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Agriculture in the Tongue River Basin: Output, Water Quality, and Implications

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AMPP: Agronomic Monitoring and Protection Program

CBM: Coalbed methane

CDL: Cropland Data Layer

DOR: Department of Revenue

FRIS: Farm and Ranch Irrigation Survey

NASS: National Agricultural Statistics Service

PDSI: Palmer Drought Severity Index

SAR: Sodium Absorption Ratio

SC: Specific Conductance

USDA: United States Department of Agriculture

USGS: United States Geologic Survey

TRB: Tongue River Basin

TRIP: Tongue River Information Project

T&Y: Tongue & Yellowstone

EXECUTIVE SUMMARY

This study considers the value of an important natural resource in Montana—the Tongue River basin and specifically the water it supplies for irrigated agriculture in the southeastern part of the state. The study identifies the agricultural value that could be at risk due to water quality changes, describes how the water resource is measured, and explores the possible impacts of changes in water availability. Along the length of the river, 25,000 acres are irrigated with water drawn from the main stem (we do not count acreage that is subirrigated or watered directly from tributaries).

These are the first panel estimates of agricultural production for section of the Tongue River Basin located in Montana. Existing annual county estimates compiled by the National Agricultural Statistics Service (NASS) were allocated using spatial weighting algorithms. Our technique is similar to those used to obtain other estimates of watershed-level production but, we argue, an improvement over those approaches. Satellite data on land cover were used to construct spatial weights. The estimated series were used to generate physical production series for the basin in the years 1980-2010. Individual data series were estimated for the primary agricultural products in the basin: alfalfa, barley, corn, and cattle. In recent years the gross revenue obtained from sales of these primary crops has exceeded $22 million each year and in recent years has been increasing. Projecting the trend forward over the next thirty years leads to a forecast of $1.3 billion in nominal gross revenue over that time period.

Extensive data on water quantity and water quality at various locations over time along the Tongue River are available from the United States Geological Survey. In addition to flow measurements, these data include measures of irrigation water quality. Irrigators are concerned about water salinity, because using saline water can damage soil under certain conditions, leading to long-term productivity declines. This study focuses on two of the most pertinent measures of salinity: specific conductance and the sodium absorption ratio. These data are presented with an emphasis on identifying the background variation in flows and quality in the river. Data on water quality are available only for relatively short periods compared to flow and agricultural data, a problem compounded by the fact that monitoring sites have moved over time. Thus, water quality variation in the river does not appear to be conclusively and causally associated with agricultural production and gross revenue in the watershed.

Additional interesting inferences about the agricultural economy of the Tongue River basin are obtained from an analysis of tax assessment data for agricultural land in the basin. The total assessed value of agricultural land in the basin is over $165 million; the land is combined with water, livestock, equipment, and other improvements to generate the agricultural product. A prospective loss of all irrigated acreage along the Tongue is estimated to reduce assessed value by over $6 million, and capitalized property tax collections on agricultural land by $1 million.

INTRODUCTION

Natural resources have long been important to economic activity in Montana. From wildlife populations to mineral deposits, different residents have recognized the natural potential of the state and worked to create wealth from different resources. Agriculture has been and remains an important means of creating economic value from natural resources—gross revenues from agriculture are larger than any other sector in Montana, though it ranks lower in terms of contribution to gross domestic product.[1] This study considers the value of a specific natural resource in Montana—water quality in the Tongue River in the southeastern part of the state. The study has three main sections: the first documents the agricultural production of the region; the second evaluates the importance of water quality to that production; and the third considers the distributional implications including contribution to public finances.

Although the region in which the Tongue River Basin (TRB) is located has the longest growing season of any portion of the state, the aridity of the climate makes agricultural production in the basin heavily dependent on irrigation water from the Tongue River. While the available quantity of water is clearly an important aspect of natural resource use, the quality of that water is also important to continued agricultural productivity. Because water quantity and quality are related, both dimensions of the resource have to be considered in any analysis of agricultural production and its value to the regional economy.

This study makes three contributions towards a better understanding of the importance of irrigation in the Tongue River Basin and the role natural resources play in agriculture more broadly. The first is to provide a long-run description and summary of agricultural activity in the basin. This unique long-term estimate of annual agricultural gross revenue captures the pertinent scale at which natural resources and agriculture interact. Second, the existing record of water quality measurements is examined. While causal effects on aggregate agricultural output are not identified, the nature of the available data itself highlights the value of consistent data collection. Third, agricultural productivity is connected to distributional measures, including the taxable value of the land and potential revenue collections.

These results are likely to interest many groups. Local government officials, producers, and other interested community members continue to seek answers to questions on this subject that have remained open for years. Local producers will be interested in the original valuations of the TRB as well as the more specific distributional data. Water quality regulators might be interested in the stated model to measure the opportunity cost of water quality changes as well as part of a broader discussion of appropriate water quality protections. Third, policymakers and others considering further energy infrastructure investments in the region might consider the impacts that water quality changes have on the existing agricultural economy. The estimates presented here are based on the production value of an ecosystem service, which is only one way to address likely impacts on a watershed level.[2]

Amid broader policy debates about natural resource use, the agricultural sector is largely taken for granted. One objective of this study is to consider more deeply the opportunity costs imposed on agriculture by alternative use of natural resources. Other studies estimate minimal, if

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[1] Annual gross revenue from agriculture has exceeded $3.5 billion in recent years, with a somewhat higher contribution from crops than livestock (NASS). Among natural resource industries (agriculture, mining, oil & gas, tourism, and timber), this is the largest contribution. However, energy (oil & gas plus coal) makes a larger contribution to value added.

[2] For an example of a study in the same region that focuses almost exclusively on employment effects, see Barkey and Polzin (2012).

any, impacts on agriculture from development of other natural resources. However, because agriculture relies on interconnected resources, impacts of changes in the quality of natural resources could be relatively large under some scenarios.

BACKGROUND

From its headwaters in the Big Horn Mountains in Wyoming, the Tongue flows approximately 250 miles along a northeasterly course to its confluence with the Yellowstone River at Miles City, Montana. The watershed drains over 5,400 square miles; thirty percent of the total watershed area is in Wyoming and 70 percent (nearly 2.5 million acres) in Montana. Just after crossing the Montana state line the river flows into the Tongue River Reservoir. The reservoir is administered by the Tongue River Water Users' Association; the reservoir stores water for 35 irrigators along the river. When full to capacity, the reservoir stores 150,000 acre-feet of water.

Below the reservoir are confluences with important tributaries: Hanging Woman Creek at Birney, Otter Creek at Ashland, and Pumpkin Creek about 12 miles before the river reaches Miles City. Near the Pumpkin Creek confluence is the diversion point for the Tongue & Yellowstone (T&Y) canal, where a significant share of water is diverted for irrigation. The T&Y canal provides water to 9,000 of the 25,000 acres irrigated by the Tongue, including about 4,800 acres along the Yellowstone River northeast of Miles City, outside the hydrologic boundary of the basin. However, because the area uses a significant share of water from the river, it is included in the analysis. About 7,800 of the 25,000 acres are irrigated by center pivot sprinkler. Over its course, the Tongue and its tributaries pass through four Montana counties: Big Horn, Rosebud, Powder River, and finally Custer. The river itself does not flow through Powder River County, but tributaries that drain a large area do. The river serves as the eastern border of the Northern Cheyenne Reservation as well as the watershed for a significant portion of the Custer National Forest. Figure 1 is a map of the Tongue River Basin area.

Agriculture dominates the local economy, although nearby energy developments make significant contributions to county-level economic aggregates. Miles City is a regional commerce hub and the largest population center in eastern Montana. The agricultural economy is based largely on range cattle production with supporting farming operations. Seasonal grazing is important for both domestic livestock and wildlife. Ranching with seasonal range use is facilitated by the availability of irrigation water that helps increase forage yields in the river bottom, producing sufficient winter feed for livestock that utilize the uplands during the growing season. In addition to range cattle operations, there are also several small-scale agricultural operations that grow a variety of crops catering to local consumer markets.

As table 1 indicates, yield gains from irrigation are substantial in the region, though considerable harvest occurs on dryland acres as well. However, 40 percent of total production comes from irrigated land, which amounts to about one-sixth of total acreage.

Table 1: All Hay vs. Irrigated Hay, Acreage and Yield, Southeast Montana Agricultural District, 2000-2008, Average Values

	Irrigated	All Hay
Acres	60,611	342,444
Tons	199,000	497,056
Yield (tons/acre)	3.28	0.69

Source: NASS. Note: The southeast agricultural district includes Carter, Custer, Fallon, Powder River, Prairie, Rosebud, and Wibaux Counties. While it is representative of the region, it does not perfectly overlap the Tongue River Basin.

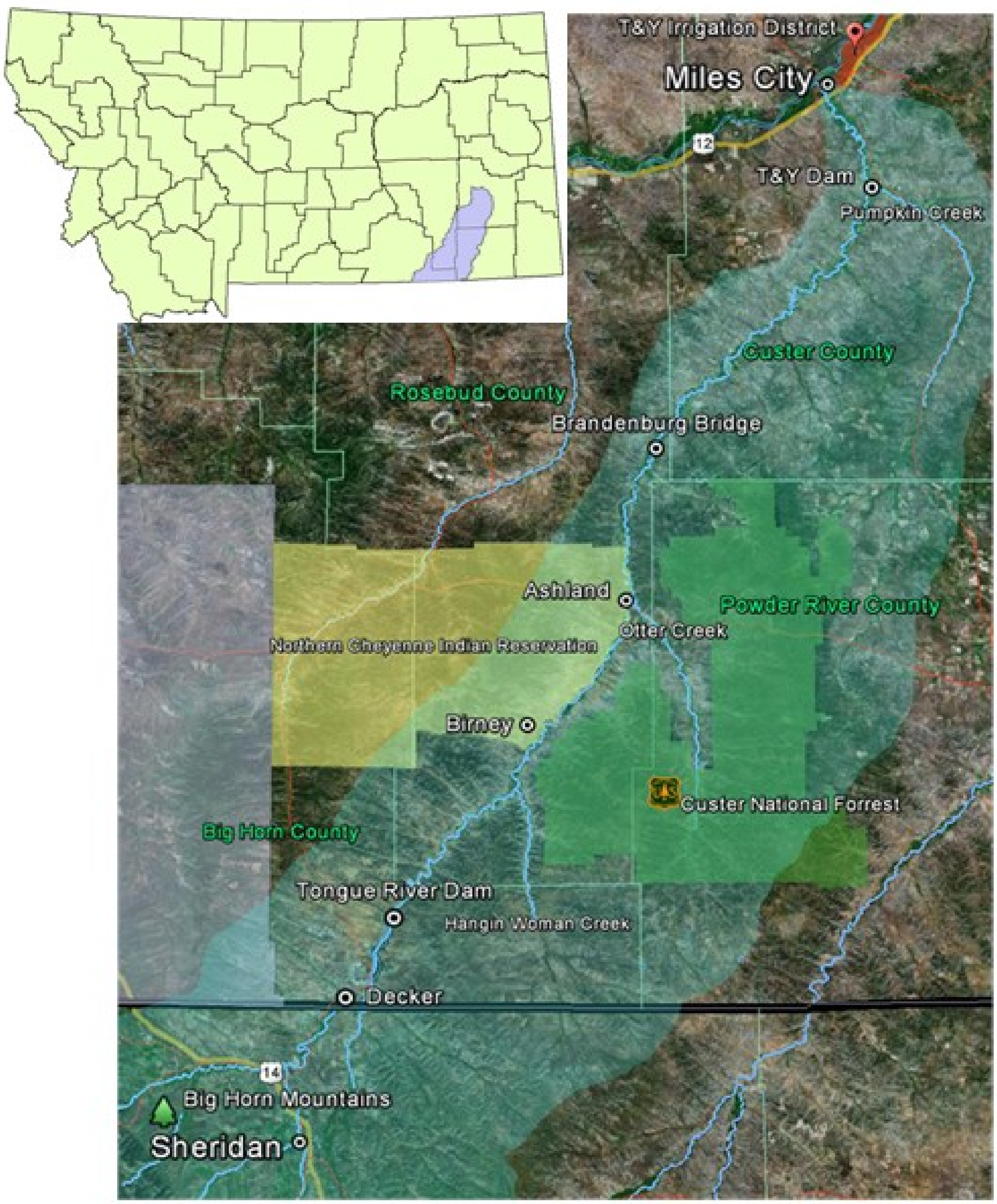


Figure 1: Map of Tongue River Basin

Around one quarter of the annual crops grown with Tongue River water are grown on the 4,800 acres irrigated by the T&Y canal that lie outside the boundary of the watershed itself. The T&Y canal controls the largest share of water from Tongue River Reservoir, with about 21 percent of the total appropriated water storage in the reservoir. The soils and long growing season in the area contribute to high yields on the T&Y acreage; about one fifth of the irrigated acreage accounts for one quarter of the yield. For a map of the T&Y Irrigation District, see figure 2.

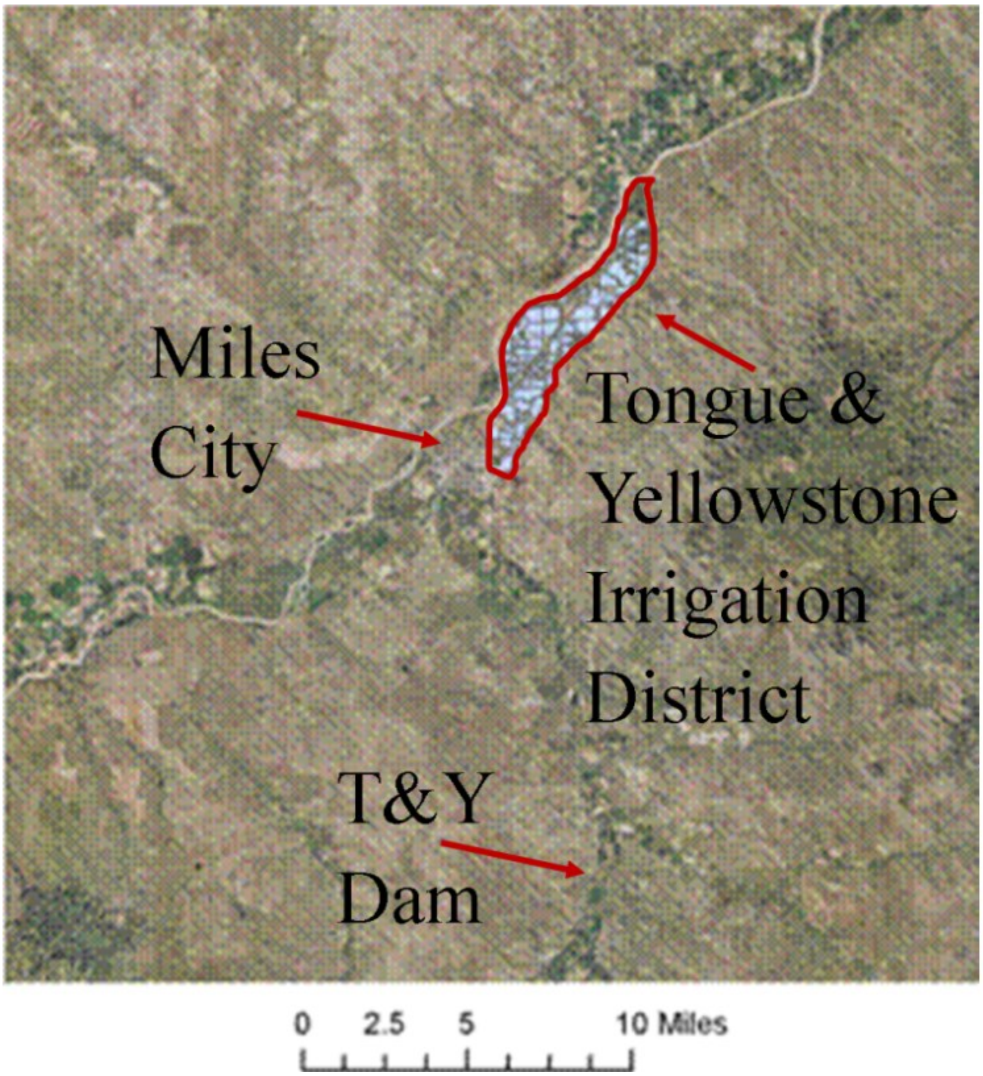


Figure 2: Map of T&Y Irrigation District

A significant portion of the agricultural product of the TRB is an input for the sizeable cattle operations of the area. For example, alfalfa hay may be fed to cattle as an intermediate input, with the marketed cattle representing the final product. This gives rise to natural concerns about double-counting by regarding intermediate goods as final products. There are two feed pellet operations along the Tongue and one more northeast of Miles City in the area served by the T&Y canal, which process alfalfa, barley, and corn into range pellets for cattle. These pellets are a seasonal feed supplement for cattle, along with both alfalfa and grass hay. Cattle enterprises are a mix between cow-calf and yearling operations, with stocking rates that are comparable to historic levels. Sheep operations have declined from their historic levels to the point of economic insignificance.

While agriculture is an important portion of the economic base, there are other industries as well. Two large surface coal mines operate near the state line in the upper drainage, and a third is located just east of the watershed boundary at Colstrip.[3] Due to the proximity to the state line, some of the economic activity associated with these operations is apportioned to Wyoming, further complicating the accounting. Federal, state, and local governments are considering proposals to expand coal mining in the watershed, both in the Otter Creek tributary near Ashland and near existing operations further south. Expansion of coal production has been the subject of intense debate.[4]

Coal mining is not the only use of the resource. Since the late 1990's, natural gas has been produced from coalbed methane (CBM) wells in the upper portion of the basin, in both Wyoming and Montana. Extracting CBM requires pumping groundwater to lower hydrostatic pressure and allow the gas to be captured. The water that is pumped out of the ground is a central issue; groundwater quality in coals is often lower than surface or irrigation water quality. Pumped water cannot be reinjected into the original formation during production and is disposed of using several methods, including evaporation and surface discharge. Although most methods attempt to isolate the pumped water, some discharge to surface water does happen (Boysen et al. 2002). Even water that leaches into shallow aquifers may affect the hydrologic regime. The quality of produced water and its interaction with natural flows have been a primary concern for irrigators. Table 2 below summarizes the current status of coalbed methane development in the area.

Table 2: Coalbed Methane Wells, September 2012

	Montana		Wyoming	
	Tongue	Other	Tongue	Other
Total Wells	1679	30	8065	63947
Producing	337	337	2353	21228

Source: Montana Board of Oil & Gas Conservation, Wyoming Oil and Gas Conservation Commission

Previous Studies

Although this report makes unique contributions to the understanding of effects and opportunity costs, it follows in a succession of investigations into the increasing salinity in the Tongue River and other nearby rivers.[5] The science of applying saline irrigation water to saline-sodic soils has been the focus of considerable previous research (Schafer 1982, Warrence and Bauder 2001). Certain clay-based soil types are particularly susceptible to structural collapse under these conditions (Ganjegunte et al. 2008). Such episodes dramatically reduce soil productivity and are a primary concern for irrigators. However, the exact combination of conditions necessary for such damage to occur is not perfectly understood.

As CBM discharge started in the late 1990s, concern about the effects on agriculture led to new research efforts on the effects of water quality change. The Agronomic Monitoring and Protection Program (AMPP) was an early agronomic experiment that specifically examined the effects of water quality on irrigation practices in the TRB. The AMPP has been succeeded by

[3] As of early 2013 one of the mines on the state line (Decker) has scaled back production due to coal market considerations.
[4] This debate centers on the routing and construction of the long-debated Tongue River Railroad.
[5] See, for example, Clark (2012), Kinsey and Nimick (2011), National Research Council (2010), Clark and Mason (2007), Dawson (2007), and references cited therein.

the Tongue River Information Project (TRIP).[6] The primary conclusion of these plot-level agronomic studies is that variation in salinity and sodium levels is not correlated with crop yield differences (Osborne et al. 2010). Drought is implicated as an important cause of the concerns since water quantity and quality are negatively correlated.

There is a difference of opinion between field studies, which have generally not found significant impacts of water quality, and lab studies, which have warned against severe impacts from degraded water quality. Vance et al. (2005) confirm that CBM produced water can alter soil chemistry by contributing to build-up of salts and sodium in the root zone. Stearns et al. (2005) examined the effect of direct application on soils and vegetation, and found that the water degraded both. However, these lab studies may omit important factors such as rainfall, which is known to interact in complex but important ways with the application of irrigation water (Suarez et al. 2006). Location and soil type of sites selected for field studies is clearly critical. Producers have offered anecdotal evidence of yield reductions, especially in the lower reaches of the river.

In addition to initial agronomic trials, the hydrologic connection between surface water, groundwater, and irrigation is a critical topic for research. The structural links between the three are not perfectly understood. The hydrologic system in the basin is complicated and not perfectly understood. Groundwater and surface water flows are related in imperfectly understood ways that change over the course of the basin. However, by computer simulation of the basin, long-run impacts on groundwater storage and availability are predicted (Myers 2009).

The interaction between the quality of water and the existing system of water rights is complex. Irrigators own rights to quantities of water, but the quality of water is generally regulated by concentration standards.[7] In Montana such standards are set by the Water Quality Division of the Department of Environmental Quality. At this point in time Total Maximum Daily Load standards have not been set for the Tongue River or Powder River watersheds. So irrigators are potentially subject to unregulated water quality variation.

AGRICULTURAL PRODUCTION

An important source of information about irrigated agriculture is the Farm and Ranch Irrigation Survey (FRIS) conducted every 5 years by the USDA with the Census of Agriculture. The most recent available survey data are from 2008, following the 2007 census. Irrigation is important in Montana—about 10 percent of the nearly 20 million acres of cropland on farms and ranches in the state is irrigated—about 1.95 million acres on 8,500 farms.[8] The figures for irrigated acreage have not changed much over successive censuses and total irrigated acreage has been very near 2 million acres for 20 years or more. In aggregate, each year Montana farmers apply 2.66 million acre-feet of water. Gravity application accounts for about 56 percent of acres irrigated and sprinklers account for about 44 percent. In the 2008 survey, 12 farms in Montana reported water quality issues as the main cause of reduced crop yields on a total of 11,496 acres. In contrast, 1,585 farms reported a shortage of water as an issue on a total of 362,461 acres. So low water quality may be an issue for some producers, but lack of water appears to affect many more producers. The main irrigated crops by acreage in Montana are shown in Table 3, along with the average yield gains that irrigation provides.

[6] The primary investigators have remained the same but the sponsors of the research have changed from a private energy developer to the Montana Board of Oil and Gas Conservation. Reports available at: http://bogc.dnrc.mt.gov/reports.asp .
[7] Fitzgerald (2012) explores the issues that this raises for water users, and suggests remedies.
[8] Figures are from 2008 Farm and Ranch Irrigation Survey (FRIS): http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/Farm_and_Ranch_Irrigation_Survey/index.php

Summarizing the agricultural productivity of the Tongue River is a challenging task because data are not collected at the watershed level. So while state or even county-level estimates are readily available, calculating the production attributable to a specific watershed is more difficult. One data option is the USDA Census of Agriculture; this census of all agricultural producers in the United States is conducted every five years. Data are reported on a number of geographic levels, including at the watershed level. Unfortunately in the case of the Tongue, only two data points are available for apportioned Census of Agriculture responses—2002 and 2007.[9] The responses also include the production of the Wyoming portion of the basin, without a clear demarcation between the two. So other data sources are needed to track historical agricultural output.

Table 3: Montana Irrigated Crop Choices: 2008 FRIS Survey

Crop	Acres Irrigated	Proportion Irrigated	Yield Increase on Irrigated
Corn--grain	28,653	1.00	N/A
Corn--silage	40,377	1.00	N/A
Wheat	212,886	0.38	122%
Barley	180,238	0.64	128%
Alfalfa Hay	657,151	0.72	233%
Other Hay	362,777	0.75	64%
Pasture	392,545	0.025	N/A

Source: 2008 FRIS, NASS. N/A: not applicable

Geospatial analysis of the basin indicates that 25,000 acres are irrigated with water sourced from the Tongue River (including the acreage served by the T&Y canal). Figure 3 shows where these acres are located. They are distributed more or less evenly along the river, with more acres lower in the basin as the valley widens. The irrigated land base allows for some very rough calculations of total agricultural production. If every acre achieved a yield of 3.42 tons alfalfa (the average yield reported in table 1), alfalfa production in the basin would be 82,000 tons per year.[10] Feeding that alfalfa to beef cows at a rate of 2 tons per head per year would support 41,000 head of cattle, a beef herd that might be expected to yield 35,000 beef calves each year.[11] The available grazing acreage in the basin is sufficient to support that number of animals through the year. This sort of approximation provides a useful reference for the following more detailed estimates of agricultural production in the basin.

Each year the NASS produces county-level estimates for dozens of categories of agricultural production. The Survey of Agriculture has data series that cover decades, particularly for principal categories of commodities. The data series used in the analysis are described in more detail in the appendix. The level of aggregation in these data does not conform to the boundaries of the TRB, which flows through parts of four counties. Aggregating county data is also not desirable because that would include production from neighboring river valleys including the Big

[9] Although the data are reported by watershed, the data are apportioned to watersheds by ZIP codes. If a ZIP code is wholly within a watershed, all census responses from that ZIP are assigned to the watershed. For ZIP codes that straddle watershed boundaries, responses are assigned to watersheds based upon the proportion of the different watersheds that are within that ZIP's county. As an example, if a ZIP code straddles watersheds A and B, and the county's area is comprised of 40 percent in watershed A, 25 percent in watershed B, and 35 percent in watershed C, then the responses would be assigned with the county watershed weights, even though watershed C isn't even in the zip code in question. (Census of Agriculture Watershed Report, pg 92, 2007)

[10] The figures for all irrigated hay in the Southeast Agricultural District compare favorably to the state-wide average for irrigated alfalfa, which is 3 tons per acre.

[11] This allows for bulls and replacement heifers, plus 95% calving success, with marketed cull cows.

Horn, Powder, and Yellowstone Rivers, and therefore overestimate production along the Tongue River. To the extent that land in those other basins might have different underlying productivity, a strict county-level estimate is biased.

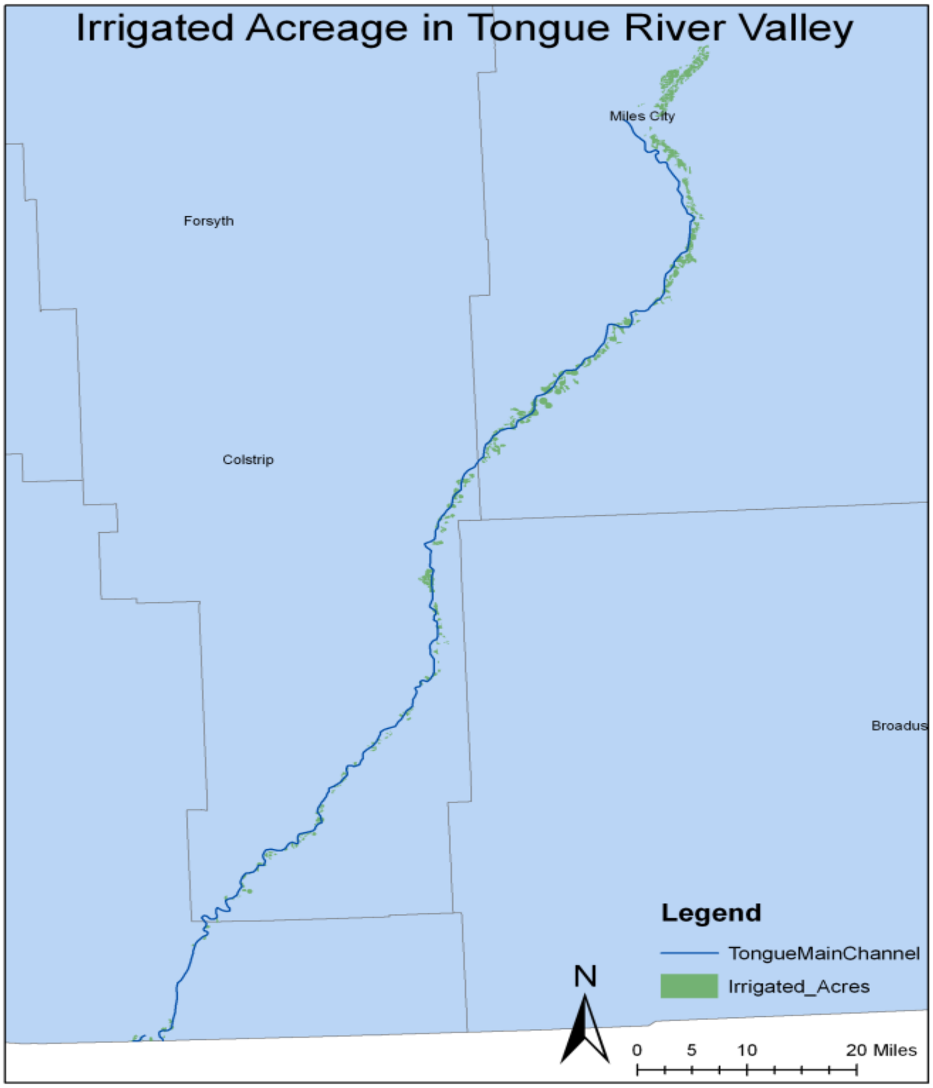


Figure 3: Acres Irrigated with Tongue River Water

Data series specific to the TRB were created by apportioning annual county estimates with three different weighting algorithms. The weighting algorithms were based on a geospatial overlay accounting for the share of each county in the basin, total crop production derived from the USDA CropScape Cropland Data Layer (CDL), and crop-specific production derived from the CropScape data. The algorithms are explained in detail in the appendix. The individual series derived from each algorithm were then compared to generate final estimates of agricultural production by commodity. Summing across the major agricultural commodities provides a long-term picture of production. The Census of Agriculture series are used to verify the accuracy of the estimated series.

Table 4: Montana Price Series for Agricultural Commodities

Year	Barley ($/bu)	Cattle-Excl. Calves ($/cwt)	Corn, Grain ($/bu)	Alfalfa ($/ton)
1980	2.70	58.00	3.60	62.50
1981	2.33	51.90	3.28	48.50
1982	2.06	48.20	2.35	50.00
1983	2.40	48.00	3.20	63.00
1984	2.41	47.20	3.10	78.00
1985	2.03	47.60	2.80	84.50
1986	1.60	49.30	2.10	51.00
1987	1.82	61.10	2.20	45.00
1988	2.82	65.70	3.15	85.00
1989	2.21	68.20	2.60	70.00
1990	2.30	70.60	2.50	65.00
1991	2.34	69.80	2.70	51.50
1992	2.39	66.50	2.50	71.50
1993	2.06	75.60	2.90	69.50
1994	2.22	71.60	2.65	71.50
1995	3.00	59.80	3.00	67.50
1996	3.07	53.80	2.60	81.00
1997	2.83	64.50	2.40	80.00
1998	2.27	62.00	1.90	73.00
1999	2.32	67.60	1.55	66.00
2000	2.38	78.30	1.53	86.50
2001	2.65	80.50	1.89	95.50
2002	2.86	70.50	2.45	85.00
2003	2.93	82.20	2.65	75.00
2004	2.85	91.00	2.42	77.00
2005	2.92	104.00	2.54	71.00
2006	3.00	93.80	3.93	78.00
2007	4.14	89.80	4.76	79.00
2008	5.78	87.50	3.80	117.00
2009	4.86	77.70	4.23	96.00
2010	4.08	90.10	6.00	79.00

Source: NASS. Note: Before 1989 alfalfa hay price is for all hay.

Gross revenue figures are then constructed by applying pertinent prices to each production series.[12] The state-wide marketing year nominal price series that are used for each commodity are detailed in table 4. These series do not account for regional basis differentials specific to southeast Montana or the Tongue River Basin.[13]

[12] Using average prices for gross revenue ignores observable quality differences, but historic price distributions are not publicly available.

[13] In principle these basis differentials could be positive or negative, with an ambiguous effect on the overall estimate.

The main agricultural products in the TRB are alfalfa hay, barley, corn, and cattle. The production estimates focus on these main series. There are other agricultural products grown in the TRB: including vegetables, other grain crops, and even grapes at a small vineyard. Lack of continuous data and the relatively small share of these products in the TRB and broader region prevent a more precise estimate. Crops that are not grown are also informative. Notable among these are sugar beets, a high-revenue crop common in both the nearby Bighorn and Yellowstone valleys, but not grown along the Tongue River. CropScape data indicate that there are small patches of sugar beets in the Tongue River, but local corroboration suggests not. By concentrating on the largest and most valuable crops, the estimated data series capture most of the physical product and gross revenue that the basin produces.

Table 5: 2011 Primary Cover.

Cover	Tongue River Basin (Whole)	Big Horn	Custer	Powder River	Rosebud
Alfalfa	27,647	102	13,002	10,913	3,630
Barley	394	4	269	103	18
Corn	2,563	0	2,364	14	185
Developed	9,835	531	6,018	1,914	1,372
Fallow and Barren	7,616	3,281	2,566	1,350	419
Forest	438,093	36,071	64,388	197,103	140,531
Grassland/Pasture/Sod	1,149,831	206,547	494,617	244,449	204,218
Other Crops	303	1	250	37	15
Other Hay	5,880	201	2,352	2,955	372
Shrubland	678,545	175,996	127,718	202,983	171,848
Water and Wetland	34,703	6402	9,643	7,141	11,517
Wheat (All Varieties)	5,824	89	3,171	2,239	325
TOTAL	2,361,234	429,225	726,358	671,201	534,450

Source: CropScape CDL. Other crops include: clover, dry beans, flaxseed, millet, oats, other small grains, peas, safflower, sorghum, and sugarbeets. Note: Totals include Tongue River watershed proper as well as the T&Y Irrigation District.

The Cropscape database is a rich and detailed source of information. Table 5 itemizes the primary landcover of the Montana portion of the TRB in 2011. Not surprisingly, the main land cover is range, typified by grassland, shrubland, and evergreen forest. Classified as land capable of growing commerciable timber, use of forest as range is not detailed. Among crops, alfalfa is by far the most prevalent, followed by corn and then grains. The other main land covers are water and wetlands, which includes both woody and herbaceous wetlands. Land that is developed or barren, which is not part of the agricultural land base, when added to fallowed crop acres, is the third largest land cover. Developed land includes towns and farmsteads.

The CDL data is not perfect, and while the results are informative they are not infallible. Remote sensing technology has improved markedly, even over the past few years as CDL data has been available to the public. One common problem is that hay, alfalfa, pasture, and grassland are mistaken and mis-categorized. Other possible confusions between types of hay and types of grain crops may exist. Despite such errors, the data provide a far more detailed picture of agricultural land use than agricultural statistics alone.

Annual agricultural production is heavily dependent on weather and rainfall and drought have substantial impacts on annual crop and livestock production in southeast Montana. Over a longer time horizon, however, producers react to prices or new technologies in ways that change the long-run output mix. Thirty years is a long enough span to see reactions to new technologies such as irrigation sprinklers and new seed varieties—and then to have those adoptions fall by the wayside in favor of new practices. An accurate picture of agricultural in the valley can only be obtained by accounting for both long- and short-run changes in agricultural production.

Crop Results

Alfalfa

Alfalfa is unusual among field crops in that it is perennial. New seedings and older stands have lower yields than well-established stands. As a result, stands of alfalfa are renewed every few years with rotations that vary between 4-10 years. Growing alfalfa requires patience and prevents farmers from reacting to annual price variations in the ways they are able to with annually-planted crops. Producers usually plant a small grain crop such as barley or wheat as a nurse crop to help establish a new alfalfa stand. These nurse crops are sometimes harvested as hay instead of for grain. Alfalfa can be grown either as a dryland crop or, if water is available, as an irrigated crop. Alfalfa yields change dramatically when the crop is irrigated (see table 1). Figure 4 shows the variation in the estimated harvested acres for both all alfalfa and irrigated alfalfa in the TRB between 1960 and 2010.

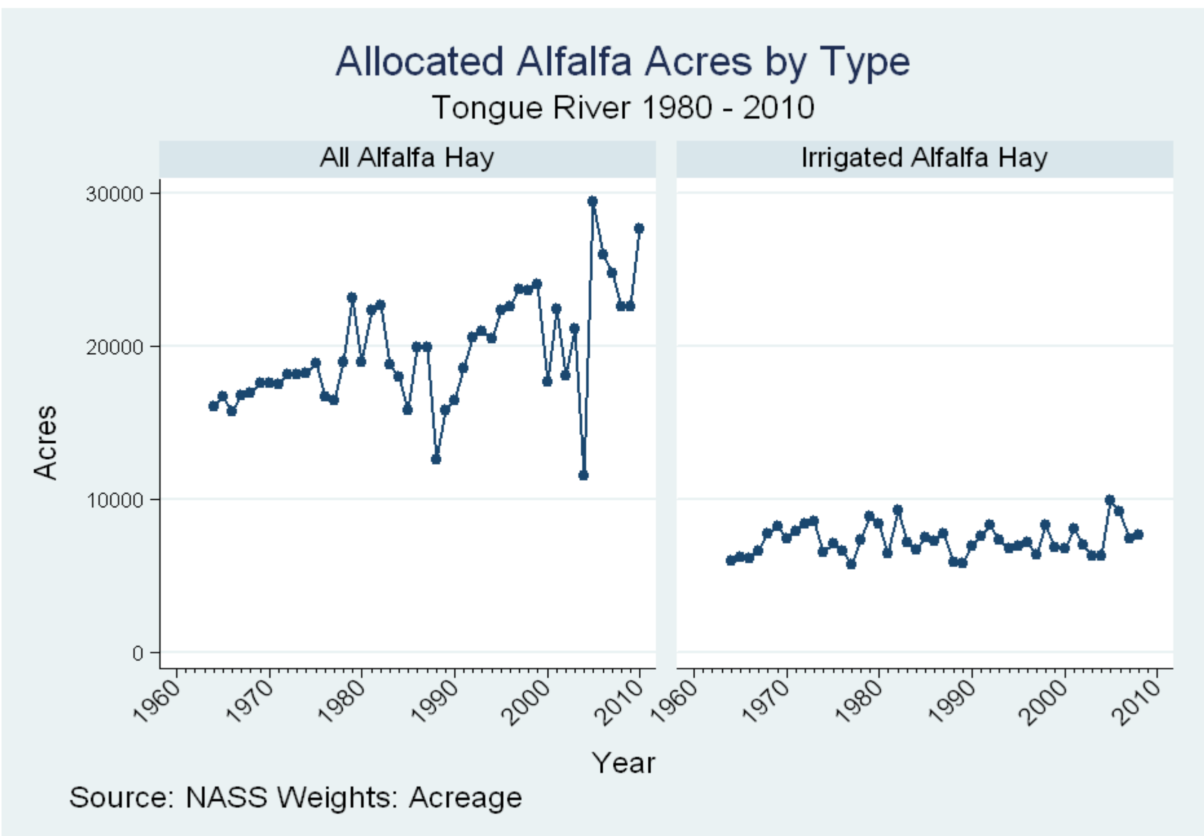


Figure 4: Alfalfa Acres

In terms of acreage, total production, and economic value, alfalfa is the most important crop in the TRB. Figure 5 plots the estimated alfalfa production from 1980-2010 along with a smoothed polynomial trend. While the scatter plot shows substantial variability between good and bad years, the trend line smoothes out the annual variability and indicates the long-term changes. Comparing figure 5 with the "back-of-the-envelope" calculations on page 7 validates the calculation. Comparisons with the two watershed-level estimates from the census are harder because the census only records irrigated acres, and does not separately report irrigated alfalfa acres.

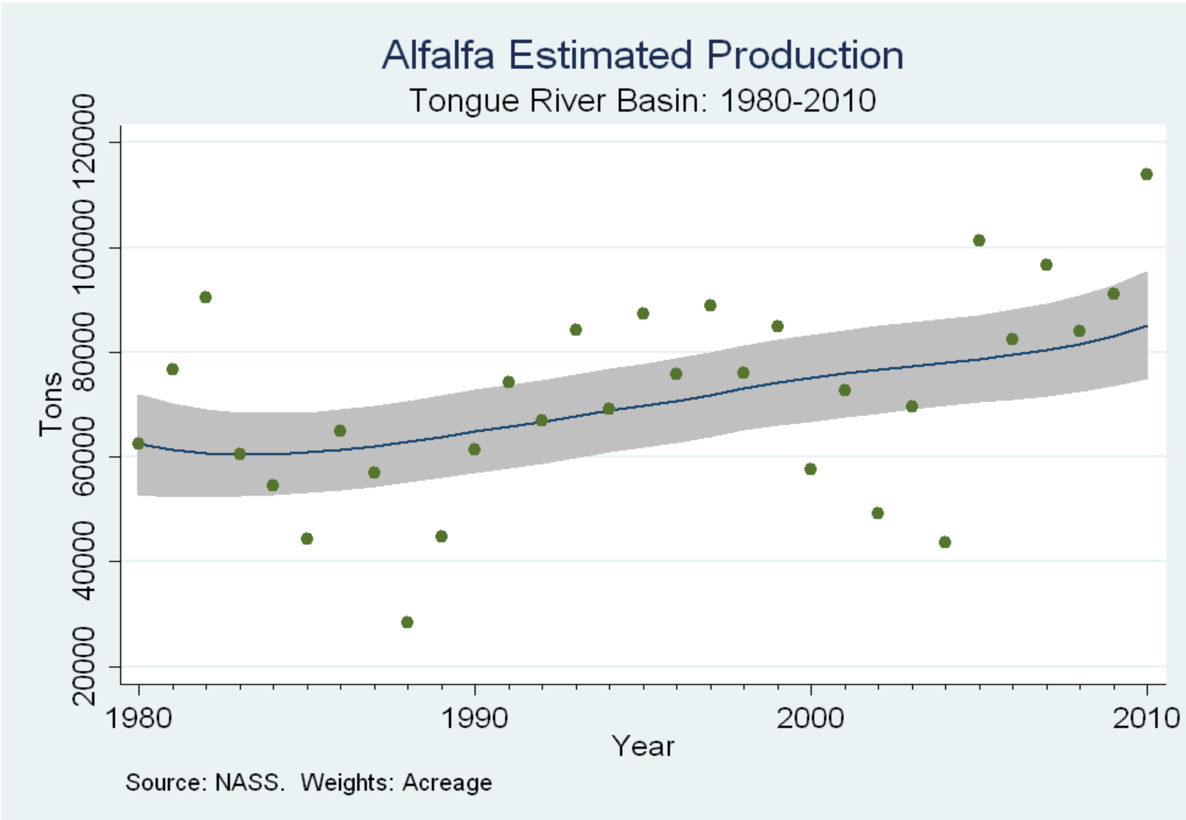


Figure 5: Alfalfa Production

After considering acres harvested and total tonnage produced, it is straightforward to calculate an average yield as a robustness or believability check. The acreage-weighted estimate has the highest implied average yield—3.4 tons per acre. This compares favorably with an irrigated yield. The average yield across all allocation schemes is 2.4 tons per acre. Recognizing that there are a substantial number of non-optimal alfalfa acres (e.g., older stands, dryland), this lesser yield might be more realistic.

Given the estimated production, the estimated gross revenue for alfalfa can be calculated using the per ton price shown in table 4. Such gross revenue estimates should be carefully considered because a substantial but unknown proportion of the hay crop is consumed rather than marketed. Nonetheless, the gross revenue estimates do help compare the relative importance of alfalfa relative to other crops. Recent alfalfa hay gross revenue levels around $7 million per year (nominal) are above a long-term trend in the range of $5.5 million. The trend is affected by drought in the late 1980s and early 2000s.

Barley

In contrast to alfalfa, the number of acres planted to barley has declined since 1980, as has barley production (see figure 6). The long run decline in barley production is smaller than the decline in acreage planted to the crop because yields have increased substantially. Since 2005, barley production has increased somewhat, most likely in response to the strong price environment for grains. However, some of the year-to-year variability in production appears to have decreased, suggesting a shift from dryland to irrigated acres. Such a shift would also help explain the dramatic increase in average yields.[14]

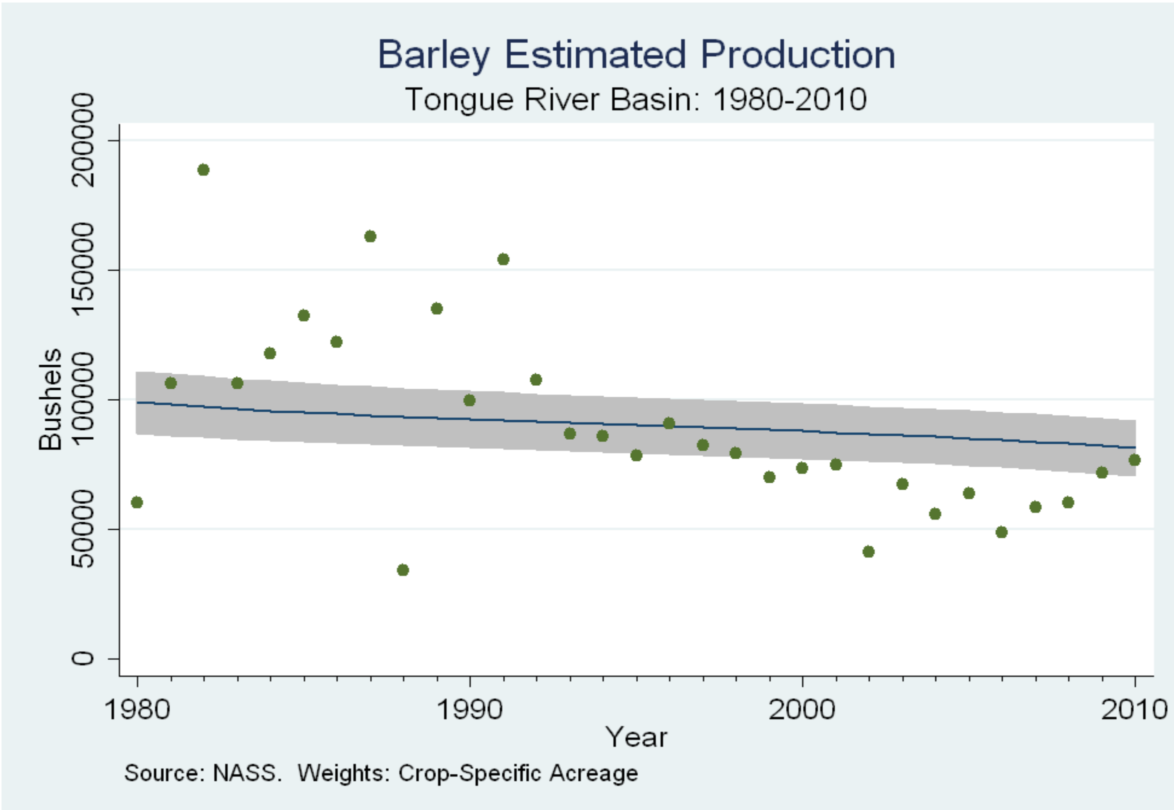


Figure 6: Barley Production

Stronger prices have also buoyed gross revenue received by barley producers. Like alfalfa, the gross revenue from barley production has been above the long-term trend for the last three years in the sample. Barley gross revenues exceeded $1 million in 2008-2010, about 20 percent above their long run trend.

Corn

In the TRB, considerably fewer acres are planted to corn than to alfalfa. In addition, corn acreage is disproportionately lower down the valley close to Miles City. A further complication is that corn acres can be managed in different ways: corn can be chopped for silage or harvested for grain. Although optimal seed varieties differ for the two uses, in principle a planted acre of corn can be chopped early if weather shocks make it less likely to make grain. Barley is similar in that different varieties are better-suited for hay or grain, but some producers may choose to harvest hay barley instead of hay (especially when barley is used as a nurse crop for alfalfa). Corn production data do not consistently distinguish between corn for grain and silage. CropScape data identify planted corn. Survey data report harvested acres by type. Figure 7 shows the tradeoff between corn for silage and corn for grain over time, and that in most years more acres are harvested for silage than for grain.

[14] Casual analysis of available data series suggests that this transition from dryland to irrigated cultivation of barley has occurred, but no further explanation is explored here.

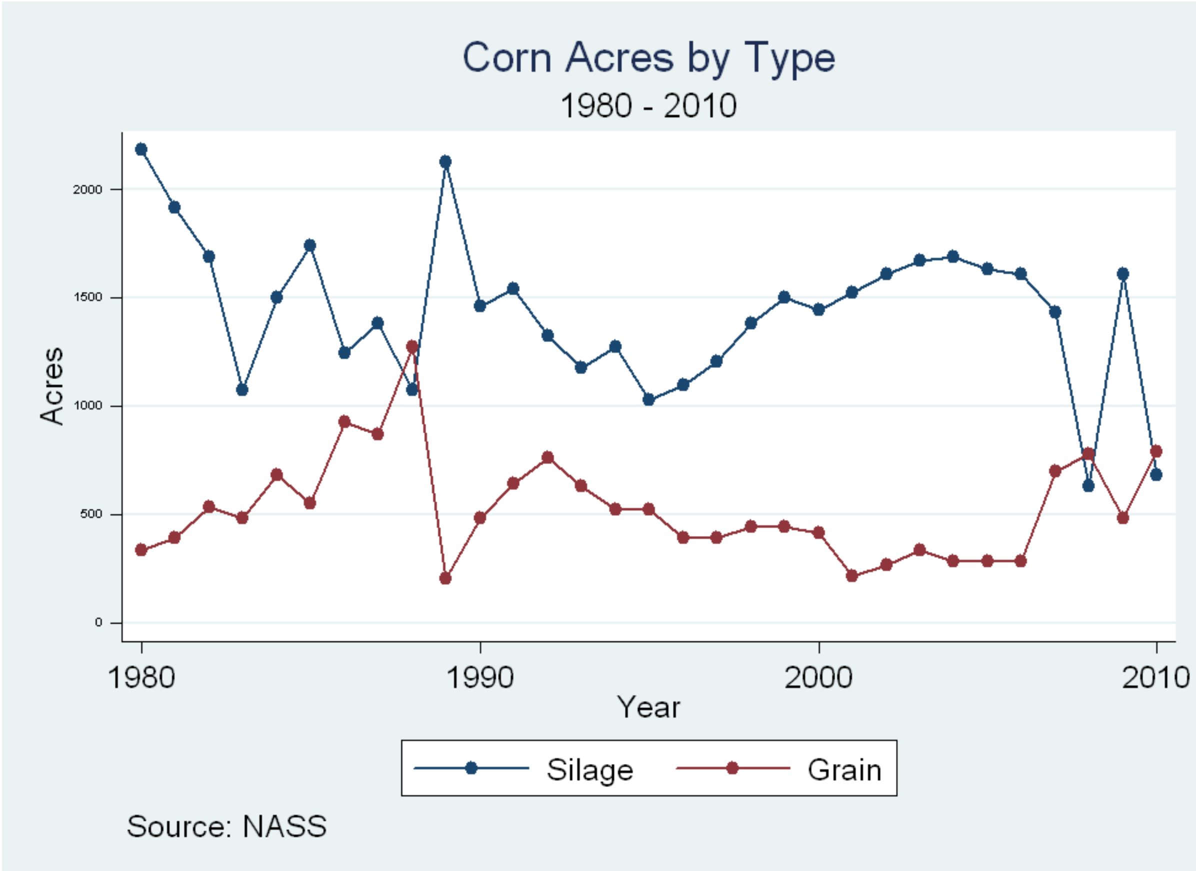


Figure 7: Corn Acres

Silage is generally consumed as an intermediate input, so double-counting issues arise again in this context. The market for silage is so thin that prices are not readily observable.[15] Concentrating on corn produced for grain is therefore easier to analyze, and involves less risk of double-counting. Figure 8 shows actual grain corn production and its long-term trend.

[15] This does not preclude contractual arrangements for acreage used for silage, or hiring the cutting and storing of silage.

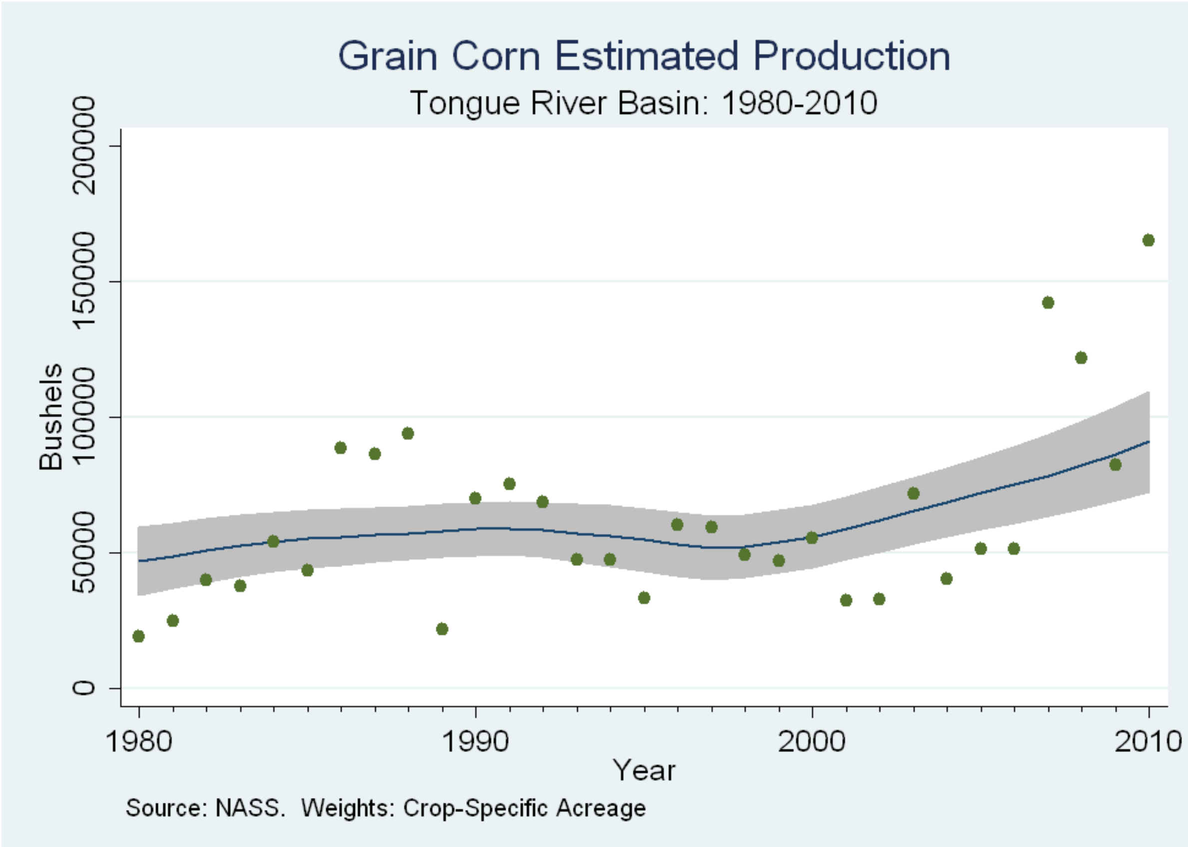


Figure 8: Grain Corn Production

Yields for grain corn have increased because of genetic improvements, which is a contributing factor in conversion of acres. Over the course of thirty years, average yields have increased by about 60 percent, from approximately 100 bushels per acre to nearly 160 bushels per acre.

Corn prices have been unusually high since the mid 2000s, and have contributed to higher revenues. Despite favorable prices, the relatively small acreage involved in grain corn production means that gross revenue from corn production is much smaller than from alfalfa. The estimated gross revenue from grain corn production exceeded $1 million in 2010, but revenues in that year were well above the long-term trend, which is just above $500,000.

<u>Cattle Results</u>

Beef cattle are central to the agricultural economy of southeastern Montana. Unlike crops, where all production is sold at market or consumed within a year or two of production, many mother cows remain in inventory for several years as they continue to produce calves. Most calves are sold within a year of their birth, with a smaller number of heifer calves kept in the herd to replace older cows. Cows remain in the herd so long as they continue to raise calves; culled animals are usually marketed. In a sense cattle present some problems similar to alfalfa due to the multi-year nature of the production process. It is often costly to expand faster than the natural rate at which herds can be increased by retaining calves.

Many beef enterprises in the valley are cow-calf operations that are inherently seasonal and so care has to be taken in enumerating the size of the herd. An unsuspecting census might conclude that the herd was twice as large after calving as before. To avoid confusion, we try to focus on the productive stock of cattle. All cattle include cows and their calves as well as other animals such as bulls and yearlings. From this figure, we then subtract the inventory of cows to estimate the productive capacity of the cattle herd.

The NASS county estimates record the number of cattle and beef cows in each county on January 1 of each year. Due to the seasonality of cattle production in southeastern Montana, this is typically after the previous year's calf crop has been weaned but before new calves are born. Assessing the annual productivity of the beef herd requires adjusting the January 1 herd figures. The primary method is to take the number of cattle in all classes and subtract the number of beef cows in the inventory. The remainder accounts for retained calves, replacement heifers, bulls, and other various cattle in the county. The identifying assumption is that the share of head sold from each class in each year is approximately equal. Marketed cattle fall into three categories: calves marketed at less than 12 months of age; yearlings marketed at more than 12 months of age; and culled animals, which are largely non-productive cows and bulls. A second way of assessing productivity is to assume a proportion of beef cows produce marketable calves. A rate of 90 percent might be representative. This measure does not account for the various classes of cattle marketed.

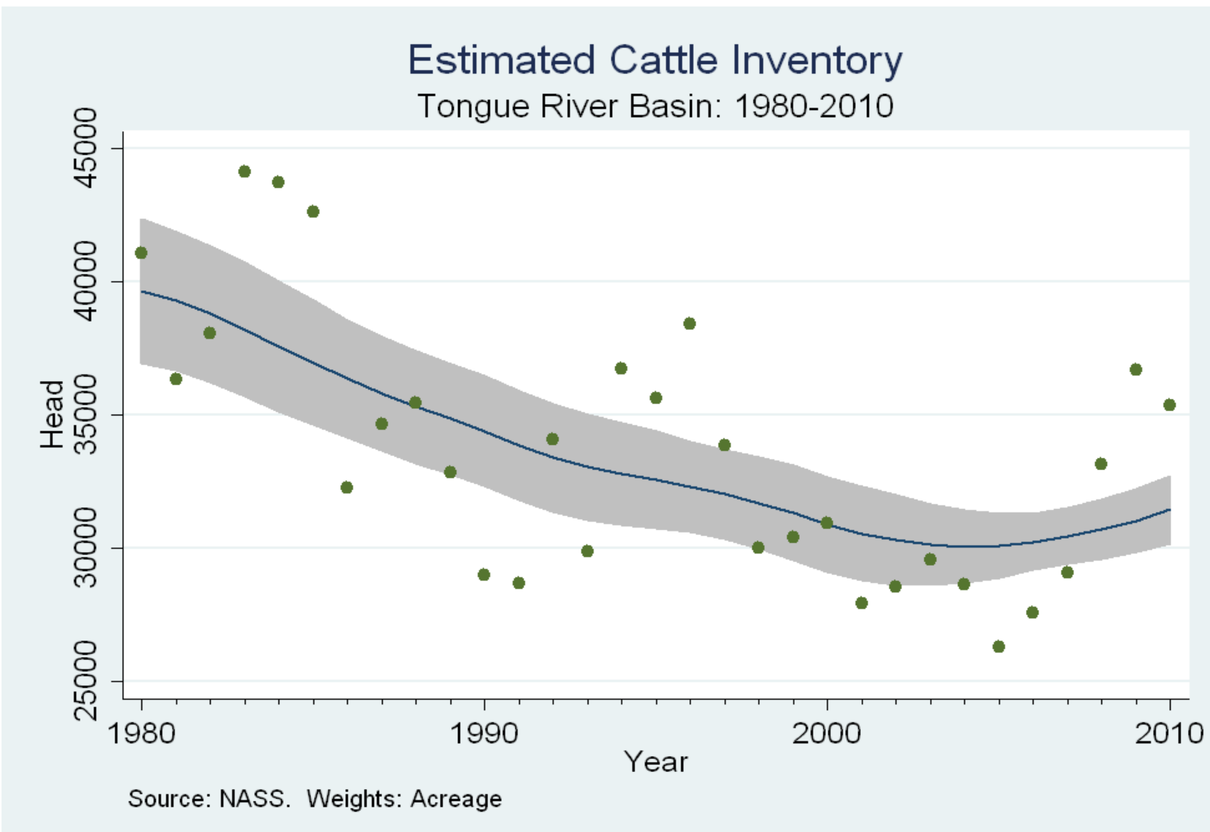


Figure 9: Estimated Cattle Inventory

The available range resource varies substantially with weather conditions and determines in large part how many cattle can be supported in the valley. Yearling stocker operations are more flexible, but may be sourcing cattle from other local producers encountering correlated weather shocks. Figure 9 shows the number of cattle estimated to reside in the Tongue watershed over the period 1980 to 2010, using as a measure the remainder of the beef herd after the beef cow inventory is subtracted. The downward trend reflects a broader national trend. An increase in carcass and calf weights compensates in part for the decline in the number of head. No specific data are available on calf weights from the valley over time.

Cattle price data for the state of Montana is available on a hundredweight basis, as reported in table 4. The estimates in figure 9 are on a per head basis. In order to calculate the average weight per head, the total quantity of marketed cattle and calves each year was collected from NASS records. Figure 10 shows the results of that series—keeping in mind that the average is statewide across all grades and classes of cattle. Basis differentials specific to southeast Montana or particular classes of cattle are unlikely to be fully captured by this measure. Lighter calves are often marketed in this part of the state. Although there are price premiums for lighter-weight calves, total revenue per head is increasing in weight. This annual average weight is then multiplied by the hundredweight price in order to yield an estimate of average price per head. Figure 11 shows the estimated annual gross revenues from cattle enterprises attributable to the TRB and the trend in those revenues. The watershed has shared the fortunes of the broader cattle market over time.

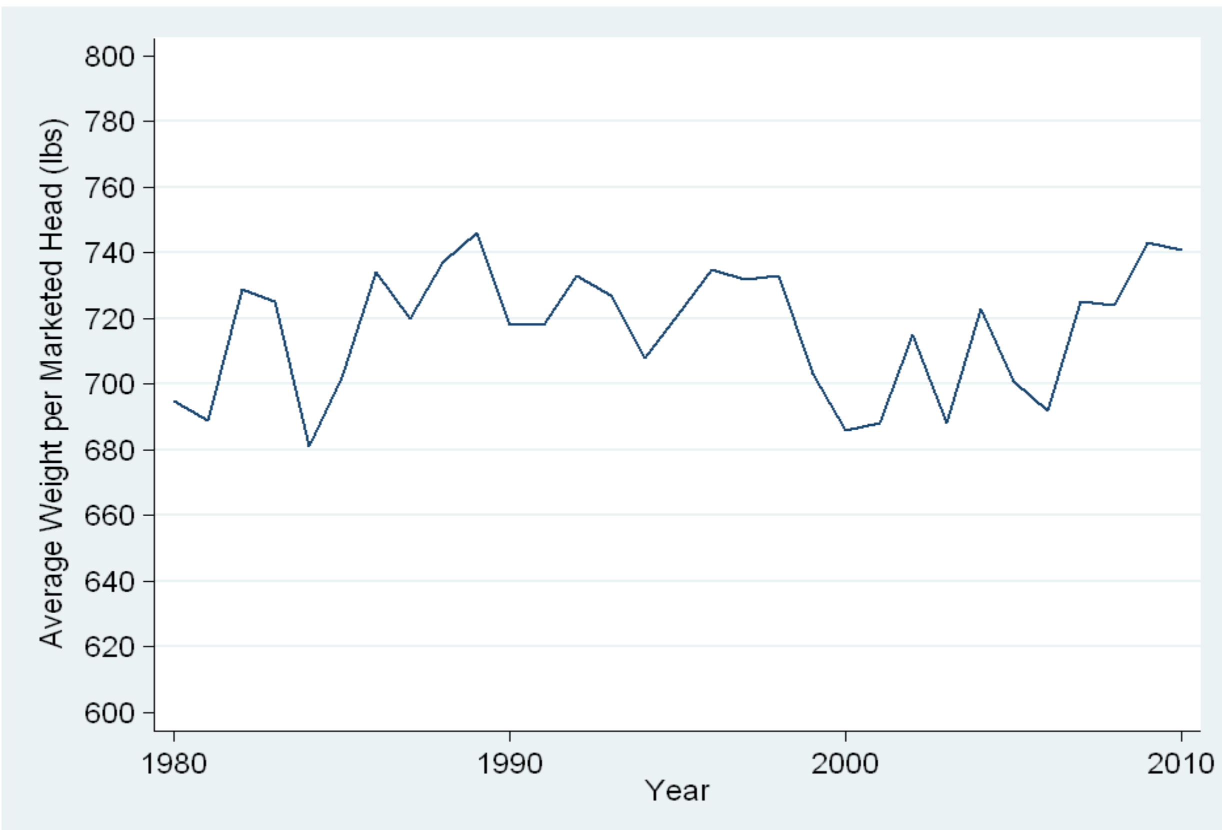


Figure 10: Average Weight per Marketed Head of Cattle, Montana, 1980-2010

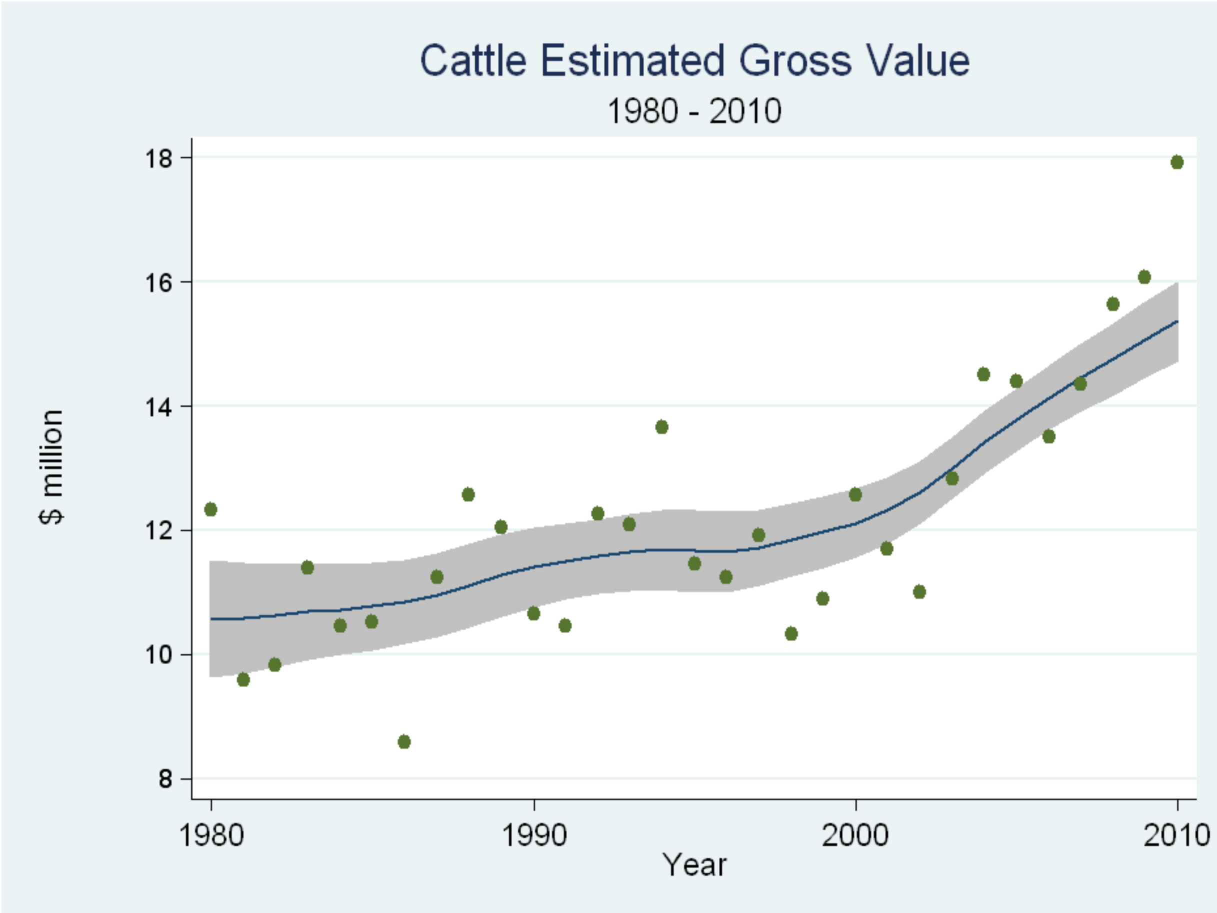


Figure 11: Estimated Cattle Gross Revenue

Total Value

By combining the gross revenue estimates for the major agricultural activities in the TRB, a thumbnail sketch of the value of agriculture in the Montana portion of the Tongue River Basin is obtained. Figure 12 depicts the individual gross revenue series for alfalfa, barley, cattle, and corn as well as the trend of the aggregate gross revenue. Due in large part to strong commodity prices over the last few years of the series, the aggregate trend is upwards. However, over the course of time, the lean years are quite noticeable. Agriculture depends on renewable resources but experiences variable revenue streams due to variability in the availability of resources (especially water), as well as broader market-wide shifts in prices. In recent years, total gross revenue from agriculture enterprises in the TRB has surpassed $20 million each year. It is important to note that these calculations exclude all forms of government payments. In the years since 1985, this has been an important source of revenue for farmers in Montana. So the gross revenue estimates are a lower bound on total revenues. To put the recent $22 million figure in perspective, during recent years the state agricultural gross revenue was on the order of $3 billion (including government payments). The TRB accounts for around 4 percent of the total acreage in farms and ranches across the state, but a smaller share of revenue.

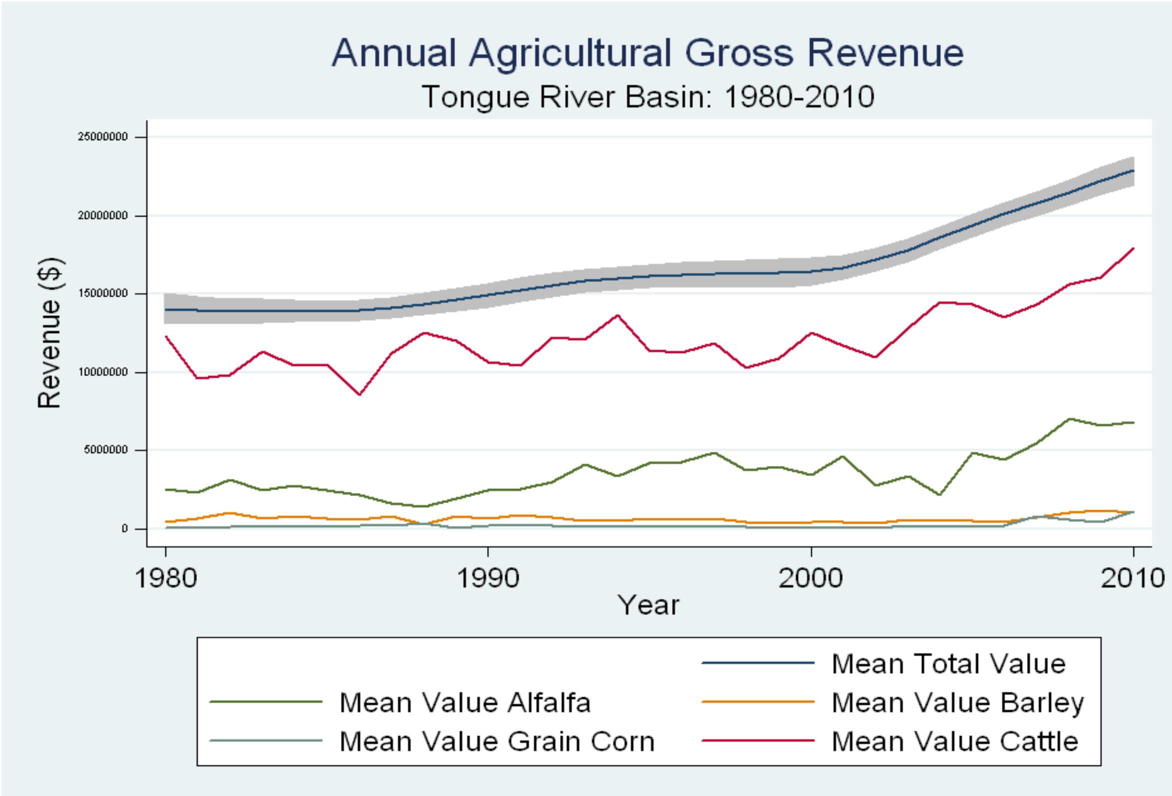


Figure 12: Aggregate Gross Value

A valuable robustness check is to compare the estimated gross revenue for the TRB with county-level estimates of farm receipts. NASS annually reports estimates of farm gross receipts by category at the county level. These data are available for 2000-2010. Figure 13 shows the comparison of the estimates developed here against the NASS gross revenue estimates converted to the TRB scale. The NASS gross revenue estimates are markedly higher. One main difference is in the revenue value of livestock. The per head value of livestock is substantially higher in the NASS gross revenue estimates (about $1000 per head) than in the estimates used here (closer to $700 per head). If all marketed animals were premium calves, this might be justified. It is also not clear how the NASS gross receipts series account for possible double-counting. The estimates here are more conservative than other measures that could be constructed from other available data.

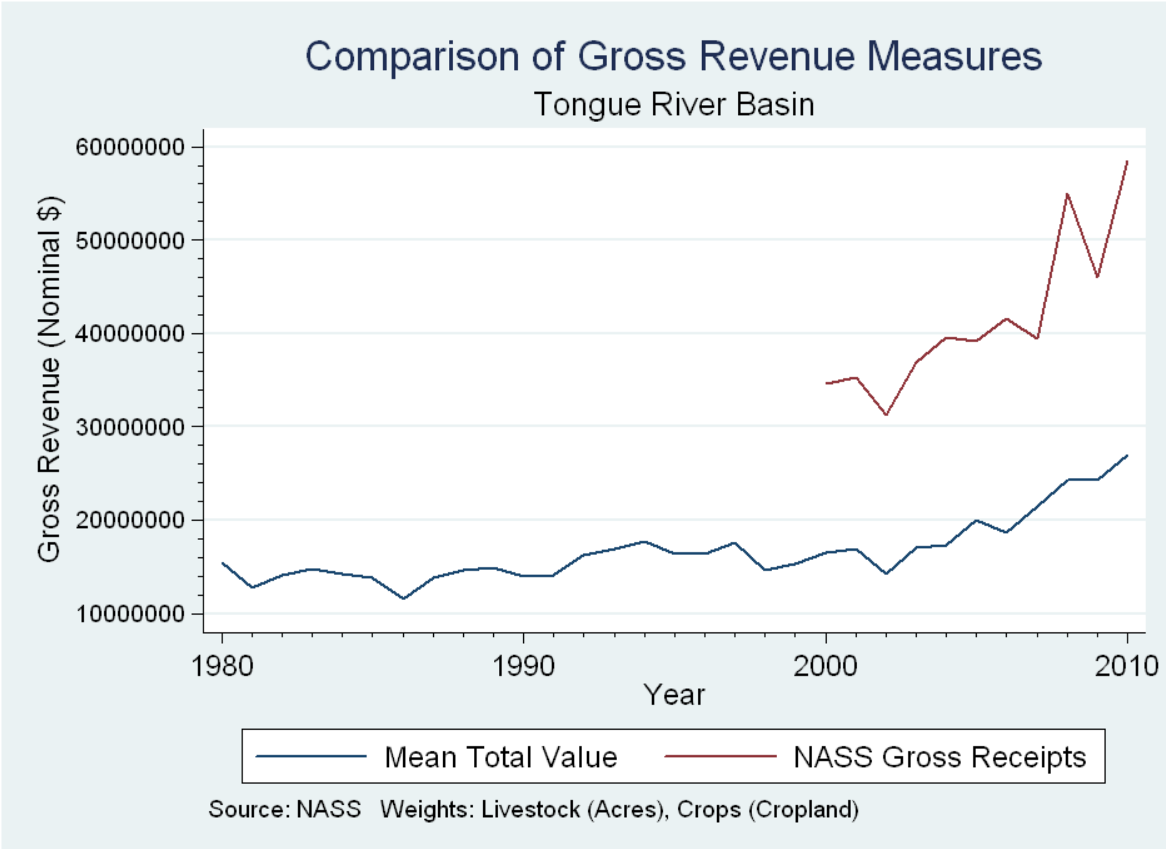


Figure 13: Comparison of Gross Revenue Measures

The historical record is interesting, but predicting future agricultural output gives a clearer picture of foregone opportunities. In order to do this, a model fitting the historic data is projected into the future. The forecast model is necessarily sparse, in part because future market conditions are unknown. However, figure 14 shows how the fitted model uses the historical data and projects in nominal dollars over the years 2010-2040. The gray lines provide confidence bands. The forecast suggests that left to its own devices, the nominal value of gross agricultural production of the TRB would likely rise to more than $60 million per year over the next thirty years. This is a marked rise from historic revenues. The sum of gross revenue over 30 years is over $1.3 billion.

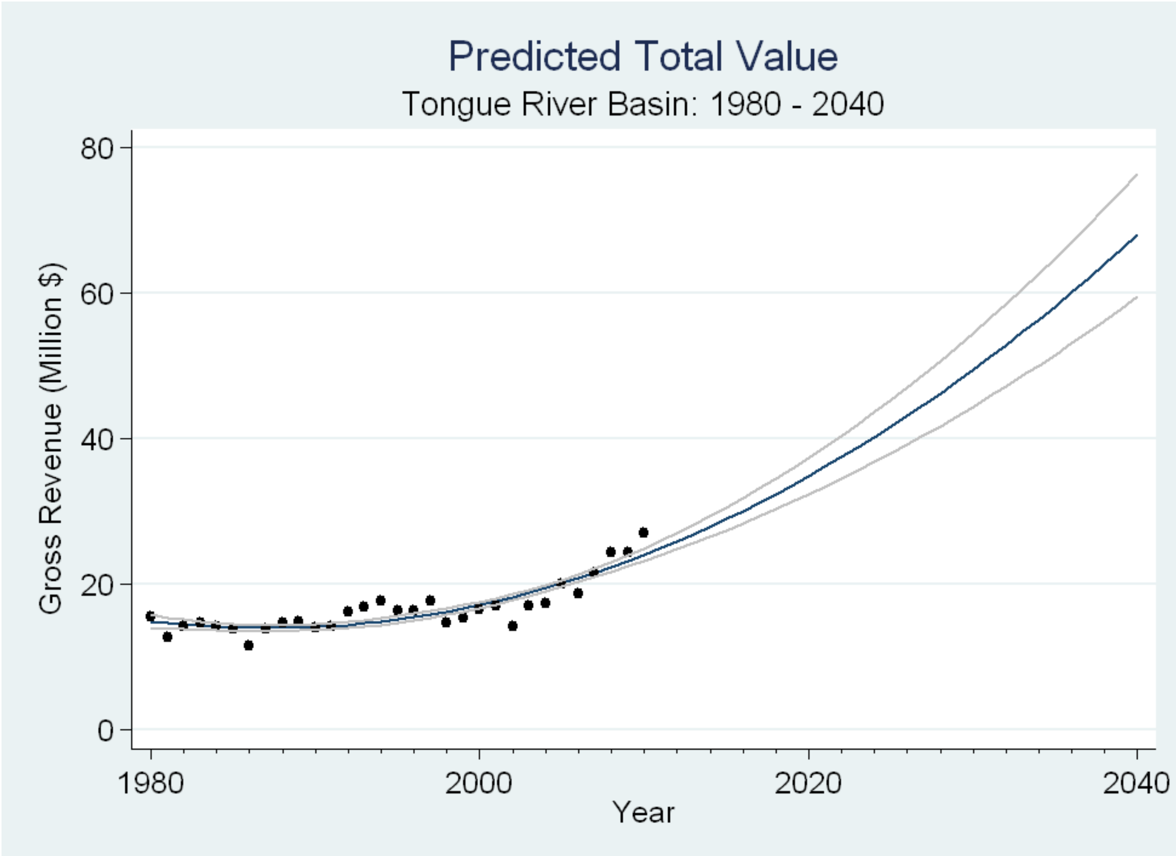


Figure 14: Gross Value Forecast

WATER QUALITY AND ITS EFFECTS

Irrigated agriculture is important in the region, but irrigation depends on the availability of adequate water resources. The sufficiency of water resources for continued agricultural productivity is a salient question. Agricultural users own water rights. Water rights specify water quantities, but not quality.[16] Water quality is generally regulated by Department of Environmental Quality. However, the department has not promulgated water quality standards for the Tongue River.

Widespread development of CBM wells in the upper reaches of the Powder and Tongue Rivers during the later 1990s and early 2000s attracted considerable research on the hydrologic effects of discharging produced water.[17] Vance et al. (2005) confirm that CBM produced water can alter soil chemistry by contributing to build-up of salts and sodium in the root zone. Stearns et al. (2005) examined the effect of direct application on soils and vegetation, and found that CBM water degraded both. These effects are most pronounced in clay soils, such as those founds in parts of the productive lower basin. Except for a few places where CBM water has been used for "managed irrigation," the question is not whether or not to irrigate. The question is how much CBM produced water can safely be used or absorbed into the existing hydrologic system. The CBM water flows into natural watercourses, including the Tongue River, where it mixes with other fresh water. Complicating the system further is the possibility of rain, which is fresh water, mixing with slightly saline irrigation water. Suarez et al. (2006) identify the (lower) threshold for potential damage to the agronomic process.

[16] For a further exploration of this issue, see Fitzgerald (2012).
[17] National Research Council (2010) has a thorough review of these studies.

A number of measures can be used to account for the quality of irrigation water, but two that account for salinity are the sodium absorption ratio (SAR) and specific conductance (SC). Taking into account the effects of different types of salts, SAR is a calculated ratio of the concentration of sodium (Na) ions to calcium (Ca) and magnesium (Mg) ions. While all three elements are potentially harmful to crops and soils, the calculation of SAR accounts for the greater impact of sodium. More dissolved salts increase SC, giving a complementary measure of salinity.

Different crops tolerate salinity to a greater and lesser extent. Table 6 shows the salinity tolerance of the primary crop types analyzed above along with some other selected crops. For each crop, the table shows the SC threshold at which yield loss might be expected to begin to occur. The SC that causes the increasing yield loss in each of the columns is also shown for each crop. Even moderate yield losses are likely to compel farmers to switch to a more salt-tolerant crop.

Table 6: Salinity Tolerance of Crops, Measured by Specific Conductance

		Yield Loss		
Crop	**Threshold (0%)**	**10%[18]**	**25%**	**50%**
Alfalfa	2000	3400	5400	8800
Barley	8000	9600	13000	17000
Corn (grain)	2700	3700	6000	7000
Corn (silage)	1800	2700	6800	8600
Orchard Grass	1500	3100	5500	9600
Peas	900	2000	3700	6500
Potato	1700	2500	3800	5900
Sorghum	4000	5100	7100	10000
Sugarbeets	6700	8700	11000	15000
Wheat	4700	6000	8000	10000

Source: adapted from (Kotuby-Amacher, 2000) Note: Specific conductance is measured in microsiemens per centimeter (µS/cm). For reference, seawater has a specific conductance of 54,000.

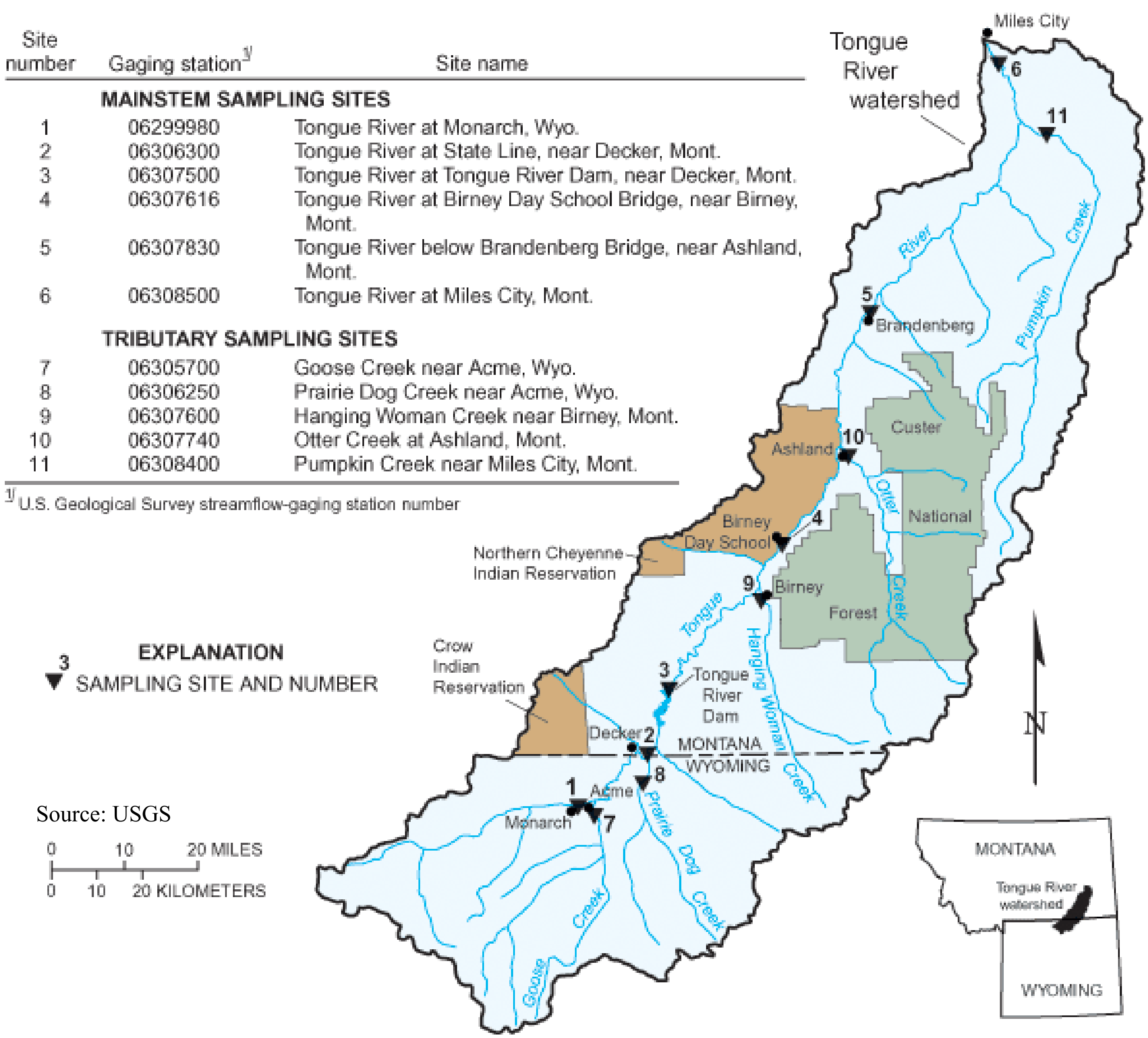
Streamflow is crucial as additional flow can dilute salt loads and improve water quality. The seasonal variation in streamflow is correlated with quality of water. Spring runoff dilutes the dissolved solids, but as flows fall later in the summer SC and SAR tend to climb. The water flows and quality in the Tongue River display strong seasonality. Spring runoff leads to the highest flows of the year in May and June, just as irrigation ditches are being opened. Flow declines as the summer wears on. Fall rains and cooler temperatures bolster flows in some years, but winter can come early. During the winter season ice often prevents continuous monitoring, but flows are generally low. Water quality is related to flows—high flows imply high quality, and vice versa.

[18] MacEwan and Howitt (2012) use field-level data to estimate these 10 percent yield loss thresholds allowing for behavioral response by farmers. Instead of surface water quality measurement, the study uses shallow groundwater salinity measurements as a proxy for salinity. Although the selection of crops is somewhat different (their data are from Kern County, California), there is some overlap. Their estimates for potato (1700), alfalfa (2200), corn (3700), and grain/wheat (6700) are not wildly different from the 0-10 percent yield losses reported in the table.

Data

The United States Geological Survey (USGS) monitors water quality and flows at a number of locations along the Tongue River. Two types of records are available in the historical data records. The first are automated reports from monitoring stations. These stations gather detailed information about flow and water quality. Because the monitoring equipment is relatively compact, and the perceptions of where data are most needed have changed over time, the location of monitoring sites changes over time. Data continuity is not aided by this flexibility. The complex hydrology of the river means that flows and quality can change in ways that are hard to understand as a monitoring site is moved up or down stream.

A second type of observations is field studies, which are conducted by hand at various locations along the river. These observations can help fill in the missing periods of time in the record from fixed site remote sensors. The set of locations where the USGS currently has monitoring stations is depicted in Figure 15.



Site number	Gaging station[1]	Site name
	MAINSTEM SAMPLING SITES	
1	06299980	Tongue River at Monarch, Wyo.
2	06306300	Tongue River at State Line, near Decker, Mont.
3	06307500	Tongue River at Tongue River Dam, near Decker, Mont.
4	06307616	Tongue River at Birney Day School Bridge, near Birney, Mont.
5	06307830	Tongue River below Brandenberg Bridge, near Ashland, Mont.
6	06308500	Tongue River at Miles City, Mont.
	TRIBUTARY SAMPLING SITES	
7	06305700	Goose Creek near Acme, Wyo.
8	06306250	Prairie Dog Creek near Acme, Wyo.
9	06307600	Hanging Woman Creek near Birney, Mont.
10	06307740	Otter Creek at Ashland, Mont.
11	06308400	Pumpkin Creek near Miles City, Mont.

[1] U.S. Geological Survey streamflow-gaging station number

Source: USGS

Figure 15: USGS Water Monitoring Sites

Figure 16 illustrates the seasonal variability in flow at the Wyoming-Montana state line. Spring runoff increases flow, which is lowest during the fall and winter months. The figure also shows the differences between water years. Some years, such as 1995 and 2011, had large flows in the early part of the year. Other years, like 2002 and 2004, saw almost no spring runoff. These stochastic flows are correlated with other weather events that make separate identification of water availability and drought infeasible.

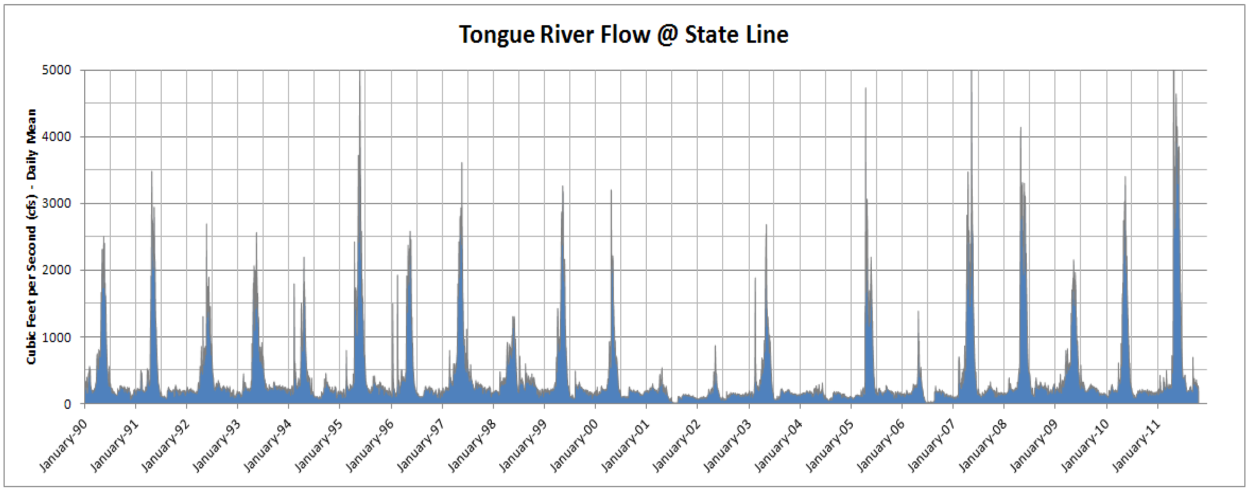


Figure 16: Tongue River Flow at State Line

Varying flows also affect water quality measures. Figure 17 shows the seasonal variability in daily maximum SAR measures at the T&Y diversion dam above Miles City over seven water years. No measurements are taken during December, January, and February when the river is iced over. The pattern through the balance of the year is for SAR to fall as flows increase with the spring runoff, then gradually climb as the flows drop through the rest of the summer and into the fall. Irrigators divert water starting in May and usually are finished in October. While SAR is one pertinent measure of water quality, SC also follows a seasonal pattern. Where on the river the measurements are taken also affects the levels of water quality measurements—this compounds the problems associated with changing monitoring sites.

Identifying Changes

Identifying the effect of variable water quality on agricultural production requires controls on other stochastic factors affecting agricultural production. These factors include weather and agricultural prices that are determined outside of the TRB. The price of cattle or corn is determined by national and international markets, but producers in the basin are apt to respond to changing price expectations by altering their production choices. These additional controls are important. Consider the effect of high SAR and SC measurements in 2001 and 2002. The effect of this water quality on agricultural production would be overstated if other pertinent variables such as the ongoing drought and changes in prices in previous years were omitted from the analysis.

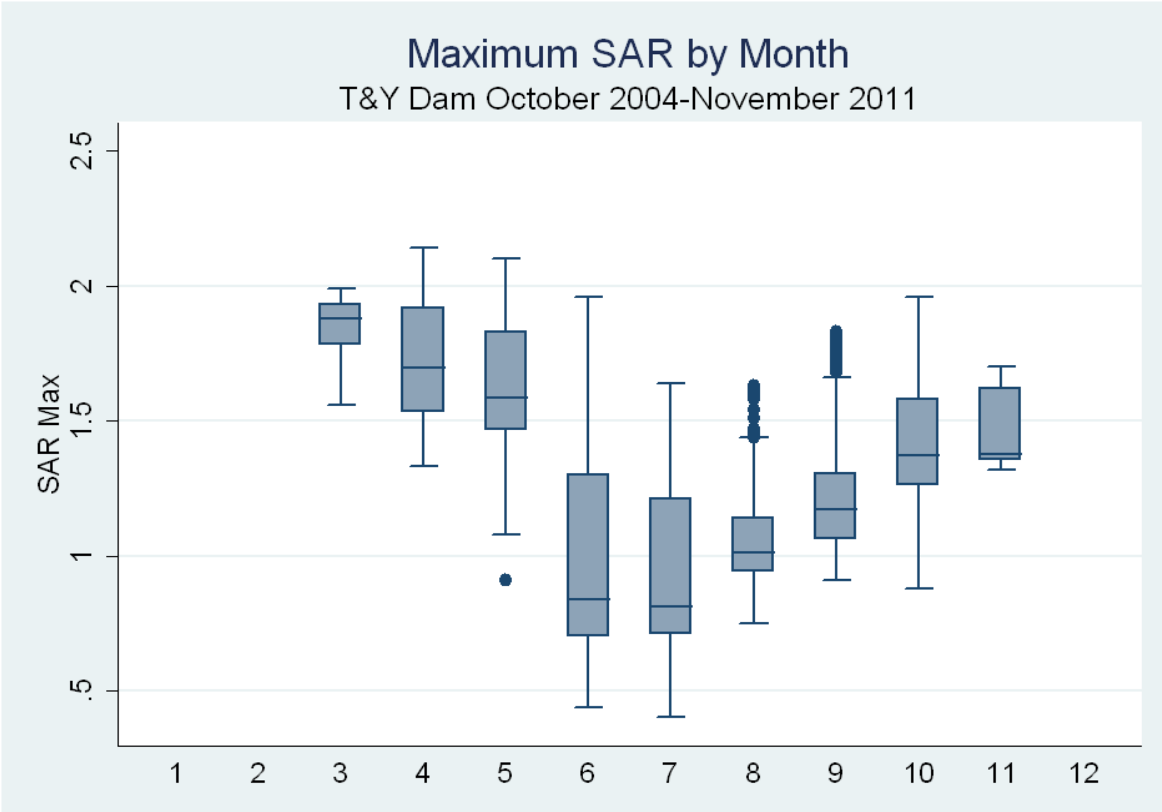
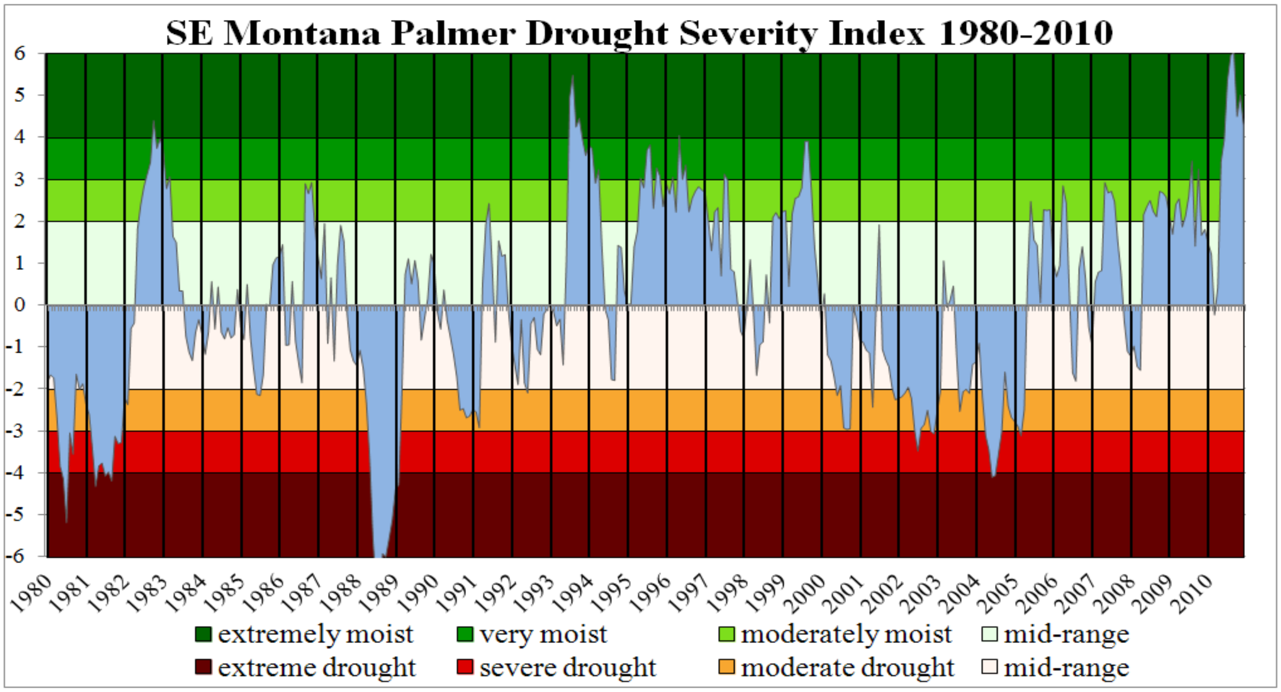


Figure 17: Seasonal Variation in SAR

Weather Data

Performance over the growing season depends on variables such as temperature, rainfall, and sunlight, as well as lagged values of those variables. For instance, a dry summer is easier to bear if the previous year was wet and a heavy snowpack contributed to groundwater stocks. The Palmer Drought Severity Index (PDSI) is a well-established data series that uses temperature and rainfall data to establish a measure of drought.[19] The measure of drought accounts for the cumulative effects of temperature and rainfall in a region. One particularly attractive attribute of the index is that it makes quantifiable comparisons of weather outcomes across years. For example, the drought of 1988 was severe but short-lived relative to persistent drought conditions in 2000 through 2005. In Montana, the PDSI is measured on a spatial level that corresponds to the agricultural districts used by NASS. The southeastern agricultural district in Montana includes Custer, Powder River, and Rosebud counties, but excludes Big Horn. Despite this omission, the southeast Montana series appears to be a good measure of aggregate weather effects in the TRB because of the extent to which drought conditions are spatially correlated. Figure 16 shows the southeastern district PDSI for 1980 to 2010.

[19] http://www.drought.noaa.gov/palmer.html



Note: Palmer Modified Drought Index for Montana including Carter, Custer, Fallon, Powder River, Prairie, Rosebud, and Wibaux Counties. The index takes negative values for drought.

Figure 18: Palmer Drought Severity Index

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Does Water Quality Variation Affect Agricultural Production?

By estimating agricultural production and incorporating all of the available field and sensor data for water quality, a statistical investigation of the impact of water quality variation is feasible.[20] Previous studies have found no significant impact of mean (average) water quality on agronomic performance. Mean water quality does not have much meaning when even short but severe episodes can have a detrimental impact on crop growth. One day of extremely salty or toxic water might not affect annual estimated mean quality by very much, but is likely to have a dramatic impact on crop growth.

Water flow and quality data are included from field and sensor data at Birney Day School. This location is between the Tongue River Dam and Ashland. As such, it may not be wholly representative of the amount and quality of water available along all reaches of the river. Other sites are available, but Birney Day School was chosen in part for its relatively continuous data series. Even there the intermittent monitoring (even field monitoring) over the past 30 years leaves gaps in the data record that severely restrict the statistical power of these estimates. Incorporating seasonality and variance in water quality does not yield significant results.

[20] In recognition of the simultaneous determination of major crops and the correlation of outcomes on account of similar shocks, we estimated a system of equations by seemingly-unrelated regression (SUR). The model parameters are interpreted as reduced-form estimates. Detailed results are available on request, and see Fitzgerald (2012).

DISTRIBUTIONAL IMPLICATIONS

Soils

One of the primary concerns about water quality change is that low-quality irrigation water can permanently damage certain soils. In addition to the measurements of water quality along the river, the distribution of soil types on irrigated acreage informs the potential distribution of impacts. While the full set of risk factors for damage is not perfectly understood, soil type is recognized as an important piece of the puzzle. Rainfall, cultivation and irrigation history, and application timing also contribute. The following is a coarse analysis of the soil distribution and the impacts that it is likely to have on agricultural production.

Irrigation and Soil Type

According to the Soil Survey Geographic Database maintained by the Natural Resources Conservation Service, the irrigated acreage along the Tongue River has 160 different soil series. A single field often contains multiple soil series. While differences between some series are minor, others represent very different soil types. Some soil series are complex, meaning that multiple soils are mixed. The county-level soil series definitions are not entirely consistent, which complicates the analysis. An ideal analysis would characterize each soil along pertinent soil characteristics such as sodicity, particle size, water capacity, and depth.

Soils are binned into six categories, as specified in table A6 in the appendix. These classifications are quite simple: predominantly clay, mixed clay-loam or clayey loam, loam, sandy loam, sandy, and other. Table 7 shows the number of acres in each of these classifications. The irrigated acreages are reported by soil type and county. Because Powder River County does not have the main stem of the Tongue, the county categories effectively partition the valley into upper (Big Horn), middle (Rosebud), and lower (Custer) sub-basins. Most of the clay soils are concentrated further down the river, in Custer County and especially in the T&Y Irrigation District.

Application technology is likely to affect the interaction between soil type and water quality as well. The 7,781 acres irrigated with center pivot sprinklers are concentrated on clay-loam and loam soil types, with less than 1,000 acres irrigated by pivot in the predominantly clay category. The other irrigated acres are not categorized by application technology.

Differences along the river are captured in table 7. The first column summarizes the irrigated acreage for the whole TRB. The other columns detail the irrigated soil types by county. Note that this table only details acres irrigated with water from the Tongue, not tributaries. As a further illustration, the 4,764 acres watered by the T&Y canal outside of the watershed proper are the lowest area that uses water from the Tongue River. This region has a higher percentage of soil types that are predominantly clay. The predominantly clay and clay-loam categories account for 2,793 of the acres, with loam most of the balance.

Table 7: Irrigated Soil Types, Acres in the TRB and each County

Soil Types	Tongue River Basin (Whole)	Big Horn	Custer	Rosebud
Predominantly Clay	3,254	71	3,183	0
Mixed Clay-Loam	7,126	161	5,855	1,110
Loam	13,950	450	7,889	5,611
Sandy Loam	1,239	57	1,120	64
Sandy	26	0	26	0
Other	81	0	22	59
TOTAL	**25,677**	**739**	**18,094**	**6,844**

To the extent that higher salinity affects particular soil types, those with a greater proportion of clay are at the greatest risk (Ganjegunte et al. 2008). Such clay soils are concentrated further down the drainage, where most of the field crop production takes place. Changes in water quality that endanger clay soils appear to imperil the most productive crop acreage in the basin. Those locations are closer to irrigated acres along the Yellowstone River that are unlikely to be affected by changing water quality in Tongue River. The proximity of other productive cropland may allow for substitution, but that is beyond the scope of this study.

Tax Implications

Hedonic land value studies are a widely-accepted way of understanding the contribution of changes in attributes such as the quality of irrigation water. However, in this particular application the small number of transactions for agricultural land in the TRB limits the options for understanding capitalization of natural resource changes. An alternative means of understanding the effects on property values is to examine available data on property tax assessments. Assessed values come with their own problems, but one advantage of such data is that the local public finance implications of water changes can be explored. Using data from the Montana Department of Revenue (DOR), a contemporary snapshot of agricultural land use in the basin provides some insights into the importance of the agricultural economy and irrigated agriculture in particular.[21]

Property taxes are calculated by a somewhat tedious formula. Every six years the DOR updates property assessments, with agricultural assessments based on underlying physical productivity. The total assessed value is adjusted by increases that phase in over time, and the amount of any exemptions. An important class of exemptions for agricultural land is due to active conservation easements. The resulting taxable market value is multiplied by the tax rate to establish the taxable value. The taxable value is finally multiplied by the relevant mill levy to determine the tax amount. Mill levies vary by specific location, and are usually for the public provision of specific local goods and services such as schools.

Table 8 describes the allocation of agricultural land in the basin among tax classifications. Acreage that is irrigated the majority of the time is classified as irrigated. The 19,217 acres reported in the tax records corresponds well to the estimate of 25,000 irrigated acres when the 4,800 acres served by the T&Y canal are taken into account. Almost all continuously cropped acres in the region are irrigated; rotational dryland crop acres appear in the summer fallow category. The bulk of the acreage in the TRB is classified as grazing land; forest acres are likely

[21] The analysis excludes the T&Y Irrigation District lands that lie outside the hydrologic boundary of the TRB.

to be grazed seasonally. Wild hay acreage can be in native grass or alfalfa, but is not usually irrigated. Farmsteads are allocated to the category main improvements to agricultural land, which helps reduce confounds from unaccounted improvements. Non-qualified agricultural lands are smaller tracts that have no known agricultural application.

Table 9 shows the average assessed value of an acre of land in each land tax classification category. Irrigated land in the Tongue is assessed with higher mean productivity than irrigated land in the county as a whole for each of the four counties in the basin. To the extent that bias inherent in assessments is not specific to the Tongue, the relatively higher assessments corroborate the attractiveness of the valley for irrigated agriculture within the region.

Table 8: Acreage by County and Land Classification Category, in and outside the TRB

	Big Horn		Custer		Powder River		Rosebud		All
	Outside	**Tongue**	**Outside**	**Tongue**	**Outside**	**Tongue**	**Outside**	**Tongue**	**Tongue**
Irrigated	65,938	1,403	22,423	10,194	11,019	91	26,894	7,529	19,217
Summer Fallow	276,179	3,660	78,634	6,897	34,544	10,629	147,517	173	21,359
Grazing	2,319,803	423,475	1,481,609	697,605	1,188,080	643,028	2,315,586	461,981	2,226,089
Non-Qualified Ag	8,869	265	15,299	5,477	1,897	1,331	11,274	1,893	8,966
Wild Hay	49,293	4,723	23,639	10,651	51,882	26,092	24,590	3,175	44,641
Forest	94,424	3,046	22,673	16,460	36,734	93,133	66,712	67,893	180,532
Farmstead	572	67	282	130	330	177	462	92	466
Other	13			2			1		2
Total	2,815,091	436,639	1,644,559	747,416	1,324,486	774,481	2,593,036	542,736	2,501,272

Note: “Other” category includes continuously cropped and other exempt agricultural land.

Table 9: Per Acre Mean Dollars Assessed Value by Land Classification Category, by County in and outside the TRB

	Big Horn		Custer		Powder River		Rosebud		All
	Outside	**Tongue**	**Outside**	**Tongue**	**Outside**	**Tongue**	**Outside**	**Tongue**	**Tongue**
Irrigated	459.06	486.10	503.33	534.31	411.48	411.48	502.17	551.17	534.04
Summer Fallow	185.29	162.08	156.23	184.31	145.09	153.56	148.82	183.67	163.42
Grazing	61.10	50.24	55.07	57.28	39.69	44.11	45.70	45.55	49.71
Non-Qualified Ag	57.79	57.79	57.79	57.79	57.79	57.79	57.79	57.79	57.79
Wild Hay	313.16	258.20	165.74	167.69	267.44	311.03	241.38	272.70	271.39
Forest	183.23	169.28	175.27	164.26	176.02	178.62	185.76	186.11	178.53
Farmstead	1,667.02	1,667.02	1,667.02	1,667.02	1,667.02	1,667.02	1,667.02	1,667.02	1,667.02

Property taxes collected from agricultural land are important to each of the TRB counties. Table 10 shows aggregate tax receipts by county from agricultural land. Column 3 shows the share of county tax revenues from agricultural land attributable to acreage in the TRB.

Table 10: Agricultural Land Tax Receipts, 2012

	(1)	(2)	(3)
County	County Total	Tongue River	Share
Big Horn	$1,328,131	$136,230	10%
Custer	$3,493,637	$1,040,892	30%
Powder River	$1,105,661	$352,010	32%
Rosebud	$1,261,274	$ 114,608	9%
Total	$7,188,704	$1,643,739	23%

Notes: This table only includes only agricultural land. Taxes on residential, commercial, and forest land are excluded. Taxes on improvements and buildings are excluded.

<u>Potential Impacts</u>

A primary concern of farmers and ranchers is that changing water quality may render the marginal benefit of irrigation to be zero or even negative. We therefore conduct a thought experiment in which we consider the tax implications of water quality so poor that it cannot be used for irrigation. The scenario applies equally to a loss of water flow so severe that water users are unable to withdraw sufficient quantities to irrigate. In this case, all previously irrigated acres can no longer be irrigated; the counterfactual then reclassifies irrigated acres as wild hay acres. Wild hay acres may be native grass or dryland alfalfa. The case in which *all* irrigated acres are converted to a lower assessment category is an upper bound on the tax consequences.

Table 11 presents the potential impacts of losing the ability to irrigate. Column 1 reports the number of acres in each county and the TRB that are classified as irrigated. Column 2 shows the average assessed values per irrigated acre (also presented in table 9). Column 3 reports the county-specific discount in assessed value per acre across the irrigated and wild hay categories. This figure represents the county-specific average percent differences in per acre assessed value between the two categories. The final column is a sum of the difference of the actual assessed value for each irrigated acre less the mean value of a wild hay acre in each county. This difference provides an estimate of the amount of assessed value that would likely be lost if land that was irrigated a majority of the time no longer could be at 2012 assessment rates.

Table 11: Tax Assessment Implications of Loss of Irrigation

	(1)	(2)	(3)	(4)
County	Classified Irrigated Acres	Mean Assessed Value per Irrigated Acre	Average Difference Between Irrigated and Wild Hay	Total Possible Assessed Value Lost
Big Horn	1,403	486.10	48.40%	365,074
Custer	10,194	534.31	68.34%	3,775,263
Powder River	91	411.48	15.35%	5,727
Rosebud	7,529	551.17	46.28%	2,001,502
Total	19,217	534.04	44.59%	6,147,566

Source: Montana Department of Revenue. Note: If irrigated acres are currently tax-exempt, assume that those acres will be tax-exempt wild hay acres.

Taxes and assessed values are different. Tax implications are reported in table 12. Column 1 of table 12 shows the total amount of tax paid in 2012 for irrigated land in each county; column 2 reports the expected receipts on those same acres if they were all switched to the wild hay category; column 3 shows the difference in receipts; and column 4 reports those changes in percentage terms. The estimated total basin-wide effect is a difference in tax collection of $67,761 in each year. The present value of continual tax collection on irrigated acreage is approximated in table 13, using different capitalization rates in each column. Typical rates suggest a capitalized present value on the order of $1 million. This calculation is on the land alone, and does not consider related improvements, equipment, and livestock. An enterprise model might suggest that the availability of irrigated acreage would change the optimal amount of capital investment that goes with the land.

Table 12: Tax Revenue Implications of Loss of Irrigation

	(1)	(2)	(3)	(4)
County	Irrigated Land Tax Receipts ($ 2012)	Counterfactual Wild Hay Tax Receipts	Annual Reduction in Receipts ($ 2012)	Percent Reduction
Big Horn	5,285	2,558	2,727	51.6%
Custer	155,609	106,350	49,259	31.6%
Powder River	471	72	399	84.7%
Rosebud	28,625	13,249	15,376	53.7%
TRB Total	189,990	122,229	67,761	35.7%

Source: Author calculations from Montana Department of Revenue data.

Table 13: Capitalization of Loss of Tax Revenue

	(1)	(2)	(3)	(4)
County	4%	6%	8%	10%
Big Horn	$68,179	$45,452	$34,089	$27,271
Custer	$1,231,485	$820,990	$615,742	$492,594
Powder River	$9,967	$6,645	$4,984	$3,987
Rosebud	$384,409	$256,272	$192,204	$153,763
Total	$1,694,039	$1,129,360	$847,020	$677,616

Considering the effect of complete loss of irrigation water also leads to a different channel of impact. The Tongue River Water Users' Association, which manages the stored water in the Tongue River Reservoir, pays the state $120,000 each year for use of the water, in addition to $3.97 per acre-foot (for about 40,000 acre-feet) each year. These rates have been in effect since 1999. A final financial contribution from the Association is operations and maintenance payments on the Tongue River Dam, which have varied between $0.75 and $1.20 per acre-foot over recent years. The aggregate impact of those payments is therefore between $308,000 and $317,000 each year.

GENERAL DISCUSSION & CONCLUSIONS

This study estimates the agricultural production in the Montana portion of the Tongue River watershed. Because water quality changes are specific to watersheds, the availability of economic estimates pertaining to the spatial extent of expected effects improves the scope of economic analysis. While the estimates focus on a handful of significant crops and the major livestock output of the basin, they are likely representative of a broader spectrum of agricultural activity.

Collectively, at most, the preliminary results assessing the impact of the Tongue River on agricultural production provide weak support for a relationship between water availability and aggregate agricultural production over time. The results for water quality are restricted by data availability and do not indicate a strong pattern. This result may not be surprising given the low correlation between diversions and water quality and quantity, at least for senior rights holders. What is not clear at this point is whether this is because there are in fact not effects on production from water quality, or whether the threshold that is needed to cause effects has not been reached, or whether there has been adaptation on a finer time scale that we are not able to observe.

Consider the effect of poor water quality on growing crops. A farmer is likely to observe even subtle signals and adjust input levels, including water application, in order to avoid economic damages. The measures of agricultural production are annual, so farmers' adjustments during the growing season are masked. Learning about how to adapt over time (such as 30 years) is also undetermined in this model. Certainly other agricultural inputs such as seed varieties and irrigation technology have improved over the time examined, so it would be presumptuous to assume that irrigators were not also learning and improving their human capital.

Montana has set aside revenues to compensate agricultural producers affected by the effluent from CBM wells. While the results here are far from showing a causal link between CBM outfalls and agricultural damages, the production and revenue figures offer a simple check on the compensation fund. Individual farmers can claim up to $50,000 in damages, with an award limited a 75 percent of total damage. Damages can be reduced land value or the losses from reduced production. The 2007 Census of Agriculture estimated 325 farms in Montana that harvest agricultural crops, which is an upper bound on the number of potential claims. If every claimant received the maximum possible amount, the total could be $16.25 million. With the 75 percent of total damage provision, the aggregate damage could be $22 million. That figure is not far from the annual gross revenue of agricultural production in the basin in 2010.

In conclusion, the study quantifies the importance of agriculture to the economy of southeastern Montana. By estimating the primary agricultural production in the Tongue River Basin, this study establishes a baseline for economic activity. Agricultural producers are involved in other related enterprises that are not included in the estimates presented here, including protecting wildlife habitat and furnishing outfitted recreational opportunities, breeding valuable horses, and growing a variety of less widespread crops. Hence, in this respect, the estimates presented here understate the importance of agriculture to the Tongue River economy

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APPENDIX
DATA SOURCES AND METHODOLOGY

Method 1: Acreage Overlay

The first series was constructed using spatial statistics software to determine how many acres in the four counties (Big Horn, Custer, Powder River, Rosebud) are in the Tongue watershed. See table A1 for the weights. For each county, the ratio of its area in the watershed and its total area was used as a weight for each individual county's contribution to the watershed series. These weights were applied to the corresponding county's annual estimates for each year. As the county and watershed boundaries are static, the weights do not change over time. This series assumes that agricultural production is equally distributed across different watersheds, and weights total county production by the fraction of acres in the TRB.

Method 2 & 3: Remote Sensing Overlay

The Cropland Data Layer (CDL) is a collection of Landsat satellite images using heat signatures to estimate the acreage of different crops is produced on an annual basis.[22] The data series is available for Montana for years 2007-2011. One advantage of this remote sensing data is that researchers are able to query each individual pixel within the image to determine the predominant vegetation within that pixel. Early satellite imagery used for agriculture had a resolution of 250 square meters (m^2) per pixel, which, although enough to aid in estimating changes in yields over time, is not detailed enough for field level data. The Landsat satellite imagery used in the CDL has pixel resolutions of 30 square meters (m^2). This more accurate data can be used to estimate field-level crop content.[5] Using the field-level estimates, a "bottom-up" estimate of production within the TRB can be constructed. By comparing the remote-sensed production within the TRB and remote-sensed production in the rest of the individual counties, a different estimate of the TRB's proportion of the county estimates is constructed. Since the CDL data is annual, some of the variation in agricultural productivity over time can be incorporated into the weighting algorithm.

The CDL provides data for nearly all crops produced, with over 100 different types of land cover identified. Major land covers in the TRB are grassland, shrubland, and forestland. The major crop types in all years are alfalfa hay, corn, and barley. Although this is a rich set of information, the CDL data provides little information on crop yields and no information on what was actually harvested.

Satellite imagery is subject to error. According to a report on the Cropland Data Layer, "Pixel counting estimates…consistently underestimate the actual acreage number as compared with NASS official estimates" (Boryan et al., 2011). NASS is able to correct for this underestimate by regressing CDL data against ground collected data from the June Agricultural Survey (JAS) and using the result to correct their produced CDL products for the rest of the year (Boryan et al., 2011). Because geo-coded JAS data is not publicly available, it is not possible to replicate this. Some crops, including alfalfa, have heat signatures that are similar to other types of vegetation. NASS computers sometimes cannot distinguish between grass, hay, and alfalfa (Cropland Data Layer FAQ). This problem was particularly pronounced in the 2008 data, but seems to have been resolved in later years.

[22] http://nassgeodata.gmu.edu/CropScape/

Primary Crop Weights

In light of the possible shortcomings of remote sensing data, two weighting algorithms were employed. The primary crop weights were calculated by determining how many acres of corn, alfalfa and barley were planted in each county. Then it was determined how many acres of those crops were planted in the TRB portions of those counties. A ratio of acres in the TRB to acres in the county for each crop was then calculated for all years CDL data was available, 2007-2011. This ratio was then averaged to determine the weights. The weights, as seen in table A2, are the estimated proportion of all acres planted in each TRB county that actually lies within the watershed boundary. These weights were then applied to annual county estimates for alfalfa, barley, and corn.

Total Cropland Weights

The total cropland weights are calculated in a similar way to the primary crop weights, except instead of calculating weights for each crop of interest, the total amount of cropland is used. The total amount of remote-sensed cropland was determined for each county, and each county's portion of the TRB. The percentage of county cropland that lies within the TRB was then determined for each year between 2007 and 2011, and then a five-year average was constructed. The weights, as seen in table A3, are the estimated percentage of all cropped acres in each county that actually lie within the TRB boundary, with the T&Y excluded.

Three data series were constructed for 1980-2010 for crops and two for cattle. The primary crop weights cannot be used for cattle as they are crop-specific.

Table A1: Simple Spatial Overlay Weights - % of Each County in the Montana Portion of the Tongue Watershed

County	Percent	Acreage
Powder River	30.79%	746,763
Custer	29.50%	715,459
Rosebud	22.01%	533,909
Big Horn	17.70%	429,304
	100.00%	2,425,435

Table A2: Primary Crop Weights – 5 year average (2007-2011) of the % of each crop in the Tongue Watershed based on CropScape satellite imagery.

County	Primary Crop - Barley	Primary Crop-Corn	Primary Crop-Alfalfa
Big Horn	1.56%	0.06%	0.12%
Custer	44.25%	25.08%	30.20%
Powder River	24.52%	45.73%	32.19%
Rosebud	23.97%	7.55%	1.01%

Table A3: Total Cropland Weights – 5 year average (2007-2011) of the % of total crops in the Tongue Watershed based on CropScape satellite imagery

County	Total Cropland
Big Horn	0.56%
Custer	23.69%
Powder River	19.10%
Rosebud	5.23%

Price Data

All crop price data is drawn from NASS' online QuickStats database. Cattle price data from before 1988 are taken from the Livestock Marketing Information Center.

Missing Data

Due to confidentially issues stemming from data being drawn from too few producers, NASS is legally obliged to refrain from publically releasing some data to the public. For the years where it is determined that the data is too confidential to release, no data is released for that category specific for the county in question. Instead, NASS combines all counties where data could not be released into an "Other Counties" category. For crops, "Other Counties" is produced for each agricultural region. Custer, Powder River, and Rosebud counties are included in the Southeast Region; Big Horn is included in the South Central region. See table A4 for a list of what data were initially missing. In order to determine an accurate picture of the agriculture in the TRB, the missing data were estimated. Depending on what data were available, this was done in several ways. The following methods were used:

1. For the missing corn data from Big Horn County from 2001 to 2007, there was only one county in the agricultural region for which data was missing. So "Other Counties" was a reasonable proxy for Big Horn
2. All Powder River numbers for CORN – ACRES PLANTED and CORN,SILAGE - PRODUCTION are calculated as follows: for all counties contained in "Other Counties" at any year from 1980-2010 the ratio of each 'missing' county to all the other counties in "Other Counties" is calculated in years where distinct data exists for the counties. These ratios are then applied to years where distinct data does not exist for some counties. For example, if Powder River and Rosebud data was combined into Other Counties for 1995, but it was for every 1990-1994 and 1996-2000, the ratio of Powder River to Rosebud would be calculated for the years available. These ratios are then averaged and then applied to the Other Counties total in 1995.
3. For the missing Powder River data for CORN, GRAIN – PRODUCTION, for the years after 1990, the weights developed for CORN – ACRES PLANTED were used.
4. For the missing Powder River data for CORN, GRAIN – PRODUCTION, for the years before 1990, the "Other Counties" data did not exist. We know that production did occur because in 1983, 11,000 bushels was reported for Powder River. The missing values for 1980-82 and 1984-1989 were estimated by taking the average percentage of Powder River production to the Southeast region total production for 1983 and for the years where it was estimated using the method in 3.
5. For all other missing data, estimates are determined by using available data to develop a ratio of the missing county (as in 2) to other counties and then applying this ratio to the "Other Counties" value.

Estimation of these missing values increases the risk of error. While cognizant of this possibility, of the methods used, those most likely to include error were used on corn data for Powder River County. In comparison to the totals, these numbers are extremely low and thus any error is extremely unlikely to significantly affect the final result. For the larger estimations, the methods used were much more accurate and either did not increase the error at all, as was the case with some data from Big Horn, or would only have increased it slightly.

Table A4: Missing NASS County Survey Data

	Big Horn	Custer	Powder River	Rosebud
BARLEY - ACRES PLANTED			2010	2009
BARLEY – ACRES HARVESTED			2010	2009
BARLEY - PRODUCTION			2010	2009
CORN - ACRES PLANTED	2001-2007		1990-2010	
CORN,GRAIN – ACRES HARVESTED	2001-2007		1980-1982 1984-2010	
CORN, GRAIN - PRODUCTION	2001-2007		1980-1982 1984-2010	
CORN,SILAGE – ACRES HARVESTED	1990-1991 2001	2010	1990-2010	2008
CORN, SILAGE - PRODUCTION	1990-1991 2001	2010	1990-2010	2008
ALFALFA – ACRES HARVESTED				
ALFALFA - PRODUCTION				

Additional Tables

Table A5: Water Quality Data Availability from Automated Stations

Station	Flow	SAR	SC
MILES CITY	1938-Present	2004-Present	2004-Present
PUMPKIN CREEK	1972-Present	X	2004-2007
T&Y DAM	2004-Present	2005-2010	2005-Present
BRANDENBERG BRIDGE	2000-2007, 1973-1984	2003-2007	2000-2007
OTTER CREEK	2003-Present, 1987-1995, 1972-1985	2004-2008	2004-2008
BIRNEY DAY SCHOOL	1979-Present	2005-2010	2004-Present
HANGING WOMAN CREEK	2003-Present, 1985-1995, 1973-1984	2004-2010	2004-Present
TONGUE RIVER DAM	1939-Present	2004-2010	2004-Present
STATE LINE	1960-Present	2003-2010	2000-Present

Note: SAR and SC generally available only for the growing season, although availability can still be spotty. For SAR and SC, "Present" means that 2011 data is available; data may not continue to be available for later years for some stations.

Table A6: Soil Series 1

Predominantly Clay	**Loam**	**Loam**
Cambeth, noncalcareous-	Archin loam	Lonna-Cambeth-Cabbart silt loams
Megonot complex	Armells-Cabbart complex	McRae loam
Gerdrum-Creed complex	Armells-Delpoint-Cabbart complex	Ryell loam
Harlake silty clay	Armells-Kirby-Cabbart complex	Spang, moist-Birney, moist-Birney complex
Kyle silty clay	Benz loam	Terrace escarpments, loamy
Lallie silty clay	Birney channery loam	Thedalund-McRae loams
Marias clay	Birney-Cabbart complex	Travessilla-Thedalund loams
Marias silty clay	Birney-Cooers-Kirby complex	Vanstel loam
Marvan silty clay	Birney-Kirby channery loams	Yamac loam
Marvan-Vanda silty clays	Birney-Kirby-Cabbart complex	Yamacall loam
Sonnett complex	Brushton silt loam	Yamacall-Birney-Delpoint complex
Sonnett-Sonnett	Busby loam	Yamacall-Busby-Blacksheep complex
Vanda clay	Cabbart-Havre loams	Yamacall-Delpoint loams
	Cabbart-rock outcrop-Delpoint complex	Yamacall-Delpoint-Cabbart loams
Mixed Clay-Loam	Cabbart-Rock outcrop-Yawdim complex	Yamacall-Havre
Archin-Gerdrum loams	Cambeth,calcareous-Cabbart-	Yamac-Birney complex
Davidell silty clay loam	Yawdim complex	Yamac-Birney-Cabbart complex
Ethridge silty clay loam	Chinook-Kremlin complex	Yamac-Cabbart loams
Glendive-Havre silty clay loams	Clapper-Harvey complex	Yamac-Redcreek loams
Harlem silty clay loam	Clapper-Midway complex	
Haverson silty clay loam	Cooers-Birney complex	**Sandy Loam**
Havre silty clay loam	Cooers-Yamac loams	Busby fine sandy loam
Havre silty clay	Delpoint-Busby-Blacksheep complex	Busby-Twilight fine sandy loam
Havre, Harlake, and Glendive soils	Delpoint-Cabbart-Yawdim complex	Chanta loam
Havre-Harlake complex	Delpoint-Yamacall-Cabbart loams	Chinook fine sandy loam
Heldt silty clay loam	Eapa loam	Glenberg fine sandy loam
Heldt-Hysham silty clay loams	Floweree silt loam	Glendive fine sandy loam
Hydro loam	Foreleft loam	Hanly loamy fine sand
Ismay silty clay loam	Glendive loam	Hanly-Glendive complex
Kobar silty clay loam	Glendive-Havre complex	Hanly-Glendive loams
Kobar-Cabbart-Yawdim complex	Harvey loam	Havre-Bigsandy loams
Kobase silty clay loam	Haverson and Glenberg soils	Ryell very fine sandy loam
Kobase-Gerdrum silty clay loams	Haverson and Lohmiller soils	Tinsley gravelly sandy loam
Lohmiller silty clay loam	Haverson loam	Tinsley very gravelly sandy loam
Lonna silty clay loam	Havre loam	Tinsley-Armells-Yamac complex
Lonna silty clay loam	Hysham loam	
Midway silty clay loam	Kirby-Cabbart-Rock outcrop complex	**Sandy**
Midway-Thedalund complex	Kremlin loam	Rivra complex
Pinehill loam	Lonna silt loam	
Sonnett loam	Lonna, Cambeth, and Yamacall soils	**Other**
Spinekop silty clay loam	Lonna-Cabbart-Yawdim complex	Floweree-Cambeth
Thurlow silty clay loam		

Note: The sum of 160 soil series on irrigated acreage takes more specific criteria than presented in the table into account.