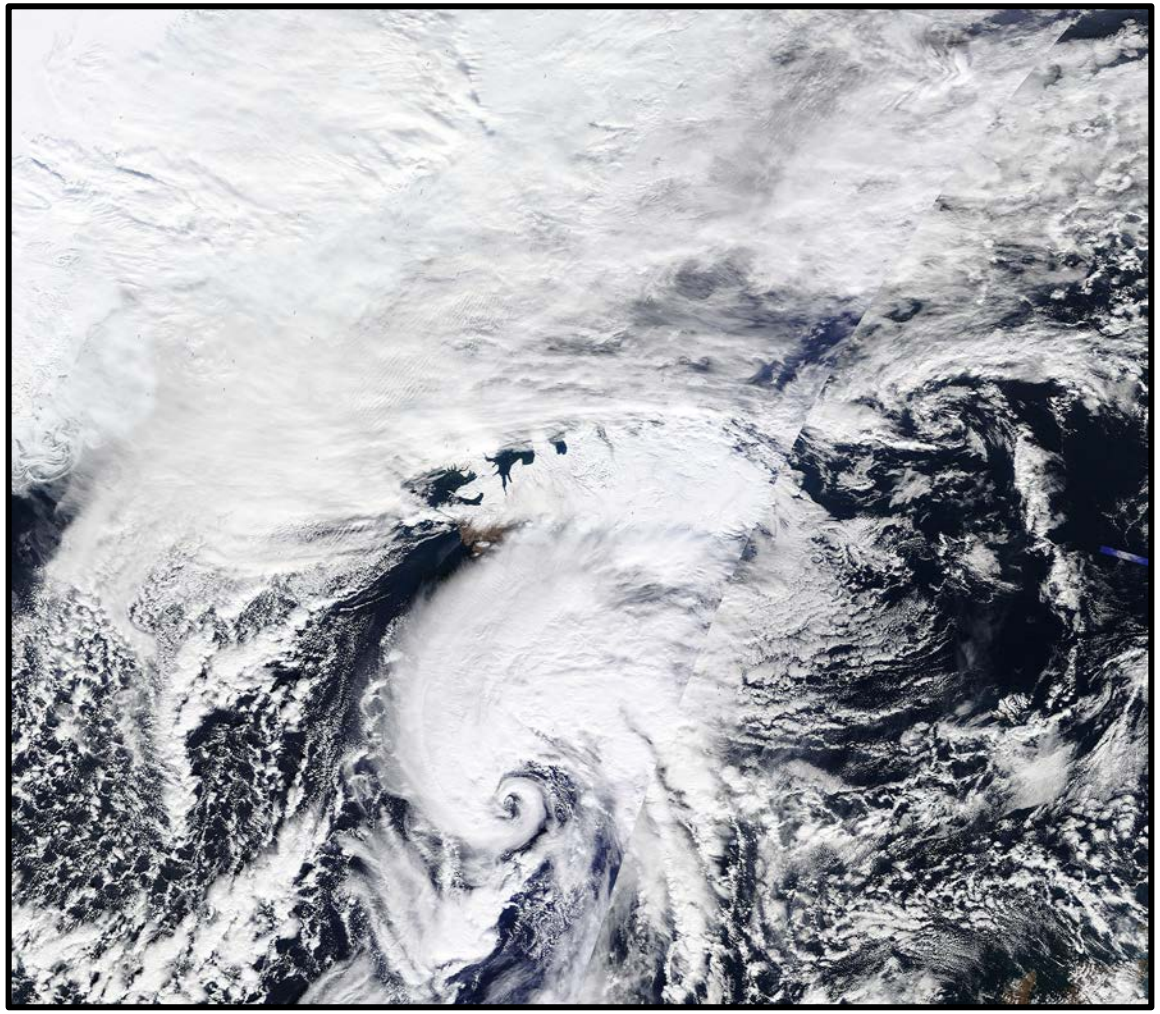
Satellite	Launched Year	Spatial Resolution	Temporal Resolution (Day)	Spectral Resolution	Radiometric Resolution
Landsat-5	1984	30 m. multispectral 120 m. TIR	16	Blue, Green, Red, NIR, SWIR-1, SWIR-2, TIR	8-bit
OrbView–2	1997	1130 m.	1	8 bands (0.402 to 0.885 μm)	12-bit
IKONOS	1999	1 m. panchromatic 4 m. multispectral	3	Panchromatic, Blue, Green, Red, NIR	11-bit
Landsat-7	1999	15 m. panchromatic 30 m. multispectral 60 m. TIR	16	Panchromatic, Blue, Green, Red, NIR, SWIR-1, SWIR-2, TIR	12-bit
Terra - MODIS	1999	250 m. B1 – B2 500 m. B3 – B7 1000 m. B8 – B36	1-2	36 bands (0.620 – 14.385 μm)	12-bit
EO-1 ALI	2001	10 m. panchromatic 30 m. multispectral	16	10 bands (0.450 – 2.350 μm)	12-bit
QuickBird-2	2001	3 m. panchromatic 15 m. multispectral	1-3	Panchromatic, Blue, Green, Red, NIR	8-bit
OrbView-3	2003	1 m. panchromatic 4 m. multispectral	3	Panchromatic, Blue, Green, Red, NIR	11-bit
GeoEye-1	2008	0.41 m. panchromatic 1.64 m. multispectral	3	Panchromatic, Blue, Green, Red, NIR	11-bit
Landsat-8	2013	15 m. panchromatic 30 m. multispectral 60 m. TIR	16	Panchromatic, Coastal, Blue, Green, Red, NIR, SWIR-2, SWIR-4, TIR	12-bit
Gaofen-1	2013	2.0 m. panchromatic 8 m. multispectral	4	Panchromatic, Blue, Green, Red, NIR	14 -bit
Sentinel-2	2015	10 m. multispectral 20 m. 60 m.	5	13 bands (0.43 – 2.28 μm)	12-bit
GeoEye-2	2016	0.31 m. panchromatic 1.24 m. multispectral	3 days	Panchromatic, Blue, Green, Red, NIR	11-bit

EOS SATELLITE LIMITATIONS

- Data lost due to cloud coverage
- Only optical variables:
  - Chl-a
  - Turbidity
  - SDD
  - TSS



HYPOTHESIS AND OBJECTIVES



HYPOTHESIS

- A combination of bands from images captured by a multispectral sensor attached to an sUAS can predict optical (TSS, Chl-a, SDD) and non-optical (TP, TN) water quality parameters in reservoirs with different trophic states

- By having the ability to capture free cloud images at a finer spatial resolution, sUAS models that predict optical and non-optical water quality parameters have the ability to generate more accurate data, than the models that rely on satellite data

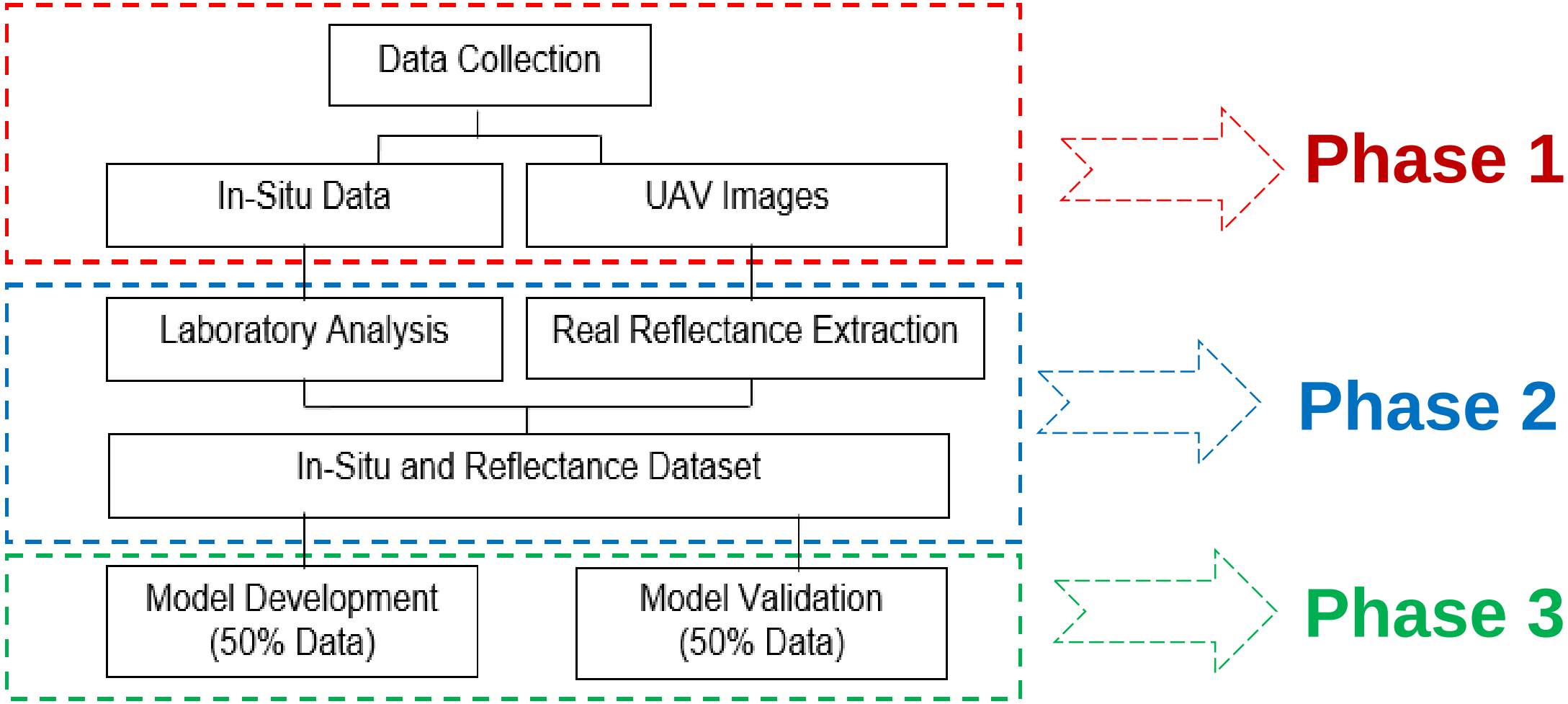
OBJECTIVES

- To develop statistical models capable of predicting optical (TSS, Chl-a, SDD) and non-optical (TP, TN) water quality parameters in reservoirs with different trophic states

- To statistically compare and evaluate the accuracy of the data generated by water quality models that rely on satellite imagery and sUAS imagery

METHODOLOGY

METHODOLOGY



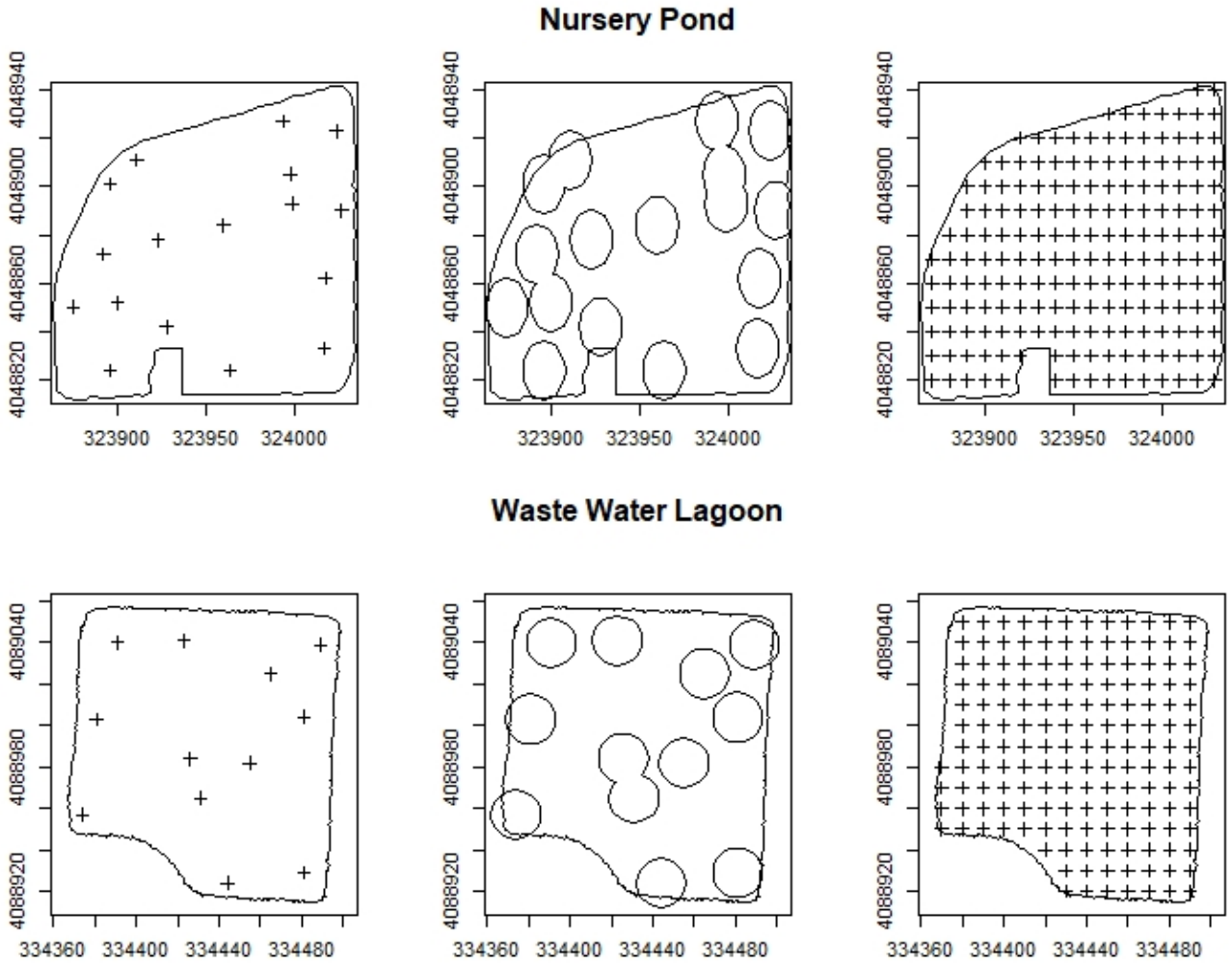
DATA COLLECTION AND ANALYSIS

MULTISPECTRAL DATA COLLECTION

LABORATORY ANALYSIS

Analyte	Method
Chlorophyll α	EPA 445.0
Total Phosphorus	EPA 365.3
Total Nitrogen	Multi N/C 2100S
Nitrate-Nitrogen	EPA 352.1
Ammonia-nitrogen	HACH 10031
Total Suspended Solids	EPA 160.2
Secchi Disk	-

SCENARIO EVALUATION



MODEL DEVELOPMENT

Model Development (50% Data)

- Regression analyses
- Water quality parameter (dependent variable)
- Refraction data from multispectral image (independent variable)

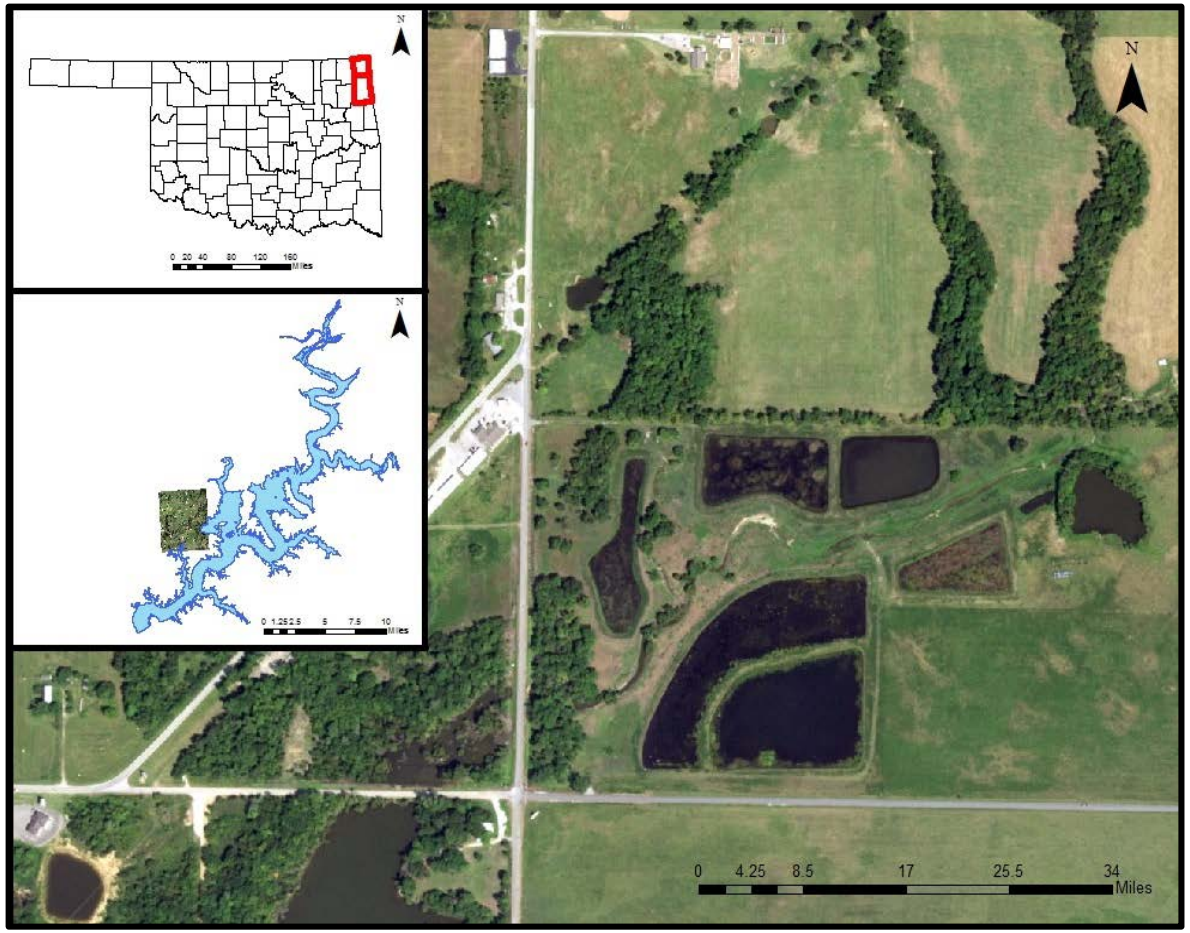
Best Fit Determination

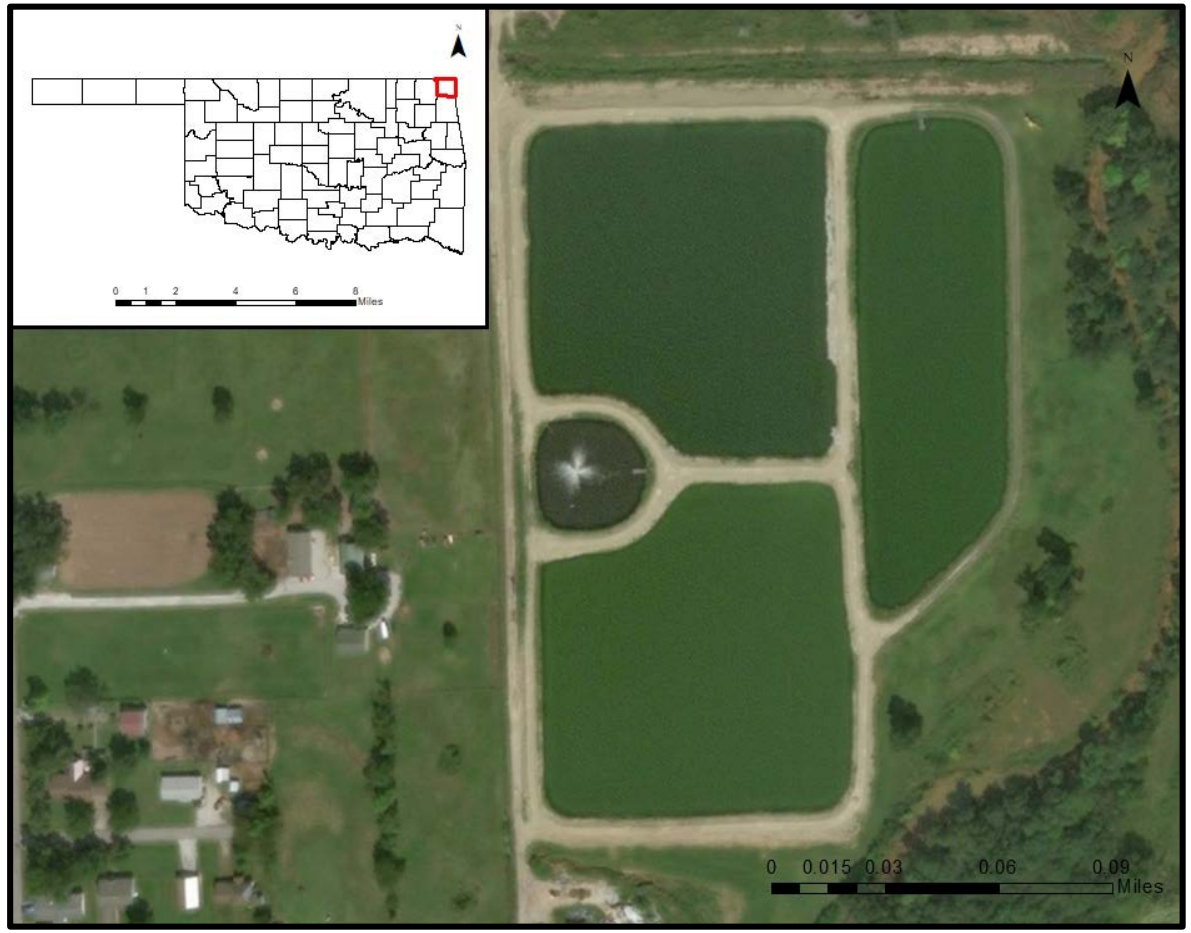
- Coefficient of determination (R^2)
- Akaike Information Criterion (AIC)

Model Validation (50% Data)

- Statistically comparison between in-situ water quality parameter measurements and predicted measurements

STUDY AREA


N
0 4.25 8.5 17 25.5 34
Miles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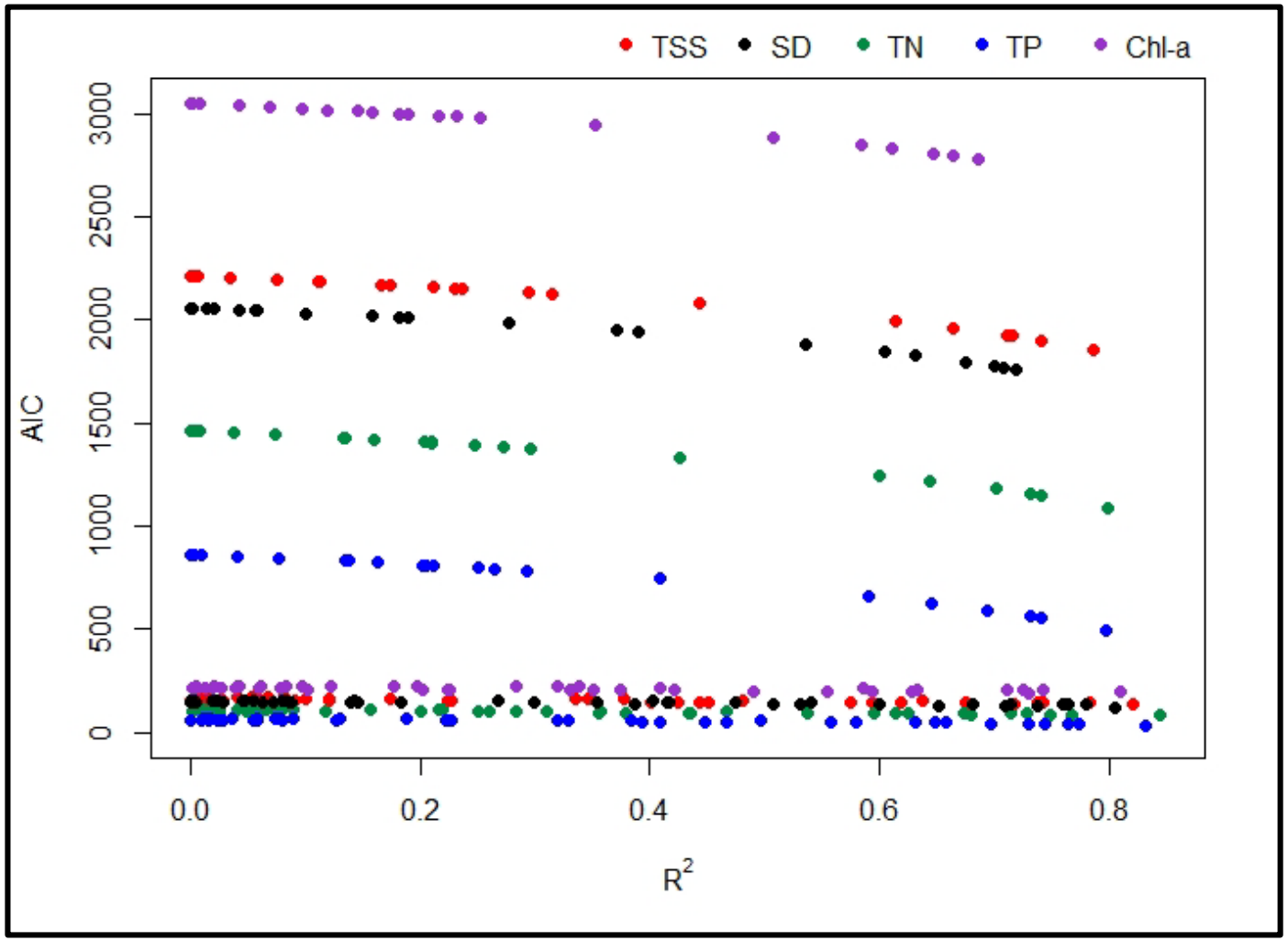
0 1 2 4 6 8
Miles
0 0.015 0.03 0.06 0.09
Miles

RESULTS


TSS
SD
TN
TP
Chl-a
AIC
0
500
1000
1500
2000
2500
3000
0.0
0.2
0.4
0.6
0.8
R^2

SINGLE VARIABLE RESULTS

- Total of 315 (single variable) linear models
  - Point Extraction = 105
  - Buffer Extraction =105
  - Kriging Extraction = 105

$$Y_i = \beta_1 x + \beta$$

MODEL DEVELOPMENT

Model Development (50% Data)

- Regression analyses
- Water quality parameter (dependent variable)
- Refraction data from multispectral image (independent variable)

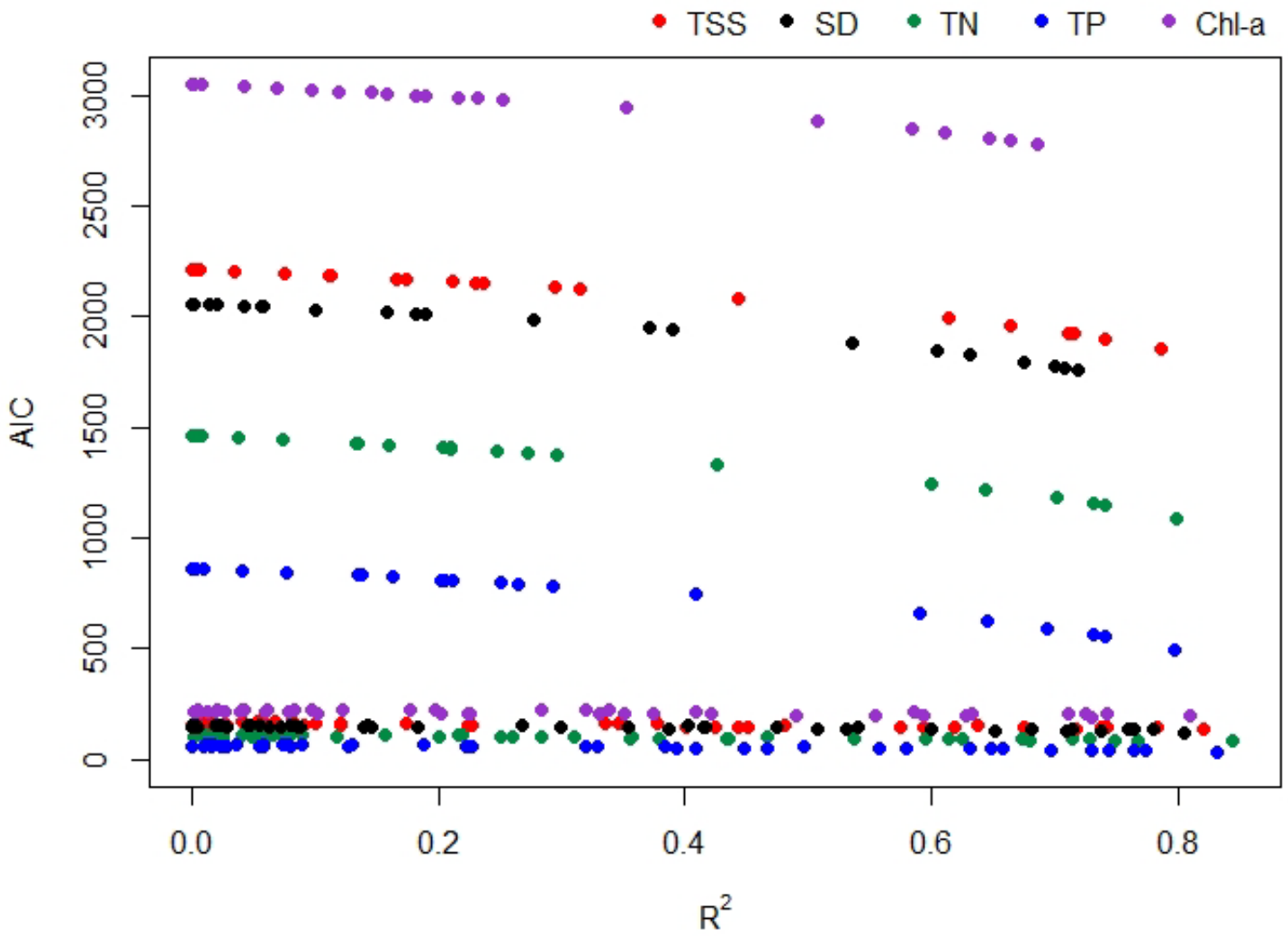
Best Fit Determination

- Coefficient of determination (R^2)
- Akaike Information Criterion (AIC)

Model Validation (50% Data)

- Statistically comparison between in-situ water quality parameter measurements and predicted measurements

LINEAR MODELS - EVALUATION



POINT EXTRACTION RESULTS

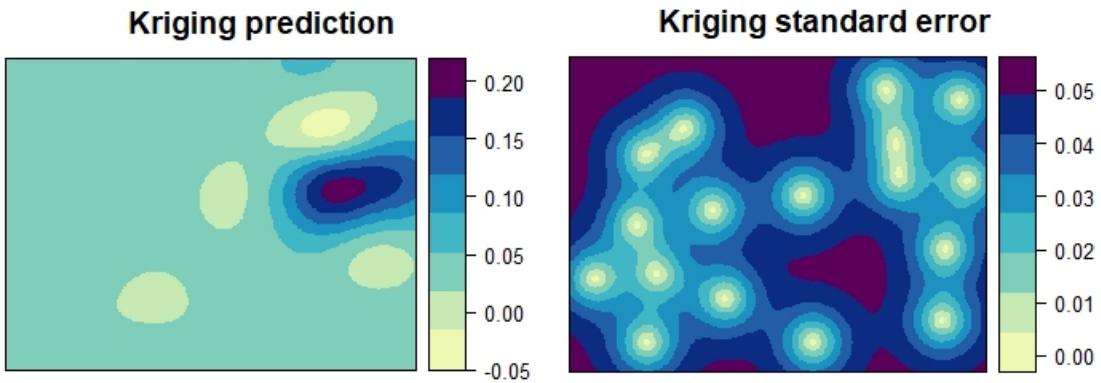
- TSS = 37.317*(Green/Red) - 47.273 (R^2= 0.821 p-val= 5.87e-7)
- SD = -786.440*(Green) + 72.929 (R^2= 0.780 p-val= 2.56e-6)
- Chl-a = 202.84*(Green/Red) - 262.58 (R^2= 0.810 p-val= 8.52e-7)
- TN = 7.0435*(Green/Red) - 8.5676 (R^2= 0.844 p-val= 1.885e-7)
- TP = 1.8392 *(Green/Red) - 2.4117 (R^2= 0.831 p-val= 3.46e-7)

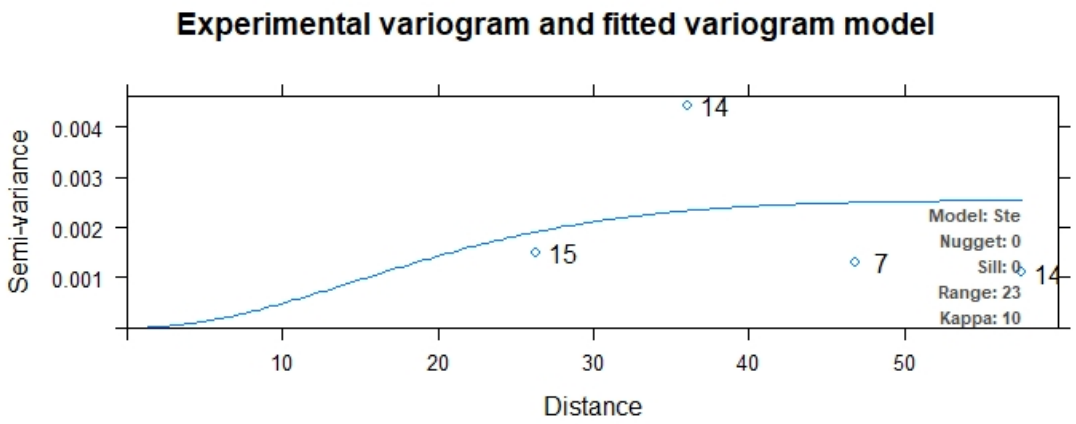
BUFFER EXTRACTION RESULTS

- TSS = 37.361*(Green/Red) - 51.626 (R^2= 0.759 p-val= 1.09e-5)
- SD = -875.989*(Green) + 77.687 (R^2=0.605 p-val= 2.469 e-6)
- Chl-a = 199.75*(Green/Red) - 280.56 (R^2= 0.730 p-val= 2.47e-7)
- TN = 6.991*(Green/Red) - 9.273 (R^2= 0.768 p-val= 8.39e-6)
- TP = 1.8464*(Green/Red) - 2.6307 (R^2= 0.764 p-val= 9.56e-6)

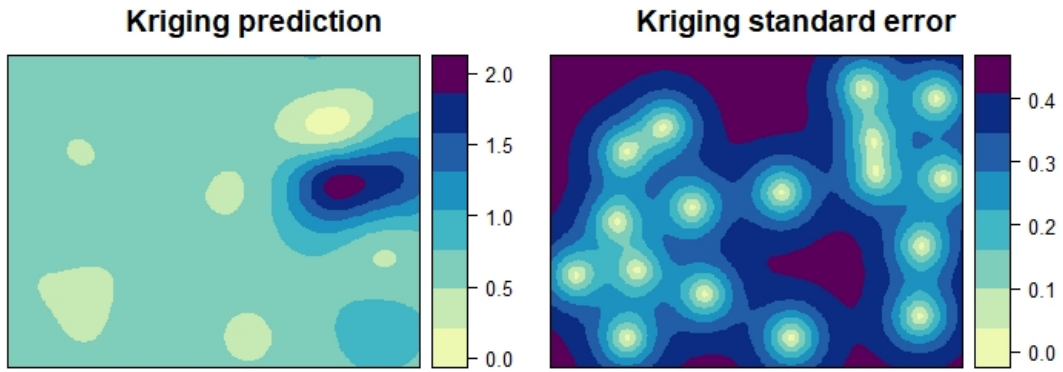
ORDINARY KRIGING - NPA

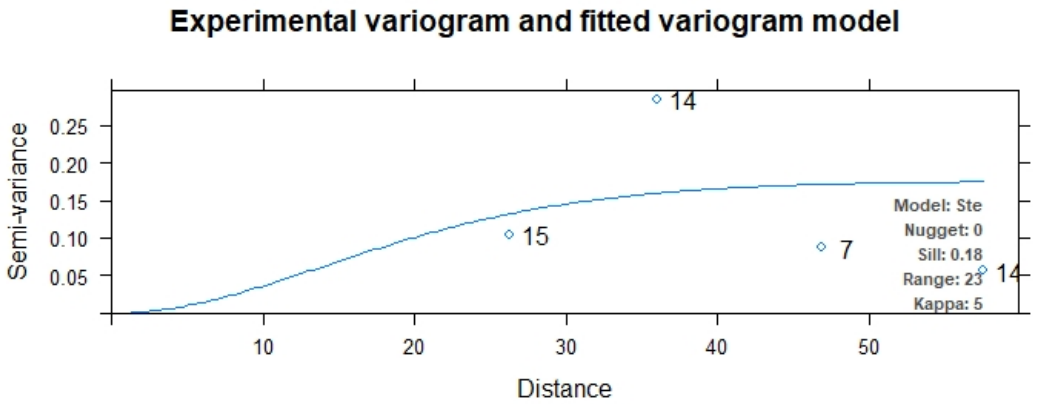
TP





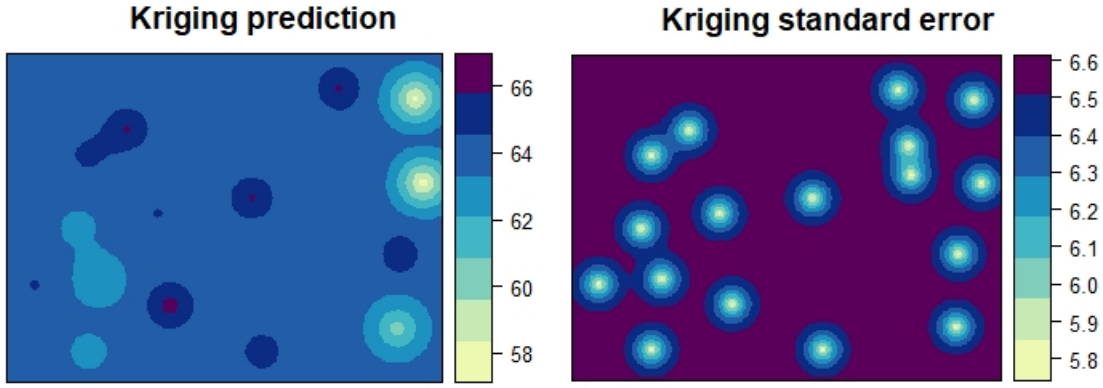
TN

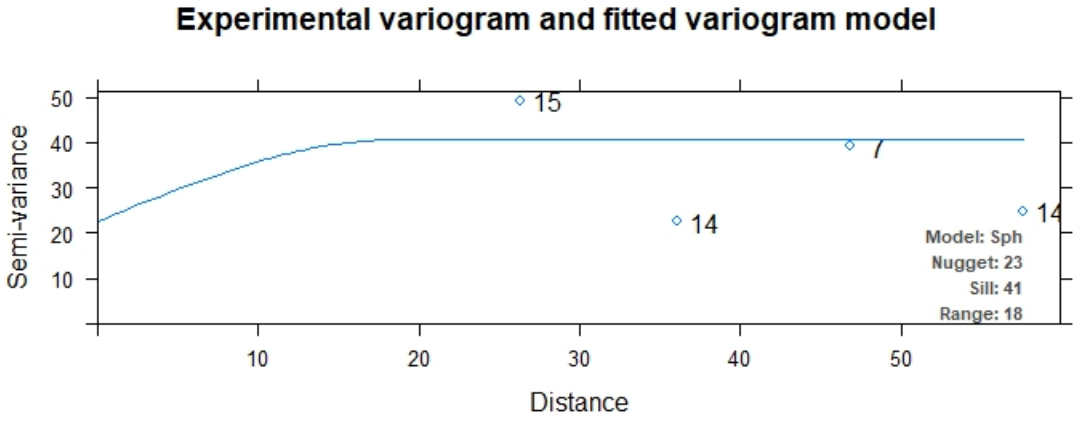




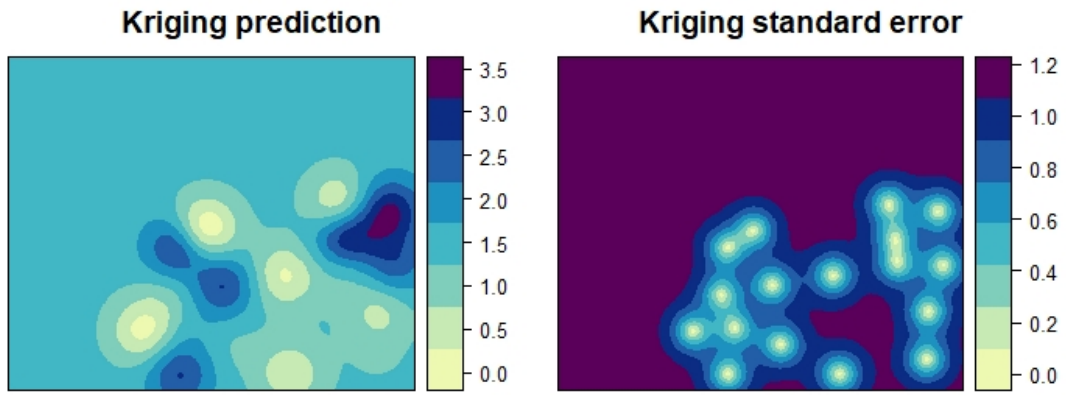
ORDINARY KRIGING - NPA

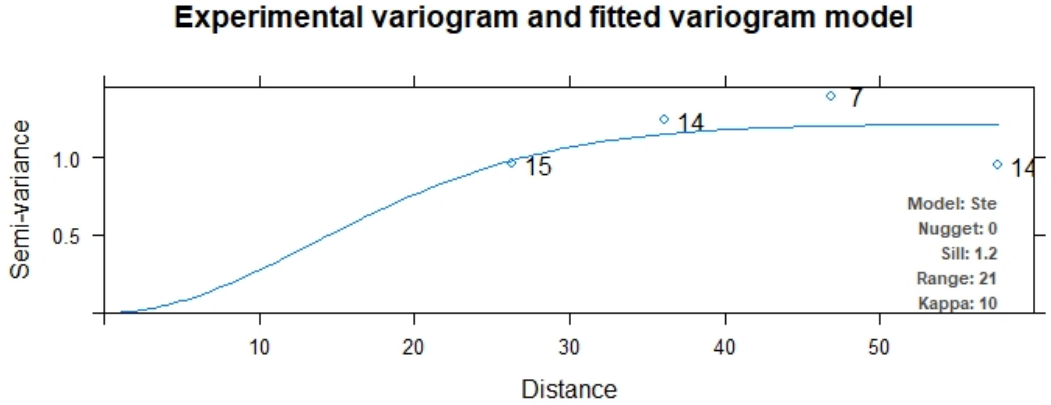
SDD





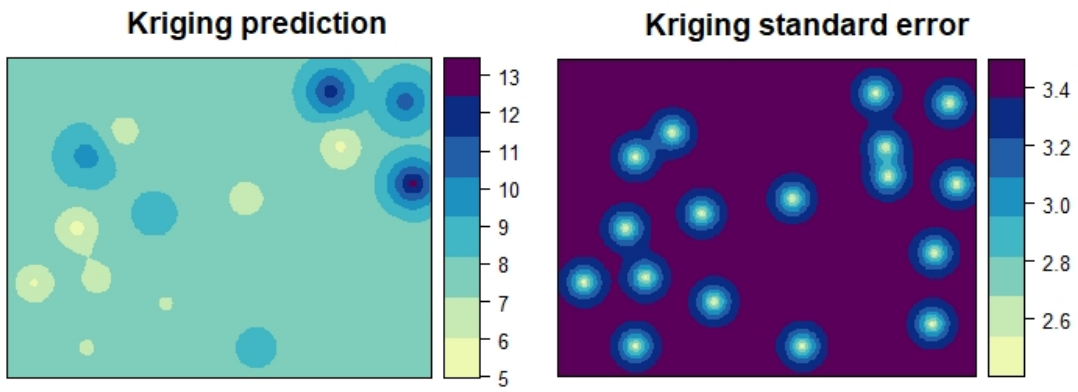
TSS

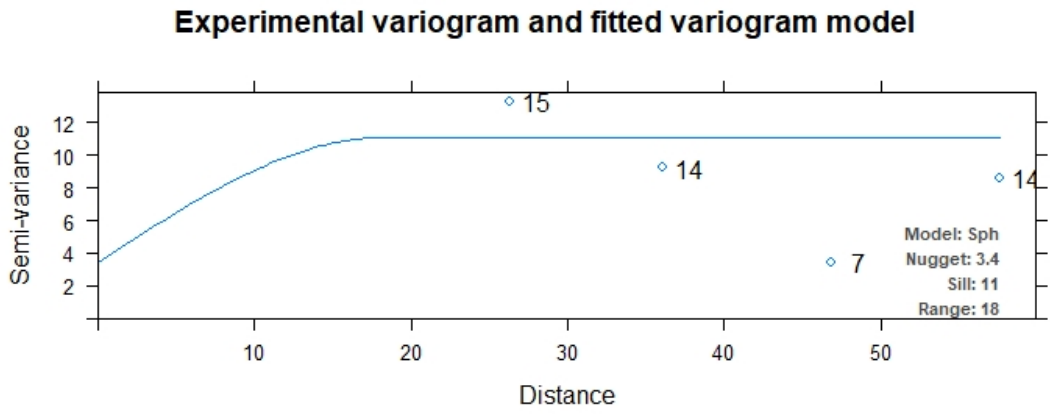




ORDINARY KRIGING - NPA

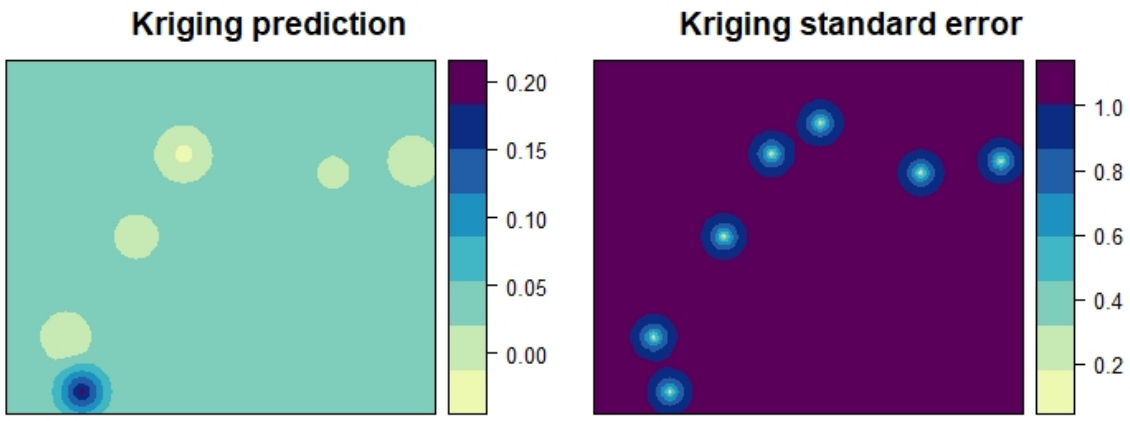
Chl-a

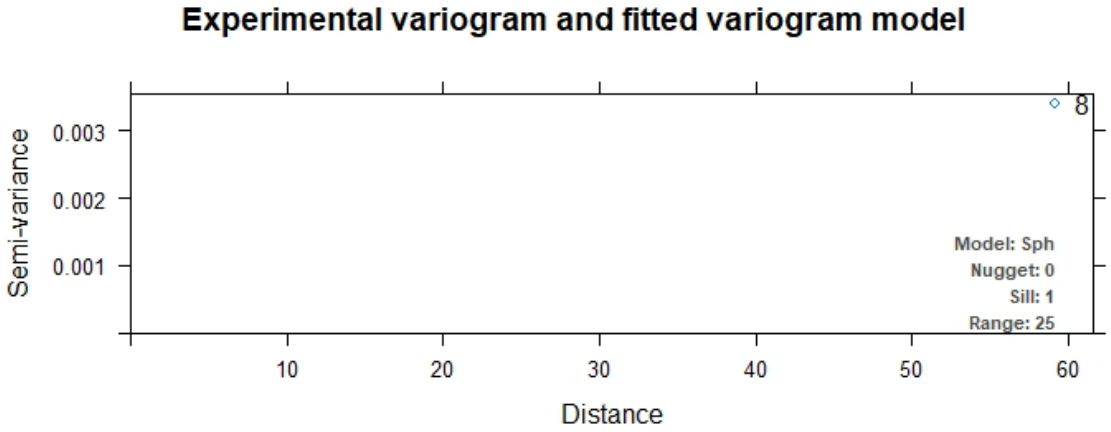




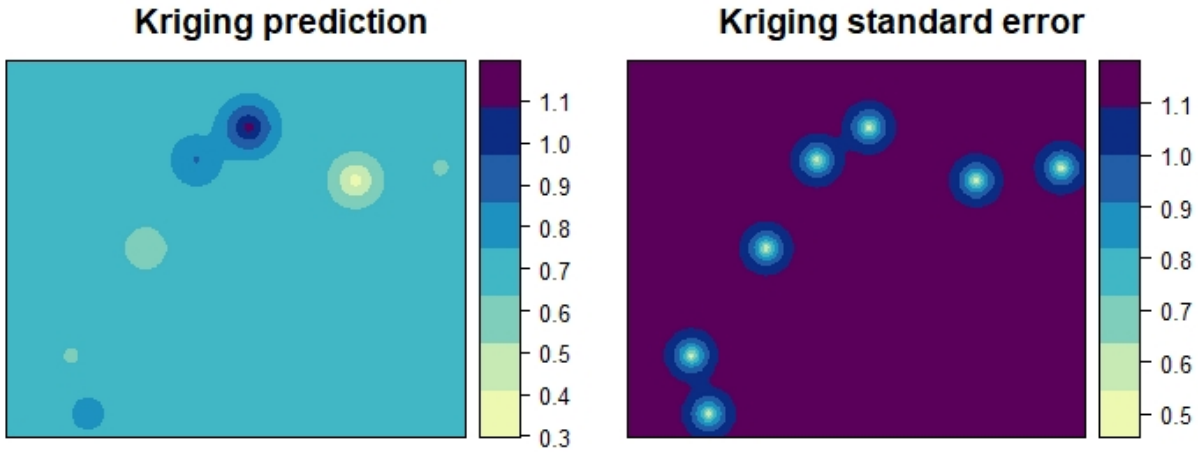
ORDINARY KRIGING - NPB

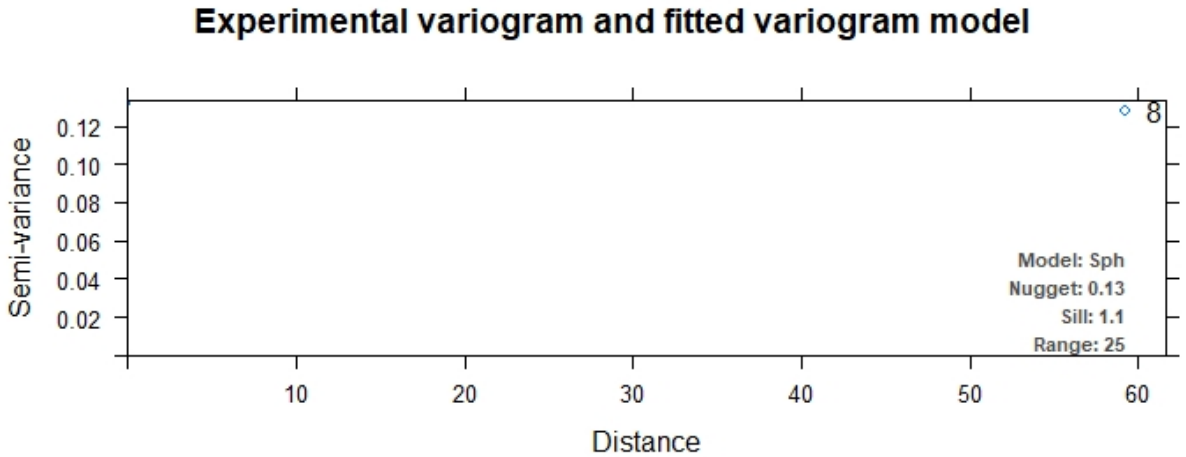
TP





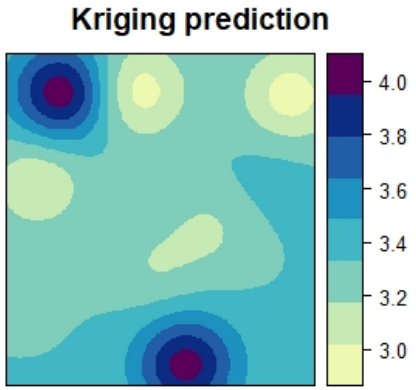
TN

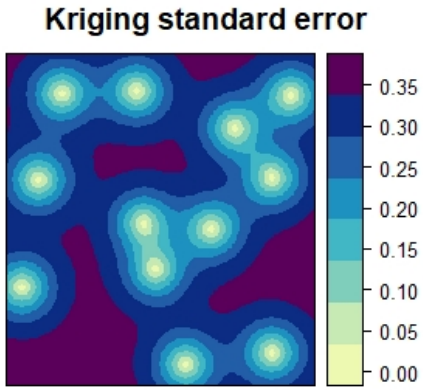


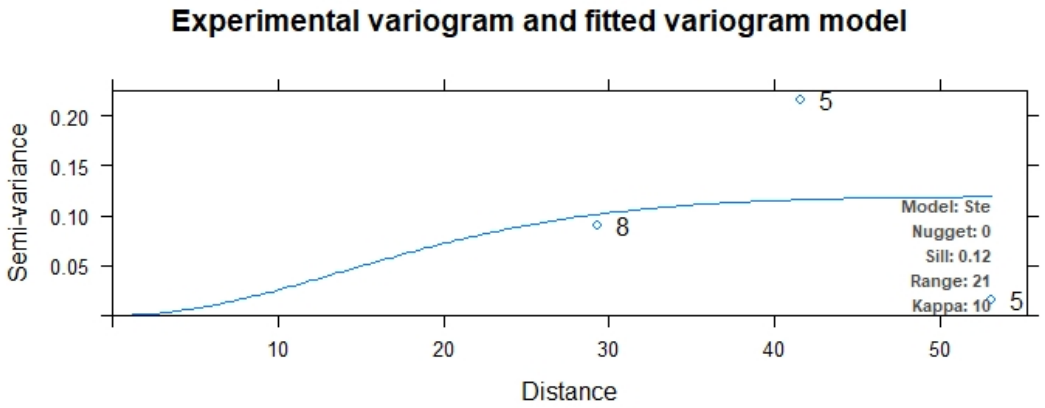


ORDINARY KRIGING - WWL

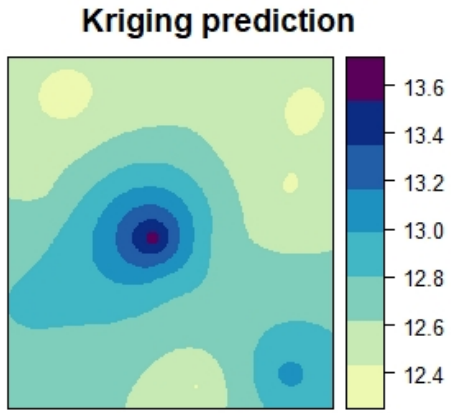
TP

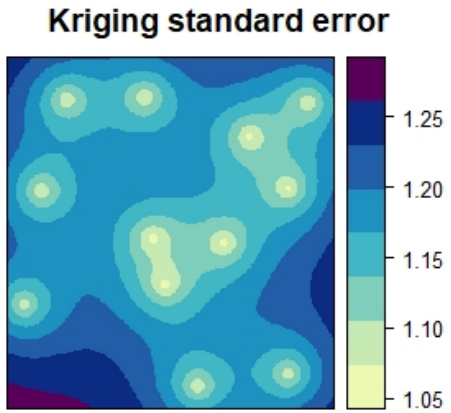


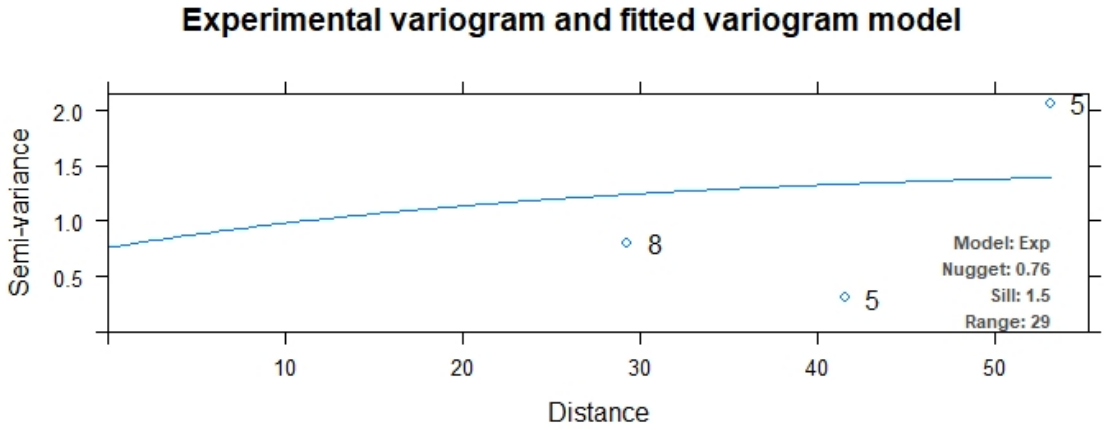




TN

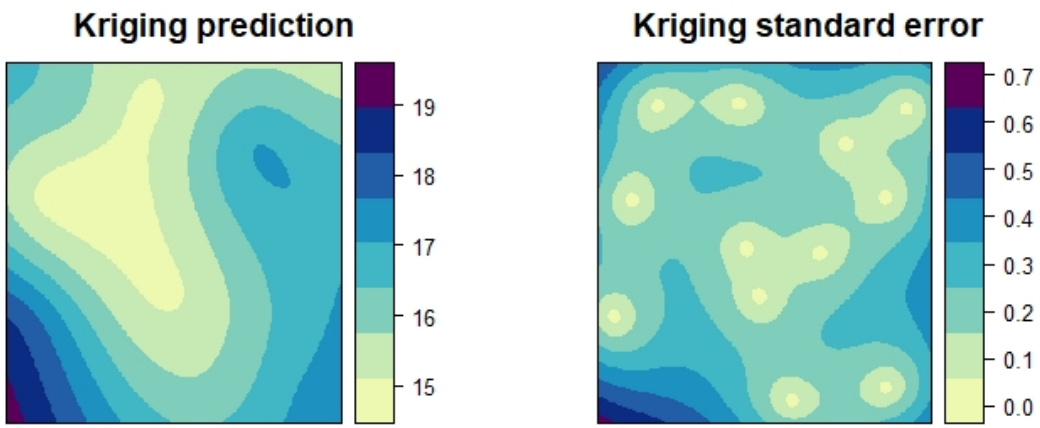


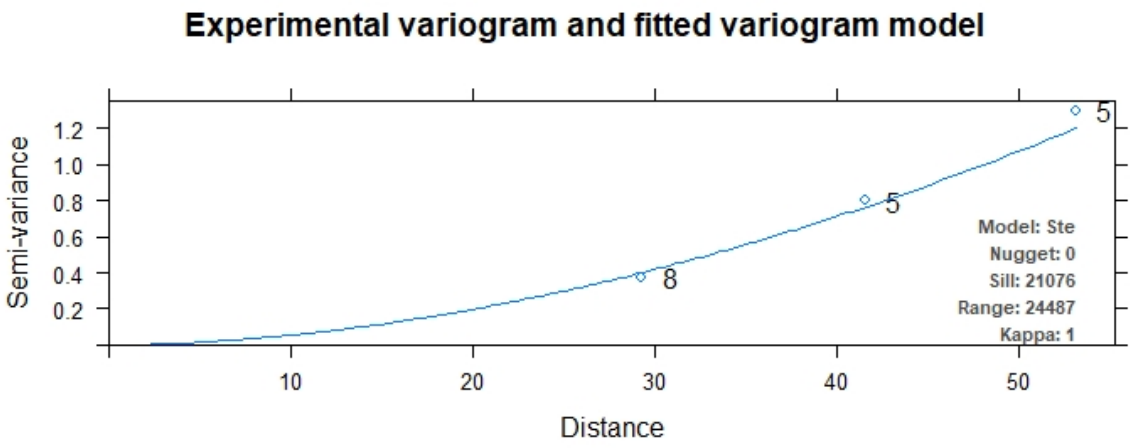




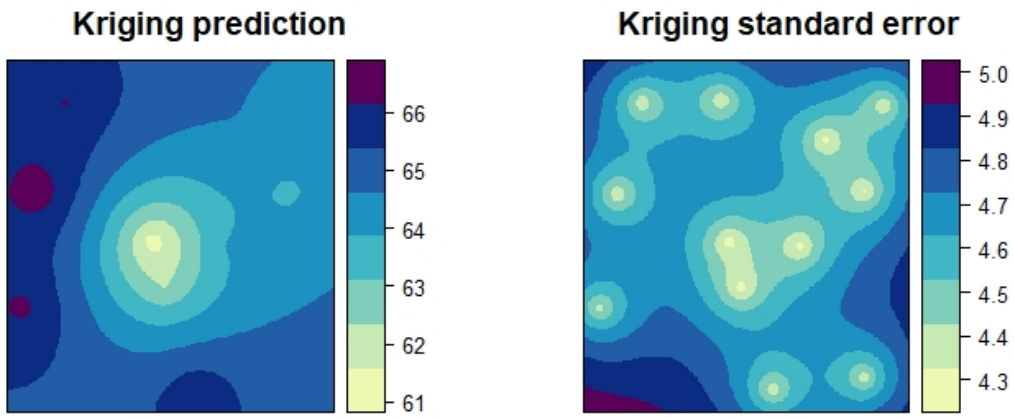
ORDINARY KRIGING - WWL

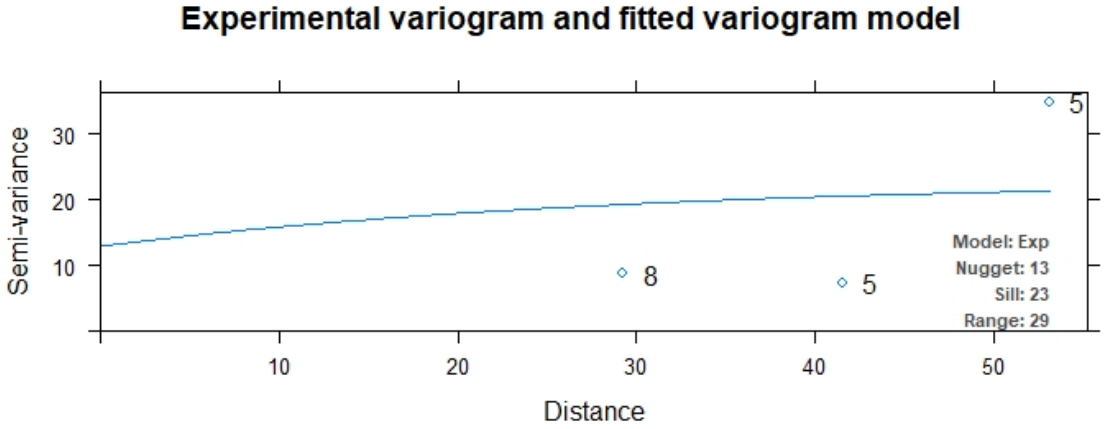
SDD





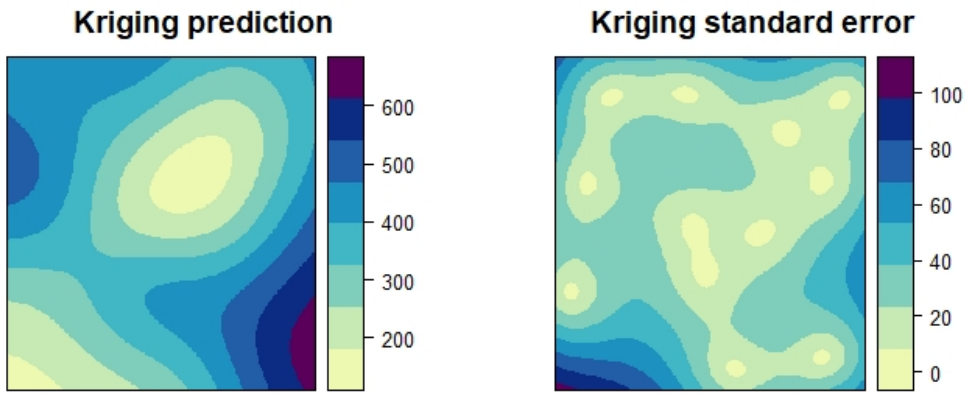
TSS

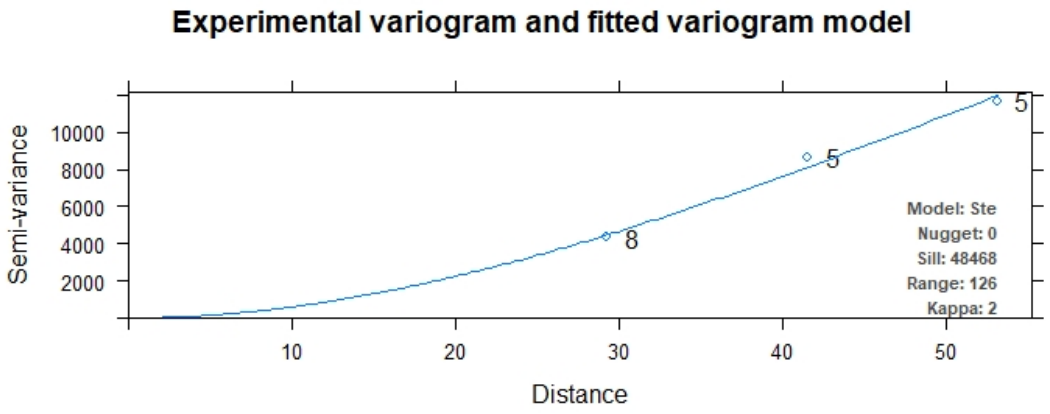




ORDINARY KRIGING - WWL

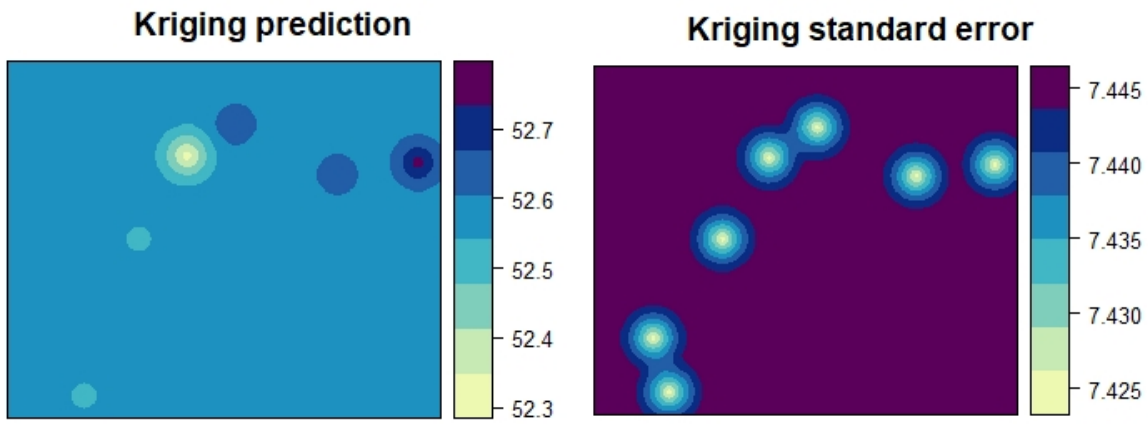
Chl-a

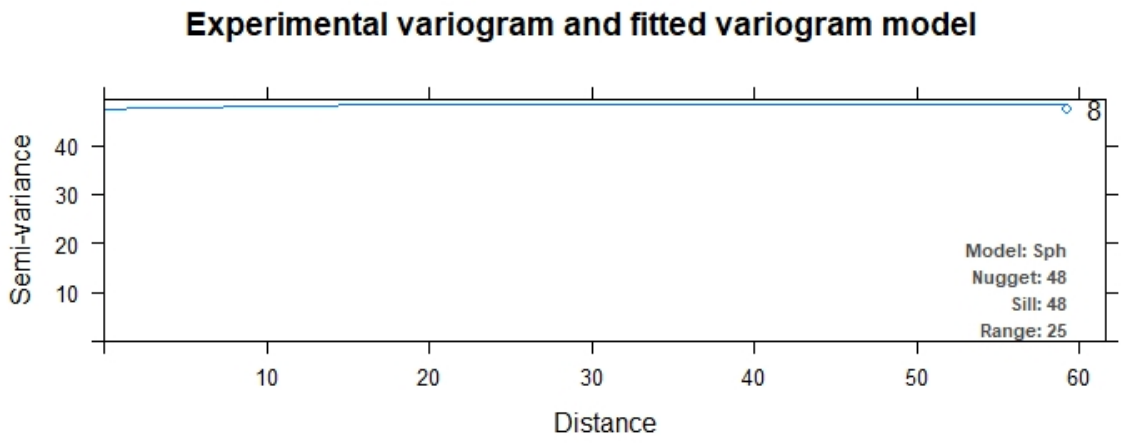




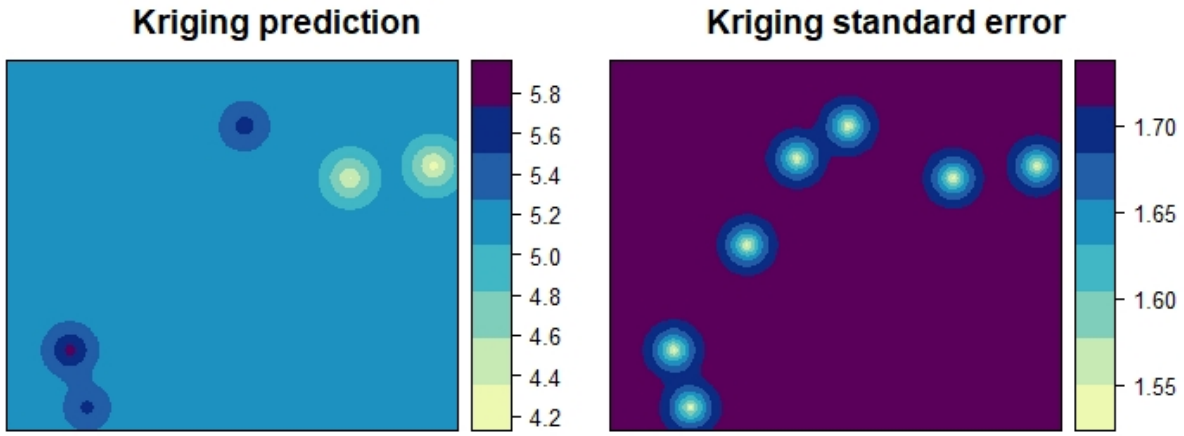
ORDINARY KRIGING - NPB

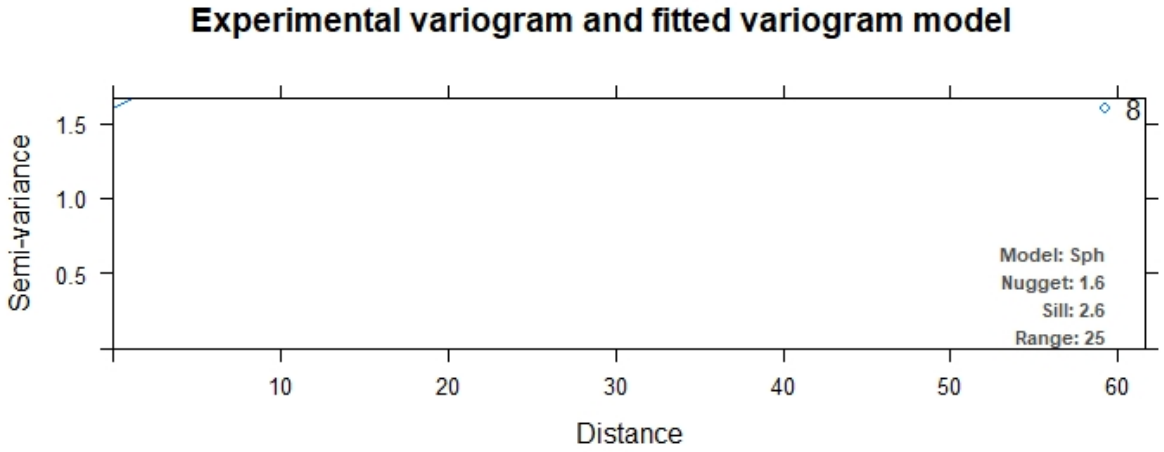
SDD





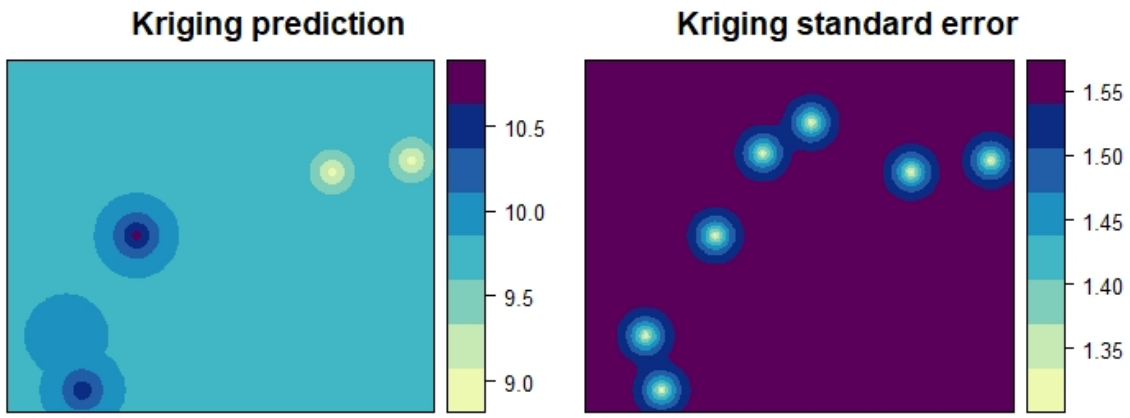
TSS

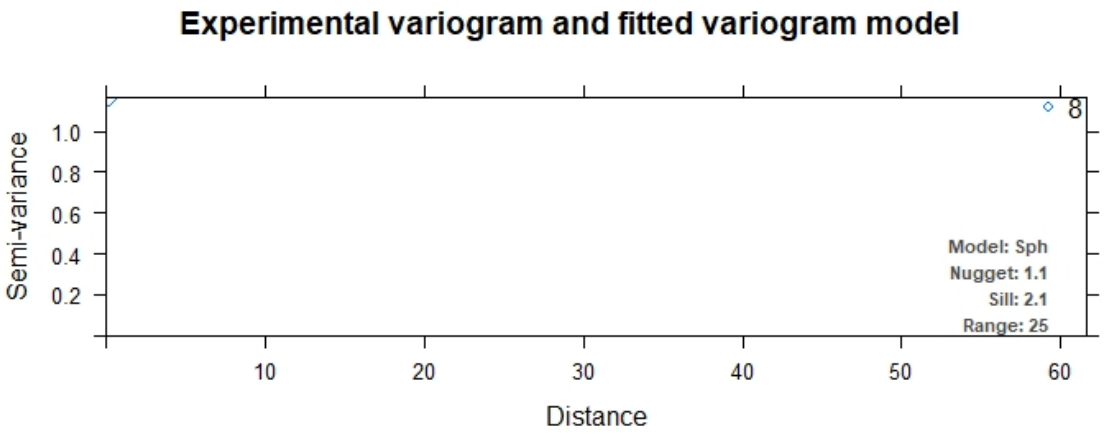




ORDINARY KRIGING - NPB

Chl-a





KRIGING EXTRACTION RESULTS

- TSS = 31.694*(Green/Red) - 35.248 (R^2= 0.787 p-val= 1.19e-78)
- SD = -875.989*(Green) + 77.687 (R^2=0.699 p-val= 7.75e-58)
- Chl-a = 199.75*(Green/Red) - 280.56 (R^2= 0.687 p-val= 1.34e-59)
- TN = 6.2312*(Green/Red) - 6.8654 (R^2= 0.799 p-val= 6.39e-82)
- TP = 1.71343*(Green/Red) - 2.04546 (R^2= 0.798 p-val= 1.71e-81)

SCENARIO CONCLUSIONS

- Statistical interpolation method (ordinary kriging) is un-necessary to improve the relationship between the different water quality parameters and the reflectance values

- Point extractions have higher R^2 values

- More doesn’t mean better!

MODEL DEVELOPMENT

Model Development (50% Data)

- Regression analyses
- Water quality parameter (dependent variable)
- Refraction data from multispectral image (independent variable)

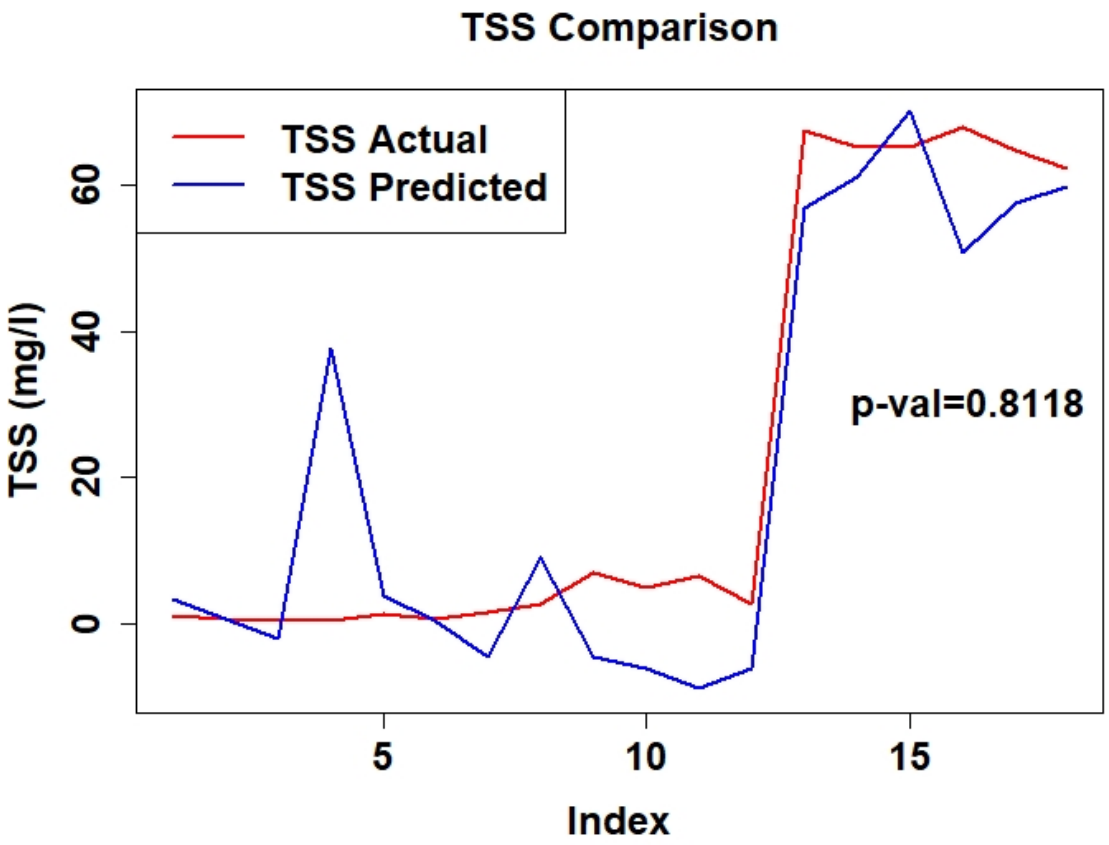
Best Fit Determination

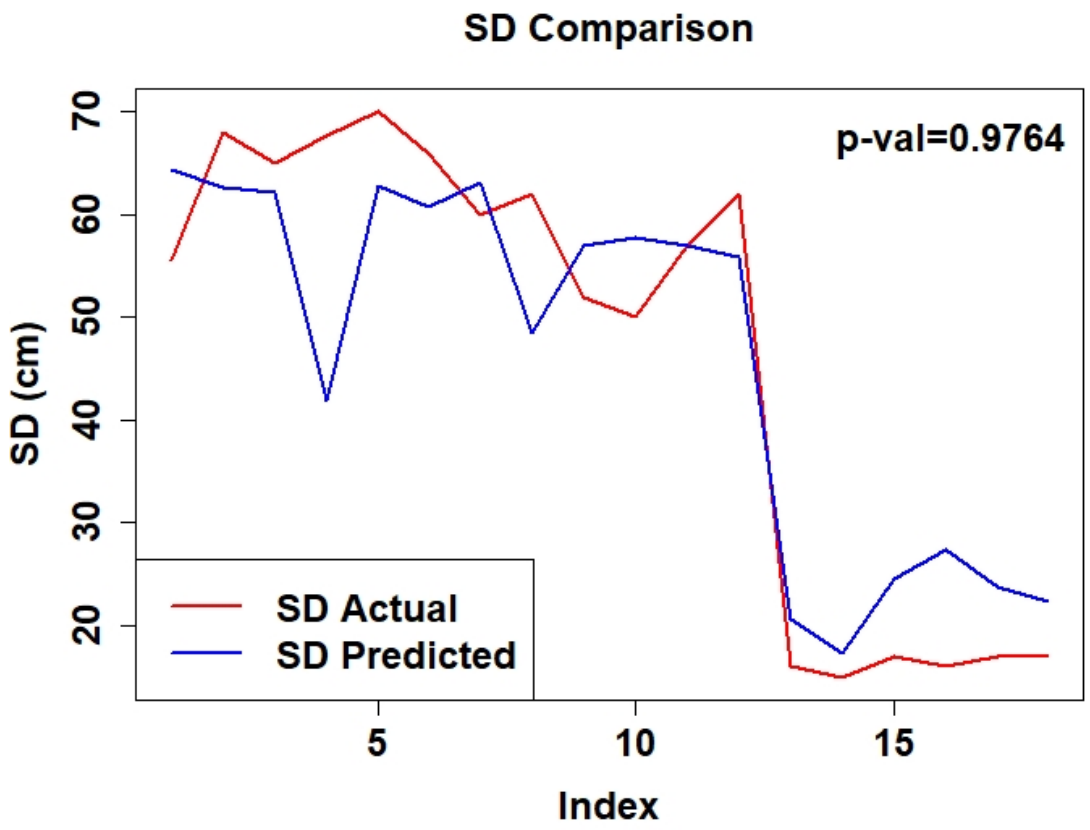
- Coefficient of determination (R^2)
- Akaike Information Criterion (AIC)

Model Validation (50% Data)

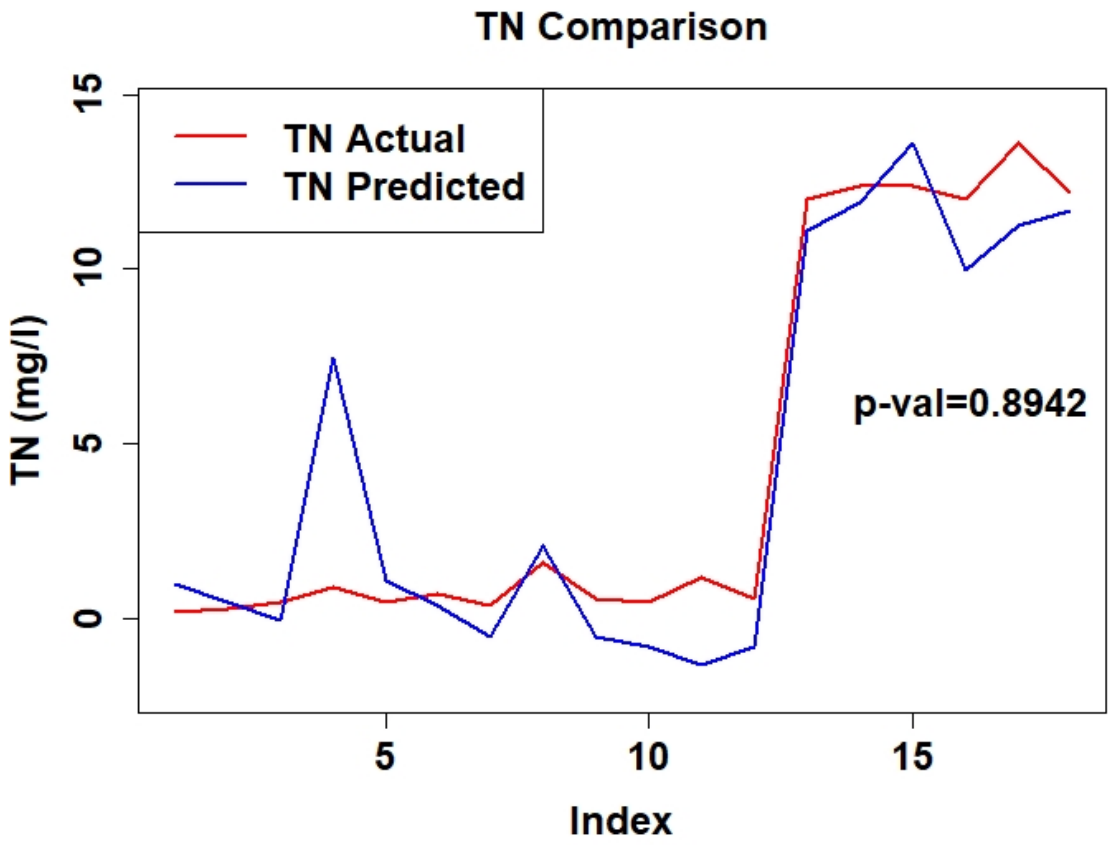
- Statistically comparison between in-situ water quality parameter measurements and predicted measurements

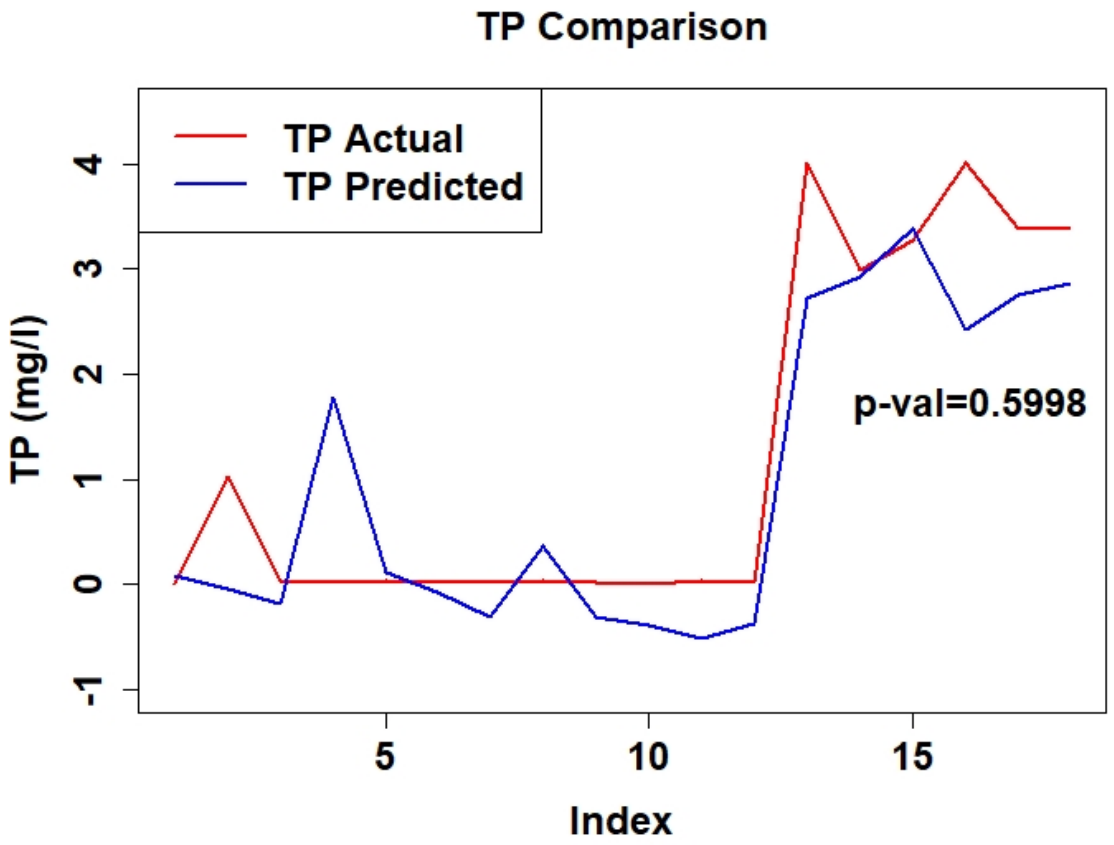
POINT EXTRACTION VALIDATION



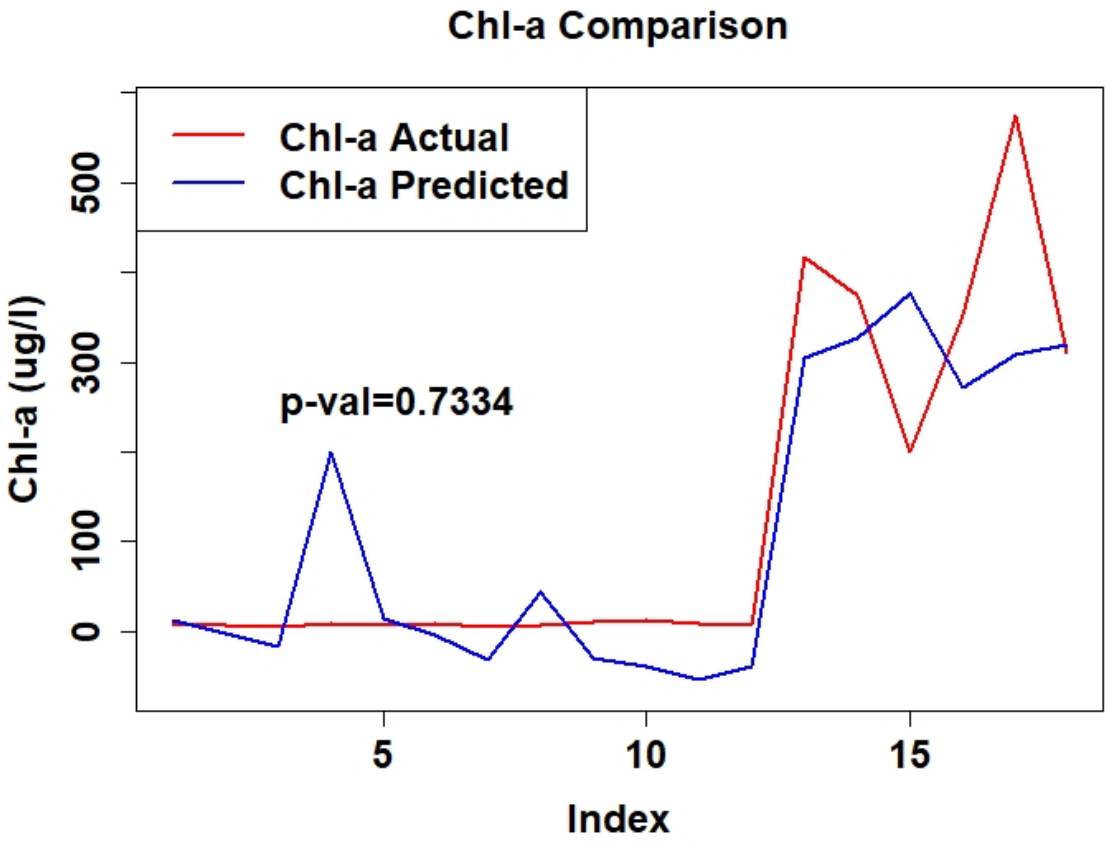


POINT EXTRACTION VALIDATION





POINT EXTRACTION VALIDATION



MULTIPLE VARIABLE RESULTS

- Total of 15 (multiple variable) linear models
  - Point Extraction

$$Y_1 = \beta + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \cdots + \beta_n x_n$$

- Model Evaluation
  - Analysis of Variance (ANOVA)

MULTIPLE VARIABLE RESULTS

- TSS = 185.16*(Green/Red) – 148.15 (Green/Blue) – 264.48 (Blue/Red) + 215.32
  (R^2= 0.883 p-val= 1.872e-6)

- SD = 78.67*(Green/Blue) – 108.33*(Green/Red) + 164.32*(Blue/Red) - 61.91
  (R^2=0.605 p-val= 2.469 e-6)

- Chl-a = -13359.30*(Red)+ 9158.79*(Green) + 27.99
  (R^2= 0.846 p-val= 2.05e-6)

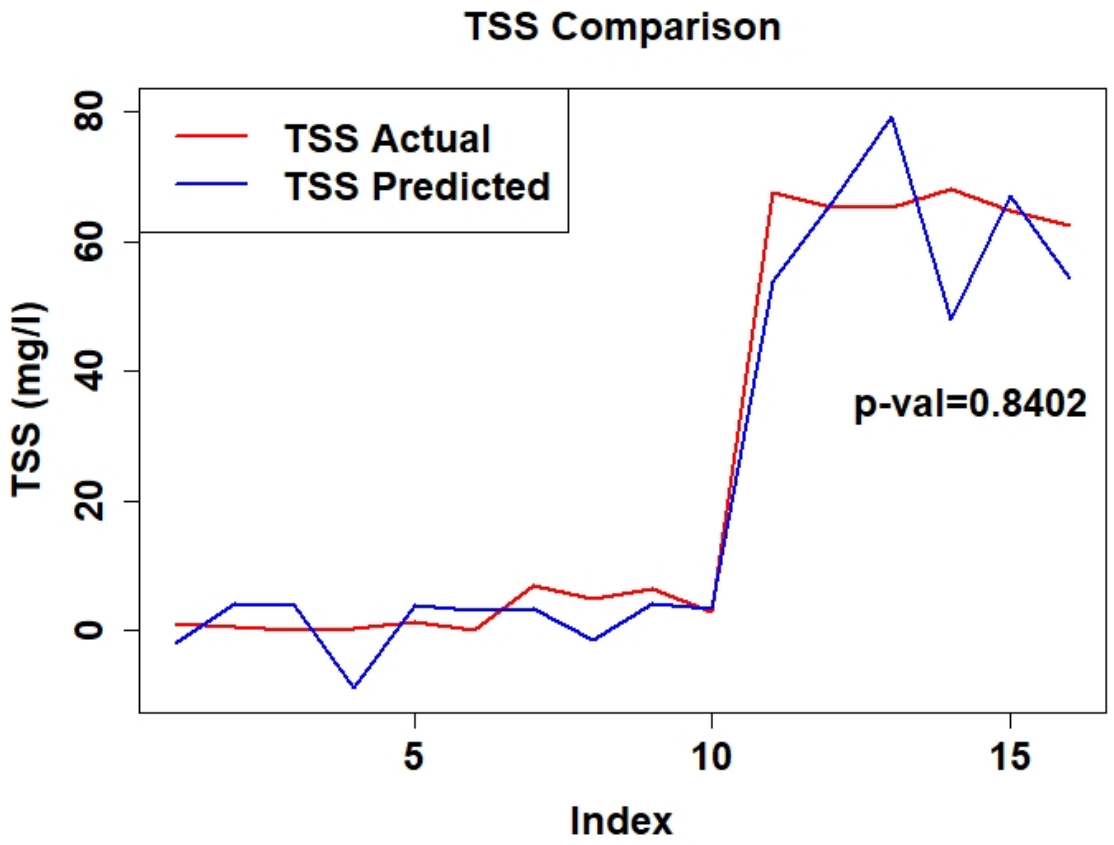
- TN = 32.935*(Green/Red) – 26.156*(Green/Blue) – 45.428*(Blue/Red) + 36.922
  (R^2= 0.9793 p-val= 3.429e-11)

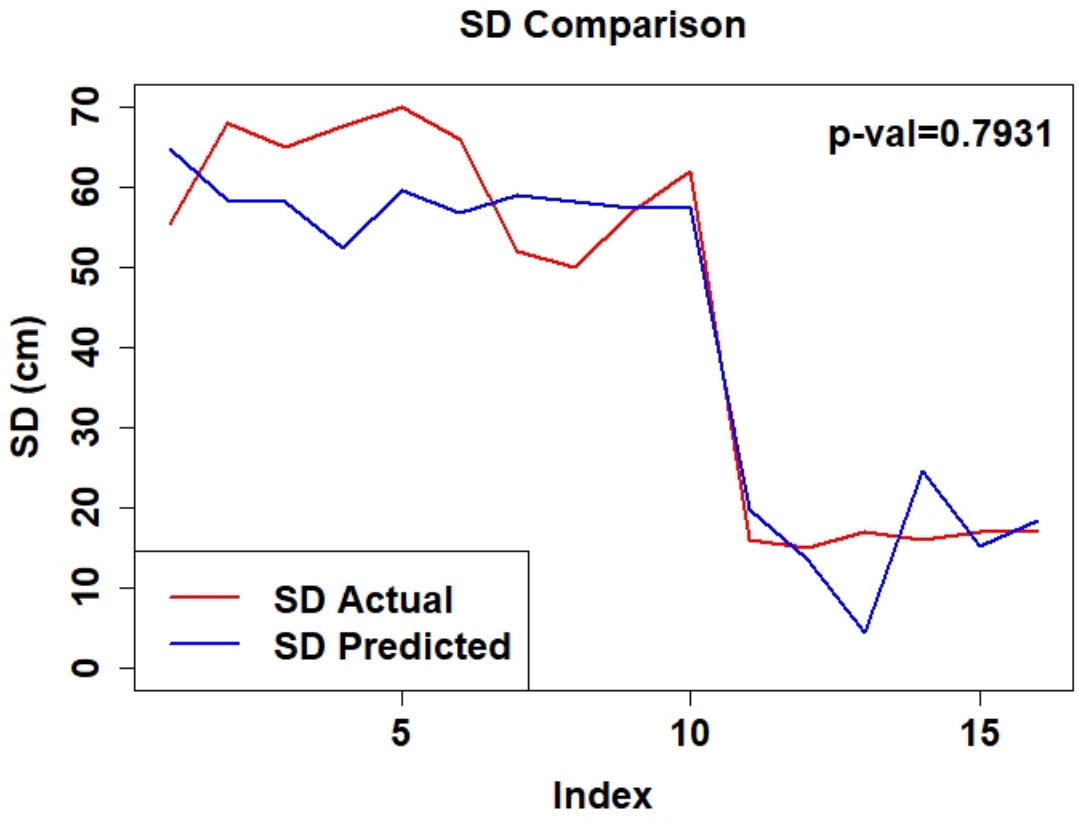
- TP = 8.8103*(Green/Red) – 6.9932*(Green/Blue) – 12.4408* (Blue/Red) + 9.9533
  (R^2= 0.984 p-val= 7.84e-12)

SINGLE VS. MULTIPLE VARIABLE

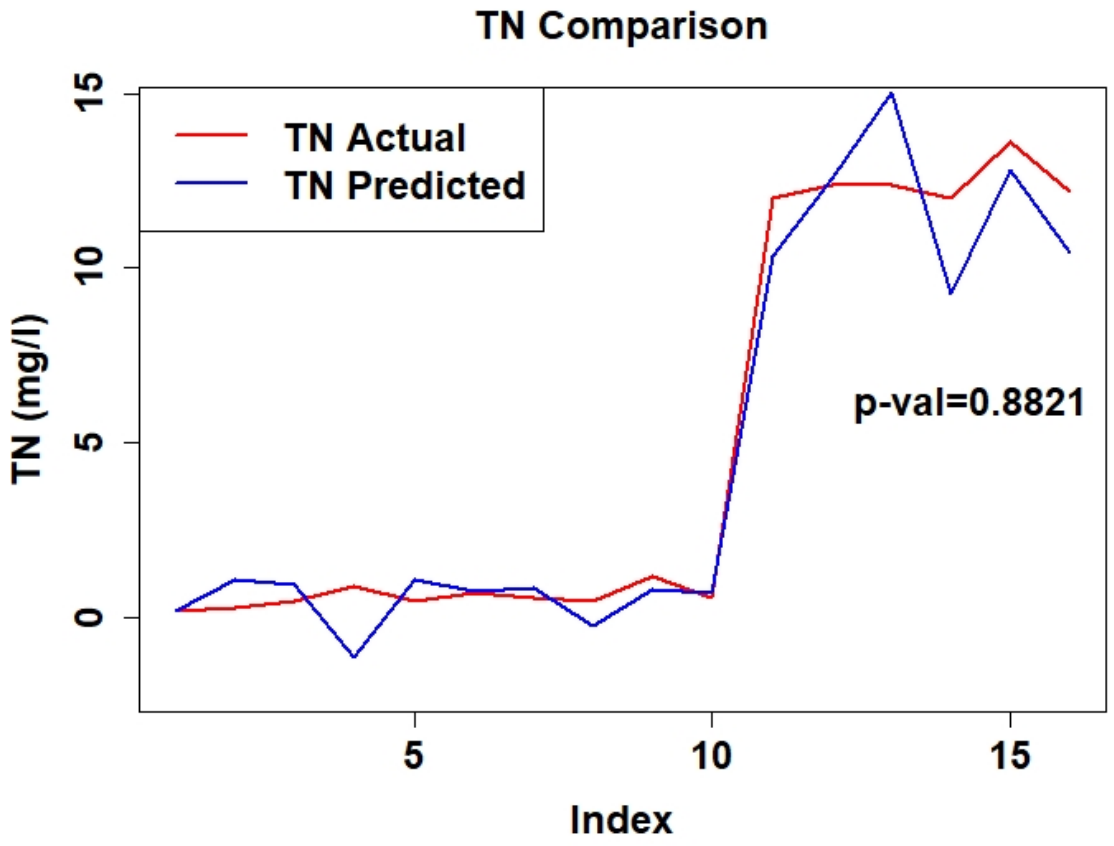
Parameter	Single Variable Model	R^2	Multi Variable Model	R^2
SD	lm(formula = SD.sub$SD ~ SD.sub$PointGreen)	0.7809	lm(formula = SD.Mod.Data$SD ~ SD.Mod.Data$B.R + SD.Mod.Data$G.R + SD.Mod.Data$G.B)	0.8883
TSS	lm(formula = TSS.sub$TSS ~ TSS.sub$G.R)	0.8211	lm(formula = TSS.Mod.Data$TSS ~ TSS.Mod.Data$B.R + TSS.Mod.Data$G.B + TSS.Mod.Data$G.R)	0.9869
TN	lm(formula = TN.sub$TN ~ TN.sub$G.R)	0.8446	lm(formula = TN.Mod.Data$TN ~ TN.Mod.Data$B.R + TN.Mod.Data$G.B + TN.Mod.Data$G.R)	0.9793
TP	lm(formula = TP.sub$TP ~ TP.sub$G.R)	0.8316	lm(formula = TP.Mod.Data$TP ~ TP.Mod.Data$B.R + TP.Mod.Data$G.B + TP.Mod.Data$G.R)	0.9835
Chl-a	lm(formula = Chloro.a.sub$Chloro.a ~ Chloro.a.sub$G.R)	0.8104	lm(formula = CHL.A.Mod.Data$Chloro.a ~ CHL.A.Mod.Data$PointGreen + CHL.A.Mod.Data$PointRed)	0.846

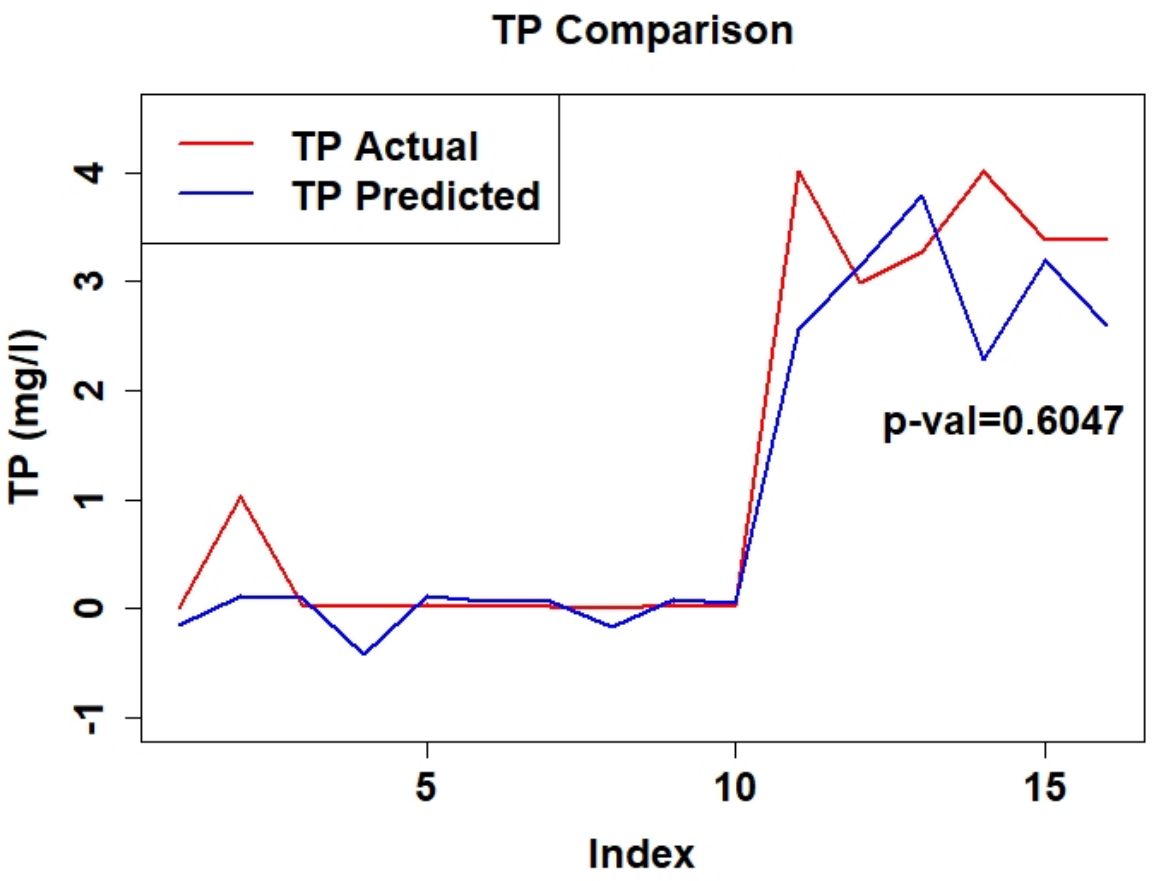
MULTIPLE VARIABLE VALIDATION



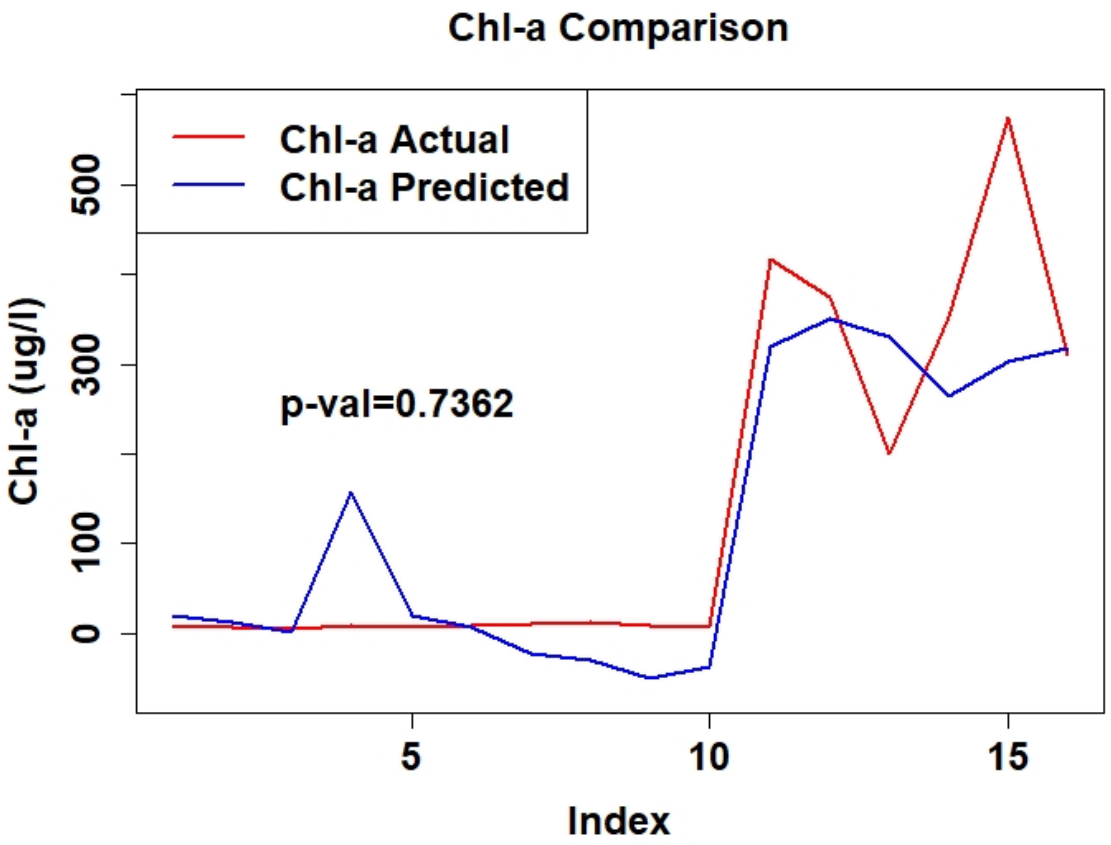


MULTIPLE VARIABLE VALIDATION

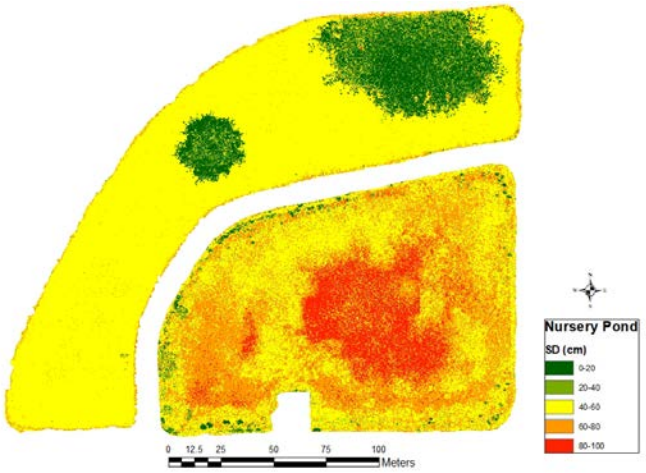


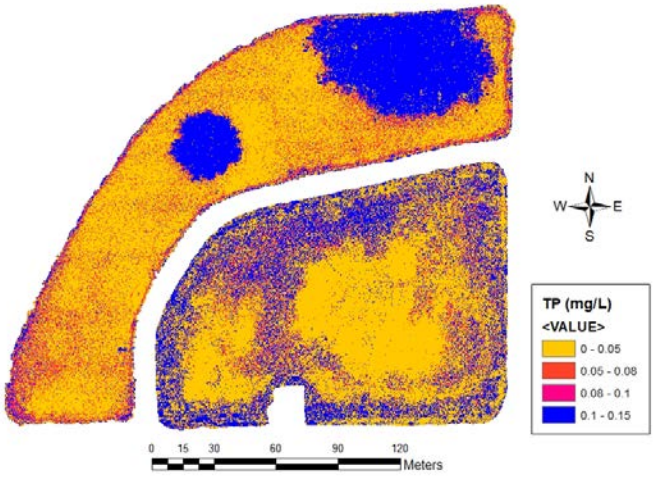


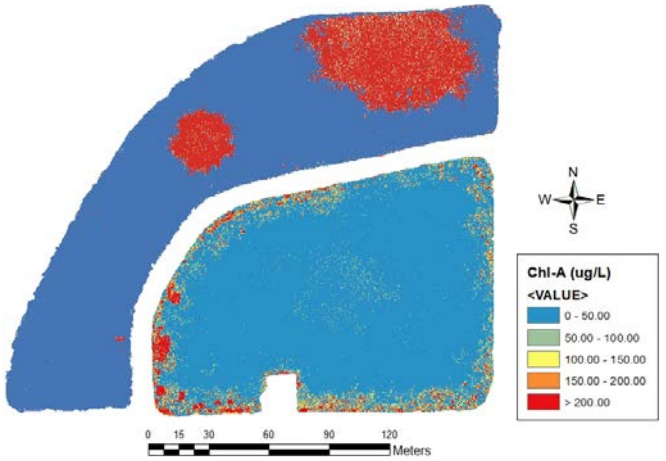
MULTIPLE VARIABLE VALIDATION

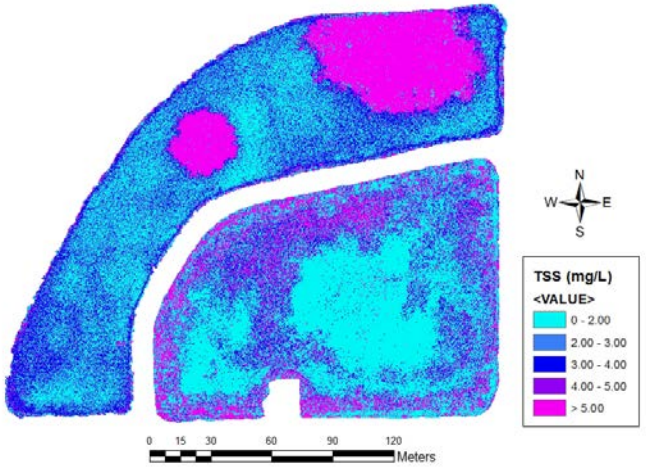


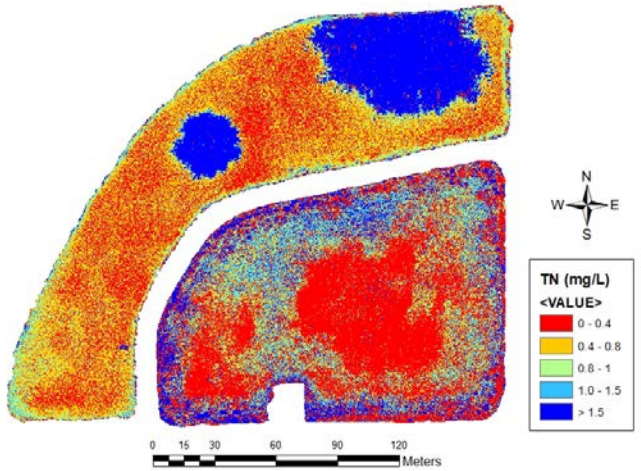
NURSERY POND – WATER QUALITY



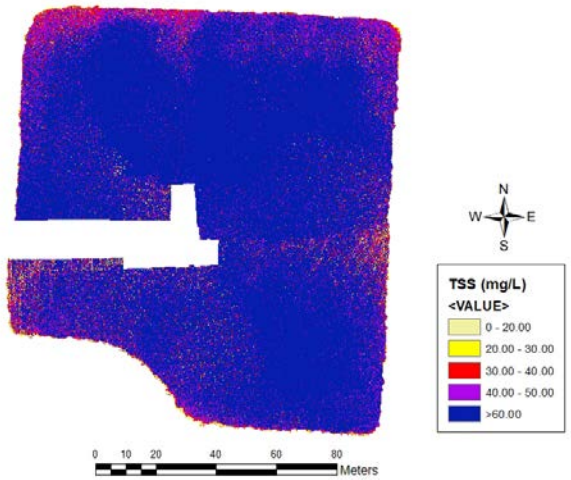


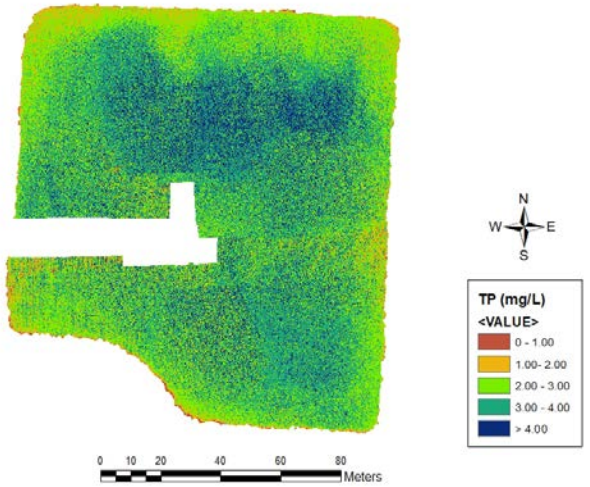


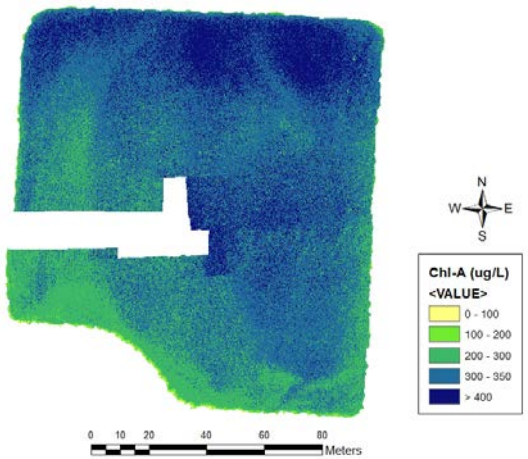


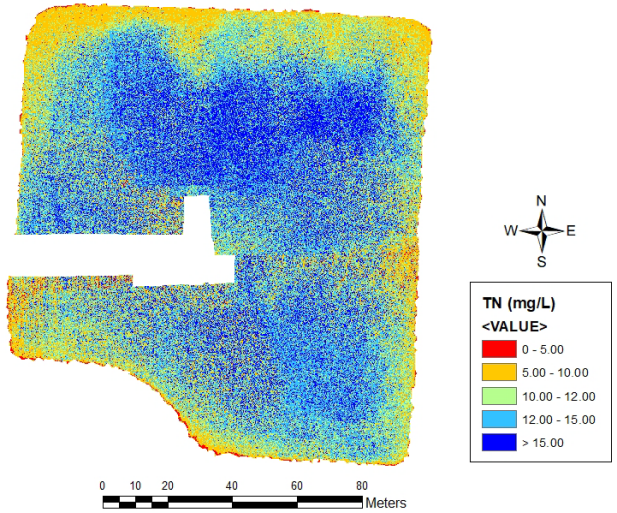


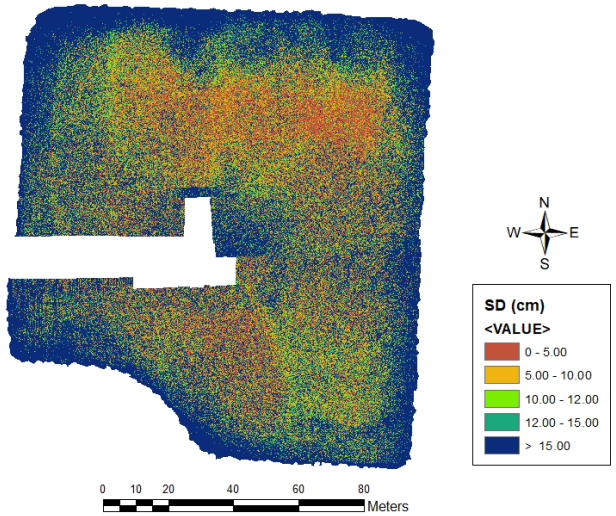
WASTEWATER LAGOONS – WATER QUALITY











FINAL CONCLUSIONS

- Optical and non-optical water quality parameters can be predicted using sUAS
- Statistical interpolation (ordinary kriging) does not improve the relationship between the different water quality parameters and the reflectance values
- Single linear models have the capability to predict different water quality parameters; however, multiple linear models can explain these relationships in a better way (higher R^2)

THANK YOU

QUESTIONS?

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