SUNY College of Environmental Science and Forestry

Digital Commons @ ESF

Dissertations and Theses

Spring 4-27-2018

Assessing Irrigation in Western New York State

Maggie Todaro
maggietodaro@gmail.com

ASSESSING IRRIGATION IN WESTERN NEW YORK STATE

by

Maggie Todaro

A thesis
submitted in partial fulfillment
of the requirement for the
Master of Science Degree
State University of New York
College of Environmental Science and Forestry
Syracuse, New York
May 2018

Department of Environmental Resources Engineering

Approved by:
Stephen B. Shaw, Major Professor
Dylan Parry, Chair, Examining Committee
Theodore Endreny, Department Chair
S. Scott Shannon, Dean, The Graduate School

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract

M. C. Todaro. Assessing Irrigation in Western New York State, 47 pages, 8 tables, 8 figures, 2018. APA style guide used.

Historically, sufficient precipitation in New York inhibited concerns about agricultural water management until recently, with intense drought occurring over the 2016 growing season. During this time, even farms with irrigation capacity reported losses. Based on reported water use of select farms, in some cases there was in increase in water use with lower precipitation, however, in other cases there was a decrease in use, presumably due to lack of supply. To determine which watersheds had insufficient water to meet demands, demand was compared to estimated streamflow to estimate available water. The Black, Tonawanda, Northrup, and Oak Orchard Creek watersheds all indicate low supply relative to demand of reporting users. A relationship between baseflow and antecedent precipitation was also established at the Black, Oatka, and Tonawanda Creek gages to help forecast summer low flows. Surficial geology and wetland area were used to explain differences between watersheds.

Key words: available water, irrigation, low flow, western New York, FRIS.

M. C. Todaro
Candidate for the degree of Master of Science, April 2018
Stephen B. Shaw, Ph.D.
Department of Environmental Resources Engineering
State University of New York College of Environmental Science and Forestry
Syracuse, New York

CHAPTER 1: INTRODUCTION

Although the majority of irrigated crop production is associated with the arid and semi-arid western United States, irrigation practices are prevalent in humid regions as well. Unlike irrigation in arid regions, where water application is essential to grow crops in nearly all years, humid region irrigation is used to both overcome periodic dry conditions as well as to ensure higher quality crops (especially fruits and vegetables).

Because irrigation in humid regions is not used by all growers and is not used all the time, irrigation planning and infrastructure is often decentralized. This decentralization also likely occurs because water is accessed by a system of riparian water rights where water within or adjacent to one's property can be freely used. Because of the decentralized nature of irrigation in the eastern US, there is little systematic evaluation of water availability.

In New York State, ~59,000 acres are irrigated annually. The 9.6% of farms across the state that employ irrigation practices do so predominantly on harvested cropland, which mainly includes vegetable land, and orchards (NYS DEC 2016). While field crops such as corn, winter wheat, and soybeans are sometimes irrigated as well, they are not the dominant focus of agricultural producers. Several studies throughout the 1950's demonstrated that for many vegetable crops in New York, revenue from increased yields outweighed the cost of irrigation (Vittum and Peck 1956, Vittum et al. 1958, Vittum et al. 1959). While no in-depth studies on irrigation practices in New York have been conducted since then, irrigation practices have continued.

Historical conditions of sufficient precipitation in New York have inhibited concerns about water management until recently, with significant drought occurring over the 2016 growing season. On July 15, 2016 New York State Department of Environmental Conservation (NYS DEC)

Commissioner Basil Seggos issued a drought watch for the entire state of New York for the first time since 2002. In his announcement, he revealed that observed precipitation was less than normal, with shortfalls of 4-8 inches being common in the 90 days leading up to the drought watch. A drought watch is triggered based on the State Drought Index, which measures precipitation levels, reservoir/lake levels, stream flow, and groundwater levels. Each indicator is assigned a weighted value that corresponds to its significance within each of the nine designated drought regions in New York State. Triggered by a lack of winter snow and above average temperatures, by late July and August of 2016, streams in western and central NY broke records for low flows. Impacts on agriculture were revealed in a report by Sweet, published by the Cornell Institute for Climate Smart Solutions, "Anatomy of a Rare Drought: Insights From New York Farmers." In a survey of over 200 farmers, over 70% of unirrigated, rain-fed crops and pasture acreage had crop losses between 30% and 90%. Fruit and vegetable producing farms with irrigation capacity also had losses up to 35%, lacking sufficient water to combat drought conditions. This report indicated that farms in western NY experienced significantly more losses than eastern NY. In particular, fruit and berry producers in western New York had the most severe losses, with 52% of fruit and 96% of berry crops lost to drought.

While unpredictable drought conditions make irrigation decision making unique in humid regions, there is a marked lack of academic literature discussing the subject. Thus, this study focuses on water availability for irrigation and associated irrigation decision-making in western New York State. Chapter 2 focuses on the relationship between available water supply and irrigation demand. Information from both public and independent surveys were compiled to determine how much we know about water use. Water use is estimated by individual records, by aggregate irrigated acreage, and for selected withdrawal points. Available water is then estimated and compared to results for water use to find where available water fails to meet the needs of users. While Chapter 2 focuses on quantifying the supply and demand of water for irrigation, Chapter 3 looks instead at the relationship between discharge and antecedent precipitation, so that deficiencies in water resources can be more easily anticipated.

The primary interest of this work is to integrate information about irrigation water use in western New York, as a means to better understand the repercussions of regionally uncharacteristic extended low-flow conditions. Establishing annual patterns of supply and demand, particularly during low flows, identifies watersheds with both sufficient and insufficient water resources to meet the demands of users. Modeling water application rates, and predicting discharge from antecedent precipitation, both indicate the degree to which water application is dependent on the physical controls of weather variables and soil water storage. Besides immediate operational and strategic questions related to water use and conservation, this work will also help advance the use of USDA FRIS data. USDA FRIS collects a large and comprehensive sample of irrigation related data, and to answer questions on water use behavior, it would seem FRIS offers an extremely valuable resource. However, given the lack of academic papers currently making use of FRIS to answer these questions, this project would in part help lay the groundwork for future intensive use of the FRIS data center, potentially leading to input on survey modifications. Hopefully, the information obtained can start to bridge the knowledge gap in understanding of water use in western New York, specifically, and for other humid regions, in general.

CHAPTER 2: THE RELATIONSHIP BETWEEN AVAILABLE WATER SUPPLY AND IRRIGATION DEMAND

I. BACKGROUND DATA

Water availability is often not a matter of concern in regions with historically wet conditions. However, during occasional periods of drought and extended low-flow conditions, some facilities face scarcities in water resources, and their irrigation is limited by available supply. In order to quantify net available water and identify sources of water insecurity, both supply and demand must be estimated. Using a simple water balance equation, available water supply is calculated for each watershed to determine if there is adequate water to meet user demands. In this chapter, water use is estimated by individual records, and by aggregate irrigated acreage. Individual records are publically available and were obtained from the Department of Environmental Conservation (DEC). Reported withdrawals as estimated by individual records are later compared to water use as estimated from the state reported water application rate. In Section 3, water use by aggregated irrigated acreage was estimated using a multivariate regression model. Using select withdrawal points, available supply is then estimated in Section 4. Watersheds with deficiencies in available water are identified as those whose withdrawal demands exceed estimated available water supply.

Irrigation in western New York is less formalized than in the western United States. Irrigation infrastructure in western New York lacks large scale capital investment provided by cooperative irrigation districts or the federal Bureau of Reclamation. Instead, irrigation is sourced locally based on riparian water rights with little centralized planning of water use. As a result, information about water use is somewhat limited and divided among a number of different sources. This section describes the data available from these different sources.

To document use, the New York State DEC has an agricultural water withdrawal reporting system where farmers can disclose information on water withdrawal from both surface and groundwater sources. The reporting system was implemented after a 2011 revision to the Water Resources Law, as a method of implementing New York's obligation to the Great Lakes-St. Lawrence River Basin Water Resources Compact. Previously, reporting only applied to public water supply. However, the compact created a regulatory program for water withdrawals in the region. Apart from agricultural facilities withdrawing over the 100,000 gallon per day threshold (that are required to file annual withdrawal reports), other farmers may do so voluntarily. Information available in these reports includes the distinction between groundwater or surface water sources, as well as average daily withdrawal. While the quantity and classification of water is important for analyzing demand, these data alone are not enough to get an accurate approximation of water use. Without information on specific water sources, such as streams, canals, etc., the information reported cannot be used beyond regional approximations of demand, and cannot indicate whether specific rivers or streams have sufficient water. Insufficient participation in filing reports is another concern. Farms using less than 100,000 gallons per day, when combined together, could still be using a significant amount of water, especially if multiple farms are obtaining water from the same source. The 100,000 gallon per day criteria is independent of farm size, and does not relate to the size of the water body. Additionally, those farmers who are required to report still might not, as it is difficult for the DEC to enforce the reporting requirement.

Another source of water resource information comes from USDA Farm and Ranch Irrigation Surveys (FRIS), a supplement to the Census of Agriculture. While FRIS have been collected since 1998, full reports are only available for 2003, 2008, and 2013. The data in these surveys are reported on the national level, the state level, and for the 20 geographically distinguished Water Resource regions in the United States. The FRIS reports have a participation rate from U.S. growers that is greater than 80%. In New York State, 35,000 surveyed producers provide information on water resources, the amount of water used, types of irrigation systems, irrigation and yield by crop, and system investments and energy costs. Table 1 shows the results of this survey at the state level. FRIS differentiates between open (field) and covered (greenhouse) acreage, and reports close to 7 million gallons of water applied per day over 47,580 irrigated open acres in NYS. This information is also broken down further by farm sizes.

Much like the DEC surveys, FRIS has several limitations. First, the data are only collected and reported every 5 years, which makes noticing trends difficult. Additionally, irrigation practices may not be necessary in all years given precipitation. So, data collected during a particularly wet or dry year might not be representative of the majority of years. Second, to maintain farmer confidentiality and statistical certainty, much of the data have been reported in aggregate at the state level, making it difficult to analyze watershed-scale regional differences that may play a major role in water use. In Section 3, I discuss efforts to gain access to individual records and to analyze some of these data at a finer scale than the state level.

In addition to quantitative data regarding water use, a portion of FRIS reports is dedicated to understanding irrigation decision making. Irrigation variations both within the same region and year, as well as over time and space, often cannot be accounted for by biophysical conditions (crop, temperature, precipitation, available water storage, etc.) alone. Having more detailed information on behavioral variations (experience, risk factors, etc.) might explain irrigation variation when other variables are held constant. These ideas are explored in Section 3 of this chapter, where a multiple linear regression model uses available water storage, temperature, and precipitation to predict water application rates. After considerable searching, only one previous study has used individual records from publically available data to construct crop-specific equations for explaining variation in water application rate, fraction of crop land irrigated, and technology adoption rates. The study by Olen et al. (2015) was conducted for Oregon, California, and Washington State, and found that (1) irrigation decisions were crop dependent and combining of crops could obscure explanatory variables; (2) that concerns over ability to mitigate frost risk often mattered more than water conservation concerns when selecting irrigation equipment; and that users with reliable, subsidized water were less likely to use water-saving measures (e.g. drip or spray irrigation).

To overcome inadequacies in publically available information, a survey was conducted by Martin (2016) in western NY at the farm level to understand how irrigation water use and decisions vary in time, and how the spatial arrangement of water resources plays a role in irrigation. The survey, designed to supplement DEC and FRIS data, collected information from agricultural producers about: 1) their irrigation water source; 2) the climatic and non-climatic factors that affect producer irrigation decisions; 3) irrigation water use rates, including differences between wet and dry years; 4) farm size and crops grown; 5) proximity and reliability of water sources; and 6) perception of additional centralized management or regulation. For non-irrigators, the survey collected information on farm characteristics (size, crops grown) and barriers preventing irrigation, with a particular focus on proximity to water sources. Using a combination of telephone and paper surveys, 32 facilities were interviewed, 17 of which had active irrigation operations at the time the surveys were conducted. Farm sizes ranged from ¼ acre to over 8,000 acres, with the average being between 100-200 acres. The combined information from public records and individual farm surveys provide a more complete picture of irrigation water use, and the factors that influence variability in use.

Table 1. At the state level, the FRIS provides the number of farms, acres irrigated, and water applied, in million gallons per day (MGD). The distinction is made between open (field) and covered (greenhouse) acreage in New York State.

FRIS	**OPEN**	**COVERED**
Number of Farms	1,400	1,066
Acres Irrigated	47,580	877
Water Applied (MGD)	6,940	275

A closer look into irrigated farmland was undertaken by Sweet (2017). The CICSS Research and Policy Brief surveyed 227 farmers throughout August and September (Drought Survey) to collect more specific information about irrigated crops and losses due to drought during the 2016 growing season. The survey was distributed both online and as paper copies with the help of the Cornell Cooperative Extension and the Farm Bureau. Farmers reported only on irrigated fruit and vegetable crops, as field crops received no irrigation. Information from the respondents included number of farms, total acreage, and mean % loss. The data was divided into Eastern and Western New York, and included respondents from nearly all counties. Genesee County with 6,346 irrigated acres, and Orleans County with 4,565 irrigated acres have some of the most irrigated acreage in New York State (USDA 2016). Results show that in Western NY, 80% of farmers estimated economic impact as "moderate" to "severe." Over the 2016 growing season, 65% of farmers relied on well and pond water for irrigation, 15% used city water, and 14% used streams, lakes, or canals. Other sources include hydrants, cisterns, and springs.

Roadside visual surveys of 27 agricultural facilities across Genesee, Monroe, Orleans, and Wyoming counties were conducted by Todaro in July of 2017. The purpose of the surveys was to gather information about the types of irrigation used in the region, and to directly check the consistency between reported irrigation use and actual use. Four main categories of farm irrigation systems are currently in use today, including flood, sprinkler, drip, and micro irrigation (ATS Irrigation 2018). The visual survey revealed that in western New York, sprinkler irrigation is the dominant method. Sprinkler irrigation is arguably the most versatile, and is not limited by size, slope, or shape of fields. Of the types of sprinkler irrigation systems, center pivots or other mechanical move units, and traveling gun systems, were the two preferential systems across the surveyed farms. Center pivots and other mechanical move irrigation systems have many suspended sprinklers which move over the fields. Traveling gun systems are comprised of a single, large sprinkler attached to hose on a large reel, which is manually moved across sections of the field. The visual survey was conducted over July 28-30, 2017. Of the 27 farms surveyed, 41% of facilities used mechanical move systems, 11% used center pivot systems, and 11% used traveling gun systems. While there was no precipitation during the course of the survey, the week preceding had precipitation every day. Consequently, the remaining 37% of facilities known to irrigate had no irrigation systems visibly operating in the fields during the survey.

While these data provide insight into water use and irrigation, the state-level spatial scale that they are reported on do not adequately explain specific sources used for water supply. Understanding water supply at the watershed-level takes into account water being withdrawn from the same source, as well as regional variations in climate and surficial geology.

II. WATER USE AS ESTIMATED BY INDIVIDUAL RECORDS

In order to effectively estimate irrigation water demand, it is essential to know specifically where water is coming from, how much is being used, how it is being used, and the variability in use through time. DEC Water Withdrawal Reports provide basic information about water use at individual sites, including location, withdrawal type (groundwater, surface water, etc.), and mean water withdrawal rates. Here, irrigation water use through time is analyzed for water users within several counties in western New York. Mean county precipitation sums for the growing season months are also included, so that variations in irrigation can be compared to variations in precipitation. A summary of a field survey of irrigation types at several sites is also included.

Not all farms in western New York irrigate consistently every year, and the majority don't irrigate at all. However, there are still farms who irrigate most years. From the data collected in Table 2, it is apparent that some users remain consistent in the volume of their annual withdrawals while others have highly variable water usage rates. The interest here is to correlate changes in water demand with varying precipitation. There were 33 facilities involved in this analysis, including 6 non-agricultural water users. In summary, 21 of 28 agricultural facilities reported irrigation at least 4 of 5 years from 2012-2016, with the remaining facilities reporting limited (3 or less) years. While 9 of the 21 facilities showed no change in application rate over the observation period, the remaining sites did show variability, with some of the biggest changes occurring between the 2015 and 2016 growing seasons. From 2015 to 2016, growing season precipitation decreased by an average of 43% across the four counties. It is difficult to discern whether sites with no change actually have no change or whether they simply do not keep accurate enough track of water usage to report the change. Thus, the primary focus should be placed on sites with variable usage rates over the five years. Although three agricultural facilities decreased their irrigation in 2016, 6 of the 8 facilities that increased irrigation did so by an average of ~150% (WWR0000128, WWR0001478, WWR0000900, WWR0001556, WWR0000894, WWR0000974). The two remaining sites (WWR0000902, WWR0001172) had increases of several hundred percent, but absolute water use was low (increasing from 0.05 MGD to 0.5 MGD and 0.09 MGD to 8.4 MGD, respectively). The facilities with decreases in irrigation (WWR0000388, WWR0000148, WWR0000679) each obtain their water from different sources including groundwater, surface water, and a combination of both.

Table 2. Major water users in Genesee, Monroe, Orleans, and Wyoming Counties. Data compiled from DEC water withdrawal reports for years 2012-2016, with distinctions between agricultural and non-agricultural water use. Withdrawal types G (ground water), S (surface water), GS (ground-surface combination), SP (spring). Withdrawals reported in million gallons per day (MGD), where values of 0 indicate no irrigation from that facility that year, and 'NI' signifies no information available for that year. Highlighted values show increased water use from 2015-2016.

Facility ID	Withdrawal Type	Agricultural or Non-Agricultural Use	County	2012 MGD	2013 MGD	2014 MGD	2015 MGD	2016 MGD
WWR0000128	G	Agricultural	Genesee	0.590	0.593	0	0	1.139
WWR0000388	GS	Agricultural	Genesee	0.070	0.070	0.070	0.07	0.05
WWR0001478	GS	Agricultural	Genesee	0.110	0.001	0.001	0.001	0.003
WWR0001178	G	Agricultural	Genesee	NI	0	0.432	NI	NI
WWR0001555	G	Agricultural	Genesee	NI	0.033	0.033	0.033	0.033
WWR0001110	G	Agricultural	Genesee	0.047	0.047	0.047	0.047	0.047
WWR0000148	G	Agricultural	Genesee	NI	0.123	0.157	0.144	0.130
WWR0000423	S	Agricultural	Genesee	NI	0.132	0.168	NI	0.232
WWR0000892	G	Agricultural	Genesee	0.098	0.078	0.078	NI	NI
WWR0001064	S	Agricultural	Genesee	1.228	1.228	1.228	1.228	1.228

WWR0000900	GS	Agricultural	Genesee	1.215	0.091	0	0.686	0.848
WWR0001292	G	Agricultural	Genesee	0.043	NI	NI	NI	NI
WWR0000554	S	Non-Agricultural	Genesee	1.050	1.05	1.05	1.05	1.05
Mean Total JJA Precipitation (in)			*Genesee*	*10.82*	*14.59*	*14.22*	*13.44*	*7.91*
WWR0000258	S	Non-Agricultural	Monroe	16.28	22.6	13.48	9.17	10.68
WWR0000465	S	Non-Agricultural	Monroe	12.5	12.44	11.33	11.011	10.94
WWR0001020	S	Non-Agricultural	Monroe	53.1	50.5	46.9	40.17	40.17
Mean Total JJA Precipitation (in)			*Monroe*	*9.27*	*12.9*	*12.07*	*13.92*	*5.69*
WWR0000819	S	Agricultural	Orleans	0.396	0.396	NI	0.053	NI
WWR0000902	SP	Agricultural	Orleans	0.006	0.011	0.011	0.050	0.534
WWR0001556	GS	Agricultural	Orleans	0.632	0.72	0	0	2.564
WWR0001172	GS	Agricultural	Orleans	0.507	0.204	0.634	0.091	8.435
WWR0001494	G	Agricultural	Orleans	0.027	0.027	0.027	0.027	NI
WWR0001327	S	Agricultural	Orleans	0.089	0.036	NI	0.018	NI
WWR0000894	S	Agricultural	Orleans	NI	0.3	0	0.167	0.314
WWR0000679	SP	Agricultural	Orleans	1.096	1.28	1.55	1.07	0.62
WWR0000096	S	Non-Agricultural	Orleans	3.8	4.9	3.6	2.5	2.5
Mean Total JJA Precipitation (in)			*Orleans*	*7.37*	*10.65*	*12.53*	*8.92*	*5.84*
WWR0000391	S	Agricultural	Wyoming	NI	0	0.0348	0.0348	0.0348
WWR0000177	G	Agricultural	Wyoming	0	0.378	0.093	0.378	0.378
WWR0000564	GS	Agricultural	Wyoming	0	0.191	0.047	0.191	0.191
WWR0000974	S	Agricultural	Wyoming	0.267	0.008	0	0.007	1.316
WWR0001455	GS	Agricultural	Wyoming	0	0.041	0.116	0.116	0.116
WWR0001516	G	Agricultural	Wyoming	0	0.075	0.075	0.075	0.075
WWR0001517	S	Agricultural	Wyoming	NI	0	0.476	NI	1.269
WWR0001041	SP	Non-Agricultural	Wyoming	3.204	0.45	0.276	0.36	0.318
Mean Total JJA Precipitation (in)			*Wyoming*	*9.98*	*14.65*	*13.1*	*15.84*	*9.89*

The primary interest of this analysis was to find a relationship between water demand and varying precipitation. The presumption was that water use would increase in 2016 due to the drier conditions during the growing season. In reality, the data lacks consistency between water users, with some facilities even decreasing demand in drier years (Table 2). Facility WWR0000388 reported water use of 0.07 MGD every year from 2012-2015. In 2016, however, that number dropped to 0.05 MGD. Decreases may possibly be due to lack of supply.

As mentioned previously, knowing only the quantity and type of water use from facilities in western New York is not enough information to make an adequate assessment of the balance of supply and demand, particularly during periods of extended low flows. To achieve that, specific bodies of water must be identified as sources. Source data for 27% of water users is available through the Martin interviews, improving the accuracy of the estimates. Withdrawal points for the remaining 73% of facilities are estimated using a visual assessment in ArcMap. During this process, the point of withdrawal is identified by following topography along a direct path from each facility to the stream which falls in the users' watershed delineation. For multiple users in a watershed, the point of withdrawal is approximated as the point in the stream which falls between all users. In Table 3, the major water users from Table 2 are assigned withdrawal points based on phone interviews carried out by Martin in 2016. and HUC-10 watershed delineation. Information about withdrawal type, source, and county is included. In Section 4, water supply is estimated for selected withdrawal points using USGS stream gage data. Once withdrawal estimates are collected, the effective impact of those withdrawals on available water supply downstream is reviewed. The result is a more thorough comprehension of where demand has exceeded supply.

Table 3. Water user source information. ***Bold*** *values signify non-agricultural users.*

Facility ID	Withdrawal Type	County	Withdrawal Source	Source Information
WWR0000128	G	Genesee	Black Creek	Watershed delineation
WWR0000388	GS	Genesee	Oak Orchard Creek	Martin Survey
WWR0001478	GS	Genesee	Black Creek	Watershed delineation
WWR0001178	G	Genesee	Oak Orchard Creek	Watershed delineation
WWR0001555	G	Genesee	Oak Orchard Creek	Watershed delineation
WWR0001110	G	Genesee	Oak Orchard Creek	Watershed delineation
WWR0000423	S	Genesee	Oak Orchard Creek	Watershed delineation
WWR0000892	G	Genesee	Oak Orchard Creek	Watershed delineation
WWR0001064	GS	Genesee	Tonawanda Creek	Martin Survey
WWR0000408	S	Genesee	Tonawanda Creek	Watershed delineation
WWR0000900	GS	Genesee	Black Creek	Martin Survey
WWR0001292	G	Genesee	Murder Creek/Tonawanda Creek	Watershed delineation
WWR0000554	**S**	**Genesee**	**Tonawanda Creek**	**Watershed delineation**
WWR0000258	**S**	**Monroe**	**Genesee River**	**Watershed delineation**
WWR0000465	**S**	**Monroe**	**Genesee River**	**Watershed delineation**
WWR0001020	**S**	**Monroe**	**Genesee River**	**Watershed delineation**
WWR0000819	S	Orleans	Genesee River	Watershed delineation
WWR0000902	SP	Orleans	Oak Orchard Creek	Martin Survey

WWR0001556	GS	Orleans	Erie Canal	Martin Survey
WWR0001172	GS	Orleans	Erie Canal	Martin Survey
WWR0001494	G	Orleans	Oak Orchard Creek	Watershed delineation
WWR0001327	S	Orleans	Oak Orchard Creek	Watershed delineation
WWR0000894	S	Orleans	Oak Orchard Creek	Watershed delineation
WWR0000679	SP	Orleans	Oak Orchard Creek	Martin Survey
WWR0000096	**S**	**Orleans**	**Sandy Creek**	**Watershed delineation**
WWR0000391	S	Wyoming	Genesee River	Watershed delineation
WWR0000177	G	Wyoming	Genesee River	Watershed delineation
WWR0000564	GS	Wyoming	Genesee River	Watershed delineation
WWR0000974	S	Wyoming	Wiscoy Creek/Genesee River	Martin Survey
WWR0001455	GS	Wyoming	Genesee River	Watershed delineation
WWR0001516	G	Wyoming	Genesee River	Watershed delineation
WWR0001517	S	Wyoming	Oatka Creek	Martin Survey
WWR0001041	**SP**	**Wyoming**	**Genesee River**	**Watershed delineation**

III. WATER USE AS ESTIMATED BY AGGREGATE IRRIGATED ACREAGE

As an alternative to using individual records to estimate demand, total irrigated acreage within a watershed of interest could be multiplied by a water application rate. The FRIS reports a statewide water application rate, but it is unclear whether the rate is accurate at a county level. One would anticipate spatial variations in water application rate due to such factors as spatial variations in precipitation (likely the most important factor), crop type, soil type, and growing season. For example, it would not be surprising if counties with low available water storage would need to be irrigated more frequently than soils with higher available water storage, even if growing season precipitation was similar.

With the USDA FRIS data, water application rates are unable to be directly reported at any scale more specific than the state level as a method of maintaining user confidentiality of FRIS respondents. However, through personal correspondence, USDA allowed special permission to access the individual records to develop a statistical model, under the condition that all analyses had to be completed at the Northeast Regional USDA Data Lab in Harrisburg, Pennsylvania by Shaw. As a work-around to accessing individual records, I developed a multivariate regression model to assess whether variations in individual application rates can be predicted by environmental variables, including available water storage (USGS 2016), average growing season temperature (NRCC 2013), and growing season precipitation (NRCC 2013). The goal is to use the model to predict water application rates in each county in New York State under differing climate conditions, rather than rely on a reported state average. In addition, access to individual records would allow FRIS data to be compared directly with individual records from DEC and Martin.

A forward selection method of stepwise regression is used to find the "best" model. The first "step" identifies the best single-variable model. Subsequent steps then add variables to maximize R^2, C_p, or both, such that the data best matches the fitted regression line. R^2 is referred to as the coefficient of determination, which evaluates the goodness-of-fit of a model by indicating how closely the regression line approximates the real data points. Maximizing R^2 means coming as close as possible to a value of 1, which means the regression line perfectly matches the data. The C_p statistic is used as a stopping criteria for stepwise regression. Checking C_p verifies that the model is not "over-fitted" by adding explanatory variables that provide negligible additional information to the model. Part of SAS output for model selection is the Akaike information criterion (AIC) test, which evaluates the goodness-of-fit between statistical models, where smaller values are more desirable. Two models are essentially indistinguishable if their $AIC<2$, which allows the user to identify the smallest number of independent variables to include in a model, where any additional information will not contribute to the goodness-of-fit of the model. The *PRESS* statistic, or, the predicted sum of squares, gives a good sense of the predictive power of the model, where minimizing *PRESS* is advantageous. A small *PRESS* signifies that the model is not overly sensitive to any single data point.

To predict water application rate (WAR), June, July, and August mean precipitation (P) and temperature (T) were included in the model as explanatory variables, as well as available water storage (AWS). The most efficient irrigation balances atmospheric and edaphic conditions. For most situations, that means keeping a continually high soil moisture throughout the growing season in order to maximize yield. Ultimately, the hotter the temperature, and the drier the soils, the more irrigation becomes necessary for crop production.

Climate data was obtained through CLIMOD2, which is run by the Northeast Regional Climate Center (NRCC) at Cornell University, and operates using the Applied Climate Information System (ACIS) to produce single-station and multi-station climate data. The multi-station data was used to obtain June, July, and August temperature and precipitation data from every station within each county in New York State. The monthly mean values were then calculated for each county, and input into the model.

The available water storage (AWS) of a soil is the amount of water that can be stored in the soil and be available for growing crops. Available water capacity (AWC) refers to the quantity of water that the soil is capable of storing for use by plants (USDA 2018). The capacity value varies depending on soil properties, the most important being content of organic matter, soil texture, bulk density, and soil structure. AWS is computed as AWC times the thickness of the soil. For example, if AWC is 0.15cm/cm, AWS for a soil thickness of 25cm is 3.75cm of water. For this model, it was crucial to attain a value for available water storage that was representative of the irrigated agricultural land in our study. Therefore, AWS in a given county was only considered for parcels in which fruit and vegetable crops were planted, which were considered the most likely to be irrigated.

The source data for calculating available water storage includes USDA SSURGO soils data, county boundaries from the NYS Office of Information Technology Services GIS Program Office (GPO), and 2015 NASS CropScape data for New York. The CropScape data was “Reclassified” in ArcMap, where fruit and vegetable cropland parcels were assigned a value of 1, and all other land was given no value. The choice to assign no value to non-produce land rather than a value of 0 is to ensure that when combined with the soils data, the 0 values do not get factored into the average. In order to work with the soils data, the data is exported to a secondary dBASE table, and reclassified such that it "remaps" based on the available water storage rather than on their assigned numerical value in the attribute table order. The output is a new raster which displays the range of available water storage for the entire state. Next, the Raster Calculator tool is used to multiply the reclassified soil layer and reclassified cropland layer. The result is a graded range of values for AWS for all land parcels growing fruit and vegetable crops. Figure 1 displays a graded range of available water storage in New York State.

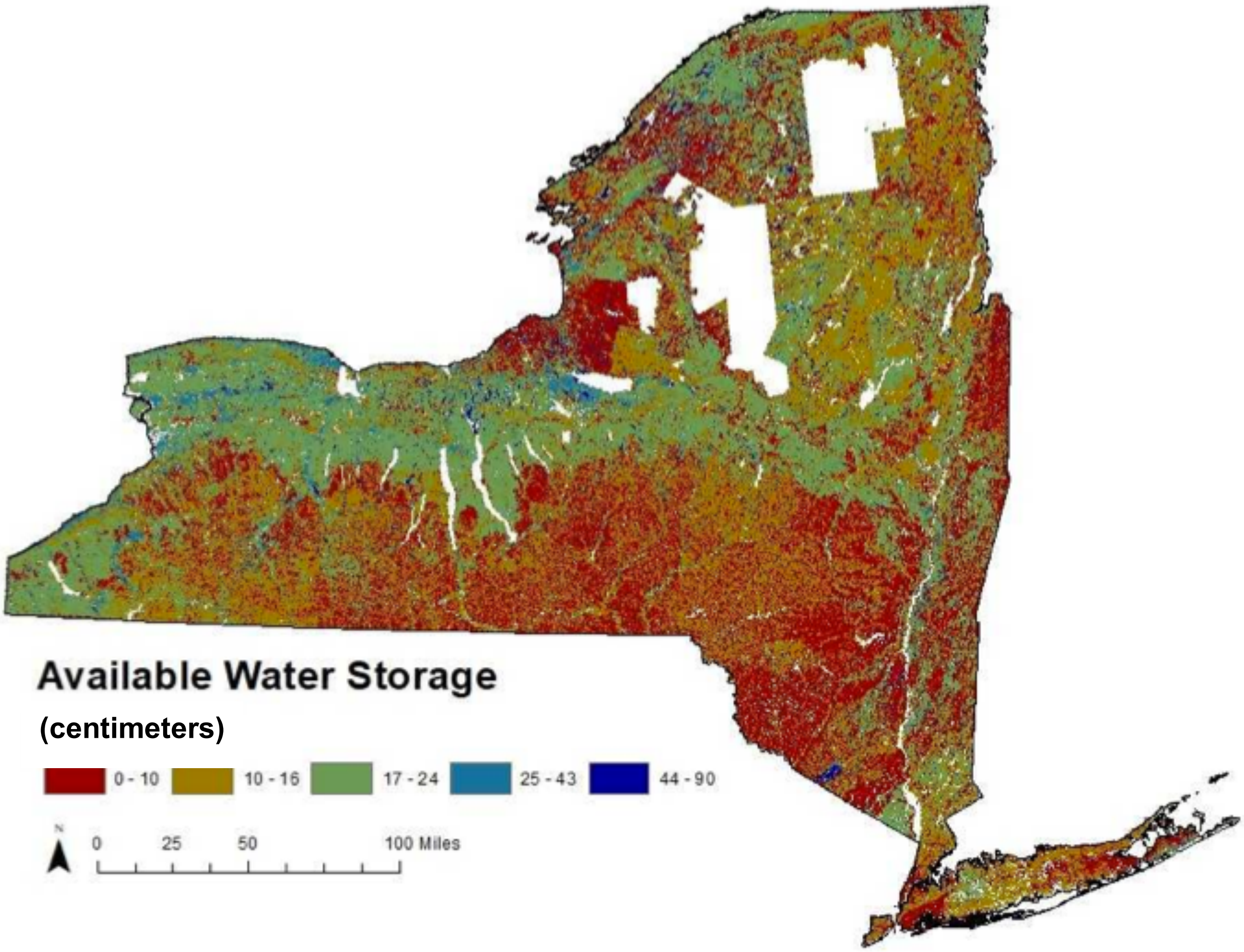


Figure 1. Available water storage (AWS) of soils in New York State. AWS is reported as available water content (cm/cm) times depth of soil (cm) and ranges from 0-90 cm. Places with missing data include water bodies and exposed bedrock.

To maintain confidentiality of individual records, all analyses had to be completed at the Northeast Regional USDA Data Lab in Harrisburg, Pennsylvania. Nationwide data was isolated to New York state records only. The categories selected for inclusion in the WAR were: K187

Vegetable, Potatoes, and Melons, K52 Corn, K222 Other crops including horticulture, K212 Fruit and nut trees including grapes.

The regression model took the form of:

$$WAR = K_1*AWS + K_2*T_{JUNE} + K_3*T_{JULY} + K_4*T_{AUGUST} + K_5*P_{JUNE} + K_6*P_{JULY} + K_7*P_{AUGUST} \quad (1)$$

where variables WAR, AWS, T_{June}, T_{July}, T_{August}, P_{June}, P_{July}, and P_{August} were unique to each county. Note, WAR is calculated as the area weighted mean of records within a given county. In 2013, the regression model was applied to a dataset of 12 counties selected such that each county had 5 or more individual records and at least 100 irrigated acres. The counties included in analysis were Columbia, Erie, Genesee, Niagara, Orange, Orleans, Ulster, Onondaga, Steuben, Schoharie, and Wyoming. Seven of the 12 counties area weighted WAR were dominated by a single record from a farm with a large cultivated area, presumably one of the reasons the application rate has not been reported at the county level. The county with the most records had 16. The median number of records was 8. In 2008, specific data records for categories K187 and K212 were not available. m

The model was run in SAS Programming at the county level, from the months June through August, for 2013. The model significance (SLS) was set to 95%. Under these conditions, the model never made it past the first "step" in the stepwise regression, indicating that there are no significant explanatory variables that can be used to determine differences in water application rates among counties. Although no significant model was derived from the data, the area-weighted county average application rates were consistently near that of the state average as reported by the USDA Farm and Ranch Irrigation Surveys (FRIS), around 0.5 ac-ft/ac over the growing season of an unspecified length.

In 2013, many counties had one record with a water application rate nearly an order of magnitude higher than the mean. There was no clear indication why this would be the case and it was not related to crop type. One explanation could be differences in subjective irrigation decision-making discussed in the FRIS surveys. When asked which methods were used in deciding when to irrigate, farmer responses in New York State include: 1) Condition of crop; 2) Feel of the soil; and 3) Personal calendar schedule. For the 1936 farms surveyed in 2013, the vast majority of farmers (>1000) relied on physical appearance of the soil or crop to dictate intra-seasonal irrigation, with very few using more objective measurements of soil moisture conditions. Therefore, even farmers experiencing the same physical conditions could have greatly differing standards for when to irrigate.

With this mean water application rate, the irrigation water use within each county can be estimated and compared to reported water withdrawals. To estimate water application rate from the state reported value, you must multiply 0.5 ac-ft/ac by % county irrigation, and absolute crop acreage in that county. Percent irrigation in each county was calculated using FRIS data, by dividing irrigated acreage by total acreage. That percentage was then multiplied by the absolute crop acreage to find water use in each county, in gallons. Absolute crop acreage was derived from CropScape data. From 2012-2016, there was very little (<1 acre) variation in absolute crop acreage, so only values from 2012 were used in the calculation. The irrigation period typically lasts 4-6 weeks, so water use is reported in MGD over a 30-day period of irrigation, as well as a 45-day period of irrigation. Table 4 shows the results of these calculations, and compares water use as estimated with the state water application rate to water use as estimated by individual records from 2012-2016. Orleans, Genesee, and Wyoming county were used in this analysis, as a result of insufficient data from agricultural users in Monroe county.

County	County % Irrigation	State Average W.A.R. (ac-ft/ac)	Absolute Crop Acreage	Water Use (MGD) as estimated from state W.A.R.		Reported Withdrawals (MGD) as estimated by individual records				
			2012	30 days of irrigation	45 days of irrigation	2012	2013	2014	2015	2016
Orleans	4.17	0.5	250213	28.35	18.9	2.36	2.58	2.22	1.42	12.47
Genesee	4.43	0.5	319837	38.49	25.66	4.5	3.49	3.31	3.26	4.76
Wyoming	2.11	0.5	383635	21.99	14.66	0.27	0.69	0.81	0.77	3.35

Table 4. Estimated water use in million gallons per day over 30 and 45-day irrigating period using state reported water application rate, % county irrigation, and absolute crop acreage.

Water use as estimated from the state reported water application rate was much higher than reported withdrawals as estimated by individual records. The disconnect could come from the inclusion of field crops such as corn, winter wheat, and soy, which make up a large portion of agricultural land in western New York. However, these types of crops are usually not irrigated. Although the state average was found to be representative of individual counties, with no significant explanatory variables in estimating water application rate, discrepancies in estimation methods for water use may emerge from individual irrigation decision making, as well as inadequacies in reporting and data.

IV. ESTIMATING WATER SUPPLY FOR SELECTED WITHDRAWAL POINTS

The goal of this section is to produce a more comprehensive understanding of surface water withdrawals on stream flow, by estimating available water supply at selected withdrawal points (i.e. points of concentrated withdrawal by agricultural users). The USGS has 264 active surface water gages in New York State, each responsible for recording current and historical water conditions. While these in-situ measurements are valuable, it is also important to know their limitations. These gages only represent flow at specific points. It is essential to be able to extend these gage flows to ungaged sites. This section considers limitations of the gage data as well as means to estimate flows at ungaged sites.

One possible limitation of USGS gage data is the accuracy, especially at low flows. USGS discharge data are obtained using a combination of field measurements and predictions using stage-discharge curves. Stage-discharge relations are developed using field measurements of discharge and stage height, which are taken every 6 to 8 weeks. Additional efforts are made to collect data at times of unusually high, and unusually low discharge flows, due to the infrequency of these events. Stage-discharge relationships are highly dependent on channel morphology and are unique to individual gages. Once field measurements are taken, subsequent stage data is transmitted via satellite to USGS servers, where the data are used to estimate stream flow in real time using the stage-discharge (rating) curve produced. The accuracy of the stage-discharge curves is dependent on taking adequate field measurements through all different stream conditions. Including direct measurements of low flow data is extremely important to the accurate estimation of low discharge values. If there are not enough measurements made at varying flow conditions, especially low flows, the stage-discharge relationship may not be representative of the actual flow conditions. For example, in the year 2016, each site included in this analysis had at least five field measurements throughout the year, including discharges ranging from 0.09 cfs to 10,400 cfs. Efforts are taken to obtain measurements to represent different stream conditions. The collection of rating points is used to establish a line of best fit through the many measurements. Details of the rating process were disclosed through personal correspondence with Alicia Gearwar, a Supervisory Hydrologist for the U.S. Geological Survey. Stage-discharge relations (ratings) are developed over a range of stages and discharges, and ratings may be adjusted as measured data becomes available. Ratings are defined as the percent error within true flow of 95% of daily flows. While each site had over 700 total field measurements, the number of measurements (rating points) going into their rating curves is different for each gage. For example, at Black Creek at Churchville (04231000), there were 10 rating points with a rating of 35.0; at Tonawanda Creek at Batavia (04217000), there were 29 rating points with a rating of 34.0, and at Oatka Creek at Garbutt (04230500), there were 4 rating points with a rating of 26.0.

Another limitation is the fact that the gage data does not reflect only natural flows; it can include human diversions and releases. One must carefully account for whether a USGS gage reflects natural flow or is impacted by monitoring both upstream and downstream of the gage through satellite imagery. Sites with dams and impoundments upstream were found to be unsuitable, as they provide regular flows of water even during periods of low flow, where there would otherwise be little to no discharge. For example, the description of Cayuga Creek near Lancaster (04215000) comments that the concrete dam configuration was modified in 1974, resulting in a lower point of zero flow. Additionally, the USGS offers additional gage details for some sites, noting any major diversions or other attributes that would influence measurements. For example, the Oak Orchard Creek (0422016550) gage could not be used, as "discharge includes undetermined diversion from Erie (Barge) Canal, 6 mi upstream from station."

Once possible limitations are addressed, one still needs to be able to make flow estimates at ungaged points. For these ungaged points, an area scaling method is applied. USGS stream gauges are used as "reference" sites, using the given drainage area of individual gauges as the "reference" areas. The proportion of a known reference discharge to a known reference area is equivalent to the proportion of an unknown discharge of interest over a known area of interest. The corresponding explanation is that every unit increase in area contributes a unit volume of water to the channel, assuming that all parts of the catchment area contribute nearly the same volume of recharge and/or discharge at the same rate (Galster et al., 2006). Watershed boundaries, water users, hydrography, and gages are represented in Figure 2.

To find the scaled discharge at a particular point of interest, the upstream area must be determined. Watersheds were delineated using using HUC-10 watershed boundaries and included hydrography, and topography. The calculations were made to propose a “worst case scenario” of water availability, so points of interest were selected based on the location of the largest water user, from both agricultural and non-agricultural facilities. Known reference discharges and drainage areas are obtained from USGS gage data. Area of interest is the watershed area for an ungaged point. Scaled discharges were calculated for the years 2012-2016 using the following formula:

$$Q_{interest\ (cfs)} = Q_{reference(cfs)}\left(\frac{A_{interest(km^2)}}{A_{reference(km^2)}}\right) \quad (2)$$

In most river systems, the mean discharge increases directly with increasing drainage area in a given basin (Leopold 1953). In this estimate of available water supply, an area-scaled discharge is calculated at water withdrawal locations of big water users in Western New York. Details of water use estimations will be discussed in the following section. Big water users are differentiated in Figure 2 based on water sources, with differentiation between groundwater, surface water, and a combination of ground and surface water. Non-agricultural users are differentiated from farms, and all use surface water sources for their supply. The discharge gages of interest and the HUC-10 watersheds they fall within are labeled for ease of identification. Flow estimates are reported in the next section as supply-demand, where estimated flow is supply and water withdrawals are demand.

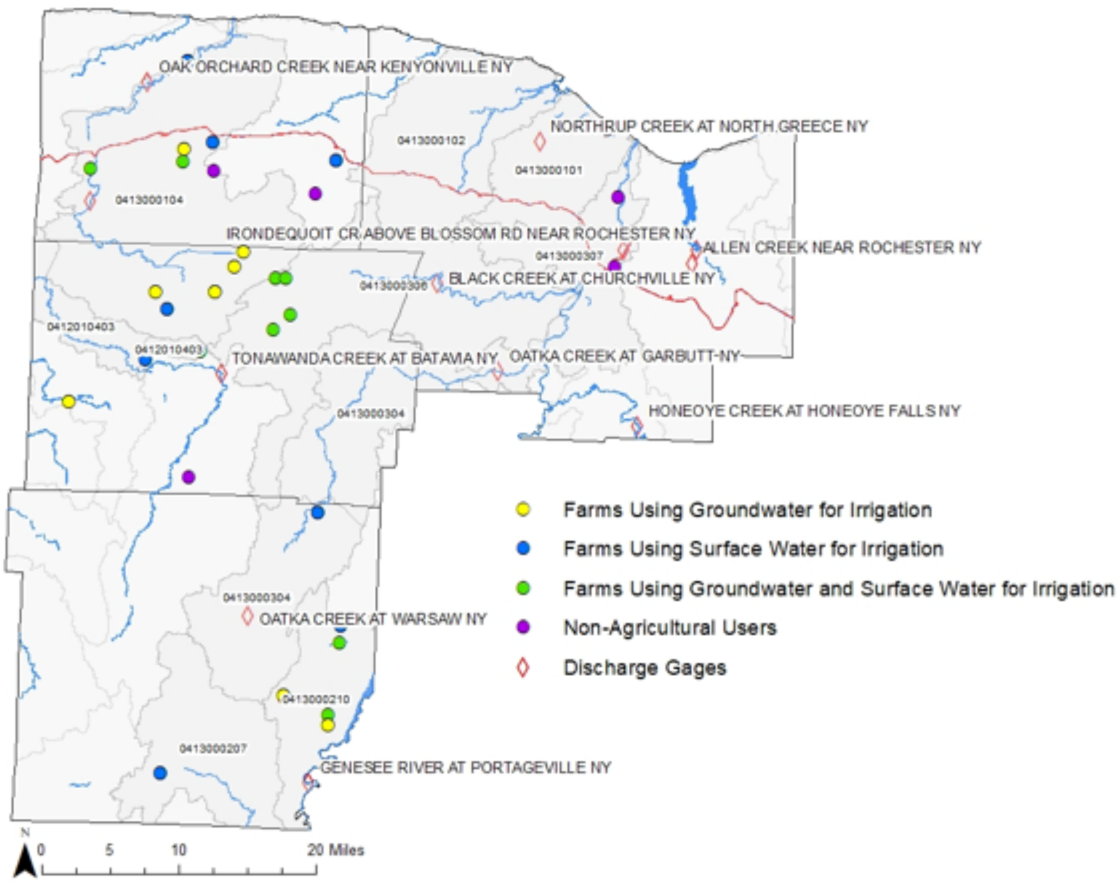


Figure 2. Big water users in Monroe, Orleans, Genesee, and Wyoming counties are represented alongside hydrography and discharge gages, within HUC-10 watershed boundaries.

V. ESTIMATING AVAILABLE WATER

For farmers to have successful irrigation operations, there must be an adequate supply of water available for them to withdraw from their respective water sources. To determine this, available water must be estimated for each watershed that is being withdrawn from, taking into consideration water removed upstream. Available water is calculated using a simple water balance equation:

$$\textit{Available Water} = \textit{Supply} - \textit{Demand} \tag{3}$$

The difference between supply and demand for primary agricultural water withdrawal points can be found in Table 6. The estimate of available water supply is constrained to the years 2012-2016. The chosen observation period seeks to complement DEC New York State Water Withdrawal reports, which have data available for those years. While the DEC reports do not publish specific water bodies that withdrawals are sourced from, the survey conducted by Martin (2016) provides that information for several agricultural users. For agricultural and non-agricultural users not covered by this survey, streams and water bodies, such as the Barge Canal, proximate to withdrawal sites are presumed to be the source of the withdrawal. The inclusion of big non-agricultural users such as wastewater treatment plants, quarries, and brine facilities, is necessary for a bona fide assessment of withdrawal impacts on discharge.

Surface water withdrawals are the primary focus of this analysis, however, in compliance with a "worst-case scenario," users reporting their water sources as "ground-surface water" combinations were treated as strictly surface water users. The HUC-10 watersheds shown in Table 5 ZXAZwere used in this analysis, and the (agricultural to non-agricultural) user ratio for each watershed is provided, a well as the watershed name and county. The Oak Orchard Creek watershed in Orleans county has the most reporting water users of all watersheds in the study area, all of which are withdrawing for agricultural use.

Table 5. Agricultural vs. Non-agricultural water users in each watershed.

HUC-10	Watershed Name	County	Agricultural	Non-agricultural
413000102	Sandy Creek – Frontal Lake Ontario	Orleans	1	2
413000210	Outlet Silver Lake – Genesee River	Wyoming	5	1
412010403	Middle Tonawanda Creek	Genesee	1	0
413000207	Wiscoy Creek	Wyoming	1	0
413000306	Black Creek	Monroe	4	0
412010401	Upper Tonawanda Creek	Genesee	1	1
413000104	Oak Orchard Creek	Orleans	10	0
413000101	Black Creek – Frontal Lake Ontario	Monroe	1	0
413000307	Genesee River	Monroe	0	2

To calculate user demand in each watershed, the reported water withdrawal data from the most intensive water users was summed. Agricultural vs. non-agricultural users are differentiated in Table 5. For example, there were 10 agricultural users, and 0 non-agricultural users within the Oak Orchard Creek watershed (0413000104). Together, those facilities accounted for 1.45 MGD in water withdrawals in 2012, 1.64 MGD in 2013, 1.48 MGD in 2014, 0.43 MGD in 2015, and 12.16 MGD in 2016. For the Oak Orchard Creek watershed, this value was subtracted from the estimated supply, calculated in the previous section, to establish net available water.

Mean monthly discharge values for August are the focal interest through the observation period. During August, the likelihood of the lowest natural flows converging with periods of maximum irrigation water withdrawals is maximized. Although the month of September has consistently lower mean flows across the years of interest, it is unlikely that farmers continue to irrigate as heavily, if at all, during that time.

Here, the goal was to see if demand ever exceed supply, and by how much. The results in Table 6 show that in 2016, two watersheds had insufficient water supply to meet user demands. Water supply for Black Creek-Frontal Lake Ontario HUC-10 watershed (413000101) is obtained from Northrup Creek, with corresponding gage at North Greece NY (0422026250). In 2016, the data showed a water deficit of close to 10 million gallons per day, if water use continued uninterrupted.

While this implies withdrawn water is greater than supply, that is not the case. Since more water could not have been withdrawn that was available, this suggests very little water water in the stream. Accordingly, a deficit of 10 MGD is unnecessary to reach the same conclusion, where values of remaining available water (supply - demand) close to or below 1 MGD also communicate little water. Another strong indicator for a decrease in water supply is a huge drop in available water from one year to the next. This can be observed in every watershed, reaffirming the dry conditions of 2016. Decrease in available water is most prominent in Black Creek at Churchville (413000306), where remaining available water went from 25.8 MGD in 2015 to 1.28 MGD in 2016.

When referencing withdrawal data in 2016, users in this watershed did not increase their water use in 2016 as expected due to lack of precipitation. This suggests that use was curtailed because of lack of supply during dry years, not lack of demand. Similarly, demand exceeded supply in Middle Tonawanda Creek (412010403) in both 2012 and 2016, and indicated low water in all years. The water surplus in remaining years is not particularly high, with the largest being 1.6 million gallons per day in 2014. Once again referencing withdrawal data in 2016, for users within the Tonawanda Creek watershed, water demand did not change significantly with drier conditions. However, remaining available water was consistently lower for the year 2016, again suggesting that the water users would have irrigated more, but were supply-limited.

When water demand exceeds available supply, it raises concerns about current and future water management. While a drought watch was issued in New York for 2016, there was no mandate for immediate action in the form of water use restrictions. In fact, the only role of a drought watch is to promote mindfulness of a noticeable lack in water supply. However, when surveys of western NY found that 80% of farmers estimated economic impact as "moderate" to "severe" in the 2016 growing season, perhaps further action is required. The ability to predict the occurrence of water deficits in a particular watershed could be extremely beneficial to irrigation planning and water resource conservation. The goal of Chapter 3 is to develop this tool, by finding a means of predicting discharge from antecedent precipitation.

Table 6. Using area-scaled discharge to represent available water supply, remaining available water (Supply-Demand) is calculated. Highlighted values indicate low water availability in that watershed.

HUC-10	Watershed Area (km^2)	Reference Gage	Drainage Area (km^2)	Supply-Demand (MGD)				
				2012	2013	2014	2015	2016
413000102	317	NORTHRUP CREEK AT NORTH GREECE	26	118.46	96.03	114.69	98.20	49.75
413000210	196	GENESEE RIVER AT PORTAGEVILLE	2548	6.49	12.40	39.13	11.05	7.05
412010403	17	TONAWANDA CREEK AT BATAVIA	443	-0.67	0.30	1.60	1.08	-0.82
413000207	268	GENESEE RIVER AT PORTAGEVILLE	2548	12.95	17.85	54.03	16.03	9.20
413000306	524	BLACK CREEK AT CHURCHVILLE	337	16.61	34.74	69.84	25.80	1.28
412010401	515	TONAWANDA CREEK AT BATAVIA	443	13.27	45.37	86.85	69.60	8.42
413000104	705	OAK ORCHARD CREEK NEAR SHELBY	378	8.50	62.00	82.37	24.36	13.37
413000101	183	NORTHRUP CREEK AT NORTH GREECE	26	18.31	8.70	22.25	18.58	-9.66
413000307	6423	GENESEE RIVER AT FORD STREET BRIDGE	6405	228.95	382.93	1525.06	533.45	202.73

CHAPTER 3: PREDICTING DISCHARGE FROM ANTECEDENT PRECIPITATION

I. HYPOTHESIS AND METHODS

As climate change becomes a universal concern, irrigation demands may increase not only in arid regions with substantial irrigation systems, but also in wet regions. In the case of extended dry periods, water use has the potential to be greater than water availability. Thus, to foresee possible water deficits, it would be valuable to have some ability to forecast future flows, especially low flows. In regions like the Northeast U.S., where there have been very few recorded periods of extended dry conditions, it is difficult to know the contribution of deep groundwater to streamflow. Most of the water that is supplying streams is from near-surface storage, and since there is usually enough precipitation to continually replenish this near-surface storage, it is often unknown how much contribution is from deep groundwater alone. However, in very low-flow conditions, where groundwater is the only contribution to streams, this deep groundwater contribution can be observed more directly.

Simple conceptual models are often used to try to estimate this deep groundwater component of streamflow. In particular, this deep groundwater contribution is often estimated using the idea of a "linear reservoir." Simply, a linear reservoir can be described as:

$$Q = k\,S \tag{1}$$

where Q is outflow, S is storage, and k is a discharge rate constant. In this approach, baseflow is calculated as the groundwater storage times a constant (Equation 1). It is assumed that watershed outflow rate is a linear function of storage based on mass balance, such that as storage approaches zero, outflow approaches zero. Here, baseflow is defined as water not related to storm events, and consists of groundwater input based on a long term change in storage.

Since very low storage conditions are not typical in Western New York, the presumed discharge rate during low storage periods (the k in Equation 4) is often determined from observations made during wetter conditions. When few low-flow values are available, we do not get an accurate representation of deep groundwater contributions to a stream during extended dry periods.

In Chapter 2, we estimated the difference between irrigation water supply and demand, and found that in some places, demand exceeded supply. For farmers who are dependent on irrigation water from those sources, it would be beneficial to have some way to predict water shortages. From that observation, the following question emerged: is there a simple way to relate streamflow during dry periods to antecedent precipitation? The presumption is that base streamflow during very dry periods is mostly contributed from the deep groundwater pool, and the stored water in this deep groundwater pool is determined by accumulated precipitation over many months. To assess this idea, I focus on baseflow in August. I hypothesize that by August, dry soils would minimize recharge and deep groundwater contributions to the stream would primarily reflect accumulated precipitation from earlier in the season. If these assumptions hold true, there would be a strong relationship between baseflow and antecedent precipitation sums, where smaller precipitation accumulations correlate to less baseflow.

To test this hypothesis, I compiled data for four different USGS gauges referenced in Chapter 2, including Tonawanda Creek at Batavia, Black Creek at Churchville, Oatka Creek at Warsaw, and Ellicott Creek. The first three gages were selected to ensure the most accurate measurements of baseflow during extended dry periods, making sure that there are no dams or impoundments that would provide supplemental stored water to the stream, even in the absence of precipitation. Ellicott Creek is regulated by seasonal manipulation of a dam several miles upstream and by intermittent pumping upstream, and is included as an example of a regulated stream. In addition to daily measurements of discharge from USGS gages, daily measurements of baseflow were derived from the discharge values, as well as daily precipitation from CLIMOD2. Baseflow separation was calculated via the local minimum method from Purdue's WHAT system (Lim 2005). Baseflow separation uses the time-series record of discharge to derive the baseflow signature. The local minimum method connects the local minimum points in a series by comparing the slope of hydrograph, which focuses attention on the baseflow rather than rising and falling limbs from quickflow response (Brodie 2003). A five-day moving window was also applied to the baseflow time series to further smooth the data and remove any small anomalies from brief precipitation events. The study periods were dependent on available data, and can be summarized in Table 1.

Table 1. Gage characteristics and study periods for each site based on available discharge data.

Watershed (HUC-10)	**Location**	**Area (square miles)**	**Record Length**
0412010403	Tonawanda Creek at Batavia, NY	170	7/30/44 – 12/26/16
0413000306	Black Creek at Churchville, NY	130	10/1/45 – 11/25/17
0413000304	Oatka Creek at Warsaw, NY	39	1/1/64 – 12/31/16
0412010404	Ellicott Creek at Williamsville, NY	82	10/1/72 – 3/4/17

The analysis was conducted in R, a language and environment for statistical computing, using the workflow shown in Figure 1 (R Core Team 2013). For each date in the record, there was information for corresponding Julian day, discharge (cfs), precipitation (inches), and baseflow (inches). As mentioned previously, August dates were identified as the most likely candidates for low-flow conditions, where you would expect baseflow to rely on long-term antecedent precipitation. The first step in the workflow is to call on dates in August that qualify under certain conditions. The exact thresholds for number of days and amount of precipitation was determined through trial and error plotting to find what combination made the most sense. Ultimately, two variations were chosen to represent the data. Next, a similar process was conducted to create a moving long-term precipitation sum to determine the antecedent precipitation. For antecedent precipitation, values are plotted for May and June, but not July and August. Since the approach presumes there to be little recharge in the summer months, recent precipitation is not included. Changing the criteria of long-term rainfall to include April did not improve the relationships. Finally, the 5-day average baseflow sum was plotted against the antecedent precipitation data of the same date range. This workflow was followed for all four sites, producing a total of 8 plots.

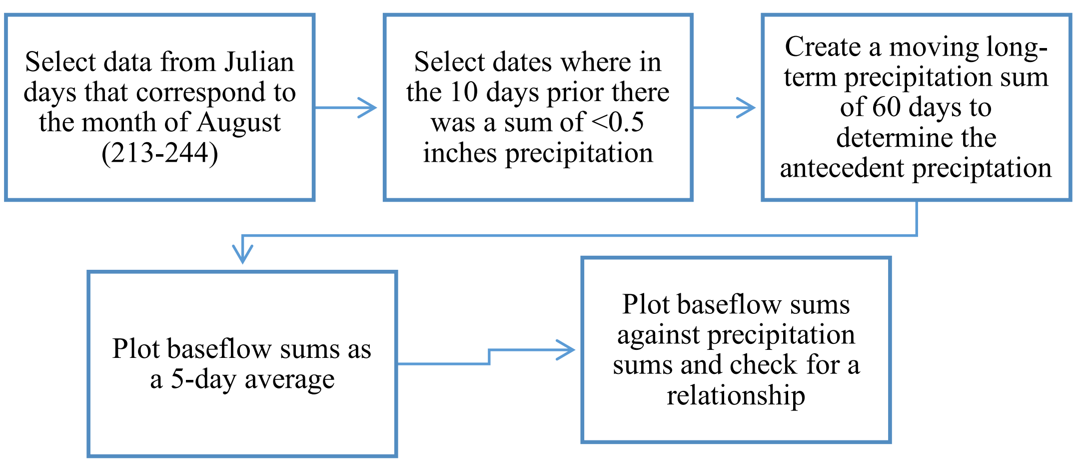


Figure 1. Workflow of R script.

II. RESULTS

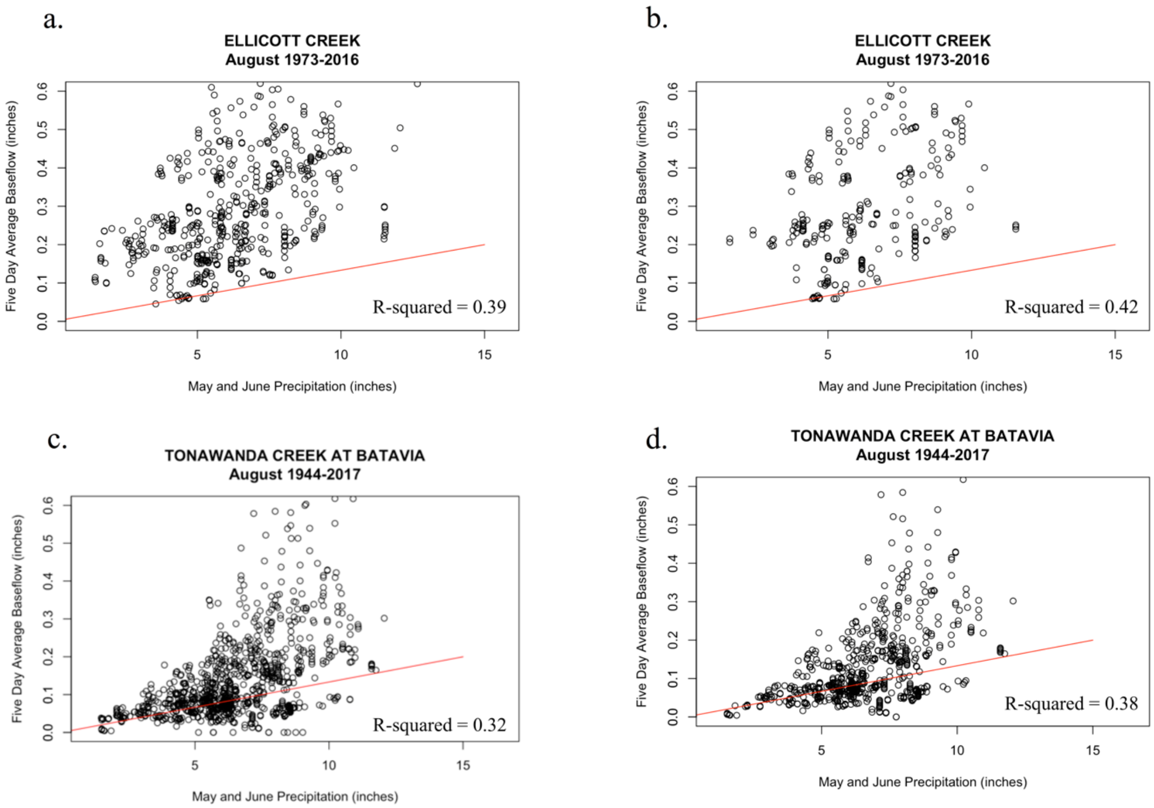
Each plot in Figure 2 displays the 60-day precipitation sum against the five-day average baseflow. The graphs change depending on the chosen parameters for antecedent precipitation. As discussed above, various combinations of precipitation period lengths and recent antecedent precipitation were tested to identify the best relationship. Despite testing many different combinations, for each gage, only two variations are shown (Figure 2) to distinguish between what parameters are most representative of baseflow related to antecedent precipitation. The parameters chosen were <0.1 inches of precipitation in the previous 3 days and <0.5 inches of precipitation in the 10 days prior, targeting low baseflow values. Additional variations of both days and precipitation did not produce plots that were much different from the two variations shown. Figures 2a, 2c, and 2e display points where in the previous 3 days, there was <0.1 inches of accumulated precipitation. Figures 2b, 2d, and 2f display points where in the previous 10 days, there was <0.5 inches accumulated precipitation. Even with filtering, high baseflow values are still present.

A regression line is then added to fit the data where baseflow is <0.2 inches. This threshold is relatively arbitrary, but values above 0.2 inches are interpreted as representative of storm event responses, rather than indicative of long-term baseflow. The regression line is mostly qualitative, but is better than a visual assessment in that overlapping data points are not missed. P value and R^2 are used as metrics to assess the strength of the regression relationship. P value fits both slope and intercept, and is minimized when the slope is non-zero. The linear pattern of the data at each gage is non-horizontal, meaning that the slopes are all significant. To evaluate which gage displayed the best relationship, R^2 is analyzed reported on the corresponding plot. While both parameterizations of accumulated precipitation over a given time yield similar results, the 10 day-

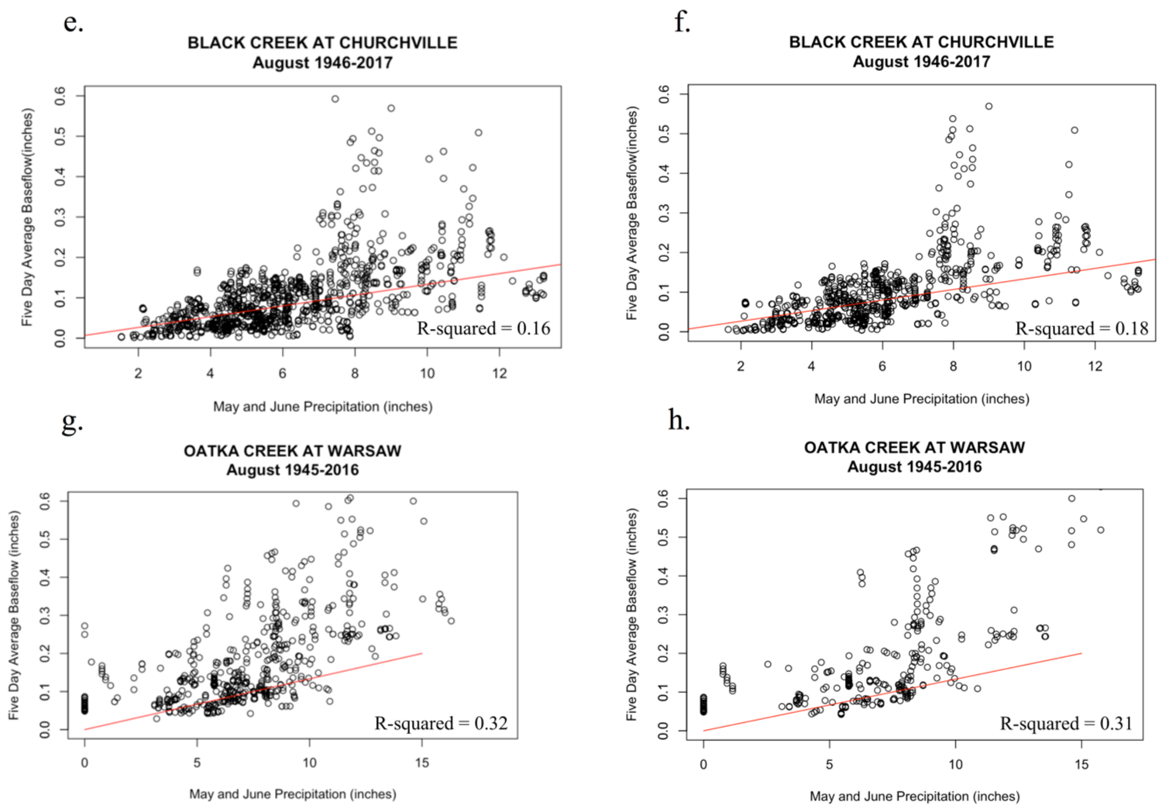
0.5inch criteria slightly improves the strength of the regression relationship at each gage, based on R^2.

To establish a relationship between precipitation and baseflow, attention is paid to the bottom edge of the data points, at the bottom left, where there is 0 baseflow and 0 antecedent precipitation. Following the prediction that May and June precipitation influences August baseflow values, a 1:1 ratio would mean that in a given year, the August baseflow would be proportional to May-June precipitation sum of that same year. The less precipitation in May and June, the less deep groundwater recharge to supply the stream, and vice versa. Thereafter, baseflow should increase in 1:1 ratio relative to May and June precipitation, with only small ranges in baseflow for any given amount of precipitation. As seen in Figure 2, at each gage, the regression line where baseflow <0.2 inches only accounts for 16-42% of variability among the data. While Ellicott Creek is used as a reference gage and produces the best-fitting regression line (Figure 2b), the regulated flow upstream from the Ellicott Creek gage buffers the natural stream responses to dry conditions, so antecedent precipitation has no effective influence over baseflow at that particular gage, despite the relationship being the strongest. The R^2 suggests a moderate relationship between spring precipitation and August baseflow in Tonawanda and Oatka Creek with Black Creek having a weaker relationship. While the range of precipitation sums received at each gage did not vary much, the baseflow response did. For example, at Tonawanda Creek (Figure 2b), a May and June Precipitation sum of 8 inches could produce an associated baseflow anywhere from 0 – 0.5 inches.

2



Figures 2a and 2c (left), plot points where in the previous 3 days, there was <0.1 inches accumulated precipitation. Figures 2b and 2d (right,) plot points where in the previous 10 days, there was <0.5 inches accumulated precipitation. The regression line is only fit to baseflow data points below 0.2 in.



Figures 2e and 2g (left), plot points where in the previous 3 days, there was <0.1 inches accumulated precipitation. Figures 2f and 2h (right,) plot points where in the previous 10 days, there was <0.5 inches accumulated precipitation. The regression line is only fit to baseflow data points below 0.2 in.

Differences in the deep groundwater-precipitation relationship between gages might be partially explained by reviewing the surficial geology and surrounding wetland at each gage. Figure 3 breaks down surficial geology at the 3 watersheds into four classifications: glacial till, recent alluvium, lacustrine silt and clay, and outwash sand and gravel. Ellicott Creek was used as a reference, and is not included in this portion of the analysis. Different sediment types have different hydraulic properties, and strongly influence permeability, groundwater recharge, and the contribution of groundwater to a given stream. Outwash sand and gravels typically have a lot of subsurface storage due to their larger pore spaces, and could be a potential source of water to streams. On the other hand, lacustrine silt and clay provides minimal storage, due to smaller pore spaces. Recent alluvium falls somewhere in between outwash sand and gravels and lacustrine silt and clay, and might be influenced by a larger area. Glacial till makes up the rest of the regional surficial geology.

The Black Creek watershed is comprised of two main classifications, lacustrine silt and clay, and glacial till. The total drainage area is just over 338 km^2, and the watershed has a wetland area of ~3 km^2. Within a 200m buffer of Black Creek, over 44% of the area was wetland. The presence of lacustrine silt and clay, and the abundance of wetland area, influence one another to create a unique groundwater recharge and stream discharge relationship.

Tonawanda Creek is a bit larger than Black Creek, with a total drainage area of ~440 km^2. Despite the larger drainage area, wetlands only account for 1.13% of land area, and 5.59% within a 200m buffer from the creek. Inconsistent surficial geology throughout the watershed may explain why wetlands are not as prominent. Upstream, there is mostly lacustrine silt and clay, but further downstream, both outwash sand and gravel, and recent alluvium are present.

The Oatka Creek watershed is larger still, with a total drainage area of 530 km^2. Within the basin, there is 3.1 km^2 of wetland, which accounts for 13.53% land cover within 200m of the stream. In terms of surficial geology, Oatka Creek runs through recent alluvium, lacustrine silt and clay, and outwash sand and gravel. In the northern part of the basin, there is mostly recent alluvium along the banks, surrounded by outwash sand and gravel. Farther south, the associated USGS gage sits on lacustrine silt and clay, but there are no mapped wetlands immediately near the gage.

The assessment of surficial geology and wetlands is intended to explain differences in the strength of the regression relationships between spring precipitation and August baseflow. Particularly, it is intended to explain why Black Creek does worse than both Tonawanda and Oatka Creek. Stream recharge is unique to individual watersheds, and surficial geology and land cover sometimes influence that recharge, providing additional water supply. Additional water regularly recharging the groundwater pool, even through the summer, discharges into the stream and may increase baseflow disproportionately to antecedent precipitation. Outwash sand and gravel substrate is present at the Tonawanda Creek gage. The presence of additional water can be observed (Figure 2b) where the same amount of antecedent precipitation can produce a large range of baseflow values. According to the data, a 60-day precipitation sum of 7.5 inches can leave the channel dry, or produce up to a 1-inch average baseflow. On the contrary, a substrate of lacustrine silt and clay provides minimal storage, where baseflow behavior strongly reflects antecedent precipitation. Black Creek (Figure 2d) demonstrates this behavior, offering a small range of baseflow given the same precipitation. The outlying points at the Black Creek gage are related to various storm events throughout the record. While the Oatka Creek gage is also on lacustrine silt and clay, the baseflow-precipitation relationship isn't as well established as it is at Black Creek, likely because of the smaller proportion of silt and clay and presence of outwash sand and gravel farther upstream in the watershed.

Analogously to receiving additional water from storage in geologic materials, wetlands can also provide water via connection to adjacent waterways. Figure 4 displays the drainage area of each gage, as well as the wetland area 200m from streams. 200m was chosen to represent the immediate vicinity of a stream, where wetlands are close enough to have influence over the stream via subsurface interactions. Each gage is evaluated based on %wetland area within the stream buffer, which is reflected in Table 2. Almost half of the area within 200m of Black Creek is wetland. A likely scenario is that the wetlands may somewhat overlap the silt and clay, in which case the silt and clay acts as an impermeable layer, creating a shallow water table and forming a wetland. The academic literature is inconclusive regarding the impact of wetland area on baseflow, but some studies do indicate that wetlands do not contribute to baseflow. Burt (1995) and others concluded that wetlands "yield little baseflow," suggesting that during dry periods coincident with the growing season, evapotranspiration rates in wetlands increase enough that no baseflow returns to the streams. Several studies are cited by Cowardin et al. (1979) where rather than augmenting low flows, wetlands further reduced them. Arguments for the opposite result are justified and documented as well. It appears that increased wetland area, such as in the case of Black Creek, must influence the groundwater-surface water interaction in some way. Further investigation is necessary to establish any defensible conclusions.

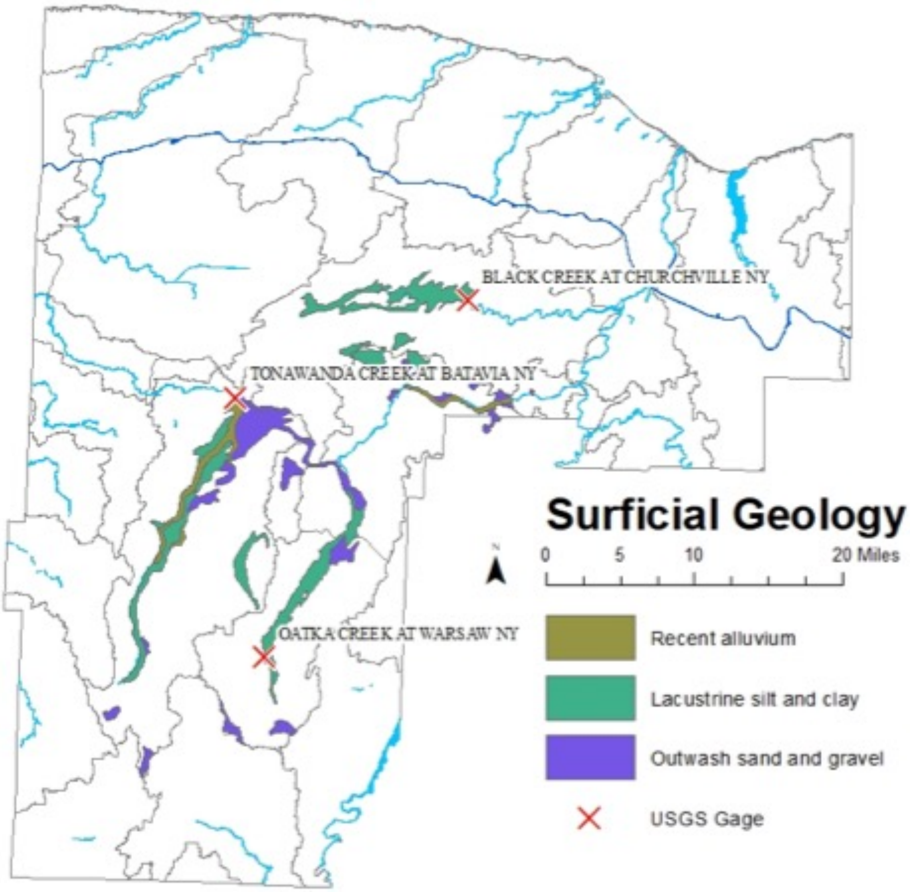


Figure 3. Surficial geology and hydrography at Tonawanda Creek, Black Creek, and Oatka Creek USGS gages. Unclassified land area is composed of glacial till.

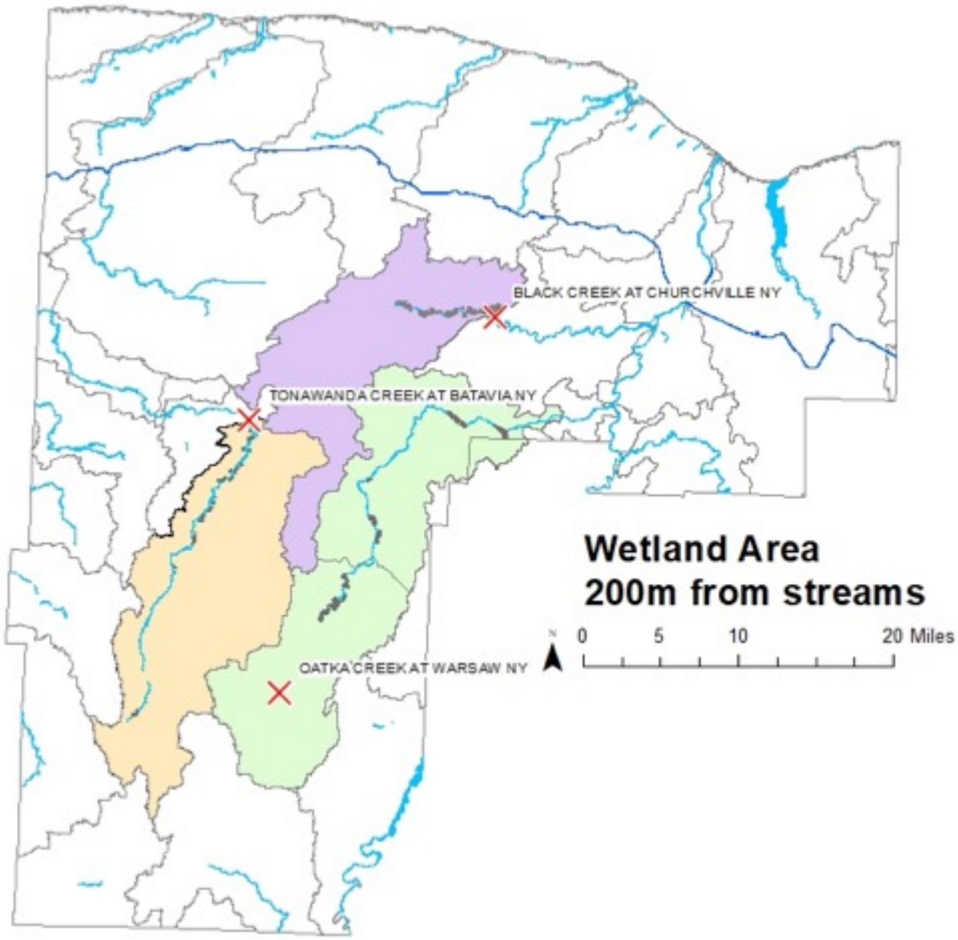


Figure 4. Wetland area 200m from streams within the watershed boundaries of Tonawanda Creek, Black Creek, and Oatka Creek USGS gages.

Table 2. Summary of drainage area, wetland area, and % wetland area within 200m buffer from Tonawanda Creek, Black Creek, and Oatka Creek.

Gage	Total Drainage Area (km^2)	Wetland Area (km^2)	Area of 200m Stream Buffer (km^2)	% Wetland Area Within Buffer
Black Creek	338.44	3.07	6.90	44.49
Tonawanda Creek	440.29	1.13	19.87	5.69
Oatka Creek	530.16	3.1	22.92	13.53

CHAPTER 4: CONCLUDING REMARKS

Understanding the availability of water for irrigation is critical to successful agricultural production on many farms in western NY. As seen in Chapter 2, in certain watersheds, there are periods where estimated supply does not meet estimated demand, whereas other watersheds have plenty of net available water supply. If all withdrawals were reported, not just those by major water users, available water might be even less. If droughts like that of 2016 become more commonplace, knowing which watersheds are prone to have insufficient water can offer a precedent for future water management.

Insight about irrigation use in western New York and other humid regions has both regional and national benefits. For example, a strategy for conserving water resources in the more arid regions of the U.S. could be to shift agricultural production to regions that usually have a surplus of water resources, like the Northeast. This project contributes to ongoing work to evaluate water conservation at a national scale, rather than trying to optimize water use within one region (Hejazi et al. 2015, Lal 2013). Global modeling studies have compared expected increases in regional irrigation demand to expected future supply to identify global regions that may have excess future water capacity (Elliot et al. 2014). Using a global hydrologic model that divided the globe into 309 food production regions, Elliot et al. (2014) found that the U.S. eastern seaboard region extending from Pennsylvania to Maine was projected to have an increase in water supply relative to water demands. They concluded that in the "northern/eastern United States… surplus water supply could in principle support a net increase in irrigation, although substantial investments in irrigation infrastructure would be required". In the last 100 years, agricultural production in the Northeast has diminished from 16% of total U.S. production to 6%, while this decline has been offset by increases in California and other western states (Alston et al. 2010). Given predictions that climate change will reduce water availability for agriculture in the western U.S. (Castle et al. 2014) but maintain or increase supplies in the northern/eastern states (Elliot 2014), it is reasonable to believe some of this production could be shifted back to the Northeast. However, without understanding how often, where, and why irrigation water is actually being used, a proper assessment of the potential for shifting agricultural production to the Northeast cannot be made.

In the cases where the Northeast experiences drier than normal conditions, action can be taken to insulate farmers from the effects. Although some relationship between baseflow and antecedent precipitation was established, there are solutions for farmers yet to be explored. For example, increasing irrigation capacity for facilities who already irrigate, and installing irrigation infrastructure for facilities who do not.

In some cases, there seems to be potential for increased irrigation via underutilized water sources. A primary candidate for accessing water in western New York is the Barge Canal, which draws water directly from Lake Erie, acting as a conduit to carry water east. The canal was completed in 1918, and has a design flow of 1000 million gallons per day (mgd), to refill the channel as locks opened for passing barges. This water could potentially be used to irrigate agricultural land in western New York.

Figure 1 shows the agricultural land devoted to fruit and vegetable production, the most irrigated crops, across the counties through which the western reach of the canal passes. The lack of centralized water infrastructure might explain why the canal is underutilized as an irrigation source, as there don't appear to be many barriers to access otherwise. Figure 2 shows agricultural land within a 3-mile buffer of the canal in Orleans and Monroe counties, as well as producers who currently employ their own irrigation practices with water not sourced from the canal. A major inhibitor to water acquisition is the cost of infrastructure necessary to facilitate the transportation of water from the canal to agricultural land. Pumps would have to be installed to bring water out of the canal to any farms up-gradient. However, at an average elevation of 155m, many farms exist down-gradient. This grants those facilities the ability to irrigate using only gravity-driven water diversion, which cuts costs of a pump. In 2012, only ~500 New York farms used pumps to discharge water from ponds, lakes, reservoirs, canals, etc., with an average pumping lift of 19 feet, and most with annual operating costs of <$1000 (FRIS). In the same year, farmers also reported diminished crop yields resulting from irrigation primarily because of shortages of surface water. For those farms up-gradient of the canal, if diminished crop yield losses were more than the cost of installation and operation of a pump to irrigate with canal water when surface water is scarce, it would make sense to use the canal.

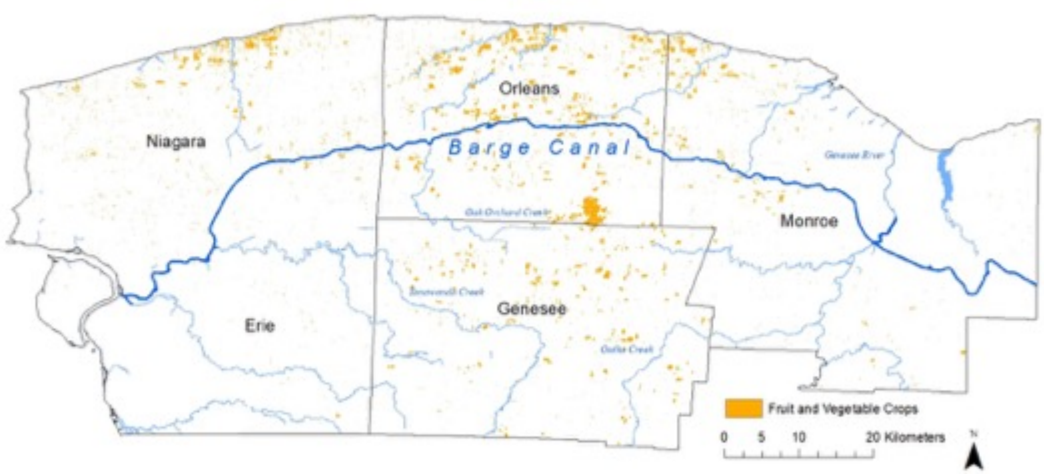


Figure 1. Fruit and vegetable crop land cover in Niagara, Erie, Genesee, Orleans, and Monroe Counties, New York.

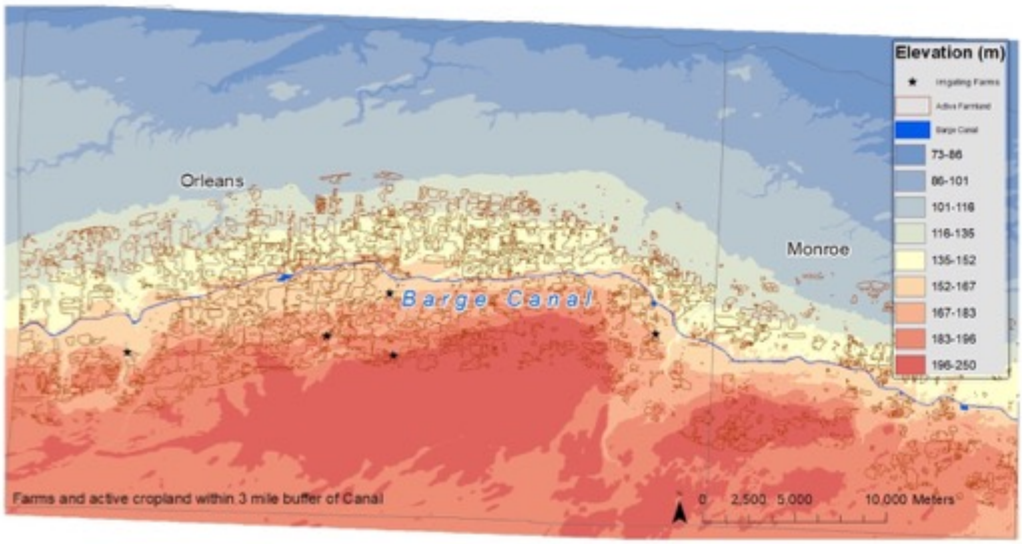


Figure 2. Elevation gradient surrounding Barge Canal, including farms and active cropland within 3-mile buffer of canal.

It is clear that water use in western New York is sometimes supply-limited based on estimates of supply and demand. In certain watersheds, in certain years, reported water use both exceeds and comes close to exceeding water supply, leaving a low net available water in the stream. Using the weak to moderate relationship between spring precipitation and August baseflow, it is possible to loosely forecast stream response to low precipitation conditions. At present, inconsistencies in water use reporting raises questions about the accuracy of reported data. However, there does appear to be potential for supplemental water from underutilized sources.

REFERENCES

Alston, Julian M., Babcock, Bruce A., and Pardey, Philip G. (2010). The Shifting Patterns of Agricultural Production and Productivity Worldwide. *CARD Books.*

Andales, A. (2014). Effects of weather on irrigation requirements. Colorado State University. *Fact Sheet No. 4.721*.

Brodie, R.S. (2003). A review and application of hydrographic baseflow separation techniques. *Centre for Resource and Environmental Studies, Australian National University.*

Bullock, A., & Acreman, M. (2003). The role of wetlands in the hydrological cycle. *Hydrology and Earth System Sciences, Vol. 7* (3): 358-389.

Carruth, A. F., Peck, N. H., & Vittum, M. T. (1959). Response of sweet corn to irrigation, fertility level, and spacing. *Cornell University Agricultural Experimental Station.*

Castle, S. L., B. F. Thomas, J. T. Reager, M. Rodell, S. C. Swenson, and J. S. Famiglietti. (2014). Groundwater depletion during drought threatens future water security of the Colorado River Basin. *Geophys. Res. Lett., Vol 41:* 5904–5911.

Cowardin, L. M. (1979). Classification of wetlands and deepwater habitants of the United States. *Office of Biological Services, U.S. Department of the Interior.*

Drought Monitor. Retrieved December 12, 2017 from http://droughtmonitor.unl.edu/

Elliott, J., D. Deryng, C. Müller, K. Frieler, M. Konzmann, D. Gerten, M. Glotter, M. Flörke, Y. Wada, N. Best, S. Eisner, B.M. Fekete, C. Folberth, I. Foster, S.N. Gosling, I. Haddeland, N. Khabarov, F. Ludwig, Y. Masaki, S. Olin, C. Rosenzweig, A.C. Ruane, Y. Satoh, E. Schmid, T. Stacke, Q. Tang, and D. Wisser. (2014). Constraints and potentials of future irrigation water availability on agricultural production under climate change. *Proc. Natl. Acad. Sci., Vol. 111* (9): 3239-3244.

Galster JC, Pazzaglia FJ, Hargreaves BR, Morris DP, Peters SC, Weisman RN. 2006. Effects of urbanization on watershed hydrology: The scaling of discharge with drainage area. *Geology Vol. 34(9):* 713–716.

Gao, H., and Sabo, J.L. 2016. Understand the impacts of wetland restoration on peak flow and baseflow by coupling hydrologic and hydrodynamic models. *American Geophysical Union.*

Gosselink, J. G., Lee, L. C., and Muir, T. A. (1990). Ecological processes and cumulative impacts: Illustrated by bottomland hardwood wetland ecosystems: Workshop: Papers. Chelsea, MI: *Lewis.*

Langbein, W. B. 1907. Hydrology and Environmental Aspects of Erie Canal (1817-1899). *United States Geological Survey.*

K.J. Lim, B.A. Engel, Z. Tang, J. Choi, K. Kim, S. Muthukrishnan, and D. Tripathy. 2005. Web GIS-based Hydrograph Analysis Tool*, WHAT. JAWRA*, *Vol. 41(6)*: 1407-1416.

Leopold, Luna B. (1953). Downstream change of velocity in rivers. *American Journal of Science, Vol. 251:* 606-624.

Martin, Sherry. (2016). Farmers' perception of irrigation use, water supply resiliency and crop response across Western New York. Capstone Synthesis, *SUNY College of Environmental Science and Forestry.*

NRCC (Northeast Regional Climate Center). Retrieved July 13, 2017 from http://www.nrcc.cornell.edu/regional/drought/drought.html.

Olen, B., Daly, C., Halbleib, M., & Wu, J. (2015). What are the Major Climate Risks for Agriculture in the U.S. Pacific Northwest*. OreCal Publications, (OreCal Issues Brief No. 014).*

Peck, N. H., & Vittum, M. T. (1956). Response of cabbage to irrigation, fertility level, and spacing. *Cornell University Agricultural Experimental Station.*

Pedersen, John T., Peters, John C., and Helwey, Otto J. 1980. Hydrographs by Single Linear Reservoir Model. *Journal of the Hydraulics Division. ACSE, Vol. 106* (HY5): 837-852.

R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Smakhtin, V.U. (2001). Low flow hydrology: a review. *Journal of Hydrology, Vol. 240*: 147-186.

Strzepek, K. M., Neumann, J. E., Smith, J. B., Martinich, J., Boehlert, B. B., Hejazi, M. I., . . . Yoon, J. (2015). Benefits of greenhouse gas mitigation on the supply, management, and use of water resources in the United States. Cambridge, MA: MIT Joint Program on the Science and Policy of Global Change.

Sweet, Shannan K. (2017). Anatomy of the 2016 drought in the Northeastern United States: Implications for agriculture and water resources in humid climates. *Agricultural and Forest Meteorology Vol. 247:* 571-581.

USDA (United States Department of Agriculture). Retrieved April 23, 2017 from https://www.agcensus.usda.gov/Publications/2012/Online_Resources/Ag_Census_Web_Map

Vittum, M. T. (1958). Response of tomato varieties to irrigation and fertility level. *Cornell*

University Agricultural Experimental Station.

Vansteenkiste, T., Tavakoli, M., Ntegeka, V., Willems, P., De Smedt, F. and Batelaan, O. (2013), Climate change impact on river flows and catchment hydrology: a comparison of two spatially distributed models. *Hydrologic Processes, Vol. 27:* 3649-3662.

Xu, Lei-Lei & Liu, Jing-Lin & Jin, Chang-Jie & Wang, An-Zhi & Guan, De-Xin & Wu, Jia-Bing & Yuan, Feng-Hui. (2011). Baseflow separation methods in hydrological process research: A review. *The Journal of Applied Ecology, Vol. 22:* 3073-3080.

Maggie Todaro

226 Miles Avenue - Syracuse NY 13210
(347) 631- 9339
maggietodaro@gmail.com

EDUCATION

Master of Science, Civil and Environmental Resources Engineering, Expected May 2018
State University of New York College of Environmental Science and Forestry (SUNY-ESF), Syracuse, NY
Thesis: *Assessing Impacts of Irrigation in Western New York State*
Advisor: Stephen B. Shaw
Bachelor of Science, Geological Sciences; Minor: Environmental Studies, May 2016
Binghamton University, Vestal, NY

- 2x Recipient of the Undergraduate Award to Support Research
- Glenn G. Bartle Award to the outstanding graduating senior in the department of Geological Sciences

PROFESSIONAL EXPERIENCE

WORK

Air Quality Monitor, J.D. Broderick & Associates Inc., Hauppauge, NY
May 2014- September 2015 (Seasonal)

RESEARCH

Research Assistant, Department of Civil and Environmental Resources Engineering, SUNY College of Environmental Science and Forestry, Syracuse, NY
August 2016- present

- Modeling water application rates for cropland and analysis of low-flow irrigation viability in Western New York

Undergraduate Research, Binghamton University, Vestal, NY
September 2015 - May 2016

- Analysis of single-phase, primary fluid inclusions in carbonate to determine ancient ocean chemistry
- Sea-floor seismic interpretation of the Kumano Basin, Japan

TEACHING

Teaching Assistant, Department of Geological Sciences, Binghamton University, Vestal, NY
August 2014 - May 2015; January 2016 - May 2016

- Environmental Studies 201, Earth Surface Processes, Dynamic Earth

Teaching Assistant, Department of Civil and Environmental Resources Engineering, SUNY College of Environmental Science and Forestry, Syracuse, NY
August 2016- present

- Introduction to Engineering Design, Hydrology in a Changing Climate

RELEVANT SKILLS

ArcGIS
Microsoft Office
Experience with R, MATLAB, SAS, AutoCAD, and Petrel
Fluent in Greek

LEADERSHIP

Captain of Binghamton University Women's Rowing 2013-2014
Founder and President of Binghamton University Geology Club 2015-2016