# Climate Variability and Water Infrastructure: Historical Experience in the Western United States


Zeynep K. Hansen
Boise State University and NBER
College of Business and Economics
Department of Economics
1910 University Drive
Boise, Idaho 83725 - 1620
phone: (208) 426 3314
fax: (208) 426 2071
ZeynepHansen@boisestate.edu

Gary D. Libecap
University of California Santa Barbara and NBER
Bren School of Environmental Science and Management
4412 Bren Hall
Santa Barbara, California 93106
Phone: 805-893-8611
Fax: 805-893-7612
glibecap@bren.ucsb.edu

Scott E. Lowe
Boise State University
College of Business and Economics
Department of Economics
1910 University Drive
Boise, Idaho 83725 - 1620
phone: (208) 426 3314
fax: (208) 426 2071
ScottLowe@boisestate.edu


May 9, 2008

Proposal and Description of Project
Very Preliminary
**Please do not quote or cite**

**Abstract / Proposal**

We have constructed (and still expanding) an integrated dataset on water supply and water infrastructure in the states in the west of 100$^{th}$ meridian. This county level data set includes details on all the constructed dams and canals as well as aquifers and streams. Our dam data (for the counties west of 100$^{th}$ meridian,) starts in 1850 and goes through 2001. We have 2,140 dam observations and have 6,004 rivers and streams observations, which will be merged with the dam data; we have 233 major canals and aqueducts, which are already merged with the dam dataset and will be merged also with the river dataset. This extensive dataset will account for the entire water supply and water distribution infrastructure in the western United States. For the river, aqueduct, and canal data we have information on the counties that each flow through.

The dataset is spatially linked to topographic characteristics, historical climate data, historical agricultural data, and historical population data at a county level using GIS. We use this data set to seek answers to several questions. First, we are interested in understanding the historical pattern of these construction projects. Specifically, we examine the factors and influences that explain the timing and the location decisions of these dams and canals. We are most interested in investigating and establishing the potential link between the climate variability (changes in annual precipitation totals and mean monthly temperatures) and the construction of water infrastructure in the western states. In addition, we analyze the impact of the water infrastructure construction on agricultural production, and on flood control. We also are interested in analyzing other determinants of investment in water storage and distribution channels, including population growth and the increased electrification of urban residences. We have detailed information on the purpose of dam construction, ranked in terms of priority. Thus, we can separately focus on dams constructed mostly for flood control, for irrigated agriculture and water / power supply for the areas with larger populations.

We hypothesize that counties, which are included in the water supply and distribution infrastructure, were better able to deal with the problems of short-term climatic variability (either due to natural variability in the hydrologic cycle or due to disruptions of the cycle) in terms of smoothing out agricultural production over time relative to those similar counties without such infrastructure. Having identified major drought periods over time, we can look at the variation in agricultural production during these drought periods before and after dam / canal construction as well as during normal climatic times in a difference-in-difference setting. Similarly, we hypothesize that the problems related to flooding in flood prone counties would lessen after the construction of dams. Since we have all the major dams and canals constructed in last 150 years in our dataset, we will examine the impact of the growth in water infrastructure construction on agricultural composition and production, and on flood control over time.

## Data Sources and Description

**Data source for major dams and canals:**

Our primary source for the dam data is U.S. Army Corps of Engineers, National Inventory of Dams (NID). This data source includes information on location, owner, year of construction, primary "purpose" of construction as well as capacity and height characteristics of dams. Construction types of dams include buttress, concrete, rock fill, masonry, arch, multi-arch, gravity, earth, stone, timber crib, and other. Ownership includes: Federal, Local (county, city, regional), Private, State, Utility, Unknown. Construction purpose includes: Flood control, debris control, fish and wildlife, hydroelectric, irrigation, navigation, fire protection, recreation, water supply, tailings, other. Dam attributes include: max dam height, max storage, normal storage, surface area, and drainage area.

Figure 1 shows a map portraying major dams in the western United States based on NID. Of the 79,777 dams in the U.S. Army Corps of Engineers National Inventory of Dams, 8,121 are considered "major," i.e. 50 feet or more in height, or with a normal storage capacity of 5,000 acre-feet or more, or with a maximum storage capacity of 25,000 acre-feet or more. Of these 8,121 dams 2,166 are west of the 100th meridian and included in our sample. About 43% of the dams in the west were constructed with irrigation as the primary purpose. Dam construction in the west peaked in the post-WWII period – the 1960s and 1970s. Over 55% of the total dam capacity in the Western United States was added in the 1950s and 1960s (see Tables 1 and 2).

Many dams have multiple purposes and some special dams are very dominant in terms of their importance and contribution to a state's overall water supply. For example, Hoover Dam with purposes of water supply, hydroelectric, irrigation provides roughly 93% of Nevada's dam total; Glen Canyon Dam (with purposes of hydroelectric, irrigation, recreation) provides over 55% of Arizona's dam total. Libby Dam (hydroelectric, flood control, recreation) and Ft. Peck (control, hydroelectric, irrigation, recreation) in Montana provide 61% of the state's total. For comparison, in Idaho, the Dworshak (flood control, hydroelectric…) on the Clearwater provides only 22% of Idaho's total.

- We have supplemented the dam data set with major aqueducts and canals. Primary source for this data is U.S. National Atlas Water Features (USGS). We have information on the location of canals and their length, so we can link all counties that have access to dam water through canal system. However, we lack information about volume or the year that they were constructed. This will limit the analysis in as much as we can only assume that the canal was constructed around the time of the dam, and thus, connected to the outlying counties at that time.

**U.S. Census of Agriculture**:

We use U.S. Census of Agriculture to obtain several different measures from 1880 – 1920 (decennial) 1924-2004 (semi-decennial), including: total farm land; total cropland and total harvested cropland; irrigated and non-irrigated acreage, by crop; tonnage/bushels, by crop; acreage with electrified well water among other agricultural variables that can be collected consistently across many census years. In addition, we will obtain crop variables that are state/region specific.

**Climate Data:**

Our climate data comes from two sources:

1. U.S. Climate Division Dataset provides averaged climate data based on climatic zones, covering 1895-present. There are 344 climate divisions or zones in the contagious U.S. This dataset is much more complete than USHCND and includes similar variables. In addition, it includes other related variables such as Palmer drought severity indices and standardized z-scores of temperature and precipitation. Palmer Drought Severity Index is a long-term drought measure that is standardized to the local climate so it shows relative drought and rainfall conditions in a region at a specific time. It uses temperature and rainfall information in a formula to determine dryness. The Palmer Index is most effective in determining long term drought—a matter of several months. It uses a 0 as normal, and drought is shown in terms of minus numbers; for example, minus 2 is moderate drought, minus 3 is severe drought, and minus 4 is extreme drought. The Palmer Index can also reflect excess rain using a corresponding level reflected by plus figures; i.e., 0 is normal, plus 2 is moderate rainfall, etc. Unfortunately, it is not particularly useful in calculating supplies of water locked up in snow.[1] For all of the preliminary models, we use the US Climate Division Dataset -- we'll use the USHistorical Climate Network Data as a robustness check. Problems with the latter are the missing observations, whereas the USCLD is complete.

2. U.S. Historical Climatology Network Data (USHCND) provides station-level data (N = 1,221), covering 1900-1995 although the coverage period of record varies for each station. Available measure include: monthly maximum, minimum, mean temps and total monthly precipitation levels.

**Other Data Sources:**

We use the topography classification is from The National Atlas of the United States of America U.S. Department of Interior, U.S. Geological Survey, which identifies plains, tablelands, open hills and mountains. The scale include: 1-4 = Plains, 5-8 = Tablelands, 9-12 = Plains with Hills or Mountains, 13-17 = Open Hills and Mountains, 18-21 = Hills and Mountains.

In addition, we are collecting soil quality (soil type) information from a database available through Natural Resource Conservation Service (NRCS). It is called the Electronic Field Office Technical Guide (eFOTG) and available by county. It contains data on the percentage of county land falling into the various classes of the Land Capability Classification System (LCC). The LCC includes eight classes of land. The first four classes are arable land--suitable for cropland--in which the limitations on their use and necessity of conservation measures increase from I through IV.

[1] The Climatic data is from the Area Resource File (ARF). The ARF file is maintained by Quality Resource Systems (QRS) under contract to the Office of Research and Planning, Bureau of Health Professions, within the Health Resources and Services Administration.

**Idaho Specific Data Sources:**

We have collected supplementary data from Idaho Department of Water Resources (IDWR) on other Idaho dams and ground water irrigation (wells) across counties. This dataset provides similar information on additional 478 active dams in Idaho although many of these dams much smaller. As shown in Table 5, the mean of maximum storage for these dams is only 687 acre / feet although the mean storage for major dams is 145, 437 acre / feet. In general, 1.75 AF of water will produce 100 bushels of wheat per irrigated acre – so a 687 AF dam will provide enough water to hydrate only about 392 acres of farmland, producing ~40,000 bushels of wheat. In addition, we have some information on approximately 160,000 residential and commercial wells in Idaho (3,622 licensed to livestock and agricultural uses with 98% dedicated towards agriculture). This collection ranges only from 1949 – 2006 and includes information on tested rating for wells (gallons per minute), depth, location, and construction year.

**Descriptive Statistics:**

Tables 1 – 5 show various descriptive statistics. Table 1 summarizes the characteristics of major dams in the western U.S. Idaho, our case study state, has 103 major dams with half of them used primarily for agriculture purposes. Table 2 shows the same 2,166 major western dams according to the year of completion. Several very large dams were constructed during 1930s and during 1950-80. Table 3 compares the dam construction activity between western and eastern states.

Table 4 shows construction dates of major Idaho dams and provides descriptive statistics on precipitation, temperature and Palmer drought index. Idaho experienced severe drought during 1930s based on Paler drought index but did not see substantial dam construction activity until 1950s. Other increased dam construction activity was during 1970s. As of 2007, 29 of the 44 counties in Idaho have a major dam – of these 29, 7 only have one dam and 3 have more than 6 dams.

The first major dam in Idaho was Swan Falls Dam, constructed in 1901 on the Snake River (Ada County), currently owned by Idaho Power Corporation (the majority power provider in the state); the largest dam is the Dworshak Dam on the Clearwater River with 717 vertical feet in height and a capacity of 3.6 million acre / feet, constructed in 1973 – it is owned by the US Army Corps of Engineers. Table 5 compares the major dams in Idaho with other dams that are not included in the National Inventory of Dams. These other dams are much smaller in storage capacity. One dam that has the maximum storage capacity of 40,000 acre / feet is in an Indian reservation and is not included in NID. In our preliminary analyses, we only use the major dams in Idaho.

**Results from Preliminary Analysis:**

We are interested in understanding the historical pattern of dam construction projects. Specifically, we examine the factors and influences that explain the timing decisions of these dams and canals. We investigate and establish a potential link between the climate variability (changes in annual precipitation totals and mean monthly temperatures) and the construction of water infrastructure in the western states. Tables 6 and 7 provide preliminary results from the state of Idaho. We estimate a logit model where the timing of dam construction is explained by lagged climatic conditions. Column1 in Table 6 shows that when previous 5 years had lower than normal precipitation, there was higher likelihood of dam construction. Similarly, if previous 5 year period had higher average temperatures, the likelihood of dam construction was higher. Columns in Table 6 show various results with 5 and 10 year lagged climate variables. Model in column 4 includes county fixed effects instead of land type fixed effects used in other models. Table 7 shows similar models but includes only the irrigation dams in the analysis. Results are similar and stronger.

In addition, we analyze the impact of the water infrastructure construction on agricultural production. We hypothesize that counties, which are included in the water supply and distribution infrastructure, were better able to deal with the problems of short-term climatic variability (either due to natural variability in the hydrologic cycle or due to disruptions of the cycle) in terms of smoothing out agricultural production over time relative to those similar counties without such infrastructure. Table 8 provides preliminary results on the impact of water infrastructure on agricultural production in Idaho. First column shows that each additional dam constructed in a county increases wheat production per harvested acres of wheat. We looked at wheat production because it was most consistently available over the years and because it did not require irrigation for production unlike potatoes, the major crop of Idaho. Similarly, larger the water volume available through dams, higher is the wheat productivity. Higher precipitation and temperature levels increase wheat productivity as well. Irrigation availability increases the irrigated cropland percentage according to column 2. Interestingly, lower precipitation levels increases the irrigated cropland percentage as well, suggesting a shift towards irrigation during periods of less rainfall. In addition, the results from the fourth column suggests that irrigation water availability increases harvested cropland as a share of total cropland.

Table 1: Descriptive Statistics on Western Dams

| State | # Dams | Storage (AF) | Mean (AF) | Primary Purpose (%) | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Irr. | H.E. | Res. | Flood. | Other |
| Arizona | 89 | 34,414,585 | 386,681 | 12% | 3% | 13% | 34% | 37% |
| California | 660 | 67,441,702 | 102,184 | 41% | 8% | 29% | 5% | 16% |
| Colorado | 379 | 14,175,785 | 37,403 | 44% | 3% | 27% | 9% | 16% |
| Idaho | 103 | 16,055,718 | 155,881 | 51% | 23% | 3% | 5% | 17% |
| Montana | 160 | 40,845,017 | 255,281 | 66% | 12% | 5% | 6% | 11% |
| New Mexico | 97 | 13,008,526 | 134,109 | 16% | 1% | 2% | 13% | 67% |
| Nevada | 56 | 30,808,684 | 550,155 | 18% | 0% | 5% | 16% | 61% |
| Oregon | 181 | 14,562,988 | 80,458 | 52% | 19% | 15% | 6% | 9% |
| Utah | 143 | 9,162,856 | 64,076 | 66% | 1% | 11% | 13% | 9% |
| Washington | 164 | 29,574,379 | 180,332 | 21% | 37% | 10% | 8% | 25% |
| Wyoming | 134 | 13,588,778 | 101,409 | 57% | 2% | 10% | 10% | 21% |
| Total: | 2,166 | 283,639,017 | 130,951 | | | | | |

Table 2: Descriptive Statistics on Western Dams

| Year Completed | # Dams | Storage (AF) | Primary Purpose (%) | | | | |
|---|---|---|---|---|---|---|---|
| | | | Irr. | H.E. | Res. | Flood | Other |
| Pre-1861 | 1 | 630 | 0% | 0% | 100% | 0% | 0% |
| 1861-1870 | 3 | 22,327 | 0% | 0% | 100% | 0% | 0% |
| 1871-1880 | 4 | 73,158 | 50% | 0% | 25% | 0% | 25% |
| 1881-1890 | 20 | 466,507 | 60% | 5% | 20% | 0% | 15% |
| 1891-1900 | 48 | 665,295 | 60% | 2% | 31% | 2% | 4% |
| 1901-1910 | 134 | 7,935,010 | 60% | 10% | 21% | 0% | 9% |
| 1911-1920 | 157 | 15,661,438 | 52% | 25% | 15% | 2% | 6% |
| 1921-1930 | 195 | 11,317,853 | 48% | 12% | 24% | 3% | 14% |
| 1931-1940 | 168 | 41,934,943 | 57% | 5% | 21% | 4% | 13% |
| 1941-1950 | 150 | 24,443,106 | 61% | 7% | 13% | 12% | 7% |
| 1951-1960 | 327 | 73,477,285 | 44% | 13% | 15% | 10% | 17% |
| 1961-1970 | 426 | 65,475,873 | 35% | 11% | 18% | 10% | 26% |
| 1971-1980 | 265 | 33,334,123 | 32% | 4% | 18% | 18% | 28% |
| 1981-1990 | 189 | 6,835,046 | 29% | 5% | 16% | 14% | 36% |
| 1991-2000 | 78 | 1,995,697 | 17% | 4% | 24% | 9% | 46% |
| 2001+ | 1 | 727 | 0% | 0% | 0% | 0% | 100% |
| Total: | 2,166 | 283,639,017 | | | | | |

Table 3: Descriptive Statistics Western vs. Eastern Dams

| | Western Dams | | | Eastern Dams | | |
|---|---|---|---|---|---|---|
| | | Storage (AF) | | | Storage (AF) | |
| Year Completed | # Dams | Total | Mean | # Dams | Total | Mean |
| Pre-1861 | 1 | 630 | 630 | 59 | 4,890,933 | 82,897 |
| 1861-1870 | 3 | 22,327 | 7,442 | 10 | 218,531 | 21,853 |
| 1871-1880 | 4 | 73,158 | 18,290 | 22 | 3,792,464 | 172,385 |
| 1881-1890 | 20 | 466,507 | 23,325 | 27 | 2,244,513 | 83,130 |
| 1891-1900 | 48 | 665,295 | 13,860 | 72 | 1,734,291 | 24,087 |
| 1901-1910 | 134 | 7,935,010 | 59,216 | 149 | 8,045,043 | 53,994 |
| 1911-1920 | 157 | 15,661,438 | 99,754 | 200 | 12,902,144 | 64,511 |
| 1921-1930 | 195 | 11,317,853 | 58,040 | 258 | 20,515,033 | 79,516 |
| 1931-1940 | 168 | 41,934,943 | 249,613 | 383 | 249,524,583 | 651,500 |
| 1941-1950 | 150 | 24,443,106 | 162,954 | 272 | 71,788,652 | 263,929 |
| 1951-1960 | 327 | 73,477,285 | 224,701 | 612 | 151,104,223 | 246,902 |
| 1961-1970 | 426 | 65,475,873 | 153,699 | 1,237 | 223,738,745 | 180,872 |
| 1971-1980 | 265 | 33,334,123 | 125,789 | 1,027 | 97,781,737 | 95,211 |
| 1981-1990 | 189 | 6,835,046 | 36,164 | 377 | 30,619,078 | 81,218 |
| 1991-2000 | 78 | 1,995,697 | 25,586 | 214 | 3,105,150 | 14,510 |
| 2001+ | 1 | 727 | 727 | 278 | 3,523,532 | 12,675 |
| Total | 2,166 | 283,639,017 | | 5,197 | 885,528,652 | |

Table 4: Descriptive Statistics for Idaho

| | Total | | | Mean | | |
|---|---|---|---|---|---|---|
| Year | # Dams | Storage (AF) | Population | PPT | Temp | Palmer Drought Severity Index |
| 1890-1900 | 0 | | 161,772 | 16.64 | 45.34 | 0.26 |
| 1900-1910 | 15 | 1,837,365 | 325,594 | 17.15 | 45.76 | 0.07 |
| 1910-1920 | 13 | 1,964,750 | 431,866 | 17.97 | 44.79 | 1.10 |
| 1920-1930 | 8 | 299,395 | 445,031 | 16.43 | 45.45 | -0.51 |
| 1930-1940 | 4 | 135,378 | 524,873 | 15.30 | 46.23 | -2.28 |
| 1940-1950 | 11 | 1,177,505 | 588,637 | 17.75 | 45.07 | 0.74 |
| 1950-1960 | 8 | 4,439,802 | 667,191 | 16.47 | 45.24 | -0.30 |
| 1960-1970 | 10 | 310,659 | 712,567 | 17.46 | 45.46 | 0.30 |
| 1970-1980 | 15 | 5,500,870 | 943,935 | 17.37 | 45.16 | 0.69 |
| 1980-1990 | 12 | 359,287 | 1,006,749 | 17.57 | 45.62 | 0.68 |
| 1990-2000 | 7 | 30,707 | 1,293,953 | 18.26 | 46.40 | 0.90 |
| Total | 103 | 16,055,718 | | | | |

Table 5: Idaho Dams and Sample Data

Idaho Dams from the NID

| | Year Completed | Maximum Storage | Height |
|---|---|---|---|
| mean | 1949 | 145,437 | 120 |
| sd | 30 | 420,210 | 131 |
| max | 1998 | 3,560,000 | 740 |
| min | 1901 | 20 | 5 |
| N | 103 | | |

Idaho Dams from the IDWR Database (excluding the NID Dams)

| | Year Completed | Maximum Storage | Height |
|---|---|---|---|
| mean | 1958 | 687 | 20 |
| sd | 30 | 2,695 | 15 |
| max | 2007 | 40,000 | 170 |
| min | 1860 | 0 | 3 |
| N | 478 | | |

*Irrigation* Dams from the IDWR Database (excluding the NID Dams)

| | Year Completed | Maximum Storage | Height |
|---|---|---|---|
| mean | 1955 | 743 | 20 |
| sd | 30 | 3,139 | 9 |
| max | 2004 | 40,000 | 67 |
| min | 1860 | 1 | 3 |
| N | 206 | | |

Table 6: Logit Models of Dam Construction (All Types of Dams)

| Lagged Average: | 5y | 5y | 10y | 10y | 10y | Mg. Eff. |
|---|---|---|---|---|---|---|
| Precipitation | -0.5409<br>(0.1002)*** | -0.3205<br>(0.1477)** | -0.4807<br>(0.1039)*** | 6.3245<br>(1.5905)*** | -0.2477<br>(0.1563) | -5% |
| Temperature | 0.1017<br>(0.0134)*** | 0.0359<br>(0.0183)** | 0.1070<br>(0.0140)*** | 0.7376<br>(0.1723)*** | 0.0445<br>(0.0195)** | 1% |
| Population | 0.7510<br>(0.0357)*** | 0.8021<br>(0.0532)*** | 0.6669<br>(0.0366)*** | 4.2568<br>(0.2564)*** | 0.6280<br>(0.0541)*** | 13% |
| Palmer Drought Severity Index | 0.0861<br>(0.0241)*** | 0.0790<br>(0.0322)** | 0.0987<br>(0.0312)*** | -0.2367<br>(0.1508) | 0.0948<br>(0.0434)** | 2% |
| Land Type Dummy (Plains and Hills) | 0.9551<br>(0.1995)*** | 1.1149<br>(0.2224)*** | 1.0388<br>(0.2039)*** | | 1.2293<br>(0.2296)*** | 21% |
| Land Type Dummy (Hills and Mountains) | 1.3325<br>(0.1906)*** | 0.9837<br>(0.2275)*** | 1.4111<br>(0.1950)*** | | 1.1203<br>(0.2372)*** | 21% |
| Land Type Dummy (Mountains) | 2.1166<br>(0.1828)*** | 1.9700<br>(0.2385)*** | 2.1367<br>(0.1853)*** | | 2.0249<br>(0.2462)*** | 38% |
| Observations | 4532 | 2678 | 4312 | 2548 | 2548 | |
| Pseudo R2 | .11 | .09 | .10 | -- | .07 | |
| Loglikelihood | -- | -- | -- | -734.38 | -- | |
| Fixed Effects (#) | NO | NO | NO | YES (26) | NO | |

Robust standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 7: Logit Models of Dam Construction (Irrigation Dams)

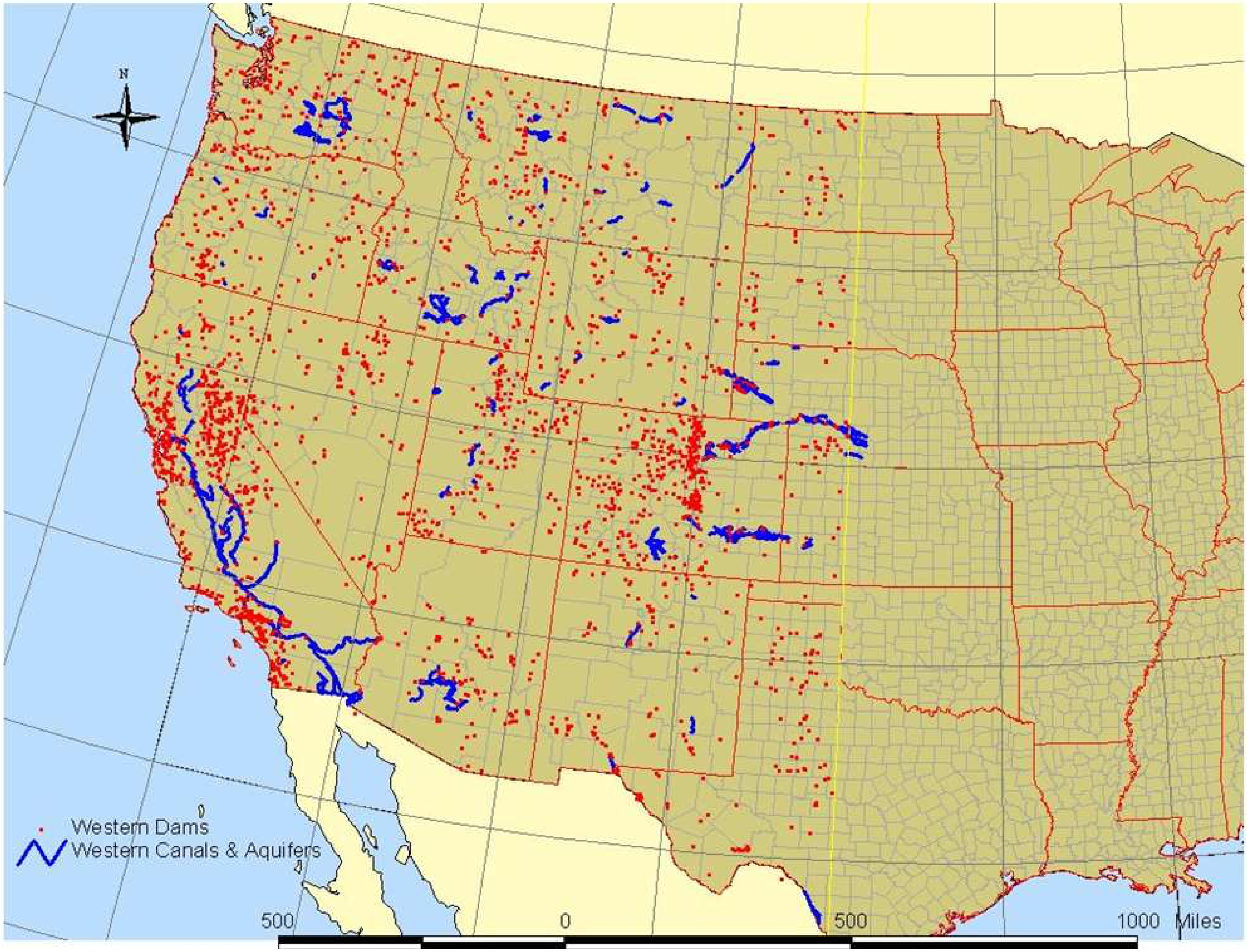
| Lagged Average: | 5y | 10y | 5y | 10y | 5y | 10y |
|---|---|---|---|---|---|---|
| Precipitation | -1.6238<br>(0.1022)*** | -1.6396<br>(0.1050)*** | 4.8227<br>(1.3640)*** | 11.1396<br>(2.5187)*** | 1.9481<br>(0.2734)*** | 3.9810<br>(0.4218)*** |
| Temperature | 0.1183<br>(0.0146)*** | 0.1267<br>(0.0155)*** | 0.5503<br>(0.1315)*** | 0.8439<br>(0.2080)*** | 0.0763<br>(0.0199)*** | 0.0644<br>(0.0208)*** |
| Population | 0.6586<br>(0.0355)*** | 0.5841<br>(0.0368)*** | 3.3780<br>(0.2167)*** | 3.1266<br>(0.2463)*** | 1.0400<br>(0.0783)*** | 1.0872<br>(0.0844)*** |
| Palmer Drought Severity Index | 0.1497<br>(0.0245)*** | 0.1507<br>(0.0318)*** | -0.2794<br>(0.1176)** | -0.6324<br>(0.2100)*** | -0.1083<br>(0.0362)*** | -0.2613<br>(0.0527)*** |
| Land Type Dummy (Plains and Hills) | 0.5298<br>(0.1956)*** | 0.5960<br>(0.1994)*** | | | 1.5218<br>(0.2232)*** | 0.5424<br>(0.2374)** |
| Land Type Dummy (Hills and Mountains) | 1.4350<br>(0.1939)*** | 1.5325<br>(0.1990)*** | | | 0.3404<br>(0.2406) | -0.1600<br>(0.2534) |
| Land Type Dummy (Mountains) | 2.1617<br>(0.1907)*** | 2.2086<br>(0.1934)*** | | | 1.6731<br>(0.2514)*** | 0.8086<br>(0.2763)*** |
| Observations | 4532 | 4312 | 2472 | 2156 | 2472 | 2156 |
| Pseudo R2 | .12 | .11 | -- | -- | .18 | .20 |
| Loglikelihood | -- | -- | -687.85 | -579.58 | -- | -- |
| Fixed Effects (#) | NO | NO | YES (24) | YES (22) | NO | NO |

Robust standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 8: OLS Models of Agricultural Productivity and Composition

| | Wheat Produced / Harvested Acres of Wheat | | Irrigated Cropland Harvested / Total Cropland | | Irrigated Cropland Harvested / Total Farm Land | | Harvested Cropland / Total Cropland | | Harvested Cropland / Total Farmland | | Irrigated Land in Farms / Total Land in Farms | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Irrigation Dam (count) | 4.3731<br>(1.7238)** | | 0.0821<br>(0.0176)*** | | 0.0065<br>(0.0085) | | -0.0184<br>(0.0180) | | 0.0057<br>(0.0101) | | -0.0122<br>(0.0103) | |
| Irrigation Dam Vol (100,000 AF) | | 1.4494<br>(0.6953)** | | -0.0019<br>(0.0033) | | -0.0007<br>(0.0040) | | 0.0075<br>(0.0027)*** | | -0.0056<br>(0.0030)* | | 0.0030<br>(0.0087) |
| Precipitation | 17.7053<br>(2.4550)*** | 18.1423<br>(2.6041)*** | -0.1763<br>(0.0518)*** | -0.1978<br>(0.0525)*** | -0.2915<br>(0.0475)*** | -0.2902<br>(0.0474)*** | 0.0150<br>(0.0266) | 0.0113<br>(0.0273) | 0.0081<br>(0.0221) | 0.0123<br>(0.0218) | -0.0232<br>(0.0229) | -0.0212<br>(0.0226) |
| Temperature | 5.5572<br>(0.6118)*** | 5.8936<br>(0.6314)*** | 0.0135<br>(0.0081) | 0.0096<br>(0.0095) | -0.0077<br>(0.0050) | -0.0076<br>(0.0051) | 0.0021<br>(0.0048) | 0.0015<br>(0.0049) | -0.0043<br>(0.0048) | -0.0036<br>(0.0048) | 0.0037<br>(0.0054) | 0.0041<br>(0.0055) |
| ln(Population) | 10.6831<br>(1.5222)*** | 11.2337<br>(1.4854)*** | 0.3806<br>(0.0711)*** | 0.4089<br>(0.0773)*** | 0.0348<br>(0.0240) | 0.0387<br>(0.0249) | 0.0043<br>(0.0336) | -0.0118<br>(0.0332) | 0.0633<br>(0.0280)** | 0.0733<br>(0.0283)** | 0.0210<br>(0.0237) | 0.0124<br>(0.0239) |
| Observations | 766 | 766 | 262 | 262 | 343 | 343 | 464 | 464 | 606 | 606 | 723 | 723 |
| Fixed Effects (Counties) | YES | YES | YES | YES | YES | YES | YES | YES | YES | YES | YES | YES |
| R-squared | 0.38 | 0.37 | 0.49 | 0.46 | 0.29 | 0.29 | 0.01 | 0.01 | 0.03 | 0.04 | 0.01 | 0.01 |

Robust standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%
RHV are lagged for models with harvest counts


N
Western Dams
Western Canals & Aquifers
500
0
500
1000 Miles