IfSAR DTM-DERIVED PREDICTIVE FLOOD MODELS: A COST-EFFECTIVE APPROACH TO TARGET SITE-SPECIFIC MOSQUITO (DIPTERA: CULICIDAE) CONTROL EFFORTS

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Title

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

DOCTOR OF PHILOSOPHY

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ABSTRACT

The study area is the 400 km^2 floodplain and wetlands of the upper Missouri River, located in the northwestern corner of North Dakota, near the community of Williston. Regional climate is semiarid, yet the Williston vector control agency battles large populations of Culicidae nearly every spring and summer. Best mosquito management practices (BMPs) are integrated, relying on a combination of thorough, routine, ground-based sampling and surveillance methods to provide important information on which control strategies and evaluations of effective are based. However, the mosquito breeding habitat near Williston is extensive and contains difficult terrain, which makes standard ground-based sampling and surveillance methods impractical. This study analyzed remotely sensed Interferometric Synthetic Aperture Radar (IfSAR) Digital Terrain Model (DTM) elevation data as a potential alternative for ground-based methods. Remotely sensed IfSAR technology is relative low-cost, has high-spatial resolution, is not limited by inclement weather, and only needs to be collected once if local topography remains stable. IfSAR elevation data provides information needed to model hydrological characteristics such as slope, aspect, water flow direction, and accumulation, important considerations in relation to mosquito control efforts. Predictive flood models, developed in this study from the IfSAR elevation data, make it possible to predict the locations of water accumulation within the floodplain as river elevations fluctuate. A vertical root mean squares error (RMSEz) assessment of the full IfSAR elevation data in all land cover classifications combined was 1.071 m, consistent with the vendor's stated RMSEz of 1 meter. The vertical accuracy of the full IfSAR data was 2.099 meters at the 95% confidence level and is consistent with the 95th percentile accuracy of 2.211 meters. The frequency distribution of errors was generally normal. This study determined that airborne, high-resolution IfSAR DTM-elevation data can serve as an alternative for ground-based sampling and surveillance methods and provide a needed decision support system (DSS) tool to the local vector control agency. The predictive flood models are a new approach for predicting the locations of accumulated water within the floodplain will decrease vector control response time and improve the targeting of site-specific control efforts, which in turn, will decrease overall costs for these services.

KEYWORDS: *Ae. vexans, Cx. tarsalis*, Vector Control, IPM, BMP, Remote Sensing; Geospatial Technologies; GIS; GPS; Floodplain and Wetlands; Interferometric Synthetic Aperture Radar; IfSAR; Digital Terrain Models; DTM

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My journey to graduate school began twenty-five years ago. The following are many individuals and groups from across the US that provided support and encouragement concerning Williston's mosquito problems, and to whom I owe much gratitude (listed in chronological order where possible): the Williston Bug Busters (Bethanne Barkie, Trudy Nelson MD, Holly Radtke, Janell Sailer, and Jan Sell); the US Army Corps of Engineers (USACE), Williston Branch Range Managers, LeRoy Phillips and Jeff Keller; scientific researcher and author, the late Cindy Duehring and her husband, Pastor Jim Duehring; WVCD field directors Carol Weisgerber, Bob Hayes, and David Benth; WVCD board of commissioners Carol Weisgerber, Dr. Paul Olson, Neil Westergard, Jolene Tinker, Dr. Wayne Anderson, and Ken Kjos; Dr. Wayne Kramer entomologist, Nebraska State Department of Health; Dr. Al Cofrancescio, entomologist, USACE Research and Development, Vicksburg, MS; Jack Stewart, Stark County, ND Vector Control Director; Joel Young, Cass County, ND Vector Control Director; Dr. Robert Novak, entomologist, past president of the American Mosquito Control Association (AMCA); Dr. Claude Schmidt, past president of the AMCA; management and staff at the Williston Daily Herald; staff members at the Williston Public Library, Williston city mayor, Ward Koeser; and Williston city commissioners Frank Underhill and Kelly Keith. I am also thankful for support from the following faculty, administration, and staff at Williston State College (formerly University of North Dakota - Williston): WSC foundation executive director Terry Olson and board members; administration employees Helen Overbo, Wanda Meyer, and Dr. Raymond Nadolny;

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DEDICATION

First and foremost, this disquisition is dedicated to my husband Mark, our children and their spouses, Amy and Chad, and Eric and Jenny, and our three grandsons, Max, Charlie, and Russell. They are the reason why finding safer, more effective mosquito control strategies were, and continue to be so important to this author.

This disquisition is also dedicated to the residents of Williston, ND, a community of about 25,000, located on the banks of the upper Missouri River. Residents of this city and surrounding area endure annual climatological events typical of the mid-continental Great Plains, with long cold winters, blizzards and ice-storms, record-breaking minus-50 degrees F temperatures, and short, hot, summers, heat waves of 90 to 100^{+} degrees F, occasional hail, tornadoes, and devastating droughts. Williston has also endured three oil boom/busts cycles since the early 1950s. Through it all, residents have maintained their community pride, sense of humor, and 'we will make it through this' determination. However, during the 1980s Williston was emotionally, physically, politically, and spiritually broken by hordes of tiny insects commonly known as mosquitoes (Diptera: Culicidae). A group of courageous women nick-named the 'Bug Busters' never gave up their determination during the late 1980s and early 1990s, to find an environmentally safe solution for Williston's mosquito problem. The group spent more than a year contacting entomologists and vector control agencies across the U.S., asked questions, and gathered documentation concerning safer pest management strategies. The information gained by their efforts was shared with community leaders and was instrumental in Williston's implementation of an integrated pest management (IPM) program. This disquisition is also dedicated to Bug Busters, Bethanne Barkie, Trudy Nelson MD, Holly Radtke, Janelle Sailer, and Jan Sell and their families.

This disquisition is also dedicated to the memory of Cynthia Froeschle Duehring, 1962 - 1999. An improper application of the organophosphate pesticide forced Cindy to stop her pre-med studies in Tacoma, WA and return to North Dakota, where she spent the rest of her life researching the toxic health effects associated with low levels of chemical exposure. The aim of Cindy's work was to stimulate society to reassess the impact of the more than 75,000 synthetic chemicals in common use, some of which have received very limited human toxicity testing. Many consumer products are protected by laws involving trade secrecy and, as such, can go virtually unregulated. In 1994, Cindy received the Resourceful

Woman Leadership Award for her work concerning toxic chemicals. Cindy's research concerning toxic pesticides was made available to local Williston vector control officials, community, county, state, and federal officials, local medical, legal, and lay people, and the local newspaper. Cindy's research was also instrumental in the WVCD's transition to a safer, more cost-effective, IPM mosquito abatement program in Williston.

On December 8, 1997, Cindy was the recipient of the Right Livelihood Award, which was presented to her husband, Jim, in the Swedish Parliament, Stockholm, Sweden (Right Livelihood Award 1997). The award recognizes the efforts of individuals worldwide who tackle challenges facing humanity, such as the pollution of air, soil and water, the dangers of nuclear war, the abuse of human rights, the destitution and misery of the poor, and the over-consumption and spiritual poverty of the wealthy. To date, laureates of the Right Livelihood Award total 162 individuals from 67 countries. Cindy was born 10 Aug 1962 in Bismarck, ND and died 29 June 1999 in Williston, ND at the age of age 35, http://www.rightlivelihoodaward.org/laureates/cindy-duehring/ (2016), accessed March 2017.

"*There are rivers of all lengths and sizes and of all degrees of wetness. There are rivers with all sorts of peculiarities and with widely varying claims to fame. But there is only one river with a personality, habits, dispositions, a sense of humor and a woman's caprice; a river that goes traveling sidewise, that interferes in politics, rearranges geography and dabbles in real estate; a river that plays hide and seek with you today and tomorrow follows you around like a pet dog with a dynamite cracker tied to its tail. That river is the Missouri*."

- George Fitch, "The Missouri River: Its Habits and Eccentricities Described by a Personal Friend," *American Magazine,* Vol. 53, No. 6 (April 1907), 637-40

"*Strength does not come from physical capacity. It comes from an indomitable will*."

- Mahatma Gandhi

"*Do nothing out of selfish ambition or vain conceit. Rather, in humility value others above yourselves, not looking to your own interests but each of you to interests of the others."*

- Philippians 2: 3-4

"*You're not going to always hit a home run in life. You're going to strike out! You're going to walk to the dugout of life, frustrated, while spectators chirp your name in judgment. They're afraid to even get on the field, and you know it. The fact that you get back up there, unafraid, going after that next home run, makes you the person you are*."

- Ron Baratono, The Writings of Ron Baratono

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LIST OF ABBREVIATIONS

2D; 2-D .... Two-dimensions; latitude (x), longitude (y)

3D; 3-D .... Three-dimensions; includes latitude (x), longitude (y), and height/elevation (z)

4D; 4-D .... 4-dimensions; includes latitude (x), longitude (y), height/elevation (z); and time (t)

A .... Approved; used by USGS Real-time-water and river gaging data

AB .... Aquatic Bed; a wetland class within the Palustrine Wetland Classification system

Abs .... Absolute

$Accuracy_z$ .... Vertical accuracy; equal to the RMSEz multiplied by the critical value for a selected confidence level

ac .... Acres

Ae. .... Generic name *Aedes* Meigen

AMCA .... American Mosquito Control Association, Mount Laurel, NJ

An. .... Generic name *Anopheles* Meigen

AOI .... Area(s) of Interest

ArcGIS .... Esri (formerly ESRI) Geographic Information Systems mapping systems software

ArcInfo .... Esri (formerly ESRI) professional level Geospatial Information Systems mapping software with full features and highest licensing

ArcScene .... Esri (formerly ESRI) Geographic Information Systems 3D mapping software

ASPRS .... American Society of Photogrammetry and Remote Sensing, Bethesda, MD

ASTER .... Advanced Space-borne Thermal Emission Reflection Radiometer sensor for land surface temperatures, reflectance, and elevations

B .... Blue; visual electromagnetic energy between 0.45 to 0.52 µm Wavelengths

B .... Represents the classification arid, used in the Köppen-Geiger (i.e., Koeppen-Geiger) World Climate Classification System

.bil .... Band Interleaved by Line; a file format for remotely sensed data with any number of bands

BM .... Benchmark; refers to National Geodetic Survey (NGS) monuments

BMP .... Best [Mosquito] Management Practices

Bs .... *Bacillus sphaericus*; aerobic, gram-positive, spore-forming bacterium used in the control of certain Diptera; bacterium produce an inclusion body toxic to larvae; when ingested the toxins bind to receptors on brush border of gastric and midgut epithelial cells and cause pore formation in cell membranes, disruption of osmosis, lysis of cells, and death of the feeding larvae; does not affect non-feeding pupae

BSk .... Represents the classifications Arid (B); Steppe (S); Cold-Arid (k) climate found areas such as western North Dakota; used in the Köppen-Geiger (i.e., Koeppen-Geiger) World Climate Classification System

BSL .... Biosafety Level

Bti .... *Bacillus thuringiensis var israelensis*; aerobic, gram-positive, spore-forming bacterium used in the control of certain Diptera; bacterium produce parasporal crystal delta-endotoxins; when ingested, endotoxins bind to the surface of midgut epithelial cells, disruption of osmosis, lysis of cells, and death of the feeding larvae; does not affect non-feeding pupae

CDC .... Centers for Disease Control and Prevention, Atlanta, GA

CE; CEV .... California Encephalitis; California Encephalitis virus; taxonomic family or genus*: Orthobunyavirus*; recommended BSL: 2; HEPA filtration is not required on lab exhaust; spherical, enveloped RNA arbovirus transmitted by Culicidae

CL .... Confidence Level; the percentage of values within a dataset that are estimated to meet the stated accuracy; e.g. 95% CL means 95% of the values in the dataset will have error equal to, or smaller than the reported accuracy value, with respect to the true value.

CNS .... Central Nervous System

Critical values of z .... A statistical factor z (i.e., z-score); used to estimate the margin of error when the number of samples is large

Cq. .... Generic name *Coquillettidia* Dyar

Cs. .... Generic name *Culiseta* Felt

Cum .... Cumulative

Cux. .... Subgeneric name *Culex* Linnaeus

CVA .... NDEP abbreviation for Consolidated Vertical Accuracy at the 95^{th} percentile in all land cover categories combined; updated to Vegetated Vertical Accuracy (VVA) by ASPRS 2014

DD; D.d.. Decimal Degrees; an alternative format for latitude and longitude

DEM .... Digital Elevation Model; includes DTMs and DSMs

DM; DM.m .... Degree Minutes; an alternative format for latitude and longitude

DMS; DMS.s .... Degree Minute Seconds; an alternative format for latitude and longitude

DRG .... Digital Raster Graphic; topographic data

DSM .... Digital Surface Model; based on unobstructed areas with moderately sloped terrain; models the top elevations of vegetation and structures; a type of DEM

DSS .... Decision Support System

DTM... Digital Terrain Model; based on unobstructed areas with moderately sloped terrain; models bare earth elevations; a type of DEM

EEE; EEEV... Eastern Equine Encephalomyelitis; Eastern Equine Encephalomyelitis virus; taxonomic family or genus: *Alphavirus*; recommended BSL: 3; HEPA filtration is not required on lab exhaust; single-stranded RNA arbovirus transmitted by Culicidae

EIA... U.S. Energy Information Administration, Washington, DC

EM .... Electromagnetic; refers to electromagnetic spectrum

EM .... Emergent; a wetland class within the Palustrine Wetland Classification system

EM1 .... Emergent (EM) wetland class; Subclass Persistent (1) within the Palustrine Wetland Classification system

ENVI .... Environment for Visualizing Images; processing software for satellite imagery; Research Systems, Inc., Melbourne, FL

EPA .... U.S. Environmental Protection Agency, Washington, DC

EPA/CDC .... Environmental Protection Agency/Centers for Disease Control and Prevention; published a joint statement on mosquito control

EDA .... Exploratory Data Analysis

Esri .... Formerly ESRI; Environmental Systems Research Institute, Redlands, CA

-ETM+, Landsat-7 .... Enhanced Thematic Mapper sensor systems mounted on Landsat-7; 1999 to date; sensors record electromagnetic energy in 15-, 30- and 60-meter spatial resolution using eight bands; archived Landsat imagery recorded by ETM+ sensors use identification letters LE (i.e., **L**andsat **E**TM+)

-ETM+, Landsat-8 .... Enhanced Thematic Mapper sensor systems mounted on Landsat-8; 2013 to date; sensors record electromagnetic energy in 15- and 30- meter spatial resolution using 11 bands; archived Landsat imagery recorded by ETM+ sensors use identification letters LE (i.e., **L**andsat **E**TM+)

EULA .... End User License Agreement; part of Intermap Technology contract with WVCD

FEMA .... Federal Emergency Management Agency, Washington, DC

FGDC .... Federal Geographic Data Committee, Reston, VA

FO .... Forested; a wetlands class within the Palustrine Wetlands Classification system

FP .... Part of NATO's MGRS coordinate system; used by military; refers to a 100,000-m^2 grid within UTM Zone 13U for the Williston, ND area

FSA .... Farm Service Agency, Washington, DC

ft, international; ift .... One standard or international foot; equals 0.3048 m

ft, US survey; sft .... United States survey ft equals 1200/3937 m; used with State Plane Coordinate Systems of 1927 and 1983

ft^2 .... Refers to international $foot^2$ or foot squared; equals 0.092903 m^2

ft msl .... Feet (foot) mean sea level

FTP .... File Transfer Protocol

FVA .... NDEP abbreviation for Fundamental Vertical Accuracy at the 95% confidence level in open terrain where errors should approximate a normal error distribution

G .... Green; visible electromagnetic energy between 0.52 to 0.6 µm wavelengths

GCS .... Geographic Coordinate System; measurements are in degrees of latitude and longitude; used with global views of the earth; no projection in GCS; not appropriate for flat maps

GDG .... Geodata Gateway; sponsored by USDA

GEOID99 .... Hypothetical model of the Earth's shape referenced to mean sea level; used as a conversion factor in geospatial technologies; updated model of the geoid for the United States and supersedes GEOID96, GEOID93, and GEOID90

GIS .... Geographic Information Systems; computer-based spreadsheet and mapping system that can store, query, update large volumes of data, and create maps if locational coordinate data are available

GME .... Geospatial Modelling Environment, Brisbane, Australia

GPS .... Global Positioning Systems, based on a reference geoid

GRS .... Geodetic Reference System

GRS80 .... Geocentric reference ellipsoid for North American Datum 1983 (NAD83)

GSD .... Ground Sampling Distance; grid spacing used with raster data

GTOPO30 .... 900-m global elevation data; ground sampling space of 30-arc-seconds (1/120th of a degree of latitude and latitude, 0.008333333333333 decimal degrees (DD; D.d), 900 m 2,952.76 ft); vertical units in meters above mean sea level

H_A .... Alternative hypothesis

ha .... Hectare; equal to 0.01 km^2; 2.47 ac; 0.004 mi.^{2}

HARN .... High Accuracy Reference Network

HH polarization .... Code letters used in active radar and Lidar technologies to identify the horizontal restriction used on light energy during transmission and reception

H_O .... Null hypothesis

HUC 10 .... Hydrologic Unit Code 10; the two-digit code number that represents the Missouri River watershed region

ICTV .... International Committee on Taxonomy of Virus

IfSAR/InSAR/ISAR .... Interferometric Synthetic Aperture Radar; IfSAR; InSAR; ISAR active remote sensing technology used to determine bare-earth elevations or height of objects; IfSAR generators are mounted on airborne or satellite platforms, and produce invisible electromagnetic energy in the 1 to 100 cm wavelengths (i.e., microwave energy range); energy is directed toward the ground or an object; the returned energy is recorded by the IfSAR sensor; the IfSAR technology requires two sets of data, either by using a single flight-pass with two generators/sensors, or two flight passes using one generator/sensor; the two sets of data are triangulated with the location of the mounted generators to produce 3-D elevation data; IfSAR technology is not the same as

SAR technology, which is used to measure the speed of moving objects such as glaciers or vehicles

IfSAR DTM .... Interferometric Synthetic Aperture Radar Digital Terrain Model

IfSAR DSM .... Interferometric Synthetic Aperture Radar Digital Surface Model

IfSAR ORI .... Interferometric Synthetic Aperture Radar Orthorectified Image

iGETT .... Integrated Geospatial Education and Technology Training, Corpus Christi, TX

k .... A letter used in Köppen-Geiger (i.e., Koeppen-Geiger) World Climate Classification System; k represents cold average annual temperatures such as western North Dakota

KLJ .... Kadrmas, Lee and Jackson Engineering, Inc., Williston, ND

km .... Kilometer; one kilometer equals 0.621 mi.

km^2 .... Kilometer^2; kilometer(s) squared; one km^2 equals 237.01 acres; 100 ha; 0.386 mi.^{2}

L .... Lacustrine; a wetland system

L1 .... Lacustrine wetland system (L), Limnetic Subsystem (lakes) (1)

L2 .... Lacustrine wetland system (L), Littoral Subsystem (high-water mark to shore) (2)

LASER .... Light Amplification by Stimulated Emission of Radiation light

Lat .... Latitude; imaginary locational lines that circle the earth east to west (i.e., parallel or horizontal to the equator), similar to rungs on a ladder; latitude value at the equator equals zero; locational coordinates are in angular units of degrees, minutes, seconds (DMS; DMS.s), degree minutes (DM: DM.m), or decimal degrees (DD; D.d); when moving north or south toward either pole, latitude values increase; 1 degree of latitude equals approximately 111 km (69 mi.) no matter the location on the earth; latitude lines are referred to as parallels

LE .... Letter system that identifies archived Landsat imagery recorded by Enhanced Thematic Mapper (ETM+) scanner systems

LEC .... North Dakota Lignite Energy Council

LiDAR .... Light Detection and Ranging; active remote sensing method that uses pulses of laser (i.e., packed beams of light in the 1064 nm range [1.064e-6 m] of the electromagnetic spectrum; high-spatial resolution technology used to measure elevations

LM .... Letter system that identifies archived Landsat imagery recorded by Multispectral Scanner (MSS) systems

Long .... Longitude; imaginary locational lines that circle the earth, pole to pole (i.e., perpendicular to the equator); locational coordinates are in angular units of degrees, minutes, seconds (DMS; DMS.s), degree minutes (DM; DM.m), or decimal degrees (DD; D.d); longitudinal lines are called meridians; zero longitude is referred to as the prime meridian and is a line from pole to pole that runs through Greenwich, England; the measure of longitude is east or west of the prime meridian; positive longitudinal numbers are east of the prime meridian; negative numbers are west of the prime meridian; at the equator; one degree of longitude at the equator equals about 111 km (69 mi.); when moving north or south of the equator, degrees of longitude decrease due to the convergence of the meridians toward either pole

LT .... Letter system that identifies archived Landsat imagery recorded by Thematic Mapper (TM) scanner systems

m .... Meter; one meter equals 0.001 km, 3.28084 ft. 0.00062 mi.

m^2 .... $Meter^2$ or meter(s) squared; one square meter equals 1e-6 km^2; 0.000247 ac, 0.0001 ha; 10.764 fft^2

MGRS.. Military Grid Reference System; alphanumeric, hierarchical system based on Universal Transverse Mercator (UTM) projection; similar to U.S. National Grid (USNG); used by the military to quickly and accurately determine any location on the earth

mi.. Mile

$mi.^2$ .... $Mile^2$ or mile(s) squared; one square mile equals 2.788e+7 ft^2; 2.58999 km^2; 640 ac; 258.999 ha

mph .... Miles per hour

MRC .... Missouri River Commission; geodetic survey of the Missouri River; 1885 to 1902

MRLC .... Multi-resolution Land Characteristics Consortium (MRLC); land use/land cover data

msl; MSL .... Mean sea level; refers to the elevation for a location; mass and gravitation impact the elevations for a locality

-MSS, Landsat-1, -2, -3........................... Multispectral Scanner systems; mounted on Landsat-1, - 2, and -3 satellites between 1972 to 1983; sensors record electromagnetic energy in 60-meter spatial resolution using four bands; archived Landsat imagery recorded by MSS systems use identification letters LM (i.e., **L**andsat **M**SS)

-MSS, Landsat-4, -5 .... Multispectral Scanner systems; mounted on Landsat-4, -5 satellites between 1983 to 2013; sensors record electromagnetic energy in 60-m spatial resolution using four bands; archived Landsat imagery recorded by MSS systems use identification letters LM (i.e., **L**andsat **M**SS)

MTI .... Mosquito Taxonomy Inventory

n .... Number of samples

N.. North

n48w102... Latitude 48 north, Longitude 102 west; part of IfSAR DTM metadata description

NAD 83; NAD83 .... North American Datum of 1983; geocentric; based on ellipsoid GRS 80

NAIP .... National Agriculture Imagery Program

NARA .... National Records and Records Administration, College Park, MD

NAVD 88; NAVD88 .... North American Vertical Datum 1988; altitude datum; a reference surface geoid for heights (elevations) based on mean sea level and gravity

NC .... The US state of North Carolina

NCBI... National Center for Biotechnology Information

NDEP .... National Digital Elevation Program

NDgisHub... North Dakota GIS Data Portal

NDGS... North Dakota Geological Survey, Bismarck, ND

ND.gov .... North Dakota State Government website

NDhealth .... North Dakota Department of Health, Bismarck, ND

ND DMR... North Dakota Department of Natural Resources, Bismarck, ND

NDSU .... North Dakota State University, Fargo, ND

NDVI... Normalized Difference Vegetative Index; uses satellite imagery to estimate the density and quality of plant growth (i.e., health)

NED.. National Elevation Dataset

NEXTmap... Intermap Technology, Inc. online geospatial store

NGA.. National Geospatial-intelligence Agency, Springfield, VA; maintains the World Geodetic System 1984 (WGS84)

NGS.. National Geodetic Survey

NHD..National Hydrography Dataset

NHDplus2..National Hydrography Dataset Plus2

NIR ....Near Infrared; invisible electromagnetic energy in the range of 0.7 to 1.1 µm wavelengths; near visible red

NLCD..National Land Cover Dataset, classification system by Anderson et al. (1976)

nm ....Nanometer; 10^{-9} meter

NMAS..National Map Accuracy Standards, 1947

NOAA ....National Oceanic and Atmospheric Administration, Silver Springs, MD

NRC..National Research Council, Washington, DC

NSSDA..National Standard for Spatial Data Accuracy (Federal Geographic Data Committee) (FGDC 1998)

NVA ....ASPRS (2014) term for Non-vegetated Vertical Accuracy at the 95% confidence level in open terrain only where errors should follow a normal error distribution

NWI ....National Wetlands Inventory, classification System; sponsored by USFWS

NWI Codes...National Wetlands Inventory Codes and Diagram; identifies wetland systems, subsystem, classes, and subclasses

NWPL..National Wetland Plant List

NWS..National Weather Service, Sloulin International Air Field, Williston, ND; NWS currently moved to Bismarck, ND

Or. ....Generic name *Orthopodomyia* Theobald

ORI...Orthorectified Image

P ....Palustrine (i.e., persistent) Wetland System

P. ....*Plasmodium*; *P. falciparium, P. malariae, P. ovale,* and *P. vivax*

P ....Provisional; used with USGS Real-time Water gaging station data if data has not been confirmed acceptable

PAB ....Palustrine Wetland System (P), Aquatic Bed Class (AB)

PAHO ....Pan American Health Organization, Washington, DC

PEM..Palustrine Wetland System (P), Emergent Class (EM)

PFO..Palustrine Wetland System (P), Forested Class (FO)

PID ....Permanent Identifier; refers to an identification system for National Geodetic Survey monuments, which uses two letters and four numbers

PLSS ....Public Land Survey System; refers to township, range, and section lines

P/R ....Path/Row; refers to the satellite orbit path and row used in Landsat World Reference System-1 (WRS-1) and Landsat World Reference System-2 (WRS-2)

Ps. ....Generic name *Psorophora* Robineau-Desvoidy

PSS ....Palustrine Wetland System (P), Scrub-Shrub class (SS)

PUB..Palustrine Wetland System (P), Unconsolidated Bottom class (UB)

QA ....Quality Assessment (assurance) of a dataset for horizontal and/or vertical accuracy and usability; steps taken to ensure a client receives a quality product

QC..Quality Control; procedures taken by data producers to ensure data is accurate

QQ Plot...Quantile-Quantile plot; probability chart that compares values of a dataset to the expected values

R...Red; visible electromagnetic energy within the 0.63 to 0.69 µm wavelength

R...Riverine Wetland System

R4...Riverine Wetland System (R); Intermittent subsystem (4)

R4US..Riverine Wetland System (R), Intermittent subsystem (4), Unconsolidated Shore class (US)

RADAR..Radio Detection and Ranging technology; active system; side-looking; microwave range of the EM spectrum

RADARSAT-1 and -2 ....Canadian commercial radar satellites

RGB..Red, Green, Blue; refers to the primary colors of light; all three colors combined result in white light; RGB processing is used largely with satellite data because their sensors collect EM energy in multiple bands; to produce an image from a Landsat-7 satellite, three of the eight EM bands collected by the satellite sensor are assigned a different primary color of light using specialized software, then combined to produce the image; the image may be in natural color or false color, depending on the specific bands used and color assigned to each band; RGB processing provides more information than using only one band of EM alone to produce an image; there are standard RGB combinations that are used for specific needs, such as defining water from land or identifying sediment in water

RM..River mile; refers to USACE mile markers for Missouri River

$RMSE_z$..Vertical Root Mean Squares Error

RNA..Ribonucleic Acid

RTK-GPS ....Real-Time-Kinematic - Global Positioning Systems

RVF; RVFV...Rift Valley Fever; Rift Valley Fever virus; taxonomic family or genus: *Phlebovirus*; recommended BSL: 3; HEPA filtration is required on lab exhaust; segmented, negative RNA arbovirus transmitted by Culicidae

S ....Köppen-Geiger (Koeppen-Geiger) World Climate Classification System; S represents Steppe (i.e., a prairie), generally a large geographic area, flat, treeless grasslands, mid-continental; often with wide diurnal temperature variations such as western North Dakota

SAS ....Statistical Analysis Software, Cary, NC

SIN: SINV ....Sinbis; Sinbis virus; taxonomic family or genus: *Alphavirus*; recommended BSL: 2; HEPA filtration is not required on lab exhaust; positive single-stranded RNA arbovirus transmitted by Culicidae

SLC ....Scan Line Corrector

SLE; SLEV ....St. Louis Encephalitis; St. Louis Encephalitis virus; taxonomic family or genus: *Flavivirus*; recommended BSL: 3; HEPA filter is not required on lab exhaust; positive, single-stranded, RNA arbovirus transmitted by Culicidae

SRTM ....Shuttle Radar Tomography Mission; topographic data collected by satellite in 2000 using interferometric radar technology

SS..Scrub/shrub Wetlands Class within Palustrine Wetland System

SSURGO..Detailed soil database; at scales of 1:12,000 or 1:63,000; sponsored by Esri

SVA ....Supplemental Vertical Accuracy; the NDEP term for reporting vertical accuracy at the 95^{th} percentile in each separate land cover category when vertical errors do not follow a normal error distribution; merged with Vegetated Vertical Accuracy (VVA) by ASPRS 2014

t ....4^{th} dimensional variable of time

T3G .... Teachers Teaching Teachers GIS, Esri workshop, Redlands, CA

.tif; .tiff .... Tag Image File format for storing/exchanging raster graphics

-TM, Landsat-4, -5 .... Thematic Mapper sensor systems mounted on Landsat-4 and -5; 1982 to 2012; TM sensors record electromagnetic energy in 30-meter spatial resolution using 7 bands; archived Landsat TM imagery identification Includes LT (i.e., **L**andsat **T**M)

TOC .... Top of Canopy

TWI .... Topographic Wetness Index; model that simulates water movement through a watershed; predicts soil moisture and areas susceptible for saturation and potential overland water flow

U .... Locational latitude band where Williston, ND is located; part of the Military Grid Reference System in Universal Transverse Mercator (UTM) projection

UB .... Unconsolidated Bottom; a wetland class within the Palustrine Wetlands Classification system

UF .... University of Florida

µm .... micrometer equals $1e^{-6}$ m or $1e^{-9}$ km

UNLP .... University of Nebraska – Lincoln Press, Lincoln, NE

Ur. .... Generic name *Uranotaenia* Lynch Arribálzaga

US .... Unconsolidated Shoreline; a wetland class within the Palustrine Wetland Classification System

U.S.; US .... United States

USNG .... U.S. National Grid locational system; similar to Military Grid Reference System (MRGS)

USACE .... United States Army Corps of Engineers, Washington, DC

USAFR .... United States Army Corps of Engineers, Washington, DC Youngstown Air Reserve Station, Ohio; consists of three Squadrons (i.e., Medical Squadron, one flying squadron, and an Operations Support Squadron); the flying squadron is the 757th Airlift Squadron and includes the only large-area fixed-wing aerial spray mission in the Department of Defense

USDA .... United States Department of Agriculture, Washington, DC

USDA-FS .... United States Department of Agriculture – Forest Service, Washington, DC

USDA-FSA .... United States Department of Agriculture – Farm Service Agency, Washington, DC

USFWS .... United States Fish and Wildlife Service, Washington, DC

USGS .... United States Geological Survey, Reston, VA

UTM... Universal Transverse Mercator projection; a locational grid system using coordinates in Northing and Easting

UVA .... Unmanned Aerial Vehicle(s); drones

VA... U.S. state of Virginia

VEE; VEEV... Venezuelan Equine Encephalitis; Venezuelan Equine Encephalitis virus; taxonomic family or genus: *Alphavirus*; recommended BSL: 3; HEPA filtration is required on lab exhaust; positive, single-stranded RNA arbovirus transmitted by Culicidae

VVA .... Vegetated Vertical Accuracy (VVA); refers to an estimate of the vertical accuracy, at the 95th percentile in vegetated terrain where errors do not approximate a normal error distribution

W .... West

WA... The U.S. state of Washington

WBD .... Watershed Boundary Dataset

WEE; WEEV .... Western Equine Encephalomyelitis; Western Equine Encephalomyelitis virus; taxonomic family or genus: *Alphavirus*; recommended BSL: 3; HEPA filtration is not required on lab exhaust; positive, single-stranded RNA arbovirus transmitted by Culicidae

WGS84; WGS 84 .... World Geodetic System 1984; the most widely used geocentric datum and geographic coordinate system (GCS) commonly used with GPS; maintained by the National Geospatial-intelligence Agency (NGS)

WHO... World Health Organization, Geneva, Switzerland

WN; WNV... West Nile; West Nile virus; taxonomic family or genus; *Flavivirus*; recommended BSL: 3; HEPA filtration is not required on lab exhaust; positive, single-stranded RNA arbovirus transmitted by Culicidae

WRBU .... Walter Reed Biosystematics Unit, Suitland, MD

WRS-1... Worldwide Reference System-1 that uses a Path/Row (P/R) Identification system for Landsat-1, -2, -3

WRS-2... Worldwide Reference System-2 that uses a Path/Row (P/R) Identification for Landsat-4, -5, -7, -8

WSC .... Williston State College, Williston, ND; formerly University of North Dakota – Williston (UND-W), ND

WSU .... Washington State University, Pullman, Washington

WVCD .... Williston Vector Control, District #1; Williston, ND

x .... Locational coordinate, latitude; east-west direction

x-Band .... Identification code used for a specific band of EM energy within the microwave range (i.e., radar); invisible 3.75- to 2.4-cm wavelengths

y .... Locational coordinate, longitude; north-south direction

YF; YFV .... Yellow Fever; Yellow Fever virus; taxonomic family or genus: *Flavivirus*; recommended BSL: 3; HEPA filtration is required on lab exhaust; positive, single-stranded RNA arbovirus transmitted by Culicidae

z .... Locational coordinate for vertical (height; elevation); defines a three-dimensional space; units of measure are in m msl or ft msl

z-factor .... A conversion factor based on latitude that must be used when creating hillshade and slope maps in GIS

z-scores; critical z-values .... Represents the number of standard deviations from the mean

ZIKA; ZIKAV .... Zika; Zika virus; taxonomic family or genus: *Flavivirus*; recommended BSL: 2; HEPA filtration is not required on lab exhaust; positive, single-stranded RNA arbovirus transmitted by Culicidae

Zone 13 .... Universal Transverse Mercator (UTM) Zone 13; appropriate UTM zone for western North Dakota

INTRODUCTION

Mosquitoes (Diptera: Culicidae) are considered by many experts to be the most dangerous pest complex on Earth (Scott 2007, American Mosquito Control Association [AMCA] 2014, World Health Organization [WHO] 2017b). Mosquitoes cause more illness, suffering, and death in humans and other animals (i.e., dogs, cattle, poultry, and certain species of migratory birds, rabbits, and horses) than any other organism on Earth. A child dies every two minutes from malaria (WHO 2016). The most efficient, cost-effective, and environmentally safe mosquito control strategies are those that integrate a combination of best [mosquito] management practices (BMPs) (i.e., Integrated Pest Management [IPM], Integrated Vector Management [IVM]) that include the elimination, reduction or management of breeding habitat, changes in local cultural practices, and the use of biological control agents, biopesticides, monomolecular films, and chemical controls (WHO 2008, Environmental Protection Agency [EPA] with the Centers for Disease Control and Prevention [CDC] [EPA/CDC 2012], AMCA 2009, 2017).

Best management practices rely on a combination of thorough, routine, ground-based sampling and surveillance techniques to provide important information on which the timely targeting and application of control strategies, and evaluation of their effectiveness are based. The unlimited variety and hidden nature of mosquito breeding habitat, and the non-random aggregation, diurnal circumnavigation, and predator-avoidance behaviors of the juvenile stages of mosquitoes (Hocking 1953) make BMPs challenging, labor-intensive, time-consuming, and expensive (Devine and Killeen 2010). Yet, even with these limitations, ground-based techniques are the best means available for distinguishing breeding from non-breeding sites, recording locational coordinates, collecting immature stages for species identification, and estimating the time remaining until emergence of adults. When ground-based data collection or the reliability of the ground-based data is compromised, so is the ability to determine the most effective combination of control strategies. This can lead to the following: underuse of larvicides and untreated breeding habitat resulting in a serious outbreak of vector-borne disease, or overuse of insecticides, which can negatively impact the environment and non-target organisms (Mahmood et al. 2016). Overuse of pesticides can also precipitate the development of insecticide resistance in the mosquito population. Insecticide resistance development can subsequently result in even larger mosquito populations to manage in the future.

Study Problem

The study area is a floodplain and wetlands area of the upper Missouri River located in the northwestern corner of North Dakota. The city of Williston, population 26,977 (US Census Bureau 2015b) is located on the north bank of the river, immediately adjacent to the study area. The city is situated approximately 24 km (15 mi.) east of the Montana-North Dakota border and 97 km (60 mi.) south of the U.S.-Canadian border. Despite the region's semiarid climate, the Williston vector control agency must fight large populations of mosquitoes nearly every spring and summer. For more than 25 years, officials responsible for administering vector control in the Williston area have sought to use BMP strategies (Williston Vector Control, District No.1 [WVCD] Annual Reports 1992 to 2016), but face many challenges.

Primary Funding Agency

This study was requested and partially funded by the Board of Directors for the Williston Vector Control, District #1 (WVCD) Williston, ND to determine if high-resolution Interferometric Synthetic Aperture Radar (IfSAR) Digital Terrain Model (DTM) elevation data could assist with the identification of mosquito breeding habitat within the Missouri River floodplain and wetlands near Williston.

Questions

What are the vertical root mean squares error (RMSEz) and vertical accuracy (accuracyz) of the IfSAR DTM elevation data (ASPRS 2014)? Can the IfSAR DTM elevation data assist the WVCD in the targeting of site-specific mosquito control efforts?

Hypothesis

H_O: The RMSEz of IfSAR DTM Type II elevation data is equal to or lower (i.e., better) than the one-meter vertical root mean squares error specified by the technology's vendor.

H_A: The RMSEz of IfSAR Type II DTM elevation data is higher (i.e., worse) than the one-meter vertical accuracy assessment value of one meter vertical root mean squares error specified technology's vendor.

Study Objective

The objective of this study was to carry out a vertical quality assessment (QA) of the IfSAR DTM elevation data applying relevant parts of the following accepted digital map and data standards and guidelines: 1) FGDC Geospatial Positioning Accuracy Standards, Part 3: National Standard for Spatial

Data Accuracy (NSSDA), 1998 (NSSDA) (FGDC, 1998); 2) Appendix A , Guidelines for Aerial Mapping and Surveying of the FEMA Guidelines and Specifications for Flood Hazard Mapping Partners, April 2003 (FEMA 2003a); 3) Guidelines for National Digital Elevation Program (NDEP), version 1.0, May 24, 2004, (NDEP 2004), 4) American Society of Photogrammetry and Remote Sensing (ASPRS) Vertical Accuracy Reporting for LiDAR Data (ASPRS 2004); and 5) The American Society of Photogrammetry and Remote Sensing (ASPRS) Positional Accuracy Standards for Digital Geospatial Data (ASPRS 2014). The ASPRS (2014) guidelines apply to LiDAR and IfSAR elevation data and is the primary guidelines for this study.

Importance of this Study

The community of Williston and its surrounding area have a long-standing and serious mosquito problem. The problem is not only the 404.68 km^2 (100,000 ac; 40468 ha; 156.25 $mi.^2$) of prime mosquito breeding wetlands immediately south of the city, but also the inaccessibility of major portions of the floodplain to conduct routine sampling and surveillance. This research provides the WVCD with the ability to use a computer and specialized geospatial technology software as an alternative to standard ground-based sampling and surveillance methods. Predictive flood models were developed for the floodplain near Williston, using high-resolution Interferometric Synthetic Aperture Radar (IfSAR) Digital Terrain Model (DTM) elevation data and Geographic Information Systems (GIS) software. The models were based on local topography, drainage patterns (i.e., slope, aspect, flow direction and accumulation) and local river elevation data from a near-by river gaging station. Geospatial technologies used in this study also included Global Positioning Systems (GPS), aerial photography and satellite imagery. Many of these technologies are used in entomological research and vector control. However, the use of high-resolution radar elevation data to identify river flow direction and accumulation (i.e., potential mosquito breeding habitat) is a new methodology for entomological research and vector control. For the community of Williston, ND, the use of geospatial technologies will be faster, less expensive, safer, and non-invasive compared to standard ground-based methods, can cover large areas that are impossible to cover by ground, and will reduce the number of breeding sites that are missed because of dense vegetation, which in turn will improve the targeting of site-specific control efforts. Because the predictive flood models can identify where water will flow and accumulate as river elevations increase, they have the potential to decrease vector control response time. Additional benefits of using the predictive flood models for Williston include a potential decrease overall vector control program costs, more comfortable, enjoyable summers for local residents, reduced vector control program costs, and reduced risks of mosquito-transmitted disease(s).

Study Implications

Mosquitoes and finding the most cost-effective, safe mosquito control methods are a concern globally. High-resolution IfSAR elevation data used in this study and the methodology to develop predictive flood models can be used by any entomological research or vector control agency world-wide.

Study Overview

Prior to this research, much time and effort were spent researching the Williston area and the severity of Williston's mosquito problem. The long-standing problem is complex and involves many biotic and abiotic factors. Although a detailed discussion of contributing factors for the Williston area is beyond the scope of this disquisition, the time spent on that pre-research was important to better understand the needs of the WVCD. This disquisition will briefly discuss land topography and hydrological characteristics, local and regional climate, land use patterns, population dynamics, state and local economy, and a brief review of historical mosquito problems for Williston and North Dakota. A thorough review of the materials and methods used to develop IfSAR-derived predictive flood models will be discussed, as will the statistical accuracy assessment of the IfSAR DTM data.

Study Location

North Dakota

The state of North Dakota is estimated to be about 178,711.25 km^2 (44,160,512 ac; 17,871,125 ha; 69,000 mi.^{2}) (U.S. Census Bureau 2015a, NDstudies 2010). North Dakota's population is estimated at 757,952 people, an average of 9.7 people per 2.59 km^2 (1 mi.^{2}) (U.S. Census Bureau 2015a). North Dakota's land use and economy are mostly based on agriculture, ranching, and energy production, all of which require a large proportion of the population to be employed outdoors. Agricultural production generates over $5 billion annually. Approximately 24 percent of the state's labor force are farmers, ranchers, or employees in farm-related jobs. The state has about 30,900 farms and ranches that encompass 90 percent of the state's land area. The average size of a North Dakota farm is 5.02 km^2

(1,260 ac; 502 ha; 1.94 mi.^{2}) (North Dakota Department of Agriculture [NDDA] [date unknown]. ND Ag Facts. http://www.nd.gov/aitc/agfacts/, accessed July 2017).

The Energy Information Administration (EIA) reported that the United States is the world's largest crude oil and natural gas liquids producer, due to the hydraulic fracturing and directional drilling in the shale formations of Texas and western North Dakota (EIA 2017). A 2016 report from the U.S. Department of Energy (i.e., based on 2014 data) stated that North Dakota was the second largest oil-producing state behind Texas. Oil and gas exploration has occurred in all North Dakota counties except Traill County. Active production occurs largely in the northwestern portion of the state, with Mountrail, McKenzie, Dunn, Bowman, Williams, and Billings counties producing the most oil. Oil production has grown from an average of 103 barrels per day during April 1951 to 1,212,014 barrels per day in June 2015 (ND DMR 2016).

Hydroelectric power, generated by the Garrison Dam and power plant located on the Missouri River, is another important source of energy production in North Dakota. The dam is located about 120 km (75 mi.) north of Bismarck and about 280 km (176 mi.) downstream from Williston. It was constructed during the 1940s and 1950s and is the fifth largest earthen dam in the world. The dam produces an average of 2.6 million megawatt hours of electricity per year (USACE. [date unknown]. http://www.nwo.usace.army.mil/Missions/Dam-and-Lake-Projects/Missouri-River-Dams/Garrison/Hydropower/, accessed April 2017). Natural gas production is the 6th largest industry in the state. North Dakota also has the second-largest reserve of lignite coal in the world, and rich supplies of clinker, clay, sand and gravel, and salt (Hoganson and Murphy 2003).

Williston, North Dakota

The city of Williston, population 26,977 (US Census Bureau 2015b), is located in on the north banks of the upper Missouri River in the northwest corner of North Dakota, approximately 24 km (15 mi.) east of the Montana-North Dakota border and 97 km (60 mi.) south of the U.S.-Canadian border. The climate for western North Dakota is classified as semiarid (i.e., receiving less than 15 in of precipitation annually) (Jensen 2009; Oregon State University 2017, Institute for Veterinary Public Health 2017). The Köppen-Geiger (Koeppen-Geiger) World Climate classification updated system identifies the Williston areas as BSk (climate B [arid], precipitation S [Steppe], and temperature k [cold arid]) (Institute for

Veterinary Public Health 2017). The following sources classify western North Dakota ecology as temperate climate and local vegetation primarily composed of grasslands and shrub land: 1) the U.S. Department of Agriculture Forest Service (USDA-FS) (Bailey 1980); 2) the U.S. Geological Survey (USGS) (Sayre et al. 2009); 3) the World Wildlife Fund (Olson et al. 2001); 4) the U.S. Environmental Protection Agency (Omernik and Griffith 2014); and 5) the U.S. Department of Agriculture – Forest Service (USDA-FS) (Bailey [no date, accessed July 2017]).

Local land use and economy of the Williston area are similar to other areas of ND, based primarily on agriculture, ranching, and energy production. Dryland farming in the Williston area is located primarily on higher ground. Dryland crops include wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), alfalfa (*Medicago sativa* L.), hay (mixture of grasses, legumes, or herbaceous plants), oats (*Avena sativa* L.), dry beans (Genus *Phaseolus* L.), and a small acreage of corn (*Zea mays* L.) (North Dakota Crops and Livestock 2009). Irrigation-based farming produces cultivated sugar beets *(Beta vulgaris* L.) (Biancardi et al. 2010) and occurs within the floodplain, between loops of the river channel. A report by Autobee (2010) provides the history of two irrigation districts that were organized during the early 1900s near Williston and are still in partial operation. A newly developed irrigation project has been developed on uplands along the Missouri River, several miles east of Williston that uses a combination of wells and river water. Agriculture and ranching are important for Williston's and North Dakota's economy, however, research by Jarju et al. (2009) and Oladepo et al. (2010) have shown that some farming and ranching practices can increase mosquito populations.

Oil and gas production in western North Dakota began in the 1950s near Tioga, about 96.56 km (60 mi.) east of Williston. Since then Williston has been actively involved in oil and gas production. However, during the most recent oil boom (i.e., 2006 to 2015), Williston has been the center of activity. An unknown number of oil companies and thousands of people from around the world moved to the area in search of work. Massive amounts of equipment and fracking materials needed for the oil and gas production are produced worldwide and shipped to Williston daily. Energy production near Williston has also included underground lignite mining, which began near Williston in the late 1800s, and was most active in the location from Williston to the current Lewis and Clark State Park between 1910 through 1940. The last underground mine, Cedar Coulee Mine was the last to close in 1967 (Hess et al. 1992, Hoganson and Murphy 2003). Underground mining was eventually abandoned in North Dakota due to the shift from coal to oil, natural gas, and hydroelectric power (Oihus 1983, Flores and Keighin 1999). Currently, most resource mining in North Dakota is carried out by using surface/strip mining practices. The following four lignite surface mines operate in the west central part of the state (i.e., northwest of Bismarck, ND): 1) the Beulah Mine, located south of the city of Beulah; 2) the Freedom Mine, which is located northwest of Beulah; 3) the Center Mine, located southeast of Center, ND; and 4) the Falkirk Mine, which is near Underwood, ND. A fifth lignite strip mine, the Savage Mine, is about 97 km (60 mi.) west of Williston near Sidney, MT (ND Lignite Energy Council [LEC] 2017).

Over the last 20 years, problems caused by abandoned lignite mines have been occurring near Williston (Hoganson and Murphy 2003). During 1988, several surface sinkholes began appearing that were determined to be related to underground mines. Exploratory drilling was used to locate mine tunnels, which were then backfilled with pressurized grout. Abandoned mines under the Scenic East Project (a residential subdivision east of Williston) began showing similar problems in 1991 and were also stabilized and filled to prevent a collapse. Similarly, pressurized grout was used along Williams County Road 9 to prevent the road from collapsing in 2006 (Eckroth 2007). Tunnels, caves, waste water storage pools, sinkholes, and abandoned mines related to energy production procedures are dangerous. However, research by Berg and Lang (1948), Whang (1961), Pickard (1982), Whelan and Warchot (2005), Zou et al. (2006), Pfeiffer et al. (2010), and WHO (2010) have also shown that these structures increase breeding, resting, and hibernation habitat for mosquitoes and increase mosquito abundance and risk of disease transmission. Additionally, mosquitoes are a problem worldwide and public health officials are concerned that vector mosquito species are being transported to new locations, adapting, and continuing to spread disease(s). Research has determined that increasing world travel and global trading of goods are the primary sources for the transport of insects to new locations (Gubler 1998, Gratz 1999, Powell and Tabachnick 2013).

The most commonly used locational coordinates for Williston, ND include: 1) unprojected Geographic Coordinate System (GCS) North American Datum (NAD) 1983 (NAD83) High Accuracy Reference System (HARN) in latitude (lat) and longitude (long): a) Degrees, Minutes, Seconds (DMS) 48° 8' 49.0884” N and 103° 37' 4.7028'' W, b) Degree Minutes (DM.m) 48° 8.81814’ N and 103° 37.07838’ W, and c) Decimal Degrees (DD; D.d) 48.146969° N and 103.6180° W; 2) unprojected GCS NAD27 in lat and long: 48.146945 N and 103.617526 W, 3) projected Universal Transverse Mercator (UTM) NAD83 [HARN] Zone 13 North (N): Easting 602796.759 - Northing 5333558.953; 4) State Plane Coordinate System NAD83 [HARN] UTM ZONE 13N, North Dakota North Zone FIPSZONE 3301, ADSZONE 4926: a) Easting 368057.948 (m) - Northing 132218.211 (m), b) Easting 1207536.784 (U.S. sft) - Northing 433785.914 (U.S. sft), and c) Easting 1207539.199 (ift) - Northing 433786,781 (ift); and 5) World Geographic System (WGS) NAD84 (WGC 84) in latitude and longitude: 48.146977 N and 103.618011 W; 5) Military Grid Reference System/US National Grid NAD83 [HARN]: UTM Zone 13N Band U FP 0279633558 NAD83 (West Virginia Department of Environmental Protection GIS Server [date unknown] accessed July 2017). Archived Landsat imagery used in this study included imagery from both Worldwide Reference Systems: 1) Landsat-1, -2, -3 imagery archived under Worldwide Reference System-1 (WRS-1) Path/Row (P/R) P37/R26, and 2) Landsat-4, -5, -7, -8 imagery archived under Worldwide Reference System-2 (WRS-2) Path/Row (P/R) P34/R27 (NASA 2017).

Study Timeline

2008

During the late summer of 2008, the WVCD board began discussing the possibility of conducting field research. During the early stages of discussion, the board had no defined plan for what type of research they needed, other than to find something that would assist them in their mosquito control efforts. The board spent about a year carefully searching for a research project that would best address the mosquito problems of the Williston area.

2009

During October-November 2009, the WVCD board approved field research within the Missouri River floodplain and wetlands near Williston and the purchase of high-resolution Light Detection and Ranging (LiDAR) elevation data. LiDAR data were chosen because of its ability to measure bare earth elevations, its ability to be analysed within Geographic Information Systems (GIS) software to identify surface topography and hydrological characteristics such as slope, aspect, flow direction, and flow accumulation, all of which are important in vector control, and its low vertical error. However, it was determined that existing LiDAR elevation data were not available for the Williston area and the purchase of new LiDAR data were deemed too expensive. During November and December, additional funding to purchase LiDAR data were requested from numerous local, state, and federal agencies (Appendices A, B, C, D, E, F) without success (Appendices G, H).

2010

January 2010

The WVCD board approved the purchase of remotely sensed, high-resolution Interferometric Synthetic Aperture Radar (IfSAR) Digital Terrain Model (DTM) Type II elevation data, hereafter referred to as IfSAR DTM or IfSAR elevation data. IfSAR elevation data were selected because of its high-spatial resolution, its ability to identify hydrological characteristics such as slope, aspect, flow direction, and flow accumulation within GIS, similar to LiDAR elevation data, and its relatively low cost compared to LiDAR and photogrammetry technologies. The vendor of IfSAR elevation data is Intermap Technology, Inc., Englewood, CO (2016). Intermap Technology, Inc. offered several types of IfSAR-based elevation data: 1) Digital Surface Models (DSMs), which provide elevations of the tops of trees and other vegetation, roads, bridges, buildings and other structures; 2) Digital Terrain Models (DTMs), which provide elevations of the bare earth; and 3) Orthorectified imagery (ORI), which is similar to low-resolution black and white photography. Based on the needs of the WVCD and the advice of Intermap Technology, Inc., IfSAR DTM type II, bare-earth elevation data were selected for the WVCD study. It was determined that the IfSAR elevation data could not be purchased, but it were obtained through licensing.

February 2010

The WVCD field director and Williams County GIS technician met to identify problem areas within the floodplain. Areas of interest (AOIs) were defined as 1) areas with consistently high mosquito production, and/or 2) areas that were difficult to carry out ground-based sampling and surveillance. After the AOIs were selected, a map of the problem areas was sent to the WVCD board for their review. The same map was sent to the vendor along with the AOIs in GIS shapefile format, for cost estimates.

February to March 2010

Between mid-February and March 2010, several revisions of the AOIs were requested by the WVCD. The updated AOI maps were resent to the WVCD board for their review. Copies of the updated AOIs and GIS shapefiles were also sent to the vendor for an updated cost estimate. This process was repeated until the WVCD board members and field director were in agreement with the locations of the

IfSAR data to order and the cost of the data. The final selected areas encompassed approximately 140.6 km^2 (34,743.02 ac; 14,060.00 ha; 54.29 $mi.^2$).

<u>April to May 2010</u>

The WVCD board chairman and the field director signed a price quote, license acceptance, and purchase authority (Appendix I) for the IfSAR DTM from Intermap Technology, Inc. The IfSAR DTM elevation data were delivered to both the WVCD field director and this author by File Transfer Protocol (FTP) on 13 May 2010 (Appendix J). The invoice for the IfSAR DTM data can be found in Appendix K.

<u>July 2010</u>

Two small areas of IfSAR elevation data were inadvertently omitted from the original order and a second order was placed for the missing areas. The omitted data and invoice were delivered by FTP (Appendix L). The combined IfSAR DTM data licensed by the WVCD for this study totaled 141.00 km^2 (34,841.86 ac; 14,100.00 ha; 54.4404 $mi.^2$). The IfSAR DTM study was carried out between July 2010 and April 2012. Planning the IfSAR DTM vertical quality assessment (QA) began in July 2010.

2011

<u>May 2011</u>

The in-field IfSAR DTM vertical QA was carried out during May 2011.

2012

<u>May 2012</u>

Predictive flood models in both hard copy and digital format and GIS shapefiles were delivered to each WVCD board member, the WVCD field director, the WVCD office, and the WVCD pilot during their regularily scheduled May 2012 WVCD board meeting. The following day, complete sets of the predictive flood models and GIS shapefiles were 1) personally delivered to the USACE, Williston Branch office, and 2) mailed to Dr. Mark Breidenbaugh, entomologist with the U.S. Air Force 910th Air Lift Wing, Youngstown, OH (USAFR 2017).

LITERATURE SEARCH

Diptera: Culicidae

Culicidae are considered by many experts to be the most dangerous pest complex on earth (Scott 2007, AMCA 2014, WHO 2017b). Over 3,500 species of Culicidae are known worldwide (AMCA 2014, Centers for Disease Control and Prevention [CDC] 2015). Culicidae are found throughout most of the world, however, many species have specific aquatic or terrestrial habitat needs and will be found only in certain locations globally. Some species of Culicidae are intolerant to temperate winters and are only found in tropical regions. According to Rueda (2008) of the 3,500 species of Culicidae known worldwide, only about 100 species of Culicidae are capable of transmitting pathogen(s) that cause disease and are therefore considered medically important species. Many medically important species of Culicidae are capable of transmitting two or more disease pathogens (CDC 2016a). Diseases transmitted by Culicidae cause more illness, suffering, death than any other animal on earth. California Encephalitis virus (CEV), Chikungunya virus, Dengue group of viruses -1, -2, -3, and -4, Eastern Equine Encephalomyelitis virus (EEEV), Rift Valley Fever virus (RVFV). St. Louis Encephalitis virus (SLEV), Venezuelan Equine Encephalitis virus (VEEV), Western Equine Encephalomyelitis virus (WEEV), West Nile virus (WNV), Yellow Fever virus (YFV), Zika virus (ZIKAV), several species of parasitic *Plasmodium*, and the parasitic microfilariae, *Dirofilaria immitis* are only a few of the pathogens that are transmitted worldwide by Culicidae. Malaria alone, causes over one million deaths annually, world-wide (AMCA 2014). According to WHO (2016), a child dies every two minutes from malaria.

Culicidae do not only transmit disease. In large numbers, they can cause serious emotional distress for individuals, families, and communities. A study conducted by the CDC and the U.S. Department of Health, Education and Welfare found that Culicidae in large numbers were both a mental and physical health problem when people could not take part in outdoor activities (Hess and Quinby 1956). Large infestations of adult female mosquitoes can also cause economic hardships and depreciated property values (Bonnefoy et al. 2008), decreased quality and yield in livestock products, such as decreased weight gain resulting in reduced meat and hide production in cattle, decreased wool value, and increased fetal abortion (Hess and Quinby 1956, Steelman et al. 1973, Steelman and Schilling 1977), decreased milk production in dairy cattle (AMCA 2014), and decreased egg production in poultry

(Shankar 2008). Also, Bishopp (1933) and Standfast and Dyce (1968) documented extreme suffering for domestic animals and wildlife, and in some cases, death due to suffocation and/or blood loss. Large populations of mosquitoes can also cause economic losses for communities, tourism-based industries, and any outdoor business (Smith 1907). Understanding the bionomics of each species of mosquito present in a locality is critical in identifying the most likely breeding sites for each species and effectively targeting control strategies.

Currently, a controversy exists surrounding the classification and names of certain culicid species, which is not likely to be resolved anytime soon. Based on the Journal of Medical Entomology Policy on Names of Aedine Mosquito Genera and Subgenera (Weaver 2005), the contentions of Savage and Strickman (2004), Savage (2005), Wilkerson et al. (2015), and Reisen (2016), combined with the fact that traditional names remain within the WRBU Systematic Catalog of Culicidae (2017), this disquisition will follow the traditional nomenclature with *Ochlerotatus* Lynch Arribálzaga as a subgenus of *Aedes* Meigen, *Aedes* (*Ochlerotatus*), as used between 1906-2000.

Emerging and Resurging Mosquito-borne Diseases

Worldwide, public health officials are concerned because some arthropods are being transported beyond their known geographical range (Powell and Tabachnick 2013). Some diseases thought to be under control are appearing in new locations (Gratz 1999). The appearance of new vector-borne diseases and the resurgence of known vector-borne diseases worldwide is complicated, but research has determined that increasing human travel and trade of goods are a primary cause of spreading infectious agents (Gratz 1999, Gubler 1998, Powell and Tabachnick 2013).

Culicidae Species Identified in North Dakota

In the United States, 176 species of Culicidae have been identified (AMCA 2014). Forty-five of the 176 species are considered medically important (WRBU 2017). According to Darsie and Anderson (1985), 38 species of Culicidae have been identified in North Dakota (Table 1). Species identified in a study carried out in North Dakota by Anderson JF et al. (2015) are also identified in both tables. One species identified by Anderson et al. (2015) is not listed by Darsie and Anderson (1985), *Aedes [Ae.] Ochlerotatus [Och.], schizopinax* Dyar. Fifteen species identified in ND are considered medically important; two species that probably occur in North Dakota are medically unknown (WRBU 2017).

Table 1. Culicidae species identified in North Dakota

No.	*Genera* (*Subgenera*) *Species* Author	Medically Important/ Biosafety Level (BSL)	Vectored Pathogen(s)	Identified in North Dakota by Anderson JF et al. 2015
1.	*Aedes* (*Aedes*) *cinereus* Meigen	No	---	Yes
2.	*Aedes* (*Aedimorphus*) *vexans* (Meigen)	Yes WEE BSL 3 WNV BSL 3	*Dirofilaria immitis* L (Yen 1938); possibly WNV (CDC 2012); (Chosewood and Wilson 2009, CDC 2017, ICTV 2017, MTI 2017, NCBI 2017, WRBU 2017)	Yes
3.	*Aedes* (*Ochlerotatus*) *campestris* Dyar and Knab	No	---	Yes
4.	*Aedes* (*Ochlerotatus*) *canadensis* (Theobald)	Yes EEE BSL 3 WNV BSL 3	EEEV, WNV (Turell et al. 2005); *Dirofilaria immitis* (WRBU 2017); (Chosewood and Wilson 2009, CDC 2017, ICTV 2017, MTI 2017, NCBI 2017)	No
5.	*Aedes* (*Ochlerotatus*) *dorsalis* (Meigen)	Yes CE BSL 2 WEE BSL 3 WNV BSL 3	CEV, WEEV (Carpenter and LaCasse, 1955); WEEV, WNV (Turell et al. 2005); (Chosewood and Wilson 2009, CDC 2017, ICTV 2017, MTI 2017, NCBI 2017, WRBU 2017)	Yes
6.	*Aedes* (*Ochlerotatus*) *excrucians* (Walker)	No	---	Yes

Table 1. Culicidae species identified in North Dakota (continued)

No.	*Genera* (*Subgenera*) *Species* Author	Medically Important/ Biosafety Level (BSL)	Vectored Pathogen(s)	Identified in North Dakota by Anderson JF et al. 2015
7.	*Aedes* (*Ochlerotatus*) *fitchii* (Felt and Young)	No	---	No
8.	*Aedes* (*Ochlerotatus*) *flavescens* (Müller)	No	---	Yes
9.	*Aedes* (*Ochlerotatus*) *intrudens* Dyar	No	---	Yes
10.	*Aedes* (*Ochlerotatus*) *melanimon* Dyar	Yes WEE BSL 3 WNV BSL 3	WEEV, WNV (Turell et al. 2005); (Chosewood and Wilson 2009, CDC 2017, ICTV 2017, MTI 2017, NCBI 2017, WRBU 2017)	Yes
11.	*Aedes* (*Ochlerotatus*) *nigromaculis* Ludlow	No	---	No
12.	*Aedes* (*Ochlerotatus*) *pionips* (Dyar)	No	---	No
13.	*Aedes* (*Ochlerotatus*) *punctor* (Kirby)	No	---	No

Table 1. Culicidae species identified in North Dakota (continued)

No.	*Genera* (*Subgenera*) *Species* Author	Medically Important/ Biosafety Level (BSL)	Vectored Pathogen(s)	Identified in North Dakota by Anderson JF et al. 2015
14.	*Aedes* (*Ochlerotatus*) *riparius* (Dyar & Knab)	No	---	No
15.	*Aedes* (*Ochlerotatus*) *sollicitans* (Walker)	Yes	---	No
16.	*Aedes* (*Ochlerotatus*) subspecies idahoensis (Theobald)	No	---	Yes
17.	*Aedes* (*Ochlerotatus*) subspecies spenceri (Theobald)	No	---	Yes
18.	*Aedes* (*Ochlerotatus*) *sticticus* Dyar	Yes WEE BSL 3 WNV BSL 3	WEEV, WNV (Turell et al. 2005); (Chosewood and Wilson 2009, CDC 2017, ICTV 2017, MTI 2017, NCBI 2017, WRBU 2017)	No
19.	*Aedes* (*Ochlerotatus*) *trivittatus* (Coquillett)	Yes	---	Yes
20.	*Aedes* (*Protomacleaya*) *hendersoni* Cockerell	No	---	No

Table 1. Culicidae species identified in North Dakota (continued)

No.	*Genera* (*Subgenera*) *Species* Author	Medically Important/ Biosafety Level (BSL)	Vectored Pathogen(s)	Identified in North Dakota by Anderson JF et al. 2015
21.	*Aedes* (*Protomacleaya*) *triseriatus* (Say)	Yes CE BSL 2 YF BSL 3 EEV BLS 3 VEE BSL 3 WEE BSL 3	LAC-strain of CEV under laboratory conditions, also YFV, EEEV, VEEV, WEEV, and possibly *Dirofilaria immitis* (WRBU 2017); (Chosewood and Wilson 2009, CDC 2017, ICTV 2017, MTI 2017, NCBI 2017)	Yes
22.	*Anopheles* (*Anopheles*) *earlei* Vargas	No	---	Yes
23.	*Anopheles* (*Anopheles*) *punctipennis* (Say)	Yes	*Plasmodium* species (Mullen and Durden 2002); (Chosewood and Wilson 2009, CDC 2017, ICTV 2017, MTI 2017, NCBI 2017, WRBU 2017)	No
24.	*Anopheles* (*Anopheles*) *quadrimaculatus* (Say)	Yes	*Plasmodium* species (Goddard 2013); *Plasmodium* species and possibly *Dirofilaria immitis* (WRBU 2017); (Chosewood and Wilson 2009, CDC 2017, ICTV 2017, MTI 2017, NCBI 2017)	No
25.	*Anopheles* (*Anopheles*) *walkeri* Theobald	No	---	No
26.	*Coquillettida* (*Coquillettida*) *perturbans* (Walker)	Yes EEE BSL 3	EEEV (Turell et al. 2005); (Chosewood and Wilson 2009, CDC 2017, ICTV 2017, MTI 2017, NCBI 2017, WRBU 2017)	Yes

Table 1. Culicidae species identified in North Dakota (continued)

No.	*Genera* (*Subgenera*) *Species* Author	Medically Important/ Biosafety Level (BSL)	Vectored Pathogen(s)	Identified in North Dakota by Anderson JF et al. 2015
27.	*Culex* (*Culex*) *pipiens* Linnaeus	Yes SIN BSL 2 WNV BSL 3 RVF BSL 3	Sindbis virus (SINV), WNV, Rift Valley Fever (RVFV), periodic Bancroftian filariasis (Harbach 1988); (Chosewood and Wilson 2009, CDC 2017, ICTV 2017, MTI 2017, NCBI 2017, WRBU 2017)	No
28.	*Culex* (*Culex*) *restuans* Theobald	Yes SIN BSL 2 WNV BSL 3	SINV, WNV (Turell et al. 2005); (Chosewood and Wilson 2009, CDC 2017, ICTV 2017, MTI 2017, NCBI 2017, WRBU 2017)	Yes
29.	*Culex* (*Culex*) *salinarius* Coquillett	Yes WEE BSL 3 WNV BSL 3	WEEV, WNV (Turell et al. 2005); (Chosewood and Wilson 2009, CDC 2017, ICTV 2017, MTI 2017, NCBI 2017, WRBU 2017)	No
30.	*Culex* (*Culex*) *tarsalis* Coquillett	Yes WEE BSL 3 SLEV BSL 3 CEV BSL 2 WNV BSL 3	WEEV, SLEV, CEV (Carpenter and LaCasse 1955); WNV (Hayes et al. 2005); SLEV, WEEV, WNV (Goddard 2013); (Chosewood and Wilson 2009, CDC 2017, ICTV 2017, MTI 2017, NCBI 2017, WRBU 2017)	Yes
31.	*Culex* (*Neoculex*) *territans* Walker	No	---	No
32.	*Culiseta* (*Culiseta*) *incidens* (Thomson)	No	---	No

Table 1. Culicidae species identified in North Dakota (continued)

No.	*Genera* (*Subgenera*) *Species* Author	Medically Important/ Biosafety Level (BSL)	Vectored Pathogen(s)	Identified in North Dakota by Anderson JF et al. 2015
33.	*Culiseta* (*Culiseta*) *inornata* (Williston)	Yes WEE BSL 3 WNV BSL 3	WEEV, WNV (Turell et al. 2005); (Chosewood and Wilson 2009, CDC 2017, ICTV 2017, MTI 2017, NCBI 2017, WRBU 2017)	Yes
34.	*Culiseta* (*Culicella*) *minnesotae* Barr	No	---	No
35.	*Culiseta* (*Culicella*) *mortisians* (Theobald)	No	---	No
36.	*Orthopodomyia* No subgenera *signifera* Coquillett	No	---	No
37.	*Psorophora* (*Grabhamia*) *signipennis* (Coquillett)	No	---	No
38.	*Uranotaenia* (*Uranotaenia*) *Sapphirina* (Osten Sacken)	No	---	No

Culicidae Species that Probably Occur in North Dakota

Darsie and Anderson (1985) also provided a list of six species of Culicidae that probably occur in North Dakota (Table 2).

Table 2. Culicidae species that probably occur in North Dakota

No.	*Genera* (*Subgenera*) *Species* Author	Medically Important Biosafety Level (BSL)	Vectored Pathogen(s)	Identified in North Dakota by Anderson JF et al. 2015
1.	*Aedes* (*Ochlerotatus*) *Implicatus* Vockeroth	No	---	Yes
2.	*Aedes* (*Ochlerotatus*) *increpitus* Dyar	No	---	Yes
3.	*Aedes* (*Rusticoidus*) *provocans* (Walker)	Unknown	---	No
4.	*Aedes* (*Ochlerotatus*) *stimulans* (Walker)	Unknown	---	Yes
5.	*Culiseta* (*Culiseta*) *impatiens* (Walker)	No	---	No
6.	*Psorophora* (*Grabhamia*) *discolor* (Coquillett)	No	---	No

Culicidae Species of Concern for Williston, ND

Two species of Culicidae are of major concern for the state of North Dakota and the community of Williston, the floodwater species *Aedes vexans* (Meigen); and the permanent water species *Culex tarsalis* Coquillett.

Aedes vexans (Meigen)

Floodwater or swamp mosquitoes are the primary source of pest mosquitoes across North America (Horsfall 1963). The term refers in large part to *Ae. vexans,* but also includes other species that breed in areas where surface water levels fluctuate or water tables rise and fall, saturating the ground during mosquito-growing season. Kramer (1987) reported *Ae. vexans* are found throughout most of the conterminous United States and lower Canada. The female prefers to oviposit near temporary water and will use a wide variety of habitats such as tire ruts, hoof prints, dredge spoil sites, and ditches. This mosquito usually prefers clear water but eggs can also be found in foul water, including water heavily polluted by cattle feces (Barr 1958). Eggs are especially abundant in depressions subject to cycles of flooding and drying such as floodplain, poorly drained soils, upstream margins of impoundments, and uneven topography (Horsfall et al. 1973). Rees (1943) noted that in Utah, this species is found wherever irrigation is practiced. This species is multivoltine, and females are capable of multiple blood-feedings and producing multiple broods of eggs. *Aedes vexans* overwinters in the egg stage (O'Malley 1990). Research by Breeland et al. (1961) reported that *Ae. vexans* eggs in Minnesota did not hatch in early spring, but rather waited until late May or early June when water temperatures were over 8 to 10°C (46.4 to 50°F). When *Aedes vexans* larvae and pupae begin appearing, they can be difficult to find because of their rapid development time. Gjullin et al. (1950) found minimum development time for *Ae. vexans* to be six days.

Both adult male and female *Ae. vexans* feed on flower nectar, especially goldenrod (Asteraceae: *Solidago*) (Knab 1907, Hearle 1926). When adult females require blood for egg production, they prefer mammals (Barr 1958). Mail (1934) noted that *Ae. vexans*, an aggressive biter, was the second most important mosquito pest in Montana, second only to *Ae. dorsalis* (Meigen). The same order of importance for these two species was suggested by Rees (1943) based on work in Utah. McClintock (1944) reported *Ae. vexans* was the most important pest mosquito in the Greater Winnipeg area. Similarly, Barr (1958) stated that *Ae. vexans* was the most important mosquito pest in Minnesota, and the same was noted by Gerhardt (1966) in South Dakota, Knight and Wonio (1969) in Iowa, and Wood et al. (1979) in Canada. Female *Ae. vexans* adults are most active under reduced illumination. Females will bite during the daytime if disturbed, but peak biting occurs just before dusk. An experiment by Horsfall et al. (1973), using adult light traps equipped to collect hourly counts, found this species to be most active between 10:00 P.M. to mid-night. However, Rees (1943) reported that females can also be active all day during cloudy weather. Barr (1958) noted this species was particularly active during light precipitation.

Numerous authors have noted that with some *Aedes* species, all eggs within a localized area do not hatch following the first inundation, often referred to as installment hatching (Parker 1916, Hearle 1926, Mail 1934, Gerhardt 1966, Wilson and Horsfall 1970, Wood et al. 1979, Edgerly et al. 1993, Eldridge 2008). Breeland and Pickard (1963) found that several inundations were necessary to induce all *Ae. vexans* eggs to hatch. When summer rains are frequent, or lake or reservoir elevations fluctuate frequently, newly hatched larvae can be found after each event of precipitation or increase in lake or reservoir elevation. Whenever multiple stages of larvae are found together within a breeding site, or multiple stages of larvae and pupae found together within a site, it is an indication that multiple surge and receding cycles have occurred over a few days (O'Malley 1990). The outcome of installment hatching is multiple events of emergence of adults over several days (Horsfall et al. 1973).

The resting habits of this species pose important implications for insecticide-based adult control programs. Barr (1958) observed that adults will rest in long grasses and shrubs during the day and on cloudy or moist days or in the evenings; however, they also can be found resting in short grasses. When females are observed in their daytime resting places they usually rest upside down on the underside of leaves or structures. If such places are to be sprayed, Barr (1958) stressed that the spray should be directed upward from below. Flight dispersal estimates for *Ae. vexans* are long. Bailey et al. (1965) found that this species began long flights shortly after sundown. Hearle (1926) and Eldridge (2008) estimated a migration distance of 16.09 km (10 mi.), while Rees (1943) documented *Ae. vexans* dispersed at 8.05 to 12.88 km (5 to 8 mi.) from their breeding site. A controversial report by Horsfall et al. (1973) found *Ae. vexans* were capable of migrating a few km to hundreds of km, depending on weather conditions. Hearle (1926) and Horsfall (1955) observed mass dispersal of *Ae. vexans* adults in orientation toward lights (i.e., an urban area) on the horizon. It has long been known that *Ae. vexans* can become naturally infected with Western Equine Encephalitis (WEE) virus, and it can also be experimentally infected with St. Louis Encephalitis (SLE) virus (Stage et al. 1952). It is also considered a possible vector of EEE (Feemster 1938) as well as a potential vector of *Dirofilaria immitis* (Leidy) (Yen 1938). This species has also been documented to carry West Nile virus (WNV) (Goddard et al. 2002, DiMenna et al. 2007).

Culex tarsalis Coquillett

Culex tarsalis Coquillett are found throughout the western, central, and southern United States, southwest Canada, and parts of Mexico (Carpenter and LaCasse 1955). This species prefers to oviposit in permanent and semi-permanent ponds comprised of either clean or foul water, especially in corrals and near livestock slaughter houses, irrigation ditches, roadside ditches with emergent vegetation, and seepage-filled hoof prints along creeks (Carpenter and LaCasse 1955). Larvae of this species begin appearing in late-spring or early summer, and adults appear mid-summer through fall. McLintock (1944) found adult females to be active for about four months in Winnipeg, Manitoba, Canada. This species overwinters as an adult female, hibernating in sheltered sites such as animal burrows, abandoned mines, rock piles, basements, caves, outbuildings, hollow logs, or tree stumps, and emerges in spring (Chapman 1961, Gerhardt 1966, Chancey et al. 2015).

This species is multivoltine, and the development time from egg to adult varies with climate. Flight dispersal range estimate for *Cx. tarsalis* is generally short by most authors. Reeves et al. (1948) marked and released 11,800 adults, of which five females were recovered. Two females were captured at the maximum flight distance of 0.81 km (0.5 mi.) from the release point and three were captured at a distance of 0.32 km (0.2 mi.). Bailey et al. (1965) observed an early evening emergence of this species from rice fields in which adults would spiral upward in erratic patterns to a range of 3.66 m (12 ft) to 4.57 m (15 ft) above the surface, with long-distance flights taking place after sundown. It was further noted that there was no apparent migratory phase before the search for a first blood meal. The authors also observed that flights by this species take place shortly after sundown, with flight height estimated between 1.5 m (4.92 ft) and 15 m (49.21 ft). When wind velocities were 3.22 km per hour (2.0 mi. per hour [mph]) or lower, dispersal flight was in all directions; however, when wind velocity exceeded 6.44 km per hour (4 mph), flight direction was only downwind. As such, the authors concluded that wind direction and velocity had major impacts on *Cx. tarsalis* dispersal. A study by Reisen (1993) estimated *Cx. tarsalis* had a maximum flight range of 27.26 km (17 mi.).

*A*vian species are preferred hosts of *Cx. tarsalis* but this species will also attack humans and cattle (Horsfall 1955). Peak biting time is at night. They are highly attracted to carbon dioxide (Reeves 1951). This species is a known vector of WEE, SLE, CE, and WNV in the United States (CDC 2016a).

Hearle (1926) considered *Cx. tarsalis* to be a serious pest due to its painful bite, with pain and swelling lasting for hours, and its persistence in entering buildings to pursue blood meal hosts. Hammon and Reeves (1943) demonstrated the ability of *Cx. tarsalis* to transmit St. Louis encephalitis virus and WEE. Woods et al. (1979) determined that *Cx. tarsalis* is a major vector of WEE, and noted that it is also capable of being naturally infected with St. Louis and California encephalitis viruses. Because WEE is primarily a disease of birds, a good method to monitor for the disease involves testing individuals of a chicken flock (i.e., sentinel birds). Horses are extremely susceptible to WEE (Go et al. 2014); however, a high virus titer, combined with high numbers of *Cx. tarsalis* is required before the disease is observed in horses. Horse fatalities always occur before symptoms are observed in humans (Aréchiga-Ceballos and Aguilar-Setién 2015).

Culicidae Species of Lesser Concern for Williston, ND

Culiseta (Culiseta) inornata (Williston)

Culiseta inornata are found throughout the United States and southern Canada. This species is abundant during the spring and fall (Kramer 1987) and Western Equine Encephalitis virus has been isolated in this species (Kramer 1987). In Minnesota, larvae can be found in water along with larvae of some *Aedes* species, and in early spring in temporary snowmelt pools (Barr 1958).

Aedes (Ochlerotatus) dorsalis (Meigen), *Aedes (Ochlerotatus) melanimon* Dyar, and *Aedes (Ochlerotatus) nigromaculis* (Ludlow)

Aedes dorsalis, *Ae. melanimon*, and *Ae. nigromaculis* are three troublesome pests. Females can be aggressive both day and night, but their preferred feeding time is during evening hours. All three species can breed in water with high salt content. Larvae of these species may share the same water as *Ae. vexans* larvae. Eggs of all three species can hatch in as little as two days after oviposition, and adults can appear as soon as four days after oviposition (Kramer 1987). All prefer irrigated areas and flooded grasslands. Adult females of *Aedes dorsalis* are vicious biters (Carpenter and LaCasse 1955, Gjullin and Eddy 1972), and both WEE and SLE have been isolated from this species (Barr 1958). Larvae of *Ae. melanimon* larvae are often found with larvae of *Ae. dorsalis* (Gjullin and Eddy 1972). Adults of *Ae. nigromaculis* are also severe biters of humans and other mammals. This species has adapted to irrigated pasture habitat, and can produce a new hatch of adults with each flooding event. Adults can fly long distances, and the species has been observed to experimentally transmit WEE, SLE, and Japanese B encephalitis viruses (Gjullin and Eddy 1972).

Culicidae Snow Species

A group of mosquito species called snow mosquitoes generally refer to the univoltine *Aedes* (*Ochlerotatus*) genera that hatch in early spring in snowmelt pools and larvae of some species can survive under ice. However, genera other than *Aedes* can hatch in icy water. Snow species appear only for a short time in early spring, but are included in this study because many are vicious biters and can torment humans, domestic animals, and livestock throughout early spring. Snow species that have been identified in North Dakota are listed in Table 3 with their medical importance. The Williston vector control has first-hand experience with snow Culicidae. Board minutes for 16 April 1973 reported that mosquito larvae were found under ice by the field director (Appendix M). Because species identification was not carried out during the 1970s, there is no additional information available. Between 1992 and 2007, numerous mosquito breeding sites near Williston were found to contain larvae in snowmelt pools and/or under ice each spring, as early as late March (D. Benth unpublished).

Table 3. Culicidae snow species identified in North Dakota

No.	*Genera* (*Subgenera*) *Species* *A*uthor	Medical Importance/Vectored Pathogen(s)/ Biosafety Level (BSL)/Biological Notes	Identified in North Dakota by Anderson JF et al. 2015
1.	*Aedes* (*Ochlerotatus*) *campestris* Dyar and Knab	Not medically important; larvae develop in pools of snowmelt or rain (McLintock 1944, Carpenter and LaCasse 1955)	Yes
2.	*Aedes* (*Ochlerotatus*) *canadensis* (Theobald)	Vectors of EEEV and WEEV EEE BSL 3; WEE BSL 3 (WRBU 2017); larvae appear in early spring in snow-water pools, but may also be found all summer in Montana (Mail 1934); (Chosewood and Wilson 2009, CDC 2017, ICTV 2017, MTI 2017, NCBI 2017)	No
3.	*Aedes* (*Aedes*) *cinereus* Meigen	Not medically important; larvae appear in wooded snow pools (Mail 1934)	No
4.	*Aedes* (*Ochlerotatus*) *fitchii* (Felt and Young)	Not medically important; larvae are found in snow-water pools on the edges of snow banks (Mail 1934, McLintock 1944)	No
5.	*Aedes* (*Ochlerotatus*) *flavescens* Müller	Not medically important; larvae are found in early spring snow pools; adults are vicious biters (Mail 1934)	Yes

Table 3. Culicidae snow species identified in North Dakota (continued)

No.	*Genera* (*Subgenera*) *Species* Author	Medical Importance/Vectored Pathogen(s)/ Biosafety Level (BSL)/Biological Notes	Identified in North Dakota by Anderson JF et al. 2015
6.	*Aedes* (*Ochlerotatus*) *intrudens* Dyar	Not medically important; adults are vicious biters both day and night (Mail 1934); larvae were found in snowmelt (McLintock (1944); larvae are found only in shaded snowmelt pools (Scholefield et al. 1981); larvae hatch in woodland snowmelt pools and adult females are troublesome biters (Wood et al. 1979)	Yes
7.	*Aedes* (*Ochlerotatus*) *pionips* Dyar	Not medically important; larvae have been found in snowmelt pools in Manitoba (Wood et al. 1979)	No
8.	*Aedes* (*Ochlerotatus*) *punctor* (Kirby)	Not medically important; adult females feed on livestock (Mail 1934); larvae are found in water of very low temperatures; adult females readily feed on humans (Barr 1958); this species hatches in early spring before ice has disappeared (Wood et al. 1979)	No
9.	*Aedes* (*Ochlerotatus*) *Subspecies* *spencerii* (Theobald)	Not medically important; in Montana, the earliest broods are found in snow water, are not harmed by nightly freezing over the ponds; this species is extremely blood-thirsty, can make life miserable for humans and animals (Mail 1934); this species is a severe biter; all eggs do not hatch at the first flooding (McLintock 1944); this species is an important livestock pest (Barr 1955); this species is the earliest to appear in spring; larvae can be found in snow pools (Wood et al. 1979)	Yes

Table 3. Culicidae snow species identified in North Dakota (continued)

No.	*Genera* (*Subgenera*) *Species* *A*uthor	Medical Importance/Vectored Pathogen(s)/ Biosafety Level (BSL)/Biological Notes	Identified in North Dakota by Anderson JF et al. 2015
10.	*Aedes* (*Ochlerotatus*) *stimulans* (Walker)	Medical importance is unknown (WRBU 2017); this species develops in huge numbers in wooded floodplain inundated by snowmelt; probably the worst pest species in early spring before *Ae. vexans* (Wood et al. 1979)	Yes
11.	*Aedes* (*Rusticoidus*) *provocans* (Walker)	Medical importance is unknown (WRBU 2017) larvae are found in woodland snowmelt pools (Wood et al. 1979)	No
12.	*Culiseta* (*Culiseta*) *incidens* (Thomson)	Not medically important; larvae are found in pools of melting snow (Gerhardt 1966)	No
13.	*Culiseta* (*Culiseta*) *inornata* (Williston)	Medically important; this species is a known vector of WEEV and WNV (Turell et al. 2005); larvae are found in snowmelt water; adults are persistent biters (Barr 1958); (Chosewood and Wilson 2009, CDC 2017, ICTV 2017, MTI 2017, NCBI 2017, WRBU 2017)	Yes

Historical Mosquito Problems in North Dakota

Mosquito problems in the Williston area are not newly developed. Historical observations suggest that they have existed for hundreds of years.

1804 to 1806: Lewis and Clark Corps of Discovery Expedition

The Lewis and Clark Corps of Discovery Expedition explored the Missouri River between 1804 and 1806 to find a route to the Pacific Ocean. Several members of the expedition kept journals in which they reported on numerous occasions, their frustrations with mosquitoes while travelling through what is now northwestern North Dakota and northeastern Montana. While on the return journey near the current site of Williston, mosquitoes prevented the men from doing their work, deprived them of much-needed sleep, and also raised health concerns. The face of the child of their interpreter, "Sharbono" (Charbonneau), had apparently been bitten so many times that Clark referred to it as being "much puffed-up and swelled" (UNLP 2005). The group's ability to hunt was also affected. Clark missed a shot at a big horn sheep because he could not keep mosquitoes off of his "gun long enough to take sight" (UNP 2005). Mosquitoes forced Clark to continue downstream instead of waiting for Lewis at the mouth of the Yellowstone River as they had previously planned. Although specific scientific documentation and analyses of mosquito populations were not made during the expedition, journal entries by expedition members were unanimous. Mosquitoes were unbearable and everyone, including "Seaman", Clark's Newfoundland dog, suffered from the persistent pests (UNLP 2005).

Mid- to Late-1880s: Malaria in North Dakota

Malaria, an often-fatal human disease, is caused primarily by the following four parasitic protozoa, *Plasmodium vivax*, *P. ovale*, *P. falciparum*, and *P. malarae*, which are transmitted by *Anopheles* mosquitoes. In a review of plasmodium infections, McKenzie and Bossert (1997) listed 39 Anopheline mosquito species capable of vectoring plasmodium infections throughout the world. Several Anopheline species are native to the United States, with one species, *An. quadrimaculatus* (Say), considered the primary vector of malaria in the eastern half of the United States (Levine et al. 2004, Kiszewksi et al. 2004). Carpenter and LaCasse (1955) and later Darsie and Anderson (1985) report the following Anopheles species native to the North Dakota: *An. earlei* Vargas; *An. punctipennis* (Say); *An. quadrimaculatus*; and *An. Walkeri* Theobald. Symptoms of uncomplicated malaria may include headache, body aches, nausea and vomiting, diarrhea and alternating cycles of moderate to severe shaking chills, high fever, and sweating (CDC 2015). The more severe, complicated malaria involves organ failure. Symptoms include CNS involvement such as seizures, coma, and/or abnormal behavior, severe anemia, hemoglobinuria, respiratory distress, abnormal blood coagulation, cardiovascular collapse, kidney failure, metabolic acidosis, and hypoglycemia (CDC 2015).

A series of four 2D maps published by Pan American Health Organization of the World Health Organization (PAHO/WHO 1969), show malarious areas within the U.S. between 1882 and 1935. Boyd (1941) reported that during 1882, malaria was present in every central-plains state from the Gulf of Mexico to Canada (Figs. 1, 2, 3. 4). Figures 1, 2, 3, and 4 have been rearranged for this disquisition.

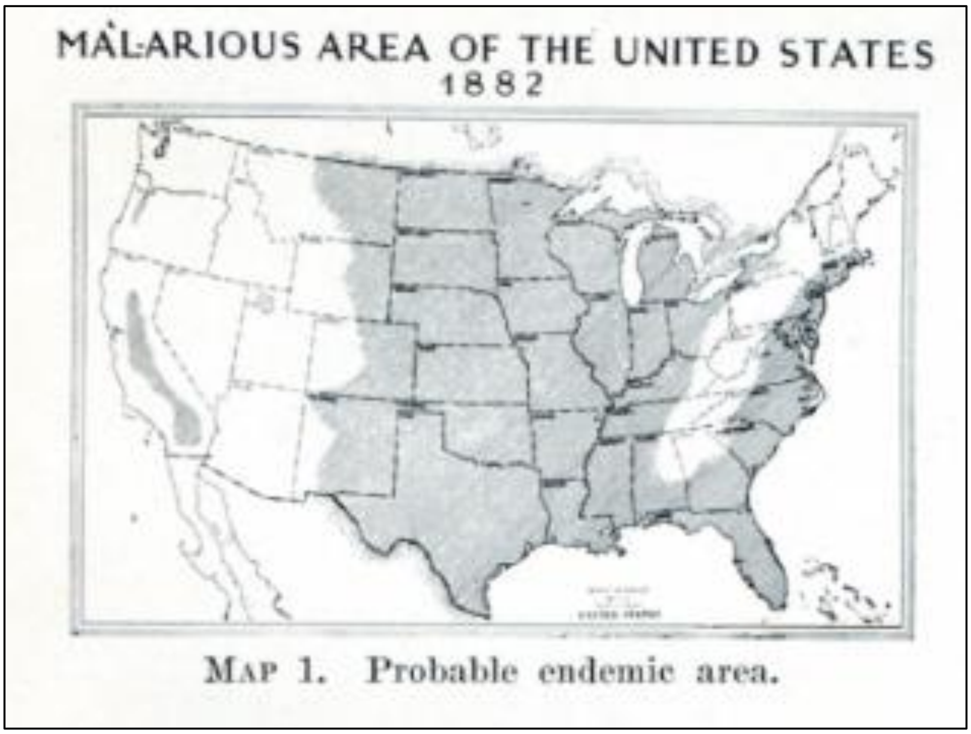

Fig. 1. Probable malarious areas of the U.S. during 1882
Data source: PAHO/WHO 1969

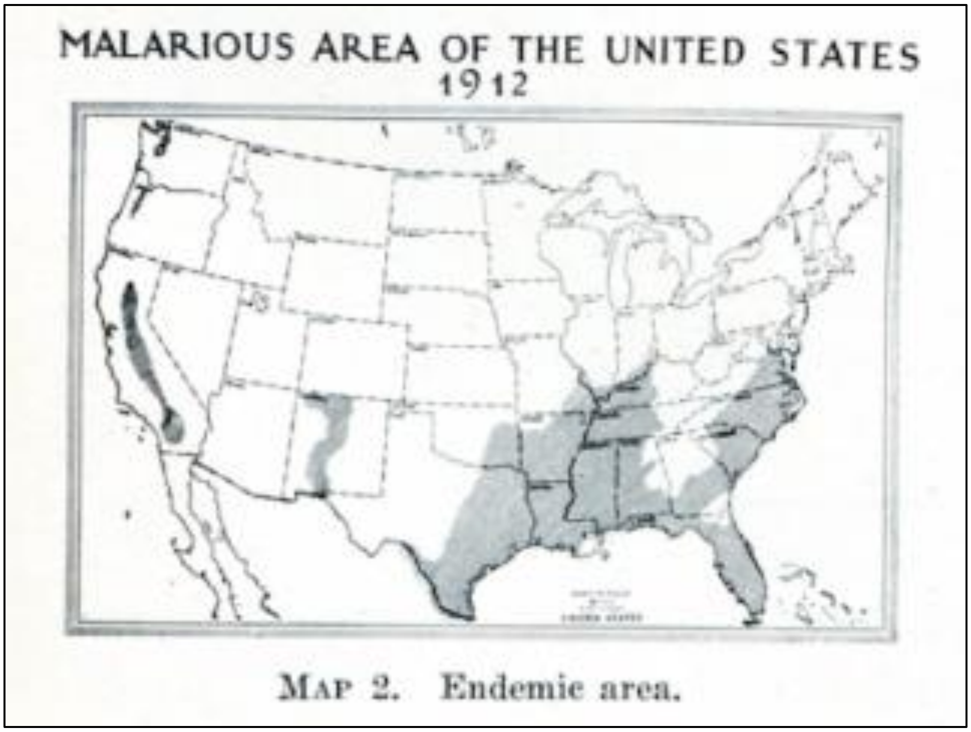

Fig. 2. Malarious areas of the U.S. during 1912
Data source: PAHO/WHO 1969

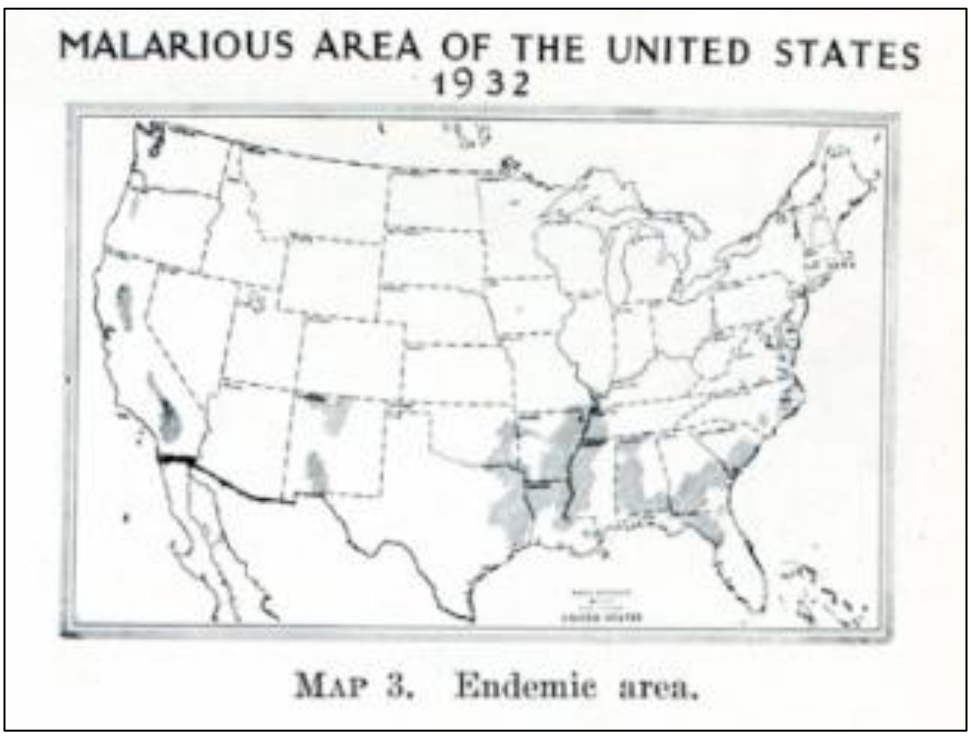

Fig. 3. Malarious areas of the U.S. during 1932
Data source: PAHO/WHO 1969

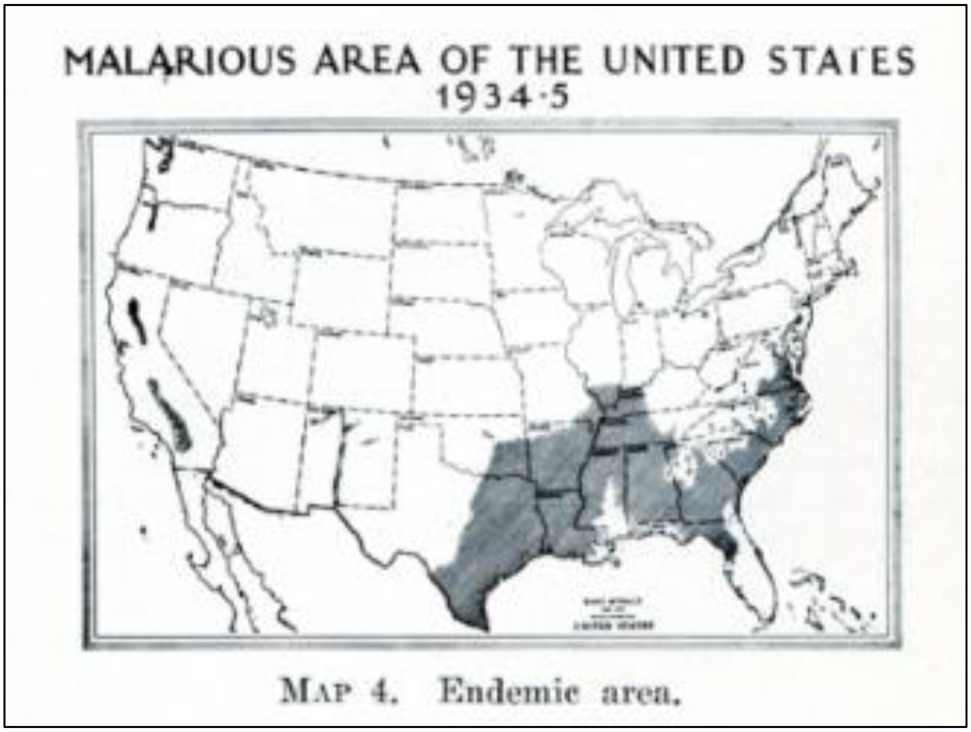

Fig. 4. Malarious areas of the U.S. during 1934 to 1935
Data source: PAHO/WHO 1969.

1941: Western Equine Encephalitis

During 1941, North Dakota, Montana, and Minnesota led the nation in human illness and deaths resulting from Western Equine Encephalitis (WEE) (Foote and Cook 1959). The most important vector of WEE is *Cx. tarsalis* (CDC 2016a), a native species in North Dakota (Darsie and Anderson 1985). The WEE virus belongs to the family *Togaviridae*, genus *Alphavirus* (CDC 2016b, International Committee on Taxonomy of Viruses [ICTV] 2016), which are positive, single-stranded RNA viruses that can be transmitted by Culicidae. Alphaviruses cause two forms of illness. One form involves the central nervous system (CNS) and symptoms may include sudden onset of fever, headache, stiff neck, which vomiting, may lead to seizures, coma, and death. The second form of WEE involves hemorrhagic signs, with respiratory involvement, leukopenia, rash, lymphadenopathy, and biphasic temperatures (Schmaljohn and McClain 1996).

1966 to 1967: Williston Vector Control, District #1

Williston Vector Control District #1 (WVCD) was the first formalized vector control district established in the state of North Dakota. The WVCD encompasses about 223 km^2 (55,104.5 ac; 22,300 ha; 86 mi.[2]), including the city of Williston and land within a 6.4 km (4 mi.) radius of the city limits. However, the area included within the District did not appear to consider the flight migration range of local mosquito species, which research has determined to exceed 32 km (20 mi.) for *Ae. vexans* the predominant Culicid species in the Williston area. Figure 5 shows a 3D map of the Missouri River valley in perspective to the surrounding rolling hills, the location of Williston, which is symbolized as a red polygon and red circle, and the location of the WVCD boundaries, symbolized as a black open polygon. The dark lines within the city boundaries represent city streets. Four buffer rings, symbolized in yellow, blue, red, and orange, represent 5-, 10-, 15-, and 20-mile adult mosquito flight dispersal ranges.

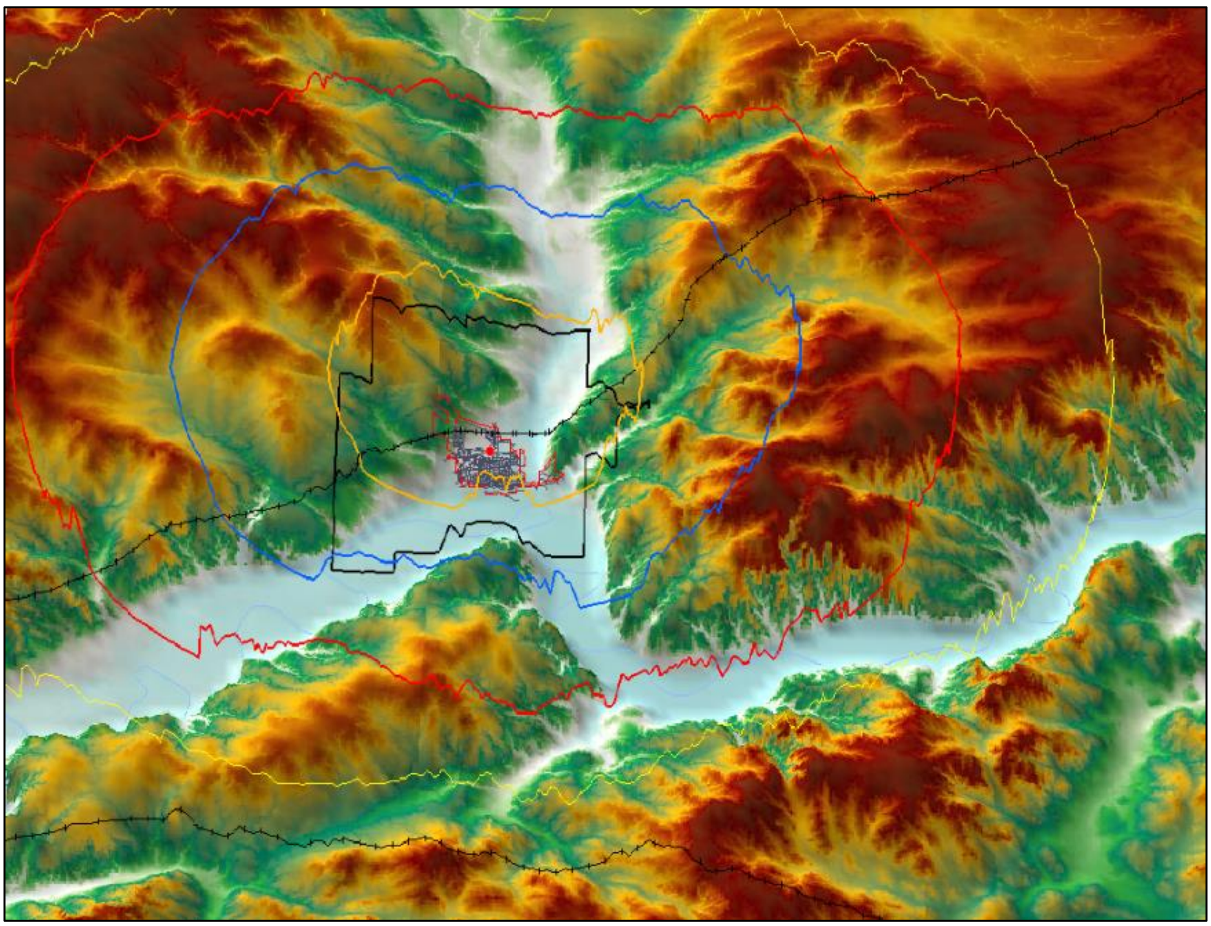

Fig. 5. 3D map of the WVCD boundaries and adult mosquito flight dispersal ranges
Data sources: National Map; NDgisHub; ND Industrial Commission, Department of Mineral Resources, Oil and Gas Division. Technologies used: ArcInfo 10.1; ArcScene 10.1

A copy of the ND Department of Health petition to form a vector control district can be found in Appendix N. The focus of the newly formed WVCD was larval control (Domerese 1989, personal communication; WVCD Annual Reports 1968 to 1979).

1975: The North Dakota Department of Health State-wide Arbovirus Surveillance Program

The North Dakota Department of Health began operating an adult mosquito light-trap/arbovirus surveillance program for WEE throughout the state during 1975. However, the surveillance program was not continuous. It first operated from 1975 to 1989, and was reinstated during 1994 to 1997. During the summer of 2000, the arbovirus surveillance program was resumed for West Nile virus (WNV) surveillance and continues to date (NDHealth 2017). The arbovirus program uses New Jersey light traps to capture adult mosquitoes for virus testing. New Jersey light traps are usually metal and are electrically operated with a seven-day timer. These traps are operated on a regular schedule for one to seven consecutive nights. Each trap contains a 25-watt light bulb, which turns on at dusk and off at dawn (John W. Hock, Co 2016, Li et al. 2015). A small fan draws the insects toward and into the trap. Traps were distributed throughout the state and each morning, local residents collect the live insects and ship them in insulated boxes with containers of ice to the Health Department laboratory in Bismarck, ND. Four New Jersey traps have been deployed within the Williston city limits by the Department of Health for several years (NDhealth 1986 to 1989; WVCD annual reports 1975-1996). Appendix O lists the number of human cases of WNV by state per year.

1983 to 1989: Highest Adult Mosquito Light Trap Counts on Record for Williston, ND

During the summer of 1980, the WVCD reduced the Culicidae larval management program and began trapping adult Culicidae for the ND Department of Health arbovirus program (WVCD 1980 to 1991). However, by the summer of 1982, large populations of adult mosquitoes began appearing in the Williston area. Each summer, mosquito populations continued to increase annually for the subsequent ten years (WVCD 1980 to1991) despite the fact that the entire region, including Williston, was experiencing severe drought conditions during those same years (Williams-Sether et al. 1994). The largest overnight adult mosquito light trap collection occurred during the night of July 3, 1989, when a total of 48,556 adult female mosquitoes were collected in four New Jersey traps. The southwest trap collected 27,520 adult female mosquitoes during that night, the southeast trap collected 9,728 adult female mosquitoes, the northwest trap collected 8,764 adult females, and the northeast trap collected 2,544 adult females (ND Department of Health 1989, WVCD annual reports 1975-1991).

1999 to 2014: Human Cases of West Nile Virus (WNV), by State

West Nile virus has been a concern in tropical areas since at least the late 1950s (Foote and Cook 1959). However, most people in the United States had never heard of the disease until the first human case was documented in New York state in 1999 (Anderson et al. 1999). The West Nile virus is a positive, single-stranded RNA virus that belongs to the family *Flaviridae*, genus *Flavivirus*, which can be transmitted to other animals by arthropods: Arachnida: Acari: Ixodidae and Insecta: Diptera: Culicidae. Seventy to eighty percent of people infected with WNV have no symptoms. If illness occurs, the virus can cause two forms of symptoms. The milder, febrile WNV occurs in about twenty percent of the patients who become infected with WNV. Symptoms may include head and/or body aches, joint pain, vomiting, diarrhea, or rash, and weakness and fatigue that may last for weeks or months (CDC 2015). The more serious form of WNV involves the CNS and may result in encephalitis or meningitis. Symptoms include headache, high fever, stiff neck, confusion, coma, body tremors, seizures, paralysis, death (CDC 2015). The CDC has tested mosquitoes for WNV since 1999 and a list of Culicid species that have been found in pools positive for WNV is provided in Appendix P (CDC 2012). Figure 6 is a 2D georeferenced U.S. state map, generated in ArcInfo 10.1, showing the cumulative number of human cases of WNV per state for the time period, 1999 to 2015 (CDC 2017).

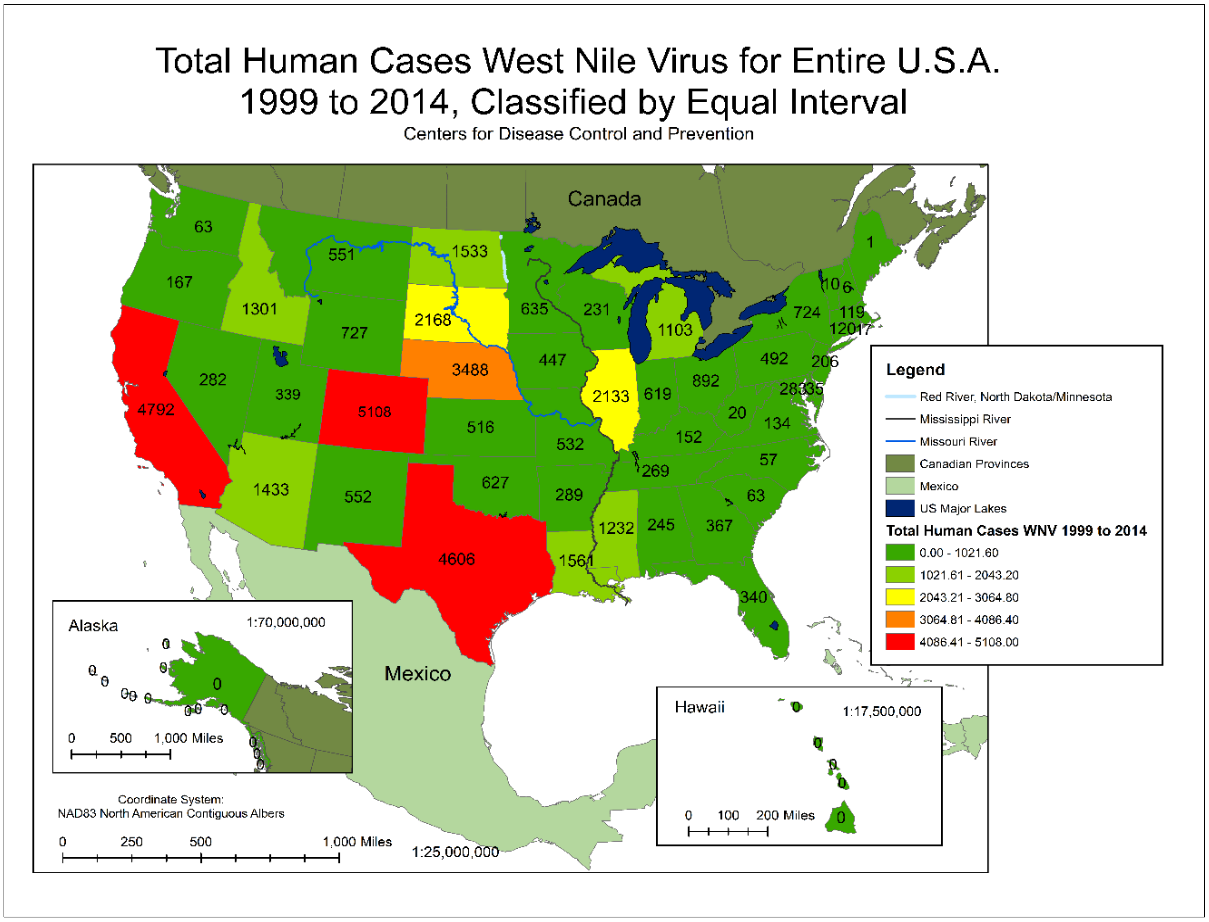

Fig. 6. Cumulative number of human cases of WNV per state, 1999 to 2014
Data sources: CDC; Background map, courtesy of Esri; NDgisHub. Technology used: ArcInfo 10.1; Excel

1999 to 2014: Human Cases of West Nile Virus (WNV), by North Dakota County

North Dakota Department of Health has documented the number of human cases of WNV per North Dakota county for the time period 1999 to 2014. That data was entered into a georeferenced map and grouped by equal interval classification method. The resulting 2D map (Fig. 7) indicates that Williams County, which includes the city of Williston, ranks along with numerous ND counties having the second lowest incidence of human WNV cases in the state.

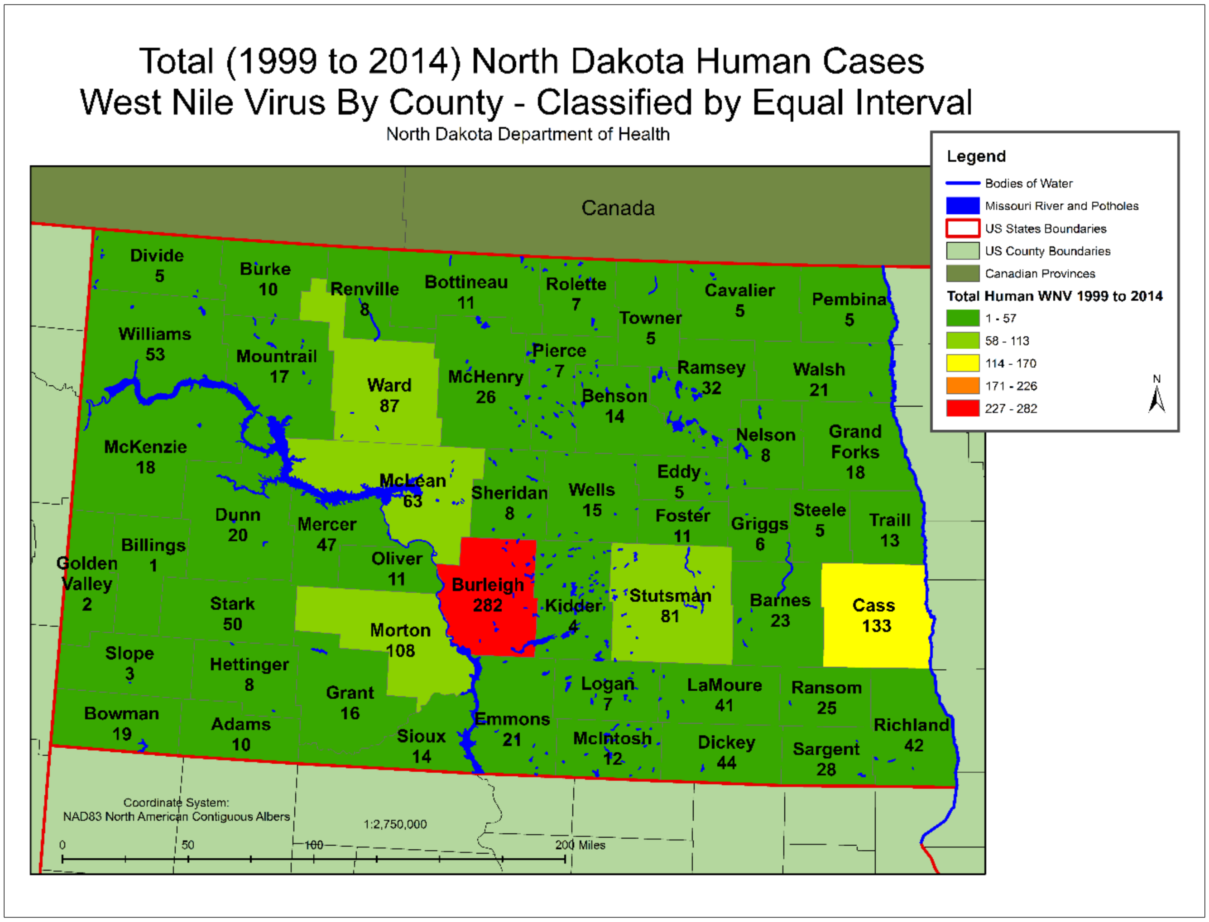

Fig. 7. Cumulative number of human cases of WNV by ND county, 1999 to 2014
Data sources: NDgisHub; ND Department of Health. Technology used: ArcInfo 10.1; Excel 10

Factors Impacting Mosquito Abundance and Distribution near Williston, ND

City Elevation

A 3-dimensional (3D) map created in ArcScene (Fig. 8) demonstrates that the majority of the city is located on the lowest areas of the bluffs surrounding the floodplain and within the floodplain. During the 1950s, a 14.5 km- (9 mi.-) long, 4.6 m- (15-ft-) high levee was constructed between Williston and the Missouri River to protect the city from flooding caused by backwater effects from high operational elevations of the downstream Garrison Dam and Reservoir (USACE 2004). The levee, symbolized as the dark brown/black line in Figure 8, curves along the southern edge of the city and extends westward along the north bank of the floodplain.

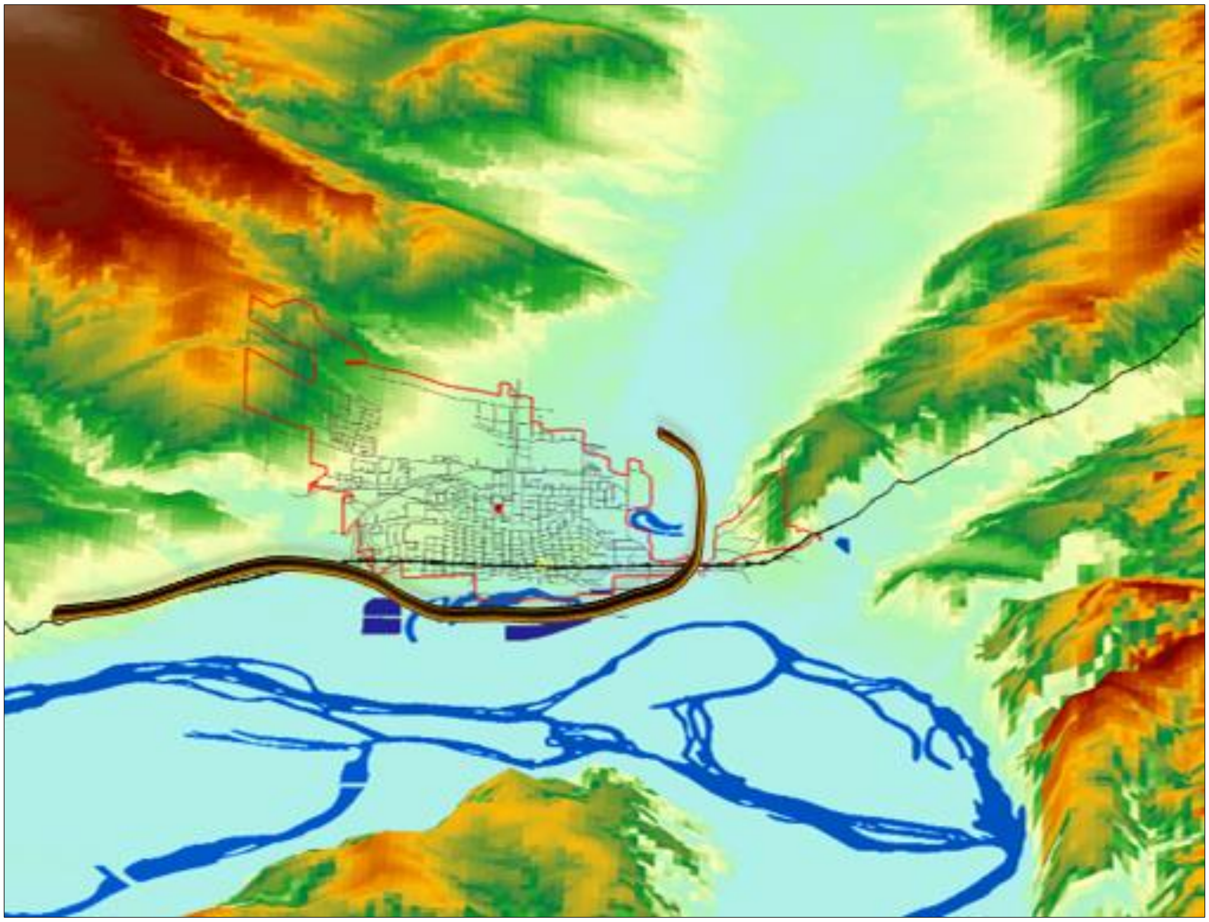

Fig. 8. 3D map of Williston city boundaries and levee
Data sources: NDgisHub; ND Industrial Commission, Department of Mineral Resources, Oil and Gas Division. Technology used: ArcScene 10.1

Elevations of the floodplain near Williston were calculated by ArcInfo to range between 558 m (1839 ft) and 569 m (1,870 ft) near Williston. Upland terrain near Williston consists of gently rolling hills. Elevations of the hills near Williston were calculated using ArcInfo to be about 770 m (2,526 ft). Difference in surface relief near Williston is about 212 m (696 ft). One of the lowest elevations for Williston is the railroad depot located on the south edge of town, symbolized in Figure 8 as a small yellow dot. A bronze, 1914 U.S. Coast and Geodetic Survey monument (i.e., National Geodetic Survey [NGS] monument), designation name G 8 is embedded in brick, four feet above ground on the south side of the Amtrak depot (NOAA 2017c) (Fig. 9). The monument is labeled 'BM' (benchmark) in USGS Quad Williston East (1976).

Fig. 9. U.S. Coast & Geodetic Survey monument, Amtrak Depot, Williston, ND
Monument name G 8, PID TG1320.

The location and low elevation of Williston within the Missouri River valley are important factors in Williston's mosquito problem. Research has shown that river valleys make ideal flight paths for adult mosquitoes, providing shade, humidity, and reduced winds in comparison to higher-ground areas and that adult mosquitoes can travel several miles along river valleys. Additionally, there are no other major cities along the river for at least 97 km (60 mi.) of Williston, which makes the city attractive to adult mosquitoes within a large upstream and downstream radius (Hearle 1926).

Missouri River and Floodplain

Approximately 404 km^2 of floodplain are located near Williston. Upstream (i.e., west) of Williston, the floodplain extends approximately 24 km (15 mi.) to the Montana-North Dakota border. Downstream (i.e., east) of Williston, the floodplain extends approximately 32 km (20 mi.), however, the extent of the downstream floodplain varies each summer, based on the operational level of the downstream Garrison Dam and reservoir. The area of Missouri River and floodplain located immediately upstream and downstream of Williston are often referred to as the Williston Reach (Wuebben and Gagnon 1995, USACE 2009) because of the uniform plant and animal life and because this stretch of river is one of only a few areas of the Missouri River that remain in its natural state.

The slope, defined as the amount or degree of deviation from a horizontal or vertical surface (American Heritage College Dictionary 2000) of the floodplain near Williston is considered gentle. Upstream (west) of Williston, the floodplain slope is about 0.197 m per km (1.04 ft per mi.) (US Congress, House 1935). Downstream (east) of Williston, the floodplain slope is about 0.143939 m per km (0.76 ft per mi.) (US Congress, House 1935). When the Missouri River overflows its banks each spring and summer near Williston, the flat and gently sloped floodplain cause the flooding water to spread over wide areas, commonly referred to as sheet flow (FEMA 2003b).

The Upstream Watershed and Annual June Rise

Upstream, a large watershed extends hundreds of miles to the Rocky Mountains in Montana, Wyoming, and part of Canada and covers a drainage area of about 426,053.4 km^2 (105,280,000 ac; 42,605,340 ha; 164,500 mi.^{2}) (Wuebben and Gagnon 1995). Each spring and summer as mountain temperatures increase, large volumes of mountain snowmelt and regional precipitation flow down the Missouri and Yellowstone Rivers and cause dramatic increases in river surface elevations throughout both river systems (USGS Real-time water 2017). The largest increases in river elevations occur during May, June, and July of each spring and summer and the phenomenon is called the June rise (Chappell [date unknown]. http://ia601406.us.archive.org/3/items/historyofmissour00chaprich/historyofmissour00chaprich.pdf, accessed April 2017).

Data from USGS gaging station #06330000 (USGS 2017) show that over the past 50 years, Missouri River elevations near Williston have ranged from a low of 557.85 m to a high of 567.09 m (1,830.20 ft to 1,860.53 ft) above mean sea level (msl), a difference of 9.25 m (30.33 ft). Over the past 50 years, the average annual June rise is 1.95 m (6.4 ft). Each year when the Missouri River transports large volumes of water during the June rise, river water overflows river banks, inundates large areas of the floodplain, and creates favorable mosquito breeding habitat near Williston.

Missouri River Surge/Recession Cycles

A close examination of the same USGS gaging station records also revealed that Missouri River elevations undergo frequent, small, and unpredictable surge/recession cycles that occur almost daily (Appendix Q). One mosquito species of concern in the Williston area, *Ae. vexans*, has a reproductive strategy that is highly adapted for sites that undergo frequent fluctuations in elevation. Their eggs do not all hatch at the first flooding event. Some eggs will hatch after two inundations, some eggs will require three inundations or more. The extensive floodplain, combined with the occurrence of multiple river surge and recession cycles, and staggered hatching of *Ae. vexans* eggs from numerous egg broods oviposited up and down the river valley, can result in nearly continuous emergence of adult *Ae. vexans* mosquitoes over many weeks (O'Malley 1999).

The Upstream Yellowstone River and its Sediment Problem

An additional problem for the Williston area is the upstream Yellowstone River that annually transports the largest amount of sediment of any tributary into the Missouri River (US Congress, House 1935). The Yellowstone River transfers the sediment to the Missouri River once the two rivers converge a few miles upstream of Williston, ND. Much of that sediment is deposited into the Missouri River channel south of Williston (USACE 2004). Thalweg elevation profiles of the Missouri River near Williston area show increased river bed elevations of about 20 to 25 feet (USACE 1993). As a result, sections of the Missouri River south of town have increasing riverbed elevations, decreasing channel capacity, increasing river surface elevations, increasing stage trends at normal discharge rates, and increasing higher ground water tables, all of which increase the frequency and duration of flooding in the area (USACE 1993).

The Downstream Garrison Dam and Reservoir

Downstream, the large, multipurpose Garrison Dam and its reservoir, Lake Sakakawea, also cause problems. When the Garrison dam and reservoir are operated at high elevations (e.g., near 564 m [1850 ft] msl), the reservoir extends upstream nearly 289.68 km (180 mi.) to where the headwaters of the impoundment are located near Williston (USACE 1998). The headwaters of the reservoir increase groundwater tables and area flooding, which are ideal mosquito breeding habitat. When the dam and reservoir are operated at low elevations (e.g., near 558 m or 1830 ft msl), large areas of mudflats, sandbars, and marsh area are exposed (Hoganson and Murphy 2003). Unfortunately, these conditions also provide nearly ideal mosquito breeding habitat (Dale and Knight 2008, Rey et al. 2012).

Wetlands near Williston, ND

Nearly all of the floodplain located immediately south of Williston is classified as wetlands by the National Wetlands Inventory (NWI) (NWI 2015, USFWS 2017). Additionally, numerous upland springs, creeks, coulees, and some prairie potholes surround Williston, and are also classified as wetlands (NWI 2015, USFWS 2017). Based on the CFR [Code of Federal Regulations]. 2012. 33 CFR 328 and the National Archives and Records Administration (NARA) Federal Register (NARA 2015) definition of waters of the United States, under the Clean Water Act proposed rules, wetlands include swamps, marshes, bogs, and similar areas. Each type of wetland varies slightly, based on landscape position, landform, water flow path, and waterbody type (National Research Council 1995, Fretweil et al. 1996, Tiner 1997).

As defined by Cowardin et al. (1979/1992, 2015; FGDC 2013; USFWS 2017), all wetlands exhibit three basic characteristics: hydrophytic plants; predominantly undrained hydric soils; and saturated substrate for some portion of the growing season. The predominant wetland type near Williston is palustrine (i.e., persistent) (Cowardin et al. 1979/1992, 2015; FGDC 2013; USFWS 2017). Wetlands provide important benefits, including water storage, water purification, increased oxygen production, local recreation areas, and habitat for a variety of wildlife including migratory waterfowl, wading birds, reptiles, fish, amphibians, and invertebrates (Dahl 2011). Research also shows that natural, unmanaged wetlands provide ideal habitat for the production of large populations of mosquitoes and, accordingly, increased risks of vector-borne disease (Rey et al. 2012, Medlock and Vaux 2011, Roiz et al. 2014). A 2-dimensional (2D) map was developed in ArcInfo using current wetland data for the conterminous U.S. identified the locations and amounts of wetlands near Williston (Fig. 10). An enlarged legend for Figure 10 is provided on the following page (Fig. 11).

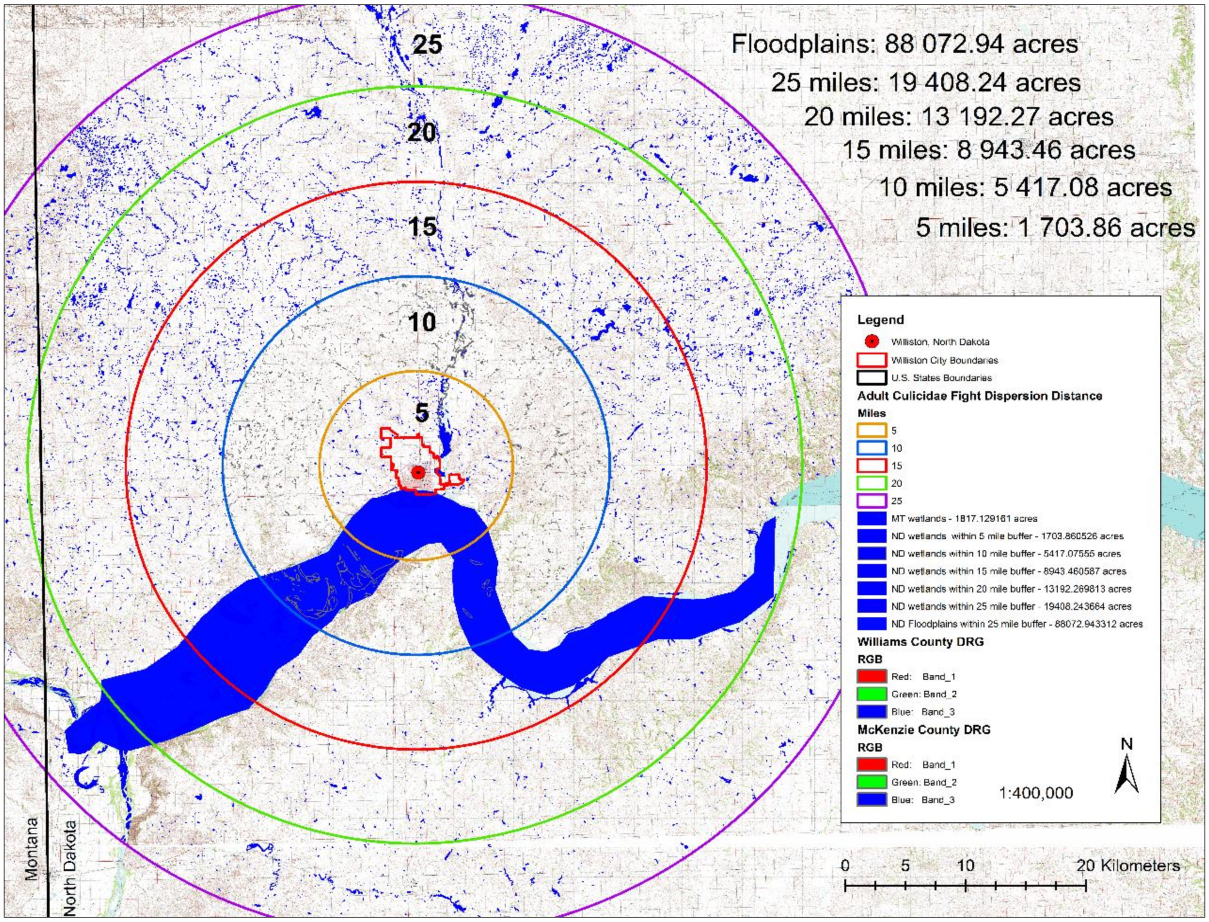

Fig. 10. National Wetlands Inventory data for the Williston area
Data sources: NDgisHub; USFWS. Technology used: ArcInfo 10.1

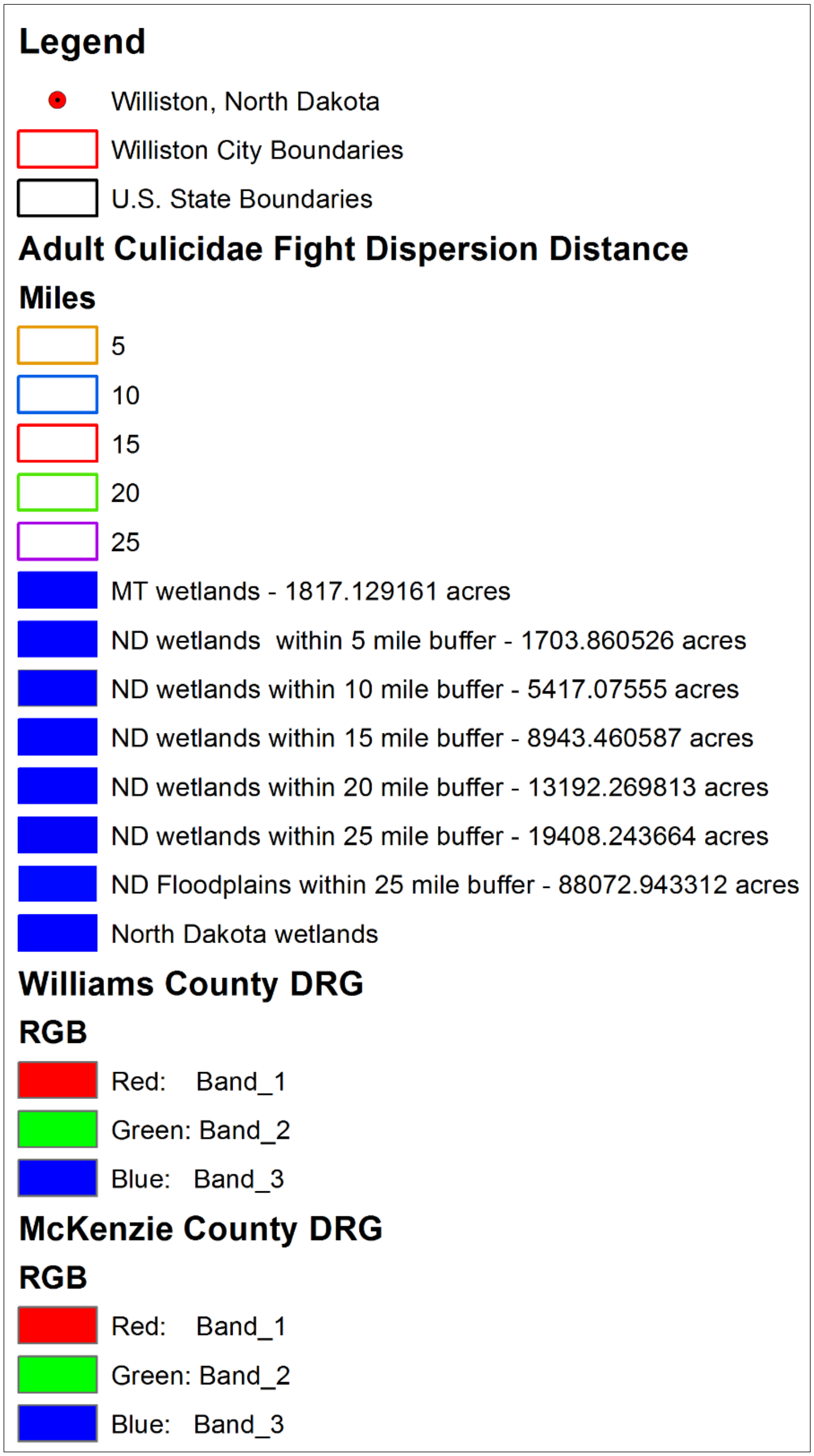

Fig. 11. Legend for Figure 10

Considering the size of the Missouri River floodplain wetlands, the amount of upland wetlands near Williston, and an estimated flight dispersal range of 40 km (25-mi.) for *Ae. vexans*, a particularly persistent mosquito common in the Williston area, there are nearly 538 km^2 (133,000 ac; 53,823.19 ha; 207.7 $mi.^2$) of wetlands (i.e., mosquito breeding habitat) that surround the city of Williston. Table 4 defines the codes for NWI wetland types found in the Williston, ND area. Table 5 identifies the extent of wetlands within

various adult mosquito flight dispersal distances of Williston.

Table 4. National wetlands and deep-water map classification codes

NWI Code	Wetland System	Wetland Subsystem	Wetland Class
PEM[1]	Palustrine	---	Emergent
PFO[2]	Palustrine	---	Forested
PSS[3]	Palustrine	---	Scrub-Shrub
PAB[4]	Palustrine	---	Aquatic Bed
PUB[5]	Palustrine	---	Unconsolidated Bottom
L1[6]	Lacustrine	Limnetic	---
L2[7]	Lacustrine	Littoral	---
R4US[8]	Riverine	Intermittent	Unconsolidated Shore

Notes:
[1] PEM: Palustrine (P); Emergent (EM)
[2] PFO: Palustrine (P); Forested (FO)
[3] PSS: Palustrine (P); Scrub-Shrub (SS)
[4] PAB: Palustrine (P); Aquatic Bed (AB)
[5] PUB: Palustrine (P); Unconsolidated Bottom (UB)
[6] L1: Lacustrine (L); Limnetic (1)
[7] L2: Lacustrine (L); Littoral (2)
[8] R4US: Riverine (R); Intermittent (4); Unconsolidated Shore (US)

Data source: USFWS, based on Cowardin et al. (1979/1992; 2013; FGDC 2015)

Table 5. Amount of wetlands within adult Culicidae flight dispersal distances of Williston, ND

Distance from Williston	Area
12.95 km (5 mi.) radius	6.90 km^2 (1,703.86 ac; 690 ha; 2.66 mi.^{2})
25.90 km (10 mi.) radius	21.92 km^2 (5,417.08 ac; 2,192 ha; 8.47 mi.^{2})
38.85 km (15 mi.) radius	36.19 km^2 (8,943.46 ac; 3,619 ha; 13.97 mi.^{2})
51.80 km (20 mi.) radius	53.29 km^2 (13,192.27 ac; 5,329 ha; 20.58 mi.^{2})
64.75 km (25 mi.) radius	78.54 km^2 (19,408.24 ac; 7,854 ha; 30.33 mi.^{2})
Missouri River Floodplain	356.42 km^2 (88,072.94 ac; 36,542 ha; 137.62 mi.^{2})
Total:	546.46 km^2 (135,033.99 ac; 54,646 ha; 210.99 mi.^{2})

Data source: USFWS, based on Cowardin et al. (1979/1992; 2013; FGDC 2015)

Other major cities in North Dakota do not have similar mosquito problems. One reason is the amount of wetlands near each city. A 2D comparison of current NWI data for the six largest North Dakota cities was made within ArcInfo (Fig. 12). All six images are at the same scale of 1:150,000. Williston has the smallest population of the six cities, yet it has the largest amount of localized wetlands. Numerous NAIP photographs were downloaded and used for base maps (North Dakota GIS Data Portal [NDgisHub] 2017, United States Department of Agriculture [USDA] Geospatal Data Gateway [GDG] 2017). The wetlands data were retrieved from the U.S. Wildlife Service (USFWS) (2017). An enlarged legend for Figure 12 is provided on the next page as Figure 13. Figure 14 was taken within the floodplain near Williston during larval ground-sampling and surveillance, 6 June 2010.

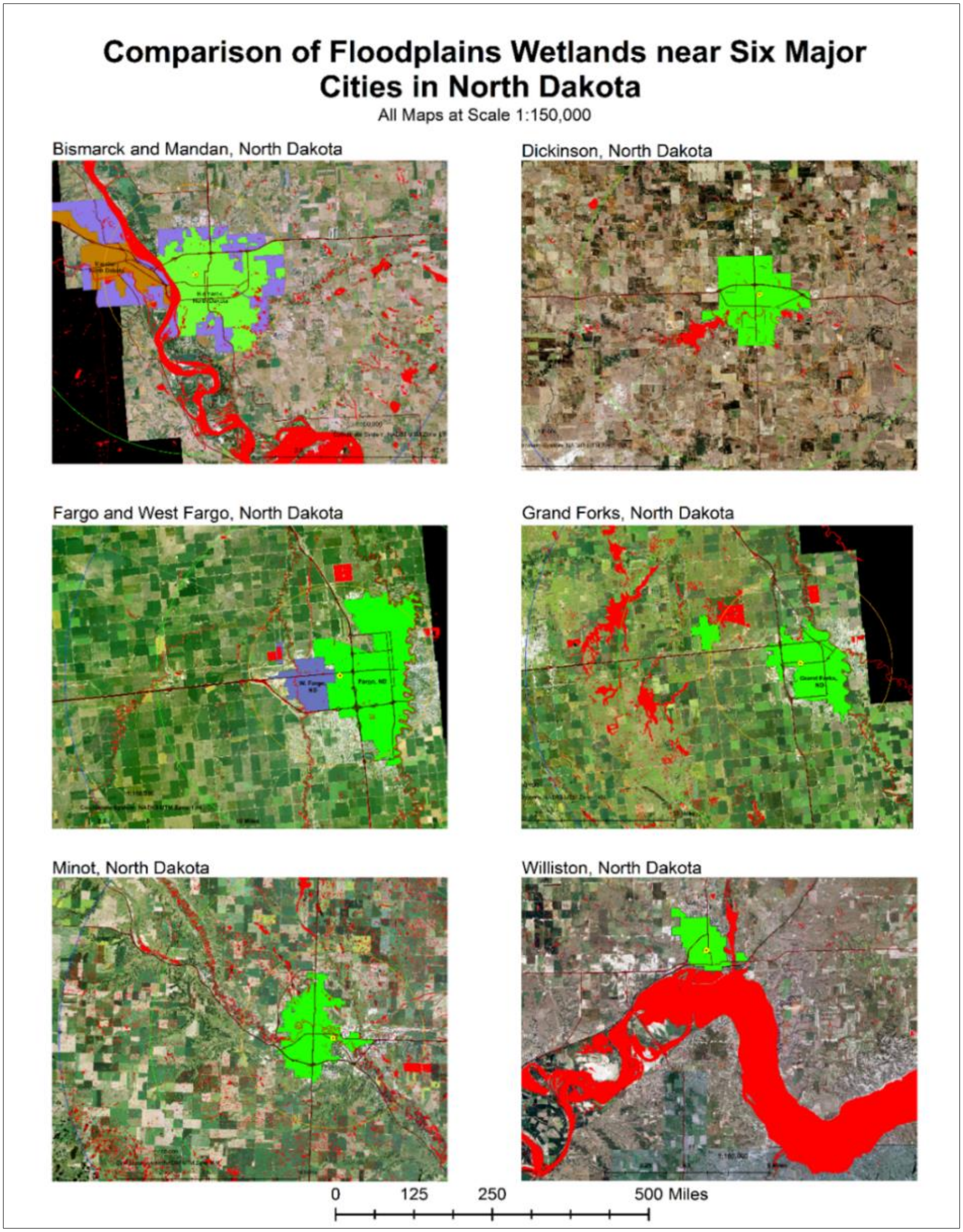

Fig. 12. Comparison of wetlands for six North Dakota cities
Wetlands are symbolized in red. Data sources: NDgisHub; USFWS. Technology used: ArcInfo 10.1

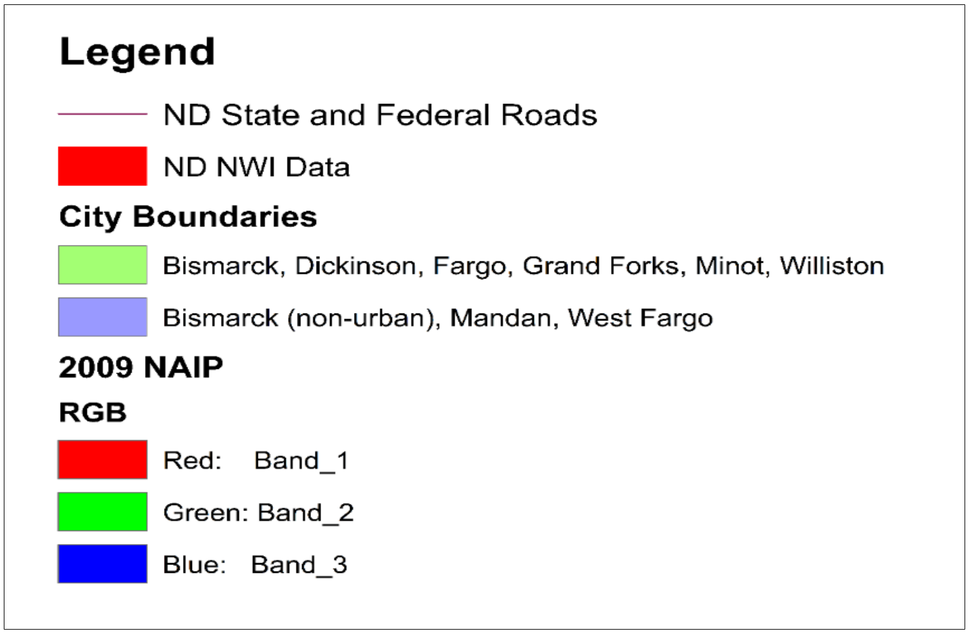

Fig. 13. Legend for Figure 12

Fig. 14. The floodplain near Williston, ND

Mosquito Experts Who have Assisted Williston

Since 1967, numerous local, state, and federal officials, and entomologists from across the U.S. have either visited Williston in person or communicated by telephone with city officials in an effort to assist with the local mosquito problem. Experts, in chronological order have included: 1) the ND Department of Health (NDhealth 1967) during the petition process to establish a vector control district (Appendix N); 2) Wayne Kramer PhD, entomologist, NE Department of Health, Lincoln, NE; 3) Alfred Cofrancesco PhD, entomologist for the USACE, Vicksburg, MS (Cofrancesco et al. 1990); 4) Jack Stewart, vector control director, Stark County, ND (Williston Daily Herald, Stewart 1991); 5) Robert Novak PhD, entomologist, past president of AMCA, 1996 to 1997, transcribed telephone conversation; 6) Claude Schmidt PhD, entomologist, past president of the AMCA, 1981 to 1982, meeting with the WVCD and documentation afterwards with a personal letter; 7) Joel Young, vector control director, Cass County, ND. (Williston Daily Herald, Young 1992); 8) George Melanson, USACE Branch Office, Williston, ND (1992); 9) Fran Kernik (Williston Daily Herald 2007); 10) John Anderson PhD, entomologist, Connecticut Agricultural Experiment Station, New Haven CT (Anderson et al. 2015); and 11) Mark Breidenbaugh PhD, entomologist, United States Air Force Reserve Spray Unit, Youngstown, OH (Williston Daily Herald 2009 to 2016).

The research of Cofrancesco et al. (1990) is of particular interest as it included Culicidae egg/soil and larval/adult mosquito density analyses within the floodplain near Williston. Five areas of the floodplain were sampled and studied using aerial photographs to identify land classifications. Areas with the largest egg counts included zones that consisted of hay and alfalfa fields, trees, active and inactive sewer treatment ponds, and small lakes. Additional areas with large egg counts consisted of zones associated with the Little Muddy River, including mud flats, sandbars, ground cover, and standing ponds. The average egg count for each of the 15.25 cm^2 (2.36 in^2) of soil in those areas was determined and extrapolated to an estimated number of eggs per unit area. The study estimated a total of 97.13 km^2 (24,000 ac; 9,713 ha; 37.50 $mi.^2$) of breeding habitat within the floodplain near Williston, and a potential of 21,968 to 308,404 mosquitoes produced each summer (Cofrancesco 1990). During the current IfSAR study, ArcInfo software tools (Environmental Systems Research Institute [Esri, formerly ESRI]) (2017a) determined approximately 358.15 km^2 (88,500.79 ac; 35,815 ha; 138.28 $mi.^2$) of breeding habitat existed within *Aedes vexans* adult flight dispersal range of the city of Williston. Using a conservative estimate of

263.046 km^2 (65,000 ac; 26,304.57 ha; 681.29mi.^{2}) to 404.69 km^2 (100,000 ac; 40,468.56 ha; 156.25mi.^{2}) of breeding habitat and Cofrancesco's (1990) estimated number of eggs per unit area, the potential number of adult mosquitoes produced within flight distance of Williston each summer could range between 7.7 and 19.4 million.

Clearly mosquito problems in the Williston area have not been resolved in the 210 years since Lewis and Clark left the area. An indicator that Williston's mosquito problems are still difficult is the fact that since the summer of 2009, the 757th Airlift Squadron of the 910th Airlift Wing, United States Air Force Reserve (USAFR) Aerial Spray Command Unit, Youngstown Air Reserve Station, Youngstown, OH (2015) uses the floodplain near Williston as a training area for its spray pilots. Dr. Mark Breidenbaugh, entomologist with the USAFR Spray Unit, directs worldwide pest control efforts to protect U.S. armed forces from arthropod vectors capable of disease transmission. He has been actively involved in using the floodplain near Williston and the city as training sites for the unit's pilots. In an interview reported by the *Missoulian* newspaper, Dr. Breidenbaugh conveyed that the mosquito problem in Williston is as bad as he has seen in traveling the world studying insects (MacPherson 2009). The additional aerial larviciding efforts carried out by the USAFR have continued each summer since 2009 and have given Williston residents more comfortable summers. However, with increasing budgetary constraints within the U.S. government and other governing bodies worldwide, there is the concern that reliance on the Air Force to secure funding each year for such programs may not be sustainable. This research, requested by the WVCD, is a positive step to prepare for such an unforeseeable event.

Geospatial Technology Science and Entomological Applications

The use of geospatial technologies in entomological research is not new. Early papers include Wagner et al. (1979) who used infrared aerial photographs to successfully generate a detailed map of mosquito breeding sites within a newly formed mosquito control district in Michigan. Fleetwood et al. (1981) used aerial surveillance to monitor and map the floodwater mosquito species *Psorophora columbiae* in Louisiana rice and fallow fields. The authors found that the combination of aerial and ground inspection methods made it possible to cover larger areas and reduce the time required for surveys, and thereby reduced inspection costs by 2.5 times compared to traditional ground-based methods. Hayes et al. (1985) used remote sensing multispectral scanners mounted on the Earth-orbiting

Landsat 1 and 2 satellites to conduct supervised ground cover classifications of areas near Lewis and Clark Lake. Aerial color-infrared (CIR) photography was used in a survey of *Ps. columbiae* oviposition sites in Texas rice production lands (Welch et al. 1989). The study suggested a possible financial savings for mosquito control districts and an increase in efficiency when aerial CIR was used to detect potential egg-laying habitat. Kline (1991) successfully used CIR photographs to locate Culicoides larval habitat in Florida, and found that the use of CIR reduced ground-based survey hours and costs, resulting in a more cost-effective use of resources.

Normal Difference Vegetative Index (NDVI), GIS, and remote sensing were analyzed by Wood et al. (1992) to determine high- and low-mosquito-producing rice fields. Results suggested that both remote sensing and GIS were beneficial for identifying high-producing fields and also assisting with targeting control efforts. Research with GIS systems found that the technology greatly shortened and simplified the process of mapping larval habitats, locating known viral cases and areas at risk, and planning emergency responses (Moore et al. 1993). Moncayo et al. (2000) incorporated GIS and remote sensing applications to determine the risks for EEE virus transmission in Massachusetts using stepwise linear regression. Results indicated that wetlands comprise the land class that contributed the most to the abundance of *Ae. canadensis, Ae. vexans,* and *Cx. salinarius* Coquillett, and also increased risk of EEE. Tracking of tagged insects using harmonic radar was explored by O'Neil et al. (2004). The authors described the development of GIS-based real-time Internet mapping tools used to enhance control efforts.

Floodplain Mapping

Digital Elevation Models (DEMs), GIS, hydrologic data (i.e., river elevations, slope, and aspect), land cover classifications, and aerial photographs were used by Puech and Raclot (2002) to determine flood levels and flow direction during floods in Herault River, France. Bates (2004) reported that topographic data provides the most important information for flood inundation studies, noting that information needed includes slope, aspect, flow direction, and flow accumulation. Several flood/inundation studies have incorporated elevation data such as IfSAR, shuttle-imaging radar (SIR), RADARSAT-1 and -2 (Canadian-sponsored high-resolution SAR imagery), and NEXRAD radar (U.S. National Weather Service Next-generation Radar) (Doppler) to define water flow and accumulation (Töyrä et al. 2002, Bates 2004, Joyce et al. 2009, Schumann et al. 2009).

Predictive Mapping

Guerra et al. (2002) used geographic information systems and environmental factors such as grasslands, forests, wetness indices, soil orders and textures, and bedrock data to successfully predict risk for Lyme disease. A study by Clennon et al. (2010) compared a 90-m spatial resolution SRTM elevation data to a 30-m spatial resolution Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) DEM. The purpose of the study was to determine if the models could locate water flow and accumulation across the landscape for predicting potential mosquito breeding habitat. Their results determined that the 90-m SRTM elevation data were better at identifying flow direction and accumulation than the ASTER elevation data. Their study also found that the integrated models were most useful in identifying areas not suitable for water accumulation and mosquito breeding. Those areas were eliminated from chemical control efforts, resulting in a more efficient focus of resources.

Cohen et al. (2010) integrated land use/land cover classification data from a 1-m IKONOS satellite image and Topographic Wetness Indices (TWI) from a 10-m DTM. Results of their study indicated that topography (i.e., DEM) and wetness indices such as TWI were useful in predicting households at risk for malaria compared to using land use/land cover indices. In Kenya, ground surveys, GIS, and topographic indices derived from a 90-m SRTM DEM and a 30-m ASTER DEM were successfully used to predict breeding habitat for malaria vectors (Nmor et al. 2013). Although the study found that predictability of the remote sensing data varied with vegetation type, the authors reported that medium- to low-spatial resolution topographic data were suitable for identifying mosquito breeding habitat. Additioinally, because a large volume of topographic data are public domain, the authors also reported that predictive models could be developed using public domain data, with little to no cost and that predictive models could be a valuable addition to mosquito control efforts worldwide.

One key benefit of geospatial technologies is the ability to program the sensors to record data automatically, thus removing bias that can occur in some forms of conventional data collection. Geospatial technologies are also non-invasive, non-destructive, quicker, and more cost-effective than standard ground-based data collection methods, and they allow for the collection of information from large areas that would be impractical or impossible to cover by ground methods. They are also safe to use, because data are collected from a distance without having to place field workers in difficult or dangerous areas (e.g., mountainous areas, high-crime areas, war zones, etc.). Digital maps and data require little space, and the media used to store the information (e.g., data disks, portable hard drives, etc.) are easy to carry and store. Digital data can be symbolized in color, making it easier to differentiate patterns, objects, or changes. Digital maps can also be updated quickly and can include realistic symbolism such as trees and buildings. Maps can also be embedded with Internet hyperlinks to web-hosted accessory data, images, and videos. Digital maps can be panned and zoomed in on for close-up views, and they also can be analyzed spatially and queried to show patterns or relationships that are impossible to determine with analog maps.

Digital maps and data can be manipulated within GIS to create 'worst case scenarios' for emergency preparedness and response planning, or for predictive models to assist officials in making various management decisions. Digital maps are normally viewed in 2-dimensional format, however, they can also be viewed three-dimensionally if elevations are included in the dataset. Digital data from the same location but from different time periods (e.g., days, weeks, years) can be mathematically subtracted within GIS to determine changes over time. Statistical analyses of digital maps are also possible because organized sets of numbers are typically hidden within the data (Berry 2007). Many digital datasets are public domain and, as such, available to the public on the Internet for download, and often at no charge (Berry 2007).

There are limitations with remote sensing technologies. Remotely sensed geospatial data are delivered in different formats, some of which are more difficult to import into ArcGIS software, to project, or to integrate with other geospatial data. Remote sensing data are also not always available for certain areas, or if available, can be extremely expensive. Many geospatial technologies cannot collect data during inclement weather, which can be problematic if critical data is needed at the time. Some remote sensing technologies, especially lower-resolution, public domain aerial photography and Landsat satellite imagery, are unable to record data under dense canopy cover or in areas of heavy ground vegetation. Remote sensing data typically also requires specialized software, often multiple programs that can require hours of training. This, in turn, mandates the use of high-speed computers with significant amounts of memory, which can be expensive.

Most public domain spatial data have low spatial and/or temporal resolution and are not appropriate for detailed research or critical analyses, especially in flood scenarios that require daily updated datasets. Remote sensing data must be corrected for atmospheric, topographic, and solar factors if they are to be compared to a spectral library. Relative atmospheric correction must be done if data from one date are to be compared to another (Jensen 2007). Remote sensing may be intrusive if active (i.e., produce their own electromagnetic energy) technologies are used (Jensen 2007). Sensors can become uncalibrated, which also can be problematic (Jensen 2007). The capability or applicability of remote sensing technology can also sometimes be overrated and oversold as the answer to any problem (Jensen 2007). Additionally, whenever new data are added to an analysis, there is the possibility of introducing additional error (Jensen 2007). Malfunction problems can also be a concern. A malfunction of the Scan Line Corrector (SLC) has caused continual data gaps in some Landsat 7 data since May 2003.

Interferometric Synthetic Aperture Radar (IfSAR) Technology

Radar technologies operate within the microwave range (i.e., one m to one mm) of the electromagnetic energy (EM) spectrum. Radar technologies produce and direct microwave energy toward objects on the earth, then record the amount of the energy that is reflected from objects. The first returned energy is the energy reflected from the upper-most surfaces, such as tops of trees, buildings, and mountain tops, and is used to produce digital surface models (DSM) elevation data. Certain bands within the microwave energy range can penetrate deeper into trees and other vegetation, but take slightly longer to return and be recorded. Digital terrain models (DTMs) are created from DSMs by removing the first return signals and using only the later signals that represent bare ground elevations. Radar technology has the advantage of being able to penetrate inclement weather conditions such as rain, snow, clouds, smog, or smoke, making it easy to collect elevation data over vast areas in nearly any type of weather, and during daylight or night hours. IfSAR elevation data can be analyzed in GIS for topographic and hydrologic characteristics such as slope, aspect, flow direction and accumulation. IfSAR technology does not leave data gaps.

The IfSAR DTM elevation data looks and functions similar to public domain DEMs within GIS software. IfSAR data are relatively low in cost, approximately \$35.00 per $kilometer^2$ (Maune 2007), need to be collected only once, and can be used for years without additional cost if local topography remains stable. IfSAR technology is limited because data collection must be done during times of the year when deciduous woody plants lack leaves, and its accuracy is only measurable within open terrain (12 inches or less vegetation), which includes bare earth, grassland, pasture, hay, low crops, and within less than 10% slope (Maune 2007). Also, IfSAR elevation data requires a computer capable of handling large datasets, expensive GIS software, and requires many hours of training of the software. IfSAR technology cannot fully penetrate vegetation as well as LiDAR data, and it does not have the high spatial resolution of LiDAR.

Based on the National Academy of Sciences' Committee on Floodplain Mapping Technologies, National Research Council (NRC) recommendations, FEMA flood insurance maps should follow National Map Accuracy Standards (NMAS) (NMAS 1947) and have a 2-ft equivalent contour accuracy in flat areas, or 4-ft equivalent contour accuracy in rolling hills. These accuracies are equivalent to vertical root mean squares error (RMSEz) values of 18.5 cm (0.61 ft) and 37 cm (1.22 ft) in flat terrain and rolling hills, respectively. Results also determined that FEMA's mapping modernization efforts should use LiDAR-based digital elevation data, which have a 2-ft equivalent contour accuracy in most terrain and land use/land cover types (NRC 2007). The study also determined that IfSAR elevation data are inadequate for FEMA flood hazard maps due to problems with penetrating vegetation and the resulting higher vertical RMSE. The committee suggested that IfSAR elevation data may be applicable for low-risk flood analyses in barren areas or those covered by low vegetation, especially where frequent or long periods of cloud cover limit the application of LiDAR technology.

Pre-IfSAR Research

The following two non-statistical analyses were carried out prior to the IfSAR study to better understand the how local weather and the Missouri River were impacting Williston's mosquito abundance. A third, non-statistical analysis was carried out using archived maps, aerial photographs, and satellite imagery to determine if changes had occurred within the floodplain near Williston.

Local Weather Variables, 1986 to 1989

All immature mosquito stages require water and a plethora of research worldwide supports direct relationships between mosquito abundance and weather variables (Ruiz et al. 2010, An G. 2011), especially precipitation and temperature. Yet, Williston, ND, located in a semiarid climate and receives less than 15 in of precipitation annually, experiences large mosquito populations nearly every spring and summer. Three important studies, Rubel and Kottek (2010), Rubel et al. (2017), and Jensen (2009) concur that western North Dakota's climate is semiarid. Because very little precipitation is received annually and many residents believe wind is blowing the mosquitoes into the city from upstream irrigation districts (from the west and southwest toward the east), a simple trend analysis was carried out to determine if any patterns could be identified among local daily weather variables and weekly adult mosquito light trap counts for the period of 1986 to 1989. This time-period was used because of the high adult mosquito infestations and the low amount of chemical larvicides used for their control during those summers (WVCD Annual Reports 1986 to 1989, City of Williston Commission Minutes 1986 to 1989). It should be noted that, although very little to no larvicide was used during those summers, chemical adulticides were used frequently, and the applications were made by using ground thermal foggers and ground and aerial ultra-low-volume spray equipment (WVCD 1986 – 1989, City of Williston Commission Minutes 1986 – 1989).

Data used for the trend analysis included weekly adult mosquito light trap counts, collected by the ND Department of Health using New Jersey light traps, and daily weather data (i.e., daily temperatures, precipitation, wind direction, and amount of sunlight), recorded by NOAA's National Weather Service at the Sloulin Field International Airport, Williston, ND). Software used included several Microsoft Office 2007 products (i.e., Word, Excel, Notepad). Trend analysis graphs were developed of the following daily climatological variables against weekly adult mosquito light trap counts for the same day and year: average daily temperature; maximum daily temperatures; average daily precipitation; average daily wind direction; and total daily minutes of sunshine. Graphs were developed in SAS (SAS Institute 2011). Traditional statistical analyses could not be carried out on these data sets because of the low number of mosquito light traps used and the short duration of trapping each summer. Results of this trend analysis failed to yield any apparent associations between any of the daily climatological variables and weekly adult mosquito counts during the summers of 1986 through 1989 (Appendix R). A 30-year study by Jensen (2009) confirmed that during the primary mosquito season (i.e., May, June, and July), the average wind direction in the Williston area is mainly from the southeast toward the northwest.

Local Missouri River Elevations, 1986 to 1989

When a series of simple trend analyses failed to detect significant correlations between weather variables and mosquito abundance, further analyses were carried out comparing daily Missouri River surface elevation data collected by USGS gaging station #06330000 for the years 1986 to 1989 to weekly adult mosquito light trap data from collections made by the ND Department of Health using New Jersey light traps (WVCD Annual Reports 1986 to 1989). The gaging station is located about 6.44 km (4 mi.) west of Williston, across the Missouri River from the city water plant. Software used in this analysis included Microsoft Office 2007 (i.e., Word, Excel, Notepad) and ArcInfo 10.1. Results of this trend analysis determined a strong association between Missouri River elevations and adult mosquito light trap counts for all years, 1986 to 1989, with the adults appearing about 10 to 12 days after an increase in river elevations. Traditional statistical analyses could not be carried out on these data sets because of the low number of mosquito light traps used and the short duration of trapping each summer. Statistical Analyst System (SAS) 9.3 was used to develop graphs of the trend analysis (Appendix S).

Tracking Changes-over-time within the Missouri River Floodplain near Williston, ND, 1804 to 2004

During the late 1700s and early 1800s, a scientific, data-gathering, exploration of the Missouri River was authorized by Congress. Journal entries from that Lewis and Clark Corps of Discovery Expedition, 1804 to 1896 indicate that the floodplain near the location of the current community of Williston, ND was covered with numerous types of vegetation including dense forest and underbrush (University of Nebraska - Lincoln [UNL-P] 2017). However, maps drawn at the time by members of the Corps of Discovery and later edited by Plamondon II (2000) did not show the dense forests that were described in the accompanying journals. Eight years after the Corps of Discover Expedition, a thorough survey of the entire Missouri River was authorized by the Missouri River Commission and carried out between 1884 and 1894. Maps drawn during that survey show that the dense forest and underbrush reported eighty years earlier by members of the Lewis and Clark Corps of Discovery still remained within the floodplain near the current community of Williston. The small community of Williston is shown on the MRC map, Plate A productive wood yard (i.e., Scott's Wood Yard) is shown located within the floodplain south of Williston. About 50 years later, a series of mosaicked aerial photographs by the USDA 1949 show that the dense forests discussed by members of the Lewis and Clark Expedition, and later drawn by the MRC, had been converted to agricultural fields. Another 50 years later (i.e., 2004), Landsat imagery show that the agricultural fields within the floodplain near Williston had been converted to wetlands.

MATERIALS AND METHODS

Public Domain Data

Numerous public domain digital datasets and data sources were used in this study, some of which included: 1) climate data (Köppen-Geiger [i.e., Koeppen-Geiger] World Climate Classification system data, Institute for Veterinary Public Health 2017; Prisim Climate Data for North Dakota, Oregon State University 2017); 2) 10-m, 30-m, 90-m, and 900-m elevation datasets (webGIS 2009, Global Topographic 30 arc-sec [GTOPO30] elevation data 2015, USGS National Elevation Dataset [NED] 2015, USGS Shuttle Radar Topography Mission [SRTM] elevation data 2015, NDgisHub 2017); 3) lake and river data (NDgisHub 2017); 4) archived and current Landsat satellite imagery (USGS EarthExplorer 2017); 5) Landsat satellite Worldwide Reference System (WRS) orbit identification data (NASA 2017); 6) Missouri River mile data (NDgisHub 2017); 7) National Aerial Imagery Program (NAIP) photographs (NDgisHub 2017, USDA GDG 2017); 8) National Hydrologic Data (NHD) (USGS NHD 2017); 9) NHDplus2 (Horizon Systems Corporation) [date unknown, accessed Aug 2017]; 10) National Land Cover Dataset (NLCD) (MRLC 2017, USGS LCI 2017); 11) National Wetlands Inventory data (NWI 2015, USFWS 2017); 12) Public Land Survey System (PLSS) data (NDgisHub 2017); 13) Soil Survey Geographic (SSURGO) database (Esri 2017b, USGS Natural Resources Conservation Service [NRCS] 2017); 14) National Geodetic Survey (NGS) monument data (NOAA 2017a, 2017b, 2017c); 15) terrestrial ecoregion data (Sayre 2009, EPA 2016, USDA Forest Service [USDAFS] 2017, World Wildlife Federation [WWF] 2017); 16) topographic (i.e., digital raster graphics [DRG]) data (NDgisHub 2017, USGS National Map 2017); 17) transportation data (NDgisHub 2017); and 18) watershed boundary data (WBD) (USGS WBD 2017).

Public domain, non-digital data and data sources used in this study included: regional climate data (Jensen 2009); local daily weather data, 1986 to 1989 (NOAA 1986 to 1989); adult mosquito light trap data, 1986 to 1989 (NDHealth 1986 to 1989); North Dakota human cases of WNV, 1999 to 2015 (NDhealth 1999 to 2015); PAHO/WHO malaria maps (CDC 2012); real-time water data (USGS Current Water Data 2017); and Williston Vector Control District #1 (WVCD) boundaries were hand-digitized.

Commercial Data

Commercial, digital data and sources used in this study include: one hundred and forty-one km^2 (34,841.9 ac; 14,100 ha; 54.44 $mi.^2$) of Interferometric Synthetic Aperture Radar (IfSAR) Type II DTM elevation data were licensed from Intermap Technology, Inc. (Englewood, CO) (Intermap Technology) 2017). Grid spacing (i.e., ground sampling distance [GSD]) of the IfSAR DTM is 5-m posting. Electromagnetic (EM) energy band identification of the IfSAR DTM is X-band (i.e., 3.75- to 2.4-cm wavelengths). IfSAR elevation data were collected using a STAR-5 active radar-generating system (Intermap Technology, Inc.) mounted on a KingAir 2000T platform Learjet (Bombardier Jet, Montréal, Québec). IfSAR collection swath width (i.e., ground footprint) was 9 km. The IfSAR elevation data were delivered as five, 7.5 arc-minute tiles, in Band-Interleaved-by-Line (i.e., .bil) format. The IfSAR elevation data is referenced to ellipsoid GRS80 [Moritz 2000]). The horizontal datum of the IfSAR elevation data is NAD83 (i.e., the surface from which horizontal zero is measured). Horizontal distance units are in geographic coordinate system (GCS). The IfSAR vertical datum is North American Vertical Datum 1988 [NAVD88] with distance units reported in meter). The complete IfSAR DTM metadata can be found in Appendix T.

Commercial, non-digital data and sources used in this study included Lewis and Clark journal data (UNL Press 2017), and Lewis and Clark maps, reconstructed by Plamondon II and published by Washington State University (WSU) (WSU 2001).

Technologies

Technologies used in this study included: Global Mapper 11 (Blue Marble Geographics 2017); ENVI 4.5 (Harris Corporation 2017); ArcInfo 10.1, ArcScene 10.1 (Esri 2017a); SAS (SAS Institute 2017); Microsoft Word, Excel, Notepad 10 (Microsoft 2017).

Digital Data Tree

A digital data tree (i.e., filing system) for storing and retrieving digital data, maps, and support documents was created in ArcInfo prior to the start of this study and filed on a two-terabyte portable storage drive. The study data were organized by type. Data file names were edited to work in ArcInfo software. Data file names also included retrieval source and date. The digital filing system shown in Table 6 is a simplified version of the data tree used in this study.

Table 6. IfSAR digital data tree

- Excel Spreadsheets
  - Adult Mosquito Light Trap Counts, 1986 to 1989
  - Missouri River Gaging Station Data, Culbertson, MT, 1986 to 1989
  - Missouri River Gaging Station Data, Williston, ND 1986 to 1989
  - Yellowstone River Gaging Station Data, Sidney, MT, 1986 to 1989
  - RTK-GPS field data QA elevations, 2011
- Grid (Raster) Data
  - 10-m DEM
  - 30-m DEM
  - 90-m DEM
  - 900-m DEM
  - IfSAR DSM
  - IfSAR DTM
  - IfSAR ORI
  - McKenzie County DRGs
  - Williams County DRGs
- Imagery
  - Aerial
  - Satellite
- Maps
- Shapefiles
  - Aquifers
  - Aspect
  - Bioregions
  - Climate Data
  - City Center and Boundaries
  - Flow Direction/Flow Accumulation
  - Hillshade
  - Slope
  - Soil Data (SSURGO)
  - Survey Monument Locations
  - State and Federal Transportation Data
  - Watershed Boundaries Data
  - WVCD Boundaries
- Statistics
  - RMSEz
  - Accuracyz
- Supporting Documents
  - Appendices Documents, scanned
  - Permission to Use E-mails/Letters, scanned
  - References Cited, scanned
  - Vertical Assessment Guidelines
- .Tiffs, .PNGs, .PDFs, Posters

IfSAR Digital Terrain Model (DTM) Elevation Data

Procurement of IfSAR DTM Elevation Data

The areas of interest [AOIs] (i.e., problem areas) of the floodplain near Williston, ND were selected by the Williston Vector Control Field Director by opening a current NAIP photograph within ArcInfo using NAD83 UTM Zone 13N coordinate system and projection. Public Land Survey System (PLSS) section data were draped over the NAIP photograph to serve as guidelines (Fig. 15). As the field director pointed out problem areas on the computer screen, the corresponding PLSS section lines were highlighted, exported to new PLSS shapefiles, labeled as AOIs, numbered, and saved to the proper file within the IfSAR data tree. The AOI shapefiles and an NAIP photograph were opened in a new ArcInfo screen. Five polygons were hand-digitized around the selected PLSS section data and symbolized with a color ramp of choice. A map was created and sent to the WVCD board and field director for their review and to Intermap Technology Inc. for a cost estimate. After several revisions to the AOIs, the WVCD and field director selected three of the five hand-digitized polygons for the study. Figure 15 shows the selected AOI polygons, symbolized in pink, green and blue polygons.

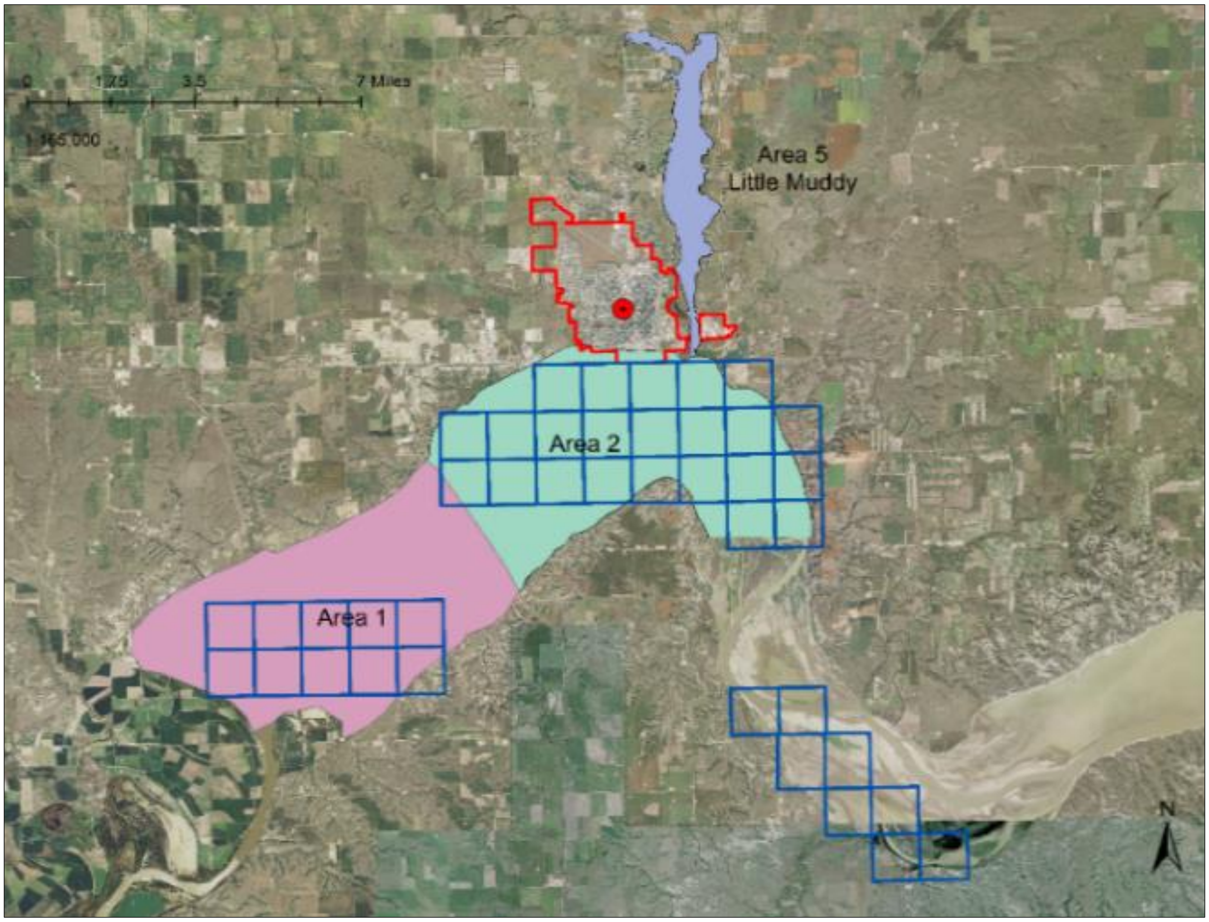

Fig. 15. Mapping technique to select AOIs for IfSAR data
Three areas of the floodplain are symbolized in color: areas #1, #2, and LIttle Muddy. Data source: NDgisHub. Technology used: ArcInfo 10.1

The IfSAR elevation data were delivered in the World Geodetic System 1984 (WGS84) (NGA [date unknown, accessed April 2017], which is the coordinate reference system used by the current Global Positioning System (GPS) (National Geospatial-intelligence Agency [NGA] [date unknown, accessed Aug 2017]). Global Mapper 11 (Blue Marble Geographics, Hallowell, ME) software was used to open and project the five tiles to the North American 1983 Universal Transverse Mercator (UTM) Zone 13 North (NAD83 UTM Zone 13 N), a common map projection used for western North Dakota. The IfSAR DTM was then saved in Tag Image File Format (i.e., *.tif), which is compatible with ArcInfo. All five IfSAR tiles were subsequently imported into ArcInfo 10.1 and draped over a current NAIP photograph. The purpose for the NAIP was to ensure proper positioning of the IfSAR DTM data. The mosaicked tiles appeared as blank, gray polygons. The five IfSAR tiles were mosaicked together using ArcToolbox Data

Management tools option, then selecting Raster, Raster Dataset, and Mosaic to New Raster. The mosaicked tile still appeared as a blank, gray polygon until the tile was symbolized in a color ramp of choice using Properties Symbology tools.

The IfSAR elevation data were removed from background pixels by using the following options in the order presented: Data Management, Raster, Raster Processing, and Clip. The IfSAR elevation data were then re-symbolized. A close examination of the IfSAR DTM pixels (i.e., cells) revealed that the IfSAR pixels were regularly spaced rectangles. However, a review of the IfSAR metadata using ArcInfo Properties Source tab, showed that each IfSAR pixel represented a ground space of 3.86 m x 3.86 m (14.86 m^2) in area. The shape of the IfSAR pixels should be square within the GIS software. It was determined that the IfSAR elevation data were not projected to the proper datum and/or coordinate system. The data were then re-projected to the proper datum and a projected coordinate system using the Export Data tool. A comparison between the projected and unprojected IfSAR DTM elevation data is shown in Figure 16.

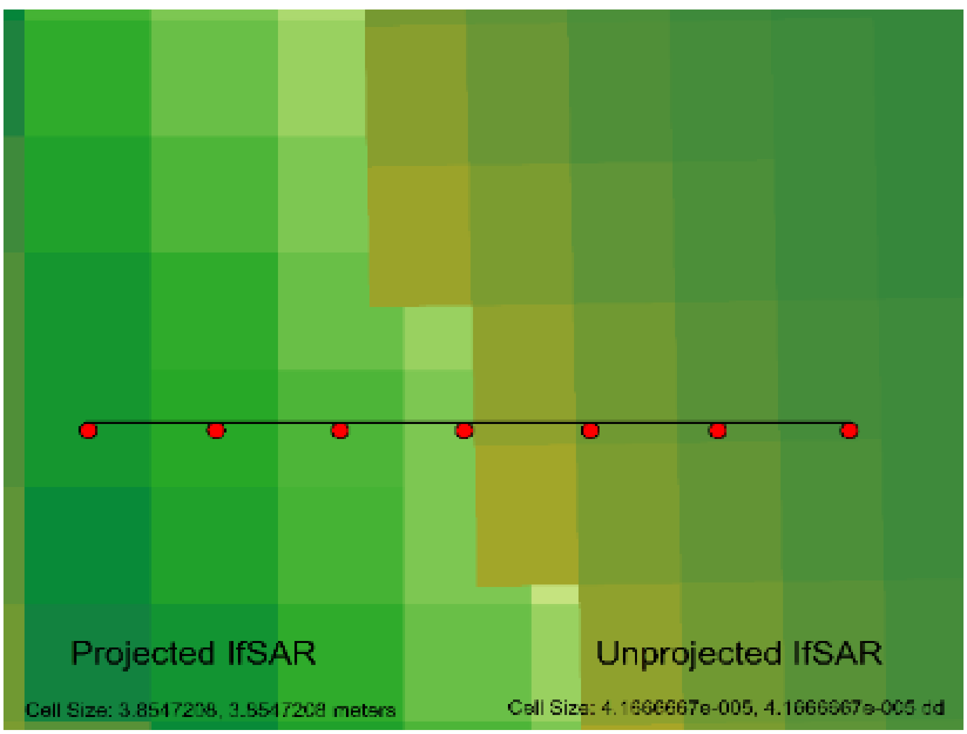

Fig. 16. Projected and unprojected IfSAR DTM data
Data sources: Intermap Technology, Inc.; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

Two small areas of IfSAR elevation data were inadvertently excluded from the original order. Therefore, a second order was placed to obtain the two missing areas. The second data order was received from the vendor by FTP and merged with the original IfSAR elevation data. With the addition of the second order, the IfSAR elevation data licensed for the WVCD study totaled 141.00 km^2 (34,841.86 ac; 14,100.00 ha; 54.4404 $mi.^2$). Figure 17 shows the complete IfSAR DTM in the correct UTM Zone 13 N projection, draped over a Williams County Digital Raster Graphic (DRG).

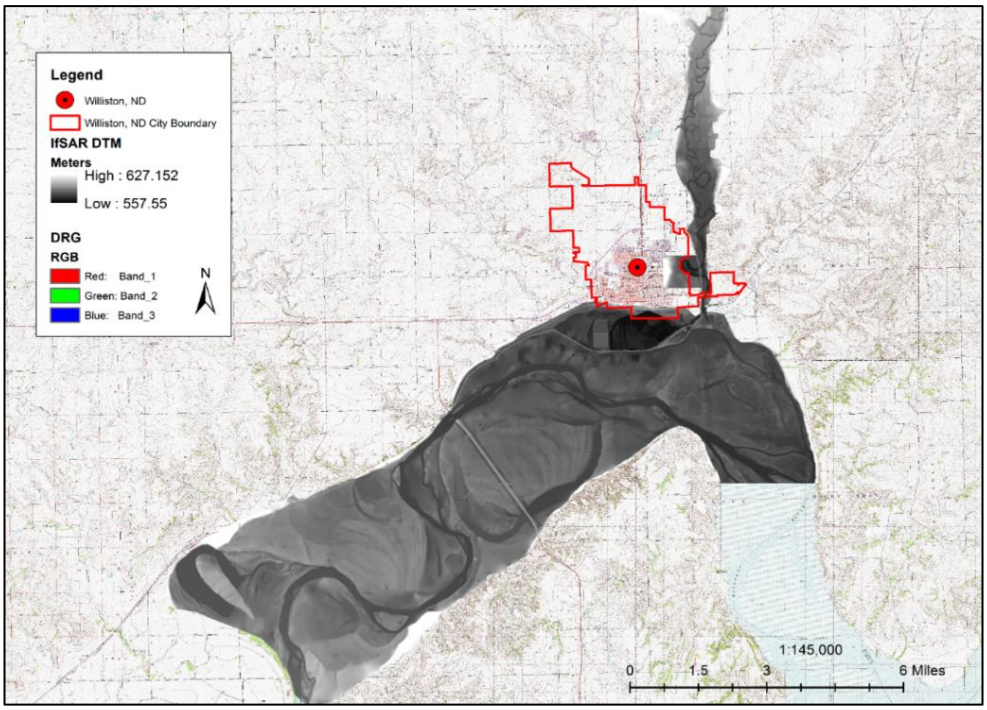

Fig. 17. 5-m resolution, IfSAR Digital Terrain Model (DTM)
Data sources: Intermap Technology, Inc.; NDgisHub; National Mapper. Technology used: ArcInfo 10.1

Testing of the IfSAR DTM Functionality in GIS

Numerous vector and raster datasets from various agencies were integrated with the IfSAR elevation data to determine the functionality of the data within GIS. Trial datasets included the following: city, county, state, and federal transportation data; hand-digitized levee data, Missouri River mile data; Williston city boundaries; hand-digitized WVCD boundaries; USACE property ownership; USAFR aerial larviciding paths; NAIP photographs; satellite imagery; digital elevation models (DEMs); digital raster graphics (DRGs); wetlands data; watershed boundary data; elevation data; land cover data; soil data; oil and gas data; Public Land Survey System (PLSS) data; and numerous other digital vector and raster datasets. Surface analyses performed on the IfSAR elevation data included minimum contours, slope, aspect, hillshading, and shaded relief. Hydrological analyses included identifying sinks, filling and smoothing sinks, and surface water flow direction and accumulation. The IfSAR elevation data were also mapped in three-dimensional format using ArcScene. In all trials, the IfSAR elevation data integrated easily with all types of raster and vector data, could be analyzed using surficial and hydrological tools in ArcInfo, could be used in elevation differencing mapping, and generated clear 3-dimensional maps.

Exploratory Data Analyses and Descriptive Statistics of the IfSAR DTM

Numerous exploratory data analyses (EDAs) were carried out with the IfSAR DTM elevation data using ArcInfo geospatial statistical tools, to identify pixel count, the mean; median; mode; maximum; and minimum elevations; standard deviation; skew; kurtosis; quartiles; and distribution of elevations. Table 7 provides a descriptive statistics summary generated in ArcInfo 10.1.

Table 7. Descriptive statistics of the IfSAR DTM

Statistic	IfSAR DTM Elevation Data (m)
Pixel Count	9,444,638.00
Minimum Elevation	557.55
Maximum Elevation	627.19
Mean Elevation	563.73
Mode Elevation	NA
Standard Deviation	3.16
Skew	4.7
Kurtosis	42.21
1st Quartile	562.12
Median	563.27
3rd Quartile	564.49

Comparison of IfSAR DTM Elevation Data to Public Domain Elevation Models (DEMs)

Numerous public domain elevation datasets are available at no cost through various government sources, however, they have low spatial resolutions and have limited applications in flood studies. Commercial IfSAR elevation datasets are available and typically have higher spatial resolution than public domain elevation dataset, but depending on the size of the study area, can be expensive, \$35.00 to hundreds of dollars per km^2. To justify the purchase of the IfSAR elevation data, it was necessary to compare various spatial resolution public domain elevation data with IfSAR-generated elevation data. Materials used in this comparison included 900-m (30 arc-second, GTOPO30) elevation data (USGS GTOPO30 2015), 90-m SRTM elevation data (USGS SRTM 2015), 30-m SRTM (USGS SRTM 2015), 10-m (USGS NED 2015), and 5-m IfSAR DTM data (Intermap Technology, Inc. 2017). ArcInfo 10.1 software was used to carry out the analysis. Comparisons of spatial resolution were carried out by creating two sets of maps (i.e., shaded relief and percent slope) for each elevation dataset (Figs. 18 to 27). Two models for each of the various public domain elevation datasets were created and compared to IfSAR models (i.e., shaded relief and slope). The lowest spatial resolution models (i.e., largest ground space per pixel; poor quality imagery) are shown first (i.e., 900-m), followed by models with increasing resolution (i.e., 90-m, 30-m, 10-m, 5-m IfSAR DTM). Results of the comparisons determined that none of the public domain elevation data of the Williston area could provide spatial detail similar to the IfSAR technology.

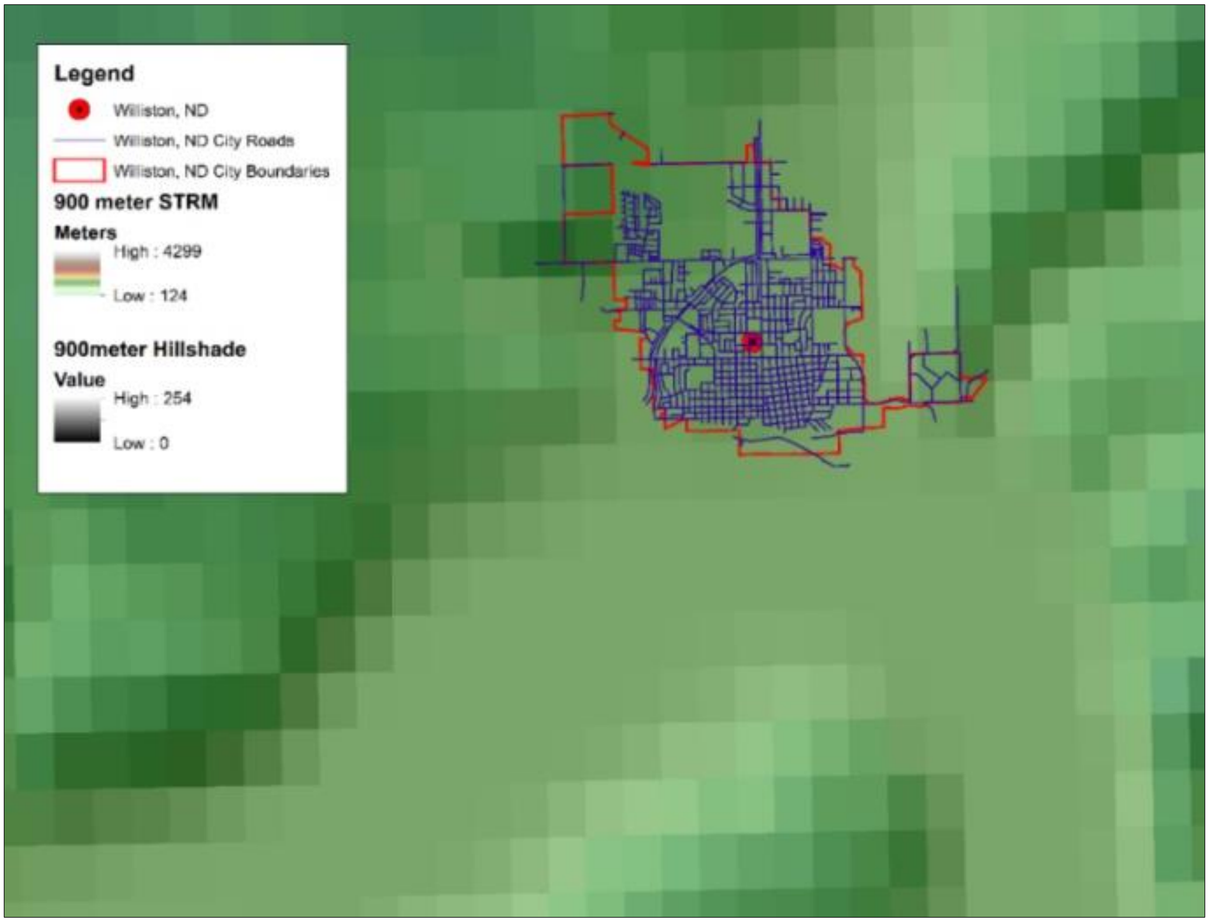

Fig. 18. 900-m resolution, shaded-relief map of the floodplain near Williston, ND
Derived from a 900-m DEM (30-arc second; 0.00833333 decimal degrees), SRTM. Data source: USGS GTOPO30. Technology used: ArcInfo 10.1

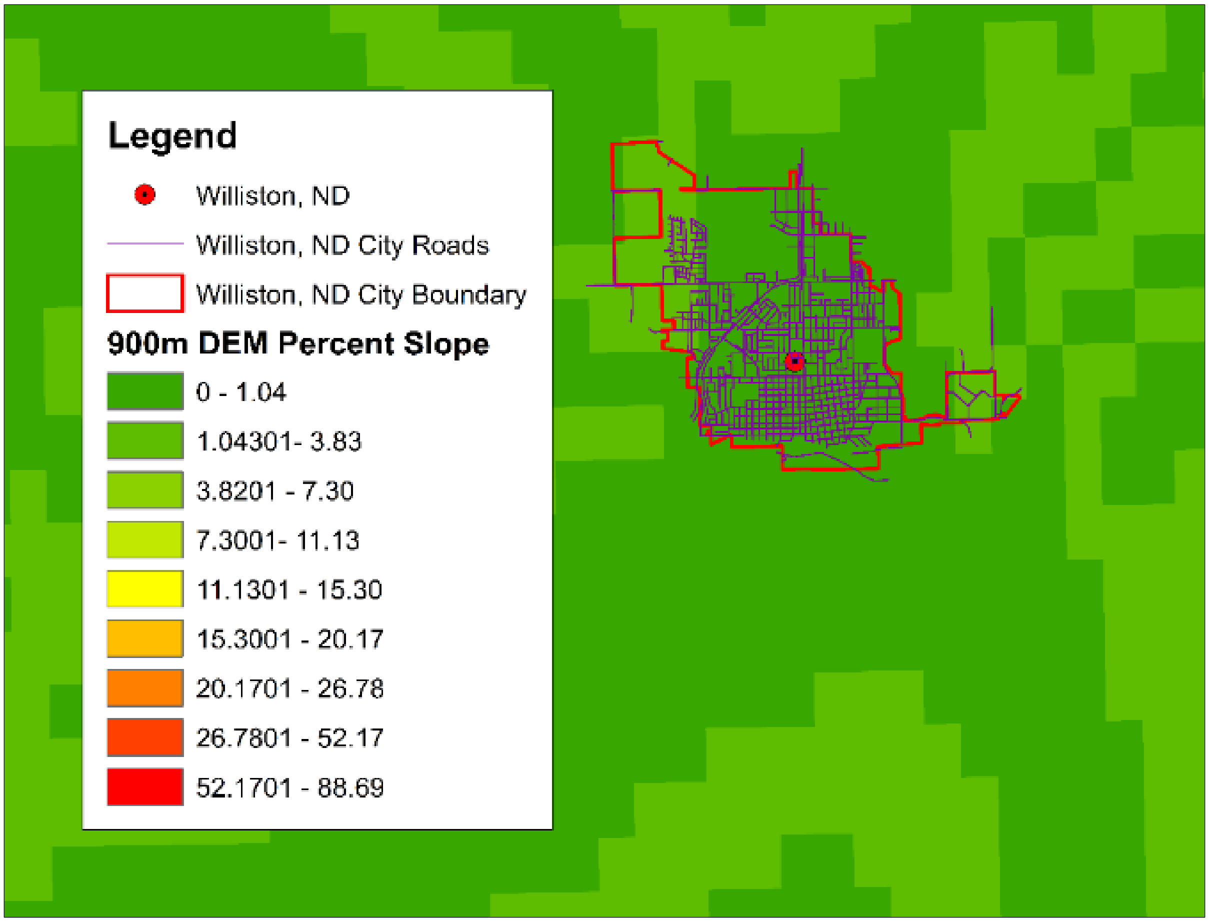

Fig. 19. 900-m resolution, percent slope map of the floodplain near Williston, ND
Derived from a 900-m DEM (30-arc second; 0.00833333 decimal degrees), SRTM. Data source: USGS GTPO30. Technology used: ArcInfo 10.1

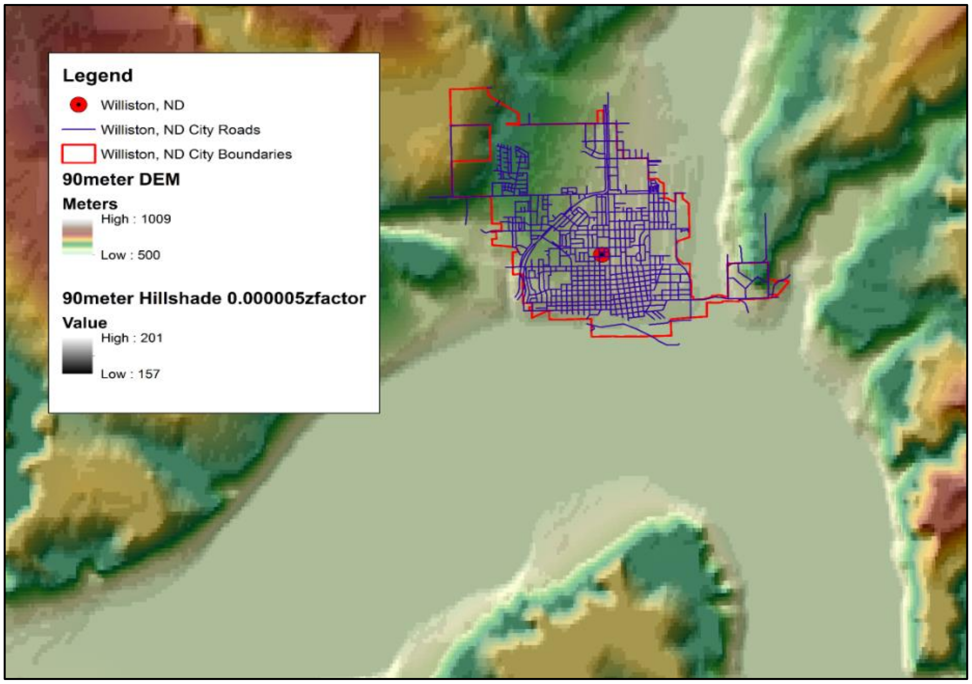

Fig. 20. 90-m resolution, shaded-relief map of the floodplain near Williston, ND
Derived from a 90-m DEM (3-arc second; 0.000833333 decimal degrees) SRTM. Data source: webGIS. Technology used: ArcInfo 10.1

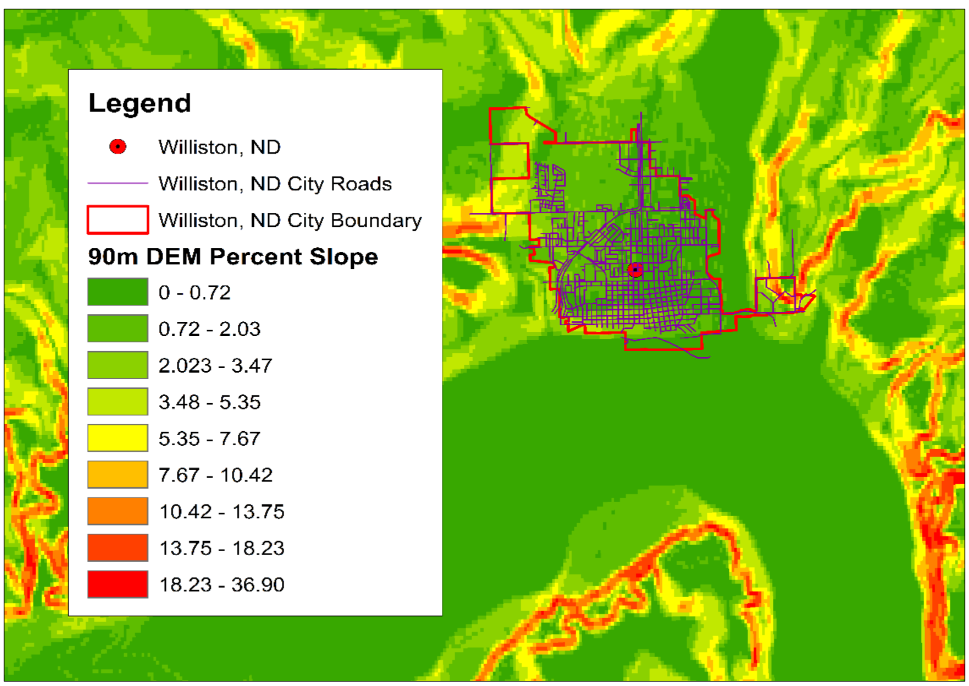

Fig. 21. 90-m resolution, percent slope map of the floodplain near Williston, ND
Derived from a 90-m DEM (3-arc second; 0.000833333 decimal degrees), SRTM. Data source: webGIS. Techology used ArcInfo 10.1

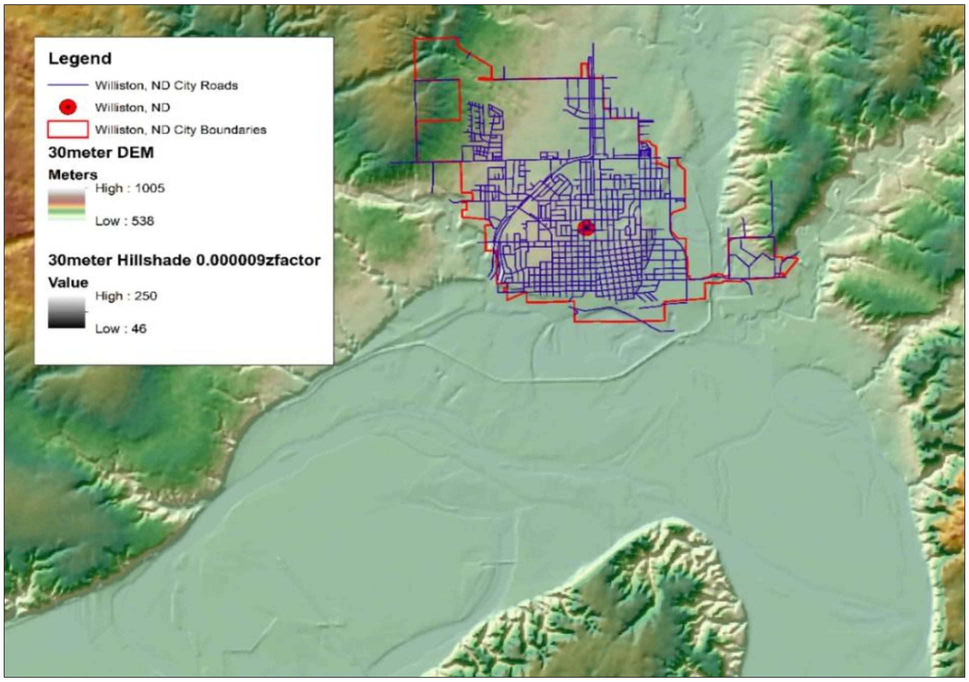

Fig. 22. 30-m resolution, shaded-relief map of the floodplain near Williston, ND
Derived from a 30-m DEM (1-arc second; 0.000277778 decimal degrees), SRTM. Data source: webGIS.
Technology used: ArcInfo 10.1

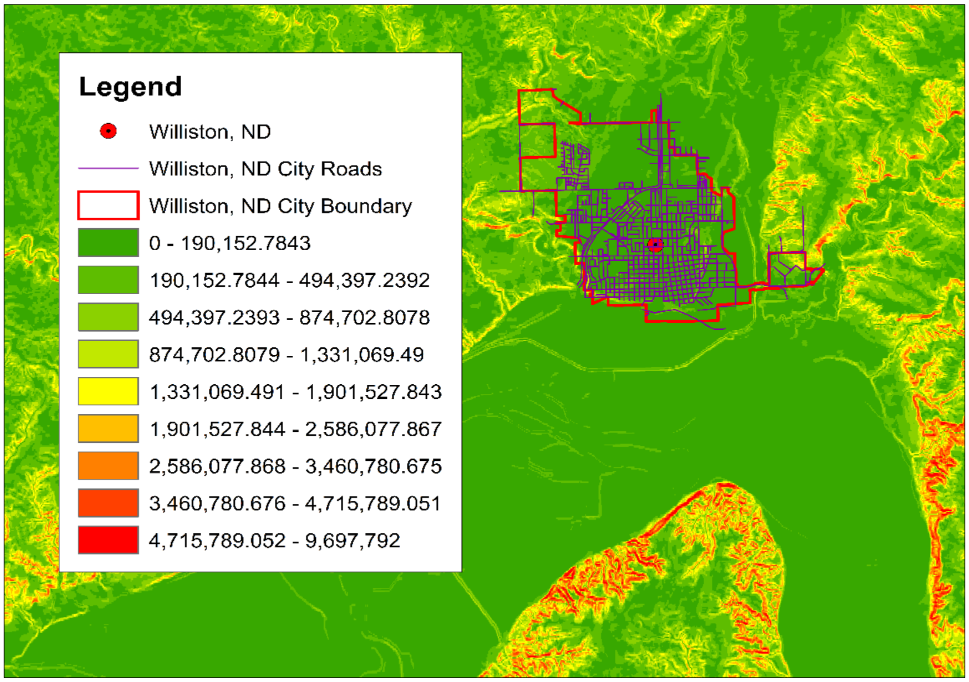

Fig. 23. 30-m resolution, percent slope map of the floodplain near Williston, ND
Derived from a 30-m DEM (1-arc second; 0.000277778 decimal degrees), SRTM. Data source: webGIS.
Technology used: ArcInfo 10.1

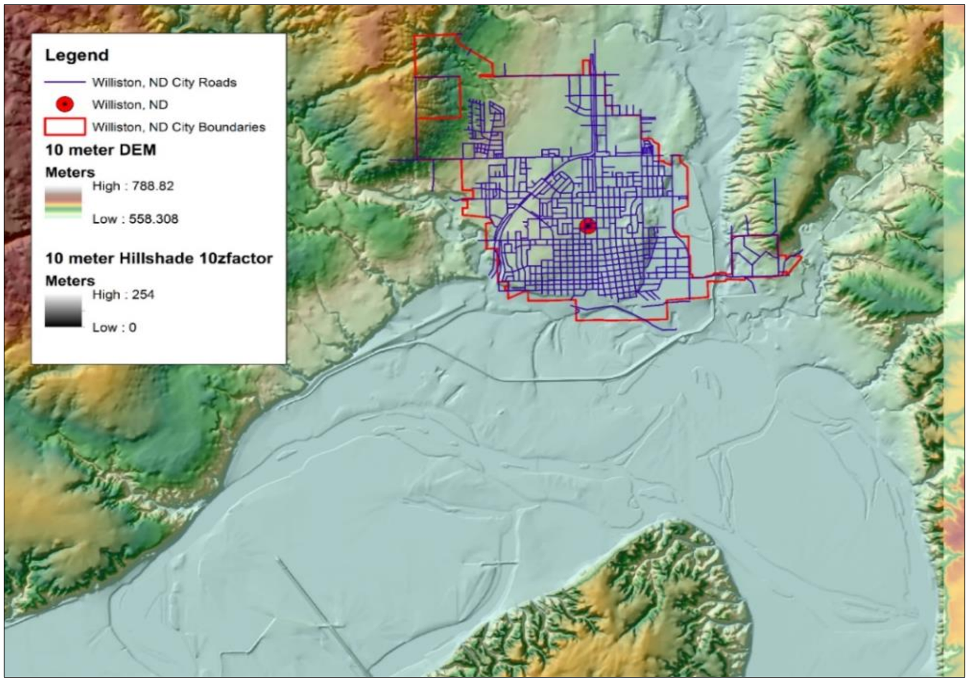

Fig. 24. 10-m resolution, shaded-relief map of the floodplain near Williston, ND
Derived from a 10-m elevation data (1/3-arc second, 0.0000925925 decimal degrees). Data source: webGIS. Technology used: ArcInfo 10.1

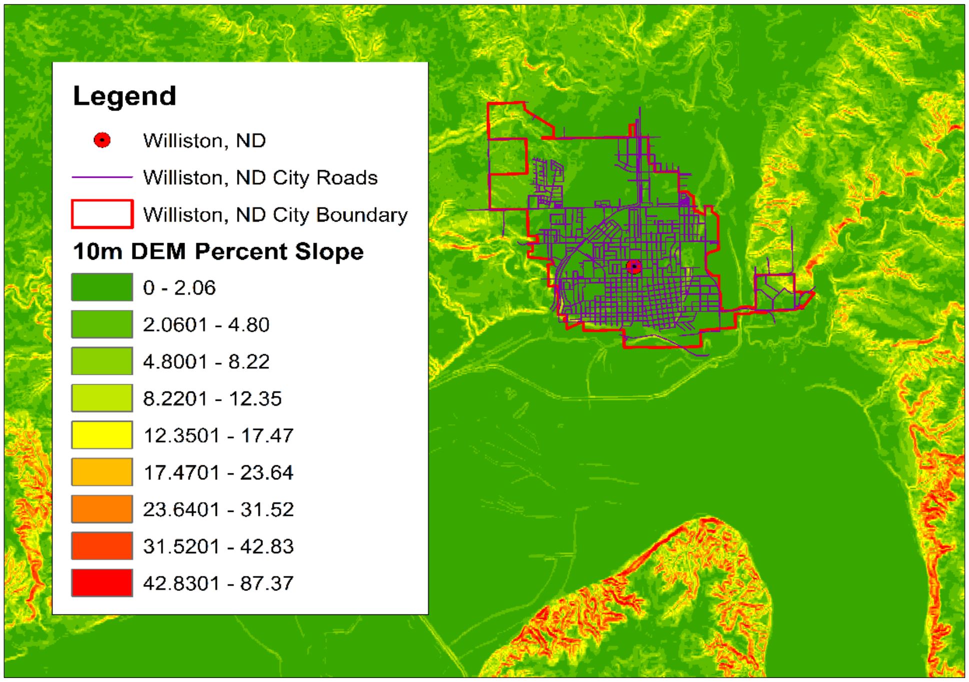

Fig. 25. 10-m resolution, percent slope map of the floodplain near Williston, ND
Derived from a 10-m elevation data (1/3-arc second, 0.0000925925 decimal degrees). Data source: webGIS. Technology used: ArcInfo 10.1

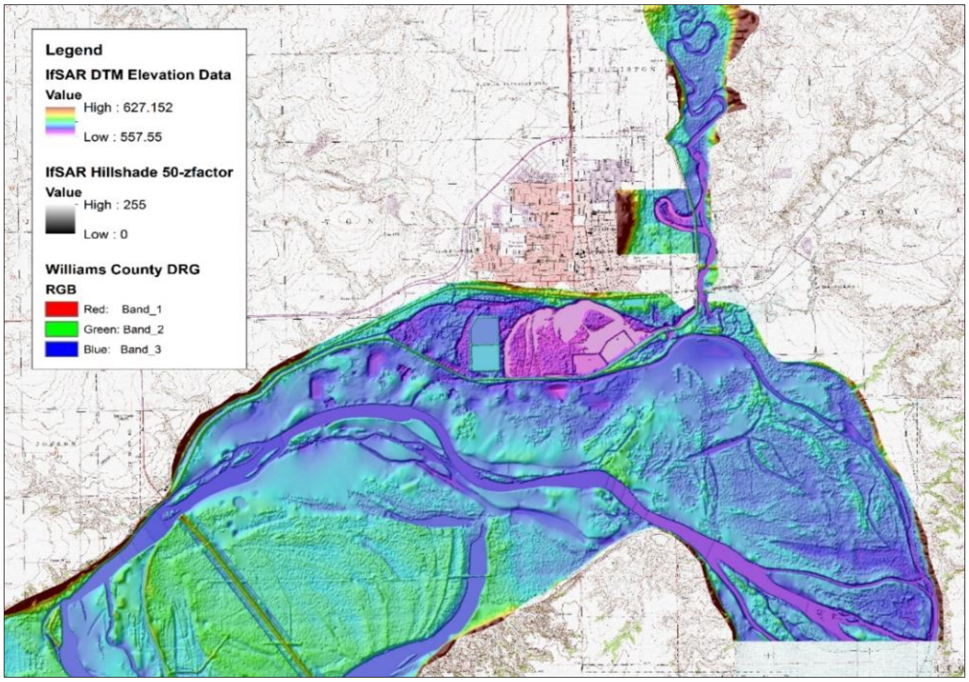

Fig. 26. 5-m resolution, shaded-relief map of the floodplain near Williston, ND
Derived from a 5-m DEM (1/6-arc second; 0.00004625 decimal degrees), IfSAR DTM. Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: Global Mapper 11; ArcInfo 10.1

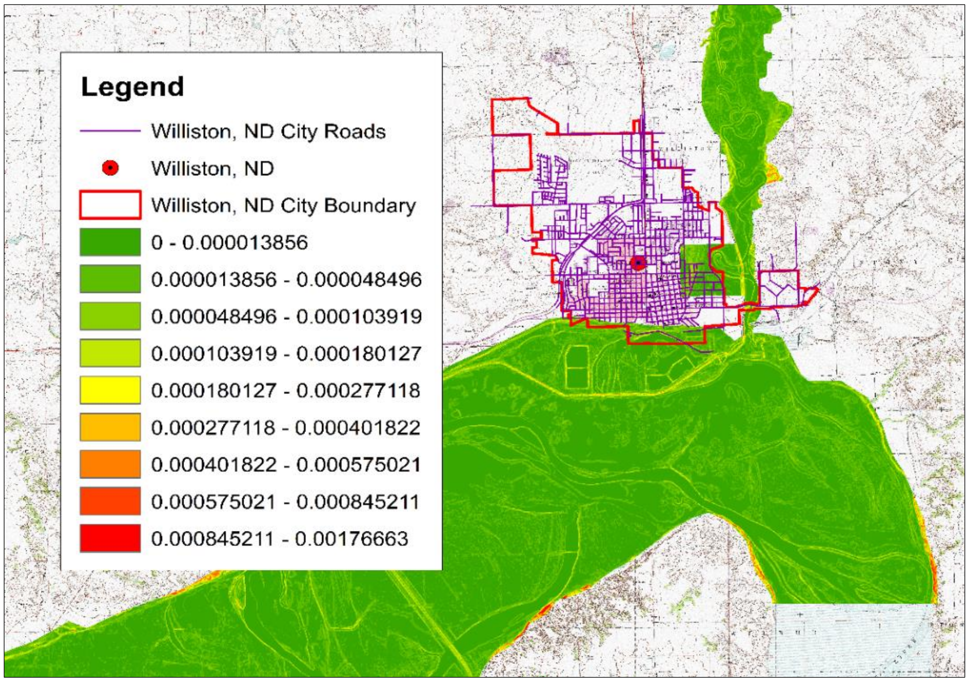

Fig. 27. 5-m resolution, percent slope map of the floodplain near Williston, ND
Derived from a 5-m DEM (1/6-arc second; 0.00004625 decimal degrees), IfSAR DTM. Data sources: Intermap Technology, Inc.; NDgisHub; National Map. Technologies used: Global Mapper 11; ArcInfo 10.1

IfSAR Digital Surface Model (DSM) Elevation Data

Intermap Technology, Inc. provided, at no cost to the WVCD, a 5-m IfSAR Digital Spatial Model (DSM) elevation dataset (Fig. 28) of the same extent as the licensed IfSAR DTM (Fig. 17). Elevation values within the DSM represent top of canopy (TOC) elevations (i.e., tops of vegetation, buildings, bridges, and other objects and surfaces).

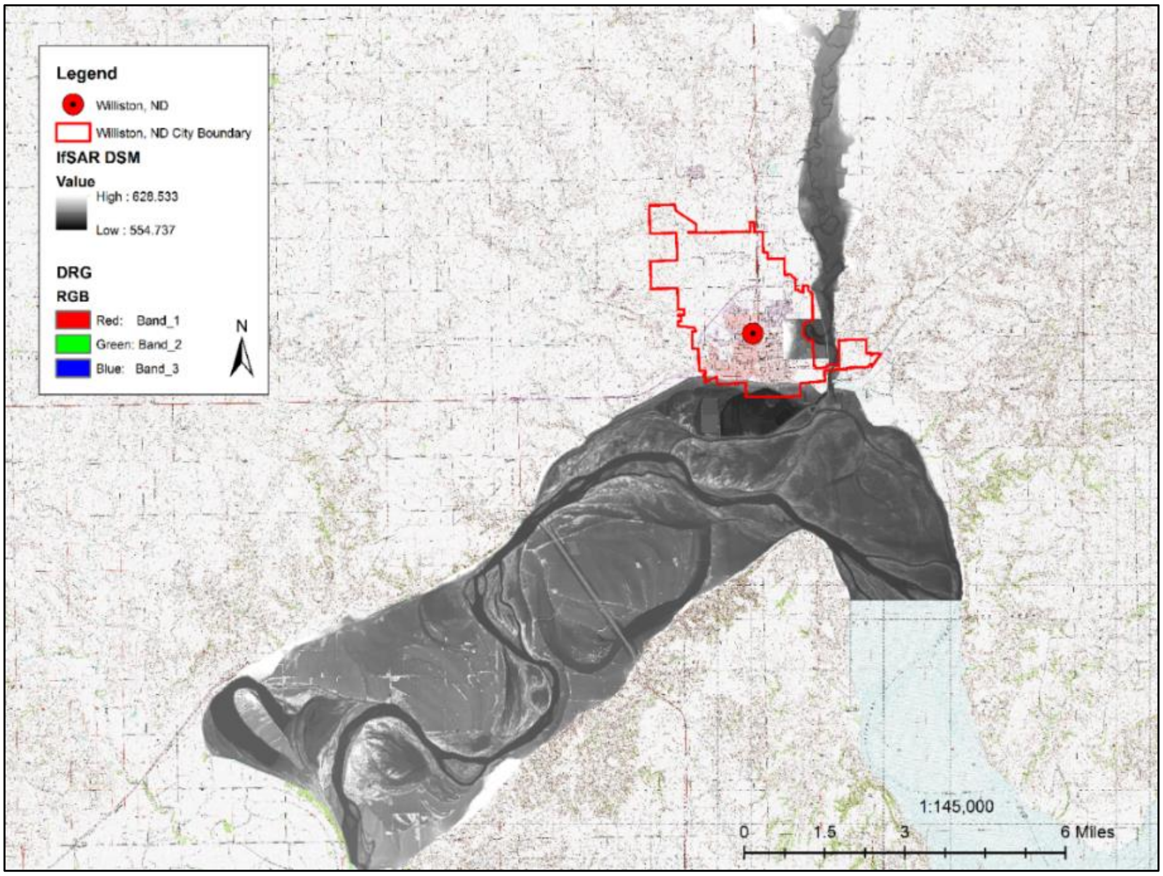

Fig. 28. 5-m resolution, IfSAR Digital Surface Model (DSM)
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

Exploratory Data Analyses and Descriptive Statistics of the IfSAR DSM

Numerous exploratory data analyses (EDAs) were carried out with the IfSAR DSM elevation data using ArcInfo geospatial statistical tools, to identify pixel count, the mean; median; mode; maximum; and minimum elevations; standard deviation; skew; kurtosis; quartiles; and distribution of elevations. Table 8 provides a descriptive statistics summary generated in ArcInfo 10.1.

Table 8. Descriptive statistics of the IfSAR DSM

Statistic	IfSAR DSM Elevation Data (m)
Pixel Count	9,857,939.00
Minimum Elevation	554.74
Maximum Elevation	628.54
Mean Elevation	564.57
Mode Elevation	NA
Standard Deviation	3.59
Skew	3.20
Kurtosis	24.36
1st Quartile	562.47
Median	563.87
3rd Quartile	565.51

DTM – DSM Differencing

The DTM bare earth elevation values were subtracted from the corresponding DSM TOC elevation values using ArcInfo Spatial Analyst Math tools. The difference between the DTM elevations and the DSM elevations provided the height of vegetation and structures within the floodplain (Fig. 29).

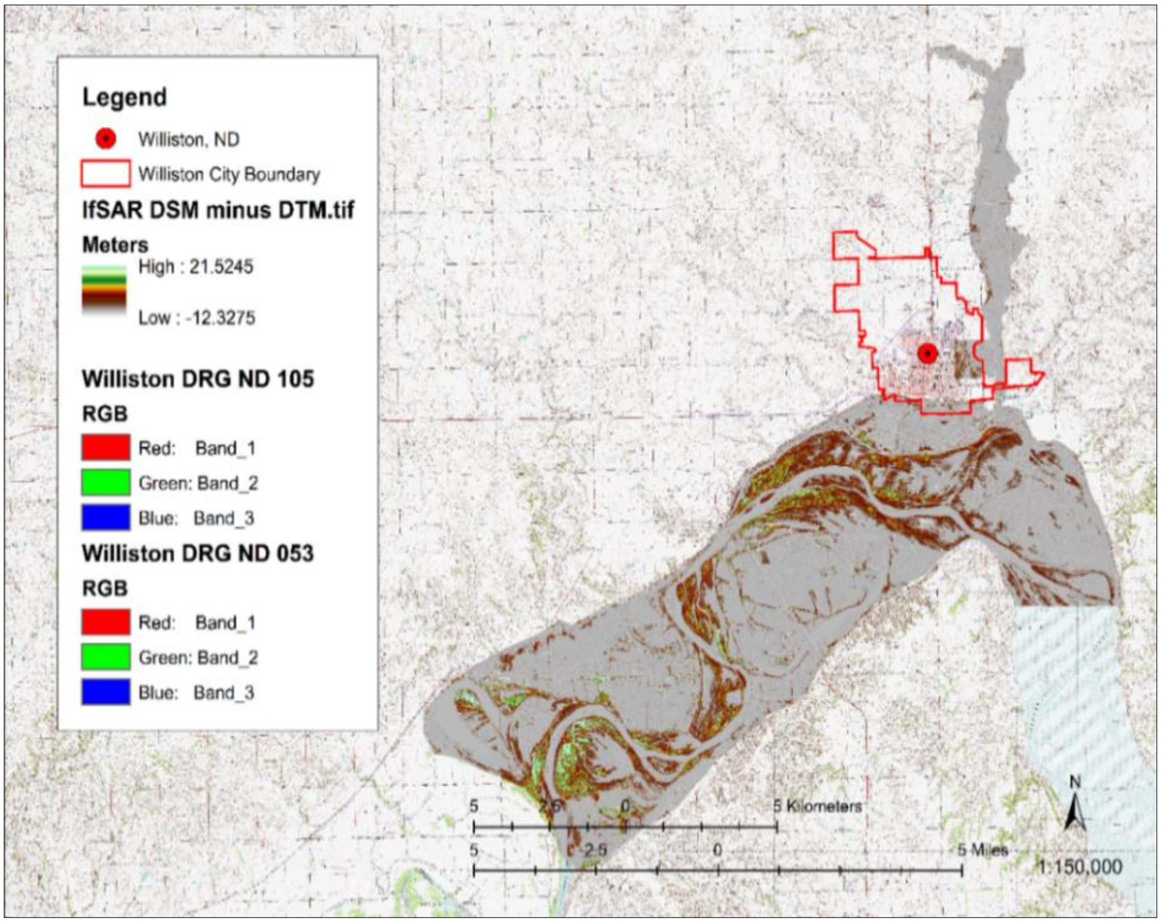

Fig. 29. IfSAR difference map (i.e., vegetation height map)
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

Exploratory Data Analysis and Descriptive Statistics of the IfSAR Difference Data

Numerous EDAs were carried out with the IfSAR difference elevation data using ArcInfo geospatial statistical tools, to identify pixel count, the mean; median; mode; maximum; and minimum elevations; standard deviation; skew; kurtosis; quartiles; and distribution of elevations. Table 9 provides the descriptive statistics summary of the IfSAR difference elevation data.

Table 9. Descriptive statistics for the IfSAR difference elevation data

Statistic	IfSAR Difference Data (m)
Pixel Count	9,850,741.00
Minimum Elevation	-12.34
Maximum Elevation	21.534
Mean Elevation	0.75
Mode Elevation	NA
Standard Deviation	1.75
Skew	2.9
Kurtosis	13.24
1st Quartile	-0.06.
Median	0.06
3rd Quartile	0.67

Comparison between IfSAR Differencing (Vegetation Height) Map and USAFR Aerial Larviciding Spray Paths, 2009

The USAFR aerial larvicide flight path data for 2009 were opened over the IfSAR difference map (i.e., vegetation height map) and visually compared. Results indicated that the most concentrated aerial larviciding by the USAFR during the summer of 2009 were applied primarily in areas of the floodplain with the tallest vegetation (Fig. 30).

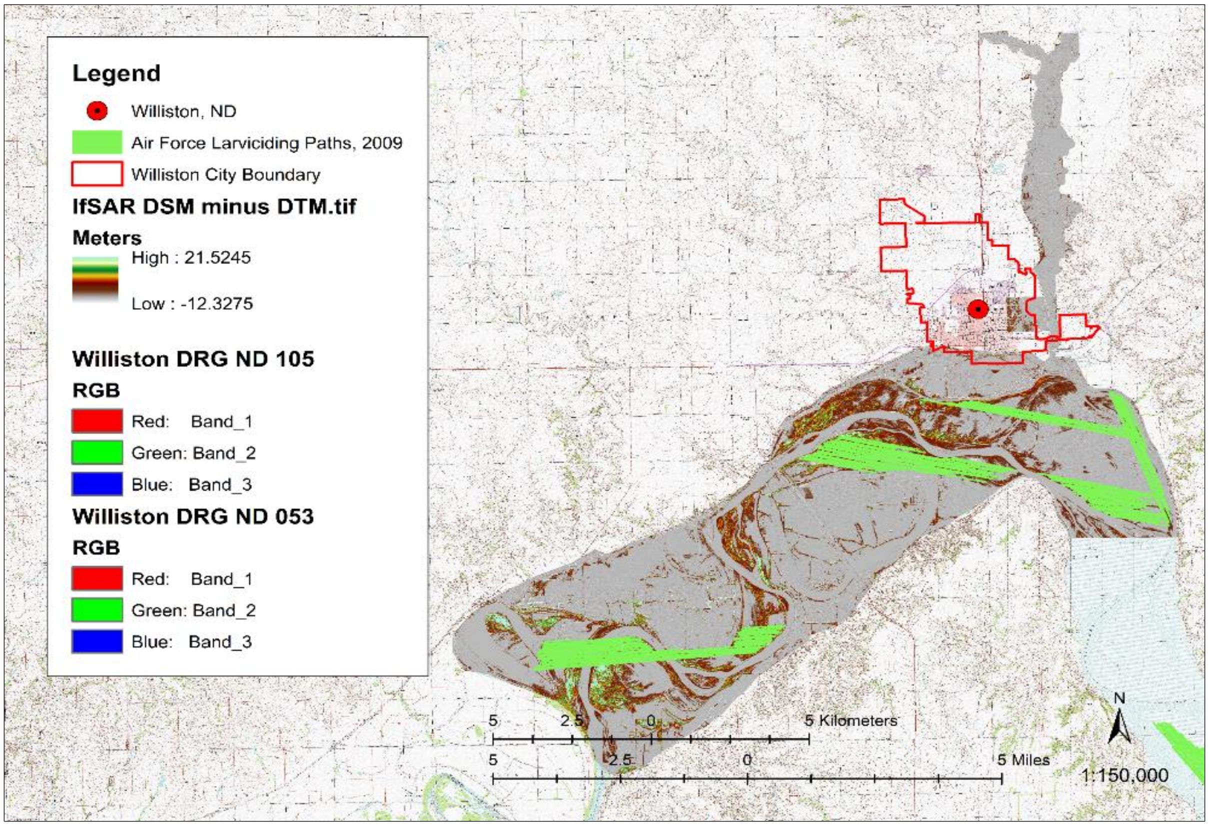

Fig. 30. IfSAR dfference map vs. USAFR aerial larviciding flight paths, summer 2009
Data sources: Intermap Technology, Inc.; National Map; NDgisHub; USAFR. Technologies used: ArcInfo 10.1; Global Mapper 11

IfSAR Orthorectified Imagery (ORI)

Intermap Technology, Inc. also provided at no cost, a 5-m IfSAR-derived Orthorectified Image (ORI) of the floodplain near Williston. The ORI (Fig. 21) shown at a scale of 1:3,940, was compared to a 2006 aerial photograph of the same location near Williston (Fig. 31), also shown at a scale of 1:3,940. The ORI appeared similar to black and white aerial photographs with poor resolution. Because the IfSAR ORI did not contain elevation data, and was difficult to view compared to an NAIP aerial image (Fig. 32), it was not used in this study.

Fig. 31. 5-m IfSAR Orthorectified (ORI) Image of the floodplain and city of Williston
Scale of 1:3940. Data source: Intermap Technology, Inc. Technologies used: ArcInfo 10.1; Global Mapper 11

Fig. 32. A 2006 NAIP aerial photograph of the floodplain and city of Williston, ND
Scale of 1:3940. Data source: NDgisHub. Technology used: ArcInfo 10.1

Preparation of IfSAR DTM Elevation Data for GIS Analyses

Conversion of the IfSAR Inaccessible Raster Elevations to an Accessible Point Elevation Format

The inaccessible attributes table was converted to an accessible format by using ArcInfo Raster-to-Point tool (Fig. 33). Justification for using the raster-to-point procedure was the fact that the IfSAR elevation data contain over 9 million pixels (i.e., over 9 million elevation values). Reviewing elevations for individual pixels is possible by using the ArcInfo Identify tool. However, conducting a vertical accuracy assessment of the entire IfSAR DTM and developing predictive flood models one pixel at a time would have been impossible.

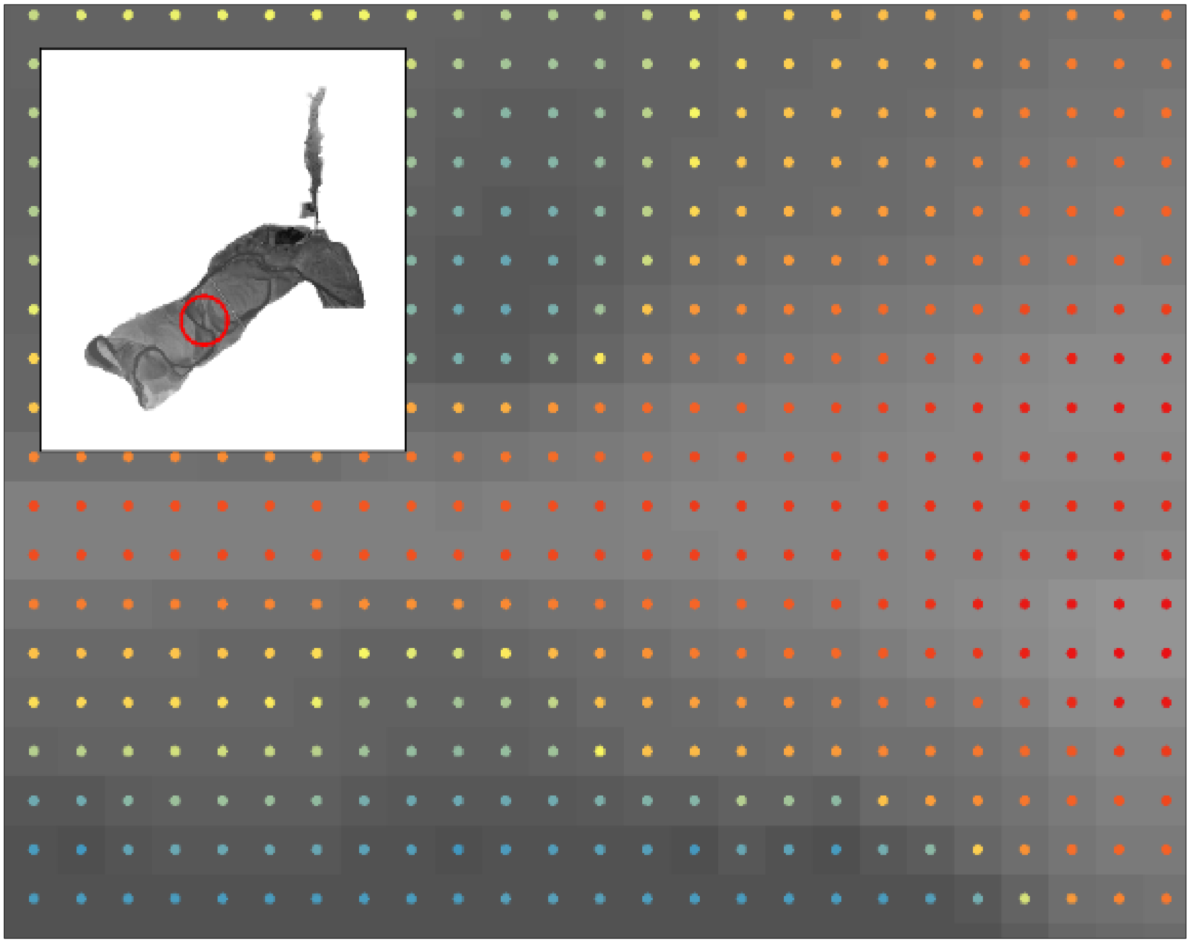

Fig. 33. IfSAR DTM elevation pixels converted to elevation points
Data sources: Intermap Technology; NDgisHub. Technologies used: ArcInfo 10.1 Raster-to-point tool; Global Mapper 11

Identification and Removal of Hand-digitiized Areas Outside of the Floodplain

During the ordering process of the IfSAR elevation dataset, the AOIs were hand-digitized slightly larger than the floodplain to ensure that problem areas along the shorelines were not missed. Once the IfSAR elevation data were delivered, the data were opened in ArcInfo to create a 2D map. The areas that were included in the AOIs but outside of the floodplain needed to be identified and removed. Three methods (i.e., a frequency distribution histogram, a normal Quantile-Quantile [QQ] plot, and z-scores) were used to identify the outlying areas.

<u>Frequency Distribution of IfSAR DTM Elevations</u>

The IfSAR DTM elevation data and a Williston DRG were opened in ArcInfo. A histogram of the IfSAR elevation point data were created using ArcInfo Geostatistical Analysis tool (Fig. 34).

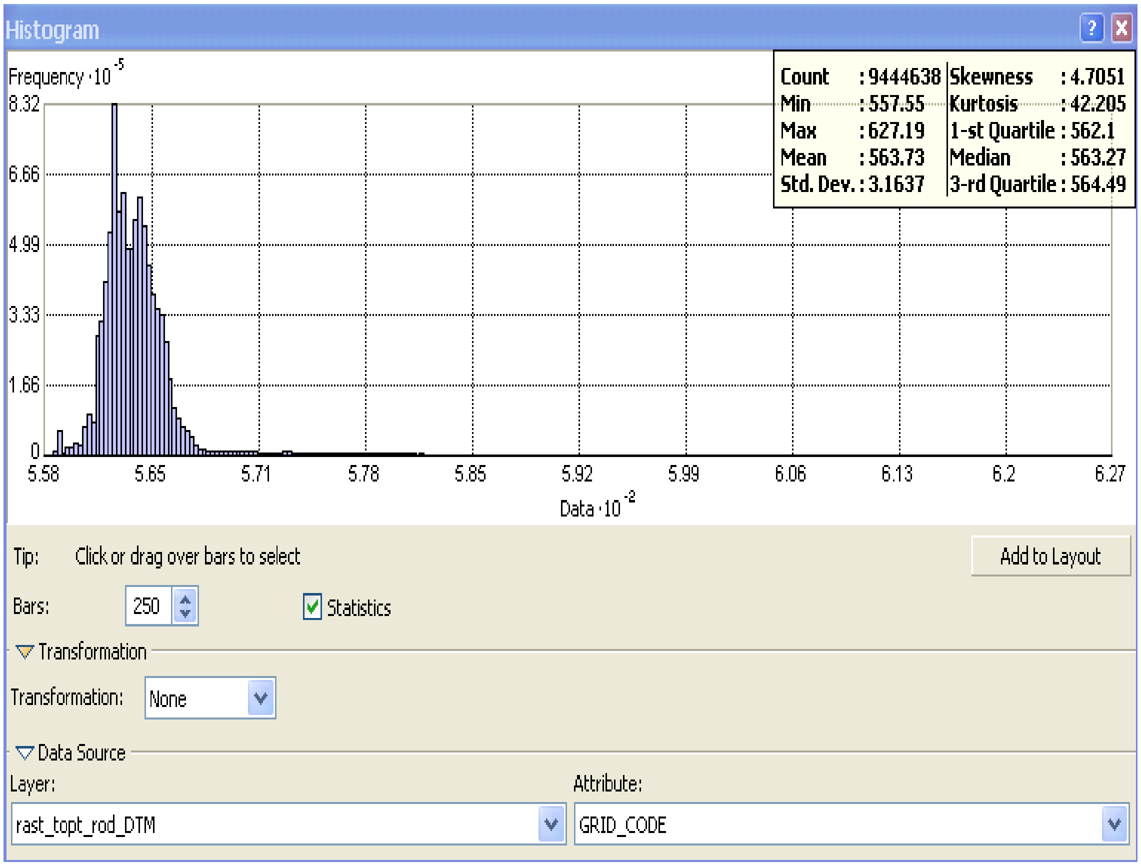

Fig. 34. Frequency distribution of the floodplain elevations near Williston, ND
Data source: Intermap Technology, Inc. Technologies used: ArcInfo 10.1 Geostatistical Analyst tool; Global Mapper 11

The IfSAR histogram was right-skewed, with floodplain elevations located between 558 m (1830.71 ft) and 571 m (1873 ft) msl. Elevations above 571 m represented the higher-elevation bluffs surrounding the floodplain and were manually highlighted on the histogram, which automatically highlighted the associated areas on the map (Fig. 35).

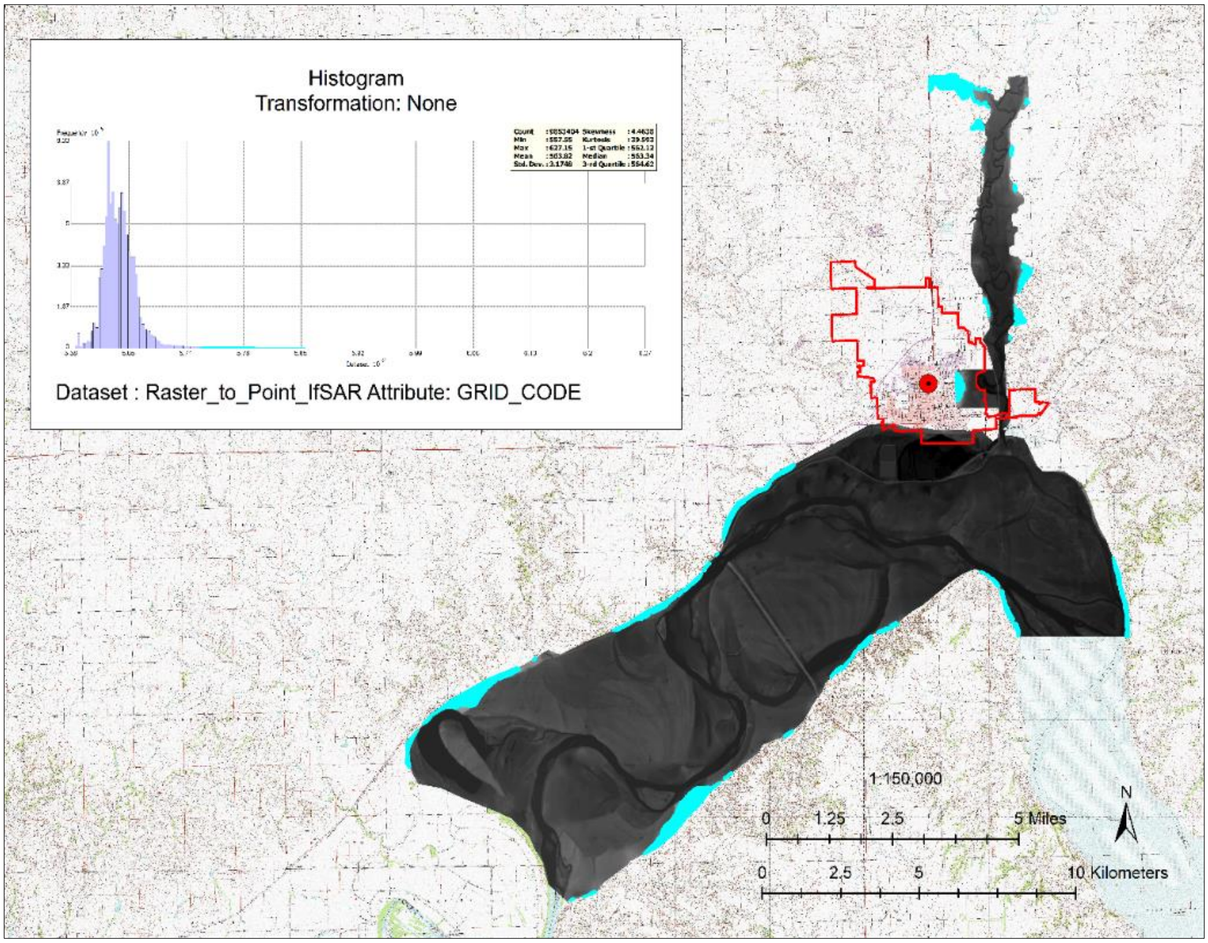

Fig. 35. Areas outside of the floodplain identified by using a frequency distribution technique
Data source: Intermap Technology, Inc.; NDgisHub. Technologies used: ArcInfo 10.1 Geostatistical Analyst tool; Global Mapper 11

Normal Quantile-Quantile (QQ) Plot

A normal QQ plot of IfSAR DTM elevation point values (Fig. 36) was created in ArcInfo using the Geospatial Analyst tool. IfSAR elevation values that did not follow the expected normal QQ curve were located between 558 m (i.e., 1870 ft) to 571 m (1873.36 ft) and manually high-lighted (Fig. 36). The procedure automatically highlighted the same elevations on the map (Fig. 37).

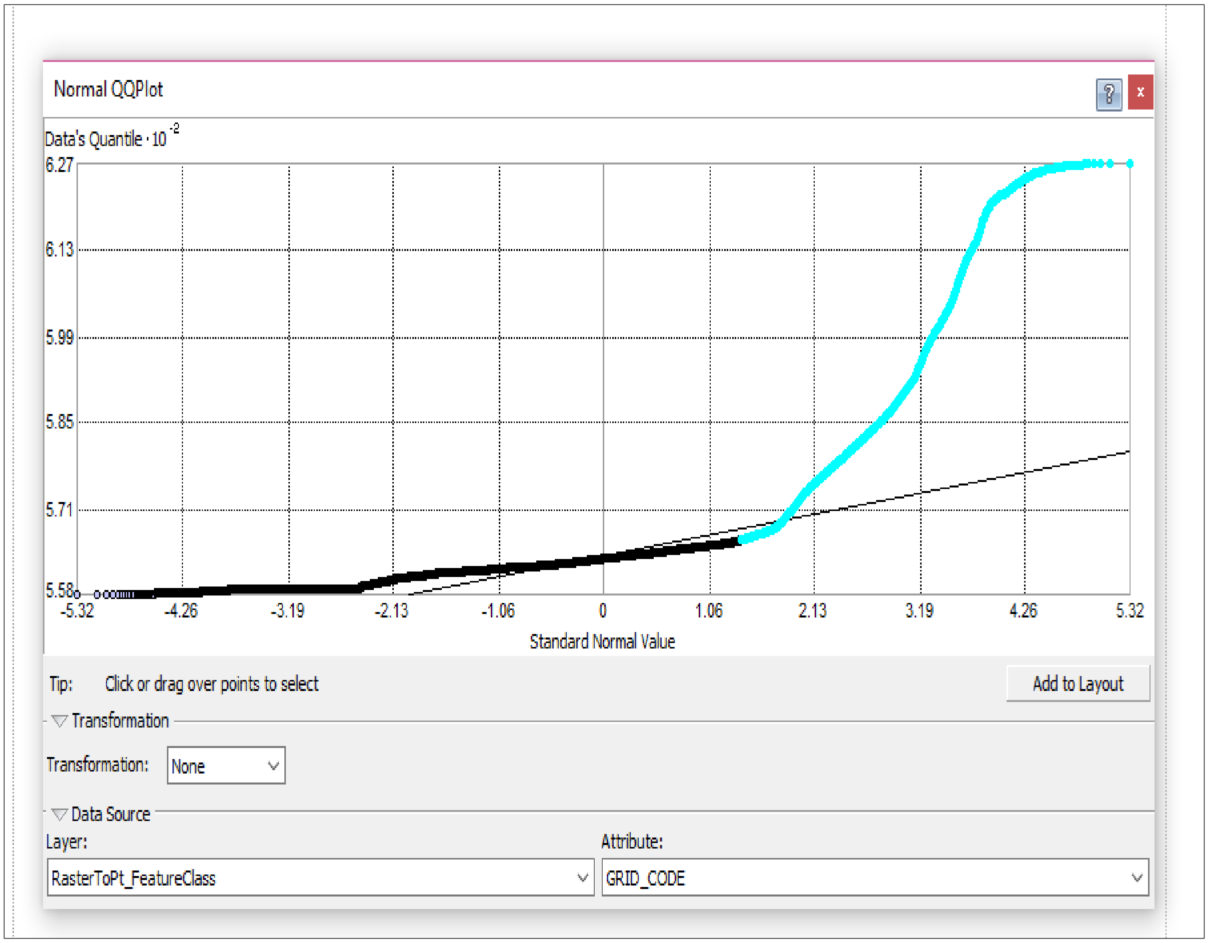

Fig. 36. Expected normal QQ plot vs. floodplain elevations near Williston, ND
Elevations outside of the expected normal are highlighted. Data sources: Intermap Technology, Inc.; NDgisHub. Technologies used: ArcInfo 10.1 Geostatistical Analyst tool; Global Mapper 11

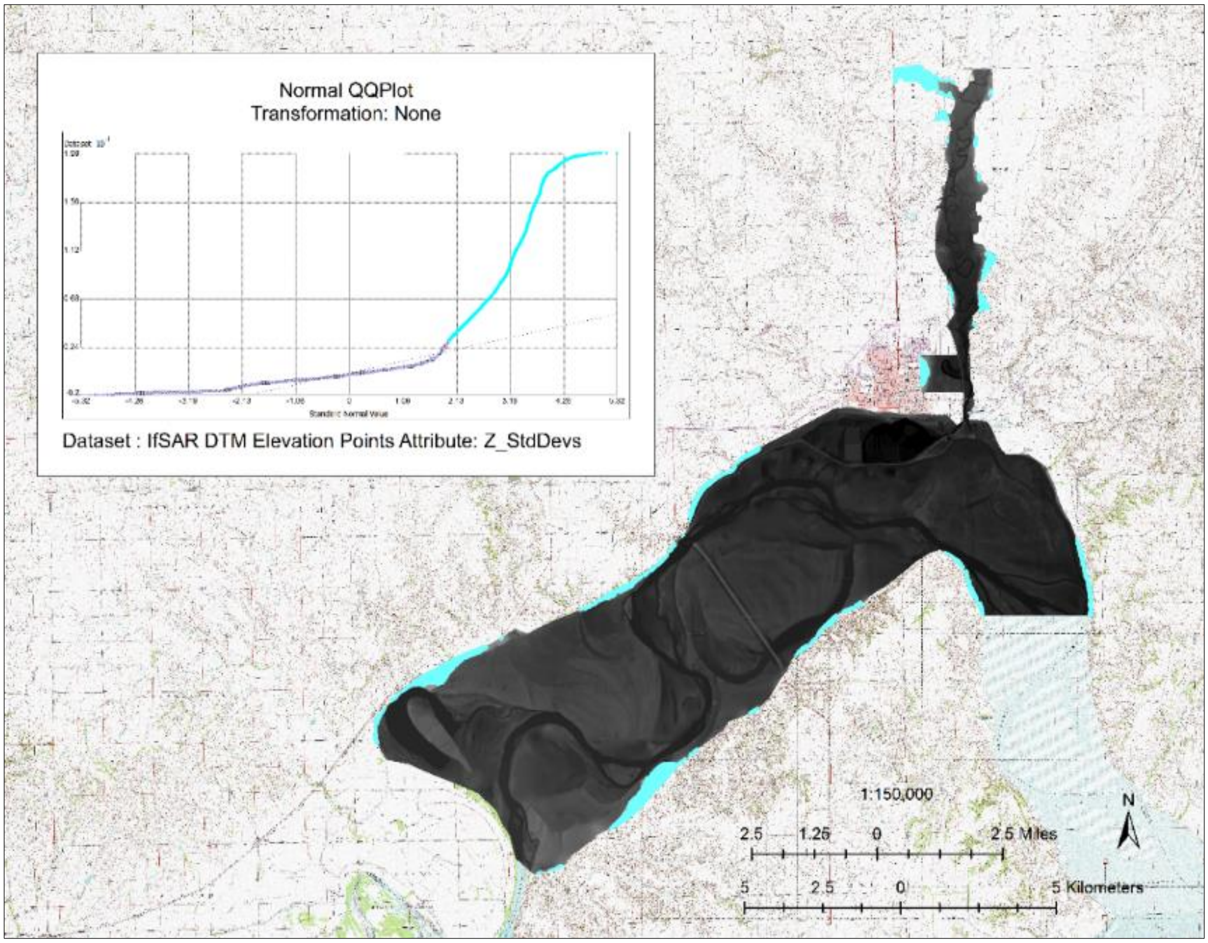

Fig. 37. Areas outside of the floodplain identified by using a normal QQ plot
Elevations outside of the expected normal are highlighted. Data sources: Intermap Technology, Inc.; NDgisHub. Technologies used: ArcInfo 10.1 Geostatistical Analyst tool; Global Mapper 11

Z-scores.

Representative numbers of standard deviation (i.e., z-scores) for the IfSAR DTM elevation data were calculated within ArcInfo using the IfSAR DTM elevation point data and the ArcInfo Editor tool. A new field was added to the table, labeled “z-sc”, and prepared for large decimal data (i.e., double precision). After the field was added, the Field Calculator tool was used to calculate z-scores for each IfSAR elevation point using the following text in the field calculator box: z-score = ([Grid Code] Minus [Mean]) / IfSAR Standard Deviation. Grid Code referred to the elevation for each IfSAR elevation data point. Mean represented the value 563.82 m determined in the descriptive statistics analysis. Standard Deviation represented the value 3.1748 m determined in the descriptive statistics analysis. After the field calculator ran, each elevation point had an associated z-score. All z-scores equal to or greater than three standard deviations were selected using the Select by Attributes tool and exported to a new GIS shapefile labeled 3z-score. A quick review of the new 3z-score shapefile confirmed that elevations within the shapefile were higher than the known floodplain elevations near Williston (i.e., 557.78 m [1830 ft] to 570 m [1870 ft] msl). The Select by Attributes tool automatically highlighted the z-scores equal to or greater than three standard deviations within the attribute table and within the map (Fig. 38).

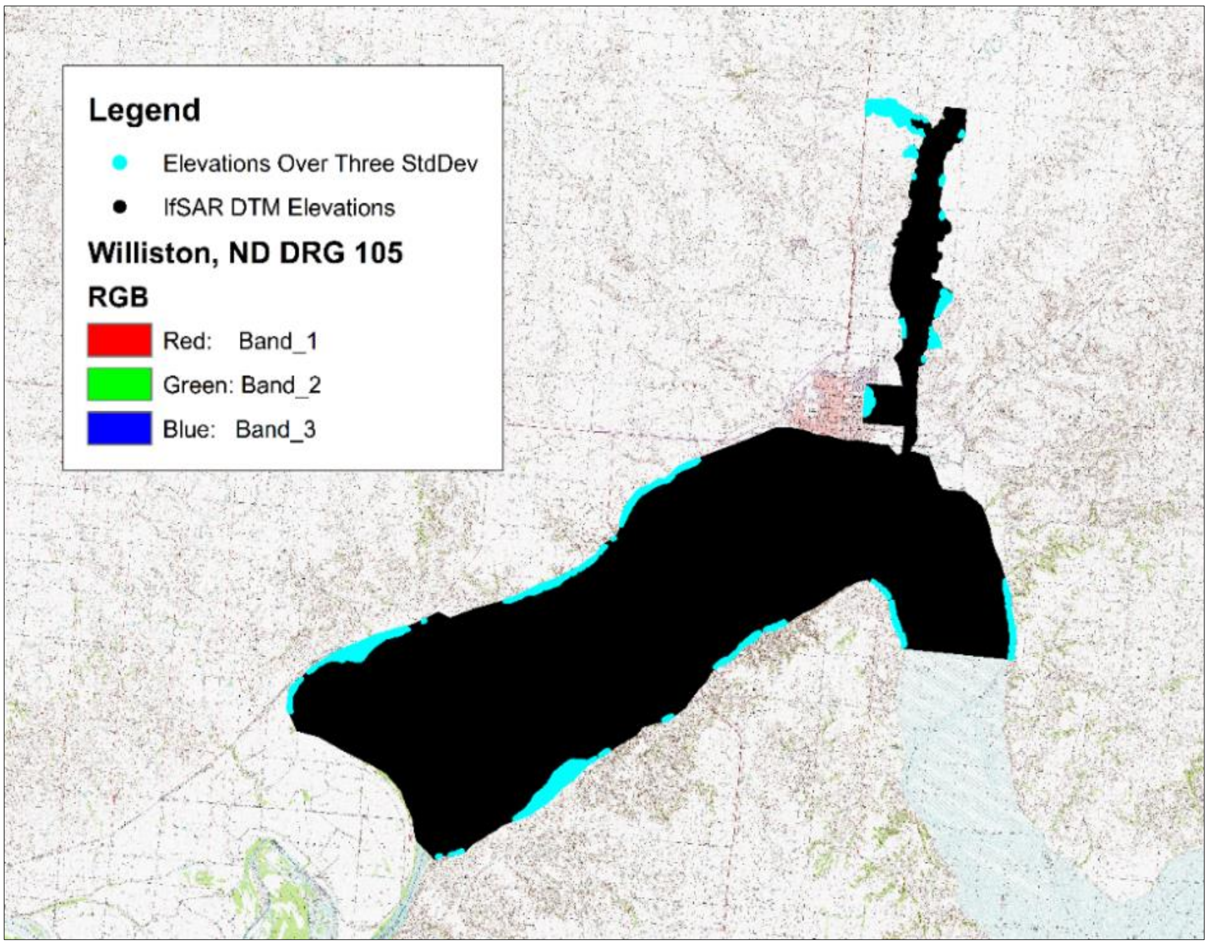

Fig. 38. Areas outside of the floodplain identified by calculating z-scores
Data sources: Intermap Technology, Inc.; NDgisHub. Technologies used: ArcInfo 10.1 Geostatistical Analyst tool; Global Mapper 11.

All three methods (i.e., histogram, QQ plot, and z-scores) gave similar results, however, the histogram and QQ plot methods required hand-digitization and were considered less accurate than the computer calculated z-score method. Using the z-score method, the following steps were used to remove the high outlying elevations within the IfSAR DTM: 1) The 3z-score map was opened in ArcInfo and the

3z-score shapefile was added to the ArcInfo Table of Contents if it was not already listed. 2) The 3z-score attributes table was opened and the z-scores were sorted from low to high. The lowest elevation value of the 3z-scores was 573.34 m (1881.04 ft) msl. 3) Elevations higher than 573.34 m were removed from the IfSAR DTM using ArcInfo Spatial Analyst, Conditional, Set Null tool using the following steps: The 'Input conditional raster' was set to 'original IfSAR DTM'; the Expression to 'VALUE' was set to 'greater than 573.34'; and the 'Input false raster or constant 'value' was set to 'original IfSAR DTM'. After the tool ran, 335,836 pixels with z-scores equal to or higher than three standard deviations were automatically removed from the IfSAR DTM dataset. All of the removed pixels were located along the edges of the IfSAR DTM (i.e., bluffs along the edges of the river valley). After the removal of the high z-score pixels, comparisons were made between the descriptive statistics of the original hand-digitized IfSAR DTM to the adjusted IfSAR DTM (i.e., the IfSAR DTM with elevations outside of the floodplain removed) (Table 10).

Table 10. Descriptive statistics for the original IfSAR elevation data vs. the descriptive statistics for the adjusted IfSAR DTM after elevations outside of the floodplain had been removed

Statistic	Original IfSAR DTM Elevations	Adjusted IfSAR DTM Elevations
Count	9,853,404.00	9,517,568.00
Minimum Elevation (m)	557.55	557.55 m
Maximum Elevation (m)	627.15	569.64 m
Mean Elevation (m)	563.82	563.36
Standard Deviation	3.18	1.73
Skewness	4.4638	0.349
Kurtosis	39.593	3.5006
1st Quartile (m)	562.12 m	562.10 m
Median (m)	563.34 m	563.25 m
3rd Quartile (m)	564.62 m	564.45 m

Statistical Analysis: Excel 2016

An updated IfSAR DTM histogram (Fig. 39) and QQ plot (Fig. 40) were created in ArcInfo using the adjusted IfSAR elevation data. The updated histogram shows a multimodal histogram with a more normal distribution. The unusual spikes of the IfSAR histogram indicate large numbers of pixels (i.e., areas within the floodplain) with the same elevation. The updated QQ plot is near normal.

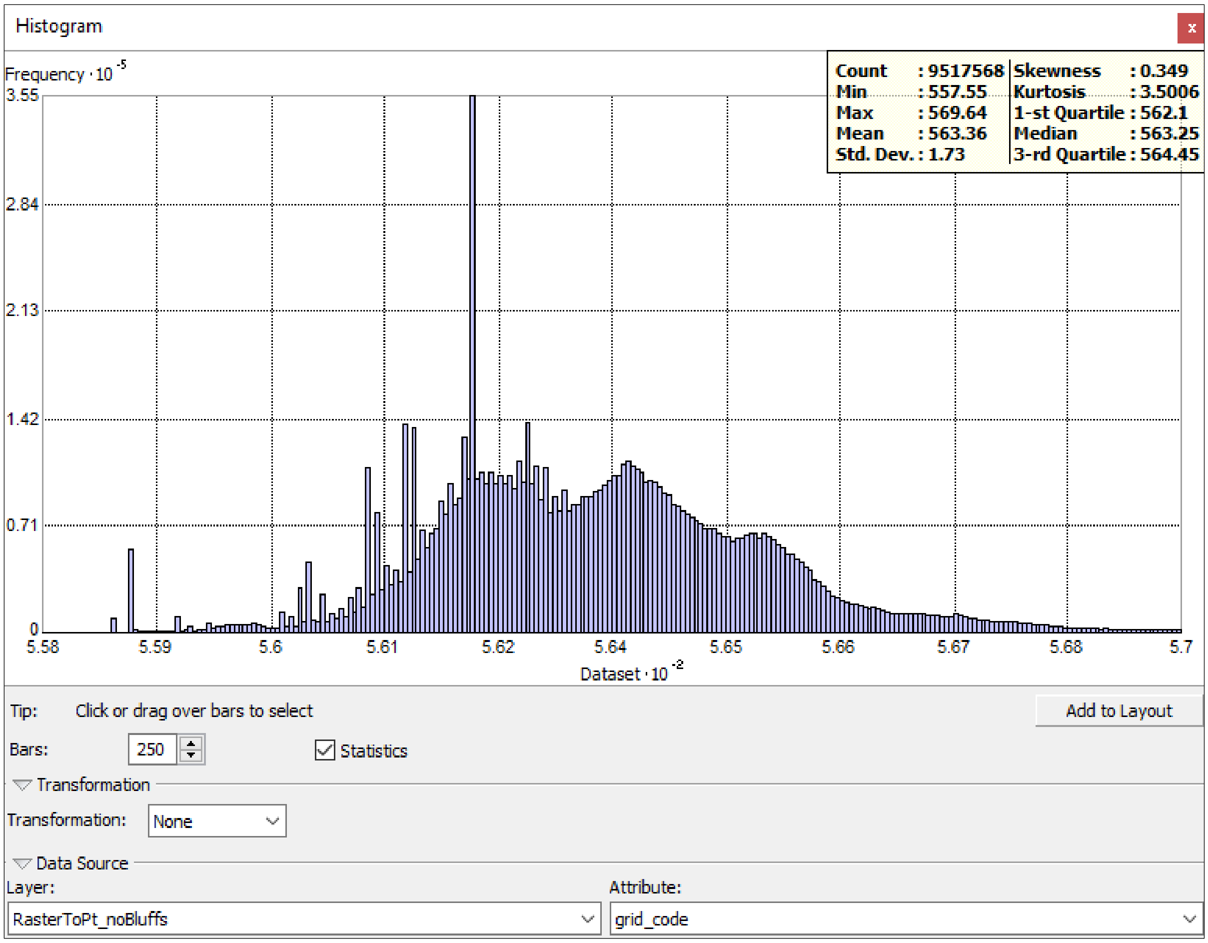

Fig. 39. Frequency distribution created from the adjusted IfSAR DTM elevations
Data source: Intermap Technology, Inc. Technologies used: ArcInfo 10.1 Geostatistical Analyst tool; Global Mapper 11

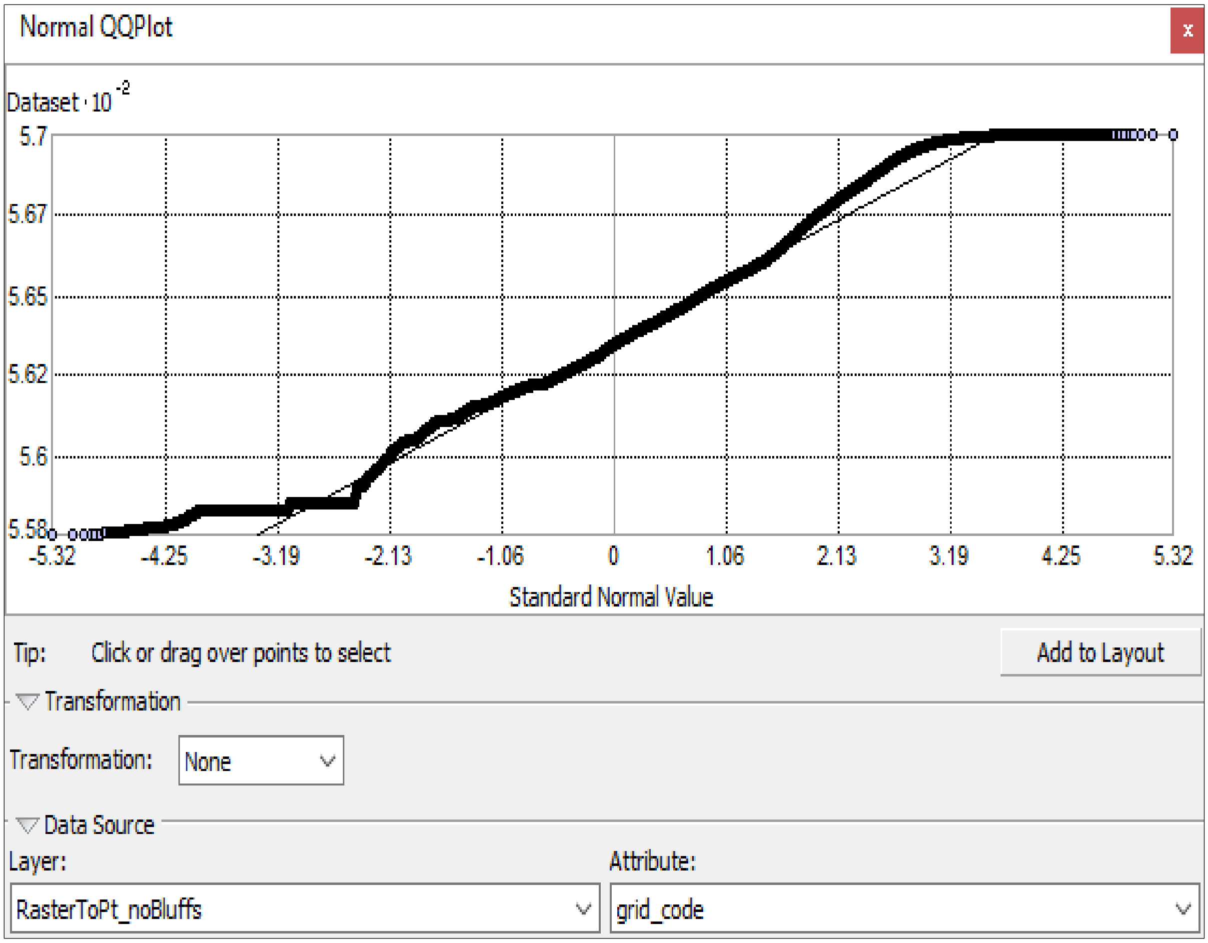

Fig. 40. Adjusted IfSAR elevation data compared to a normal QQ plot
Data source: Intermap Technology, Inc. Technologies used: ArcInfo 10.1 Geostatistical Analyst tool; Global Mapper 11

Hydrological Analyses of the IfSAR DTM

All immature stages of mosquitoes require water, which flows and accumulates based on terrain, soil, geological, vegetation, and numerous characteristics. The primary hydrological analyses tools available in ArcInfo include slope, aspect, flow direction, and flow accumulation, which are important considerations in mosquito control.

Slope

A slope chart of the Missouri River floodplain was created using the adjusted IfSAR DTM within ArcInfo Spatial Analyst Surface tools. Units of slope in Figure 41 are in degrees. Results revealed that about ninety-nine percent of the floodplain near Williston has a slope of less than ten degrees (i.e., less than 17.45 percent).

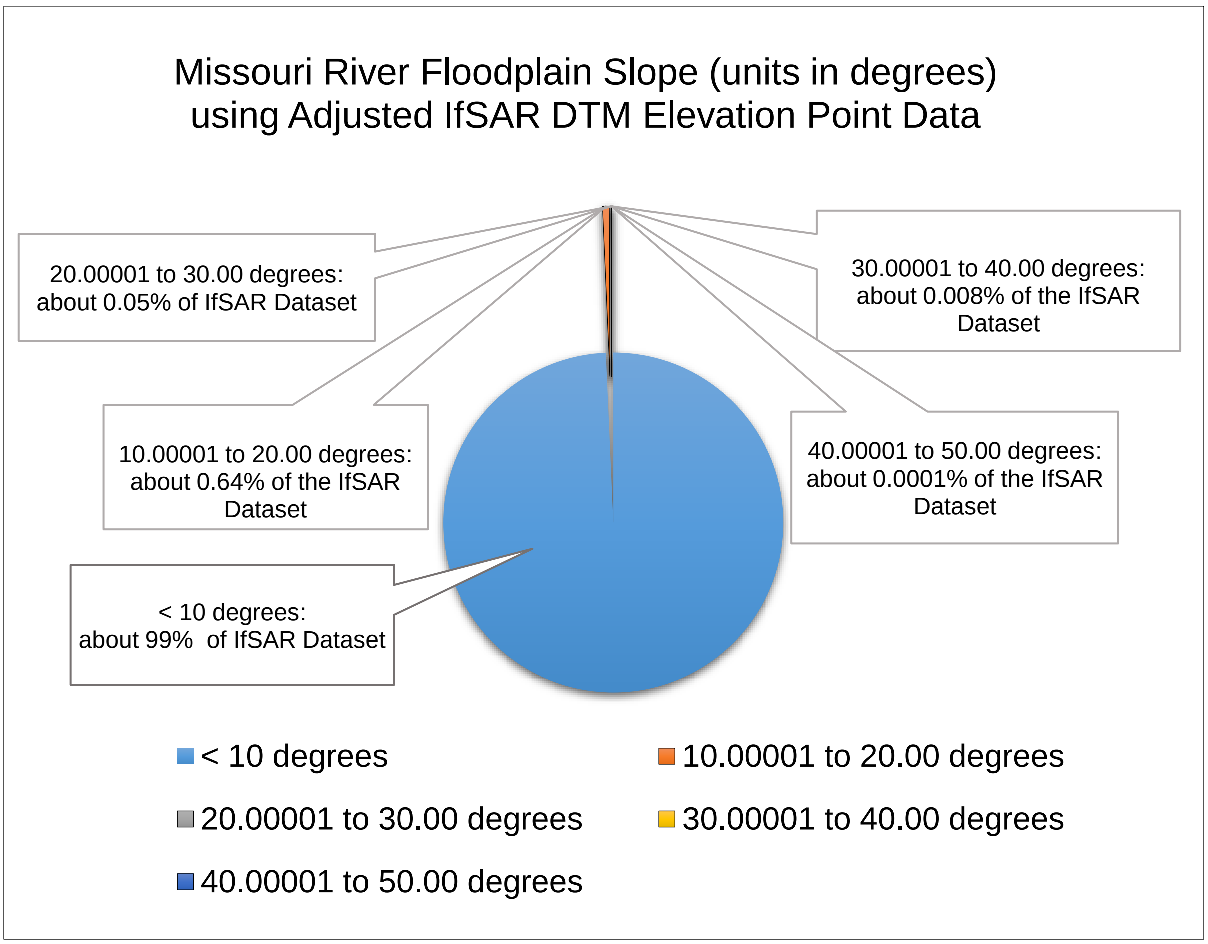

Fig. 41. Slope of the floodplain near Williston, ND
Derived from the adjusted 5-m IfSAR DTM. Units of slope are in degrees. Data source: Intermap Technology, Inc. Technologies used: ArcInfo 10.1; Excel 10

Aspect

Aspect, defined as the direction something faces (American Heritage College Dictionary 2000), is measured clockwise in degrees, from 0 degrees, which faces due north to 360 degrees making a full circle. Flat areas are reported as -1. An aspect chart of the Missouri River floodplain was created using the adjusted IfSAR DTM and ArcInfo Spatial Analyst Surface tools. Results showed that the aspect of slope within the floodplain near Williston is nearly equal in all directions (Fig. 42)

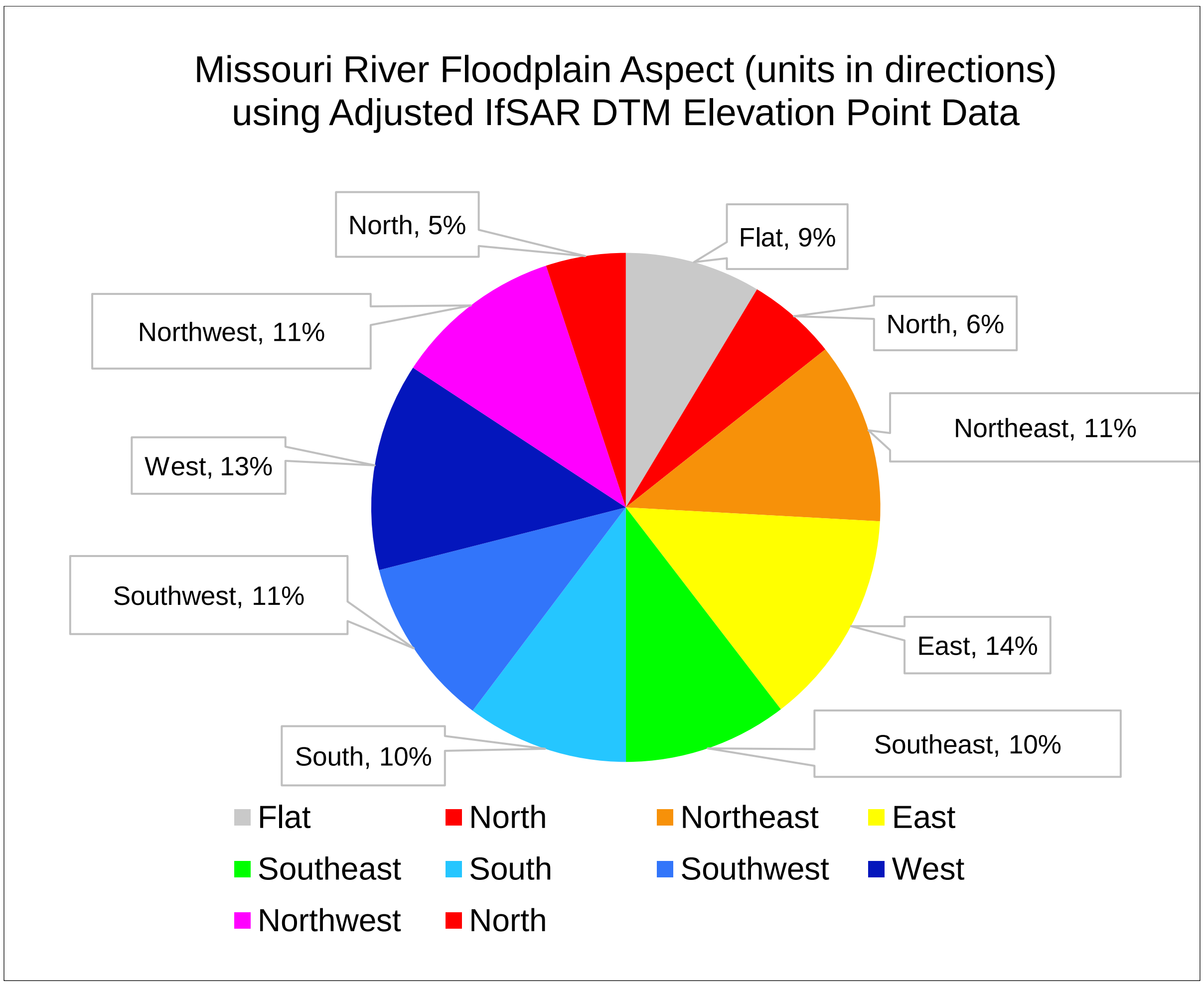

Fig. 42. Aspect of the floodplain near Williston, ND
Derived from the adjusted 5-m IfSAR DTM. Units of aspect are in compass direction. percent t. Data source: Intermap Technology, Inc. Technologies used: ArcInfo 10.1; Excel 10

Flow Accumulation

A 10-m elevation data and the 5-m IfSAR DTM were opened in ArcInfo. The 5-meter IfSAR DTM was placed over the 10-m NED. A flow accumulation (i.e., water pooling) map of the floodplain near Williston was created using Spatial Analyst Hydrological tools. Results showed that water accumulation, depicted in Figure 43 as white specks, occurred throughout the floodplain near Williston. The light blue lines in Figure 43 were added to visually divide the floodplain into smaller areas.

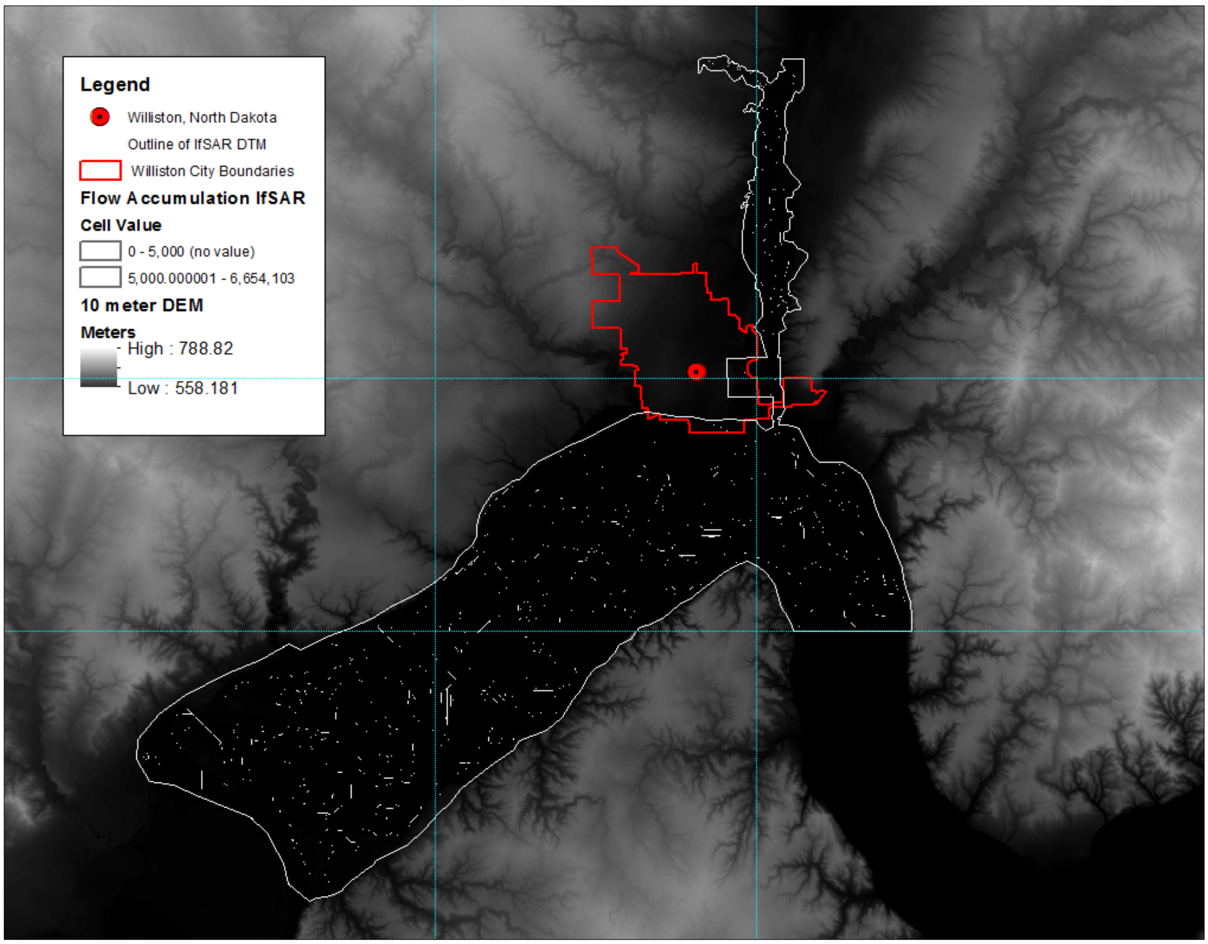

Fig. 43. 5-m resolution, flow accumulation map of the floodplain near Williston, ND
Derived from the 5-m DTM. Data sources: Intermap Technology, Inc.; NDgisHub. Technologies used: ArcInfo 10.1 Hydrology tools; Global Mapper 11

Shaded Relief Map

A 2D shaded-relief map of the floodplain near Williston was created within ArcInfo using the Spatial Analyst Surface tools (Fig. 44). Justification for the shaded relief map was the fact that the shaded relief technique improves the visualization of the terrain by illuminating the topography as the sun would, including the proper location of shadows. The process improved the visibility of the terrain within the floodplain including side channels and oxbows.

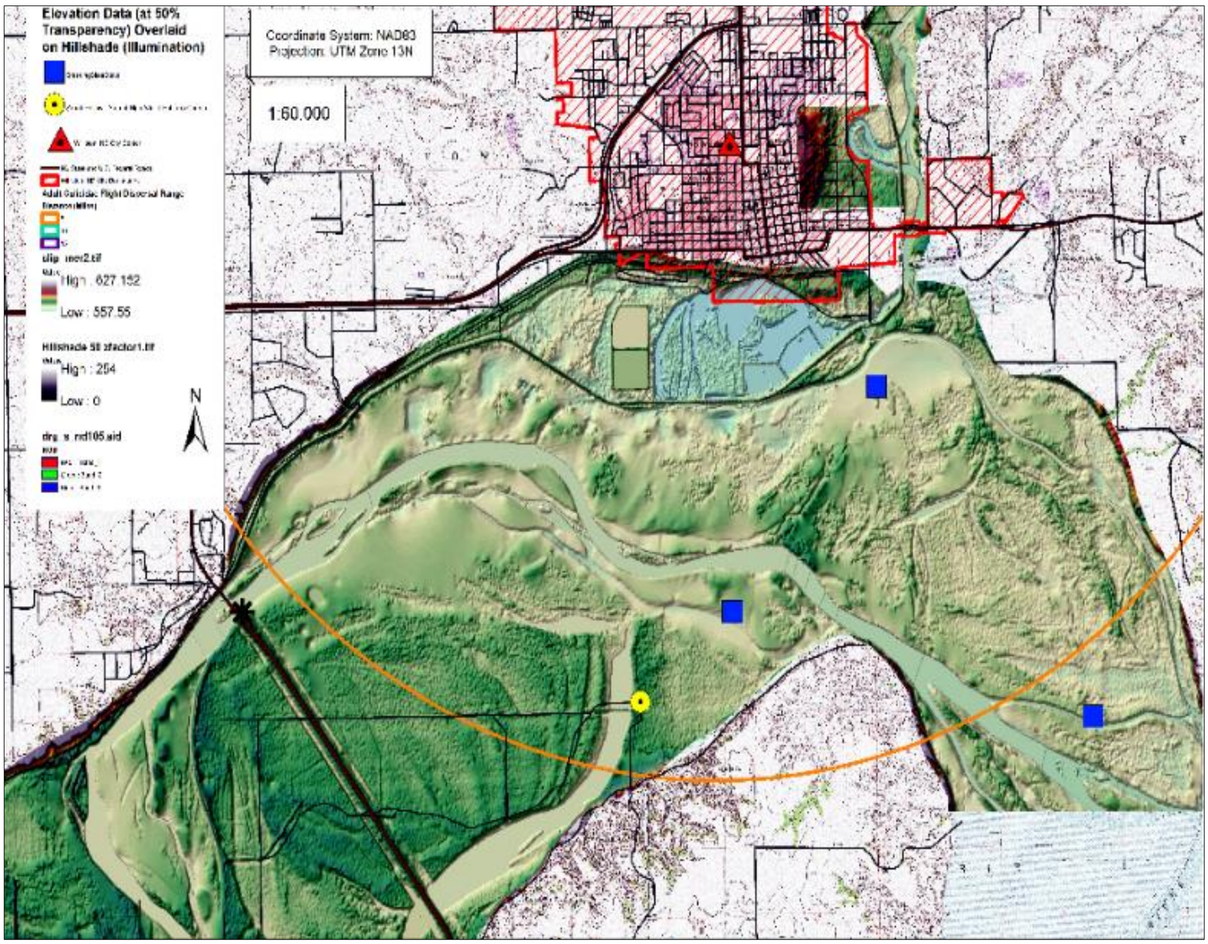

Fig. 44. 5-m resolution, shaded relief map of the floodplain near Williston, ND
Data sources: Intermap Technology, Inc.; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

Minimum Contour Interval

Minimum contour interval maps of the Williston floodplain were created in ArcInfo Spatial Analyst Contour tools, following the NMAS (Bureau of the Budget 1947) guidelines and RMSEz x 3.2892. The input value was the vendor-declared RMSEz of one meter. Results showed that the minimum allowed contour interval for the IfSAR DTM is only 3.29 m (10.79 ft) (Fig. 45), which is not adequate for identifying minor surge and recession cycles of the Missouri River near Williston.

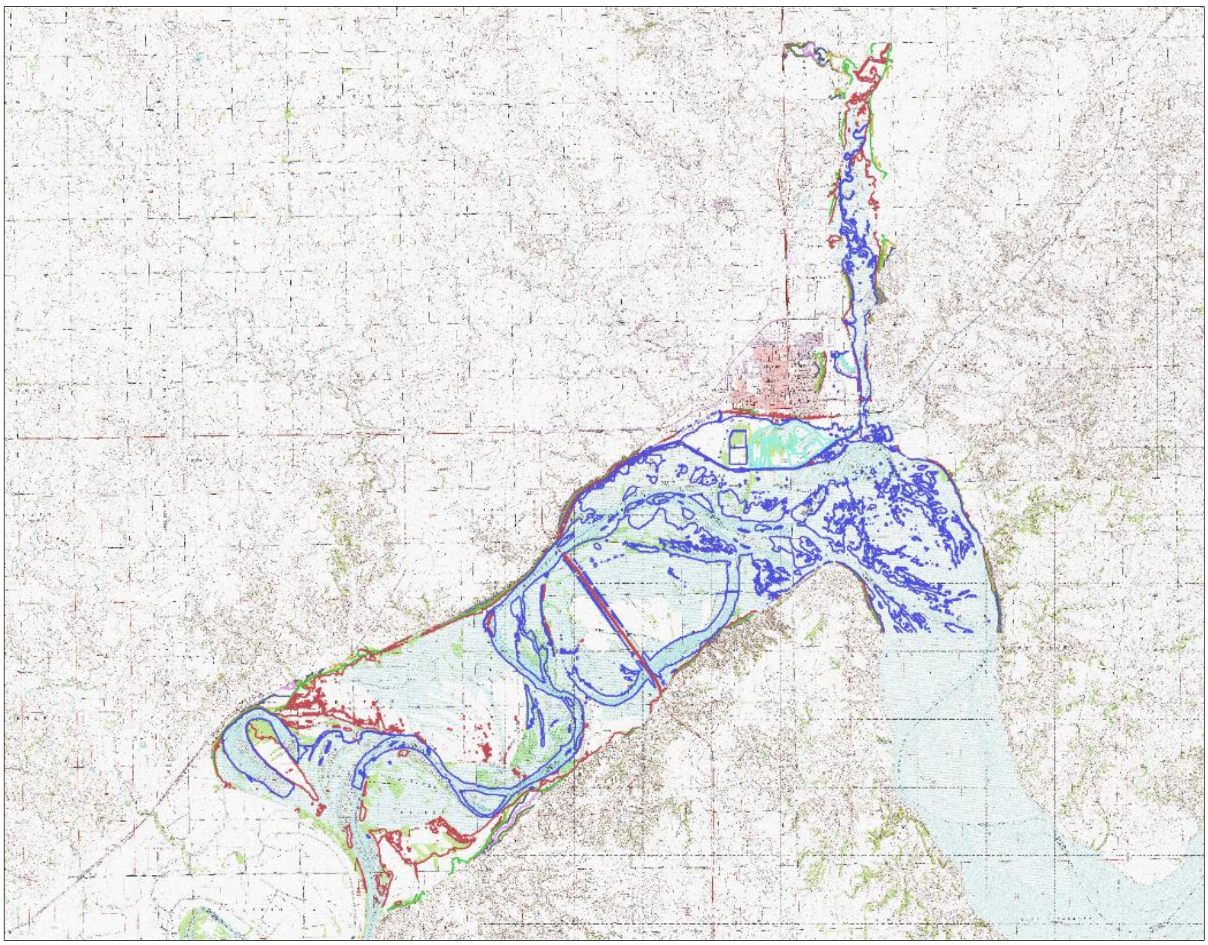

Fig. 45. Minimum allowed elevation contours of the floodplain near Williston, ND. Contours were derived from the 5-m IfSAR DTM RMSEz of one meter. Data sources: Intermap Technology, Inc.; NDgisHub. Technologies used: ArcInfo 10.1 Surface Analysis tools; Global Mapper 11

Predictive Flood Model Building

Predictive flood models for the floodplain near Williston were created in ArcInfo using the following steps. Missouri River elevation data from the USGS river gaging station, number 06330000, were retrieved from the USGS real-time water website, entered into an Excel spreadsheet, and organized from low to high elevations. River elevation data from the USGS website covered the years 1967 to 2015. The range of river elevations near Williston, ND were calculated and results determined a minimum river elevation of 560.22 m (1838 ft) msl and a maximum river elevation of 567.23 m (1861 ft) msl. The total range of river elevations near Williston was 7.01 m (23 ft) msl. To create the predictive flood models, Missouri River elevations were expanded to a low of 557.784 m (1830 ft) and a high of 568.147 m (1865 ft), a total range of 10.36 m (35 ft). The adjusted IfSAR point data was opened in ArcInfo. The Selection by Attributes tool was used to select floodplain elevations of 557.784 m (1830 ft) to 557.9364 m (1830.5 ft). The selected elevations were exported to a new shapefile, labeled 1830_1830_5ft, and saved. The Selection by Attributes tool was then used to select floodplain elevations from 557.9364 m (1830.5 ft) to 560.832 m (1840 ft). The selected elevations were exported to a new shapefile, labeled, and saved. Every six-inch elevation increase between 557.784 m (1830 ft) to 568.147 m (1864 ft) were selected, exported to a new shapefile, labeled, and saved. Each foot of elevation required the creation of four predictive flood models. The 35-ft range of elevations used in this study required the creation of 140 predictive flood models. Predictive flood models for every twelve inches of elevation increase are provided in Figures 46 to 80.

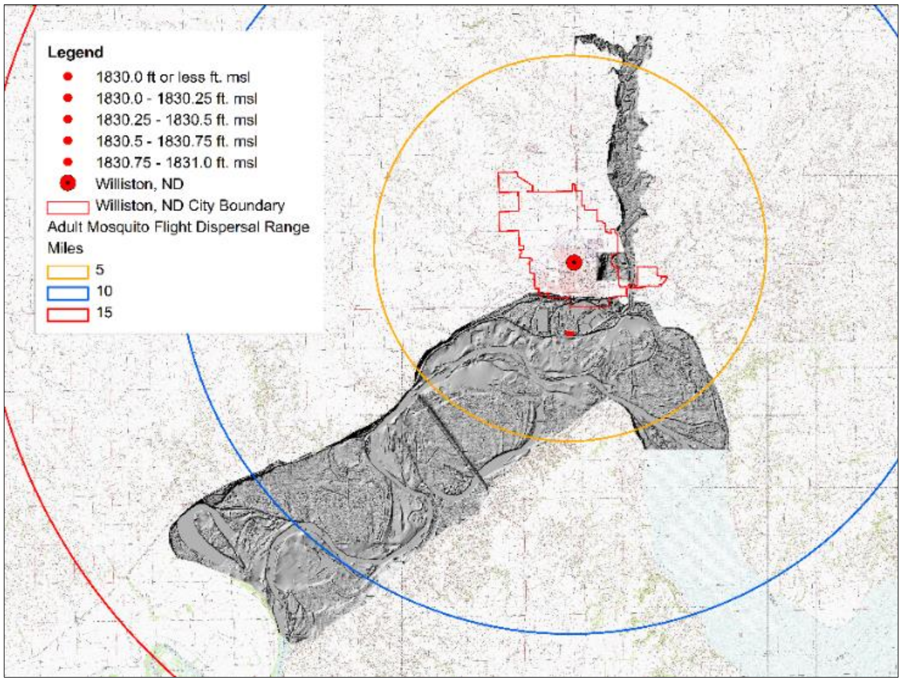

Fig. 46. Predictive flood model, 1830 to 1831 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

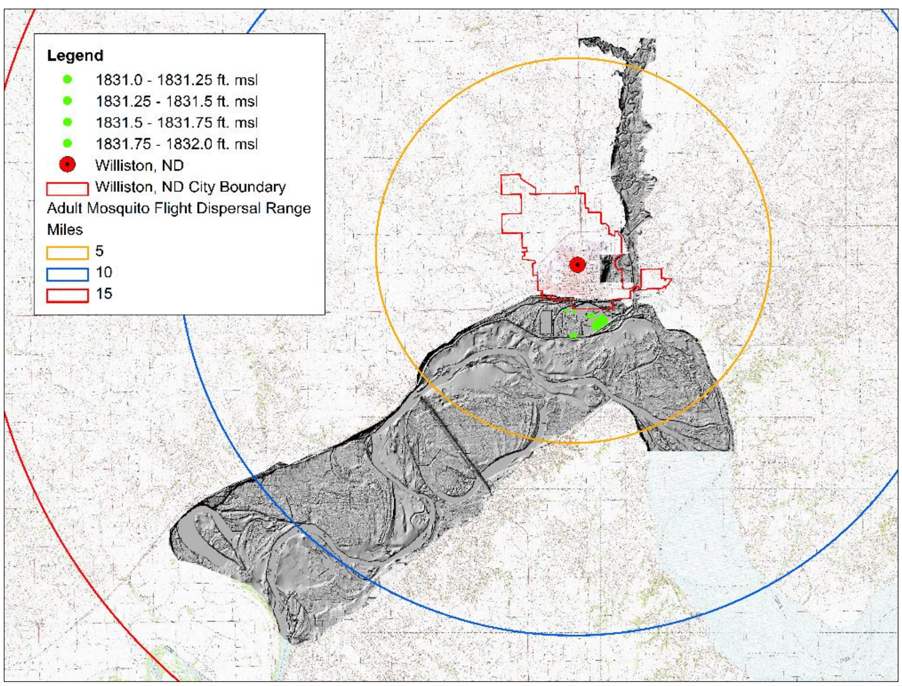

Fig. 47. Predictive flood model, 1831 to 1832 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

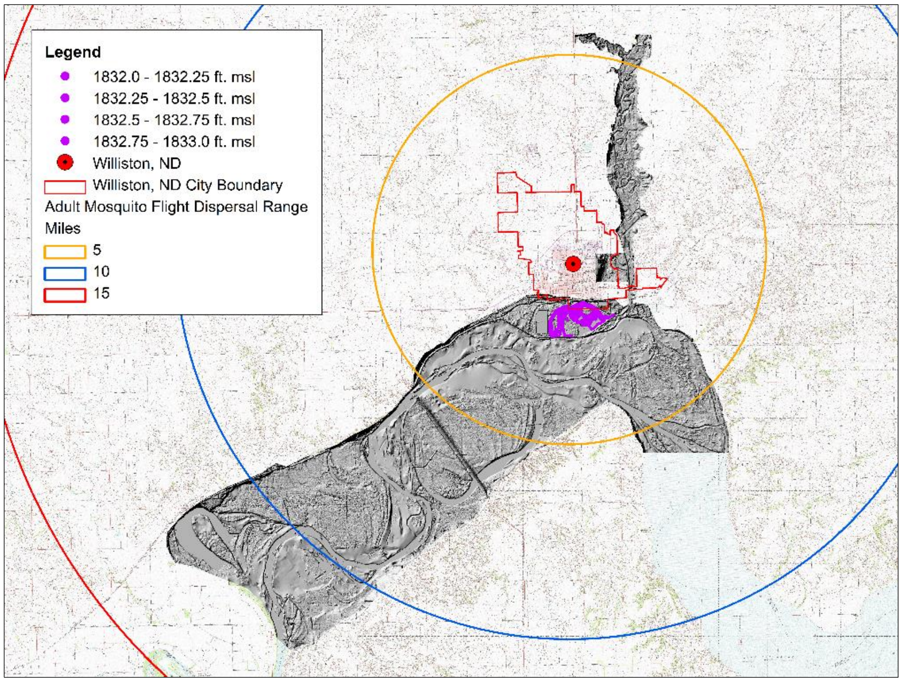

Fig. 48. Predictive flood model, 1832 to 1833 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

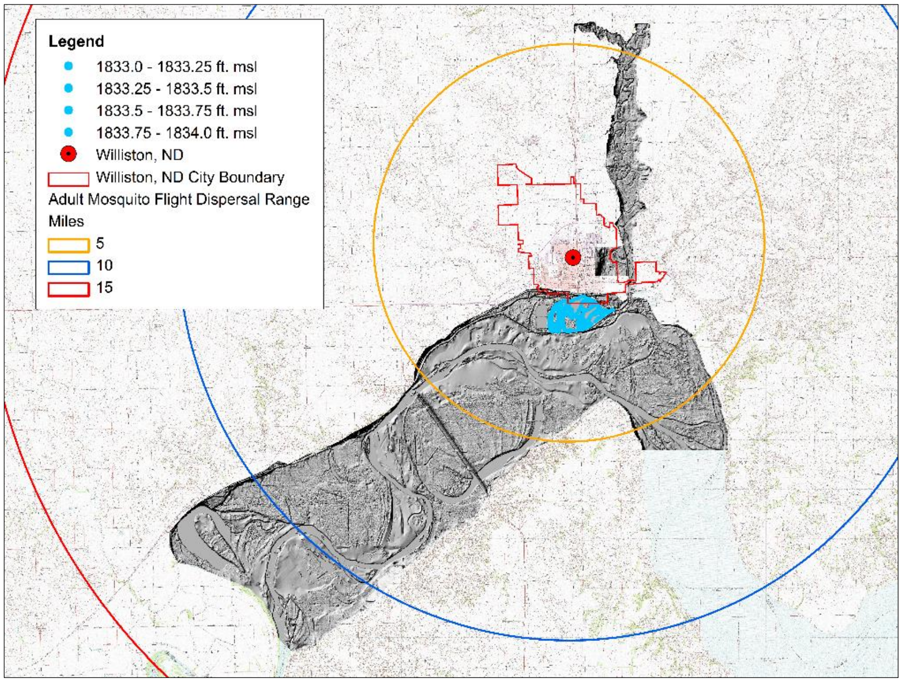

Fig. 49. Predictive flood model, 1833 to 1834 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

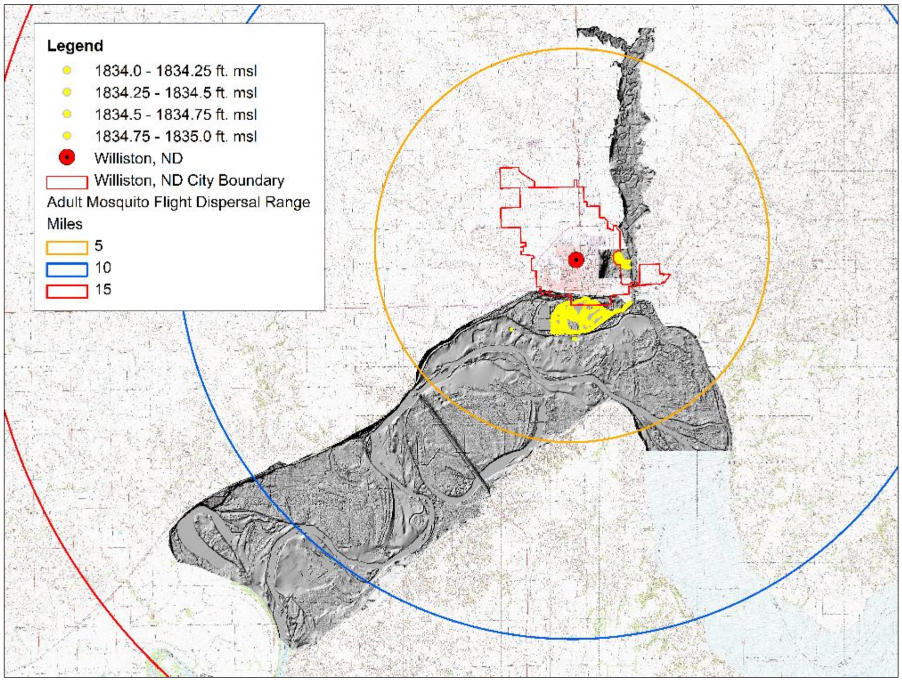

Fig. 50. Predictive flood model, 1834 to 1835 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

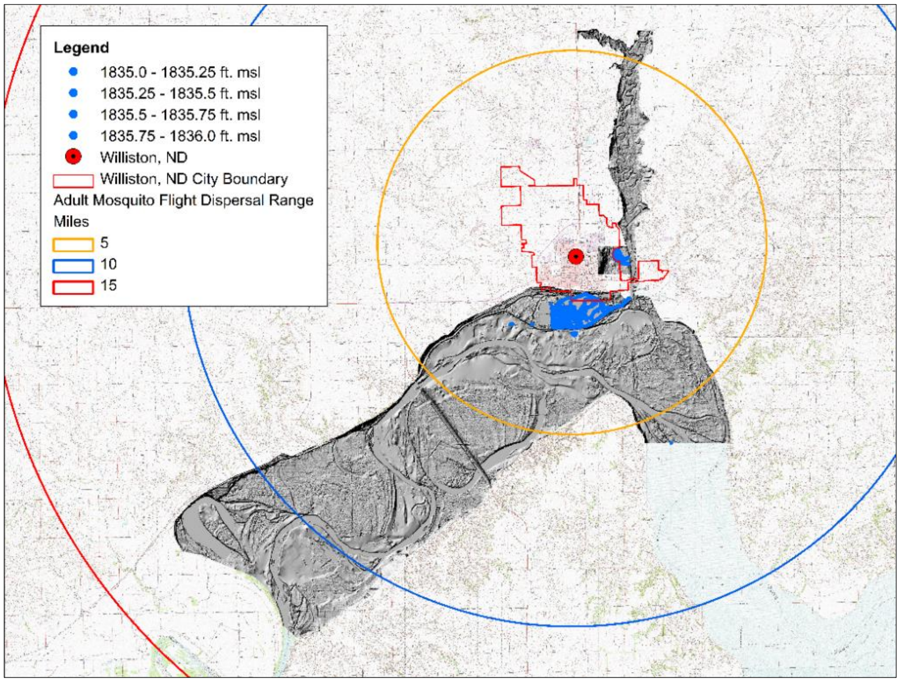

Fig. 51. Predictive flood model, 1835 to 1836 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

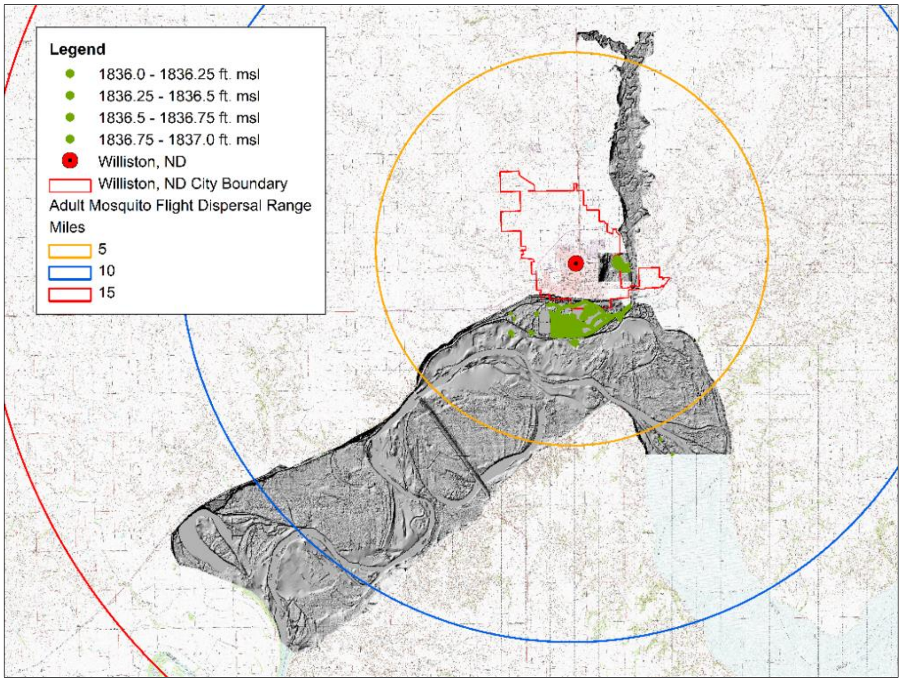

Fig. 52. Predictive flood model, 1836 to 1837 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

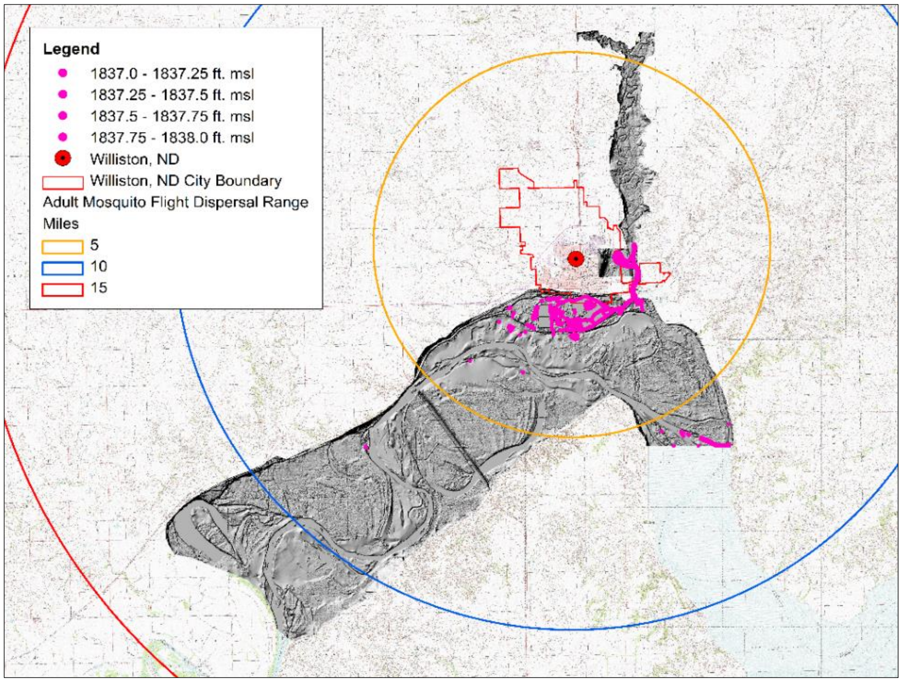

Fig. 53. Predictive flood model, 1837 to 1838 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

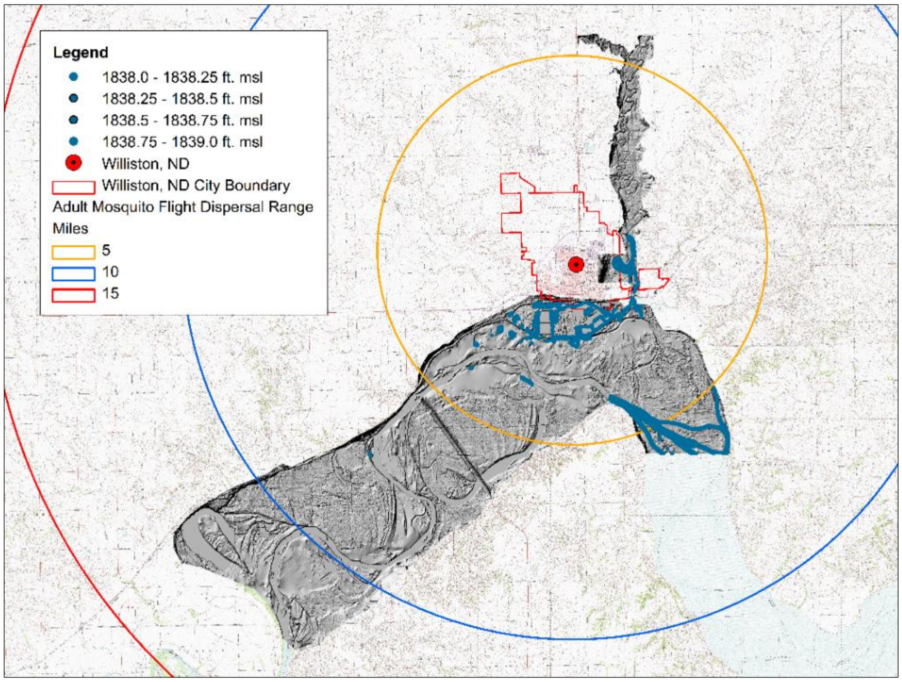

Fig. 54. Predictive flood model, 1838 to 1839 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

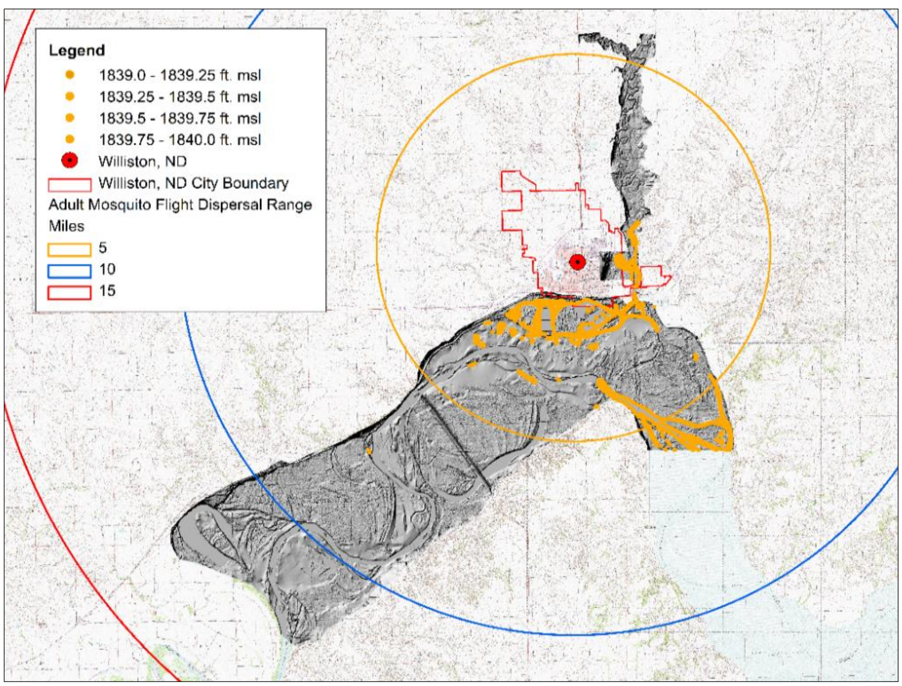

Fig. 55. Predictive flood model, 1839 to 1840 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

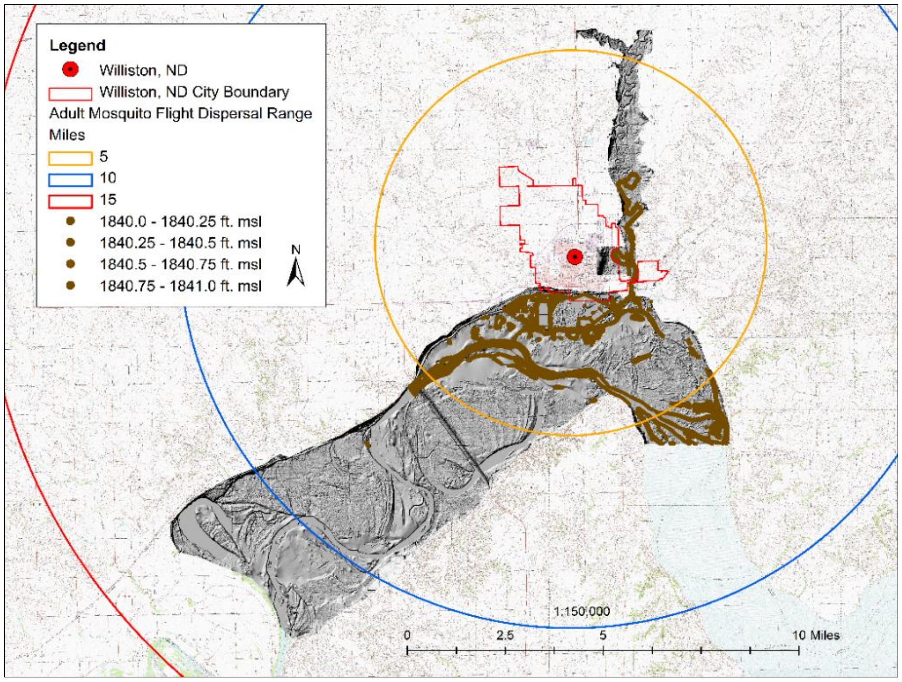

Fig. 56. Predictive flood model, 1840 to 1841 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

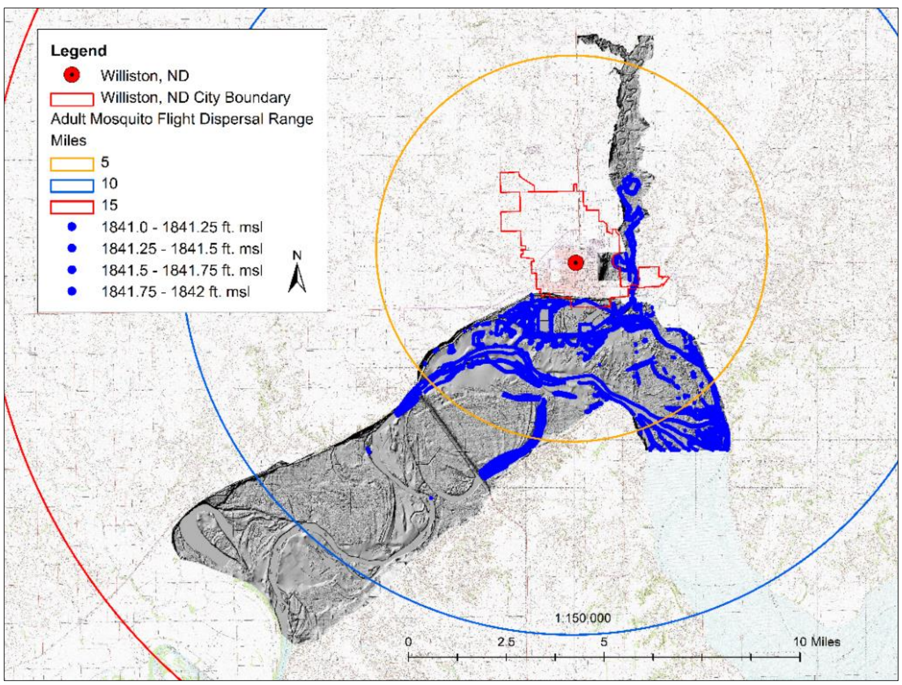

Fig. 57. Predictive flood model, 1841 to 1842 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

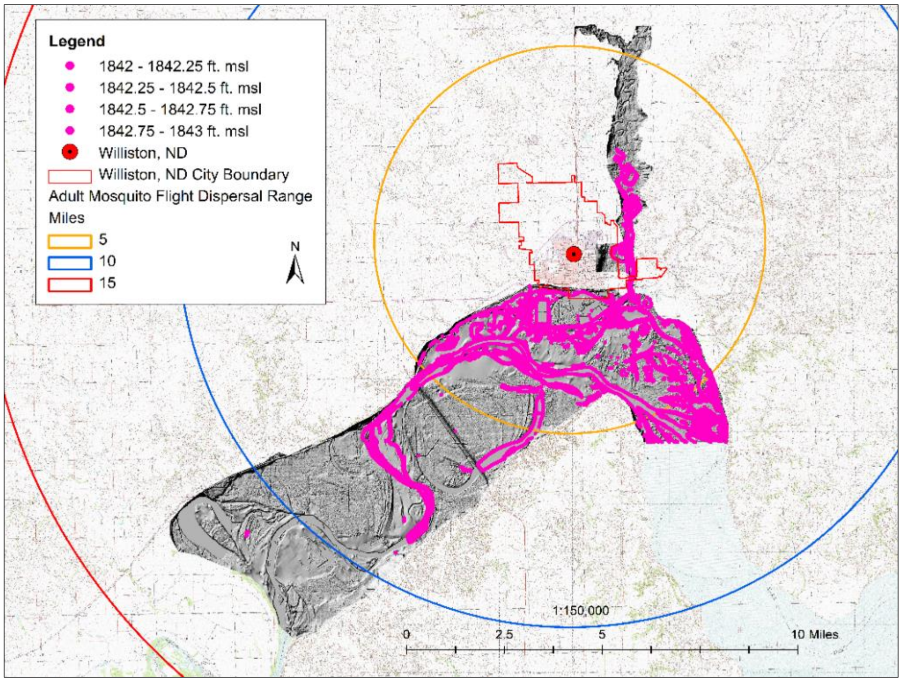

Fig. 58. Predictive flood model, 1842 to 1843 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

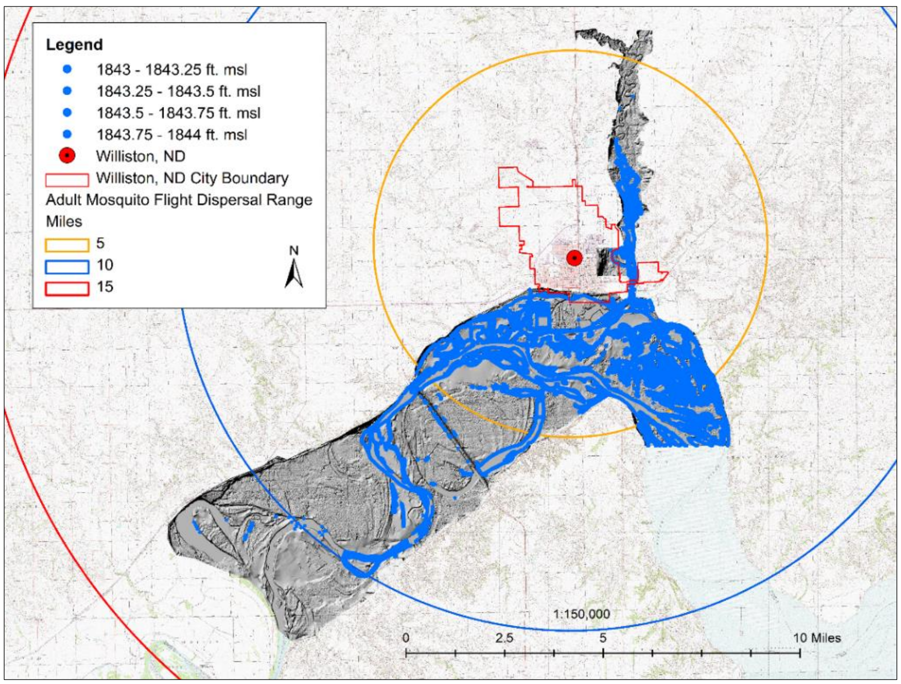

Fig. 59. Prodictive flood model, 1843 to 1844 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

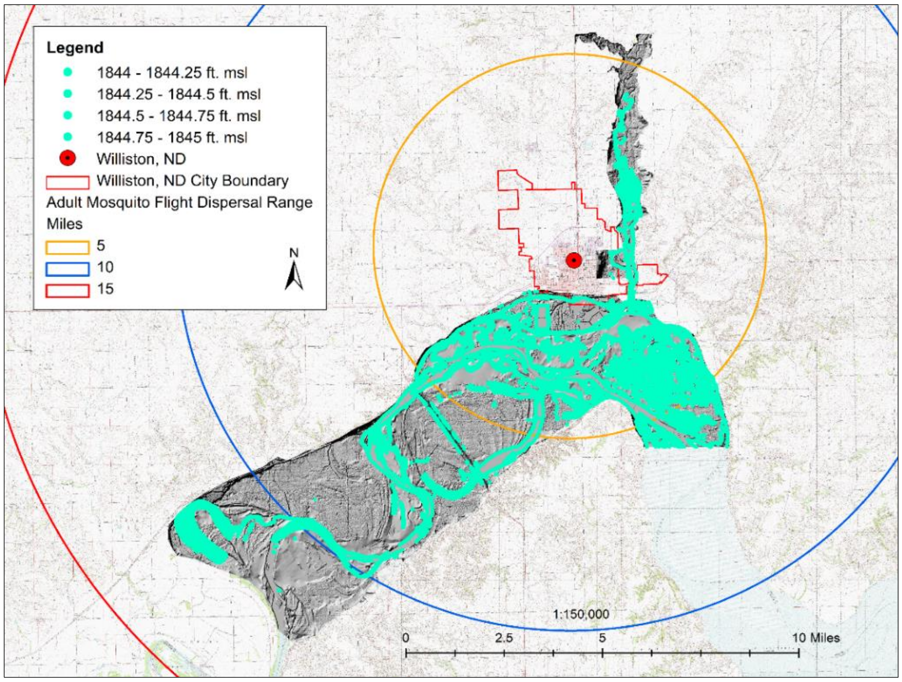

Fig. 60. Predictive flood model, 1844 to 1845 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

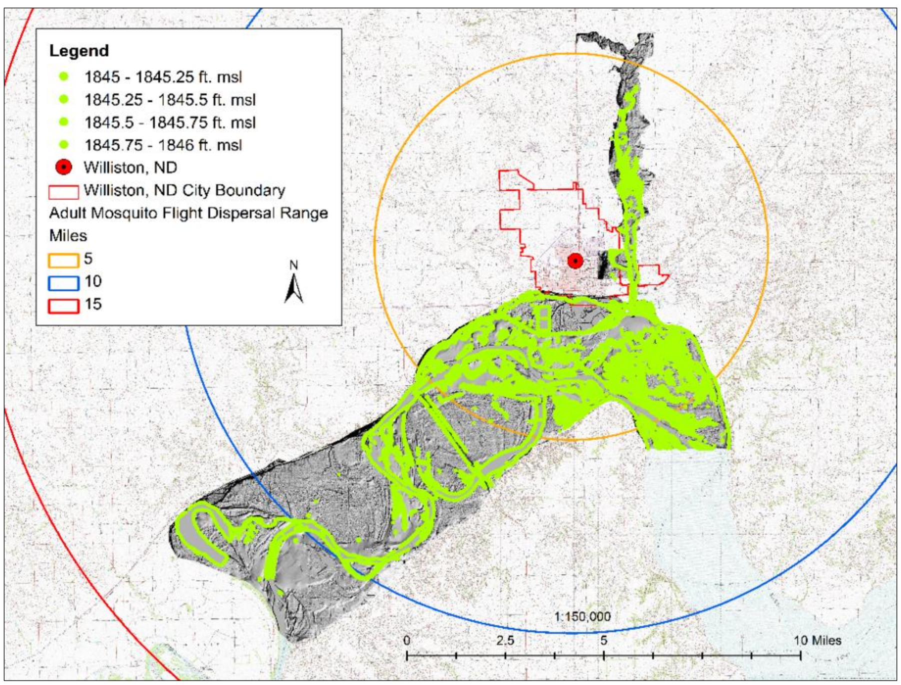

Fig. 61. Predictive flood model, 1845 to 1846 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

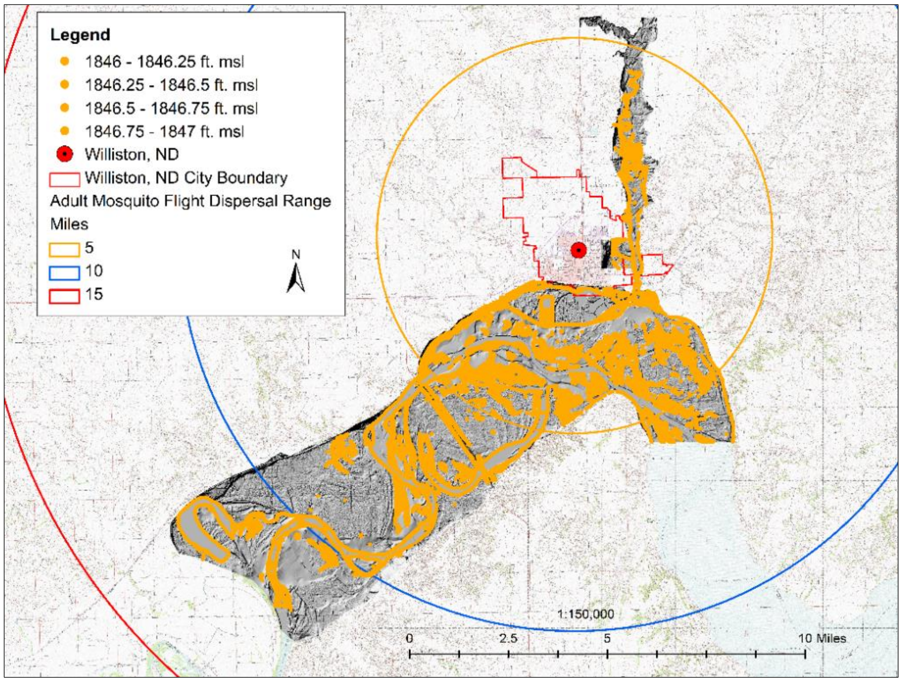

Fig. 62. Predictive flood model, 1846 to 1847 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

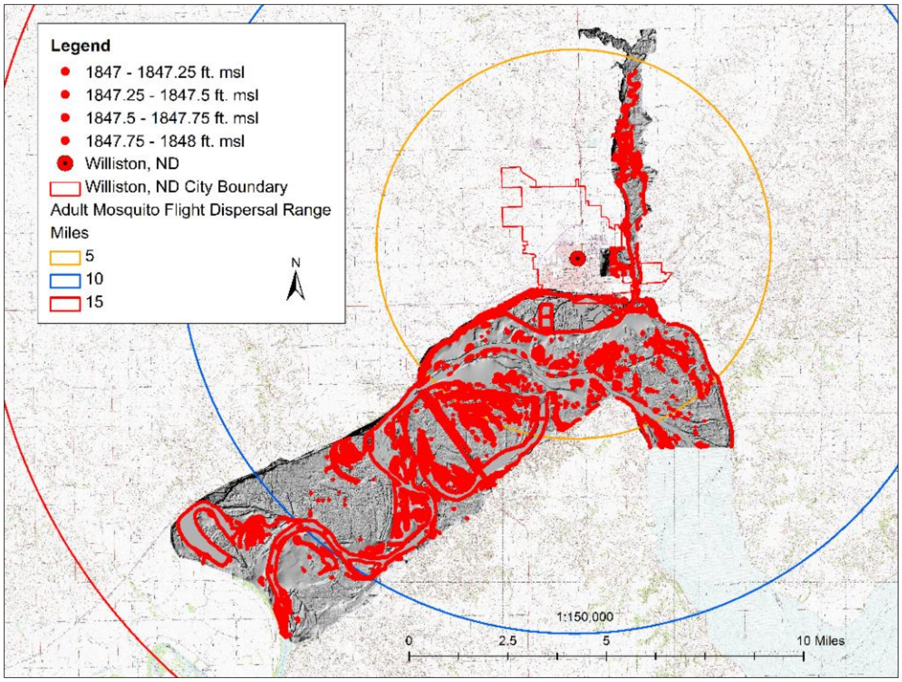

Fig. 63. Predictive flood model, 1847 to 1848 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

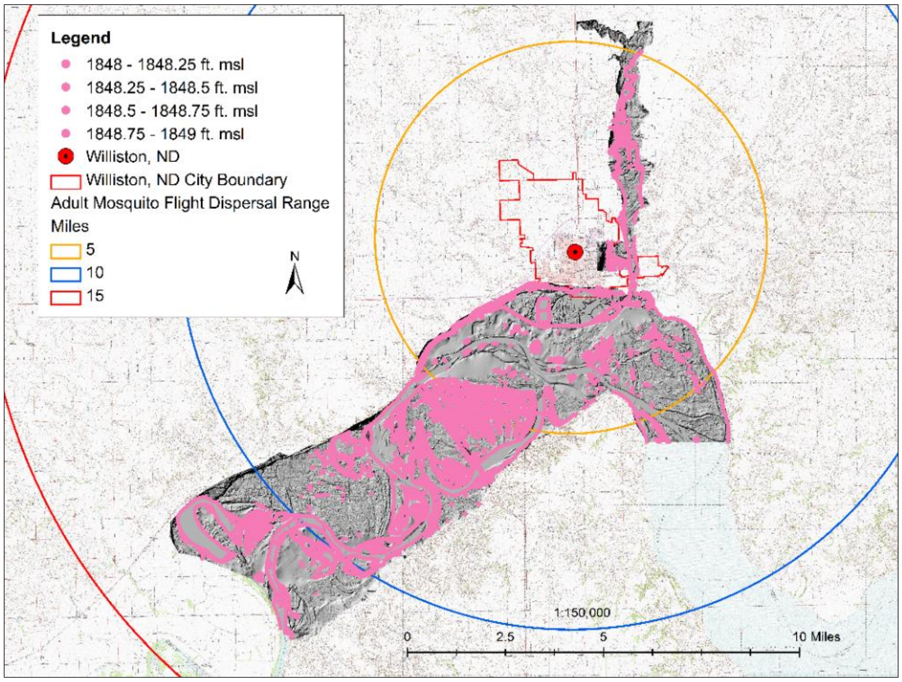

Fig. 64. Predictive flood model, 1848 to 1849 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

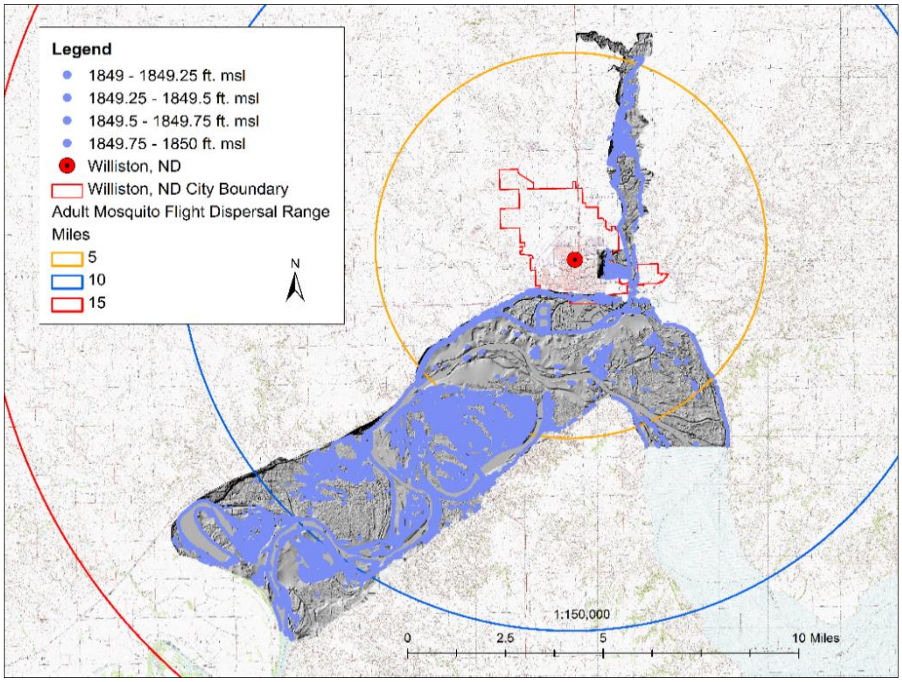

Fig. 65. Predictive flood model, 1849 to 1850 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

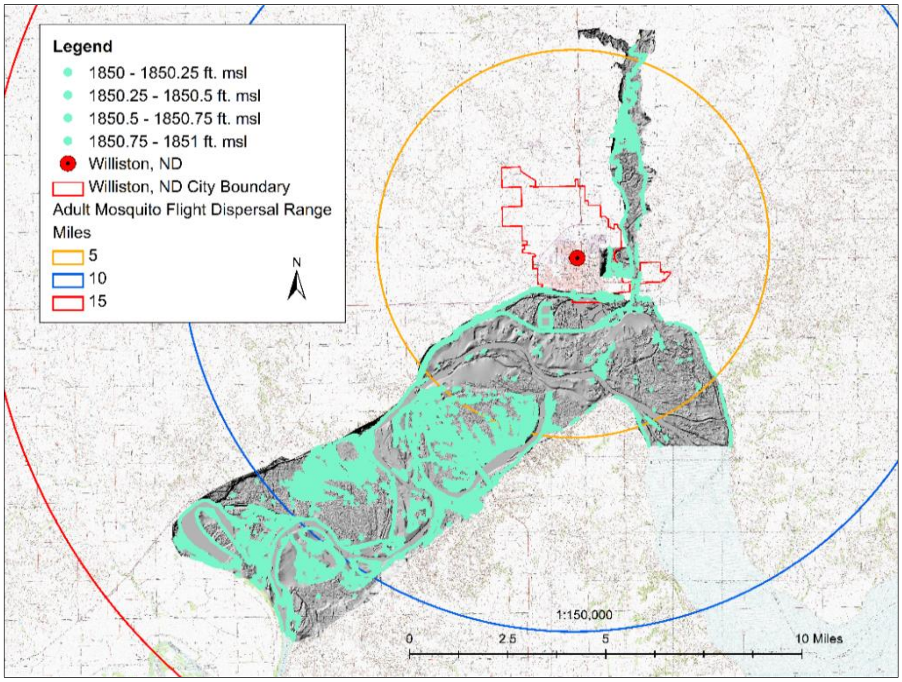

Fig. 66. Predictive flood model, 1850 to 1851 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

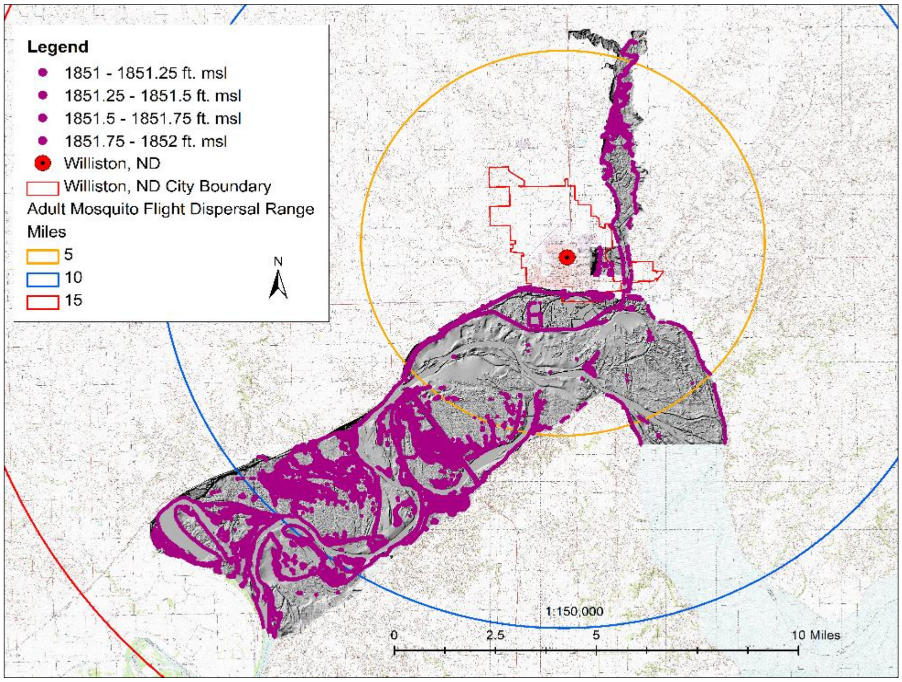

Fig. 67. Predictive flood model, 1851 to 1852 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

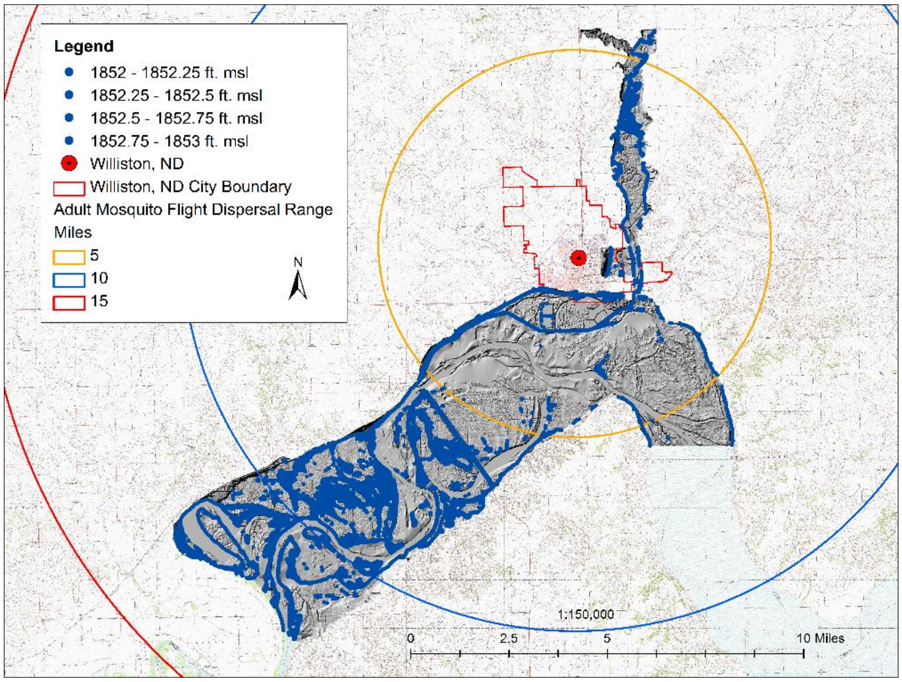

Fig. 68. Predictive flood model, 1852 to 1853 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

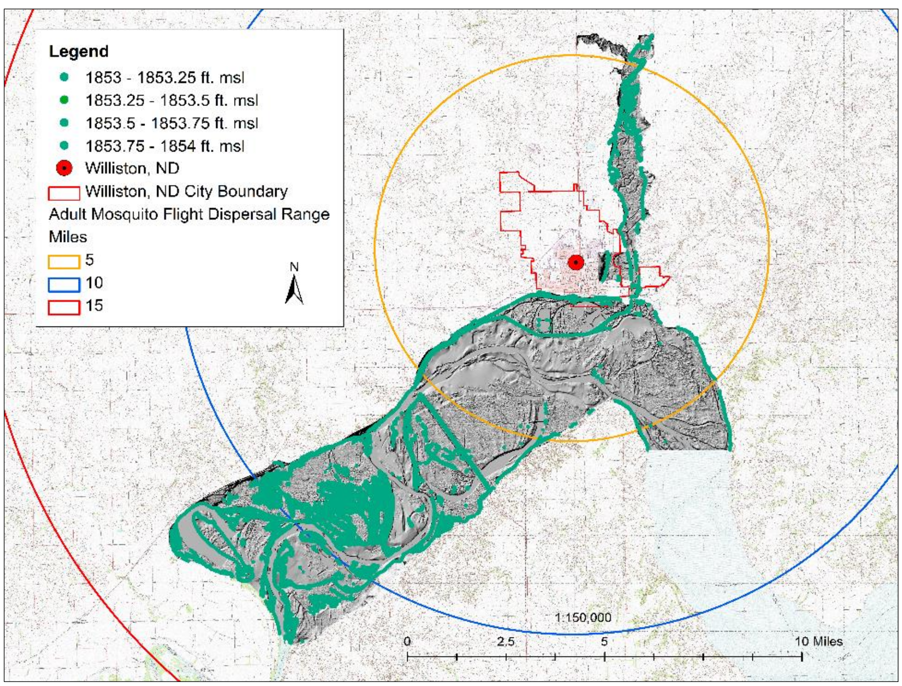

Fig. 69. Predictive flood model, 1853 to 1854 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

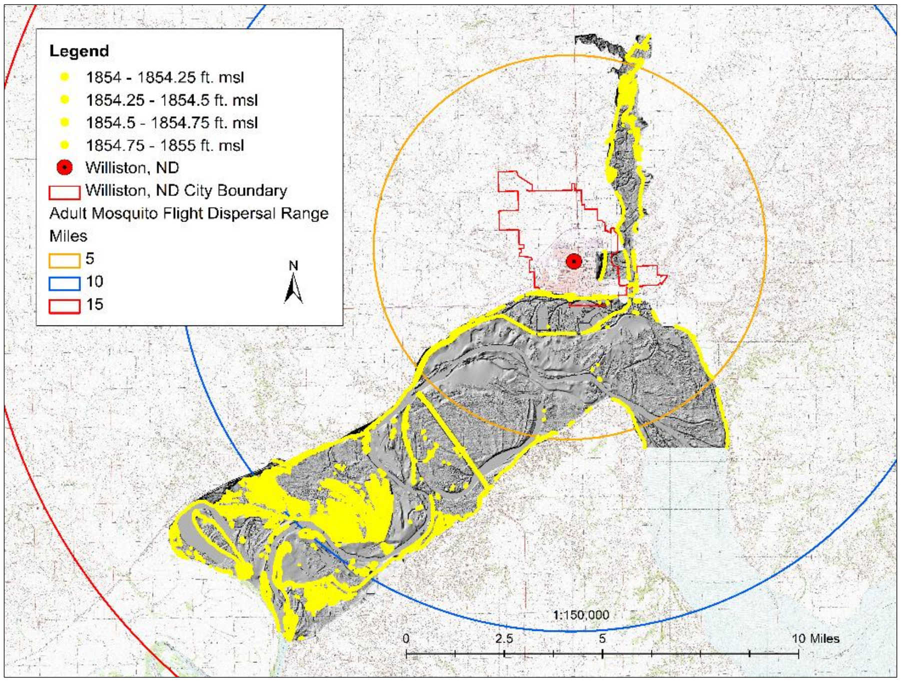

Fig. 70. Predictive flood model, 1854 to 1855 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

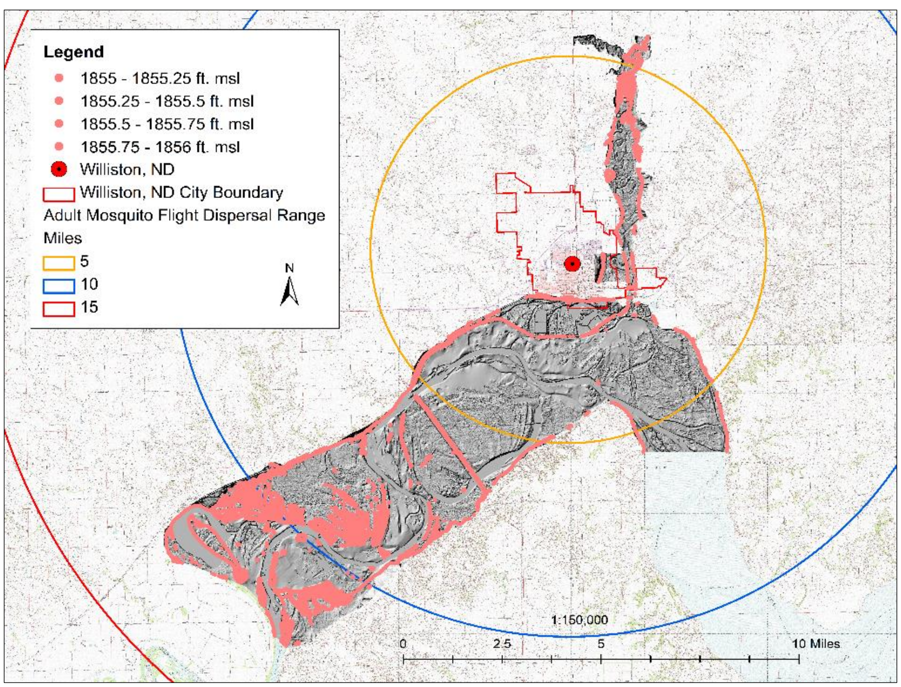

Fig. 71. Predictive flood model, 1855 to 1856 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

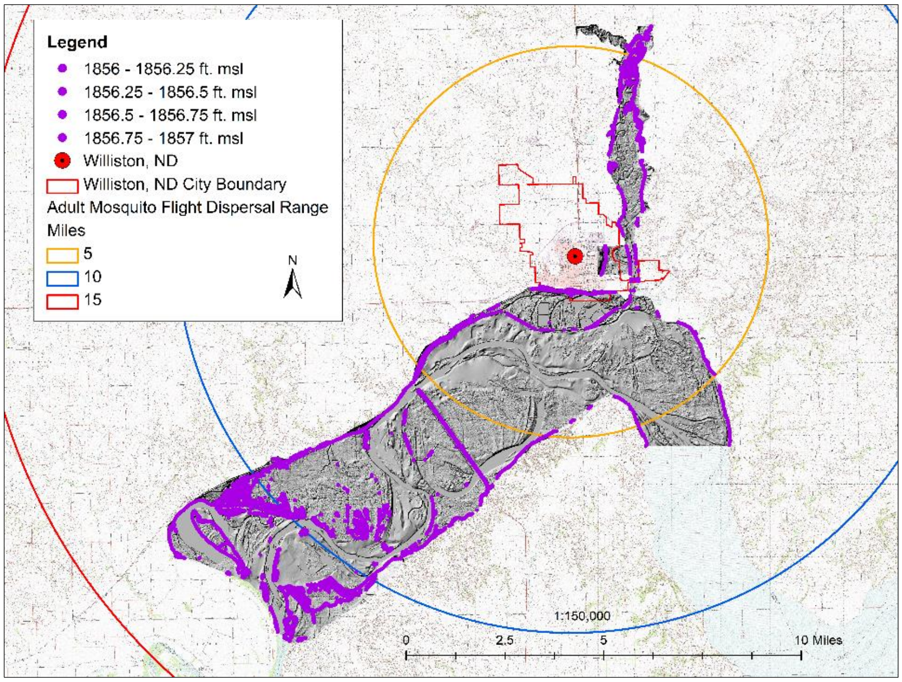

Fig. 72. Predictive flood model, 1856 to 1857 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

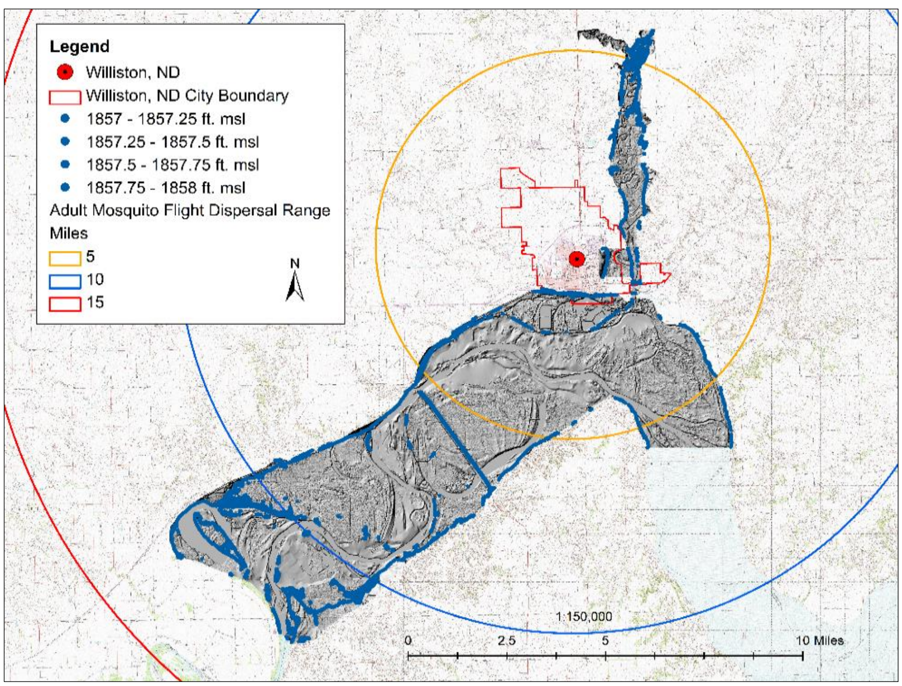

Fig. 73. Predictive flood model, 1857 to 1858 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

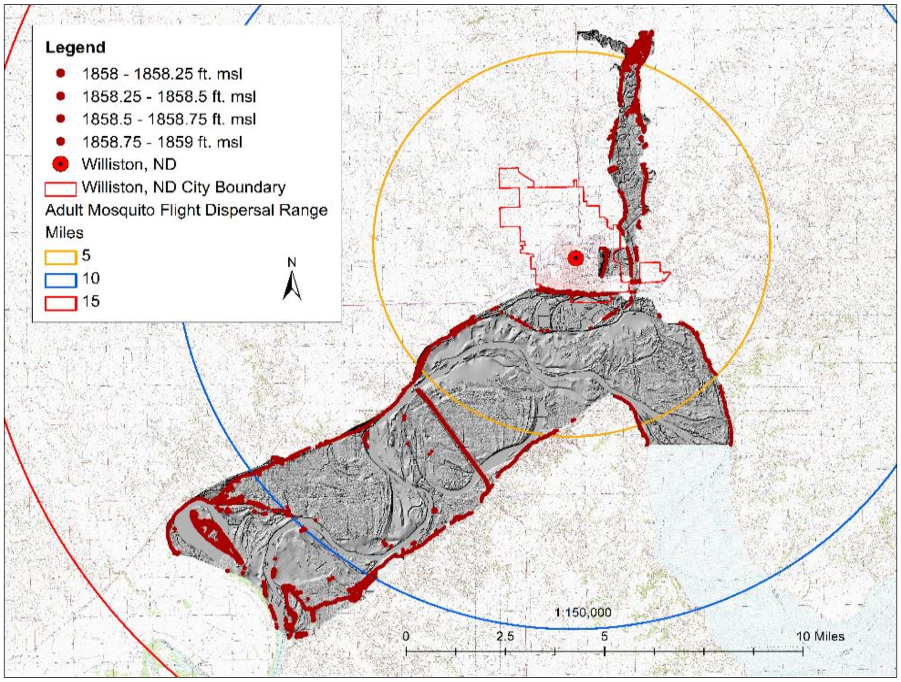

Fig. 74. Predictive flood model, 1858 to 1859 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

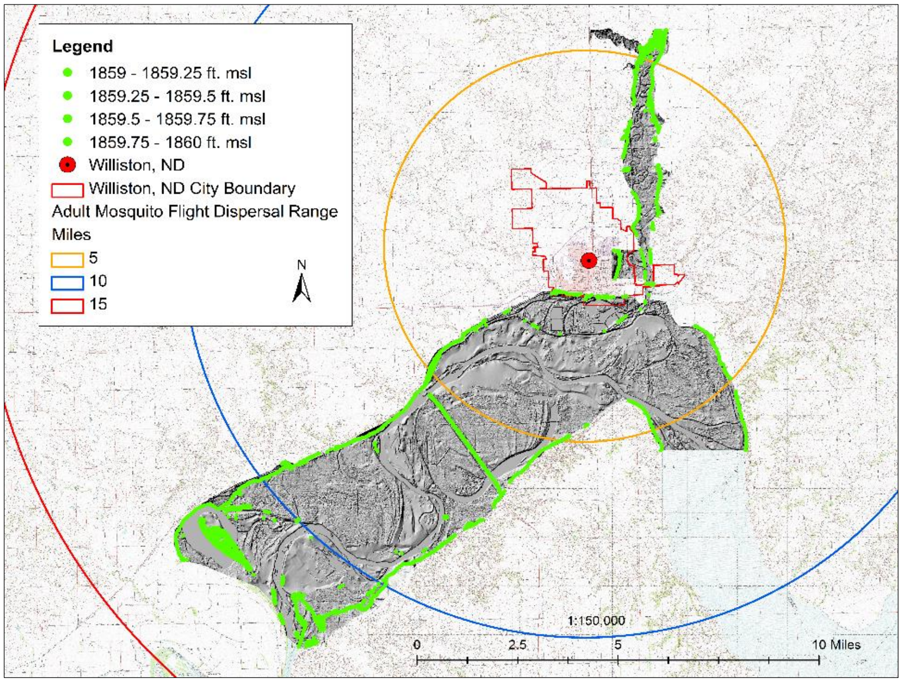

Fig. 75. Predictive flood model, 1959 to 1860 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

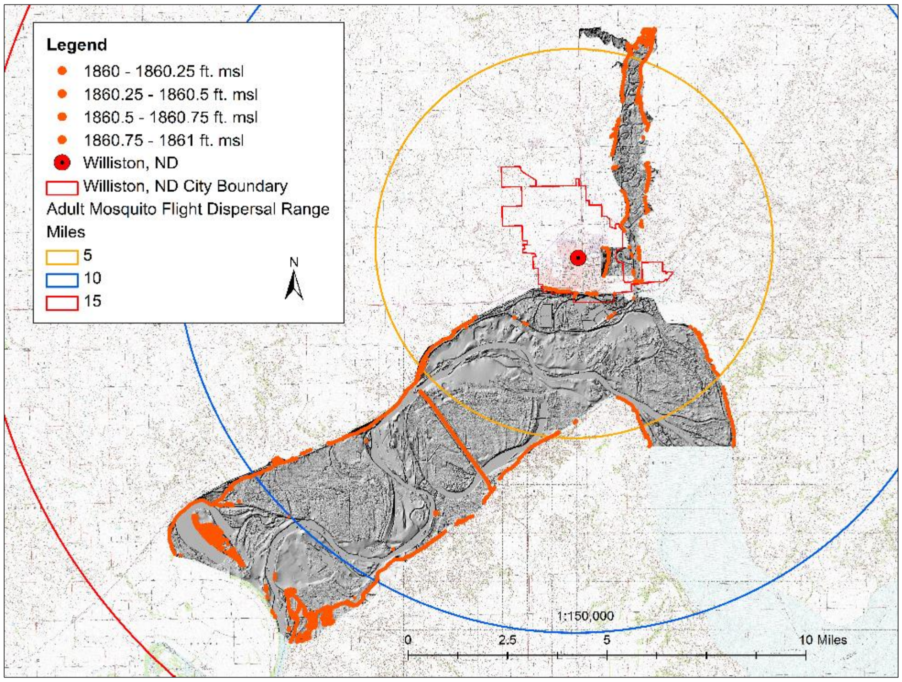

Fig. 76. Predictive flood model, 1860 to 1861 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

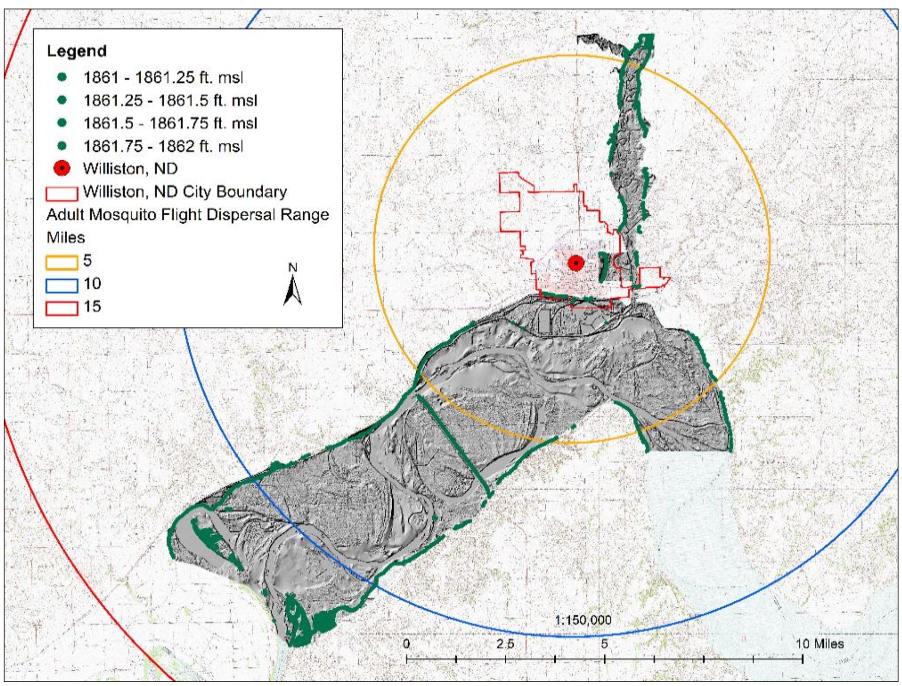

Fig. 77. Predictive flood model, 1861 to 1862 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

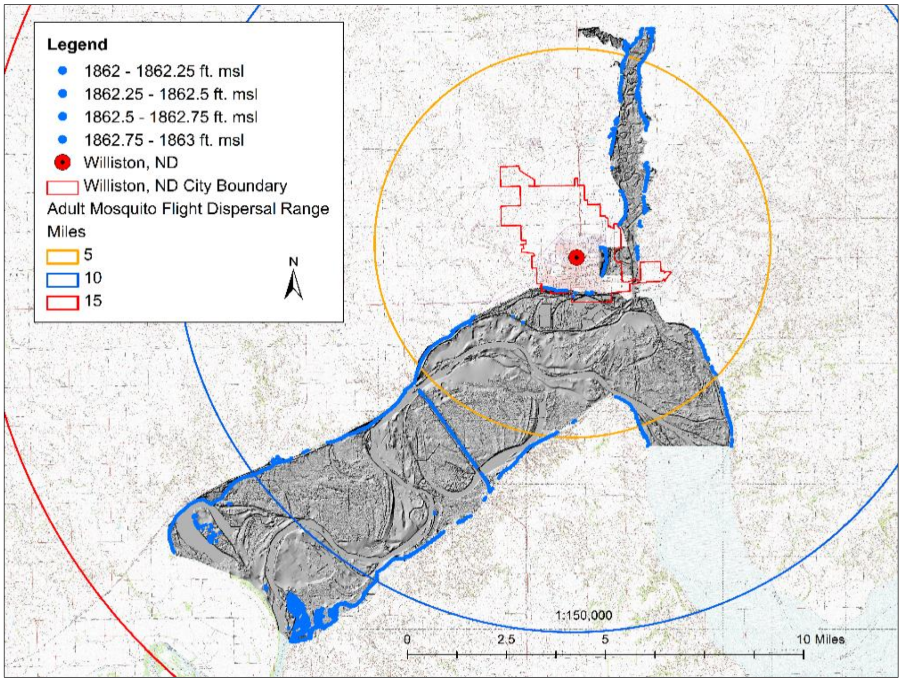

Fig. 78. Predictive flood model, 1862 to 1863 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

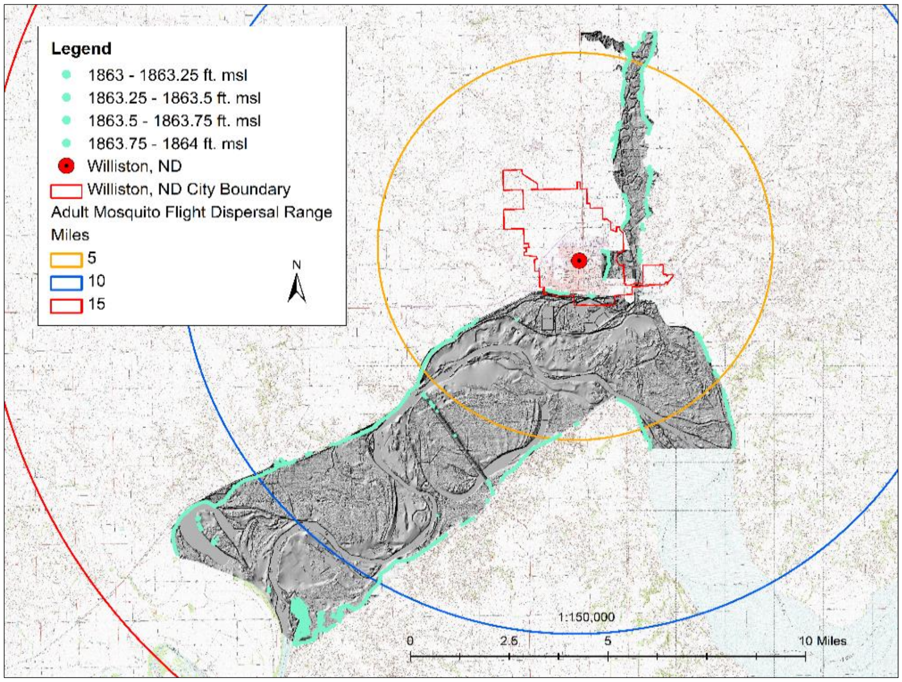

Fig. 79. Predictive flood model, 1863 to 1864 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

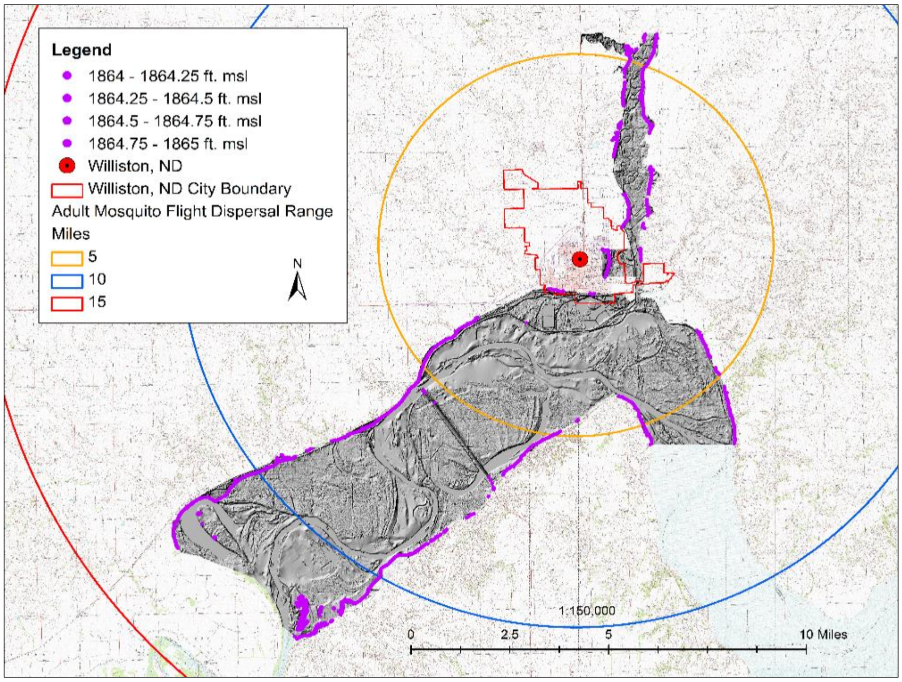

Fig. 80. Predictive flood model, 1864 to 1865 ft msl
Data sources: Intermap Technology, Inc.; National Map; NDgisHub. Technologies used: ArcInfo 10.1; Global Mapper 11

Comparison of the Predictive Flood Models to Landsat Imagery

Comparisons among predictive flood models and Landsat imagery were carried using the following procedures: all available Landsat satellite imagery for the Williston area (i.e., 1972 to 2014) and that collected during April to October were downloaded from USGS EarthExplorer (2017), and processed using Environment for Visualizing Images (ENVI) software (Harris Corporation, Broomfield, CO 2017) to make the imagery usable within ArcInfo. During the processing in ENVI, various electromagnetic (EM) spectral band combinations such as Red/Green/Blue [RGB] 321; 765; and 453 were used on each Landsat image, based on the available bands. Each ENVI-processed image was labeled by date of acquisition, placed in appropriate subfolders labeled by year, then folders were labeled by decade (i.e., 1970s, 1980s, 1990s, 2000s, 2010s); all Missouri River elevations recorded by gaging station number 06330000 near Williston, ND (i.e., 1967 to 2015) were retrieved from the USGS Real-time Water website (2017) and entered into an Excel spreadsheet along with the associated dates of acquisition, labeled and saved; Missouri River elevation data and Landsat imagery were compared by date and each Landsat image was relabeled to include the river elevation for that date and resaved. Visual comparisons among Landsat imagery and predictive flood models based on similar river elevations were positive (Figs. 81 to 90).

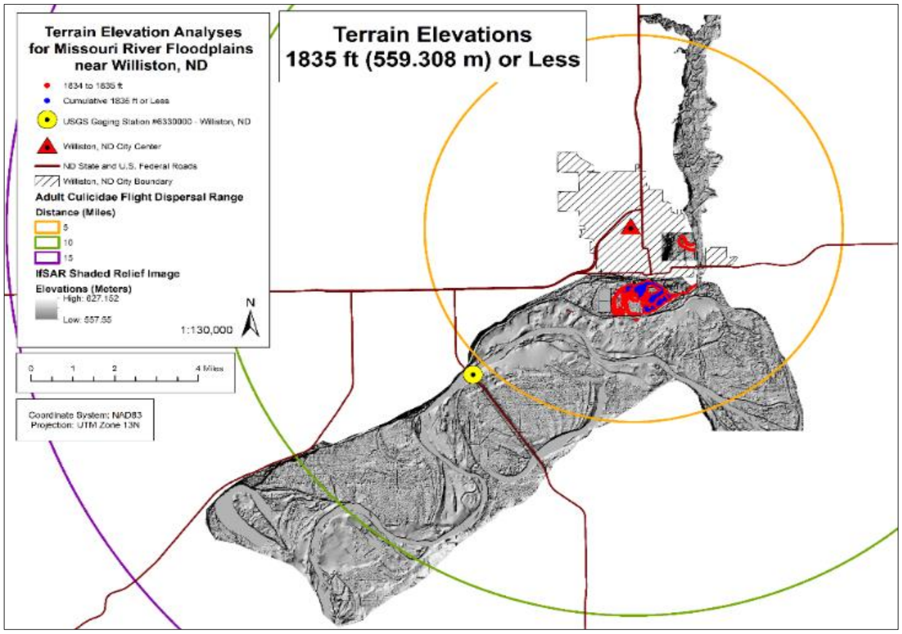

Fig. 81. Predictive flood model, 559.31 m (1835 ft) msl or less
Data sources: Intermap Technology, Inc. Technologies used: ArcInfo 10.1; Global Mapper 11

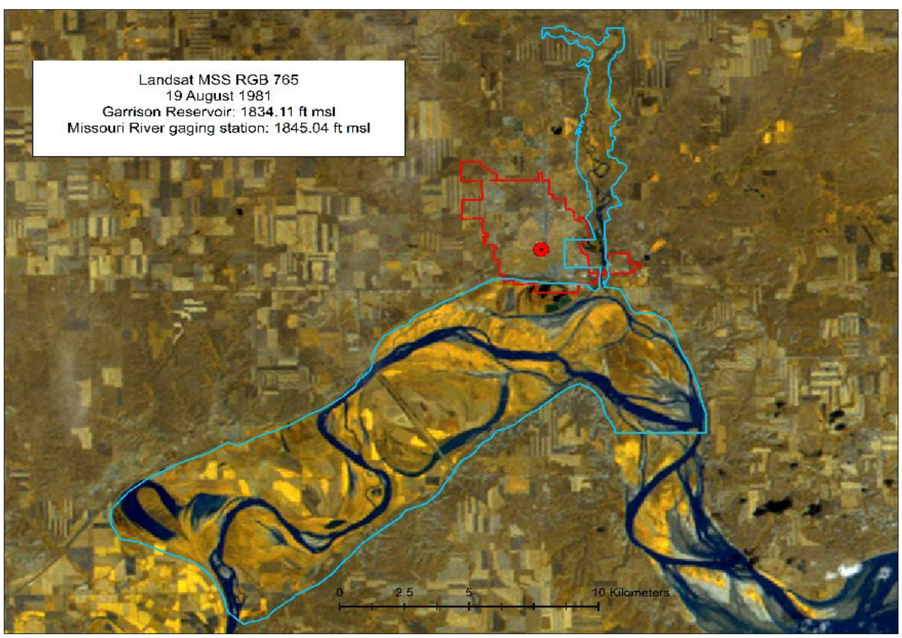

Fig. 82. Landsat-MSS image, 19 Aug 1981
Scene ID: LM203702611981231AAA03. RGB 765. WRS P34R27. Garrison Reservoir gaging station elevation reading: 1834.11 ft msl

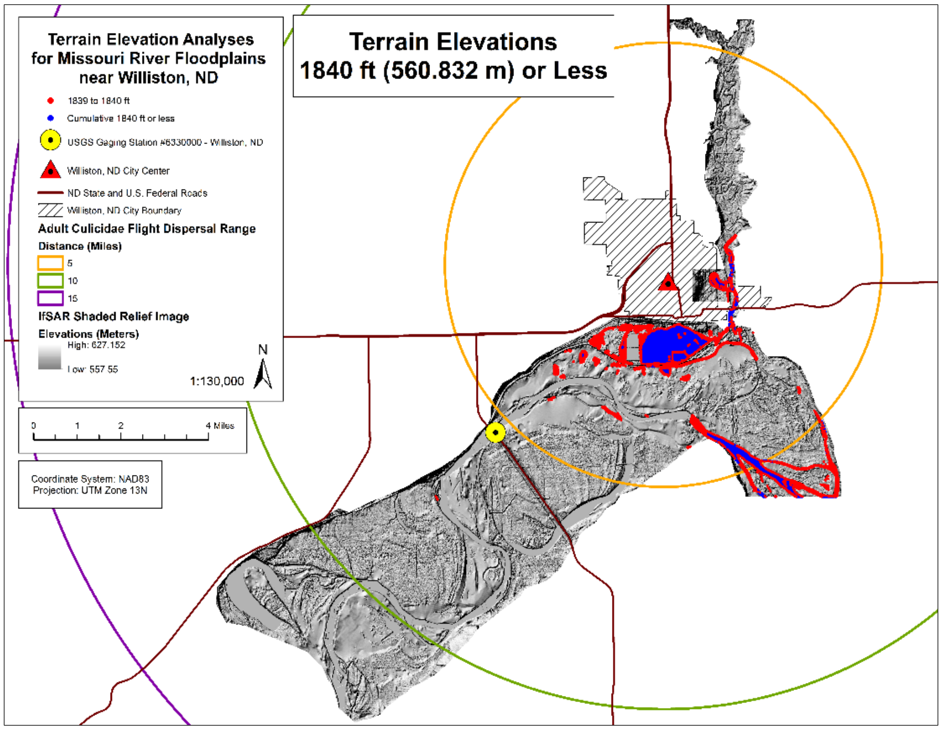

Fig. 83. Predictive flood model, 560.83 m (1840 ft) msl or less
Data sources: Intermap Technology, Inc. Technologies used: ArcInfo 10.1; Global Mapper 11

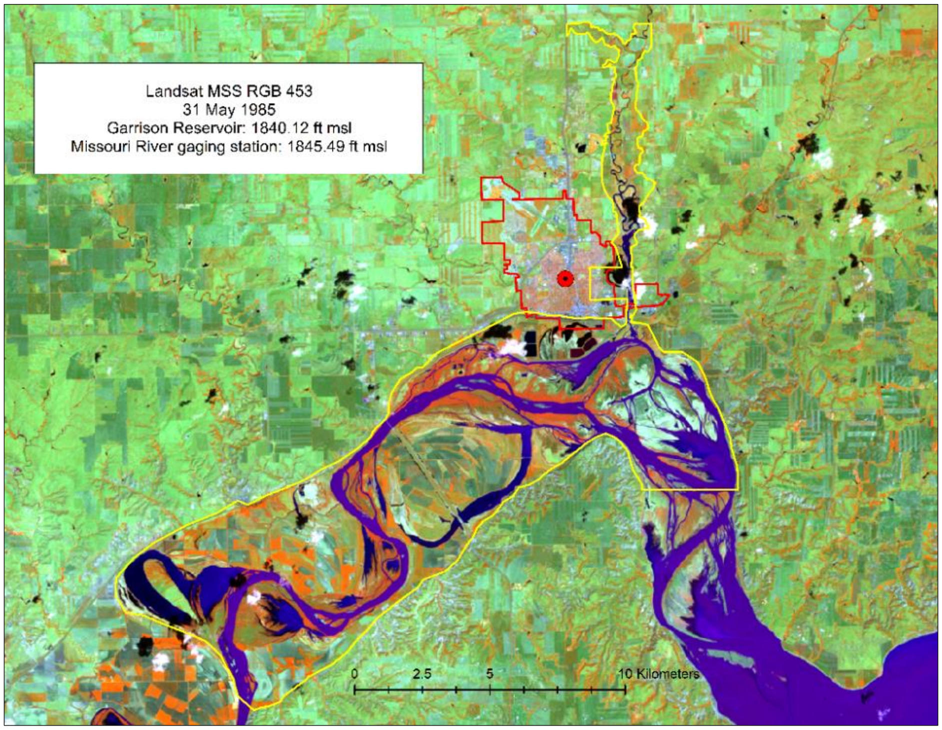

Fig. 84. Landsat TM image, 31 May 1985
Scene ID: LT50340271985151PAC03. RGB 453. WRS P34R27. Garrison Reservoir gaging station elevation reading: 1840.1 ft msl

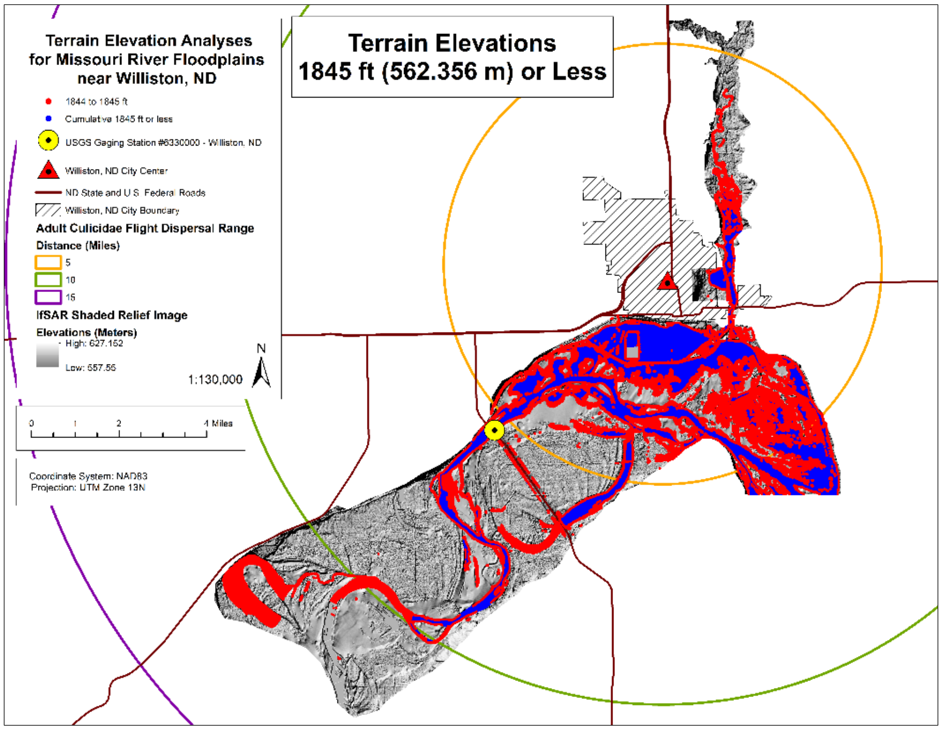

Fig. 85. Predictive flood model, 562.36 m (1845 ft) msl
Data sources: Intermap Technology, Inc. Technologies used: ArcInfo 10.1; Global Mapper 11

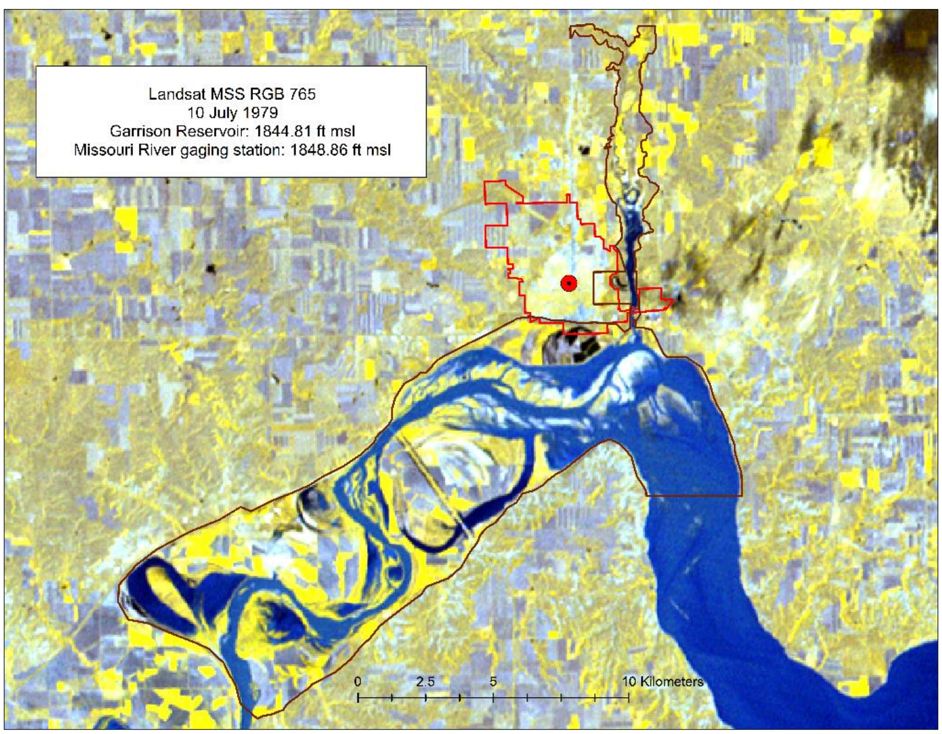

Fig. 86. Landsat MSS image, 10 July 1979
Scene ID: LM30370261979162AAA09. RGB 765. WRS P27R36. Garrison Reservoir gaging station elevation reading: 1844.81 ft msl

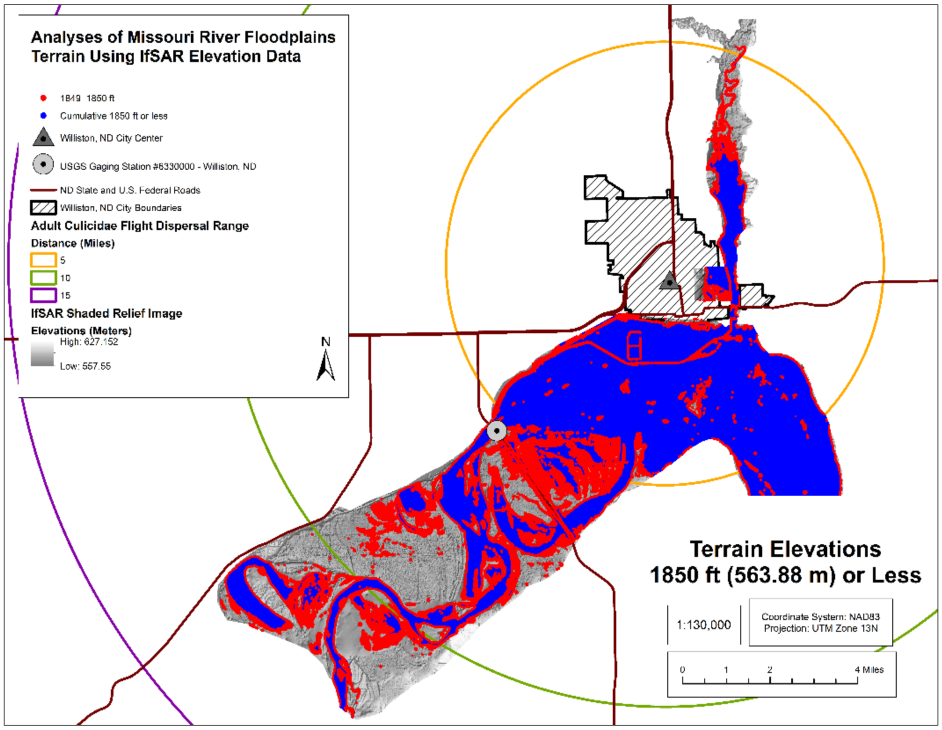

Fig. 87. Predictive flood model, 563.88 m (1850 ft) msl or less
Data sources: Intermap Technology, Inc. Technologies used: ArcInfo 10.1; Global Mapper 11

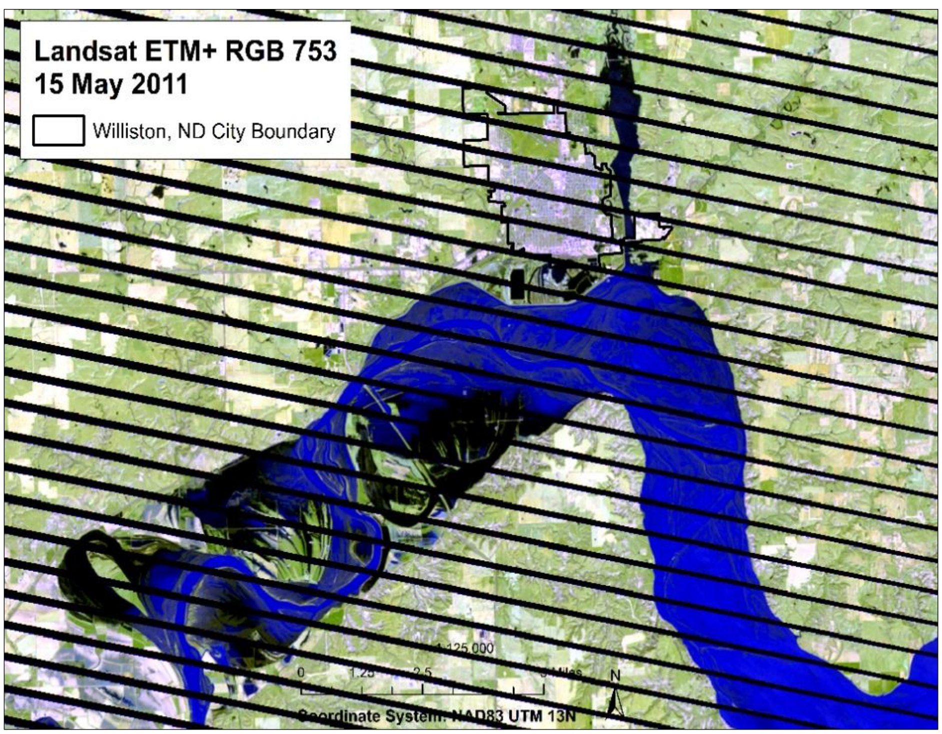

Fig. 88. Landsat-ETM+ image, 15 May 2011
Scene ID: E07_L1TP_034027_20110515_20160913_01_T1. RGB 753. WRS P34R27. Missouri River gaging station elevation reading: 1850.93 ft msl

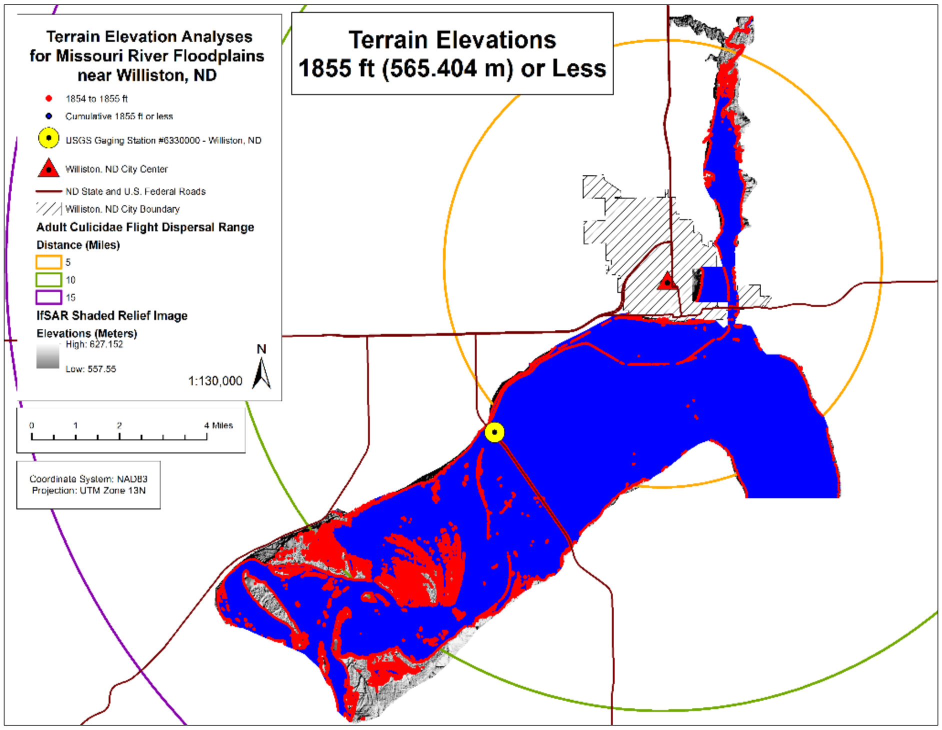

Fig. 89. Predictive flood model, 564 m (1855 ft) msl or less
Data sources: Intermap Technology, Inc. Technologies used: ArcInfo 10.1; Global Mapper 11

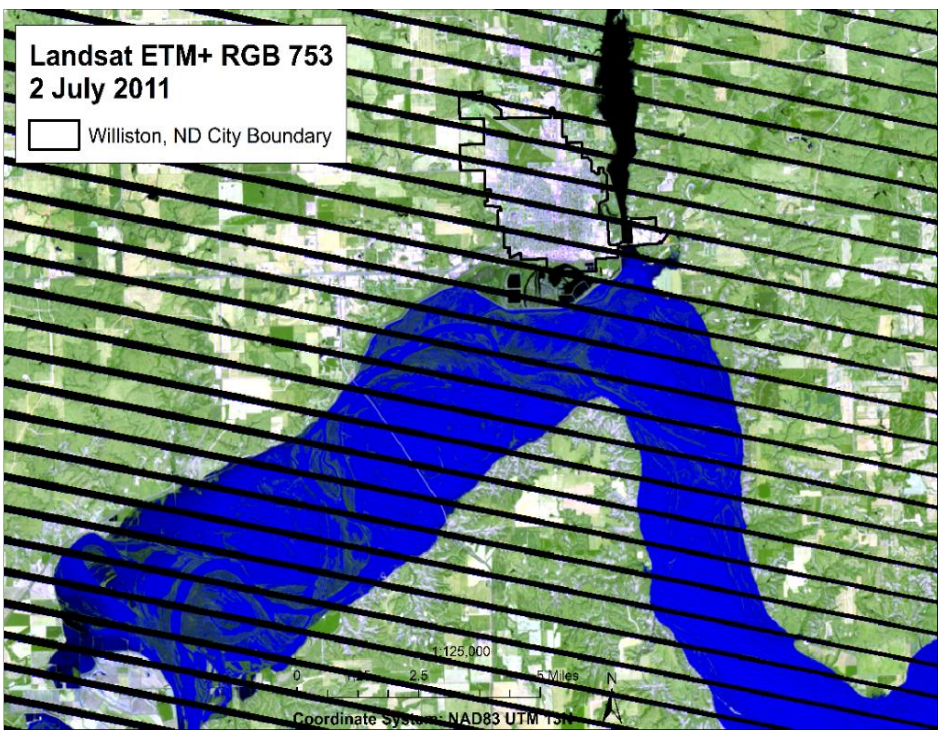

Fig. 90. Landsat-7 ETM+ image, 2 July 2011
Scene ID: LE79340272011183EDC00. RGB 753. WRS P34R27. Missouri River gaging station elevation: 1860.0 ft msl

Vertical Quality Assessment (QA)

Vertical Quality Assessment Standards and Guidelines

The procedures used in this study to determine the vertical QA of the IfSAR DTM elevation data were based on portions of the following five accepted standards and guidelines: 1) the FGDC Geospatial Positioning Accuracy Standards, Part 3: National Standard for Spatial Data Accuracy (NSSDA), 1998 (NSSDA FGDC, 1998); 2) Appendix A of the Guidelines for Aerial Mapping and Surveying, FEMA Guidelines and Specifications for Flood Hazard Mapping Partners, April 2003 (FEMA 2003); 3) Guidelines for National Digital Elevation Program (NDEP), version 1.0, May 24, 2004, (NDEP 2004); 4) American Society of Photogrammetry and Remote Sensing (ASPRS) Vertical Accuracy Reporting for LiDAR Data (ASPRS 2004); and 5) ASPRS Positional Accuracy Standards for Digital Geospatial Data (ASPRS 2014). ASPRS (2014) applies to IfSAR and LiDAR data and was the primary reference for this study.

Identification of Land Use/Land Cover Classes within the Floodplain near Williston

FEMA (2003), NDEP (2004), and ASPRS (2004) QA standards and guidelines require that vertical quality control points must be distributed to represent the various types of land cover and topography that characterize the area being assessed (Maune 2007). National Land Cover Data (NLCD) for the northern-third of the United States were downloaded from Multi-resolution Land Characteristics Consortium (MRLC) (MRLC 2017) and opened in ArcInfo. The dataset covered several states, including North Dakota. The dataset was reduced to the extent of the IfSAR DTM using the ArcInfo Extract by Mask tool. A land cover map for the floodplain near Williston was created and symbolized based on the land classification definitions by Anderson et al. (1979) (Fig. 91). Fifteen of the land use land cover classes were identified within the extent of the IfSAR DTM (Fig. 92).

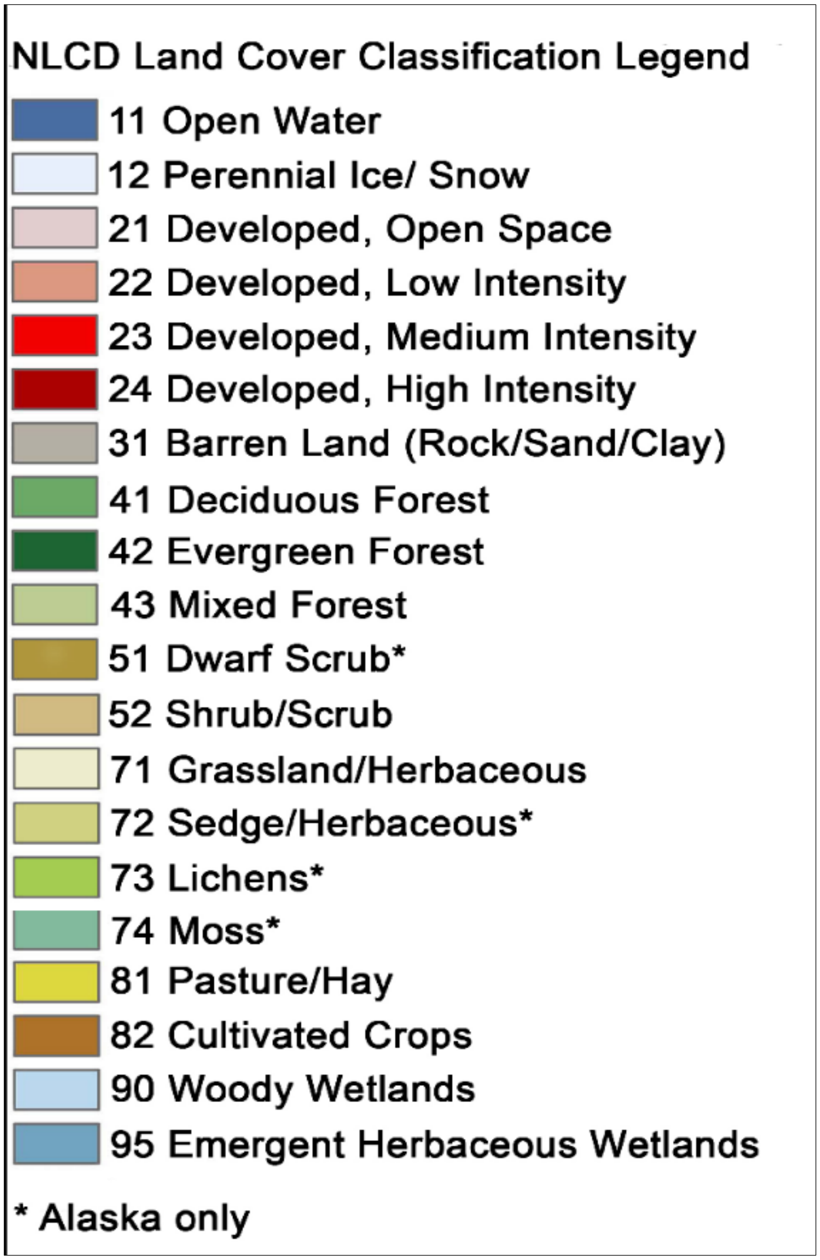

Fig. 91. Legend for Multi-resolution Land Characteristics Consortium (MRLC) National Land Cover Data
Data source: MRLC. Technology used: ArcInfo 10.1

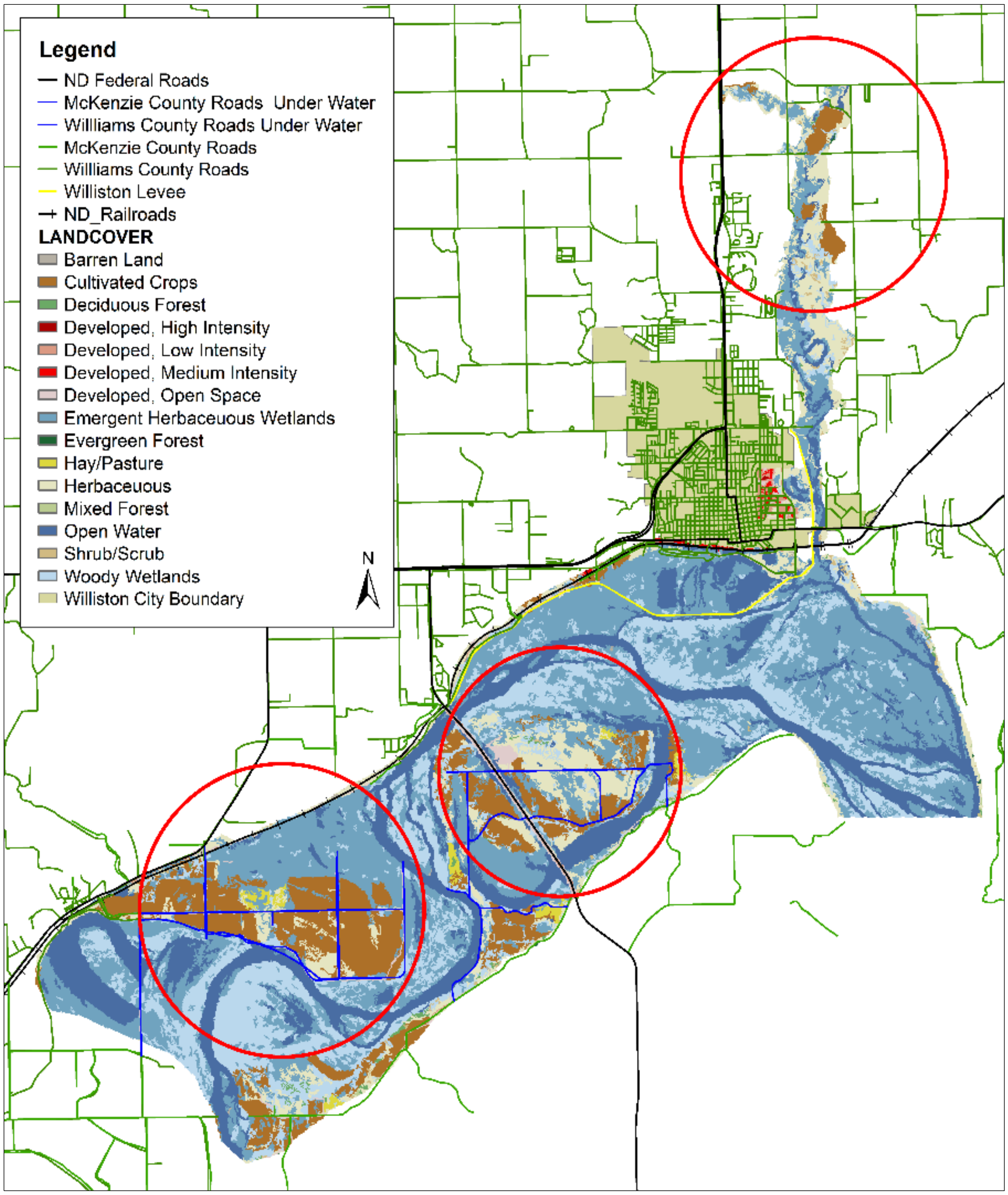

Fig. 92. A 2011 National Land Cover Data map of the floodplain near Williston, ND
Red circles identify areas where accuracy assessment sampling could be safely collected. Data sources: MRLC; NDgis HUB. Technology used: ArcInfo 10.1

Percentages of land use/land cover within the original NLCD dataset for the northern-third of the U.S. dataset were compared to percentages of land use/land cover within the extent of the floodplain near Williston (Table 11). Justification for the comparison was to ensure that the ArcInfo Mask tool was used during the masking procedure and not the ArcInfo Clipping tool.

Table 11. Comparison of land use/land cover percentages

Anderson et al. (1976) Land Use/Land Cover Classifications			Percentages of Land Use/Land Cover	
ID	Code No.	Classification Type	Entire Northern Third of the U.S.	Extent of the Floodplain near Williston, ND
1	11	Open Water	4.94	18.92
2	12	Perennial Snow, Ice	0.012	0.00
3	21	Developed, open spaces	2.90	1.75
4	22	Developed, low intensity	1.30	0.68
5	23	Developed, medium intensity	0.58	0.23
6	24	Developed, high intensity	0.16	0.21
7	31	Barren	1.15	0.07
8	41	Forests, deciduous	10.77	0.32
9	42	Forests, evergreen	11.69	0.03
10	43	Forests, mixed	1.98	0.50
11	51	Dwarf Shrubs	0.00	0.00
12	52	Scrub, Shrub	19.98	0.32
13	71	Grassland, herbaceous	13.85	9.70
14	72	Sedge, herbaceous	0.00	0.00
15	73	Lichens	0.00	0.00
16	74	Moss	0.00	0.00
17	81	Pasture, Hay	6.60	0.56
18	82	Cultivated Crops	14.8	11.46
19	90	Woody Wetlands	3.36	19.27
20	95	Emergent Herbaceous Wetlands	1.16	36.62

Aggregation of Land Use/Land Cover Classes within the Floodplain near Williston

The 15 land classifications within the floodplain near Williston were reduced to five classes using ArcInfo Reclass tool and the following groupings: 1) Urban (developed open space, low, medium, and high intensity); 2) Forests (deciduous, mixed and evergreen), Dwarf Shrub, and Shrub/Scrub; 3) Low Grasslands, Herbaceous, Pasture, Hay; 4) Crops; and 5) Wetlands (Fig. 93).

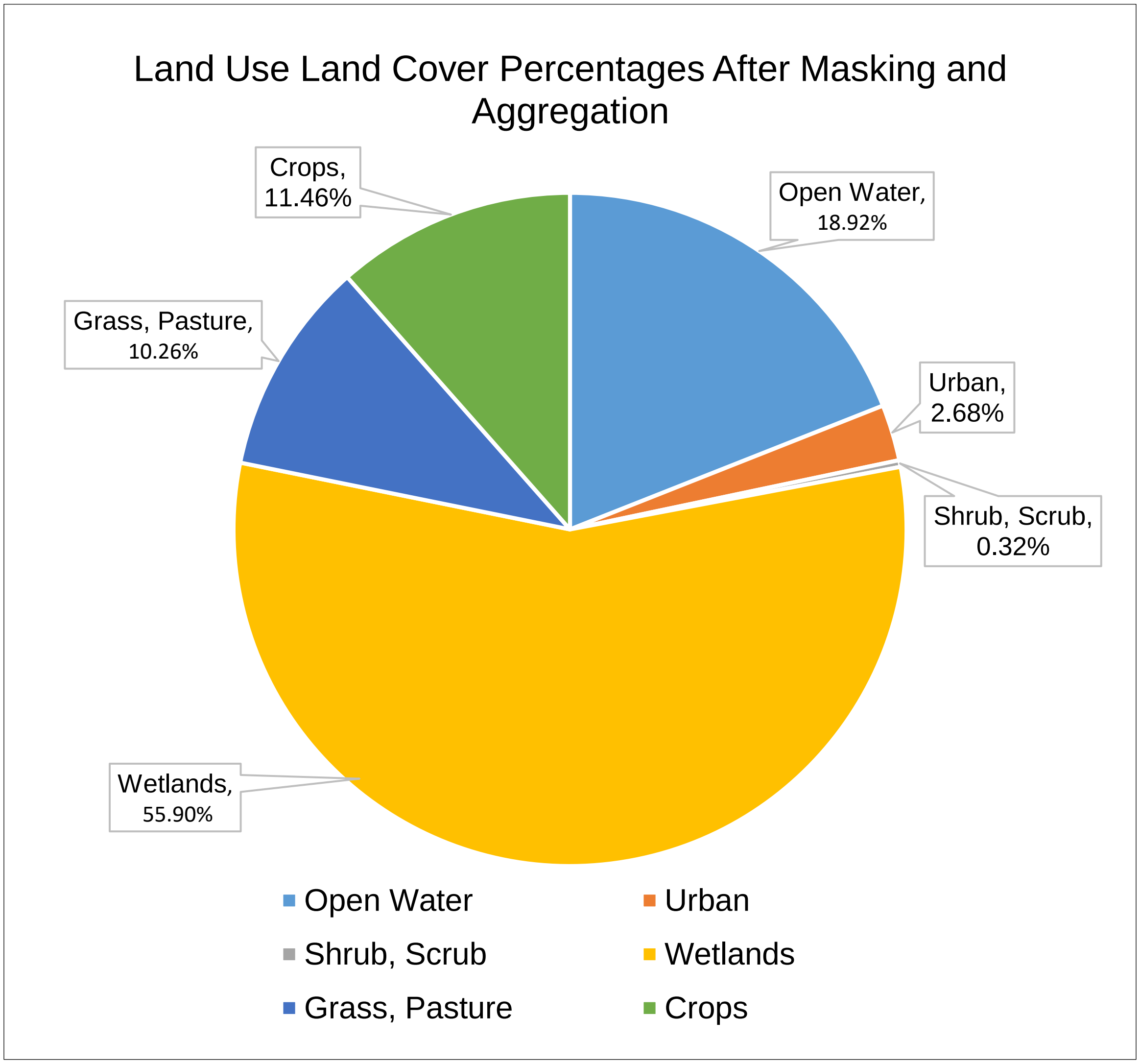

Fig. 93. Pecentages of land use/land cover classifications for the floodplain near Williston, ND
Data source: MRLC. Technologies used: ArcInfo 10.1; Excel 10

The Anderson et al. (1976) landuse/land cover classifications of perrenial ice and snow, barren land, shedge, lichens, and moss were not applicable to the Williston floodplain and were omitted from this study. The land use/land cover classification of open water was include in the percentages analysis, but was omitted from the other RTK-GPS analyses.

National Geodetic Survey (NGS) Monuments near Williston

Kadrmas, Lee and Jackson Engineering, Inc. preformed the RTK-GPS control point survey relative to survey monuments within the Williston area. Figure 94 identifies the locations of all NGS monuments near Williston.

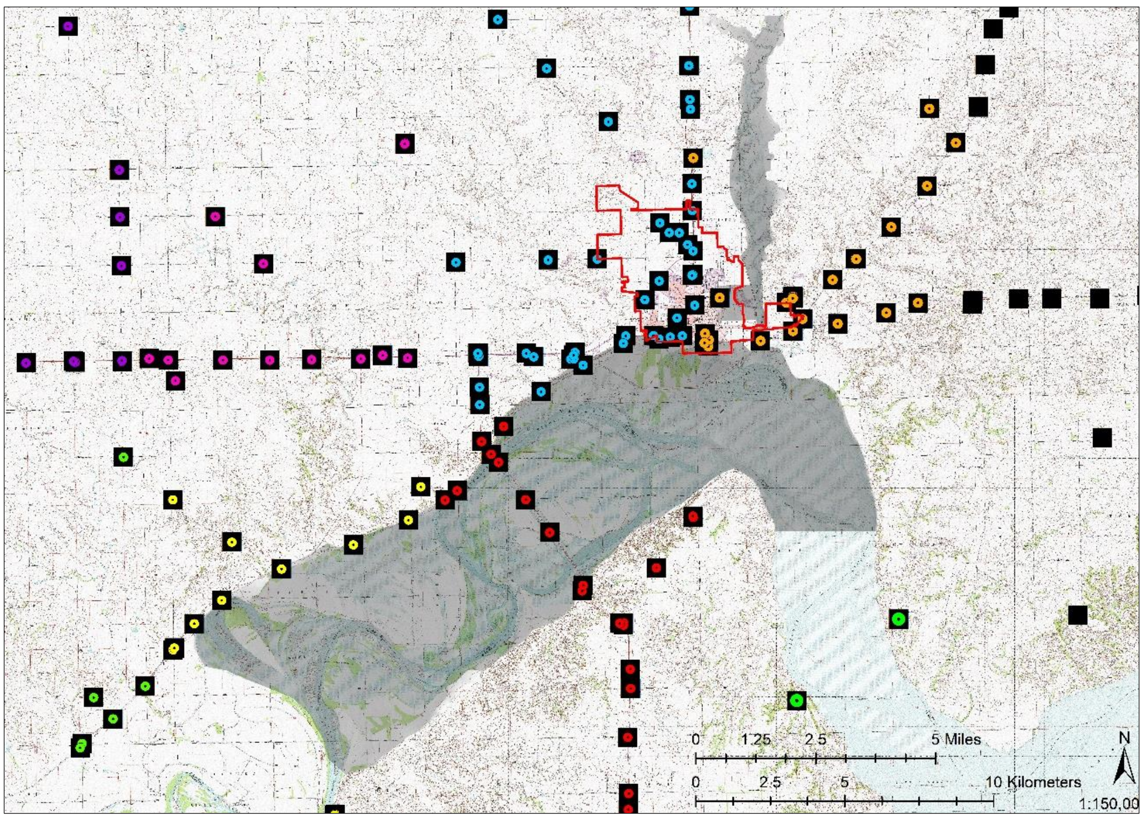

Fig. 94. Location of National Geodetic Survey (NGS) monuments near Williston, ND
Data sources: NGS; National Map; NDgisHub. Technologies used: ArcInfo 10.1

Calculation of the Minimum Number of RTK-GPS Control Points Needed

The updated ASPRS (2014) guidelines recommend the collection of 100 vertical control points for the first 2,500 km^2 of area. The study area near Williston, ND covered 141.00 km^2. The number of RTK-GPS control points collected for this study totaled 203. The ASPRS (2014) guidelines also recommend for every 500 km^2 of area, 20 static (i.e., non-moving) control points must be collected within open terrain (i.e., bare earth or vegetation less than 12 inches) and 5 static control points must be collected within non-open terrain. The number of RTK-GPS control points collected within open terrain totaled 122. The number of RTK-GPS control points collected within non-open terrain totaled 81.

Selection of the RTK-GPS Control Point Locations

Based on earlier guidelines and the ASPRS (2014) guidelines, vertical control points do not need to be clearly-defined point features. Hawth's Random Sample tool was downloaded from SpatialEcology (2009), currently Geospatial Modeling Environment [GME] (2014) to a desktop computer. The program was installed and automatically opened in ArcInfo 10.1. National Land Cover Data were opened in ArcInfo and used as the base map. Grids were drawn over areas of the floodplain where field workers could safely enter and carryout ground-sampling and surveillance. A sample size of 1000 points was entered into the software and the tool randomly selected x and y coordinates within the drawn grids (Fig. 95).

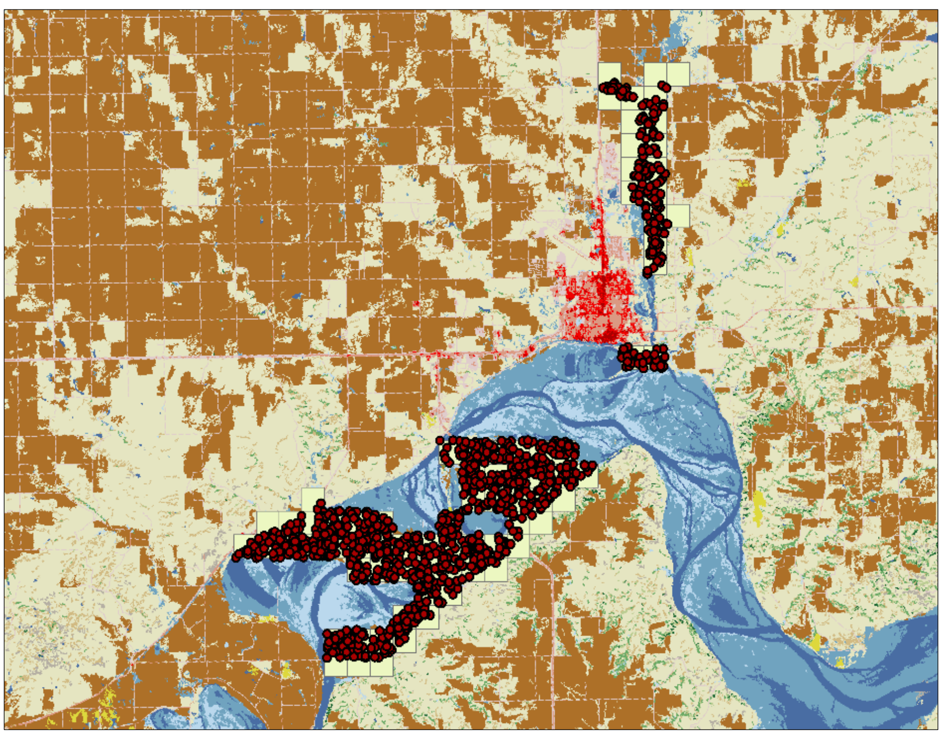

Fig. 95. Random RTK-GPS control point locations selected by Hawth's random sampling tool within ArcGIS
Data source: MRLC. Technologies used: ArcInfo 10.1; GME

In-field RTK-GPS Vertical Quality Assessment (QA)

The IfSAR RTK-GPS QA survey was planned for two days in early May 2011, but was postponed for two weeks because of a four-day blizzard and power outage. During that two-week waiting period, the Missouri River rose to the highest elevations on record and remained at those elevations during most of the summer and fall (Fig. 96).

Fig. 96. Flooding of the Missouri River, summer 2011
Highway 85 west of Williston, ND

Despite the severe Missouri River flooding in much of the sampling area, a sufficient number of RTK-GPS vertical control points were collected over a two-day period, May 20 and 24, 2011 following standard RTK-GPS guidelines such as NOAA Technical Memorandum NOS NGS-58 (1997). Figures 97 to 103 are snapshots of the two-day survey. The KLJ confirmation of work letter and cost estimate for the RTK-GPS survey can be found in Appendix U, and the KLJ proposal agreement form can be found in

Appendix V. Maps of the RTK-GPS vertical control point locations are presented in Appendix W. KLJ field notes are in Appendix X and the KLJ OPUS Report can be found in Appendix Y. Figures 97 and 98 show the setup of the base station on day 1, at NGS survey monument, designation name Williston 2 Reset, PID TG1311 (1986) (NGS TG1311 2017), east of Williston, near the Williston city dump grounds. Figure 99 was taken on day 2 at NGS survey monument, designation name E 462, PID TG1543 (1981), near Highway 85 and the Williston City Water Plant. Figure 100 was taken on day 2 as the base station was placed at the third survey monument, designation name CP, PID [number unknown]. Figures 101 to 103 show the collection of RTK-GPS control points.

Fig. 97. National Geodetic Survey monument, designation name Williston 2 Reset, PID TG1311 Day 1, USGS Quad Williston E. Kadrmas, Lee and Jackson Engineering survey crew setup the base station, Appendix W, Benchmark #1

Fig. 98. National Geodetic Survey monument, designation name Williston 2 Reset, PID TG1311
Day 1. Monument is a bronze disk is mounted on top of a concrete post. USGS Quad Williston E, near Williston city dump grounds, shown also in Appendix W Benchmark #1

Fig. 99. National Geodetic Survey monument, designation name E 462, PID TG1543
Day 2. Monument is a covered underground 10-ft rod. USGS Quad Williston SW, near Highway-85, shown also in Appendix W, Benchmark #2

Fig.100. Survey monument, designation name CP, PID [number unknown]
Day 2. Monument is northeast of Trenton, ND near highway. Shown in Appendix W, Benchmark #3

Fig. 101. RTK-GPS control point location, Highway 85 picnic area, south of the Missouri River Day 2, Appendix W, control points 500 to 509

Fig. 102. RTK-GPS control point location, Ecology Park east of Williston, ND
Day 2, Appendix W, control points 459 to 468

Fig. 103. RTK-GPS control point location, southeast of Trenton, ND
Day 2, Appendix W, control points 540 to 550

Spacing of the RTK-GPS Control Points

A total of 203 RTK-GPS control points was collected within the floodplain near Williston, ND over a two-day period, for the purpose of calculating the vertical error and accuracy of the IfSAR DTM elevation data. A consistent distance between control points was maintained by the survey crew by marking off ten steps from the previous control point. The spacing ensured that each RTK-GPS control point would be collected within a different 5-m IfSAR elevation pixel (Fig. 104).

Fig. 104. Spacing of RTK-GPS control points
Data sources: Intermap Technology, Inc.; KLJ Engineering; NDgisHub. Technology used: ArcInfo 10.1

Distribution of the RTK-GPS Control Points by Land Use/Land Cover Classification

Weather and flood conditions made it impossible to collect the RTK-GPS control points within the locations previously selected by the Hawth's Random tool. As an alternative, the KLJ field crew and this author selected the RTK-GPS checkpoint locations, based first on safety for the survey crew, and second, by vegetation classification. Twenty-five locations were used to collect the 203 control points. Between six to ten RTK-GPS control points were collected per location. Fig. 105 demonstrates the locations used for the RTK-GPS control point data collections and the vegetation classification at each location.

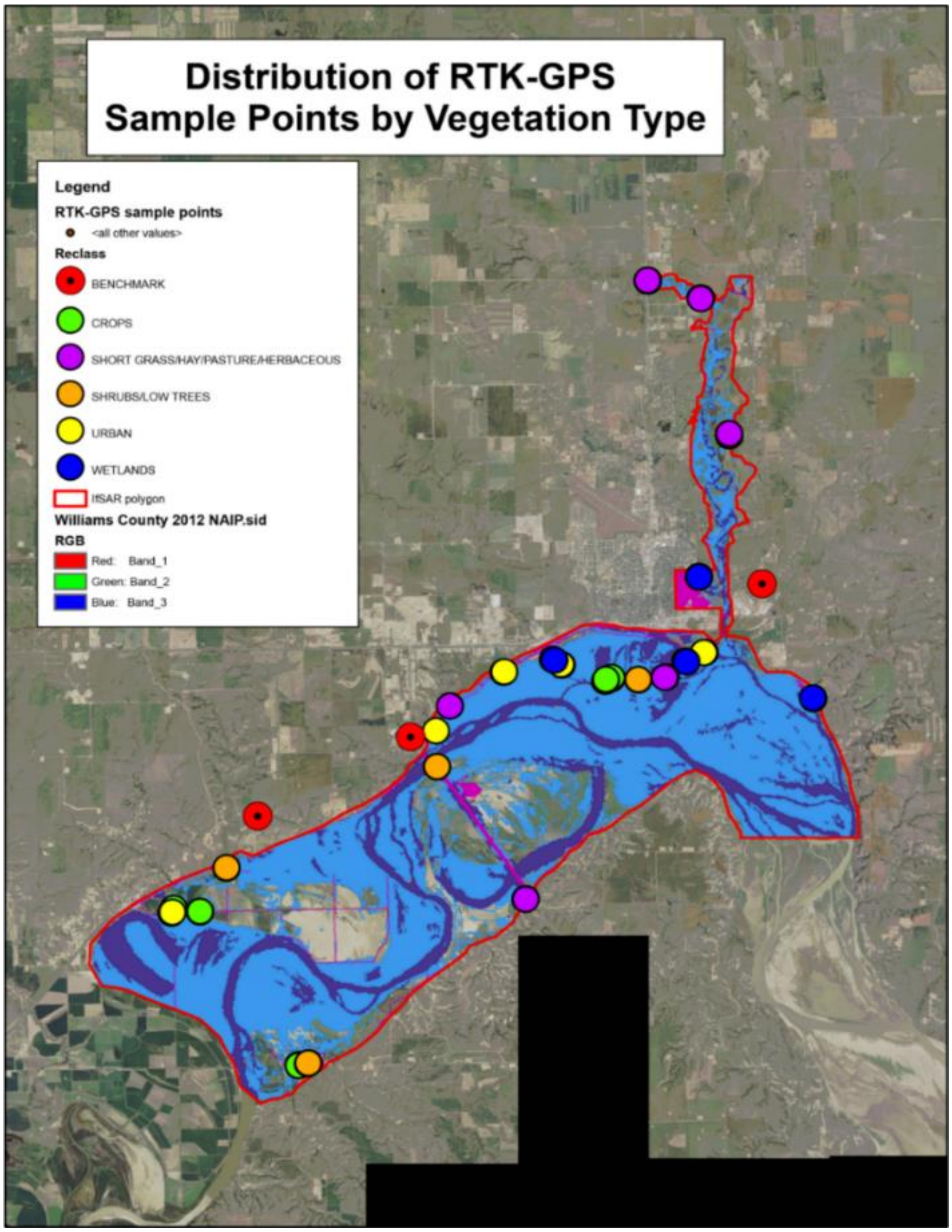

Fig. 105. Distribution of RTK-GPS control points based on land cover classification
Data sources: KLJ Engineering; NDgisHub. Technology used: ArcInfo 10.1

Distribution of the RTK-GPS Control Points by Survey Monument

A spider diagram was created in ArcInfo to visualize the locations of elevation survey monuments and their associated RTK-GPS QA sample locations (Fig. 106).

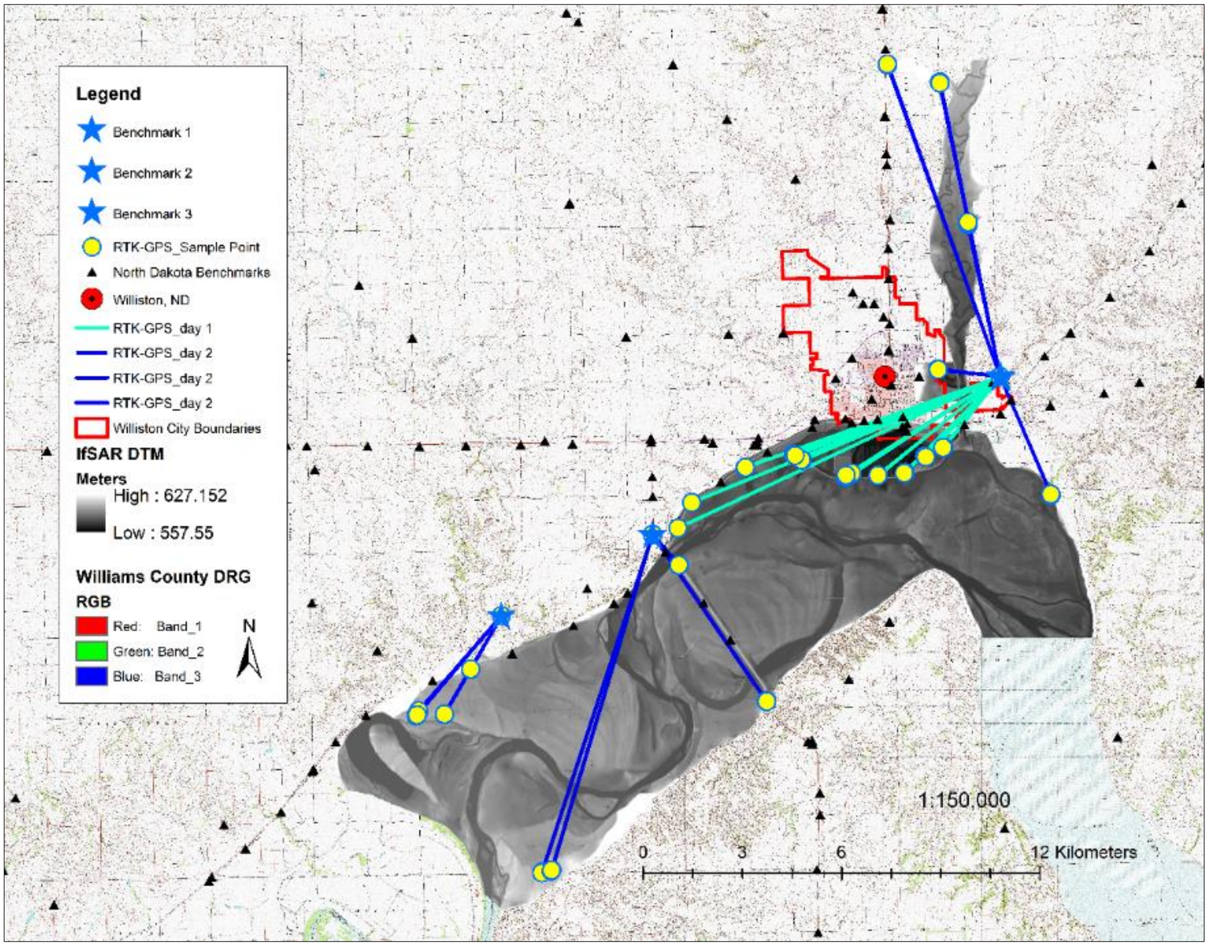

Fig. 106. Distribution of RTK-GPS control points based on the location of survey monuments
Data sources: Intermap Technology, Inc.; KLJ Engineering; NDgisHub; Nationa Map. Technology used: ArcInfo 10.1

Computing the Vertical Error (RMSEz) of the IfSAR DTM

The vertical accuracy of the IfSAR DTM was determined by comparing the IfSAR DTM elevations against its associated RTK-GPS control point elevation. The vertical accuracy analysis of the IfSAR DTM was based on methods outlined in the Geospatial Positioning Accuracy Standards, Part 3: National Standards for Spatial Data Accuracy (NSSDA) developed by the Federal Geodetic Data Committee (FGDC-STD-007.3-1998) and the ASPRS Accuracy Assessent Guidelines for Geospatial Data (2014). The difference between the RTK-GPS control points and IfSAR DTM elevation represented the residual error for that point. Statistical analyses were performed on the residual errors. The RTK-GPS accuracy assessment data are located in Appendix Z.

The overall vertical IfSAR DTM error (i.e., RMSEz) was was calculated using RMSEz = Sqrt [(∑(Elevation $_{IfSARI(i)}$ – Elevation $_{RTK\text{-}GPS(ii)}$)^2)/n], where n equals the total number of control points and (i) represents any RTK-GPS control point, and (ii) represents the associated IfSAR elevation checkpoint. It is a presumption in this study that the RTK-GPS control points are free from error and that differences in elevations between the IfSAR DTM and the RTM-GPS are caused by the IfSAR technology, provided the RTK-GPS technology is at least three time greater than the expected accuracy of the IfSAR DTM (NSSDA FGDC 1998, FEMA 2003, ASPRS 2004, NDEP 2004, ASPRS 2014). The same formula was also used to calculate the IfSAR DTM RMSEz for each aggregated land use/land cover class. Accuracyz at the 95 percent confidence level is calculated from RMSEz x 1.960. The ninty-fifth percentile rank is calculated by 1) ordering the absolute error value from small to large; 2) determining the rank of the 95th percentile value by calculating (95 divided by 100) times the number of samples minus 1; 3) than adding 1 to that value. The 95th percentile value is determined by locating the 95th percentile rank in the ordered absolute error values (ASPRS 2014). The ASPRS (2014) guidelines recommend reporting 1) Non-vegetated Vertical Accuracy (NVA) at the 95% confidence level for all non-vegetated land cover categories combined and 2) Vegetated Vertical Accuracy (VVA) at the 95th percentile in all vegetated land cover categories combined.

Criteria for Acceptance

The criteria for acceptance of the IfSAR DTM product is a RMSEz equal to or less than 1 meter for all land use/land cover classifications combined.

RESULTS

Table 12 provides a descriptive statistics summary for the IfSAR DTM Error Data

Table 12. Descriptive statistics for the IfSAR DTM Error

IfSAR DTM Error Data	
Mean vertical Error (m)	- 0.801
Standard Error (m)	0.050
Median Vertical Error (m)	- 0.698
Mode	0.066
Standard Deviation (m)	0.712
Sample Variance (m)	0.506
Kurtosis	1.745
Skewness	- 0.617
Range (m)	4.636
Minimum Vertical Error (m)	- 3.259
Maximum Vertical Error (m)	1.376
Sum of Vertical Errors (m)	- 1.628
QA Control Point Count	203
Largest Error (m)	1.376
Smallest Error (m)	- 3.259
Confidence Level (95.0%)	0.0985
RMSEz (m)	1.071
Vertical Accuracy (Accuracyz at 95% CL) (RMSEz x 1.96) (m)	2.099
Equivalent Contour Interval (RMSEz x 3.2898) (m)	3.523
Rank of the 95^{th} Percentile Error	192.900
VVA for vegetated terrain; 95^{th} Percentile Error (m)	2.211

Figure 107 provides an error histogram for the IfSAR DTM. The mean vertical error of -0.801 meters and the error histogram indicate that the IfSAR DTM is systematically lower than the RTK-GPS control points. Sources of the systematic error could be due to 1) erroneous control points collected along the top of the Williston levee where control points were within a few meters of the levee edges (i.e., significant breaklines); 2) vertical datum inconsistencies between the RTK-GPS and the IfSAR DTM; or 3) the methodology used to determine the IfSAR DTM elevations associated with the RTK-GPS control points (Continental Mapping 2017).

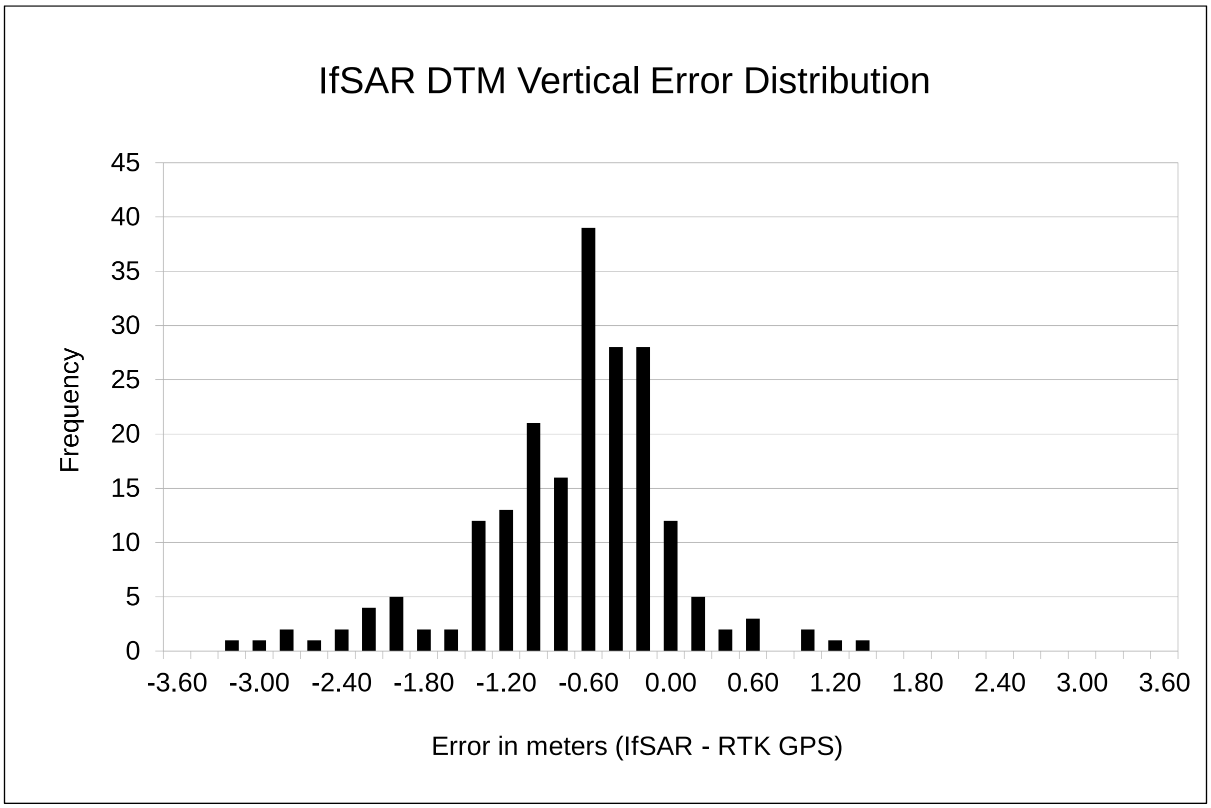

Fig. 107. IfSAR DTM Error Distribution
Data sources: Continental Mapping Consultants; Intermap Technology, Inc.; KLJ. Technology used: Excel 10

Table 13 provides the results of the IfSAR DTM vertical accuracy assessment root mean squares error (RMSEz) (i.e., blunders) across all land use/land cover classifications within the floodplain near Williston.

Table 13. Vertical Accuracy Statistics based on NSSDA/FEMA Guidelines

Land Class	n	Mean Abs. Diff. (m)	Med. Abs. Diff. (m)	Skew	Std. Dev. (m)	Min. Abs. Diff. (m)	Max. Abs. Diff. (m)	95th Perc. Value (m)	RMSEz (m)	Accz. (m) (RMSEz x 1.96)
Comb.	203	80.1	69.8	-0.62	71.2	-325.9	287.18	CVA: 2.211	1.071	209.92
Crops	42	1.012	1.046	0.026	0.387	0.388	1.837	SVA: 1.568	1.082	---
Emer. Wet.	47	0.889	0.606	1.865	0.748	0.003	3.259	SVA 1.485	1.156	---
Shrub Scrub	32	0.372	0.313	0.303	0.268	0.039	77.87	SVA: 0.773	0.456	---
Grass Past. Hay	48	0.610	0.679	-0.414	0.271	0.012	1.192	SVA: 0.950	0.666	---
Urban	34	1.487	1.438	-0.061	0.722	0.155	2.872	SVA: 2.468	1.648	----
Non-Open Terr. (Emerg Wet, Urban)	81	1.140	0.865	0.852	0.791	0.003	3.258	SVA: 2.738	1.385	---
Open Terr. (grass, pasture hay, shrub, scrub)	122	0.690	0.695	0.336	0.398	0.012	1.837	SVA: 1.230	0.796	---

Figure 108 graphically displays the frequency distriution of the RMSEz, by land cover class, shown in Table 13.

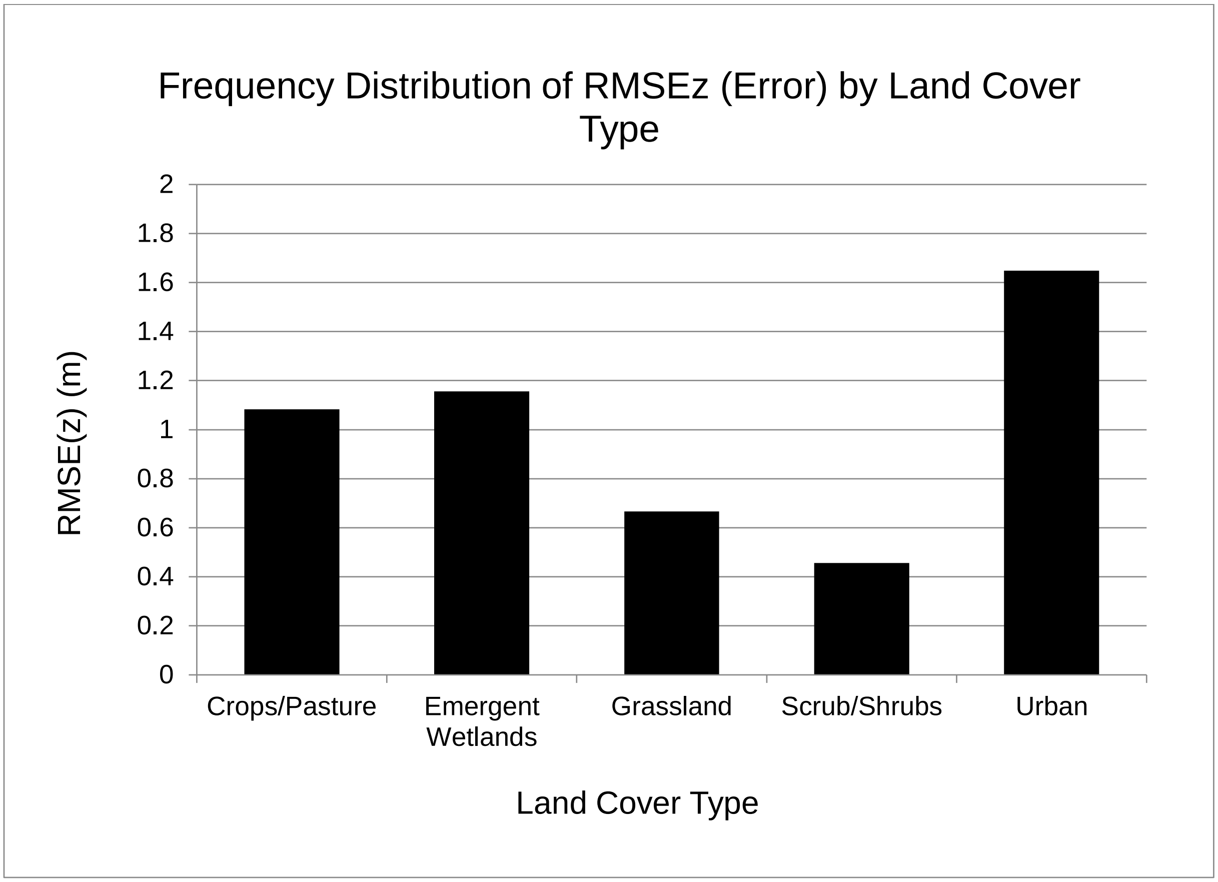

Fig. 108. Frequency distribution of the IfSAR DTM RMSEz by land use/land cover classification
Data sources: Intermap Technology, Inc.; KLJ; MRLC. Technology used: ArcInfo 10.1; Excel 10

Table 14 provides a list of locations where the IfSAR DTM RMSEz was equal to, or more than three standard deviations from the mean.

Table 14. Locations of IfSAR blunders (i.e., errors) equal to or greater than three standard deviations

No.	RTK-GPS ID	RTK-GPS (m msl.)	Land-use Class	IfSAR Raster-to-point Elev. (m)	Diff. (m)	Abs. Diff. (cm)	Blunders (=/> 3 Std. Dev) (Y/N)
1	100	563.918	Urban	561.489	-2.429	242.851	Y
2	101	564.005	Urban	561.535	-2.470	246.954	Y
3	102	564.027	Urban	561.784	-2.243	224.246	Y
4	103	563.983	Urban	561.966	-2.018	201.748	Y
5	117	561.015	Emerg. Wetlands	557.756	-3.260	325.984	Y
6	118	561.073	Emerg. Wetlands	557.970	-3.103	310.333	Y
7	120	560.909	Emerg. Wetlands	558.249	-2.740	273.979	Y
8	121	560.981	Emerg. Wetlands	558.828	-2.153	215.337	Y
9	122	560.897	Emerg. Wetlands	558.828	-2.069	206.890	Y
10	151	567.939	Urban	565.724	-2.215	221.506	Y
11	153	567.944	Urban	565.854	-2.090	209.000	Y
12	154	567.946	Urban	565.768	-2.178	217.758	Y
13	155	567.937	Urban	565.099	-2.838	283.811	Y
14	156	567.919	Urban	565.046	-2.873	287.280	Y
15	200	568.420	Urban	566.153	-2.267	226.700	Y
16	413	568.453	Emerg. Wetlands	566.216	-2.237	223.700	Y

Figure 109 identifies the locations from Table 14, where the IfSAR DTM RMSEz were equal to, or greater than three standard deviations from the mean.

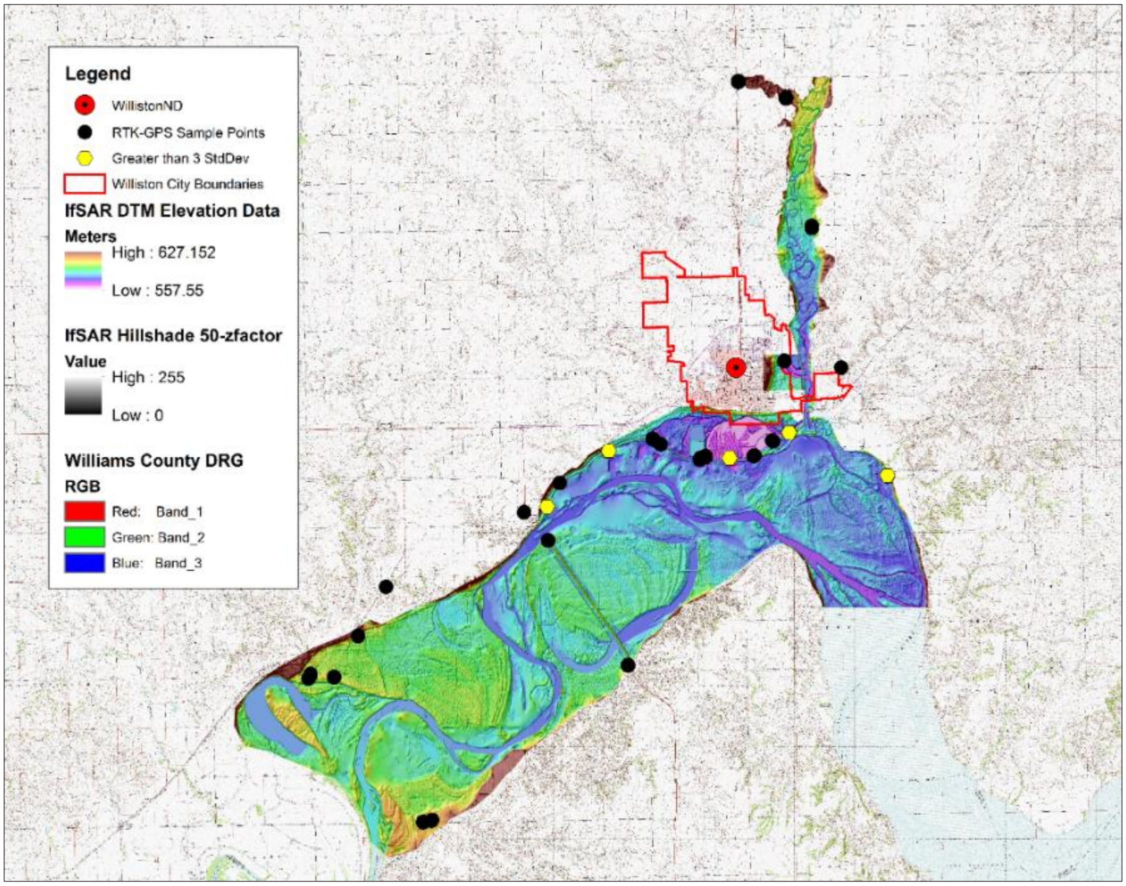

Fig. 109. IfSAR RMSEz blunder map
Data sources: Intermap Technology Inc.; KLJ; NDgisHub; National Map. Technologies used: ArcInfo 10.1; Excel 10

The objective of this study was to determine the amount of error within the IfSAR DTM elevation data. The RMSEz computed for the full IfSAR DTM elevation data in all land use/land cover classifications combined was 107.1 cm, consistent with the vendor's stated vertical RMSE of 1 meter (100 cm). The RTK-GPS control point error distribution is normal (Fig. 108), which validates the use of the NSSDA 95% Confidence Level Accuracy calculation. The vertical accuracy of the IfSAR DTM elevation data at the 95% Confidence Level is 209.9 cm, consistent with the computed 95thpercentile accuracy of 221.029 centimeters.

DISCUSSION

The Williston, ND area has a long history of abundant mosquitoes that can be traced back more than 200 years with journals written by members of the Lewis and Clark Corps of Discovery Expedition, 1804 to 1806. Williston's mosquito problem is complex and involves numerous biotic and abiotic factors, some of which are briefly reviewed in this study. A large bank of research worldwide has documented the impact of both water resource projects and weather variables on mosquito abundance and distribution. However, pre-research for this study determined that only Missouri River elevations have an impact on Williston's mosquito abundance, with a lag time of about 12 to 14 days. Best mosquito management practices are integrated, relying on a combination of routine ground-based sampling and surveillance methods to provide important information on which control strategies and evaluations of effectiveness are based. However, the extensive floodplain, limited access, difficult terrain, and limited funding have made thorough, routine, ground-based procedures impractical for the Williston vector control agency.

This research, requested and partially funded by the WVCD, analysed remotely sensed, high-resolution Interferometric Synthetic Aperture Radar (IfSAR) Digital Terrain Model (DTM) elevation data as a potential alternative for ground-based sampling and surveillance. Predictive flood models, developed from the IfSAR elevation data using GIS technology, make it possible to predict locations of inundation within the floodplain as river elevations fluctuate each mosquito season. The RMSEz computed for the full IfSAR DTM elevation data in all land use/land cover classifications combined was 1.071 m, consistent with the vendor's stated RMSEz of 1 meter. The vertical accuracy of the IfSAR DTM elevation data at the 95% confidence level is 209.9 cm.

However, there are limitations with these models. They will not provide the WVCD with the same type of information as ground-based methods. Learning how to interpret and use the models may take time and much trial and error. In addition, before the WVCD can use the predictive maps, the WVCD must conduct in-field ground-truthing of the models. The purpose of the ground-truthing is to identify patterns among the models and the actual locations of flooding on the ground. Those patterns will assist the WVCD in understanding, analyzing, and interpreting the models. The process of ground-truthing should be manageable and should not result in significant additional costs. It will, however, take a few summers to carry out. Once ground-truthing is completed, the predictive models will provide the Williston vector control agency with a new approach for locating potential mosquito breeding habitat, could serve as an early warning system for the WVCD; that is, quickly pin-pointing the expected locations of flood inundation as the Missouri River undergoes its normal surge/recession cycles each summer will give vector control officials more time to plan strategies and improve the targeting of site-specific control efforts, which in turn will reduce overall program costs.

Problems Encountered during this Study

The 2011 flood near Williston made it impossible to use the computer-generated Hawth's random sampling sites. The associated high-water levels and dangerous currents resulted in the need to use convenient sampling sites to ensure safety of the surveying crew. To reduce bias as much as possible, the RTK-GPS surveyors entered safer areas, but made the decisions concerning where to start and end collecting samples within each location. The option to postpone the RTK-GPS survey for a few weeks was not possible for the engineering company, as we had already postponed the survey by several weeks after the aforementioned blizzard. Unfortunately, flood conditions remained throughout most of the summer in the Williston area. As a result, the selection for RTK-GPS control points were clustered, and only along the edges of the floodplain where the surveyors could safely enter. In other words, the RTK-GPS control points were collected using unacceptable data collection standards.

Concerns with this Study

The IfSAR-derived predictive flood models developed during this research may not have sufficiently high spatial resolution for mosquito control purposes. Neither the WVCD nor this author will know if IfSAR DTM elevation data or the IfSAR-derived flood models can assist the WVCD with predicting of inundated areas of the floodplain until the models are tested in the field, and that cannot be done until the WVCD completes ground-truthing of the models. Additionally, the mean vertical error of -0.801 meters and the error histogram indicate that the IfSAR DTM is systematically lower than the RTK-GPS control points. That error needs to be investigated to determine the cause, determine if any actions should be taken, and documented. Discrepancies between a ground control point survey and a data set that exceeds three times the specified RMSE error limit are called blunders and must also be investigated, and either corrected or explained (ASPRS 2014).

Suggested Future Research for the Williston Area

Analyze Normalized Difference Vegetation Indices (NDVI) for the Floodplain near Williston and Determine if NDVI Values Vary from Year-to-Year

Some research suggests that human cases of mosquito-borne illnesses such as WNV and WEE increase during hot, dry conditions (Epstein 2001, Epstein and Defilippo 2001, Shaman et al. 2005, Paz et al., 2008; Reisen et al. 2008, Wang 2010, Johnson and Sukhdeo 2013, Paz et al. 2013). The large upstream watershed above Williston carries large volumes of water every spring and summer, no matter what local weather conditions are in the uplands surrounding Williston. An NDVI analysis (An G. 2011) may show that the floodplain near Williston is not greatly impacted by a local drought. That information could provide insight into why Williams County has relatively fewer cases of human WNV than other counties such as Cass and Burleigh, even though the Williston area contains more wetlands and has a larger abundance of mosquitoes. It would be important that the analysis include numerous years of data with varying environmental conditions, such those when the Williston area was experiencing droughty summer conditions and those characterized as being normal and/or above normal in relation to summer precipitation.

Map the Missouri River Wetland Plants for the Floodplain near Williston

Several studies have documented associations between certain plant and mosquito species. Fleetwood et al. (1978) observed specific plant and mosquito species associations along coastal marshes in Louisiana. Maire (1982) found correlations between vegetation and mosquito larval abundance. Walton et al. (1990) found that *Cx. tarsalis* larval abundance was associated with the percentage of *Typha* species root and stem density. Water movement and depth, and plant species were found to be the main factors in the variation in spatial distribution of mosquito species (Almirón and Brewer 1996). Jiannino and Walton (2004) found that dense emergent vegetation encourages the production of pestiferous and disease-vectoring mosquitoes by reducing fast flowing water currents and providing shelter from predators. Their research also showed that vegetation provided food resources for mosquito larvae. They also determined that plant genera such as *Schoenoplectus* (*S.*) (Reichenbach) Palla, *Typha* L., and *Phragmites* Adans., which tend to be found in wetlands, can support high production of mosquitoes, but that mosquito larval abundance and adult emergence were significantly higher in areas containing *S. californicus* (C.A. Mey.) Palla than in areas predominated by *Typha* species. Their study also found that few mosquitoes were produced in deep, open water areas of wetlands. Arum et al. (2016) reported vegetation resting preferences of mosquitoes may be associated with arbovirus disease risks. Rydzanicz et al. (2011) determined that egg distribution of certain mosquito species was correlated to plant species and moisture gradient. Knowing the plant species favored by *Ae. vexans* and *Cx. tarsalis* would be helpful to the WVCD in identifying potential breeding habitat. Cowardin et al. (1979/1992) suggests plant species belonging to the following genera are commonly found within palustrine emergent wetlands: *Typha* L. (cattails); *Carex* L. (perennial sedges), *Scirpus* L. (a bulrush genus), *Juncus* L. (rushes), *Cladium* Browne (sawgrass), and *Phragmites* species. The MRLC land cover dataset (MRLC 2017) uses the land use/land cover classifications of Anderson et al. (1976), but does not provide identification of specific vegetation types within its dataset. The USACE (2017) provides a list of wetlands plants typical for each U.S. region and state and would be important resource information for the agency.

Purchase Additional IfSAR Elevation Data and Expand the Number of Predictive Flood Models to Include Areas Southeast of Williston

An important area of the floodplain southeast of Williston was not included in the IfSAR elevation data acquired for this research. The location is a high sediment deposition area of the river southeast of the city (USACE 1993, 2009). This area also has the lowest elevation of the floodplain near Williston. As such, it will most likely be the area in which the river overflows its banks first. It would be beneficial to the WVCD to license additional IfSAR elevation data for that section of the river and develop additional predictive flood models.

Obtain LiDAR when it becomes Available and Combine with the Existing IfSAR Elevation Data

Research is being carried out on how to combine IfSAR and LiDAR elevation data to produce better maps than those created by individually using either LiDAR or IfSAR data. Following the 1997 flood of the Red River of the North, the USACE (Damron and Daniel 2000) conducted a pilot study to develop a data fusion technique to merge the two DEMs and determine the proportions of each to use to produce high-resolution data. LiDAR provides high-resolution DEMs, but with a narrow ground footprint. Should LiDAR elevation data become available for the Williston area at a low cost or available as public domain, it would be an important addition for the WVCD.

Analyze Rocky Mountain Snow-pack Data for Numerous Years and Compare to Missouri River Elevations near Williston for the Same Time Period

It may helpful to determine if Rocky Mountain snow-pack levels correlate with Missouri River elevations near Williston during the following spring and summer. This data could be mapped within GIS software. Incorporating the fourth-dimension (4D) of time will make it possible for the WVCD to identify patterns, which in turn could serve as an early warning system for the WVCD to plan for subsequent mosquito control seasons.

Determine if Unmanned Aerial Vehicles (UAVs) (i.e., drones) could be used to Locate Mosquito Breeding Habitat within the Floodplain near Williston

Drones are used worldwide in numerous search/data gathering applications. This would not necessarily require the WVCD to purchase drones, but rather they could coordinate with local UAV hobbyists, and work with them to develop protocols for using UAVs when applicable.

Obtain, Map, and Analyze Local Groundwater Table Data

It might be useful to review local groundwater tables and determine if they have changed over time. This would provide useful information in relation to how long flooded areas remain saturated after inundation.

Evaluate Sedimentation Status and Progression for the Garrison Reservoir

The last known sedimentation study of the Garrison Reservoir was conducted in 1988. Both the city of Williston and the WVCD should know how much sediment has accumulated within the reservoir and river channels near Williston since then. The information will provide a better understanding of the river, the floodplain, the delta formation within the channels, and the amount of flooding occurring within the floodplain, all of which will help vector control officials better prepare for and execute mosquito management strategies each summer.

CONCLUSIONS

The objective of this study was to determine the amount of vertical error (i.e., RMSEz) within the IfSAR DTM elevation data and thereby the accuracy of the predictive flood models developed during this study. Results of the IfSAR vertical quality assessment (QA) determined that the IfSAR DTM elevation data has better than the vendor declared 1-m RMSEz in three out of the five land cover classes within the floodplains and an overall RMSEz of 1.071 m in all land classifications combined, which is in line with the vendor declared RMSEz of 1.00 m. Overall vertical accuracy (i.e., accuracyz) of the IfSAR DTM elevation data is 209.9 cm at the 95% confidence level. Based on NRC (2007) recommendations, IfSAR DTM elevation data is not adequate for critical flood insurance analyses. However, for vector management purposes, IfSAR DTM elevation data and the IfSAR-derived predictive flood models would be a cost-effective alternative to expensive, labor-intensive ground-based sampling and surveillance methods, especially when mosquito breeding habitat are too large, difficult or dangerous to access, or in situations where funding is limited. This research offers a new approach for locating accumulated water and potential mosquito breeding habitat and would be beneficial to entomological researchers and vector control programs worldwide.

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APPENDIX A. REQUEST FOR FUNDING ASSISTANCE TO PURCHASE LIDAR DATA

The following letter was mailed to 1) ND GIS Technical Committee, Bismarck, ND, 2) ND State Water Commission, Bismarck, ND, and 3) Senator Dorgan, Washington, DC requesting assistance with LiDAR funding.

December 10, 2009

ND GIS Technical Committee
900 E. Boulevard Ave.
Bismarck, ND 58505-0850

Dear ND GIS Technical Committee,

The Williston Vector Control District #1 Board (WVCD) has asked me to contact your committee to concerning possible cost-share assistance. The reason I was requested to contact you is twofold. First, my knowledge of the problem. I became very familiar with Williston's mosquito problem though my service on the Upper Missouri-Lake Sakakawea Planning Committee from 1989-1992 and the Williston Vector Control Board of Directors (WVCD) from 1991-1999. Second, my knowledge of the relatively new technology that could be of benefit to Williston's mosquito control program. The technology is Light Detection and Ranging (LiDAR) which is a remote-sensing system that uses aircraft-mounted lasers for collecting topographic data. It is currently used by the National Oceanic and Atmospheric Administration and NASA scientists to document topographic changes along shorelines. The WVCD would like your committee to consider their application for cost-share assistance for LiDAR technology in the Williston floodplain.

Enclosed is a summary of why I believe LiDAR could be critical to the success of Williston's vector control efforts, including an appendix with documentation and supporting letters.

On behalf of the WVCD, and actually the entire community, thank you for your kind consideration of this application. We will never eliminate the mosquito problem, but the use of LiDAR provides hope of making the efforts of all more efficient and effective!

Sincerely,

Jackie Stenehjem
Assistant Professor
Williston State College
Williston, ND

Enclosure: Summary

SUMMARY

Re: LiDAR Technology Could Help Williston, ND Battle Mosquitoes

Prepared for: The Honorable Byron Dorgan, U.S. Senator
322 Hart Bldg
Washington, DC 20510-0001

Prepared by: Jackie Stenehjem
Date: December 9, 2009

Williston's Integrated Pest Management Program
The Williston Vector Control District (WVCD) has, over the last eighteen years, implemented an Integrated Pest Management (IPM) program to control mosquitoes. The most important part of that IPM program is the identification of immature mosquito breeding sites and the subsequent application of larvicides to stop their development into adult mosquitoes.

Each spring and summer the WVCD applies larvicides along the floodplain of the Missouri River near Williston. The floodplain near Williston is huge. A 1989 study led by Dr. Alfred F. Cofrancesco, Jr., Entomologist, U.S. Army Corps of Engineer's, Waterways Experiment Station, Vicksburg, Mississippi, determined that mosquito breeding occurs in the floodplain when melting snow and/or rains cause rises in the water level of the Missouri River where the rising water inundates mosquito eggs oviposited in soil. The study estimated that at that time (1989) more than 24,000 acres of this type of habitat were located in the immediate area of Williston.

Expanding Mosquito Breeding Area
Those 24,000 acres are only part of Williston's mosquito problem today. Data from the National Wetlands Inventory (NWI) website, dated September 21, 2009, indicate that the entire floodplain directly south of the city of Williston to the headwaters of Lake Sakakawea is wetlands and, therefore, possible mosquito breeding habitat. The amount of total wetlands varies each summer depending on the lake elevation. Using a 2005 National Agricultural Imagery Program (NAIP) aerial photo and ArcGIS software, I estimate the area between the city of Williston and Lake Sakakawea to be approximately 80,000 to 100,000 acres of wetlands (Appendix A).

The floodplain near Williston has not always been wetlands. Maps made in 1894 by the Missouri River Commission (MRC) show the small city of Williston. The floodplain located directly south of the city of Williston was a forest (Appendix B). Approximately fifty years later, a 1949 aerial photo shows the city of Williston had grown and the forested floodplain directly south of Williston had been converted to farm land (Appendix C). Another 60 years later, the farmland located directly south of the city of Williston is now massive wetlands (Appendix D).

Between the years 1946-1988, the U.S. Army Corps of Engineers (USACE) conducted sedimentation studies on the upper Missouri River. In 1990, the USACE published a report titled, 'Lake Sakakawea Headwaters Aggradation Study' which documented that at the time (1988) over 30 feet of sediment had been deposited in the Missouri River channel near Williston since the construction of the Garrison Dam (Appendices E and F).

Each summer, snowmelt from the mountains in Montana and Wyoming flow past Williston. That mountain snowmelt, called the June rise, together with the decreased river channel capacity, cause massive annual flooding near the city. This results in the breeding of mosquitoes in what was once productive farmland/forest. It is unknown how much more sediment has been deposited in the Missouri River near Williston since 1988...because the1990 study was the last sedimentation study of the Garrison Reservoir.

Aedes vexans and *Culex tarsalis* are the two main species of mosquitoes of concern in the Williston area. Both species are capable of vectoring serious diseases and *A. vexans* is a vicious pest. The distance from the city of Williston to the backwaters of Lake Sakakawea is within the flight ranges for both species.

Normal Mosquito Control Methods Are Difficult and Hazardous

Because of the size of the wetlands and the inaccessibility, aircraft are used to apply the larvicides. Applying larivcidal chemicals to the entire floodplain would be wasteful and cost prohibitive because development of immature mosquitoes occurs in a patchy distribution. Therefore, the WVCD uses field crews who traverse the area on foot, by ATV, truck, etc. to check for the presence of standing water and mosquito larvae. The following items are major challenges to controlling mosquitoes on such a large floodplain: 1) many areas of the floodplain are impossible and/or dangerous for field crew members to enter because of associated water hazards such as deep mud and river currents; 2) flooding is so expansive that field crew members are physically unable to check the entire area each time the river elevation fluctuates.

DEM-derived Elevation Contours for Williston-area Floodplain Are Not Available

The WVCD believes it would be more time-efficient, less expensive and more effective if they could identify those areas that are flooding and holding water after the river recedes by using high-resolution Digital Elevation Models (DEMs) of the floodplain. High resolution elevation data would identify exactly where the Missouri River was overflowing its banks each day during the June rise. That knowledge would allow for the identification of precisely targeted locations and direct the judicious use of mosquito larvicides more quickly and effectively. At present high-resolution DEMs are not available for the Williston-area floodplains (Appendix G).

LiDAR Technology Has Potential to Help Williston's Mosquito Control Efforts

Remote-sensing technology exists, called Light Detection and Ranging (LiDAR) which uses aircraft-mounted lasers for collecting topographic data. It can accurately measure bare earth elevations to within 15 cm vertical accuracy. LiDAR-derived elevation data is used by FEMA to develop flood insurance maps throughout the U.S. and along the coastlines of the U.S. to develop baseline elevation data for hurricane emergency preparedness and response plans, determine potential flood elevations, areas at risk, and economic losses. LiDAR is currently being used in eastern North Dakota to help acquire and economic losses. LiDAR is currently being used in eastern North Dakota to help acquire the same flood risk information for the Red River of the North Project. LiDAR-derived elevation data of Williston's floodplain would be extremely helpful to the WVCD for implementing an even more effective mosquito control program.

Last summer, a U.S. Air Force Reserve (USAFR) Spray Unit responsible for controlling mosquitoes during wartime, used the Williston floodplains as a training site for its mission by applying aerial larvicide. The Air Force worked with both the local USACE and the WVCD and applied larvicide over large areas of the Missouri floodplains near Williston (Appendix H). The effort has been mutually beneficial as the Air Force completes training requirements while helping to reduce Williston's mosquito population. The Air Force plans to return next spring, 2010.

Major Mark Breidenbaugh, PhD, USAFR, Research Entomologist with the U.S. Air Force Spray Unit was in Williston several times to plan and supervise aerial application of the larvicide. In an interview with the Air Force Times, posted July 5, 2009, Major Breidenbaugh stated that he "has traveled the world studying insects and Williston's mosquito problem is as bad as he's seen" (Appendix I).

I have spoken with Major Breidenbaugh and Jeff Keller, Natural Resource Manager of the Williston Office of the USACE, concerning the use of LiDAR technology to help with applications of larvicide chemicals near Williston. Both are very supportive and believe LiDAR data would help increase the efficiency of the larvicide applications (Appendices J and K). Letters of support are also enclosed from Fran Bosch, Williston Vector Control Field Director; Williston City Commission; and Williams County Commission (Appendices L, M, and N).

<u>LiDAR Technology Is Expensive</u>
LiDAR data is very expensive. Fugro Horizons, Rapid City, South Dakota, a company that operates the aircraft-mounted lasers to collect the topographic data, provided the LiDAR of the Red River of the North. Fugro representatives estimated the cost for LiDAR data over a small area (20-40 square miles) of the floodplain directly south of Williston at $40,000 - $60,000.

To be sure LiDAR-derived elevation contours are accurate, a third-party accuracy assessment should be done on the LiDAR data coordinates. Houston Engineering, Fargo, was the engineering firm which conducted the accuracy assessment of the Red River LiDAR project data. A Houston Engineering representative estimated the cost for a third-party accuracy assessment of that same small Williston area of LiDAR data would be approximately $10,000. Total cost for a LiDAR study of a small portion of the Missouri River near Williston is approximately $50,000-$70,000. The WVCD has only a $20,000 budget for proposed LiDAR data and research.

<u>Williston Needs Help</u>
You recently secured $4.5 million for a Missouri River study and other appropriations for various river/basin/flood studies in North Dakota. I contacted your Washington, D.C. office recently and asked if a portion of the $4.5 million Missouri River study could be

Public Benefit of Williston Floodplain LiDAR Data

LiDAR data is expensive. It is extremely important to the WVCD that if they are able to purchase LIDAR data of the Williston floodplain that the data is maintained, stored and made available for others to use. Water issues have been and will always be a major concern in North Dakota. A public benefit of LiDAR data of the Williston floodplains is that the data could be a valuable tool for other agencies which deal with the upper Missouri River and its floodplain, the Garrison Dam, river ecosystems, wetlands, wildlife and wildlife habitat, ND water quality issues, water-borne diseases, etc. Such agencies might include the USACE, Game and Fish, U.S. Wildlife, Ducks Unlimited, National Wildlife Federation, Bureau of Reclamation, CDC, as well as local city, county and state agencies, and the general public.

Storage, Maintenance, and Service of Williston LiDAR Data For Others To Use

Steve Shivers, USGS ND/SD Geospatial Liaison has obtained an agreement with USGS to maintain, store and service the Williston LiDAR data on the USGS Center for LiDAR Coordination and Knowledge (CLICK) website. In addition, Charles Fritz, Director, International Water Institute, Fargo, has also agreed to maintain, store and service the Williston LiDAR data on their website.

Who Will Develop Contour Elevations Data from the Williston Floodplain LiDAR?

The plan is that I will develop elevation contours. I am an assistant professor at Williston State College where I teach GIS and remote sensing, precision agriculture, and several medical transcription courses. My geospatial education and training include:

A. Three GIS and remote sensing courses from Dr. Peter Oduor, NDSU, Fargo;
B. A remote sensing course from St. Mary's University, Winona, MN;
C. Integrating GIS and remote sensing course from Texas A&M, Corpus Christi, TX;
D. Precision agriculture course from NDSU, Fargo;
E. Member of 'Integrated Geospatial Education Technology and Training' (iGETT), held at Texas A&M, Corpus Christi, TX (sponsored by NSF, ESRI, NASA, and others), several weeks of training during summers of 2007 and 2008;
F. Member of 'Teachers Teaching Teachers' (T3G) Training, Redlands, CA, summer 2009 (sponsored by ESRI);
G. Various GIS/remote sensing conferences and workshops (EROS, October 2009; ND GIS Users' Conference, Grand Forks, November 2009
H. Published: 156 page Learning Unit for iGETT, 'Potential Flood Elevations and Economic Losses After A Catastrophic Dam Failure', published on iGETT website, http://igett.delmar.edu/TR_LearningUnits.html
I. Published: Map for T3G training, 'Historic Gillman Ranch – Riverside, California. Analysis: Location of Invasive Tree of Heaven, *Ailanthus altissima* vs. Elevation and Landcover', page 65 in the fall 2009 issue of the ESRI ArcUser magazine, http://www.esri.com/news/arcuser/1009/files/arcuser47.pdf
J. LiDAR training: Gritt May, International Water Institute, Fargo, developed the elevation contours for the Red River of the North LiDAR project. I spent one afternoon with Grit, a few weeks ago learning how to take raw LiDAR data and convert to contour data.
K. Additional LiDAR training: ESRI online LiDAR course.
L. Future training: plan to work with Grit again, and also continue taking LiDAR training or courses when available. Plan to hire Grit to do random analyses on Williston LiDAR contours.

Williston Needs Help

Would you please consider helping Williston with cost-share assistance for LiDAR technology of the Williston floodplain? I cannot promise that LiDAR technology will solve all of Williston's mosquito problems, but LiDAR offers the city the possibility of increased efficiency of application of larvicide chemicals.

Thank you for your kind consideration of this request!

APPENDIX

A. NWI wetlands data for Williston, ND and Missouri River area
B. 1894 Missouri River Commission map of Williston and Missouri River area
C. 1949 aerial photo of Williston and Missouri River area
D. 2005 NAIP aerial photo of Williston and Missouri River area
E. Map of 1960 river mile markers
F: 1990 Lake Sakakawea Headwaters Aggradation Study, Plate VI.233.
G. 10 m DEM of Williston and Missouri River area
H: USAFR larvicide spray paths for Williston floodplain, summer 2009
I. Interview with Mark Breidenbaugh, Ph.D., Entomologist, Air Force Times, 7/05/09
J. Letter of support from Mark Breidenbaugh
K. E-mail of support from Jeff Keller, Natural Resource Manager, Williston office USACE
L. Letter of support from Fran Bosch, Williston Vector Control Field Director
M. Letter of support from Williston City Commission
N. Letter of support from Williams County Commission

The following appendices will be also included in the master copy:

O. USGS paper: 'Use of Light Detection and Ranging (LiDAR) to obtain high-resolution Elevation Data for Sussex County, Delaware'; Fact Sheet 2008-3088, Dec. 2008
P. USGS paper: 'LiDAR-derived flood-inundation maps for real-time flood-mapping applications, Tar River Basin, North Carolina'; SIR No. 2007-5032, 2007
Q. LiDAR and Digital Elevation Data', accessed Dec. 09, 2009 http://www.ncfloodmaps.com/pubdocs/lidar_final_jan03.pdf

APPENDIX B. MARK BREIDENBAUGH IN SUPPORT OF LIDAR FUNDING

DEPARTMENT OF THE AIR FORCE
757AS -- AERIAL SPRAY UNIT
YOUNGSTOWN AIR RESERVE BASE, UNIT 24
VIENNA OH 44473-5926

1 December 2009

To Whom it May Concern:

I am writing a letter to support the Williston Vector Control, District #1 Board (WVCD) in their development of light detection and ranging data (LiDAR) for the region surrounding Williston, North Dakota. The resulting LiDAR generated data, specifically, the high-resolution digital elevation technology, has a strong potential for aiding the WVCD's development of a stronger integrated mosquito management plan. The district's biologists would use this technology to remotely identify breeding locations of pestiferous and vector mosquitoes.

The Air Force recently began working with the Army Corps of Engineers to apply larvicides on the floodplain associated with the Missouri and Yellowstone River confluence. Because developing mosquito larvae are not evenly distributed across the floodplain, extensive scouting is required to target the larvicide applications in pockets where the pests reside. LiDAR should provide a means to identify such areas based on physical characteristics which can be extracted from the data.

In short, LiDAR data should increase the Air Force's ability to accurately apply larvicides in areas where the target pests are most dense. Correctly applied, LiDAR will be an important additional component to the WVCD's integrated mosquito management strategies.

Sincerely,

//signed//

Major Mark Breidenbaugh, PhD, USAFR
Research Entomologist
Youngstown Air Reserve Station (757 AS/DOS)
Vienna, Ohio 44473

APPENDIX C. WILLIAMS COUNTY COMMISSION IN SUPPORT OF LIDAR FUNDING

Williams
COUNTY

NORTH DAKOTA
BETH M. INNIS
County Auditor

December 10, 2009

To Whom it may concern:

The Williams County Commission is in full support of the Williston Vector Control District in their application for funding to purchase LiDAR digital elevation data for the purpose of helping to increase their larviciding efficiency.

The purchase of this equipment will make it easier and more efficient for Vector Control to estimate where the river has overflowed, causing mosquitoes to breed.

We ask that you consider and approve any application for funding of this project.

Respectfully,

Beth M. Innis
Williams County Auditor

P.O. Box 2047
Williston, ND 58802-2047
701-577-4500
701-577-4510 (fax)

APPENDIX D. WILLISTON CITY COMMISSION IN SUPPORT OF LIDAR FUNDING

City of WILLISTON
NORTH DAKOTA

P.O. Box 1306
Williston ND 58802-1306
PHONE: 701-577-8100
FAX: 701-577-8880
TDD State Relay: 711

December 4, 2009

To Whom It May Concern:

The Board of City Commissioners fully supports the efforts of Williston Vector Control District to pursue funding to purchase LiDAR digital elevation data in order to increase efficiency of larviciding.

The Garrison Dam with its varying water level created 20,000+ acres of swampy land which is an ideal breeding ground for mosquitoes. Much of this area is very difficult, often dangerous, and sometimes impossible for crews to reach to check for larvae. Consequently, the District has to rely on the airplane pilot to estimate where the river has overflowed its banks, causing flooding of low areas and creating ideal areas for mosquito breeding. This is a very inefficient way to control mosquitoes, which expose our citizens to various diseases.

Digital elevation data will be an important tool in increasing the safety and comfort of our citizens. We ask that you carefully consider and approve any application submitted for funding this project.

Sincerely,

E. Ward Koeser
President
Board of City Commissioners

APPENDIX E. WILLISTON VECTOR CONTROL, DISTRICT #1 IN SUPPORT OF LIDAR FUNDING

Williston Area Vector Control District
PO Box 17
1719 42nd St W
Williston, ND 58802-0017

We who are about to spray,
salute you!

December 3, 2009

To Whom It May Concern:

I am writing to express my strong support for the research program that Jackie Stenehjem is submitting through NDSU involving the use of LiDAR technology to map the Missouri River floodplain near Williston, ND.

The Williston Vector Control District has a continuing interest in the use of LiDAR mapping to enhance its efforts to control mosquito populations along the floodplain. The possibility of using this technology not only to locate and treat newly flooded areas but also pre-treating closed depressions before a flooding event is very important to the District.

The prospect of using LiDAR in conjunction with standard surveillance practices and historical data represents an important step forward in the difficult business of forecasting mosquito hatches and timing the application of pesticides to control their numbers.

We would like to offer an in-kind support of monitoring mosquito populations using trapping data as well as landing rates and, in addition, we would like to attend management and progress meetings at the District's expense.

I look forward to hearing that you have been successful in obtaining support.

Sincerely,

Francis Bosch, Director
Williston Vector Control District

Francis Bosch, Vector Control Director
Phone 701.577.4563
franb@co.williams.nd.us

APPENDIX F. USACE, WILLISTON, ND BRANCH OFFICE IN SUPPORT OF LIDAR FUNDING

Subject:	RE: support letter
Date:	Wed, December 16, 2009 6:31 pm
From:	Keller, Jeffrey E NWO
To:	Jacquelin Stenehjem

Jackie:

I do support this use of this study and the data that would be collected. One thing I would like to explore though is to see if it is possible to use the Air Force or some government agency to conduct this study. You may use this as my letter of support for the project.

Jeffrey E Keller

APPENDIX G. REPLY LETTER FROM NORTH DAKOTA GIS COORDINATOR

nd GIS north dakota GEOGRAPHIC INFORMATION SYSTEMS

Jackie Stenehjem
1201 4th Avenue East
Williston, ND 58801

January 27, 2010

Dear Jackie:

The North Dakota GIS Technical Committee (GISTC) discussed in great detail your December 10, 2009 request for possible cost-share assistance at our normally scheduled meeting last week. A number of concerns were raised such as how river dynamics and the amount of water being released from Ft. Peck and/or the Garrison dams would make this data dated in a short amount of time, heavy vegetation interfering with determining the true surface, whether or not contracting more of the work would be more efficient, and the accuracy of the mapping vs. the accuracy of applying pesticide by plane.

At the end of the discussion we determined that for maximum state agency benefit we would be interested in participating in your project if the study area were to be a larger contiguous area covering Williston and the floodplain. If LiDAR is collected aerial photography should also be collected to assist in verification.

Budget permitting the GISTC does participate in data collection projects that have benefits to multiple state agencies and which cover a city or county. In the recent past the GISTC has partnered with local and federal agencies in the acquisition of aerial photography with associated elevation and contour data. With each of these projects our contribution has been $5,000 sent directly to the vendor collecting the data.

Please keep me informed on the progress of your project and how we may be able to assist.

Sincerely,

Bob Nutsch

GIS Coordinator
State of North Dakota
328-3212
bnutsch@nd.gov

APPENDIX H. REPLY LETTER FROM THE NORTH DAKOTA STATE WATER COMMISSION

North Dakota State Water Commission

900 EAST BOULEVARD AVENUE, DEPT 770 • BISMARCK, NORTH DAKOTA 58505-0850
701-328-2750 • TDD 701-328-2750 • FAX 701-328-3696 • INTERNET: http://swc.nd.gov

February 2, 2010

Jackie Stenehjem
Assistant Professor
Williston State College
Williston, ND 58802

Dear Jackie,

We have reviewed your letter dated December 10, 2009, in which you on behalf of the Williston Vector Control District request cost-share assistance from the North Dakota State Water Commission for the acquisition of LiDAR data. The District strongly supports your NDSU research program involving the use of LiDAR technology to map the Missouri River floodplain near Williston to assist with vector control efforts.

The District has a continuing interest in the use of LiDAR mapping to enhance its efforts to control mosquito populations along the floodplain. According to your request, the data would be used to locate and treat newly flooded areas and to pre-treat closed depressions before a flooding event. Using LiDAR in conjunction with standard surveillance practices and historical data would assist in forecasting mosquito hatches and timing the application of pesticides to control their numbers.

It is the policy of the State Water Commission to provide cost-share funding for water development projects. The acquisition of LiDAR data used to construct projects to protect communities from flooding is eligible under the Commission's cost-share policy. These projects are commonly associated with dams, dikes, levees, diversion channels, and water retention structures/methods.

Per the Commission's ***Cost-Share Policy, Procedure, and General Requirements*** vector control is not considered a water development project eligible for cost-share assistance. Although the importance of acquiring the LiDAR data is understood, funding from the State Water Commission for Williston's vector control efforts is not consistent with our policy and thus is not eligible for cost-share participation.

Should you have any question or concerns please contact me.

Sincerely,

Dale L. Frink, State Engineer

DLF/CM: 1315

JOHN HOEVEN, GOVERNOR
CHAIRMAN

DALE L. FRINK
SECRETARY AND STATE ENGINEER

APPENDIX I. IfSAR PRICE QUOTE, LICENSE ACCEPTANCE, AND PURCHASE AUTHORITY

INTERMAP TECHNOLOGIES™ **Price Quotation Direct**

Price Quotation #10JD003_Revised	
Date	28 April 2010
License Type	Perpetual
Quote Expiration	30 days after Date
Company	
Attention	Jackie Stenehjem
Address	1201 4th Ave, E Williston, ND 58801
Telephone/Fax	701-572-5602
Email	Jacquelin.stenehjem@wsc.nodak.edu
Billing Contact	Fran Bosch
Billing Address	PO Box 17, Williston, ND 58802
Telephone/Fax	701-577-4561 / 701-577-4570
Email	franb@co.williams.nd.us
Area of Interest (AOI)	Three areas in Williston, ND totaling 215.60 square km. Appendix A of this Price Quotation provides a map with a polygon depicting the AOI. This AOI definition will be used to create the deliverables, unless otherwise indicated.
Intended Use	Flood Mapping
Product Deliverable	1. NEXTMap® Type II Digital Terrain Model (DTM) v1.5 data in .BIL file format. 2. FGDC compliant metadata will be provided with NEXTMap® DTM data products in xml format. 3. The most recent release of Global Mapper by Intermap terrain and image data visualization and utility software. 4. NEXTMap® data will be provided in a seamless mosaic, unless other tiling schema is noted below. 5. NEXTMap® data will be projected to the Lat/Long coordinate system, NAD83 horizontal datum, NAVD88 vertical datum, with horizontal measurement units in decimal degrees and vertical measurements units in meters. 6. All data will be delivered via FTP.
Option 1- Area 1, 65 km2	**Price for Product License**

Intermap Technologies | Price Quotation Direct Version | 2010-14-04
Price Quotation # 10JD003

SALES.FRM.0008 v1.6 | Page 1 of 12 | Company Confidential

Digital Terrain Model (DTM)	$2,275.00 USD
Global Mapper Software	$349.00 USD
Product Discount (%)	(-$349.00 USD)
Grand Total	**$2,275.00 USD**

Option 2- Area 2, 64.8 km2	**Price for Product License**
Digital Terrain Model (DTM)	$2,268.00 USD
Global Mapper Software	$349.00 USD
Product Discount (%)	(-$349.00 USD)
Grand Total	**2,268.00 USD**

Option 6- Little Muddy, 10.8 km2	**Price for Product License**
Digital Terrain Model (DTM)	$378.00 USD
Global Mapper Software	$349.00 USD
Product Discount (%)	(-$349.00 USD)
Grand Total	**$378.00 USD**

Delivery Schedule

Intermap has completed acquisition and processing activities for the proposed data set. Delivery can be made within two weeks of receipt of this executed Price Quotation, depending on the order backlog at that time.

Data Specifications

NEXTMap® Product Deliverable	Pixel Size/ Post Spacing*	Accuracy (RMSE)
Type II Digital Terrain Model (DTM)	5.0 m	1.0 m vertical, 2.0 m

		horizontal

*** Unless otherwise specified the default post spacing for meter based projections will be 5 m and feet based projections will be 16 ft.**

Send executed Price Quotation or direct all inquires to:

Intermap Technologies Inc.
c/o Jennifer Dubrow
8310 South Valley Highway, Suite 400
Englewood, CO 80112-5809
Tel: 303-708-0955, ext 399
Fax: 303-708-0952
Email: jdubrow@intermap.com

Intermap Product Descriptions

More information on Intermap products, including their accuracy, specifications, and characteristics can be found in the Product Handbook at http://www.intermap.com/producthandbook.

Digital Terrain Model (DTM)

A DTM is a raster elevation model of the bare earth that has had vegetation, buildings and other cultural features digitally removed, leaving just the underlying terrain. The DTM has been derived from the Digital Surface Model and reflects elevation measurements of the bare earth. Intermap has two versions of DTM data: v1.0 and v1.5. Some applications are suited to DTM v1.0, which has had most terrain features removed. Other applications require DTM v1.5, which has had all identifiable terrain features removed and is a better representation of the bare earth. The accuracy values provided are for measurements made in unobstructed areas with slopes less than 10°. Accuracy will degrade on slopes greater than 10°.

INTERMAP TECHNOLOGIES INC.
GENERAL CONDITIONS OF PRICE QUOTATION AND CONTRACT

1. **Definitions.**
"Licensee" shall mean the Government Agency, Company or Person to whom the "Company" (hereinafter defined), has supplied a Price Quotation to perform services and/or to provide products.
"Company" shall mean Intermap Technologies Inc.
"Price Quotation" shall mean the written offer to perform services and/or to provide products that accompanies and references these General Conditions of Price Quotation and Contract.
"Products" shall mean the deliverable data products proposed herein to be provided to the Licensee by the Company in any resulting contract.
"Work" shall mean the requirements described within the Price Quotation to be performed by the Company in performing the services and/or delivering the products.
"Contract" shall mean written acceptance by the Licensee, of the Price Quotation and the terms and conditions herein.

2. **Validity of Price Quotations.** Unless stated otherwise in the Price Quotation, the offer, including price shall remain valid for a period of 30 days. If the Price Quotation specifically states a period of validity, that period shall supersede the stipulation of 30 days included herein. On the expiry of the period of validity, unless otherwise agreed in writing by the Company, the Price Quotation shall be deemed to be withdrawn.

3. **Licensed Data.** This Price Quotation is based on providing a data license to the Licensee for its use of the data products defined herein. Please refer to the attached Intermap End User License Agreement. This license will be incorporated into any contract(s) resulting from this Price Quotation.

4. **Indemnification.** If a third party makes a claim against Licensee that the Products directly infringe any patent, copyright or trademark or misappropriate any trade secret ("IP Claim"); the Company will (i) defend Licensee against the IP Claim at the Company's cost and expense, and (ii) pay all costs, damages and expenses (including reasonable legal fees) finally awarded against Licensee by a court of competent jurisdiction or agreed to in a written settlement agreement signed by the Company arising out of such IP Claim. If the Products are held to infringe or are believed by the Company to infringe, the Company shall have the option, at its expense, to (a) replace or modify the Products to be non-infringing, or (b) obtain for Licensee a license to continue using the Products. If it is not commercially reasonable to perform either of the foregoing options, then the Company may terminate the Products license for the infringing Products and refund the license fees paid for those Products upon return of the Products by Licensee.

5. **Taxes.** Unless otherwise specifically stated, the prices quoted in the Price Quotation do NOT include any taxes, duties or official levies which if applicable, or become applicable, during the course of the contract, must be added to the quoted prices.

6. **Payment.** Payment for the services provided and/or the products produced shall be in accordance with the schedule of payments set out in the Price Quotation or such schedule mutually agreed to in writing by the Licensee and the Company. The Company's commercial terms are net 30 days. Outstanding accounts beyond 30 days will be subject to interest at the rate of 2 % per month or the highest rate allowed by applicable law, whichever is lower.
Payment to the Company shall not be conditioned upon any corresponding payment to the Licensee by any third party, in respect of the Work covered by any of the Company's invoices.
The Company reserves the right to require evidence of satisfactory credit and payment history for the Licensee before undertaking the proposed Work and providing any Products or Services.

7. **Freight.** F.O.B. Origin.

8. **Price Quotation Requirements.** The deliverable products and/or services are defined in the Price Quotation. All prices quoted by the Company are in respect to the stipulated areas and dimensions only. Separate Price Quotations must be requested by the Licensee where a change of requirements is anticipated.

9. **Schedule of Delivery.** The schedule defined in the Quotation was calculated based on the assignment of the Company's production resources at the time the Quotation was submitted. The actual production schedule will be dependent upon the assignment of the Company's production resources at the time the Price Quotation is accepted and a contract is executed.

10. **Contract.** The Company requires written confirmation that the Price Quotation, which includes the terms and conditions and End User License Agreement (EULA) herein, is accepted by the Licensee prior to beginning the performance of any part of the Work. Such written acceptance shall reference the Price Quotation (of which the terms and conditions herein form a part) and shall constitute a written contract between the Licensee and the Company. Written acceptance of this Price Quotation shall be construed as acceptance of the technical specifications defined herein, or referenced by the Price Quotation.

11. **Relationship of the Parties.** The Company is an independent contractor; nothing in this Agreement shall be construed to create a partnership, joint venture or agency relationship between the parties.

INTERMAP TECHNOLOGIES INC.
END USER LICENSE AGREEMENT

This End User License Agreement ("EULA") is a legal and binding agreement between Intermap Technologies Inc. ("Intermap") and the company, individual, group or other legal entity ("Customer") identified on the order form confirmation generated by Intermap ("Confirmation") for the data, databases and data products of Intermap and its third party providers identified in the Confirmation ("Data") and any software, hardware, documentation, updates, supplements, and other services identified in the Confirmation or otherwise provided by Intermap and its third party providers to Customer with this EULA (Data and such other items collectively "Product(s)"), unless other terms accompany those items, in which event those terms apply to such items.

1. **License Grant.** The Products are licensed to Customer, not sold. Subject to the terms and conditions of this EULA, Intermap grants Customer a limited, revocable, non-transferable, non-exclusive license for the time period specified in the Confirmation to: (a) internally use the Product solely for the purpose set forth in the Confirmation; (b) make copies of the Data as reasonably necessary to achieve the purpose set forth in the Confirmation and for backup purposes; (c) make derivative works of the Data for Customer's internal business purposes solely as permitted in the Confirmation; and (d) permit Customer's contractors and consultants to access and make copies of the Data solely for use on behalf of Customer, provided that such contractors and consultants agree in writing: (i) to be bound by the same Product limitations applicable to Customer, and (ii) to return the Products and any derivative works to Customer, and keep no copy thereof, upon completion of the contracting or consulting engagement. Conduct in violation of this EULA by such other parties will be deemed to be a material breach of this EULA by Customer.

2. **Reservation of Rights; Restrictions.** All rights not expressly granted to Customer are reserved by Intermap and its licensors. Unless applicable law grants Customer additional rights despite this limitation, Customer will refrain from, and prevent others from, using the Products in any manner or for any purpose not expressly authorized by this EULA, including without limitation:
   a. sublicensing, transferring, selling, leasing or assigning any of the rights granted herein (and any attempt to do so is void).
   b. copying the Products.
   c. publishing, disclosing, making available, distributing, transmitting or allowing a third party (except third parties explicitly permitted in Section 1 of this EULA) to access the Product in whole or in part. Notwithstanding the foregoing, disclosure of Products pursuant to a judicial or administrative order will not be deemed to be a breach of the foregoing obligation, provided Customer (i) provides timely written notice of such order to Intermap and (ii) reasonably cooperates with Intermap's efforts to contest or limit the scope of such order.
   d. unless explicitly permitted in the Confirmation, create derivative works for distribution (where "derivative works" is defined under United States copyright law (17 U.S.C. §101) and, to the extent applicable, international copyright law).
   e. reverse engineering, decompiling, or disassembling the Product, except as expressly permitted by applicable law (and only then, to the extent permitted by such law and provided further that Customer promptly notifies Intermap of any such activity).
   f. using any trademarks of Intermap.
   g. using the Product to provide a service bureau, time share or other services to third parties.
   h. hosting or storing any portion of the Product on equipment not owned or controlled by Customer.
   i. using any portion of the Product in a manner that does not comply with applicable law, regulations, or governmental orders including, without limitation, all applicable privacy laws.

3. **Protection;Cooperation.** Customer will (a) appropriately notify its employees of its rights and obligations hereunder; (b) use its best efforts to maintain the confidentiality and security of the Products and prevent the unauthorized disclosure or use of the Products; (c) immediately notify Intermap upon discovering evidence of a current or threatened misuse or unauthorized use or disclosure of the Products; and (d) at Customer's own cost, use its best efforts and cooperate with Intermap to promptly cure such.

4. **Ownership.** Intermap and its licensors retain ownership of the Products and all portions thereof, including all rights under copyright law, trademark law, patent law, trade secret law, and all other forms of proprietary and intellectual property protection; and such Products will continue to be subject to the provisions of this EULA, even if Intermap expressly authorizes Customer to: (a) modify, merge, incorporate, or combine the Products, or any portion thereof, into any software, hardware, or other data, or (b) convert or translate the Products into another data format.

5. **Restrictions on NEXTMap® Britain End Users.** In addition to the other restrictions set forth herein, Customer will not use NEXTMap® Britain to create or distribute flood maps, flood hazard maps, flood insurance rate maps, flood models, or any map, image or representation of flood modeling or risk in any manner. The foregoing restriction applies only to End Users of the NEXTMap Britain Product and may not apply to Customer.

6. **Government Uses.** If Customer is a federal, state, or local government agency, the Product is licensed solely to the particular agency and not to any other government agency. The Product is a "commercial item" as that term is defined

at 48 C.F.R. 2.101 (Oct. 1995), consisting of "commercial computer software" and "commercial computer software documentation," as such terms are used in 48 C.F.R. 12.212 (Sept. 1995). Consistent with 48 C.F.R. 12.212 (Sept. 1995) and 48 C.F.R. 227.7202-1 throughout 227.7202-4 (June 1995), all U.S. Government End Users acquire the Products with only those rights set forth herein. If the Products or any permitted derivative works are used in connection with the performance of any government contracts or subcontracts, Customer will ensure that (i) the Products and any derivative works will not constitute a deliverable under any governmental contracts or subcontracts; and (ii) in no event will a government entity acquire any rights other than those provided in this Section. The foregoing limitations apply only to government End Users and may not apply to Customer.

7. **LIMITED WARRANTY; DISCLAIMER; LIMITATION OF LIABILITY.**
   a. Intermap warrants for the longer of sixty (60) days after the delivery of the Products or as required by applicable law that the Data delivered to Customer will be of the geographic area of interest ordered and the media used to carry the Data will be free from material physical defects. CUSTOMER'S SOLE REMEDY AND INTERMAP'S SOLE OBLIGATION UNDER THIS LIMITED WARRANTY IS FOR CUSTOMER TO RETURN THE DEFECTIVE MEDIA TO INTERMAP WITHIN THE WARRANTY PERIOD, AND TO RECEIVE REPLACEMENT MEDIA. IF INTERMAP CANNOT REPLACE THE MEDIA, INTERMAP WILL REFUND THE AMOUNT CUSTOMER PAID FOR THE PRODUCTS. This warranty does not cover problems caused by customer's acts (or failure to act), the acts of others, or events beyond Intermap's reasonable control.

   b. EXCEPT FOR THE LIMITED WARRANTY SPECIFIED HEREIN, THE PRODUCTS ARE PROVIDED "AS IS" WITHOUT WARRANTY OF ANY KIND, AND ALL WARRANTIES EXPRESS OR IMPLIED, INCLUDING WARRANTIES OF NONINFRINGEMENT, MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE ARE HEREBY DISCLAIMED. NOT LIMITING THE FOREGOING, INTERMAP DOES NOT WARRANT THAT THE PRODUCTS WILL MEET CUSTOMER'S NEEDS OR EXPECTATIONS OR THAT USE OF THE PRODUCTS WILL BE ERROR FREE OR UNINTERRUPTED. IN NO EVENT WILL INTERMAP BE LIABLE FOR ANY CLAIM OR LOSS INCURRED BY CUSTOMER, INCLUDING WITHOUT LIMITATION INCIDENTAL, INDIRECT, SPECIAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES, EVEN IF ADVISED OF THE LIKELIHOOD OF SUCH DAMAGES. INTERMAP'S LIABILITY WILL NOT EXCEED THE LICENSE FEES PAID BY CUSTOMER TO INTERMAP WITH RESPECT TO THE PRODUCTS AT ISSUE. THE FOREGOING LIMITATIONS APPLY TO ALL CAUSES OF ACTION, INCLUDING WITHOUT LIMITATION BREACH OF CONTRACT OR WARRANTY OR TORT AND IS A MATERIAL INDUCEMENT FOR INTERMAP GRANTING THE RIGHTS HEREIN. Because some states and jurisdictions do not allow the foregoing limitations, such limitations may not apply to Customer.

8. **Indemnification.** Customer will defend, indemnify, and hold Intermap, its affiliates, directors, employees, licensors, and agents harmless from and against any claim, action, proceeding, loss, cost, expense, damages, and liability, including reasonable attorneys' fees, arising from: (1) Customer's use or other actions relating to the Products and/or (2) Customer's breach of any provision of this EULA.

9. **Term and Termination.**
   a. This EULA becomes effective upon use of the Product and will continue in force until terminated as provided herein. This EULA will terminate immediately if Customer fails to comply with any of its terms.
   b. Upon expiration or termination of this EULA for any reason, Customer will deliver to Intermap all copies and embodiments of the Products and derivative works, if any, and certify in writing that no copies are left in Customer's possession.
   c. Sections 2 through 8, 9(b) and (c), 10, 11 and 14 survive expiration or termination of this EULA.

10. **Governing Law.**
   a. This Agreement is governed and interpreted in accordance with the laws of the State of Colorado without regard to its conflicts of law provisions. The United Nations Convention on the International Sale of Goods does not apply.
   b. Any dispute arising between the parties out of or in connection with this Agreement will be finally resolved by arbitration conducted by one arbitrator in Denver, Colorado pursuant to the International Arbitration Rules of the American Arbitration Association ("AAA") applicable to commercial disputes. The Federal Arbitration Act, 9 U.S.C. Sec. 1-16, not state law, will govern such dispute. The arbitrator's award will be final and binding and may be entered in any court having jurisdiction thereof. Each party will bear its own costs and attorneys' fees, and will share equally in the fees and expenses of the arbitrator. The arbitration will be conducted in English, the governing language of this Agreement.
   c. Nothing in this section will restrict the ability of Intermap or its licensors to pursue any legal or equitable remedy or to obtain an injunction to protect any rights Intermap or its licensors may have rising out of or relating to the Product or any of Intermap or its licensors' intellectual property rights. Any breach of this Agreement by Customer will cause Intermap and its licensors irreparable harm for which there is no adequate legal remedy. In the event of any actual or threatened breach of this Agreement by Customer, Intermap and/or its licensors are entitled to obtain injunctive and all other appropriate relief from a court of competent authority, without being required to: (i) show any actual damage or irreparable harm, (ii) prove the inadequacy of its legal remedies, or (iii) post any bond or other security.

11. **Assignment.** Neither this EULA nor any of the rights granted by it may be assigned or transferred by Customer, including assignments or transfers by operation of law, as well as by contract, merger or consolidation. This Agreement is binding upon and will inure to the benefit of both parties and permitted successors.

12. **Export Licensing Notification.** The products delivered hereunder are subject to the export licensing regulations of the United States. Customer will comply with such regulations in its use of the Products. Customer is solely responsible for obtaining any and all required government authorizations, including without limitation, any export or import licenses and foreign exchange permits.

13. **Audit.** At Intermap's request, Customer will provide assurances that Customer is using the Products consistent with the terms of this EULA. Upon notice, Intermap may inspect Customer's premises and systems relating to the use of the Products to ensure compliance with this EULA.

14. **Miscellaneous.** This EULA and the Confirmation is the complete and exclusive agreement between Customer and Intermap with respect to the Products and may be amended or modified only in a written instrument signed by a duly authorized representative of both parties. In the event of a conflict between the EULA and the Confirmation, the terms of this EULA prevail. If any part of this EULA is found invalid, such invalidity will not affect the validity of remaining portions of this EULA, and the parties will promptly substitute for the invalid provision a provision that most closely approximates the intent and economic effect of the invalid provision. Failure by a Party to complain of any act or failure to act of the other Party or to declare the other Party in default, irrespective of the duration of such default, will not constitute a waiver of rights hereunder. This EULA will be interpreted solely in the English language, and no translation into any foreign language will have any effect.

Licensee Acceptance and Purchase Authority:

The undersigned, duly authorized representative of the Licensee hereby accepts this Price Quotation and authorizes the Company to provide the Licensee the products and services defined herein. By accepting this Price Quotation the Licensee accepts this document in its entirety including the End User License Agreement and the General Conditions of Price Quotation and Contract without modification.

Licensee Name Williston Vector Control District

Date 4-28-10

Name Barbara Peterson

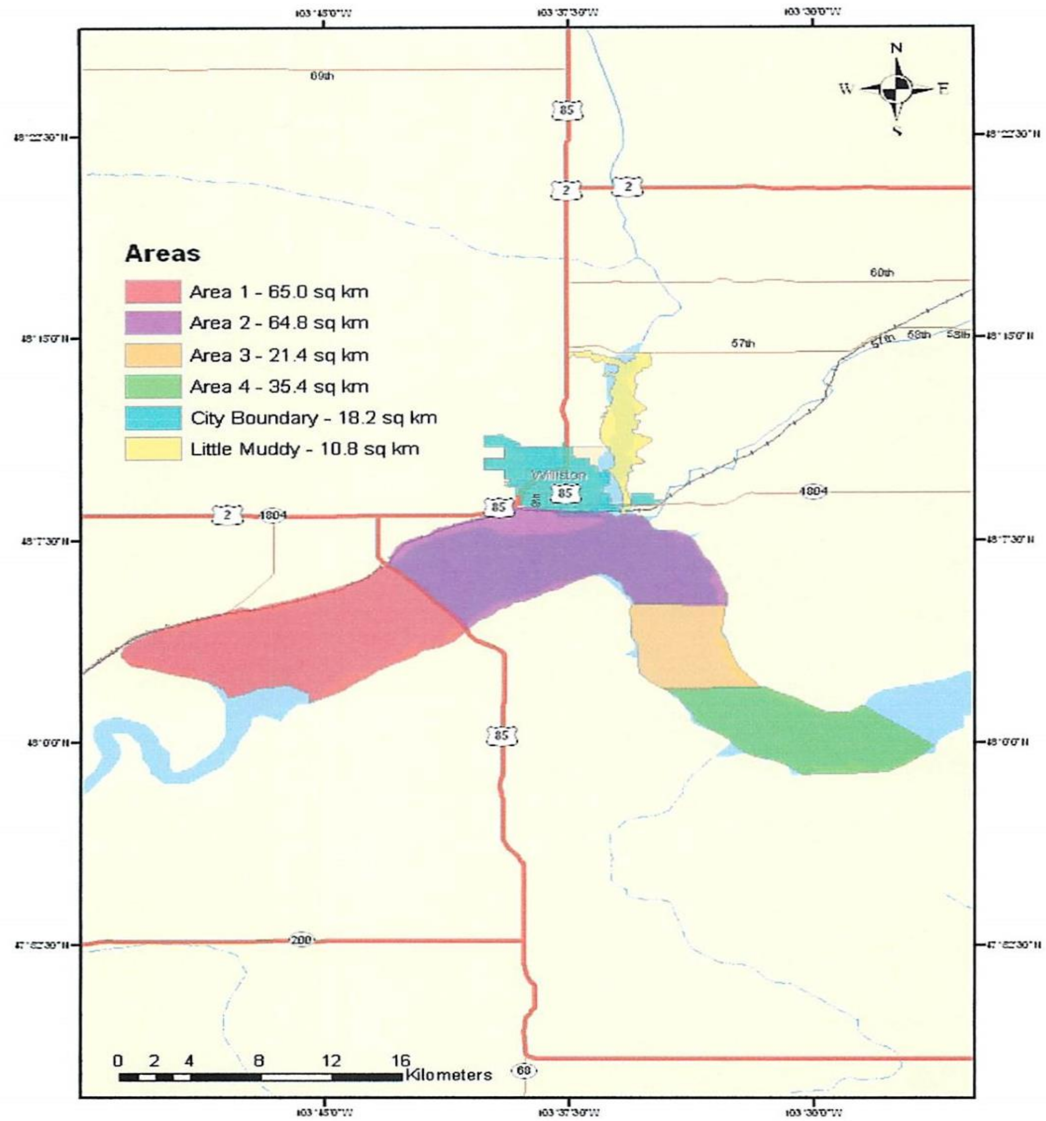
Title President

Signature Barbara Peterson

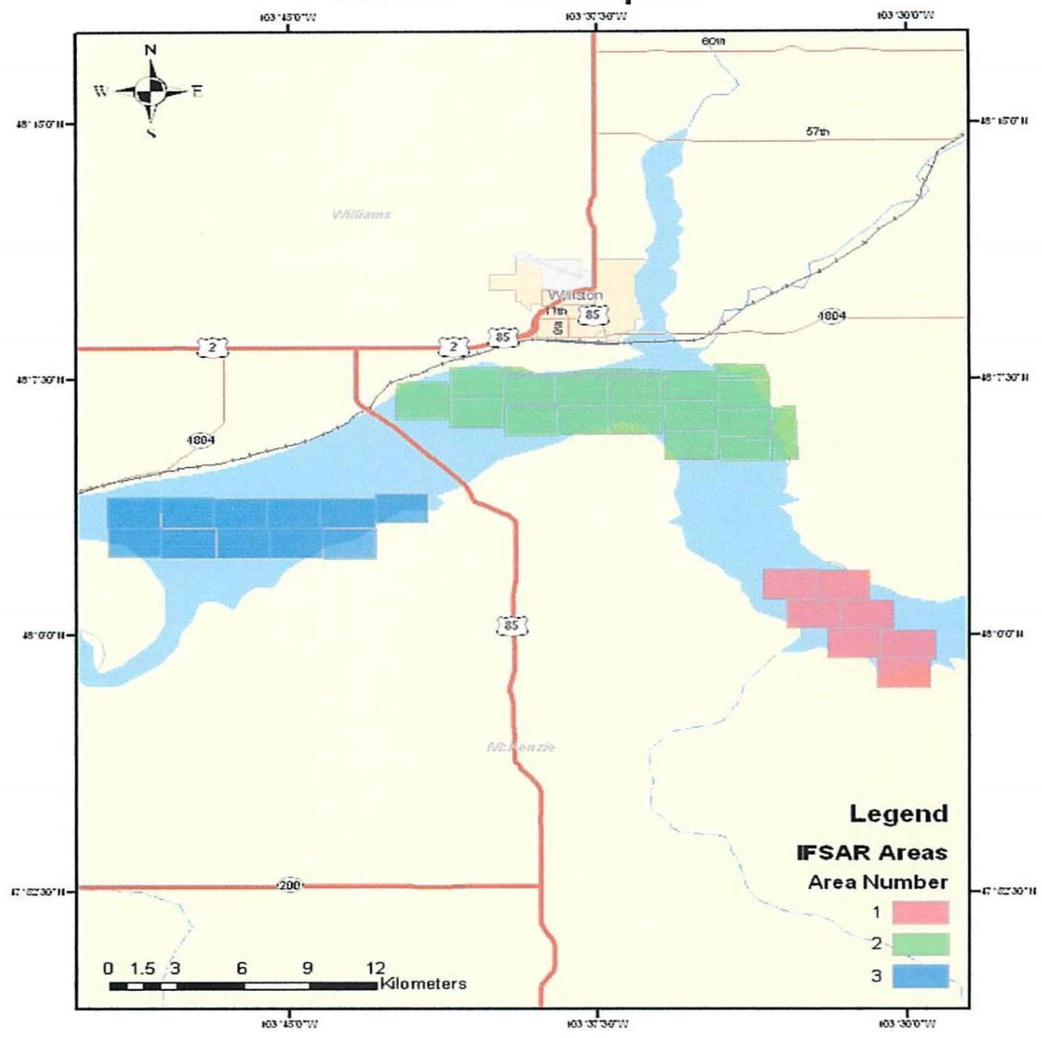
Purchase Order # or Reference ____________________

Appendix A
Licensee's Area of Interest

Attached to and made a part of Intermap Technologies Inc. EULA and the Intermap Technologies Inc. Price Quotation #10JD003, dated 14 April 2010.


Areas
Area 1 - 65.0 sq km
Area 2 - 64.8 sq km
Area 3 - 21.4 sq km
Area 4 - 35.4 sq km
City Boundary - 18.2 sq km
Little Muddy - 10.8 sq km
69th
60th
57th
Williston
85
2
1804
200
68
0 2 4 8 12 16 Kilometers
N
W
E
S

Area 1 = 28.6 sq km
Area 2 = 43.4 sq km
Area 3 = 17.8 sq km



APPENDIX J. DELIVERY DATE OF IFSAR DTM DATA

MAIL@WSC Page 1 of 2

Current Folder: **INBOX** **Sign Out**

Compose Addresses Folders Options Search Help NDSU-ITS

Message List | Delete Previous | Next Forward | Forward as Attachment | Reply | Reply All

Subject: Intermap Data Order 10JD003 for Williston Vector Control District
From: "Chris Lloyd" <clloyd@intermap.com>
Date: Thu, May 13, 2010 5:17 pm
To: "Jacquelin.stenehjem@wsc.nodak.edu" <Jacquelin.stenehjem@wsc.nodak.edu> (more)
Cc: "Jennifer Dubrow" <jdubrow@intermap.com> (more)
Priority: Normal
Options: View Full Header | View Printable Version | Download this as a file | View as HTML

Dear Jacquelin and Fran,

Thank you for your order, we appreciate your business.
The Intermap DTM v1.5 data you requested is available for immediate download via Box.net. Please see the login information below and let us know if you have any questions.

https://intermap.box.net/shared/qrfrpxv22o
Password: WVCD130510

Did you know you can access Intermap data anytime through our online data store?
For immediate access visit: www.TerrainOnDemand.com<http://www.TerrainOnDemand.com>
For more information on using Intermap products in commonly used software applications, refer to the Quick Start Guide of Intermap's Product Handbook.
http://www.intermap.com/right.php/pid/3/sid/311

Sincerely,
Chris

Christopher Lloyd
GIS Analyst | Intermap Technologies, Inc. | Denver, Colorado, USA
Tel. +1 303.708.0955 x236 | Fax. +1 303.708.0952
clloyd@intermap.com<mailto:clloyd@intermap.com> |
www.Intermap.com<https://exchange.usa.net/exchweb/bin/redir.asp?URL=http://www.inte
| www.AccuTerra.com<http://www.accuterra.com/>
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https://webmail.wsc.nodak.edu/src/read_body.php?mailbox=INBOX&passed_id=36217&s... 5/14/2010

APPENDIX K. INVOICE FOR LICENSE OF IFSAR DTM DATA, FIRST ORDER

Intermap Technologies Inc.
8310 South Valley Highway
Suite 400
Englewood Colorado 80112-5812

Invoice	INVITI000001909
Date	5/25/2010
Page	1

Bill To:

Williston Vector Company
PO BOX 17
Williston ND 58802
United States

Ship To:

Williston Vector Company
1201 4th Ave, E
Williston ND 58801
United States

Purchase Order No.	Customer ID	Salesperson ID	Shipping Method	Payment Terms	Req Ship Date	Order No.
10JD003_REVISED	WILLIS01		FTP	Net 30	5/25/2010	01160

Ordered	Item Number	Description	Unit Price	Ext. Price
65.00	DTM05MT2V1.5	Digital Terrain Model v1.5 - 5m Posting - Type II	US$35.00	US$2,275.00
1.00	PARTGM	Global Mapper	US$349.00	US$349.00
1.00	DISCOUNTSTANDARD	Product Discount	(US$349.00)	(US$349.00)
64.80	DTM05MT2V1.5	Digital Terrain Model v1.5 - 5m Posting - Type II	US$35.00	US$2,268.00
1.00	PARTGM	Global Mapper	US$349.00	US$349.00
1.00	DISCOUNTSTANDARD	Product Discount	(US$349.00)	(US$349.00)
10.80	DTM05MT2V1.5	Digital Terrain Model v1.5 - 5m Posting - Type II	US$35.00	US$378.00
1.00	PARTGM	Global Mapper	US$349.00	US$349.00
1.00	DISCOUNTSTANDARD	Product Discount	(US$349.00)	(US$349.00)

Payment Instructions:
Wells Fargo Bank NA
ABA 121000248
Swift WFBIUS6S
Account 402-0003505

Subtotal	US$4,921.00
Misc	US$0.00
Tax	US$0.00
Freight	US$0.00
Trade Discount	US$0.00
Total	US$4,921.00

APPENDIX L. INVOICE FOR LICENSE OF IFSAR DTM DATA, SECOND ORDER

INTERMAP

Thank you for your order, Jackie Stenehjem
Below is your NEXTMap Web Store order summary:

Billing Date: 10/29/2012 4:20:57 PM
E-mail Address: jacquelin.stenehjem@my.willistonstate.edu
Billing Address:

Jackie Stenehjem
1611 8th St. S.

Fargo, North Dakota 58103
United States

Order Details:

Order Number	48d1a4e7-9257-41ca-9752-c7301e309bfe
Order Date	10/29/2012 4:20:57 PM
Order Notes	
Payment Method	Credit Card
Order Items	

Name	Price
Basic: AOI.KMZ (DTM)	$480.00

Purchase Amount	$480.00
Tax	$0.00
Total	$480.00

Order Summary:

Puchase Amount	$480.00
Tax	$0.00
Total	**$480.00**

For questions, please call Intermap Customer Service at +1 877-837-7246 (please select option 1, toll free in US) for more information. Or, please email at webstoresupport@intermap.com

APPENDIX M. MOSQUITO LARVAE FOUND UNDER ICE, WILLISTON, APRIL 13, 1973

MINUTES
of
Williston Vector Control District No. 1

The 124th Meeting of the Williston Vector Control District No. 1 was called to order at 8:00 P.M., 16 April 1973, at the Health Unit offices, 210 First Avenue East, Williston, North Dakota.

ROLL CALL:

Commissioners: Ervin Rolfstad, Tomy Clausen, Joan Mendro
Advisor/Treas: Frank L. Onufray
Secretary: Sylvia Shae

READING OF THE MINUTES OF THE PREVIOUS MEETING:

The minutes of the previous meeting (2 April 1973) were read; being no corrections, deletions, or omissions, the minutes were approved as read.

READING OF COMMUNICATIONS:

Letter from Williston City Auditor Larvick regarding appointments of Mrs. Joe Mendro and Ervin Rolfstad.

Letter and information from Goodwin Hoff, Fargo City Sanitarian, regarding hand spreader equipment.

REPORTS:

Tomy Clausen stated he had contacted Civil Defense Director Groethe regarding a four-wheel drive vehicle, and that Groethe will keep him informed if such a vehicle becomes available.

OLD BUSINESS:

Discussion was held in regard to the hand spreader equipment, and the secretary was instructed to send information on the equipment to Summer Director Domrese for his comments.

NEW BUSINESS:

Discussion was held regarding the recent larvae collections made by Charisse Clausen, noting the larvae were found on April 7th underneath a cover of ice, and numerous large larvae were found on April 14th.

Frank L. Onufray reported he had talked to a couple auditors regarding the personal property payback payments, and the mill levy funds should be available early in May.

NEXT MEETING:

Being no further business, the meeting adjourned, with the next meeting to be Monday, 7 May 1973.

Sylvia Shae

Sylvia Shae
Secretary

APPENDIX N. PETITION TO ESTABLISH A VECTOR CONTROL DISTRICT FOR WILLISTON

NOTICE OF PUBLIC HEARING
PETITION TO ESTABLISH VECTOR CONTROL DISTRICT

Notice Is hereby given that a Petition has been filed with the ND State Health Council proposing to establish a Vector Control District pursuant to the provisions of Chapter 23-24 of the ND Century Code, said district legally described as follows:

> All of Sections 6 and 7 in Township 153 North, Range 100 West of the Fifth Principal Meridian, McKenzie County, ND; and all of Sections 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 17, and 18 in Township 153 North, Range 101 West of the Fifth Principal Meridian, McKenzie County, ND; and all of Sections 32, 33, 34, and 36 in Township 154 North, Range 101 West of the Fifth Principal Meridian, McKenzie County, ND; and all of Section 6 in Township 153 North, Range 101 West of the Fifth Principal Meridian, McKenzie County, ND; and all of Section 6 in Township 153 North, Range 101 West of the Fifth Principal Meridian, Williams County, ND; and all of Sections 5, 6, 7, 8, 9, 10, 16, 17, 18, 19, 20, 21, 29, 30, and 31 in Township 154 North, Range 100 West of the Fifth Principal Meridian, Williams County, ND; and all of Sections 1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, and 36 in Township 154 North, Range 101 West of the Fifth Principal Meridian, Williams County, ND; and all of Sections 19, 20, 29, 30, 31, and 32 in Township 155 North, Range 100 West of the Fifth Meridian, Williams County, ND; and all of Sections 23, 24, 25, 26, 27, 28, 29, 32, 33, 34, 35, and 36 in Township 155 North, Range 101 West of the Prime Meridian, Williams County, ND.

Freeholders within the limits of the proposed Vector Control District, as herein legally described, will be heard on the feasibility, desirability, necessity or practical pertaining to the establishment of the proposed district at a public hearing to be held in the Williams County Courthouse in the City of Williston, State of ND, at the hour of 2:00 o'clock in the afternoon of the 27th day of October 1966. The testimony of freeholders will be received in oral or written form.

Dated at Bismarck, ND, this 28th day of September 1966.
ND State Health Council

By____________________________________

W. Van Heuvelen, Executive Officer
ND State Department of Health

Reproduced by J. Stenehjem 2017

APPENDIX O. HUMAN CASES OF WNV PER STATE, PER YEAR, 1999 to 2015

West Nile virus disease cases reported to CDC by state of residence, 1999-2015

State	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Alabama	0	0	2	49	37	16	10	8	24	18	0
Alaska	0	0	0	0	0	0	0	0	0	0	0
Arizona	0	0	0	0	13	391	113	150	97	114	20
Arkansas	0	0	0	43	25	28	28	29	20	9	6
California	0	0	0	1	3	779	880	278	380	445	112
Colorado	0	0	0	14	2,947	291	106	345	576	71	103
Connecticut	0	1	6	17	17	1	6	9	4	8	0
Delaware	0	0	0	1	17	0	2	0	1	1	0
Dist. of Columbia	0	0	0	34	3	2	5	2	0	8	2
Florida	0	0	12	28	94	41	21	3	3	3	3
Georgia	0	0	6	44	50	21	20	8	50	8	4
Hawaii	0	0	0	0	0	0	0	0	0	0	0
Idaho	0	0	0	0	1	3	13	996	132	39	38
Illinois	0	0	0	884	54	60	252	215	101	20	5
Indiana	0	0	0	293	47	13	23	80	24	4	4
Iowa	0	0	0	54	147	23	37	37	30	6	5
Kansas	0	0	0	22	91	43	25	30	40	31	13
Kentucky	0	0	0	75	14	7	5	6	4	3	3
Louisiana	0	0	1	329	124	109	171	180	40	49	21
Maine	0	0	0	0	0	0	0	0	0	0	0
Maryland	0	0	6	36	73	16	5	11	10	14	1
Massachusetts	0	0	3	23	17	0	6	3	6	1	0
Michigan	0	0	0	614	19	16	62	55	17	17	1
Minnesota	0	0	0	48	148	34	45	65	101	10	4
Mississippi	0	0	0	192	87	51	70	183	136	65	53
Missouri	0	0	0	168	64	36	30	62	77	15	5
Montana	0	0	0	2	222	6	25	34	202	5	5
Nebraska	0	0	0	152	1,942	53	188	264	163	47	52
Nevada	0	0	0	0	2	44	31	124	12	16	12
New Hampshire	0	0	0	0	3	0	0	0	0	0	0
New Jersey	0	6	12	24	34	1	6	5	1	10	3
New Mexico	0	0	0	0	209	88	33	8	60	8	8
New York	62	14	15	82	71	10	38	24	22	46	7
North Carolina	0	0	0	2	24	3	4	1	8	3	0
North Dakota	0	0	0	17	617	20	86	137	369	37	1
Ohio	0	0	0	441	108	12	61	48	23	15	2
Oklahoma	0	0	0	21	79	22	31	48	107	9	10
Oregon	0	0	0	0	0	3	7	69	26	16	11
Pennsylvania	0	0	3	62	237	15	25	9	10	14	0
Puerto Rico	0	0	0	0	0	0	0	0	0	0	0
Rhode Island	0	0	0	1	7	0	1	0	1	1	0
South Carolina	0	0	0	1	6	2	5	1	5	1	3
South Dakota	0	0	0	37	1,039	51	229	113	208	39	21
Tennessee	0	0	0	56	26	14	18	22	11	19	9
Texas	0	0	0	202	720	176	195	354	260	64	115
Utah	0	0	0	0	1	11	52	158	70	26	2
Vermont	0	0	0	1	3	0	0	0	0	0	0
Virginia	0	0	0	29	26	5	1	5	5	1	5
Washington	0	0	0	0	0	0	0	3	0	3	38
West Virginia	0	0	0	3	2	0	0	1	0	1	0
Wisconsin	0	0	0	52	17	12	17	21	13	8	1
Wyoming	0	0	0	2	375	10	12	65	181	8	12
Total	**62**	**21**	**66**	**4,156**	**9,862**	**2,539**	**3,000**	**4,269**	**3,630**	**1,356**	**720**

Source: ArboNET, Arboviral Diseases Branch, Centers for Disease Control and Prevention

West Nile virus disease cases reported to CDC by state of residence, 1999-2015 (cont)

State	2010	2011	2012	2013	2014	2015	Total
Alabama	3	5	62	9	2	9	254
Alaska	0	0	0	0	0	0	0
Arizona	167	69	133	62	107	103	1,539
Arkansas	7	1	64	18	11	18	307
California	111	158	479	379	801	783	5,589
Colorado	81	7	131	322	118	101	5,213
Connecticut	11	9	21	4	6	10	130
Delaware	0	1	9	3	0	6	41
Dist. of Columbia	6	15	10	1	3	5	96
Florida	12	24	73	7	17	13	354
Georgia	13	22	99	10	13	15	383
Hawaii	0	0	0	0	1	0	1
Idaho	1	3	17	40	19	13	1,315
Illinois	61	34	290	117	44	77	2,214
Indiana	13	9	77	23	10	21	641
Iowa	9	9	31	44	15	14	461
Kansas	19	4	56	91	54	34	553
Kentucky	3	5	23	3	1	2	154
Louisiana	27	10	335	54	125	5	1,580
Maine	0	0	1	0	0	1	2
Maryland	23	19	47	16	6	45	328
Massachusetts	7	6	33	8	6	10	129
Michigan	29	34	202	36	1	18	1,121
Minnesota	8	2	70	79	21	9	644
Mississippi	8	52	247	45	43	38	1,270
Missouri	3	10	20	29	13	29	561
Montana	0	1	6	38	5	3	554
Nebraska	39	29	193	226	142	68	3,558
Nevada	2	16	9	11	3	7	289
New Hampshire	1	0	1	1	0	0	6
New Jersey	30	7	48	12	8	26	233
New Mexico	25	4	47	38	24	14	566
New York	128	44	107	32	26	57	785
North Carolina	0	2	7	3	0	4	61
North Dakota	9	4	89	125	23	23	1,557
Ohio	5	21	121	24	11	35	927
Oklahoma	1	1	191	89	18	89	716
Oregon	0	0	11	16	8	1	168
Pennsylvania	28	6	60	11	13	30	523
Puerto Rico	0	0	1	0	0	0	1
Rhode Island	0	1	4	1	0	0	17
South Carolina	1	0	29	7	3	0	64
South Dakota	20	2	203	149	57	40	2,208
Tennessee	4	18	33	24	16	8	278
Texas	89	27	1,868	183	379	275	4,907
Utah	2	3	5	7	2	8	347
Vermont	0	1	3	2	0	0	10
Virginia	5	9	30	6	7	21	155
Washington	2	0	4	1	12	24	87
West Virginia	0	2	10	1	0	0	20
Wisconsin	2	3	57	21	6	9	239
Wyoming	6	3	7	41	5	8	735
Total	**1,021**	**712**	**5,674**	**2,469**	**2,205**	**2,175**	**43,937**

Source: ArboNET, Arboviral Diseases Branch, Centers for Disease Control and Prevention

APPENDIX P. CULICIDAE SPECIES IDENTIFIED IN POSITIVE POOLS FOR WNV

Mosquito species in which West Nile virus has been detected, United States, 1999-2012

Mosquito Species
Aedes aegypti
Aedes albopictus
Aedes atlanticus/tormentor
Aedes atropalpus
Aedes canadensis
Aedes cantator
Aedes cinereus
Aedes condolescens*
Aedes dorsalis
Aedes dupreei
Aedes epactius
Aedes fitchii
Aedes fulvus pallens
Aedes grossbecki
Aedes infirmatus
Aedes japonicus
Aedes melanimon
Aedes nigromaculis
Aedes provocans
Aedes sollicitans
Aedes squamiger
Aedes sticticus
Aedes stimulans
Aedes taeniorhynchus
Aedes triseriatus
Aedes trivittatus
Aedes vexans
Anopheles atropos
Anopheles barberi
Anopheles bradleyi/crucians
Anopheles franciscanus
Anopheles freeborni
Anopheles hermsi
Anopheles punctipennis
Anopheles quadrimaculatus
Anopheles walkeri
Coquillettidia perturbans
Culex apicalis
Culex bahamensis
Culex coronator
Culex erraticus
Culex erythrothorax
Culex nigripalpus
Culex pipiens
Culex quinquefasciatus
Culex restuans
Culex salinarius
Culex stigmatosoma
Culex tarsalis
Culex territans
Culex thriambus
Culiseta incidens
Culiseta impatiens
Culiseta inornata

Mosquito Species
Culiseta melanura
Culiseta morsitans
Culiseta particeps
Deinocerites cancer
Mansonia titillans
Orthopodomyia signifera
Psorophora ciliata
Psorophora columbiae
Psorophora ferox
Psorophora howardii
Uranotaenia sapphirina

* This species was detected in 2003 in Monroe County, FL; but was not reported to ArboNET

APPENDIX Q. SURGE AND RECESSION CYCLES OF MISSOURI RIVER ELEVATIONS, 2009

Operator	Gaging Station No.	Date	Elevation (m msl)	Approved (A) Provisional (P)	Elevation (ft msl)
USGS	6330000	1/1/2009	16.93	A	1847.13
USGS	6330000	1/2/2009	17.06	A	1847.26
USGS	6330000	1/6/2009	17.12	A	1847.32
USGS	6330000	1/7/2009	17.03	A	1847.23
USGS	6330000	1/8/2009	16.98	A	1847.18
USGS	6330000	1/9/2009	16.91	A	1847.11
USGS	6330000	1/10/2009	16.77	A	1846.97
USGS	6330000	1/11/2009	16.77	A	1846.97
USGS	6330000	1/12/2009	16.85	A	1847.05
USGS	6330000	1/13/2009	16.82	A	1847.02
USGS	6330000	1/14/2009	16.80	A	1847.00
USGS	6330000	1/15/2009	16.90	A	1847.10
USGS	6330000	1/16/2009	16.99	A	1847.19
USGS	6330000	1/17/2009	17.06	A	1847.26
USGS	6330000	1/18/2009	16.96	A	1847.16
USGS	6330000	1/19/2009	16.82	A	1847.02
USGS	6330000	1/20/2009	16.84	A	1847.04
USGS	6330000	1/21/2009	16.78	A	1846.98
USGS	6330000	1/22/2009	16.75	A	1846.95
USGS	6330000	1/23/2009	16.76	A	1846.96
USGS	6330000	1/24/2009	16.81	A	1847.01
USGS	6330000	1/25/2009	16.81	A	1847.01
USGS	6330000	1/26/2009	16.66	A	1846.86
USGS	6330000	1/27/2009	16.38	A	1846.58
USGS	6330000	1/28/2009	16.21	A	1846.41
USGS	6330000	1/29/2009	16.01	A	1846.21
USGS	6330000	1/30/2009	15.77	A	1845.97
USGS	6330000	1/31/2009	15.58	A	1845.78
USGS	6330000	2/1/2009	15.54	A	1845.74
USGS	6330000	2/2/2009	15.67	A	1845.87
USGS	6330000	2/3/2009	15.81	A	1846.01
USGS	6330000	2/4/2009	15.97	A	1846.17
USGS	6330000	2/5/2009	16.14	A	1846.34
USGS	6330000	2/6/2009	16.18	A	1846.38
USGS	6330000	2/7/2009	16.33	A	1846.53
USGS	6330000	2/8/2009	16.42	A	1846.62
USGS	6330000	2/9/2009	16.50	A	1846.70
USGS	6330000	2/10/2009	16.73	A	1846.93
USGS	6330000	2/11/2009	16.89	A	1847.09
USGS	6330000	2/12/2009	16.94	A	1847.14
USGS	6330000	2/13/2009	16.92	A	1847.12

Operator	Gaging Station No.	Date	Elevation (m msl)	Approved (A) Provisional (P)	Elevation (ft msl)
USGS	6330000	2/14/2009	16.91	A	1847.11
USGS	6330000	2/16/2009	16.77	A	1846.97
USGS	6330000	2/17/2009	16.63	A	1846.83
USGS	6330000	2/18/2009	16.42	A	1846.62
USGS	6330000	2/19/2009	16.33	A	1846.53
USGS	6330000	2/20/2009	16.42	A	1846.62
USGS	6330000	2/21/2009	16.49	A	1846.69
USGS	6330000	2/22/2009	16.44	A	1846.64
USGS	6330000	2/23/2009	16.45	A	1846.65
USGS	6330000	2/24/2009	16.40	A	1846.60
USGS	6330000	2/25/2009	16.31	A	1846.51
USGS	6330000	2/26/2009	16.26	A	1846.46
USGS	6330000	2/27/2009	16.26	A	1846.46
USGS	6330000	2/28/2009	16.29	A	1846.49
USGS	6330000	3/1/2009	16.23	A	1846.43
USGS	6330000	3/2/2009	16.02	A	1846.22
USGS	6330000	3/3/2009	15.82	A	1846.02
USGS	6330000	3/4/2009	15.79	A	1845.99
USGS	6330000	3/5/2009	15.80	A	1846.00
USGS	6330000	3/6/2009	16.39	A	1846.59
USGS	6330000	3/7/2009	17.03	A	1847.23
USGS	6330000	3/8/2009	17.62	A	1847.82
USGS	6330000	3/9/2009	18.00	A	1848.20
USGS	6330000	3/10/2009	17.79	A	1847.99
USGS	6330000	3/11/2009	17.47	A	1847.67
USGS	6330000	3/12/2009	16.95	A	1847.15
USGS	6330000	3/13/2009	16.16	A	1846.36
USGS	6330000	3/14/2009	15.62	A	1845.82
USGS	6330000	3/15/2009	15.35	A	1845.55
USGS	6330000	3/16/2009	15.40	A	1845.60
USGS	6330000	3/17/2009	16.27	A	1846.47
USGS	6330000	3/18/2009	17.57	A	1847.77
USGS	6330000	3/19/2009	18.15	A	1848.35
USGS	6330000	3/20/2009	18.28	A	1848.48
USGS	6330000	3/21/2009	18.48	A	1848.68
USGS	6330000	3/22/2009	19.20	A	1849.40
USGS	6330000	3/23/2009	19.54	A	1849.74
USGS	6330000	3/24/2009	19.52	A	1849.72
USGS	6330000	3/25/2009	18.95	A	1849.15
USGS	6330000	3/26/2009	18.38	A	1848.58
USGS	6330000	3/27/2009	18.07	A	1848.27
USGS	6330000	3/28/2009	17.89	A	1848.09

Operator	Gaging Station No.	Date	Elevation (m msl)	Approved (A) Provisional (P)	Elevation (ft msl)
USGS	6330000	3/29/2009	17.89	A	1848.09
USGS	6330000	3/30/2009	17.87	A	1848.07
USGS	6330000	3/31/2009	17.96	A	1848.16
USGS	6330000	4/3/2009	18.33	A	1848.53
USGS	6330000	4/4/2009	17.57	A	1847.77
USGS	6330000	4/5/2009	16.00	A	1846.20
USGS	6330000	4/6/2009	14.94	A	1845.14
USGS	6330000	4/7/2009	14.34	A	1844.54
USGS	6330000	4/8/2009	14.64	A	1844.84
USGS	6330000	4/9/2009	15.10	A	1845.30
USGS	6330000	4/10/2009	15.89	A	1846.09
USGS	6330000	4/11/2009	15.57	A	1845.77
USGS	6330000	4/12/2009	15.15	A	1845.35
USGS	6330000	4/13/2009	14.96	A	1845.16
USGS	6330000	4/14/2009	15.11	A	1845.31
USGS	6330000	4/15/2009	15.21	A	1845.41
USGS	6330000	4/16/2009	15.39	A	1845.59
USGS	6330000	4/17/2009	15.51	A	1845.71
USGS	6330000	4/18/2009	15.47	A	1845.67
USGS	6330000	4/19/2009	15.39	A	1845.59
USGS	6330000	4/20/2009	15.23	A	1845.43
USGS	6330000	4/21/2009	14.94	A	1845.14
USGS	6330000	4/22/2009	14.65	A	1844.85
USGS	6330000	4/23/2009	14.45	A	1844.65
USGS	6330000	4/24/2009	14.42	A	1844.62
USGS	6330000	4/25/2009	14.45	A	1844.65
USGS	6330000	4/26/2009	14.65	A	1844.85
USGS	6330000	4/27/2009	15.07	A	1845.27
USGS	6330000	4/28/2009	15.62	A	1845.82
USGS	6330000	4/29/2009	15.83	A	1846.03
USGS	6330000	4/30/2009	15.76	A	1845.96
USGS	6330000	5/1/2009	15.79	A	1845.99
USGS	6330000	5/2/2009	15.85	A	1846.05
USGS	6330000	5/3/2009	15.94	A	1846.14
USGS	6330000	5/4/2009	15.81	A	1846.01
USGS	6330000	5/5/2009	15.71	A	1845.91
USGS	6330000	5/6/2009	15.79	A	1845.99
USGS	6330000	5/7/2009	16.14	A	1846.34
USGS	6330000	5/8/2009	16.21	A	1846.41
USGS	6330000	5/9/2009	16.19	A	1846.39
USGS	6330000	5/10/2009	16.30	A	1846.50
USGS	6330000	5/11/2009	16.39	A	1846.59
USGS	6330000	5/12/2009	16.58	A	1846.78

Operator	Gaging Station No.	Date	Elevation (m msl)	Approved (A) Provisional (P)	Elevation (ft msl)
USGS	6330000	5/13/2009	16.74	A	1846.94
USGS	6330000	5/14/2009	16.83	A	1847.03
USGS	6330000	5/15/2009	16.75	A	1846.95
USGS	6330000	5/16/2009	16.84	A	1847.04
USGS	6330000	5/17/2009	16.97	A	1847.17
USGS	6330000	5/18/2009	17.07	A	1847.27
USGS	6330000	5/19/2009	16.94	A	1847.14
USGS	6330000	5/20/2009	16.80	A	1847.00
USGS	6330000	5/21/2009	16.81	A	1847.01
USGS	6330000	5/22/2009	17.32	A	1847.52
USGS	6330000	5/23/2009	18.77	A	1848.97
USGS	6330000	5/24/2009	19.96	A	1850.16
USGS	6330000	5/25/2009	20.10	A	1850.30
USGS	6330000	5/26/2009	19.82	A	1850.02
USGS	6330000	5/27/2009	19.72	A	1849.92
USGS	6330000	5/28/2009	19.79	A	1849.99
USGS	6330000	5/29/2009	19.88	A	1850.08
USGS	6330000	5/30/2009	19.92	A	1850.12
USGS	6330000	5/31/2009	19.78	A	1849.98
USGS	6330000	6/1/2009	19.65	A	1849.85
USGS	6330000	6/2/2009	19.76	A	1849.96
USGS	6330000	6/3/2009	19.92	A	1850.12
USGS	6330000	6/4/2009	19.89	A	1850.09
USGS	6330000	6/5/2009	19.92	A	1850.12
USGS	6330000	6/6/2009	19.81	A	1850.01
USGS	6330000	6/7/2009	19.53	A	1849.73
USGS	6330000	6/8/2009	19.32	A	1849.52
USGS	6330000	6/9/2009	19.18	A	1849.38
USGS	6330000	6/10/2009	19.26	A	1849.46
USGS	6330000	6/11/2009	19.57	A	1849.77
USGS	6330000	6/12/2009	19.44	A	1849.64
USGS	6330000	6/13/2009	19.11	A	1849.31
USGS	6330000	6/14/2009	19.27	A	1849.47
USGS	6330000	6/15/2009	19.56	A	1849.76
USGS	6330000	6/16/2009	19.53	A	1849.73
USGS	6330000	6/17/2009	19.61	A	1849.81
USGS	6330000	6/18/2009	19.85	A	1850.05
USGS	6330000	6/19/2009	20.20	A	1850.40
USGS	6330000	6/20/2009	20.49	A	1850.69
USGS	6330000	6/21/2009	20.65	A	1850.85
USGS	6330000	6/22/2009	20.84	A	1851.04
USGS	6330000	6/23/2009	20.95	A	1851.15

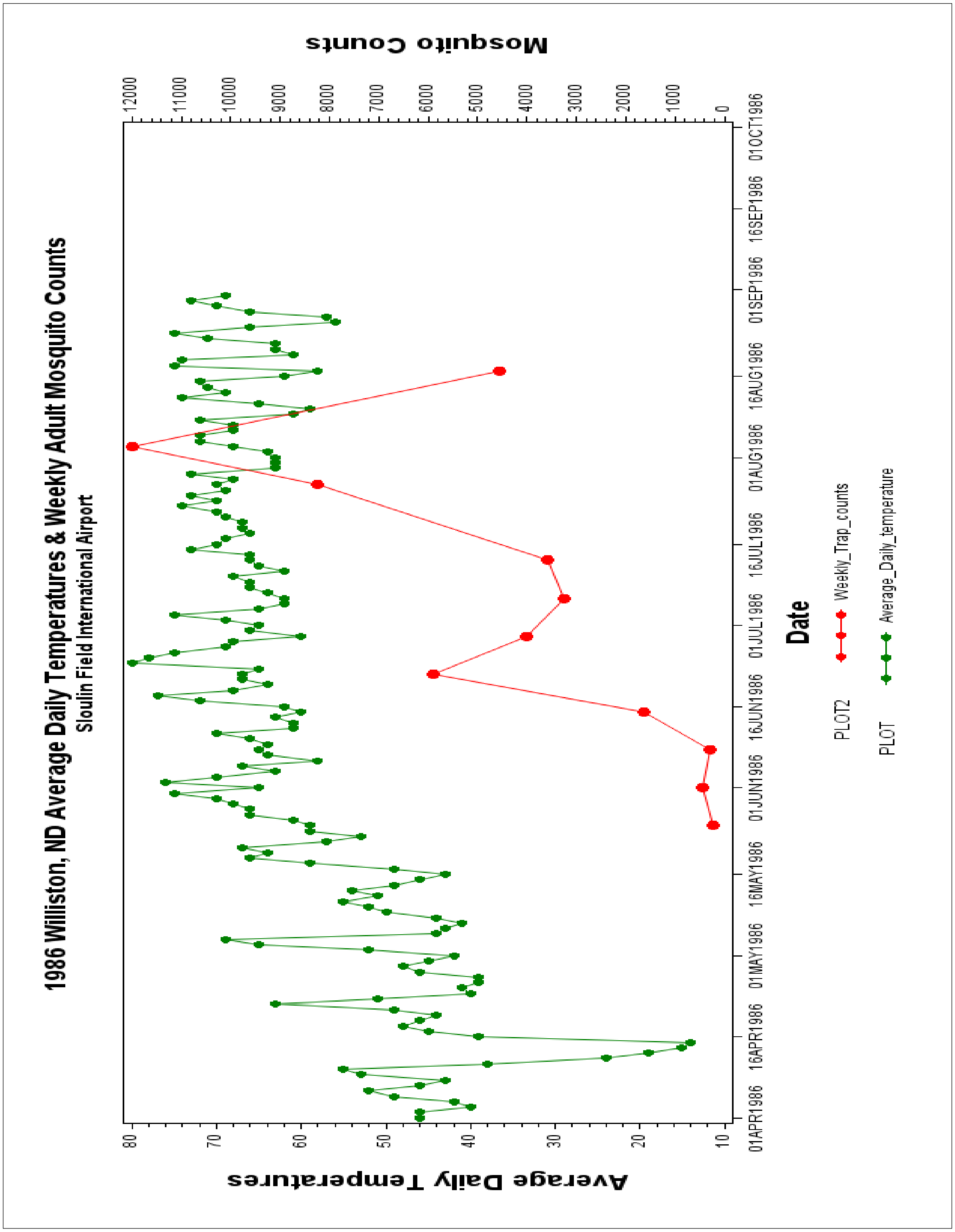
Operator	Gaging Station No.	Date	Elevation (m msl)	Approved (A) Provisional (P)	Elevation (ft msl)
USGS	6330000	6/24/2009	20.95	A	1851.15
USGS	6330000	6/25/2009	21.03	A	1851.23
USGS	6330000	6/26/2009	21.24	A	1851.44
USGS	6330000	6/27/2009	21.13	A	1851.33
USGS	6330000	6/28/2009	20.82	A	1851.02
USGS	6330000	7/1/2009	20.99	A	1851.19
USGS	6330000	7/2/2009	20.89	A	1851.09
USGS	6330000	7/3/2009	20.76	A	1850.96
USGS	6330000	7/4/2009	20.80	A	1851.00
USGS	6330000	7/5/2009	20.82	A	1851.02
USGS	6330000	7/6/2009	20.92	A	1851.12
USGS	6330000	7/7/2009	20.96	A	1851.16
USGS	6330000	7/8/2009	20.89	A	1851.09
USGS	6330000	7/9/2009	20.67	A	1850.87
USGS	6330000	7/10/2009	20.41	A	1850.61
USGS	6330000	7/11/2009	20.18	A	1850.38
USGS	6330000	7/12/2009	19.95	A	1850.15
USGS	6330000	7/13/2009	19.73	A	1849.93
USGS	6330000	7/22/2009	17.10	A	1847.30
USGS	6330000	7/23/2009	16.76	A	1846.96
USGS	6330000	7/24/2009	16.46	A	1846.66
USGS	6330000	7/25/2009	16.33	A	1846.53
USGS	6330000	7/26/2009	16.13	A	1846.33
USGS	6330000	7/27/2009	15.98	A	1846.18
USGS	6330000	7/28/2009	15.83	A	1846.03
USGS	6330000	7/29/2009	15.80	A	1846.00
USGS	6330000	7/30/2009	15.90	A	1846.10
USGS	6330000	7/31/2009	15.87	A	1846.07
USGS	6330000	8/1/2009	15.95	A	1846.15
USGS	6330000	8/2/2009	16.08	A	1846.28
USGS	6330000	8/3/2009	16.04	A	1846.24
USGS	6330000	8/4/2009	15.91	A	1846.11
USGS	6330000	8/5/2009	15.80	A	1846.00
USGS	6330000	8/6/2009	15.76	A	1845.96
USGS	6330000	8/7/2009	15.69	A	1845.89
USGS	6330000	8/8/2009	15.63	A	1845.83
USGS	6330000	8/9/2009	16.15	A	1846.35
USGS	6330000	8/10/2009	16.60	A	1846.80
USGS	6330000	8/11/2009	16.52	A	1846.72
USGS	6330000	8/12/2009	16.30	A	1846.50
USGS	6330000	8/13/2009	16.10	A	1846.30
USGS	6330000	8/14/2009	15.87	A	1846.07

Operator	Gaging Station No.	Date	Elevation (m msl)	Approved (A) Provisional (P)	Elevation (ft msl)
USGS	6330000	8/15/2009	15.92	A	1846.12
USGS	6330000	8/16/2009	15.76	A	1845.96
USGS	6330000	8/17/2009	15.62	A	1845.82
USGS	6330000	8/18/2009	15.65	A	1845.85
USGS	6330000	8/19/2009	15.69	A	1845.89
USGS	6330000	8/20/2009	15.55	A	1845.75
USGS	6330000	8/21/2009	15.51	A	1845.71
USGS	6330000	8/22/2009	15.49	A	1845.69
USGS	6330000	8/23/2009	15.35	A	1845.55
USGS	6330000	8/24/2009	15.26	A	1845.46
USGS	6330000	8/25/2009	15.14	A	1845.34
USGS	6330000	9/1/2009	14.82	A	1845.02
USGS	6330000	9/2/2009	14.72	A	1844.92
USGS	6330000	9/3/2009	14.74	A	1844.94
USGS	6330000	9/4/2009	14.77	A	1844.97
USGS	6330000	9/5/2009	14.69	A	1844.89
USGS	6330000	9/6/2009	14.73	A	1844.93
USGS	6330000	9/7/2009	14.73	A	1844.93
USGS	6330000	9/8/2009	14.67	A	1844.87
USGS	6330000	9/9/2009	14.71	A	1844.91
USGS	6330000	9/10/2009	14.67	A	1844.87
USGS	6330000	9/11/2009	14.59	A	1844.79
USGS	6330000	9/12/2009	14.66	A	1844.86
USGS	6330000	9/13/2009	14.71	A	1844.91
USGS	6330000	9/14/2009	14.74	A	1844.94
USGS	6330000	9/15/2009	14.66	A	1844.86
USGS	6330000	9/16/2009	14.64	A	1844.84
USGS	6330000	9/17/2009	14.62	A	1844.82
USGS	6330000	9/18/2009	14.62	A	1844.82
USGS	6330000	9/19/2009	14.61	A	1844.81
USGS	6330000	9/20/2009	14.38	A	1844.58
USGS	6330000	9/23/2009	14.06	A	1844.26
USGS	6330000	9/24/2009	14.04	A	1844.24
USGS	6330000	9/25/2009	14.02	A	1844.22
USGS	6330000	9/26/2009	14.01	A	1844.21
USGS	6330000	9/27/2009	13.79	A	1843.99
USGS	6330000	9/28/2009	13.89	A	1844.09
USGS	6330000	9/29/2009	14.30	A	1844.50
USGS	6330000	9/30/2009	14.23	A	1844.43
USGS	6330000	10/1/2009	13.83	A	1844.03
USGS	6330000	10/2/2009	13.90	A	1844.10
USGS	6330000	10/3/2009	14.04	A	1844.24

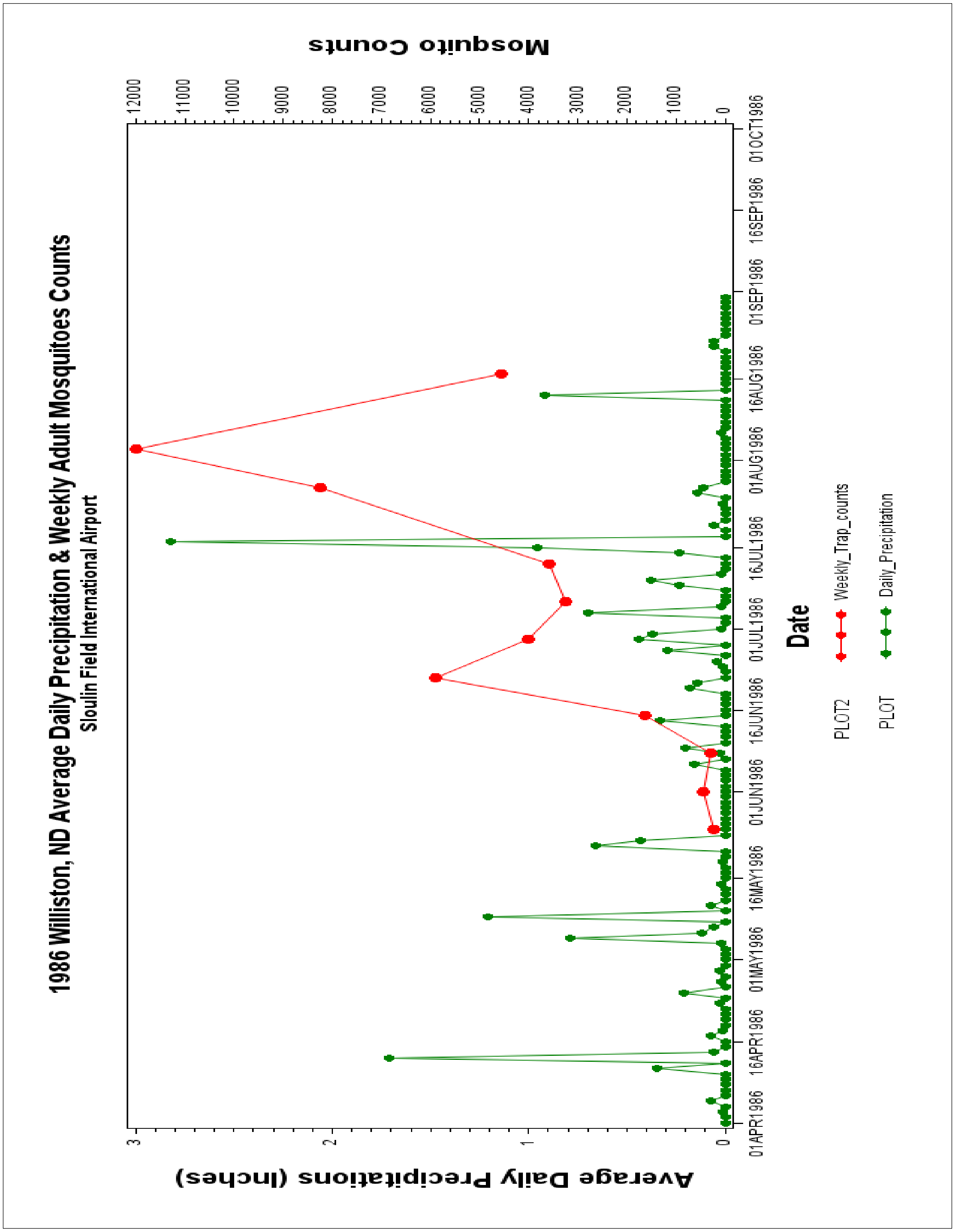
Operator	Gaging Station No.	Date	Elevation (m msl)	Approved (A) Provisional (P)	Elevation (ft msl)
USGS	6330000	10/4/2009	14.10	A	1844.30
USGS	6330000	10/5/2009	14.17	A	1844.37
USGS	6330000	10/6/2009	14.22	A	1844.42
USGS	6330000	10/7/2009	14.16	A	1844.36
USGS	6330000	10/8/2009	14.29	A	1844.49
USGS	6330000	10/9/2009	14.34	A	1844.54
USGS	6330000	10/10/2009	14.28	A	1844.48
USGS	6330000	10/11/2009	14.35	A	1844.55
USGS	6330000	10/12/2009	14.37	A	1844.57
USGS	6330000	10/13/2009	14.49	A	1844.69
USGS	6330000	10/14/2009	14.56	A	1844.76
USGS	6330000	10/15/2009	14.41	A	1844.61
USGS	6330000	10/16/2009	14.34	A	1844.54
USGS	6330000	10/17/2009	14.37	A	1844.57
USGS	6330000	10/18/2009	14.34	A	1844.54
USGS	6330000	10/19/2009	14.36	A	1844.56
USGS	6330000	10/20/2009	14.54	A	1844.74
USGS	6330000	10/21/2009	14.60	A	1844.80
USGS	6330000	10/22/2009	14.53	A	1844.73
USGS	6330000	10/23/2009	14.38	A	1844.58
USGS	6330000	10/24/2009	14.29	A	1844.49
USGS	6330000	10/25/2009	14.16	A	1844.36
USGS	6330000	10/26/2009	14.17	A	1844.37
USGS	6330000	10/27/2009	14.40	A	1844.60
USGS	6330000	10/28/2009	14.36	A	1844.56
USGS	6330000	10/29/2009	14.37	A	1844.57
USGS	6330000	10/30/2009	14.39	A	1844.59
USGS	6330000	10/31/2009	14.41	A	1844.61
USGS	6330000	11/1/2009	14.35	A	1844.55
USGS	6330000	11/2/2009	14.28	A	1844.48
USGS	6330000	11/3/2009	14.26	A	1844.46
USGS	6330000	11/4/2009	14.22	A	1844.42
USGS	6330000	11/5/2009	14.26	A	1844.46
USGS	6330000	11/6/2009	14.22	A	1844.42
USGS	6330000	11/7/2009	14.11	A	1844.31
USGS	6330000	11/8/2009	14.21	A	1844.41
USGS	6330000	11/9/2009	14.17	A	1844.37
USGS	6330000	11/10/2009	14.13	A	1844.33
USGS	6330000	11/11/2009	14.09	A	1844.29
USGS	6330000	11/12/2009	14.08	A	1844.28
USGS	6330000	11/13/2009	14.09	A	1844.29
USGS	6330000	11/14/2009	14.09	A	1844.29

Operator	Gaging Station No.	Date	Elevation (m msl)	Approved (A) Provisional (P)	Elevation (ft msl)
USGS	6330000	11/15/2009	14.08	A	1844.28
USGS	6330000	11/16/2009	14.10	A	1844.30
USGS	6330000	11/17/2009	14.14	A	1844.34
USGS	6330000	11/18/2009	14.17	A	1844.37
USGS	6330000	11/19/2009	14.07	A	1844.27
USGS	6330000	11/20/2009	14.06	A	1844.26
USGS	6330000	11/21/2009	14.04	A	1844.24
USGS	6330000	11/22/2009	13.99	A	1844.19
USGS	6330000	11/23/2009	14.04	A	1844.24
USGS	6330000	11/24/2009	14.00	A	1844.20
USGS	6330000	11/25/2009	13.92	A	1844.12
USGS	6330000	11/26/2009	13.99	A	1844.19
USGS	6330000	11/27/2009	13.95	A	1844.15
USGS	6330000	11/28/2009	13.92	A	1844.12
USGS	6330000	11/29/2009	13.92	A	1844.12
USGS	6330000	11/30/2009	13.90	A	1844.10
USGS	6330000	12/1/2009	13.82	A	1844.02
USGS	6330000	12/2/2009	13.82	A	1844.02
USGS	6330000	12/3/2009	13.94	A	1844.14
USGS	6330000	12/4/2009	14.53	A	1844.73
USGS	6330000	12/5/2009	14.16	A	1844.36
USGS	6330000	12/6/2009	13.97	A	1844.17
USGS	6330000	12/7/2009	13.96	A	1844.16
USGS	6330000	12/8/2009	13.72	A	1843.92
USGS	6330000	12/9/2009	13.78	A	1843.98
USGS	6330000	12/10/2009	13.83	A	1844.03
USGS	6330000	12/11/2009	13.55	A	1843.75
USGS	6330000	12/12/2009	13.30	A	1843.50
USGS	6330000	12/13/2009	13.20	A	1843.40
USGS	6330000	12/14/2009	13.14	A	1843.34
USGS	6330000	12/15/2009	13.32	A	1843.52
USGS	6330000	12/16/2009	13.57	A	1843.77
USGS	6330000	12/17/2009	13.87	A	1844.07
USGS	6330000	12/18/2009	14.07	A	1844.27
USGS	6330000	12/19/2009	14.15	A	1844.35
USGS	6330000	12/20/2009	14.14	A	1844.34
USGS	6330000	12/21/2009	14.38	A	1844.58
USGS	6330000	12/22/2009	14.68	A	1844.88
USGS	6330000	12/23/2009	15.03	A	1845.23
USGS	6330000	12/24/2009	15.31	A	1845.51
USGS	6330000	12/25/2009	15.41	A	1845.61
USGS	6330000	12/26/2009	15.36	A	1845.56

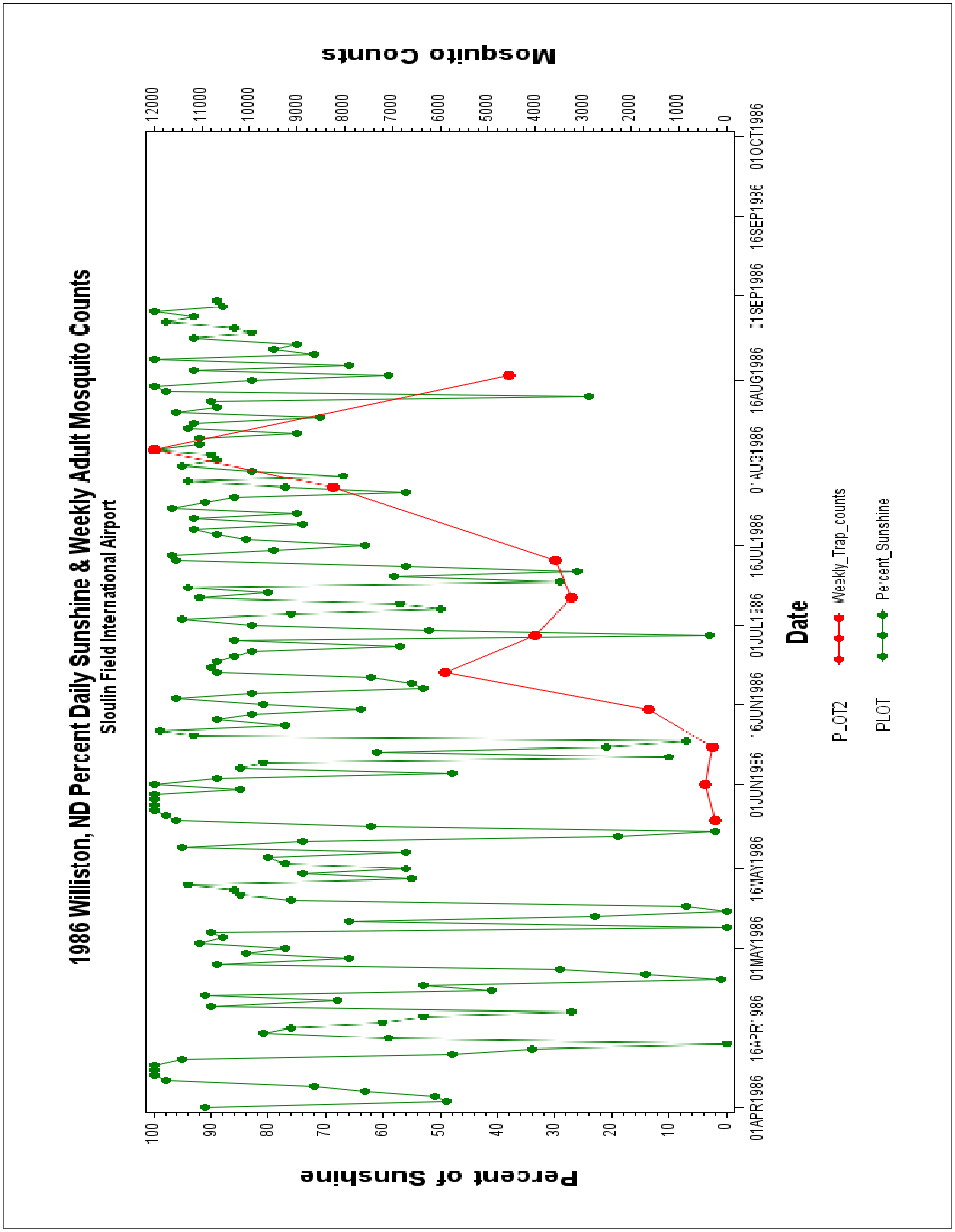
APPENDIX R. TREND ANALYSIS: DAILY WEATHER VARIABLES VS. WEEKLY ADULT MOSQUITO COLLECTIONS, 1986 to 1989



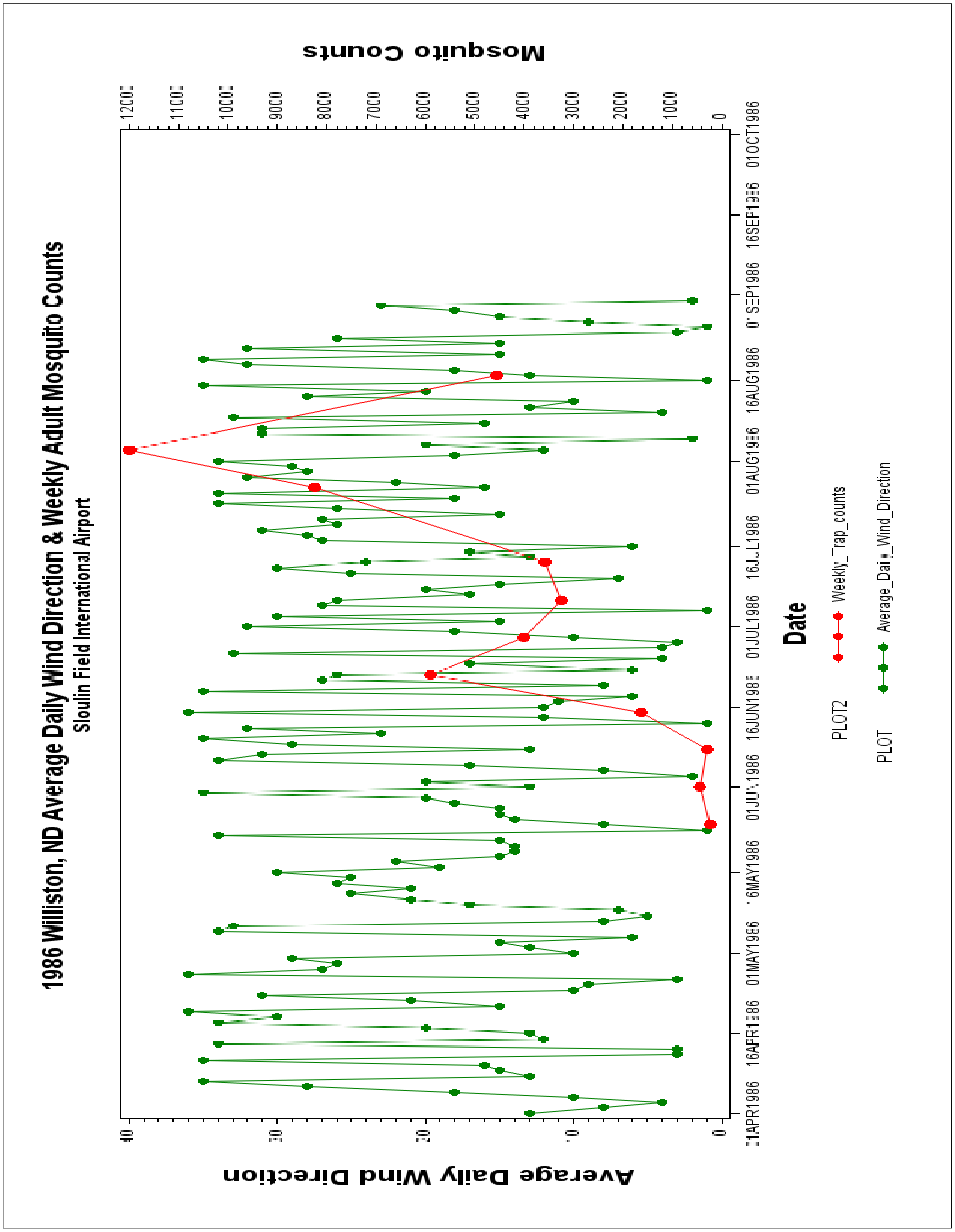
Data source: NOAA daily weather data and ND Department of Health adult mosquito light trap counts



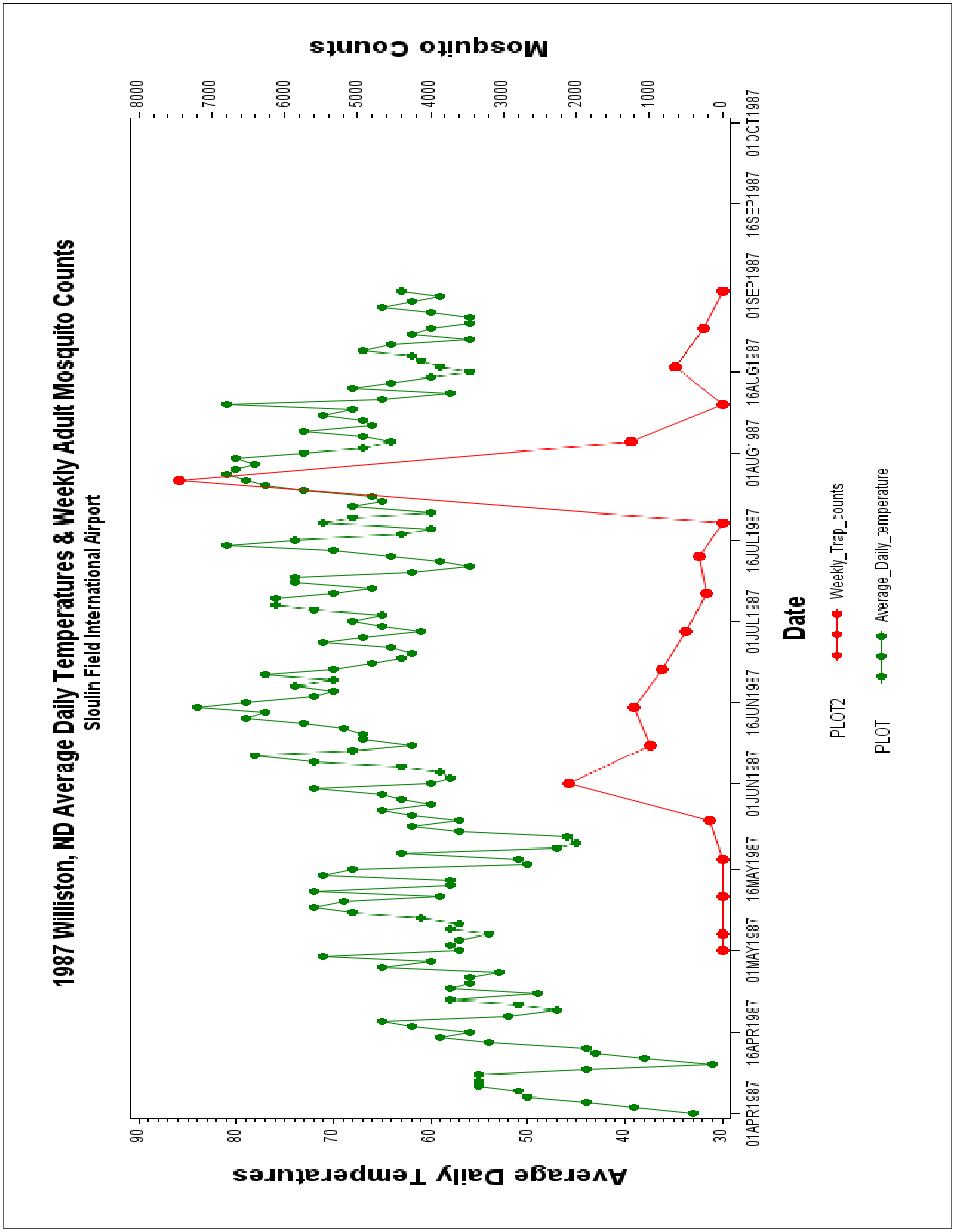
Data source: NOAA daily weather data and ND Department of Health adult mosquito light trap counts



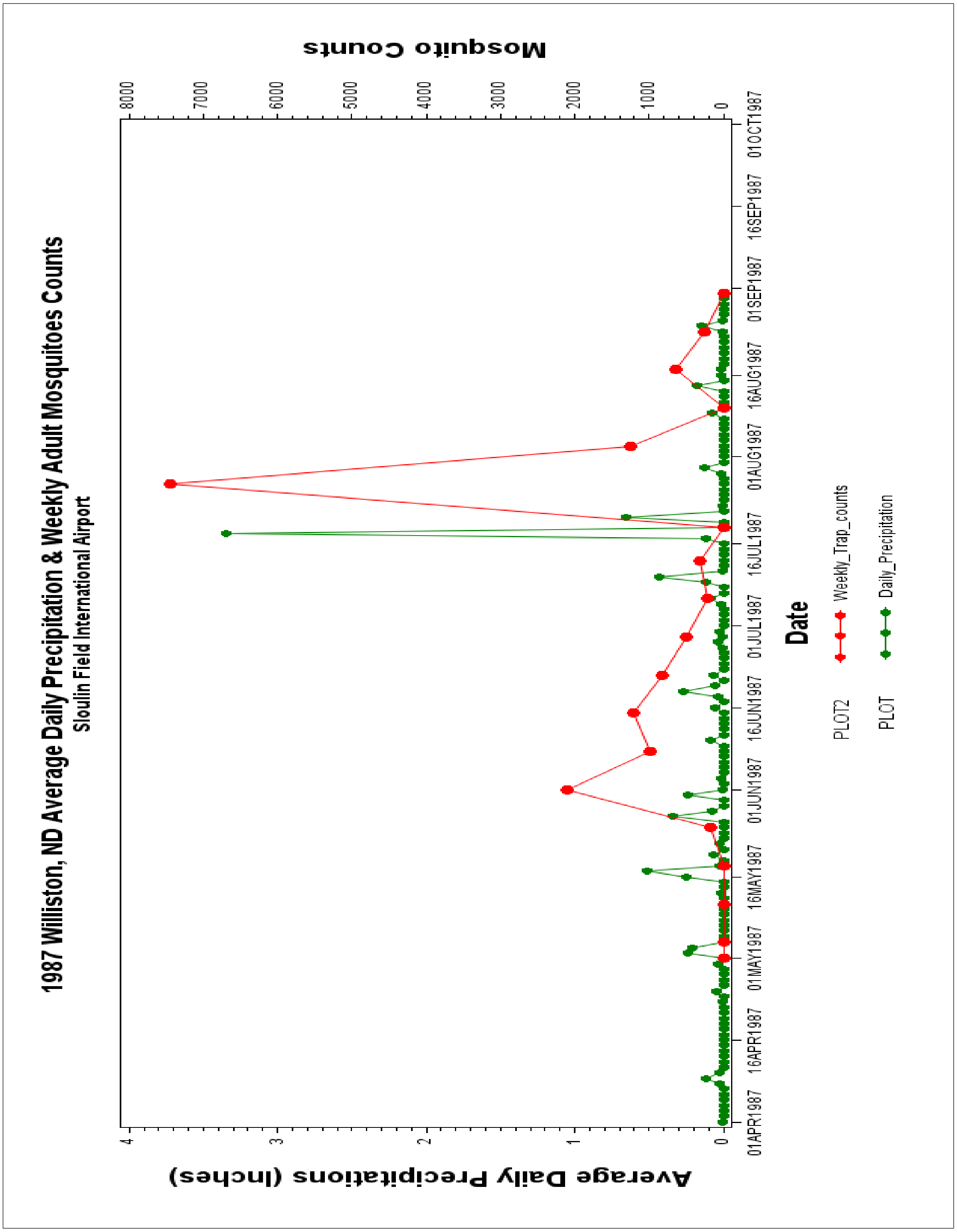
Data source: NOAA daily weather data and ND Department of Health adult mosquito light trap counts



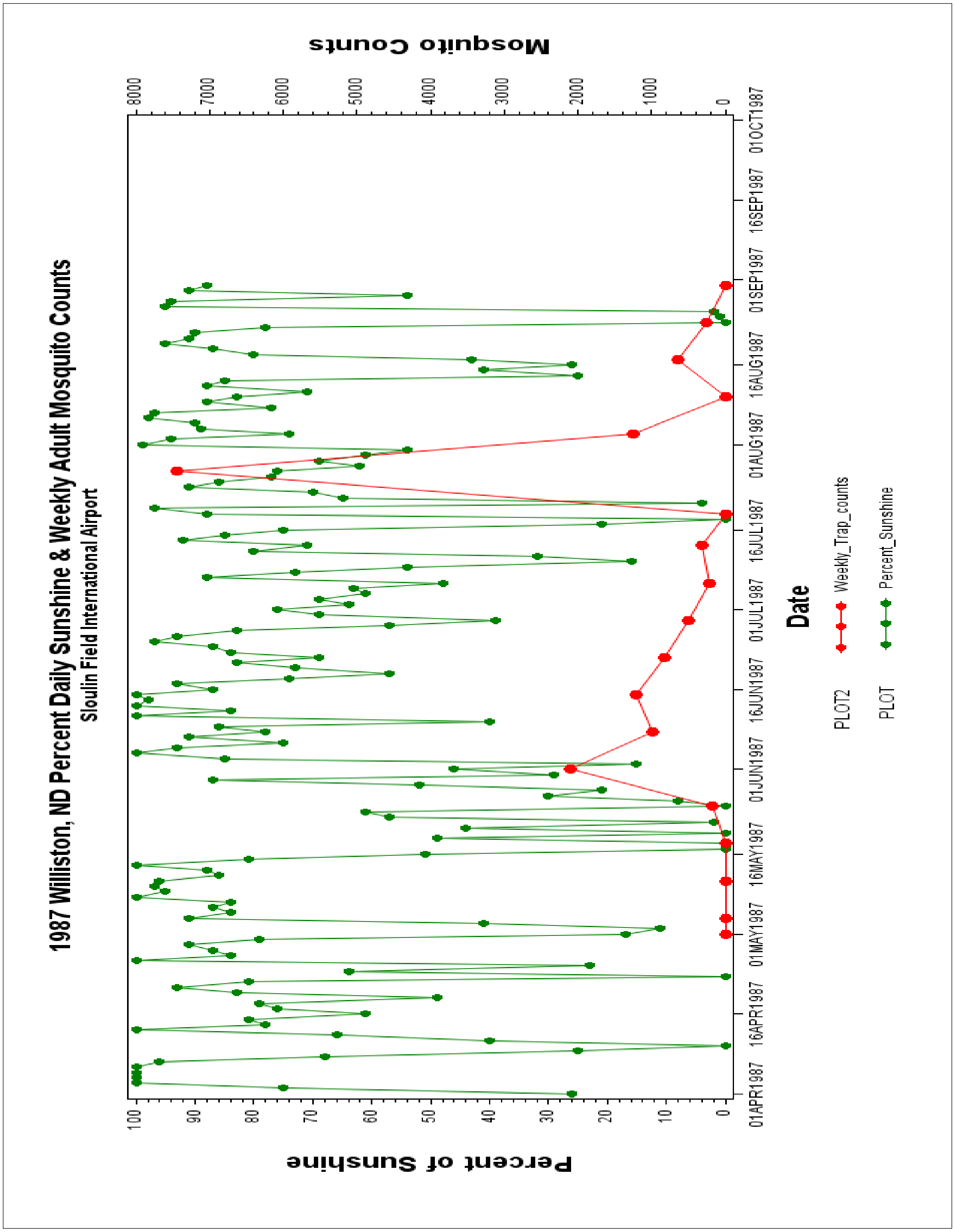
Data source: NOAA daily weather data and ND Department of Health adult mosquito light trap counts



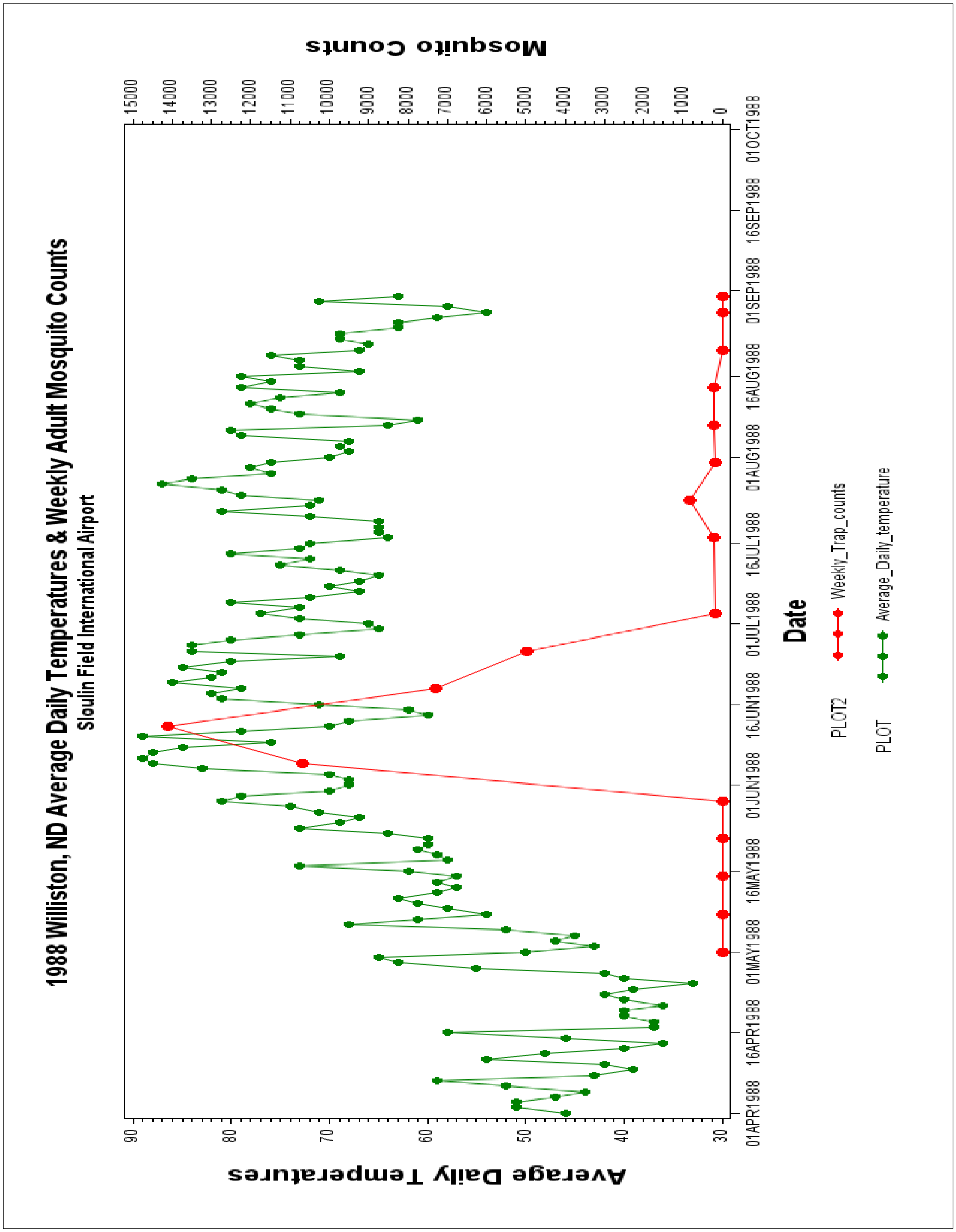
Data source: NOAA daily weather data and ND Department of Health adult mosquito light trap counts



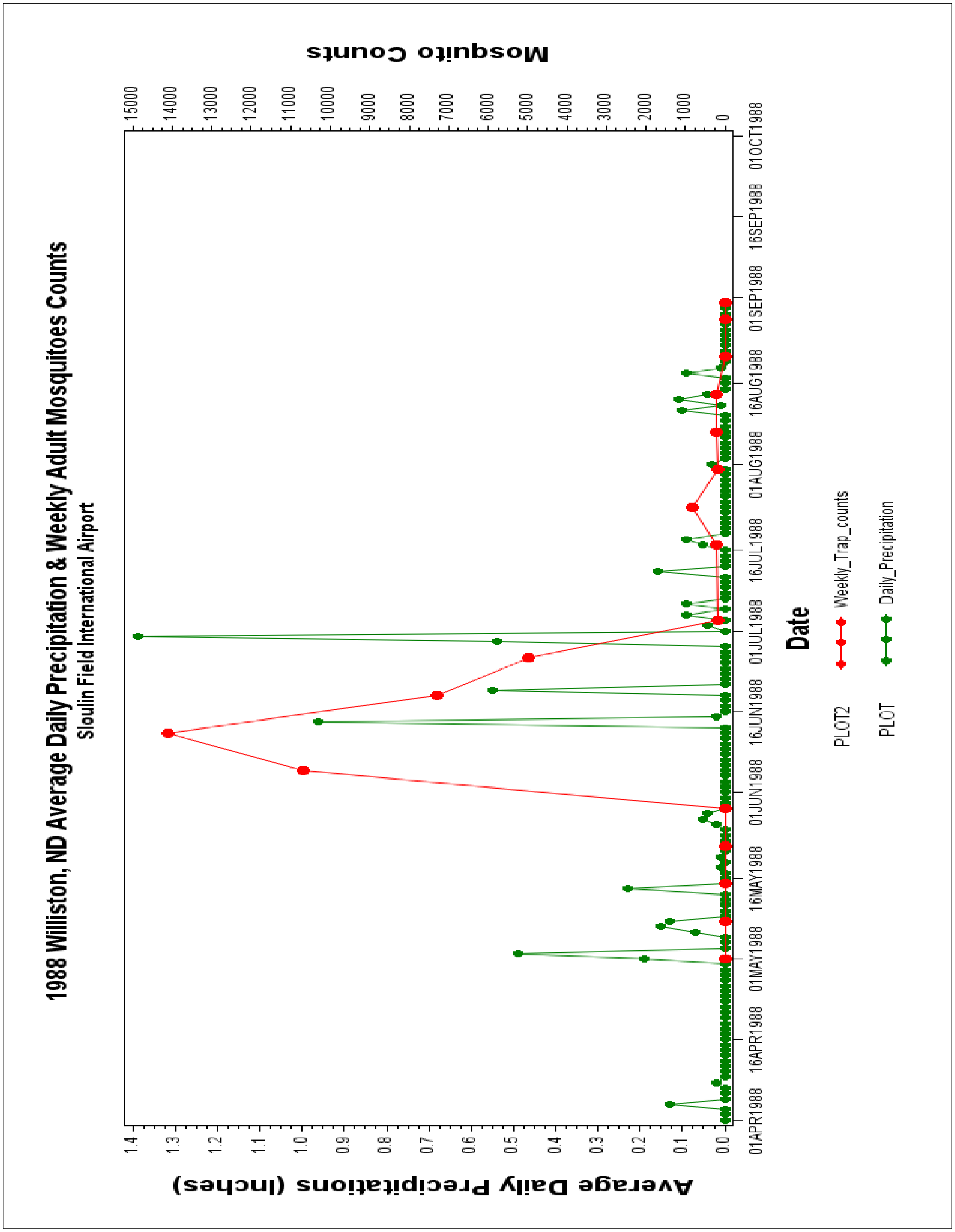
Data source: NOAA daily weather data and ND Department of Health adult mosquito light trap counts



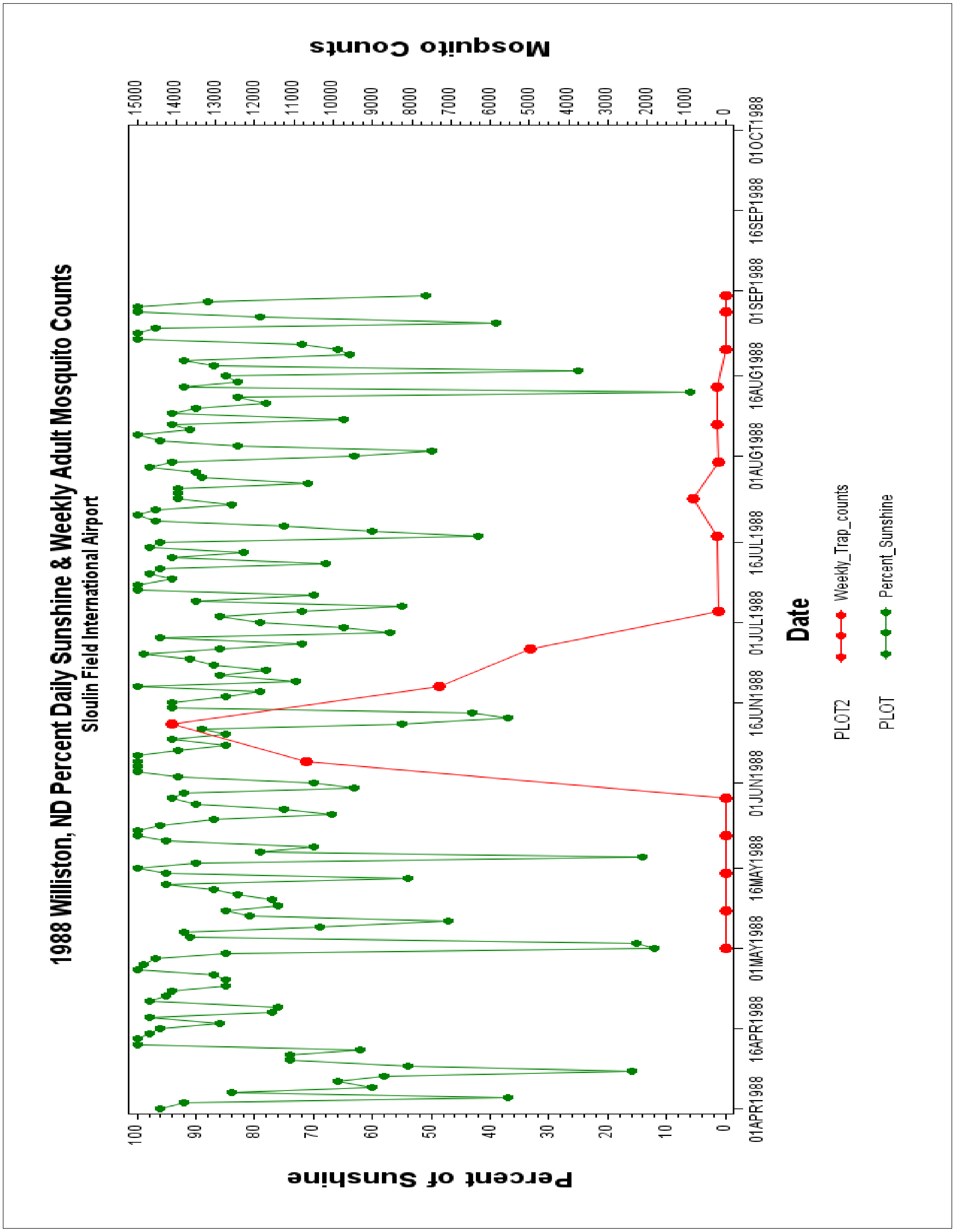
Data source: NOAA daily weather data and ND Department of Health adult mosquito light trap counts



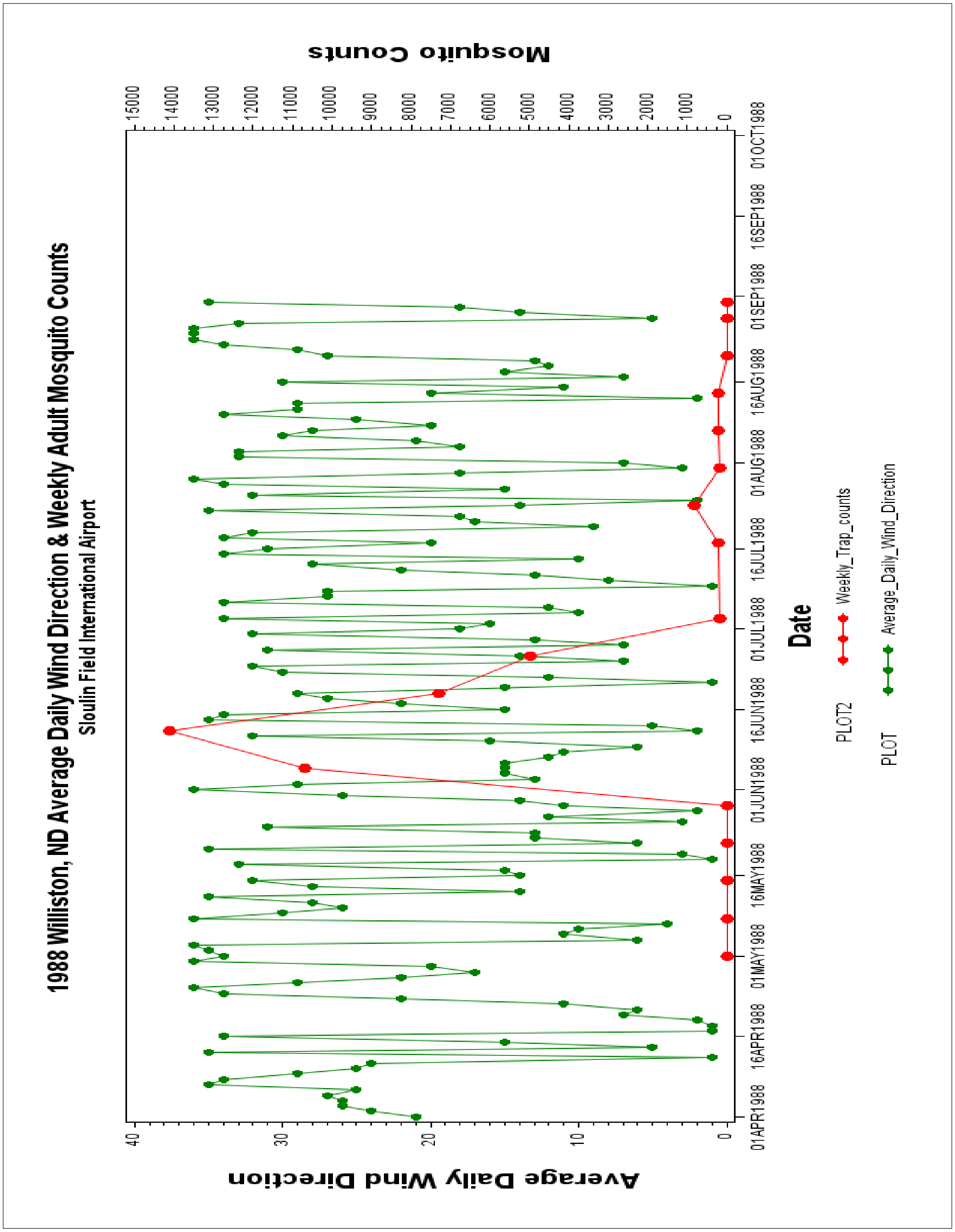
Data source: NOAA daily weather data and ND Department of Health adult mosquito light trap counts



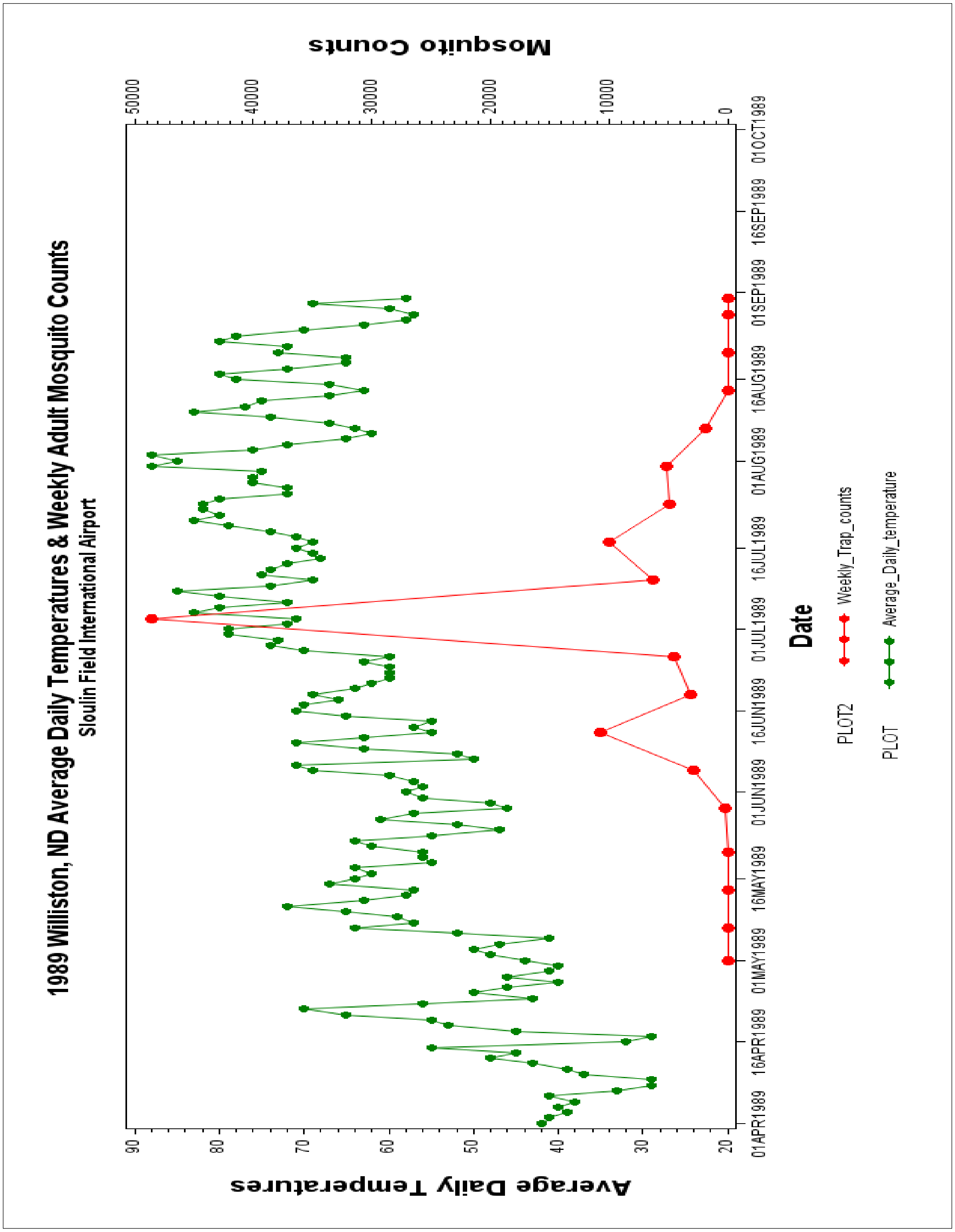
Data source: NOAA daily weather data and ND Department of Health adult mosquito light trap counts



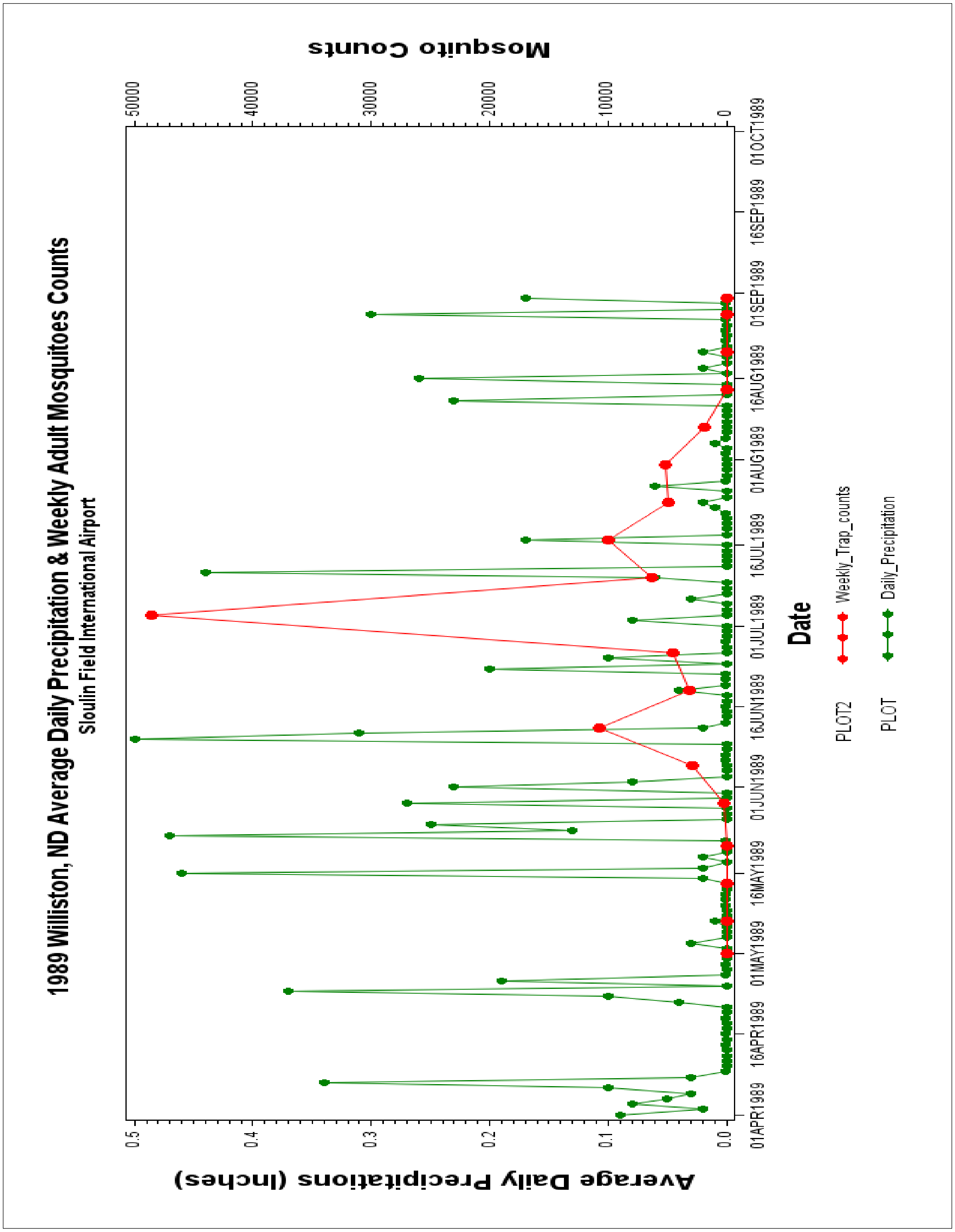
Data source: NOAA daily weather data and ND Department of Health adult mosquito light trap counts



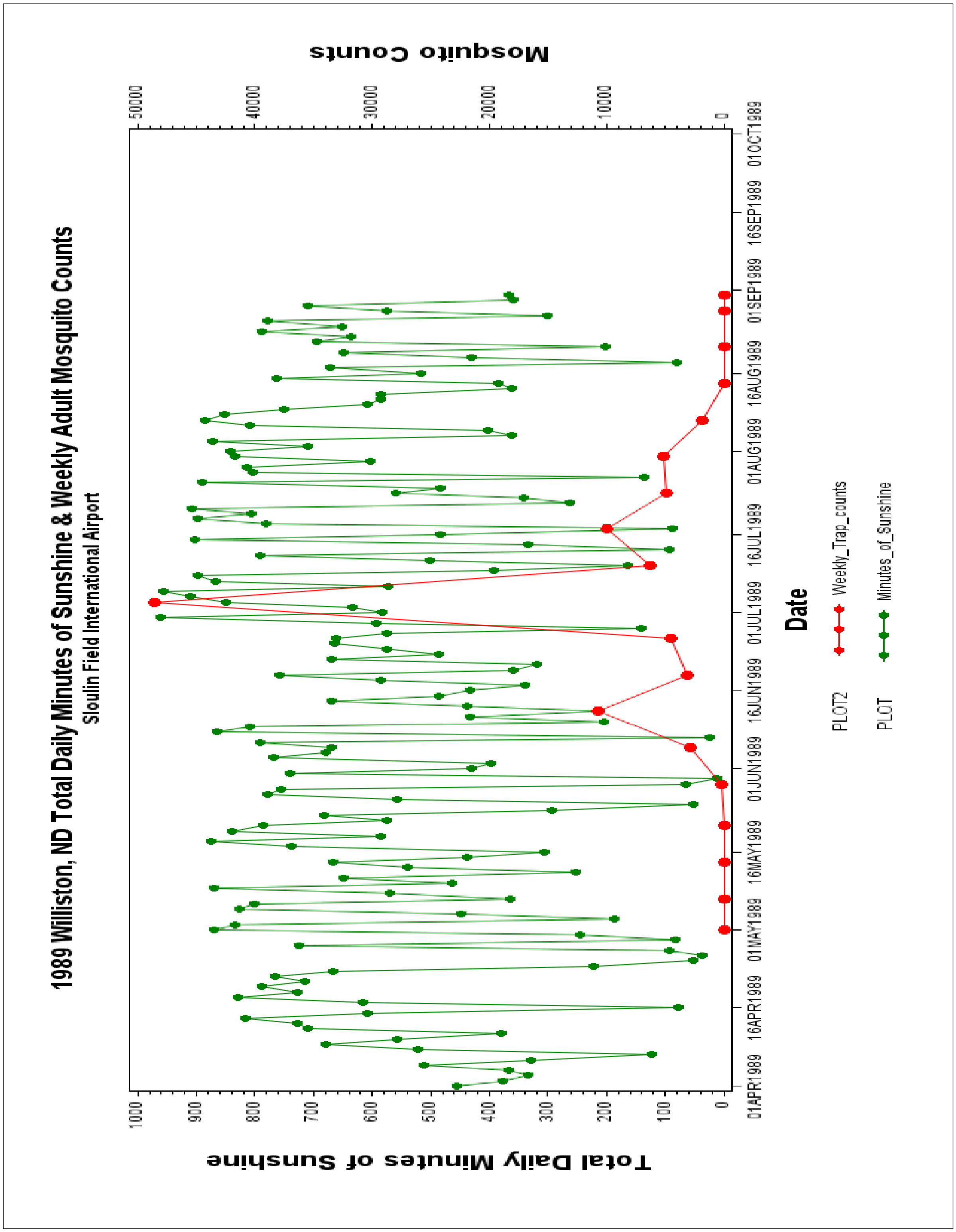
Data source: NOAA daily weather data and ND Department of Health adult mosquito light trap counts



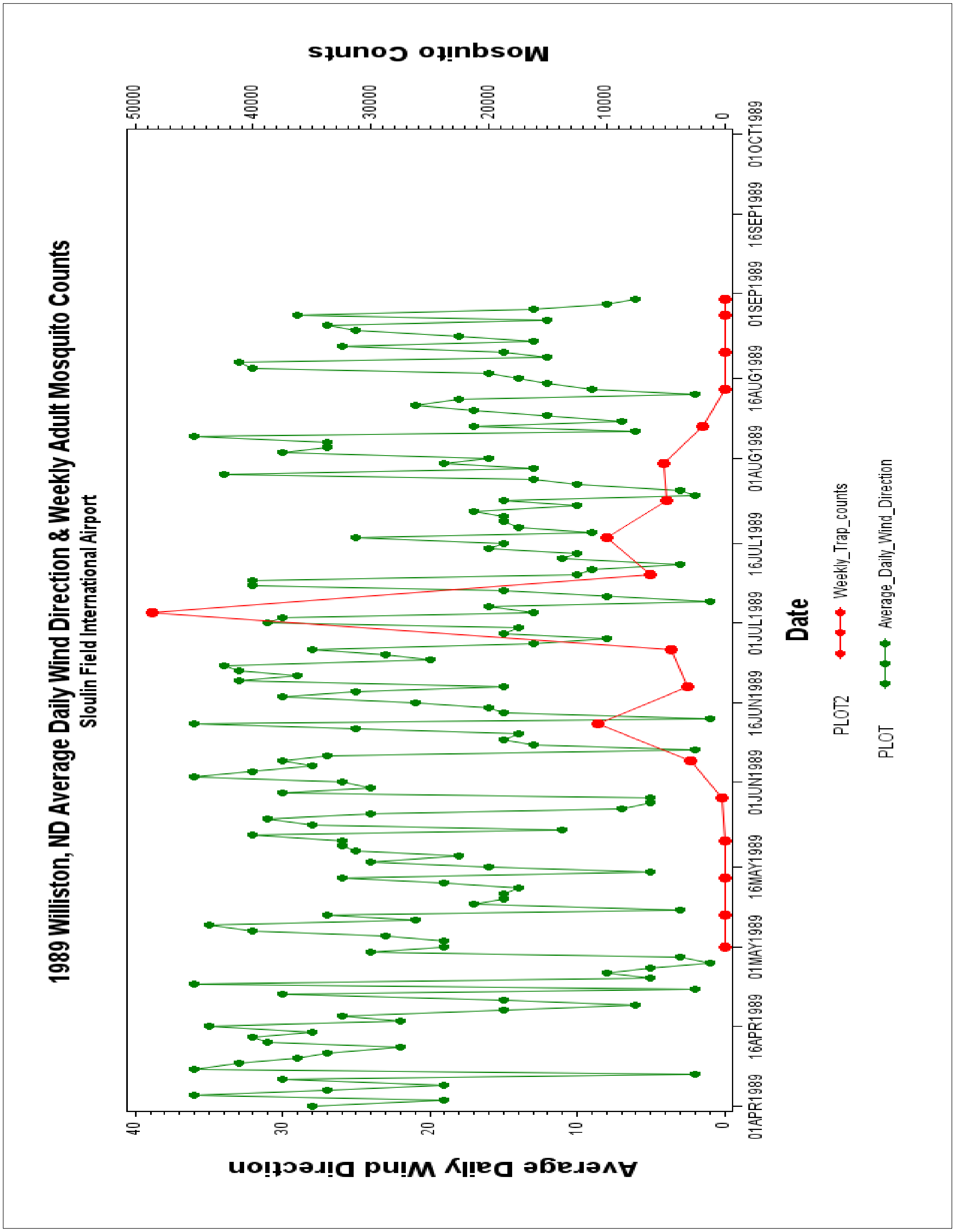
Data source: NOAA daily weather data and ND Department of Health adult mosquito light trap counts



Data source: NOAA daily weather data and ND Department of Health adult mosquito light trap counts

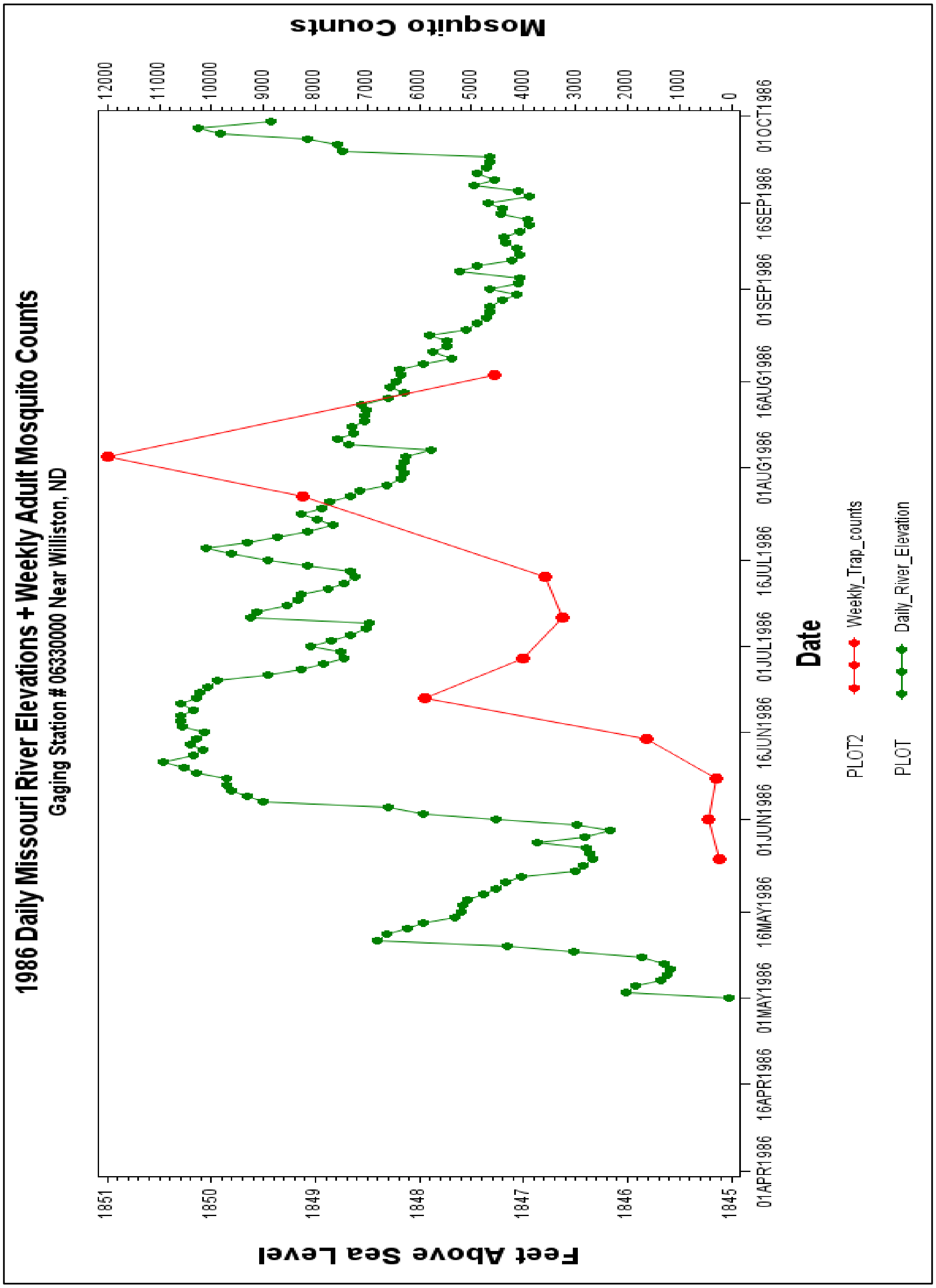


Data source: NOAA daily weather data and ND Department of Health adult mosquito light trap counts

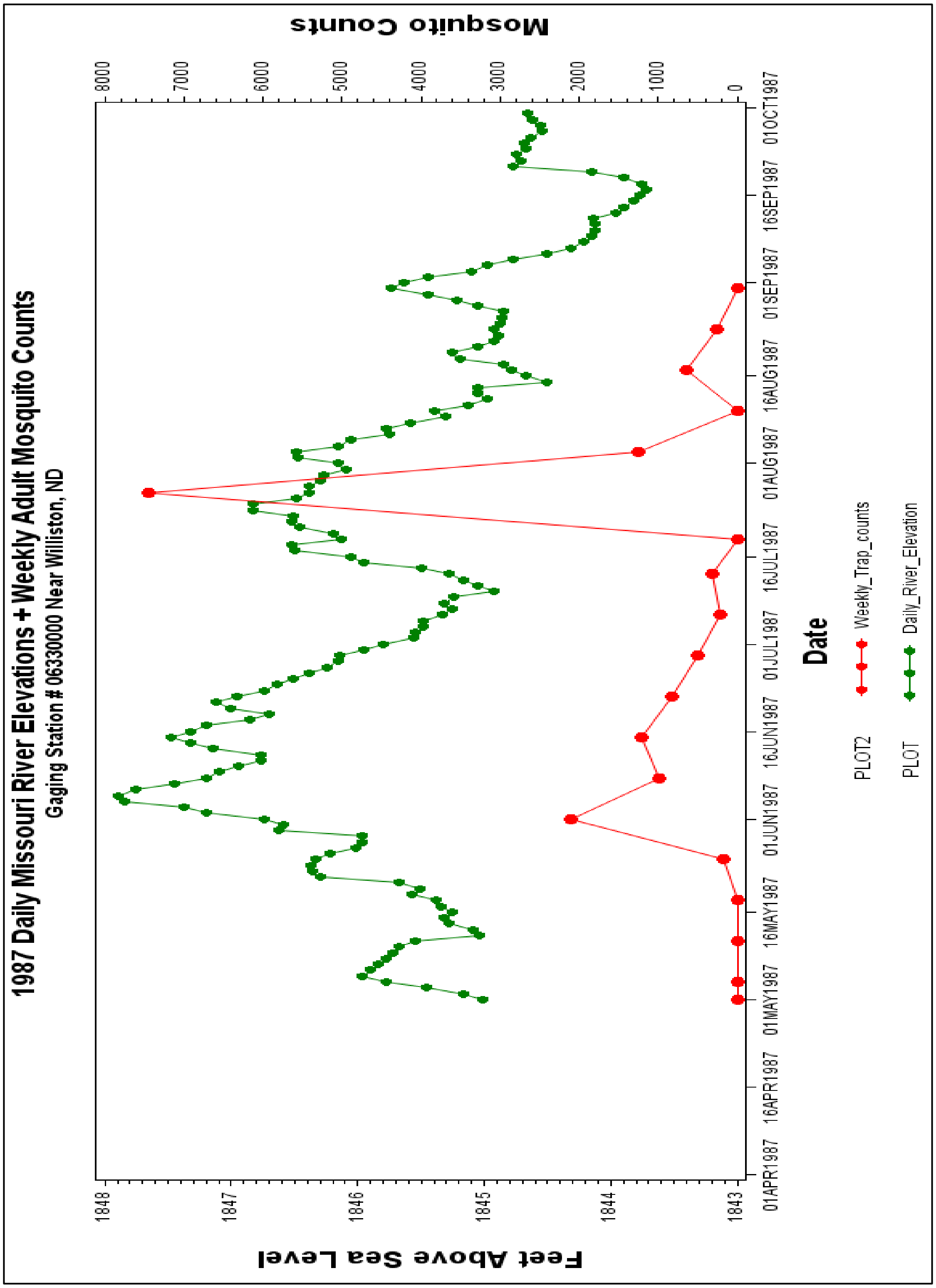


Data source: NOAA daily weather data and ND Department of Health adult mosquito light trap counts

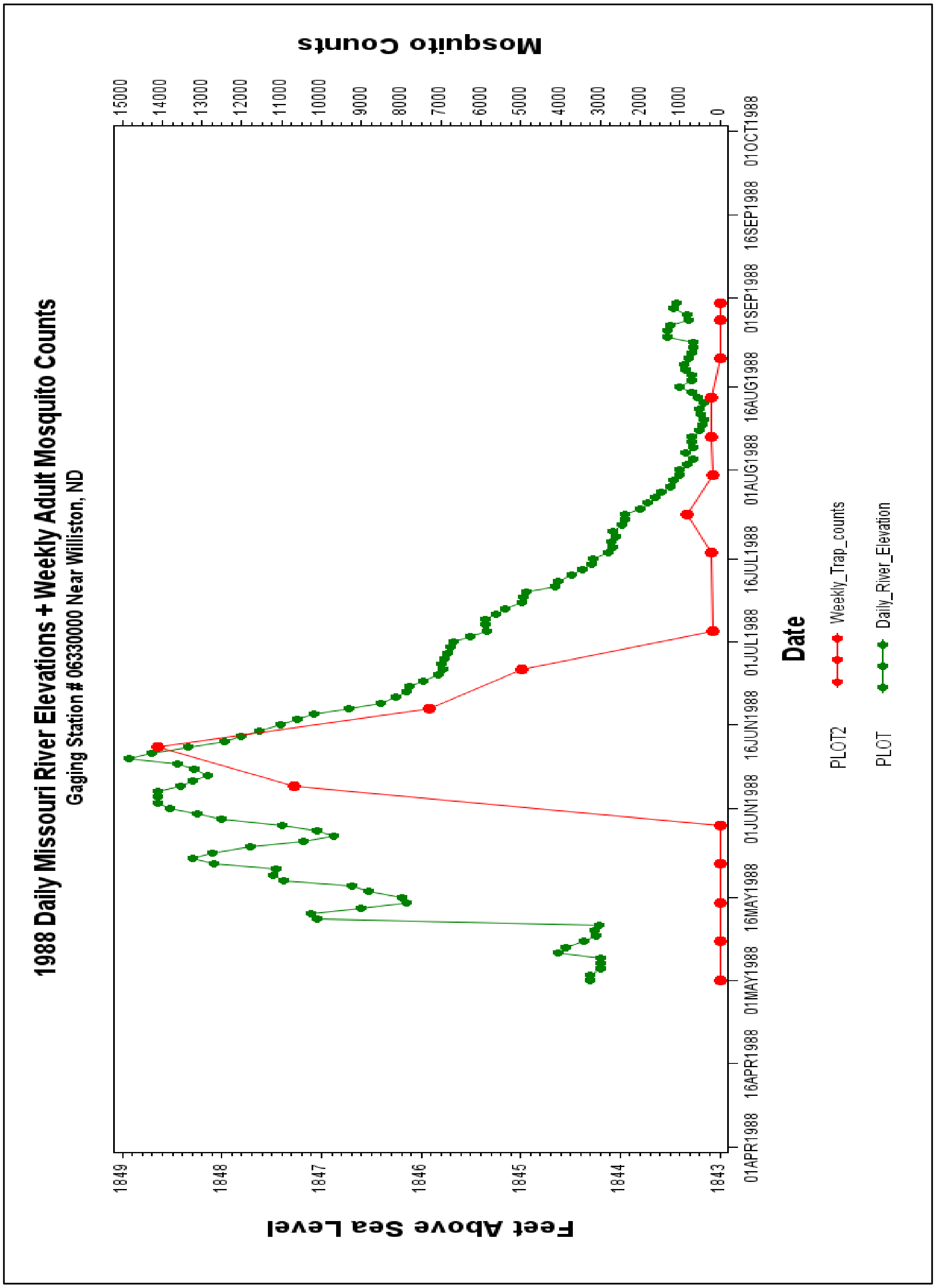
APPENDIX S. TREND ANALYSIS: DAILY MISSOURI RIVER ELEVATIONS VS. WEEKLY ADULT MOSQUITO COLLECTIONS, 1986 to 1989



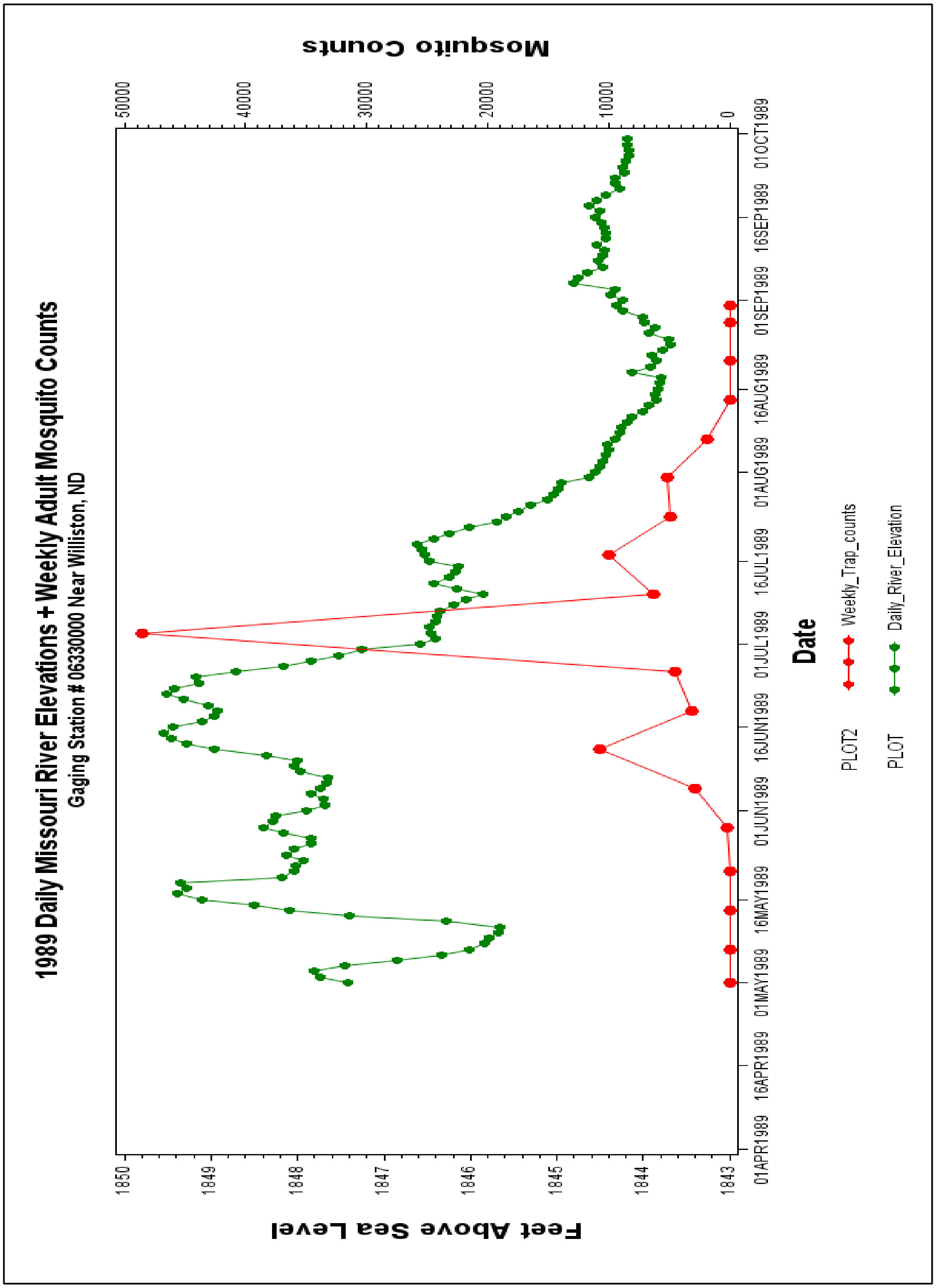
Data source: USGS daily river gaging data and ND Department of Health adult mosquito light trap counts



Data source: USGS daily river gaging data and ND Department of Health adult mosquito light trap counts



Data source: USGS daily river gaging data and ND Department of Health adult mosquito light trap counts



Data source: USGS daily river gaging data and ND Department of Health adult mosquito light trap counts

APPENDIX T. IfSAR DTM METADATA

Williston, ND IfSAR_n48w102e7dtm.bil

Metadata:

- Identification Information
- Data Quality Information
- Spatial Data Organization Information
- Spatial Reference Information
- Entity and Attribute Information
- Metadata Reference Information

Identification_Information:
Citation:
Citation_Information:
*Originator:*Intermap Technologies Inc.
*Publication_Date:*20120201
Title:
n48w102e7dtm.bil
*Edition:*1
*Geospatial_Data_Presentation_Form:*Digital Elevation Model
Series_Information:
*Series_Name:*Digital Terrain Models
*Issue_Identification:*Core Product Version: 4.2, Edit Rule Version: 2.0
Publication_Information:
*Publication_Place:*Englewood, CO
*Publisher:*Intermap Technologies Inc.
Description:
Abstract:
Intermap's DEM products are 3D raster datasets with elevations captured at 5-meter postings or every 5 meters. They are generated using Intermap's STAR technology (Interferometric Synthetic Aperture Radar), which is mounted to an aircraft. The Digital Terrain Model (DTM) data product represents the bare earth and is derived from the Digital Surface Model (DSM) using Intermap's proprietary algorithm and editing processes. Accuracy statements are based on unobstructed areas of moderately sloped terrain. Diminished accuracies are to be expected in areas of extreme terrain and dense vegetation. The DTM is stored as a contiguous dataset spanning continental land masses where we have captured data. It is available in specific areas of interest or in 7.5-minute by 7.5-minute tile areas. For more detailed information, refer to Intermap's Product Handbook at http://www.intermap.com/images/handbook/producthandbook.pdf.
Purpose:
The DTMs are used as a fundamental layer of information in 3D geospatial analysis and spatial information Decision Support Systems

(DSS). Typical applications include storm surge analysis, flood planning and watershed analysis, radio propagation modeling, and contour generation. A number of the priority layers of spatial information recognized by the National Spatial Data Infrastructure may be derived from Intermap Technologies' DEMs including elevation, shoreline delineation, hydrography, slope, and aspect layers.

Time_Period_of_Content:
Time_Period_Information:
Range_of_Dates/Times:
*Beginning_Date:*20070428
*Ending_Date:*20070429
Currentness_Reference:
The above dates refer to the time of field data acquisition and therefore reflect ground conditions at that time.
Status:
*Progress:*Complete
*Maintenance_and_Update_Frequency:*Ongoing
Spatial_Domain:
Bounding_Coordinates:
West_Bounding_Coordinate:-102.875020833
East_Bounding_Coordinate:-102.749979167
*North_Bounding_Coordinate:*48.625020833
*South_Bounding_Coordinate:*48.499979167
Keywords:
Theme:
*Theme_Keyword_Thesaurus:*MEL_Scientific-Engineering_Field_Thesaurus
*Theme_Keyword:*Elevation
*Theme_Keyword:*Cartography
*Theme_Keyword:*Geodesy
*Theme_Keyword:*Geography
*Theme_Keyword:*Hypsography
*Theme_Keyword:*Mapping
*Theme_Keyword:*Photogrammetry
*Theme_Keyword:*Stereophotogrammetry
*Theme_Keyword:*Topography
*Theme_Keyword:*Radar
*Theme_Keyword:*Interferometric
*Theme_Keyword:*Remote
*Theme_Keyword:*Sensing
*Theme_Keyword:*SAR
*Theme_Keyword:*DEM
*Theme_Keyword:*DTM
*Theme_Keyword:*DSM
*Theme_Keyword:*ORI
*Theme_Keyword:*INSAR

*Theme_Keyword:*IFSAR ¶
*Theme_Keyword:*IFSARE ¶
*Theme_Keyword:*GEOSAR ¶
*Theme_Keyword:*height ¶
Place: ¶
*Place_Keyword_Thesaurus:*None ¶
*Place_Keyword:*North Dakota ¶
*Place_Keyword:*United States ¶
Stratum: ¶
*Stratum_Keyword_Thesaurus:*MEL_Environmental_Domain_Thesaurus ¶
*Stratum_Keyword:*Terrain ¶
*Stratum_Keyword:*Earth ¶
*Stratum_Keyword:*Surface ¶
*Stratum_Keyword:*Ground ¶
*Stratum_Keyword:*First ¶
Temporal: ¶
*Temporal_Keyword_Thesaurus:*2007 ¶
*Temporal_Keyword:*April ¶
*Access_Constraints:*Purchase ¶
Use_Constraints: ¶
End User License Agreement ¶

¶

Data_Quality_Information: ¶
Attribute_Accuracy: ¶
Attribute_Accuracy_Report: ¶
Calculation of the digital elevation model is described in the Intermap Technologies Core Product Handbook User's Guide. http://www.intermap.com/images/handbook/producthandbook.pdf ¶
Logical_Consistency_Report: ¶
None ¶
Completeness_Report: ¶
None ¶
Positional_Accuracy: ¶
Horizontal_Positional_Accuracy: ¶
Horizontal_Positional_Accuracy_Report: ¶
All data products are accurate to 2.0 meters or better in unobstructed areas with slopes less than 10 degrees. ¶
Vertical_Positional_Accuracy: ¶
Vertical_Positional_Accuracy_Report: ¶
1 meter RMSE or better in unobstructed areas with slopes less than 10 degrees. ¶
Lineage: ¶
Process_Step: ¶
Process_Description: ¶
The NEXTMap DTM data products are derived using Intermap Technologies' STAR airborne Interferometric SAR data acquisition

system. The data for this tile was captured at 22300 feet above mean sea level with a primary look direction of North and the swaths with IDs 66, 71, 72 and 73. Areas of missing data are filled with ancillary data where available or are interpolated using a continuous curvature spline algorithm. In larger areas of missing data, Intermap's proprietary editing process utilizes ancillary elevation data from secondary sources to fill the areas of missing data. Most incidents of missing data are due to radar shadow and layover in high-relief areas such as mountainous regions and highly developed urban areas and correspond to the look direction of the radar. Bodies of water are assigned an elevation which corresponds to the shoreline at the time the data was captured. Areas of null data are assigned the value -10000.
*Process_Date:*20111215

Spatial_Data_Organization_Information:
*Direct_Spatial_Reference_Method:*Raster
Raster_Object_Information:
*Raster_Object_Type:*Grid Cell
*Row_Count:*3001
*Column_Count:*3001

Spatial_Reference_Information:
Horizontal_Coordinate_System_Definition:
Geographic:
*Latitude_Resolution:*0.0000416667
*Longitude_Resolution:*0.0000416667
*Geographic_Coordinate_Units:*Decimal degrees
Geodetic_Model:
*Horizontal_Datum_Name:*NAD83
*Ellipsoid_Name:*GRS80
*Semi-major_Axis:*6378137.0
*Denominator_of_Flattening_Ratio:*298.257222101
Vertical_Coordinate_System_Definition:
Altitude_System_Definition:
*Altitude_Datum_Name:*NAVD88(Geoid99)
*Altitude_Resolution:*0.01
*Altitude_Distance_Units:*meters
*Altitude_Encoding_Method:*Implicit coordinate

Entity_and_Attribute_Information:
Detailed_Description:
Entity_Type:
*Entity_Type_Label:*32-bit image
Entity_Type_Definition:
The DEM is a 32 bit image on a 7.5-minute by 7.5-minute (lat/long) grid. The origin of the post is center center.

Entity_Type_Definition_Source: ¶
http://www.intermap.com/images/handbook/producthandbook.pdf ¶
Attribute: ¶
Attribute_Label:Elevation value per grid cell. ¶
Attribute_Definition: ¶
Height of the geoid, relative to mean sea level. ¶
Attribute_Definition_Source: ¶
http://www.intermap.com/images/handbook/producthandbook.pdf ¶
Attribute_Domain_Values: ¶
Range_Domain: ¶
Range_Domain_Minimum:657.132 ¶
Range_Domain_Maximum:761.889 ¶
Attribute_Units_of_Measure:meters ¶
Attribute_Measurement_Resolution:0.01 ¶
Overview_Description: ¶
Entity_and_Attribute_Overview: ¶
NEXTMap USA Block Number: 03008 ¶
Entity_and_Attribute_Detail_Citation: ¶
http://www.intermap.com/images/handbook/producthandbook.pdf ¶
¶
Metadata_Reference_Information: ¶
Metadata_Date:20120201 ¶
Metadata_Contact: ¶
Contact_Information: ¶
Contact_Organization_Primary: ¶
Contact_Organization:Intermap Technologies Inc. ¶
Contact_Position:Data Archive Manager ¶
Contact_Address: ¶
Address_Type:mailing address ¶
Address:8310 South Valley Highway, Suite 400 ¶
City:Englewood ¶
State_or_Province:CO ¶
Postal_Code:80112-5815 ¶
Country:USA ¶
Contact_Voice_Telephone:(303) 708-0955 ¶
Contact_Facsimile_Telephone:(303) 708-0952 ¶
Contact_Electronic_Mail_Address:service@intermap.com ¶
Metadata_Standard_Name:FGDC Content Standards for Digital Geospatial Metadata ¶
Metadata_Standard_Version:FGDC-STD-001-1998 ¶

APPENDIX U. KLJ RTK-GPS CONFIRMATION LETTER

Kadrmas Lee & Jackson
Engineers Surveyors Planners

February 2, 2011

Williams County Vector Control
c/o Jacquelin Stenehjem
Williams County Court House
205 E Broadway
Williston, ND 58801

Re: Survey Estimate

Dear Jacquelin:

This letter is to follow up on our conversation in my office the other day.

The services that KL & J intends to provide are as follows:

- Provide appropriate survey control to establish an appropriate datum.
- Locate four groups of twenty spot elevations as determined by you.
- Provide raw survey data of these points to you in a format usable to adjust your remotely sensed data.

We plan to provide you one 2 man survey crew and Trimble GPS equipment for two days to collect the groups of points.

The cost for this service will be billed hourly but not to exceed $3800.00 without prior written permission.

We will also have to execute a standard KL & J service contract prior to beginning the work at the end of March or beginning of April.

Sincerely,

Kadrmas, Lee & Jackson, Inc.

Don Leischner

Survey Coordinator

701 572 6352
222 Airport Road
Williston, ND 58801-2976
Fax 701 572 2019
kljeng.com

APPENDIX V. KLJ RTK-GPS SURVEY PROPOSAL AND AGREEMENT

Kadrmas Lee & Jackson
Engineers Surveyors Planners

SURVEYING SERVICES PROPOSAL & AGREEMENT

Project No.: 8611024 **Order Date:** 4-18-11

Client Information:

Name: Williston Vector Control **Home #:** ____ **Cell #:** ____ **Business #:** 701-577-4563
Billing Address: 205 E Broadway
City: Williston **State:** ND **Zip Code:** 58801
Authorized By: Barb Peterson **Home #:** ____ **Cell #:** ____ **Business #:** ____

Survey Location:

_____ ¼, Section _____, Township _____ North ☐ South ☐, Range _____ West ☐ East ☐;

_____ ¼, Section _____, Township _____ North ☐ South ☐, Range _____ West ☐ East ☐;

_____ ¼, Section _____, Township _____ North ☐ South ☐, Range _____ West ☐ East ☐;

Lot(s) _____, Block _____ Addition/Subdivision: _____

City of Williston, Williams County, State: NORTH DAKOTA

Client Desires Survey Completed By (Date): April 2011 **Estimated Completion Date of Services:** April 2011

Detailed Description of Services: Locate 20-30 points in Williams County based on vegetation type to assist Vector control in data rectification.

Plat to Be Furnished: ☐ Yes ☒ No **Description to Be Furnished:** ☐ Yes ☒ No

Other Comments Regarding Plat or Deliverables: Delivering raw survey data in state plane coordinates

Does Client or Caller Know of any Existing Survey Monuments or of a Recent Survey that has been done Nearby (Provide Details): ____

Estimated Cost for Services: $3800.00

Special Conditions to Be Considered: _____

Terms and Conditions

- Payment for services is due and payable when billed. Any amount not paid within 30 days will be subject to a late payment charge of 1½% per month. Payment is based upon Hourly Rates plus Expenses and it will be an amount equal to KL&J's Direct Labor Costs times a designated factor for labor, overhead and profit for the services of all KL&J's personnel engaged on the Project, plus Reimbursable Expenses and KL&J's Consultant charges times a factor of 1.15, if any.
- Payment for services does not include any agency review fees, submittal fees, filing fees, permit fees, or other such fees. Client will pay all such fees directly.
- To the fullest extent permitted by law, Client and KL&J (1) waive against each other, and the other's employees, officers, directors, agents, insurers, partners, and consultants, any and all claims for or entitlement to special, incidental, indirect, or consequential damages arising out of, resulting from, or in any way related to the Project, and (2) agree that KL&J's total liability to Client under this Agreement shall be limited to the total amount of compensation received by KL&J.
- KL&J agrees, to the fullest extent permitted by law, to indemnify and hold harmless the Client, its officers, directors and employees (collectively, Client) against all damages, liabilities or costs, including reasonable attorneys' fees and defense costs, to the extent caused by the KL&J's negligent performance of professional services under this Agreement and that of its consultants or anyone for whom KL&J is legally liable. The Client agrees, to the fullest extent permitted by law, to indemnify and hold harmless the KL&J, its officers, directors, employees and consultants (collectively, KL&J) against all damages, liabilities or costs, including reasonable attorneys' fees and defense costs, to the extent caused by the Client's negligent acts in connection with the Project and the acts of its contractors, subcontractors or anyone for whom the Client is legally liable. Neither the Client nor the KL&J shall be obligated to indemnify the other party in any manner whatsoever for the other party's own negligence.
- The project schedule is dependent upon Client and or agency reviews and comments being received in a timely manner. An initial schedule will be submitted when written notice to proceed is received from the Client. The schedule will be updated during the progression of the services as needed.
- If electronic files are provided to client, any use or reuse of original or altered digital files or data will be for the specific project or purpose intended. Client will, to the fullest extent permitted by law, indemnify and hold KL&J harmless from any and all claims, suits, liability, demands or costs arising from manipulation, use or reuse of digital files or data.
- The standard of care for all services performed or furnished by KL&J under this Agreement will be the care and skill ordinarily used by members of the subject profession practicing under similar circumstances at the same time and in the same locality. KL&J makes no warranties, express or implied, under this Agreement or otherwise, in connection with KL&J's services.
- This Agreement is to be governed by the law of the state in which the Project is located.

IN WITNESS WHEREOF, the parties hereto have executed this agreement and the Client hereby authorizes the above-described services to be performed by Kadrmas, Lee & Jackson under the above Terms and Conditions set forth.

Client: ____ Signature: Barbara Peterson

Date: 4-27-11 Printed Name & Title: Barbara Peterson, Vector Board

Kadrmas, Lee & Jackson, Inc. ("KL&J") Signature: [signature]

Date: 4-18-11 Printed Name & Title: Rick Leach - Survey PM

For Office Use Only (Please refer to KL&J Project Setup Form)

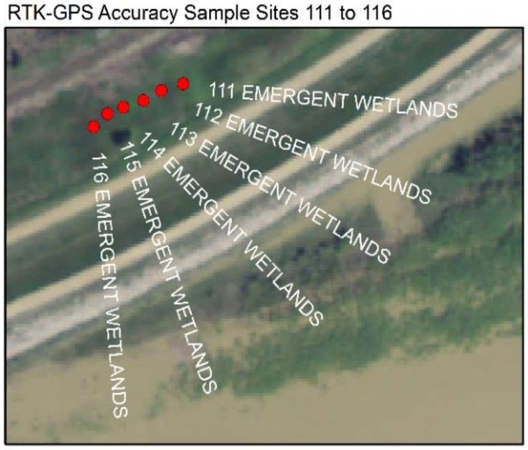
Billing Group:	1	Work Group Code:	16	KL&J Project Type:	35
Billing Type:	C	Client Type Code:	6	Work Completed By:	____
Project Manager:	8485 Initials DL	KL&J Location Code:	8	Field Book:	____
Rate Schedule Code:	3.4	Federal 330 Code:	S10	Date Survey Completed:	____

APPENDIX W. KLJ RTK-GPS CONTROL POINT LOCATIONS

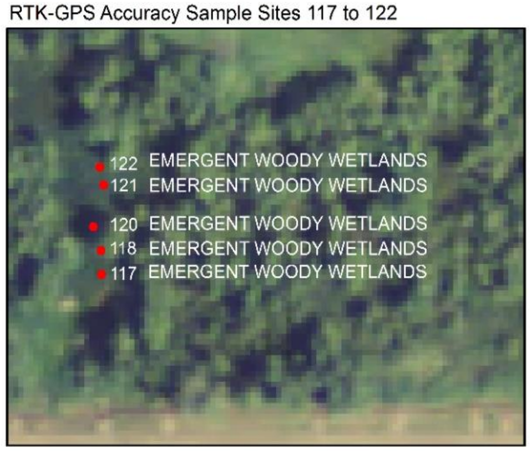
RTK-GPS Accuracy Sample Sites 100 to 105

RTK-GPS Accuracy Sample Sites 106 to 110

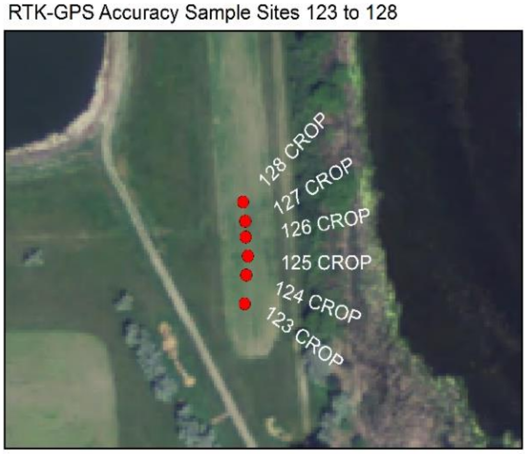
RTK-GPS Accuracy Sample Sites 111 to 116



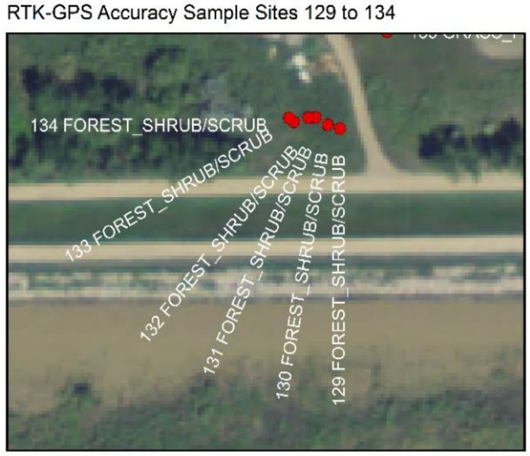
RTK-GPS Accuracy Sample Sites 117 to 122



RTK-GPS Accuracy Sample Sites 123 to 128

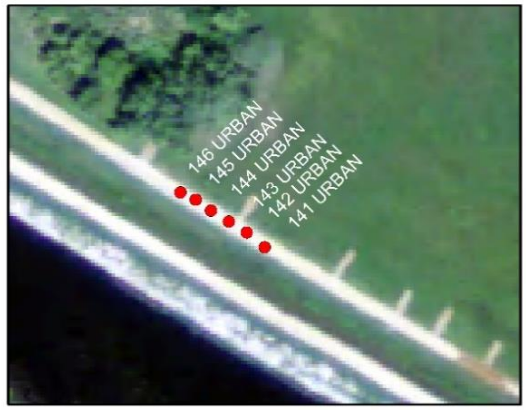


RTK-GPS Accuracy Sample Sites 129 to 134



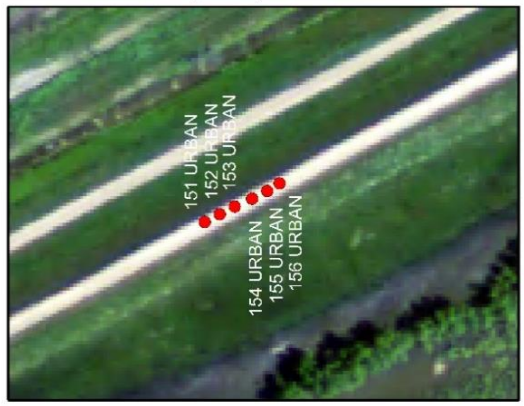
RTK-GPS Accuracy Sample Sites: 135 to 140

RTK-GPS Accuracy Sample Sites: 141 to 146

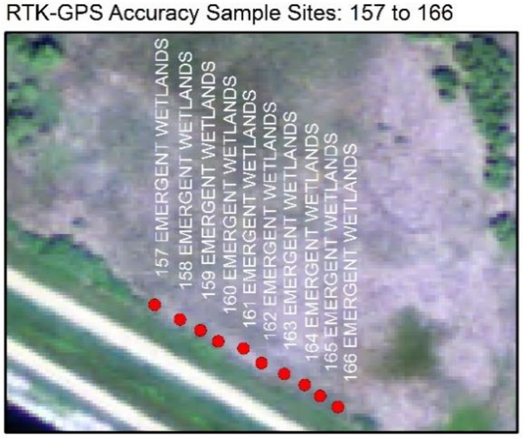


RTK-GPS Accuracy Sample Sites: 147 to 149

RTK-GPS Accuracy Sample Sites: 151 to 156



RTK-GPS Accuracy Sample Sites: 157 to 166

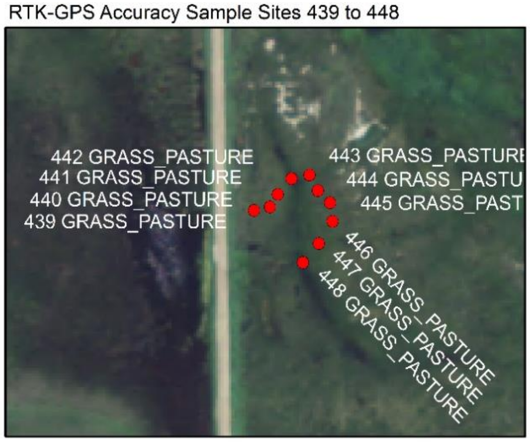


RTK-GPS Accuracy Sample Site: 200

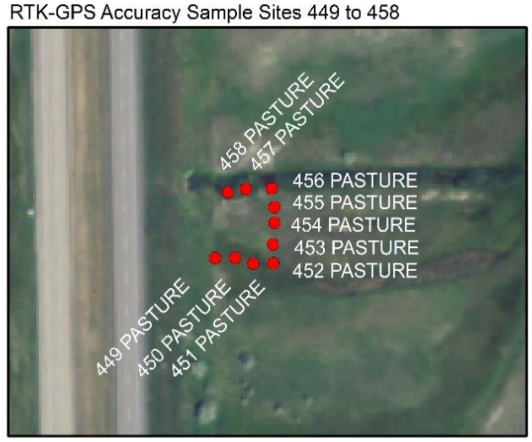
RTK-GPS Accuracy Sample Sites 413 To 423

RTK-GPS Accuracy Sample Sites 424 to 438

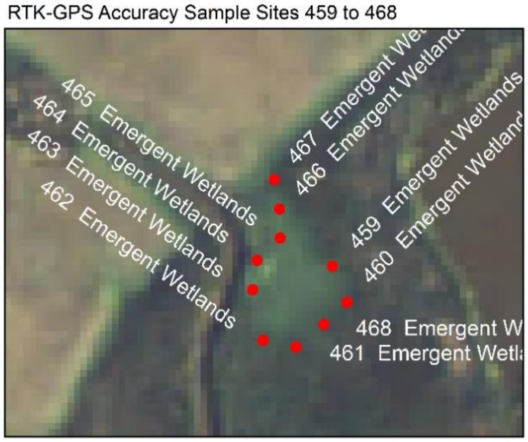
RTK-GPS Accuracy Sample Sites 439 to 448



RTK-GPS Accuracy Sample Sites 449 to 458



RTK-GPS Accuracy Sample Sites 459 to 468

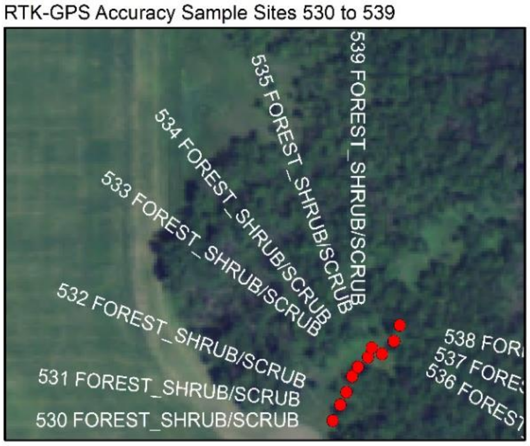


RTK-GPS Accuracy Sample Sites 500 to 509

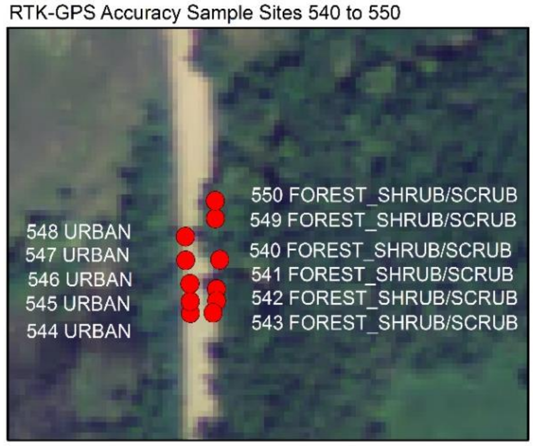
RTK-GPS Accuracy Sample Sites 510 to 519

RTK-GPS Accuracy Sample Sites 520 to 529

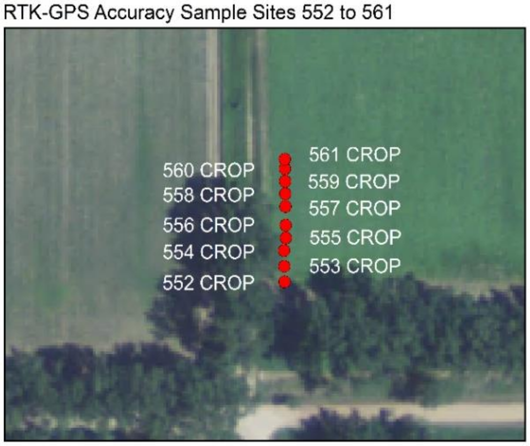
RTK-GPS Accuracy Sample Sites 530 to 539



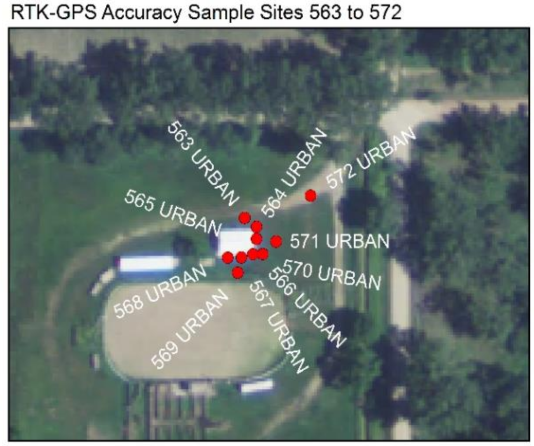
RTK-GPS Accuracy Sample Sites 540 to 550

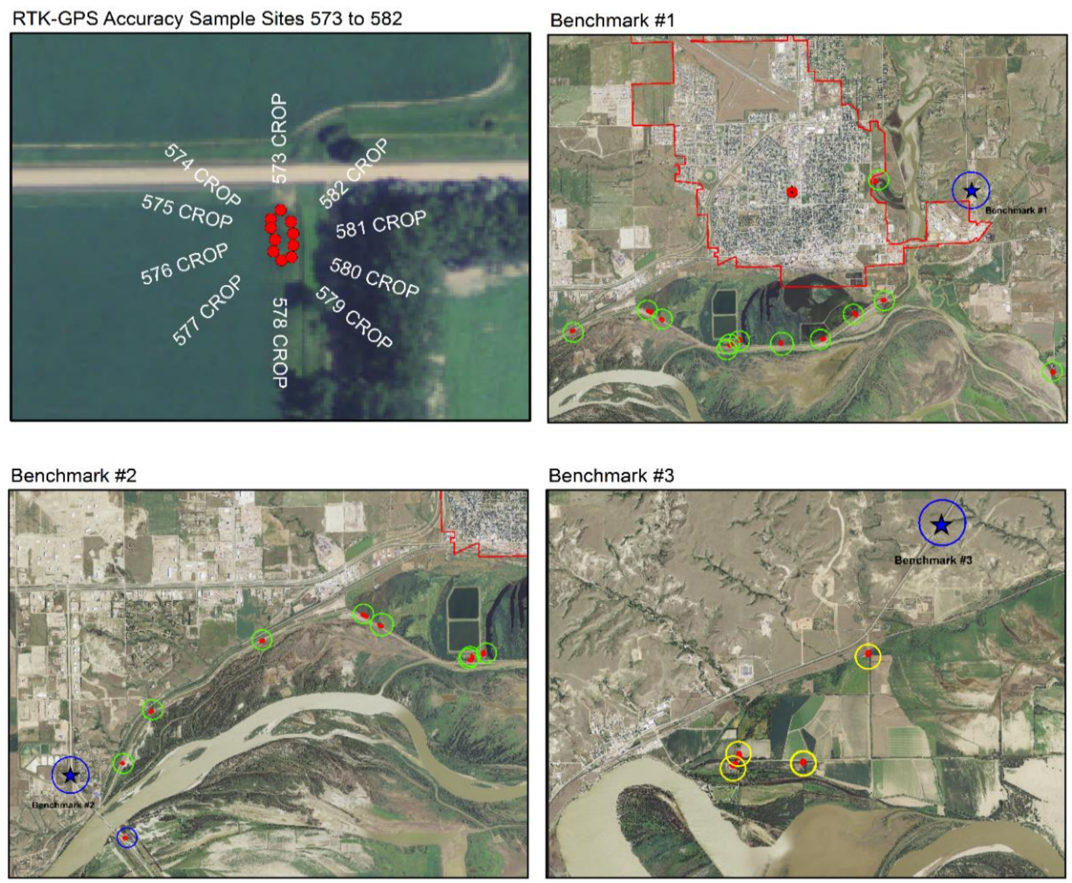


RTK-GPS Accuracy Sample Sites 552 to 561



RTK-GPS Accuracy Sample Sites 563 to 572




RTK-GPS Accuracy Sample Sites 573 to 582
573 CROP
574 CROP
575 CROP
576 CROP
577 CROP
578 CROP
579 CROP
580 CROP
581 CROP
582 CROP
Benchmark #1
Benchmark #1
Benchmark #2
Benchmark #2
Benchmark #3
Benchmark #3

APPENDIX X. KLJ RTK-GPS FIELD NOTES

Book O-100
pg 62

#8611024
Williston Vector Control/
Williams Co.
No. DAK

NAD83
NAVD 88
Ground. Coord.

Book O-100
pgs 62-65

TSC 2 Data
5700 BASE
5800 ROVER

5/20/2011
A. Staloch
A. Lambert
Jackie Stenjum
5/24/2011
A. Staloch
A. Lamb
Jackie St.

Book 0-100
Pg 43

#1001 RTK NGS Williston 2
OPUS
LAT 48-09-21.10632N
LONG 103-34-52.42729W
Hgt 2008.894
ELEV 2068.429
N 45203.154
E 97800.225
5/20 HI = 3.82 / 1.108 M
5/24 HI = 3.87

#8946 BASE GPS 85-2
LAT 48-06-54.43306N
LONG 103-43-24.83195W
Hgt 1944.807
ELEV. 2004.346
N 30282.171
E 63063.759
5/24 HI = 4.51 / 1.32 M

#7538 CP
LAT 48-05-37.88516N
LONG 103-47-08.07532W
Hgt 1999.824
ELEV 2059.369
N 22520.006
E 47912.503
5/24 HI 3.89

Book 0-100
Pg. 69

5/20/2011

#100 to #105 — URBAN POINTS @ COR OFFICE

#106 to #110 — EMERGANT WETLANDS ALONG COR ROAD

#111 to #116 — GRASSLAND W/ WET Bottom ALONG COR ROAD

#117 to #122 — EMERGANT WOODY WETLAND ALONG COR Road

#123 to #128 — CROPLAND ALONG COR ROAD

#129 to #134 — SHRUBS ALONG COR Road

#135 to #140 — GRASSLAND ALONG COR ROAD

#141 to #146 — GRAVEL ROAD COR ROAD - LOWER LEVEL

5/20/2011

#147 to #149 — GRASSLAND / Broom Grass ALONG COR Road.

#151 to #156 — TOP OF DIKE COR ROAD

#157 to #166 — Emergant wetlands Along Cor Rd.

#200 CP 25+00

LAT 48-06-59.98941N
LONG 103-42-47.81398W
Ht 1805.356
ELEV. 1864.892
N 30846.382
E 65575.515

5/24/2011

#413 to GRASSLAND @ Scout
#416

#417 to EMERGANT GRASSLANDS
#423 @ Scout

#424 to GRASSLANDS @ white Bridge
#430 WATERS EDGE

#431 to GRASSLANDS @ white Bridge
#438

#439 to SPRING FED PASTURE
#448

#449 to SPRING FED PASTURE
#468 by Hwy 2

#500 to FOREST @ Lewis & Clark
#509 Boat Ramp

#510 to CROPLAND by
#519 Schmitz Farm

5/24/2011 Book 0-100 Pg 65

#530 to FOREST by
#538 Schmitz Farm

#539 to FOREST @
#550 Trenton Bottoms

#552 to CROPLAND @ Trenton
#561 Bottoms

#563 to URBAN @
#572 Trenton Rodeo Grounds

#573 to CROPLAND @ Trenton
#582 Bottoms

#5000 CP NGS E462 1981
LAT 48-06-53.90289N
LONG 103-43-25.21513W
Ht 1942.810
ELEV 2002.349
N 30228.423
E 63037.792

APPENDIX Y. KLJ RTK-GPS OPUS REPORT

Point 1000
Vector Control
8611024

Andrew Staloch

From: opus [opus@NGS.NOAA.GOV]
Sent: Tuesday, May 24, 2011 5:38 PM
To: andrew.staloch@kljeng.com
Subject: OPUS solution : 14211402.11o 000235136

```
 FILE: 14211402.11o 000235136

                           NGS OPUS SOLUTION REPORT
                           ========================

All computed coordinate accuracies are listed as peak-to-peak values.
For additional information: http://www.ngs.noaa.gov/OPUS/about.html#accuracy

      USER: andrew.staloch@kljeng.com                DATE: May 24, 2011
RINEX FILE: 1421140o.11o                             TIME: 22:38:06 UTC


  SOFTWARE: page5  1009.28 master2.pl 0518113      START: 2011/05/20  14:40:00
 EPHEMERIS: igr16365.eph [rapid]                     STOP: 2011/05/20  18:51:00
  NAV FILE: brdc1400.11n                         OBS USED:  9505 /  9859   :  96%
  ANT NAME: TRM41249.00      NONE              # FIXED AMB:    55 /    57   :  96%
ARP HEIGHT: 1.108                              OVERALL RMS: 0.015(m)


 REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)            ITRF00 (EPOCH:2011.3827)

        X:     -1001107.647(m)   0.018(m)         -1001108.442(m)   0.018(m)
        Y:     -4144022.753(m)   0.019(m)         -4144021.513(m)   0.019(m)
        Z:      4728911.454(m)   0.013(m)          4728911.425(m)   0.013(m)

      LAT:   48  9 21.10727      0.017(m)       48  9 21.13121      0.017(m)
    E LON:  256 25  7.57439      0.013(m)      256 25  7.52291      0.013(m)
    W LON:  103 34 52.42561      0.013(m)      103 34 52.47709      0.013(m)
   EL HGT:         612.312(m)    0.021(m)             611.611(m)    0.021(m)
 ORTHO HGT:        630.458(m)    0.037(m) [NAVD88 (Computed using GEOID09)]

                        UTM COORDINATES    STATE PLANE COORDINATES
                         UTM (Zone 13)         SPC (3301 ND N)
Northing (Y) [meters]     5334597.294          133096.210
Easting (X)  [meters]      605513.559          370831.341
Convergence  [degrees]     1.05702770         -2.29284568
Point Scale                0.99973679          0.99993661
Combined Factor            0.99964086          0.99984066

US NATIONAL GRID DESIGNATOR: 13UFP0551334597(NAD 83)


                           BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
DI2260 P054 TEREKALAKAMT2006 CORS ARP      N455046.833 W1042629.062  264966.7
DI1073 NDMB MINOT AFB BASE CORS ARP        N482458.097 W1011948.595  169547.3
AJ7216 BSMK BISMARK CORS ARP               N464916.027 W1004900.042  255764.6
```

1

NEAREST NGS PUBLISHED CONTROL POINT

```
TG1311      WILLISTON 2 RESET           N480921.106 W1033452.427      0.0
```

This position and the above vector components were computed without any knowledge by the National Geodetic Survey regarding the equipment or field operating procedures used.

```
 8002   The Opus solution for your submitted RINEX file appears to be
 8002   quite close to an NGS published control point. This suggests that
 8002   you may have set your GPS receiver up over an NGS control point.
 8002   Furthermore, our files indicate that this control point has not
 8002   been recovered in the last five years.
 8002   If you did indeed recover an NGS control point, we would
 8002   appreciate receiving this information through our web based
 8002   Mark Recovery Form at
 8002   http://www.ngs.noaa.gov/products_services.shtml#MarkRecoveryForm.
 8002
```

2

APPENDIX Z. KLJ RTK-GPS IfSAR ACCURACY ASSESSMENT DATA

					Day 1 In-Field RTK-GPS Elevation Measurements			
No.	Point No.	Easting	Northing	Land Cover Type	RTK-GPS Elev.	IfSAR Elev.	Diff. (m)	Abs. Diff. (cm)
1	100	603810.4	5332479	Urban	563.917	561.489	-2.42749	242.749
2	101	603803.7	5332478	Urban	564.004	561.535	-2.46852	246.852
3	102	603797.1	5332476	Urban	564.026	561.784	-2.24144	224.144
4	103	603791.1	5332476	Urban	563.982	561.966	-2.01646	201.646
5	104	603785.9	5332475	Urban	563.915	562.473	-1.44257	144.257
6	105	603780.0	5332475	Urban	563.882	562.567	-1.32480	131.480
7	106	603249.3	5332192	Emergent Wetlands	560.354	559.489	-0.86493	86.493
8	107	603243.1	5332201	Emergent Wetlands	560.042	558.562	-1.48012	148.012
9	108	603236.3	5332208	Emergent Wetlands	560.370	558.981	-1.38975	138.975
10	109	603227.9	5332218	Emergent Wetlands	560.301	558.730	-1.57062	157.062
11	110	603264.1	5332193	Emergent Wetlands	560.288	559.539	-0.74892	74.892
12	111	602645.1	5331725	Emergent Wetlands	561.220	560.599	-0.62112	62.112
13	112	602637.0	5331723	Emergent Wetlands	561.230	560.799	-0.4316	43.160
14	113	602630.3	5331719	Emergent Wetlands	561.227	560.857	-0.36965	36.965
15	114	602622.9	5331717	Emergent Wetlands	561.242	560.898	-0.34357	34.357
16	115	602617.0	5331715	Emergent Wetlands	561.202	560.919	-0.28264	28.264

					Day 1 In-Field RTK-GPS Elevation Measurements			
Obs	Point No.	Easting	Northing	Land Cover Type	RTK-GPS Elev	IfSAR Elev	Diff. (m)	Abs. Diff. (cm)
17	116	602611.9	5331710	Emergent Wetlands	561.148	560.927	-0.22094	22.094
18	117	601818.5	5331627	Wetlands	561.014	557.756	-3.25883	325.883
19	118	601818.4	5331631	Wetlands	561.072	557.97	-3.10232	310.232
20	120	601816.8	5331636	Wetlands	560.988	558.249	-2.7388	273.878
21	121	601818.9	5331644	Wetlands	560.98	558.828	-2.1524	215.236
22	122	601818.1	5331647	Wetlands	560.896	558.828	-2.0679	206.793
23	123	601018.3	5331675	Crops, Pasture	562.981	561.275	-1.7061	170.605
24	124	601018.8	5331685	Corps, Pasture	562.891	561.331	-1.5603	156.029
25	125	601019.5	5331692	Crops, Pasture	562.912	561.075	-1.8371	183.706
26	126	601018.6	5331698	Crops, Pasture	562.872	561.304	-1.5681	156.806
27	127	601018.5	5331704	Crops, Pasture	562.847	561.304	-1.5428	154.282
28	128	601017.6	5331711	Crops, Pasture	562.786	561.341	-1.4447	144.469
29	129	600839.6	5331591	Shrub, Scrub	563.377	562.807	-0.5699	56.994
30	130	600835.9	5331592	Shrub, Scrub	563.389	562.893	-0.4957	49.565
31	131	600832.1	5331594	Scrub, Shrubs	563.218	562.850	-0.3685	36.848
32	132	600829.9	5331594	Scrub, Shrubs	563.251	562.850	-0.4011	40.109

					Day 1 In-Field RTK-GPS Elevation Measurements			
Obs	Point No.	Easting	Northing	Land Cover Type	RTK-GPS Elevation	IfSAR Elevation	Diff. (m)	Abs. Diff. (cm)
33	133	600825.5	5331593	Scrub, Shrubs	563.193	562.988	-0.2051	20.512
34	134	600824	5331594	Scrub, Shrubs	563.175	562.829	-0.34564	34.564
35	135	600854	5331619	Crops, Pasture	563.161	562.071	-1.08992	108.992
36	136	600853.9	5331626	Crops, Pasture	563.132	562.022	-1.10943	110.943
37	137	600853	5331632	Crops, Pasture	563.146	562.001	-1.14524	114.524
38	138	600853	5331638	Crops, Pasture	563.112	562.001	-1.1108	111.080
39	139	600852.1	5331644	Crops, Pasture	563.076	562.031	-1.04456	104.456
40	140	600851.2	5331650	Crops, Pasture	563.064	562.031	-1.03352	103.352
41	141	599532.1	5332093	Urban	563.669	562.783	-0.88611	88.611
42	142	599526.8	5332097	Urban	563.652	562.797	-0.8547	085.470
43	143	599521.6	5332100	Urban	563.604	562.51	-1.09389	109.389
44	144	599516.3	5332104	Urban	563.553	562.273	-1.2803	128.030
45	145	599511.8	5332107	Urban	563.493	561.99	-1.50284	150.284
46	146	599507.3	5332109	Urban	563.418	562.202	-1.21625	121.625
47	147	596188.6	5330837	Grassland	562.824	562.157	-0.66675	66.675
48	148	596183.5	5330834	Grassland	562.783	562.175	-0.60717	60.717
49	149	596178.4	5330829	Grassland	562.753	562.16	-0.59311	59.311

					Day 1 In-Field RTK-GPS Elevation Measurements			
Obs	Point No.	Easting	Northing	Land Cover Type	RTK-GPS Elevation	IfSAR Elevation	Diff. (m)	Abs. Diff. (cm)
50	151	597787	5331870	Urban	567.938	565.724	-2.21404	221.404
51	152	597791.4	5331873	Urban	567.942	566.102	-1.84032	184.032
52	153	597795.9	5331875	Urban	567.942	565.854	-2.0883	208.830
53	154	597801	5331877	Urban	567.945	565.768	-2.17655	217.655
54	155	597805.5	5331879	Urban	567.936	565.099	-2.83709	283.709
55	156	597809.1	5331882	Urban	567.917	565.046	-2.87178	287.178
56	157	599258.2	5332269	Wetlands	561.647	561.259	-0.38879	38.879
57	158	599265.7	5332265	Wetlands	561.613	561.026	-0.58701	58.701
58	159	599271.7	5332262	Wetlands	561.631	561.086	-0.54536	54.536
59	160	599277	5332258	Wetlands	561.676	561.097	-0.57985	57.985
60	161	599284.4	5332256	Wetlands	561.572	560.939	-0.63296	63.296
61	162	599289.7	5332252	Wetlands	561.671	561.189	-0.48135	48.135
62	163	599296.5	5332249	Wetlands	561.675	561.055	-0.61971	61.971
63	164	599302.5	5332245	Wetlands	561.652	561.153	-0.49895	49.895
64	165	599307	5332242	Wetlands	561.752	561.242	-0.5103	51.030
65	166	599312.3	5332239	Wetlands	561.722	561.07	-0.65243	65.243
66	200	595766.1	5330067	Urban	568.419	566.153	-2.26618	226.628
67	413	607050	5331083	Emergent Wetlands	568.452	566.216	-2.23507	223.507

					Day 2 In-Field RTK-GPS Elevation Measurements			
Obs	Point No.	Easting	Northing	Land Cover Type	RTK-GPS Elevation	IfSAR Elevation	Diff. (m)	Abs. Diff. (cm)
68	414	607053.1	5331075	Emergent Wetlands	566.362	565.959	-0.40385	40.385
69	415	607055.5	5331069	Emergent Wetlands	565.339	566.716	1.37675	137.675
70	416	607057.2	5331059	Emergent Wetlands	565.281	566.339	1.0582	105.820
71	417	607053.5	5331054	Emergent Wetlands	564.782	565.374	0.59201	59.201
72	418	607052	5331057	Emergent Wetlands	564.431	565.374	0.94283	94.283
73	419	607052.6	5331062	Emergent Wetlands	564.664	565.466	0.80225	80.225
74	420	607052.5	5331068	Emergent Wetlands	564.933	565.533	0.60086	60.086
75	421	607051	5331069	Emergent Wetlands	564.498	564.878	0.38041	38.041
76	422	607047.9	5331074	Emergent Wetlands	564.828	565.395	0.56741	56.741
77	423	607043.4	5331079	Emergent Wetlands	564.677	564.674	-0.00315	0.315
78	424	604528.8	5339216	Grassland	565.608	564.763	-0.84521	84.521
79	425	604531.2	5339209	Grassland	565.387	564.747	-0.63955	63.855
80	426	604529.3	5339193	Grassland	565.339	564.433	-0.90627	90.627
81	427	604531.7	5339181	Grassland	565.324	564.422	-0.90262	90.262
82	428	604536.3	5339172	Grassland	565.23	564.478	-0.75223	75.223
83	429	604535	5339164	Grassland	565.318	564.52	-0.79826	79.826
84	430	604527.8	5339153	Grassland	565.33	564.439	-0.89035	89.035

					Day 2 In-Field RTK-GPS Elevation Measurements			
Obs	Point No.	Easting	Northing	Land Cover Type	RTK-GPS Elevation	IfSAR Elevation	Diff (m)	Abs. Diff. (cm)
85	431	604548.6	5339152	Grassland	565.562	564.851	-0.71111	71.111
86	432	604549.2	5339159	Grassland	565.482	564.815	-0.66708	66.708
87	433	604549.8	5339169	Grassland	565.432	564.909	-0.5231	52.310
88	434	604550.3	5339179	Grassland	565.603	564.986	-0.61719	61.719
89	435	604549.4	5339189	Grassland	565.718	565.028	-0.69041	69.041
90	436	604547.7	5339201	Grassland	565.842	565.117	-0.72486	72486
91	437	604544.6	5339209	Grassland	565.834	565.085	-0.74923	74.923
92	438	604543.7	5339218	Grassland	565.873	565.12	-0.7526	75.260
93	439	603670.2	5343391	Crop	570.859	570.715	-0.14403	14.403
94	440	603676.2	5343392	Crop	570.959	570.583	-0.3767	37.670
95	441	603679.1	5343397	Crop	570.889	570.587	-0.30183	30.183
96	442	603684.1	5343403	Crop	570.68	570.555	-0.12472	12.472
97	443	603690.8	5343404	Crop	570.78	570.53	-0.24929	24.929
98	444	603693.9	5343398	Crop	570.826	570.516	-0.30997	30.997
99	445	603698.4	5343394	Crop	570.809	570.468	-0.34154	34.154
100	446	603699.3	5343387	Crop	570.763	570.444	-0.31926	31.926
101	447	603694.2	5343379	Crop	570.846	570.485	-0.36048	36.048

					Day 2 In-Field RTK-GPS Elevation Measurements			
Obs	Point No.	Easting	Northing	Land Cover Type	RTK-GPS Elevation	IfSAR Elevation	Diff. (m)	Abs. Diff. (cm)
102	448	603688.4	5343373	Crop	570.811	570.53	-0.2813	28.130
103	449	602091.3	5343917	Crop	583.313	583.325	0.01207	01.207
104	450	602098.8	5343918	Crop	583.239	582.731	-0.5081	50.810
105	451	602105.5	5343915	Crop	583.201	582.664	-0.53653	53.653
106	452	602112.9	5343916	Crop	583.096	582.57	-0.5261	52.610
107	453	602112.8	5343922	Crop	583.235	582.496	-0.73925	73.925
108	454	602113.4	5343930	Crop	583.197	582.432	-0.76463	76.463
109	455	602113.3	5343936	Crop	583.624	582.433	-1.19147	119.147
110	456	602112.4	5343942	Crop	582.819	582.433	-0.3868	38.680
111	457	602102.8	5343942	Crop	582.767	582.496	-0.27114	27.114
112	458	602096.1	5343941	Crop	582.715	582.763	0.04826	4.826
113	459	603640.9	5334813	Emergent Wetlands	560.969	560.387	-0.58274	58.274
114	460	603643.2	5334807	Emergent Wetlands	560.964	560.964	0.6406	64.060
115	461	603635.1	5334801	Emergent Wetlands	560.919	560.919	0.6442	64.420
116	462	603629.9	5334802	Emergent Wetlands	561	560.27	-0.72992	72.992
117	463	603628.3	5334809	Emergent Wetlands	560.858	560.441	-0.41698	41.698

					Day 2 In-Field RTK-GPS Elevation Measurements			
Obs	Point No.	Easting	Northing	Land Cover Type	RTK-GPS Elevation	IfSAR Elevation	Diff. (m)	Abs. Diff. (cm)
118	464	603628.9	5334814	Emergent Wetlands	561.11	560.503	-0.60631	60.631
119	465	603632.6	5334817	Emergent Wetlands	561.153	560.552	-0.60125	60.125
120	466	603632.5	5334822	Emergent Wetlands	561.159	560.566	-0.59233	59.233
121	467	603631.7	5334826	Emergent Wetlands	560.986	560.762	-0.22407	22.407
122	468	603639.5	5334804	Emergent Wetlands	560.919	560.284	-0.63492	63.492
123	500	595792.8	5328962	Scrub, Shrubs	565.304	565.394	0.08942	8.942
124	501	595795	5328959	Scrub, Shrubs	565.223	565.488	0.26558	26.558
125	502	595796.5	5328957	Scrub, Scrub	565.214	565.317	0.10371	10.371
126	503	595798.8	5328958	Scrub, Shrubs	565.213	565.317	0.10462	10.462
127	504	595800.2	5328960.5	Scrub, Shrubs	565.214	565.149	-0.06554	6.554
128	505	595803.2	5328961	Scrub, Shrubs	565.233	565.149	-0.08444	8.444
129	506	595804.6	5328963	Scrub, Shrubs	565.239	565.081	-0.15792	15.792
130	507	595801.7	5328963	Scrub, Shrub	565.214	565.149	-0.06524	6.524
131	508	595799.4	5328963	Scrub, Shrubs	565.205	565.149	-0.0567	5.670
132	509	595796.4	5328965	Scrub, Shrubs	565.204	565.155	-0.04926	4.926
133	510	598444.5	5324876	Grassland	566.38	565.56	-0.81996	81.996

					Day 2 In-Field RTK-GPS Elevation Measurements			
Obs	Point No.	Easting	Northing	Land Cover Type	RTK-GPS Elevation	IfSAR Elevation	Diff. (m)	Abs. Diff. (cm)
134	511	598440.6	5324882	Grassland	566.298	565.525	-0.77307	77.307
135	512	598442	5324886	Grassland	566.327	565.526	-0.80184	80.184
136	513	598444.2	5324891	Grassland	566.309	565.51	-0.79863	79.863
137	514	598445.6	5324897	Grassland	566.314	565.529	-0.78525	78.525
138	515	598450.8	5324900	Grassland	566.431	565.495	-0.93581	93.581
139	516	598453.8	5324895	Grassland	566.404	565.438	-0.96623	96.623
140	517	598454.7	5324890	Grassland	566.461	565.463	-0.99723	99.723
141	518	598454	5324884	Grassland	566.404	565.552	-0.85234	85.234
142	519	598455.5	5324881	Grassland	566.436	565.742	-0.69349	69.349
143	520	591661.2	5319763	Crops, Pasture	567.833	567.412	-0.42108	42.108
144	521	591661.1	5319770	Crops, Pasture	567.85	567.385	-0.46464	46.464
145	522	591660.9	5319778	Crops, Pasture	567.918	567.371	-0.54683	54.683
146	523	591660.1	5319784	Crops, Pasture	567.931	567.355	-0.57574	57.574
147	524	591653.4	5319784	Crops, Pasture	567.948	567.385	-0.56217	56.217
148	525	591652.7	5319778	Crops, Pasture	567.971	567.396	-0.57594	57.594
149	526	591652.9	5319770	Crops, Pasture	567.885	567.425	-0.45971	46.971

					Day 2 In-Field RTK-GPS Elevation Measurements			
Obs	Point No.	Easting	Northing	Land Cover Type	RTK-GPS Elevation	IfSAR Elevation	Diff. (m)	Abs. Diff. (cm)
150	527	591652.2	5319764	Crops, Pasture	567.91	567.441	-0.4689	46.890
151	528	591653	5319761	Crops, Pasture	567.844	567.456	-0.38884	38.884
152	529	591655.3	5319760	Crops, Pasture	567.924	567.456	-0.46869	46.869
153	530	591931.9	5319811	Scrub, Shrubs	567.92	567.195	-0.72444	72.444
154	531	591934.8	5319817	Scrub, Shrubs	567.978	567.201	-0.77747	77.747
155	532	591936.9	5319821	Scrub, Shrubs	567.955	567.185	-0.76919	76.919
156	533	591939.1	5319827	Scrub, Shrubs	567.984	567.206	-0.77874	77.874
157	534	591941.3	5319830	Scrub, Shrubs	567.97	567.21	-0.7599	75.990
158	535	591944.9	5319833	Scrub, Shrubs	567.918	567.221	-0.6971	69.710
159	536	591950.1	5319835	Scrub, Shrubs	567.877	567.235	-0.64179	64.179
160	537	591954.5	5319839	Scrub, Shrubs	567.878	567.276	-0.60236	60.236
161	538	591956.7	5319845	Scrub, Shrubs	568.003	567.29	-0.71286	71.286
162	539	591946.4	5319837	Scrub, Shrubs	567.887	567.21	-0.6773	67.730
163	540	589501.3	5325843	Scrub, Shrubs	566.639	566.6	-0.03888	3.888
164	541	589500.6	5325837	Scrub, Shrubs	566.653	566.372	-0.28105	28.105
165	542	589500.7	5325835	Scrub, Shrubs	566.597	566.372	-0.22466	22.466

					Day 2 In-Field RTK-GPS Elevation Measurements			
Obs	Point No.	Easting	Northing	Land Cover Type	RTK-GPS Elevation	IfSAR Elevation	Diff. (m)	Abs. Diff. (cm)
166	543	589500	5325833	Scrub, Shrubs	566.564	566.212	-0.35239	35.239
167	544	589495.5	5325832	Scrub, Shrubs	566.55	566.197	-0.35296	35.96
168	545	589495.5	5325835	Scrub, Shrubs	566.62	566.371	-0.24887	24.887
169	546	589495.4	5325838	Scrub, Shrubs	566.738	566.371	-0.36682	36.672
170	547	589494.6	5325842	Scrub, Shrubs	566.815	566.66	-0.15475	15.475
171	548	589494.5	5325847	Scrub, Shrubs	566.998	566.75	-0.24779	24.779
172	549	589500.4	5325850	Scrub, Shrubs	567.161	566.906	-0.25565	25.565
173	550	589500.4	5325854	Scrub, Shrubs	567.276	567.096	-0.18025	18.025
174	552	587923.8	5324557	Crops, Pasture	567.141	565.941	-1.20049	120.049
175	553	587923.7	5324563	Crops, Pasture	567.109	565.91	-1.19889	119.889
176	554	587923.6	5324569	Crops, Pasture	567.075	565.906	-1.16951	116.951
177	555	587924.3	5324573	Crops, Pasture	567.065	565.836	-1.22848	122.848
178	556	587924.2	5324578	Crops, Pasture	567.046	565.815	-1.23028	123.028
179	557	587924.1	5324584	Crops, Pasture	567.031	565.885	-1.14631	114.631
180	558	587924.1	5324589	Crops, Pasture	566.971	565.89	-1.08108	108.108
181	559	587924	5324593	Crops, Pasture	566.974	565.919	-1.05544	105.544

					Day 2 In-Field RTK-GPS Elevation Measurements			
Obs	Point No.	Easting	Northing	Land Cover Type	RTK-GPS Elevation	IfSAR Elevation	Diff. (m)	Abs. Diff. (cm)
182	560	587923.9	5324598	Crops, Pasture	566.924	565.944	-0.98091	98.091
183	561	587923.9	5324601	Crops, Pasture	566.884	565.964	-0.91913	91.913
184	563	587854.3	5324471	Urban	567.551	566.117	-1.43333	143.333
185	564	587858.9	5324468	Urban	567.585	566.056	-1.52819	152.819
186	565	587858.9	5324463	Urban	567.593	566.092	-1.50078	150.078
187	566	587857.5	5324458	Urban	567.597	566.269	-1.32805	132.805
188	567	587853.1	5324456	Urban	567.613	566.224	-1.38937	138.937
189	568	587847.9	5324456	Urban	567.593	566.34	-1.25286	125.287
190	569	587851.7	5324451	Urban	567.602	566.39	-1.21171	121.171
191	570	587861.2	5324458	Urban	567.569	566.224	-1.34517	134.517
192	571	587866.4	5324462	Urban	567.58	566.062	-1.51843	151.843
193	572	587879.5	5324479	Urban	567.542	565.9	-1.64196	164.196
194	573	588703.2	5324507	Crops, Pasture	566.82	565.803	-1.01736	101.736
195	574	588699.6	5324504	Crops, Pasture	566.813	565.78	-1.03257	103.357
196	575	588699.6	5324501	Crops, Pasture	566.788	565.78	-1.00757	100.757
197	576	588701.2	5324496	Crops, Pasture	566.802	565.708	-1.09361	109.361
198	577	588700.5	5324492	Crops, Pasture	566.831	565.685	-1.14637	114.637

					Day 2 In-Field RTK-GPS Elevation Measurements			
Obs	Point No.	Easting	Northing	Land Cover Type	RTK-GPS Elevation	IfSAR Elevation	Diff. (m)	Abs. Diff. (cm)
199	578	588703.5	5324488	Crops, Pasture	566.856	565.69	-1.16587	116.587
200	579	588707.2	5324490	Crops, Pasture	566.821	565.699	-1.1224	112.240
201	580	588707.9	5324494	Crops, Pasture	566.761	565.724	-1.03728	103.728
202	581	588707.8	5324498	Crops, Pasture	566.777	565.758	-1.01888	101.888
203	582	588707	5324503	Crops, Pasture	566.774	565.78	-0.99355	99.355