**An Empirical Analysis of Climate Uncertainty and Land-use Transitions in the U.S. Pacific and**

**Mountain Regions**

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Selected Paper prepared for presentation for the 2016 Agricultural & Applied Economics

Association, Boston, MA, July 31-August 2

Preliminary results were presented in this paper.

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Abstract : This paper uses most recent plot-level data from the National Resource Inventory

(NRI) over the period 2002 to 2012. Using these data with county-level land-use net returns, we

first examine the land-use transitions among crop, pasture, range, forest, urban and

Conservation Reserve Program (CRP) and find that land-use net returns are the main

determinants from land-use transitions and land with low soil quality is more likely to be used

for low-productive land activities, such as grazing. Second, we predict land-use changes under

future climate projections using projected land-use net returns from hedonic regressions for

crop, pasture, range, forest and urban. Our estimation results of the land-use model are

consistent to economic theory as well as to previous literature that we have positive

coefficients on crop and urban land use net returns and negative coefficients on the transition

costs. We also find that crop and pasture land use net returns increase as the mean

precipitation increase and pastureland net return is reduced if growing season degree-days are

increased, suggesting the substation effects between crop and pasture land use when the

temperature is optimal for plant growing. When predict into the future, we find the expansion

of urban land with expenses of crop and CRP land.

## 1. Introduction

The relationship between climate change and land-use is complicated and bidirectional. Land use and land cover contributes to climate change through direct physical changes in the surface energy budget (e.g., albedo) as well as indirect changes through the emission or sequestration of carbon. Meanwhile, since the net returns to alternative land uses can be affected by climate (e.g. Mendelsohn et al. 1994; Albouy et al. 2016), then land use change can be affected by changes in climate. Understanding the potential for adaptation to climate change through land use change will be important for ongoing technology and infrastructure investments in the public and private sectors, for conservation planning (Lawler et al. 2009) and for the various policies that address agriculture directly or indirectly (Antle and Capalbo, 2010).

In this paper, we use econometric analysis to estimate the effects of climate change on land-use changes on private land between urban, cropland, pasture, Conservation Reserve Program (CRP) land, rangeland and forest land use and land cover. We do the analysis for the Pacific and Mountain regions in the United States, where we observe large climate variation as well as significant patterns of land-use change. Our approach linking climate change to land-use change includes several contributions. First, by explicitly incorporating the effects of climate on the net returns to multiple broad land-use types, we include human's adaptive behavior to update the land-use transition matrix in predicting future land-use change . Second, we use the most recently available plot-level NRI data from 2012 and compile many independent data sources to update and expand a nationally-consistent database of land-use net returns originally developed by Lubowski, et al. (2006) and Lubowski, et al. (2008). Third, we use the most recent downscaled climate projections from multiple Global Climate Models (GCMs) to

project future land-use changes to the end of 21$^{st}$ century, allowing us to assess uncertainty in estimates of climate impacts in the topic of land-use changes (Burke, et al., 2015).

**2. Literature Review**

Economic land use models have been examined using structural models, typically global or regional economic models. These models represent bio-physical processes and link them to economic decisions explicitly and then simulate resource allocation decisions with and without economic responses to climate change (Adams, et al., 1990, Nelson, et al., 2014, Reilly, et al., 2003). An important feature of these models is that they can account for bio-physical responses to effects such as increased concentrations of atmospheric carbon dioxide and unobserved temperature thresholds on crop growth. However, most of these models are subject to aggregation challenges because they focus on large regions, usually a country or a region that is much bigger than a county in the United States. Land-use changes from these models are mean results of a certain region, making it hard to interpret as individual decisions.

Using plot level data from the National Inventory Resource (NRI), previous econometric studies of large-scale land-use change have estimated the effects of net returns on land-use conversion (Lubowski, et al., 2006, Lubowski, et al., 2008), yet ignored the effects of climate change when projecting future land-use change (Lawler, et al., 2014, Ordonez, et al., 2014, Radeloff, et al., 2012). To introduce climate change into plot-level econometric land use models, Haim, et al. (2011) project regional and national land-use change under two emission scenarios from the Intergovernmental panel on climate change (IPCC). In their study, Haim et al. modified the net returns in the land use model for the IPCC scenarios according to assumed trends in population / income and by using agricultural / forestry price and yield projections

from integrated assessments models. Recent literature on climate change and agriculture argue that using two scenarios is not enough to capture the uncertainty of changes in policy as well as in climate (Auffhammer, et al., 2013, Burke, et al., 2015).

The literature on climate change in agriculture shows climate having a strong influence on the net returns to using land for agriculture (Burke, et al., 2015, Deschenes and Greenstone, 2007, Deschênes and Greenstone, 2012, Fezzi and Bateman, 2015, Kelly, et al., 2005, Mendelsohn, et al., 1994). This literature uses reduced form econometric models to examine the relationship between land values and weather or climate variables to predict changes in future land values or net returns due to climate change. These studies assume implicit adaption within agriculture; however, they rarely suggest specific land-use change adaptations that can be made in response to climate change among agriculture and other sectors.

For the urban land sector, empirical studies have estimated cross-city real estate hedonic pricing regressions to predict how climate is capitalized into the value of real estate (Albouy, et al., 2013, Albouy and Lue, 2015, Kahn, 2009, Sussman, et al., 2014) and how climate can affect people's housing location and migration decisions (Fan, et al., 2016, Sinha and Cropper, 2013). Haim, et al. (2011) estimates urban net returns as a function of population change and per capita income, and uses IPCC scenarios of population and income changes to relate climate change to urban returns. As discussed earlier, the relationship between climate change and urban net returns through changes in population and per capita income is not clear.

We combine methods from the econometric land-use and climate research in the following manner. First, we estimate how climate affects net returns to multiple broad land uses using newly available national net returns data and employing the standard hedonic

approach. We focus on lands in crops, pasture, range, and urban uses, and ignore forests for the present study, given that there is very little movement into and out of forestland in the western United States during our study period of 2002 to 2012 (Tables 1 and 2), though urban development can be the cause of localized forest losses near major western cities. We then develop an econometric land-use choice model as a function of the net returns to land use, and use the estimated climate-net returns link to simulate future land-use change to the end of 21st century under climate change uncertainty.

**3. Methods**

*3.1 Economic Model of Land-use Change*

We estimate an econometric model of land-use transitions for parcels beginning in the uses of cropland, pasture, and rangeland. We consider changes among these three categories, in addition to conversions of agricultural lands into urban development or inclusion in the Federal Conservation Reserve Program. Each landowner is assumed to allocate a homogeneous land parcel to the use generating the largest present value of net returns minus conversion costs. As shown in previous literature (Plantinga 1996), this is the optimal allocation rule when landowners have static expectations of conversion costs and future net returns. Thus, we assume that the owner of parcel $i$ in use $j$ at the start of period $t$ will convert to use $k$ if

$$R_{ikt} - rC_{ijkt} \geq R_{ijt} \text{ for all alternative uses } k(k = 1, 2, ..., K) \tag{1}$$

where $R_{ikt}$ is the annualized net return to use $k$ in time $t$ and $r$ is the interest rate. $C_{ijkt}$ is the one-time cost of converting land from use $j$ to use $k$ with $C_{ijjt} = 0$. Following the discrete-

choice literature, the net return from use $k$, assuming the parcel begins in use $j$, depends on a random component, $\varepsilon_{ijkt}$, which is unobservable:

$$\pi_{ijkt} = R_{ikt} - rC_{ijkt} + \varepsilon_{ijkt} \tag{2}$$

We denote the deterministic component of net returns, $R_{ikt} - rC_{ijkt}$, as $\beta'_{jk} x_{ijkt}$, where $\beta_{jk}$ is a vector of parameters to be estimated and $x_{ijkt}$ is a vector of observable variables. The probability that parcel $i$ will convert from use $j$ to use $k$ in time $t$ is defined as

$$pr(\beta'_{jk} x_{ijkt} - \beta'_{jl} x_{ijlt} > \varepsilon_{ijlt} - \varepsilon_{ijkt}) \text{ for all land uses} \tag{3}$$

If we assume the error terms are independent, identically distributed (IID) type I extreme value, we obtain a conditional logit model with the following transition probability:

$$P_{ijkt} = \frac{\exp(\beta'_{jk} x_{ijkt})}{\sum_{l=1}^{K} \exp(\beta'_{jl} x_{ijlt})} \tag{4}$$

The specification of equation (4) embodies the well-known independence of irrelevant alternatives (IIA) assumption, and depicts the probability that plot $i$ will convert from use $j$ to use $k$ during transition time t.

*3.2 Econometric Model of Net Returns: Hedonic model*

To estimate equation (4), we use net returns from historical periods to calculate the annualized net return to an acre of land for each possible land use. However, to link transition probabilities to climate, we follow Mendelsohn, et al. (1994) and Deschenes and Greenstone (2007) and estimate a Hedonic model of net returns of crop, pasture, range and urban in county $c$ and time $t$ :

$$RS_{ct}^k = \alpha_c + \gamma_t + Z_{ct}^{'}\delta + \sum_j \eta_j f_j(W_{jct}) + u_{ct} \tag{5}$$

where $RS_{ct}^k$ is the net return in county $c$ at year $t$ for $k$ land uses, and the unit is dollar per

acre in 2010 value. $\alpha_c$ and $\gamma_t$ is a full set of county and year fixed effects, respectively. $Z_{ct}$ is a

vector of explanatory variables that will affect the demand of land uses. The variables of

interest are the variables depicting weather, $W_{jct}$. The set of variables included in $W_{jct}$ could

vary across land uses. Finally, $u_{ct}$ depicts unobservables that affect net returns.

**4. Data**

*4.1 Land use and change Data*

In this study, we focus on broad use of non-federal land in eleven states located in the Rocky

Mountains and Pacific West region, including Washington(WA), Oregon(OR), California(CA),

Arizona(AZ), Nevada(NV), Idaho(ID), Montana(MT), Wyoming(WY), Utah(UT), Colorado(CO) and

New Mexico(NM). This study region covers 360 million acres of land, and land use in this region

is diverse and dynamic. In 2012, 61% of private-owned land was in grazing, 15% in forest

production, 18% in crop or crop-mix, and 4% in urban use.

Plot-level land-use data for privately owned plots from 2002 to 2012 were obtained

from the National Resource Inventory (NRI) of U.S. Department of Agriculture. The NRI is a

longitudinal panel survey of land use, land cover and soil characteristics in the contiguous

United States. Specifically, we use observations of plot-level land-use changes over two recent

time intervals (2002-2007 and 2007 to 2012), and Table 1 and table 2 show changes in major

land uses for these two time intervals, respectively. In general, most land remains in its own use

with slight changes to or from other uses. These two land-use transition tables provide the

basic information to determine the choice set for each land use at the starting period. Please note that some land uses are not a choice option for others because there are too few plots observed in transition.[1] In addition, we do model the decision to exit CRP land in this iteration of the model, though Lubowski and Roberts (2008) have shown how to model this decision using older NRI data.

*4.2 Net Return Data*

County-level annualized per acre net returns of five major non-federal land uses, including crop, pasture, range, and urban were collected and calculated separately.[2] Per acre profits for crops, pasture and range are naturally computed in annual terms from farm income and expenses. Per acre profits of urban are the net present values with an assumed interested rate of five percent to obtain an annualized measure. All net returns are in 2010 values and we use the average of land use profits three years preceding the starting year of each land use to set the static landowner expectations as to the net returns for each land-use choice.

4.2.1 Agriculture net returns

Annual county-level data of farm income and expenses for crop and livestock production were collected from the Bureau of Economic Analysis (BEA) from 1969 to 2011.[3] To get agricultural net returns per acre, we first calculate the cost revenue ratio in county $i$ at time $t$, denoted as $ratio_{it}$:

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[1] We exclude land use from a choice set if there are less than 30 plots made the transition. Based on this criterion, forest land is only the choice set for urban. CRP is the choice option for cropland and pastureland.
[2] We could not get plot-level annualized net returns because the plot-level land-use data from NRI does not provide the location information of each plot for the confidentiality issue. Thus, we apply the county average annualized net return per acre to all plots within the county.
[3] The annual farm income and expenses data are updated to present, however, we only need data match with the NRI land-use data, which is dated back to 2012.

$$ratio_{it} = \frac{C_{it}}{R_{it}} = \frac{C_{it}}{S_{itc} + S_{itl} + GovP_{it}}$$

where $C_{it}$ is the total production expenses; $R_{it}$ is the total farm production revenue, including

sales from crop production ($S_{itc}$), sales from livestock production ($S_{itl}$) and total governmental

payments ($GovP_{it}$).

Next, we compute the crop net return per acre in county $i$ at time $t$, $NR_{itc}$, using the

following formula:

$$NR_{itc} = (S_{itc} + GovP_{it} - CRPP_{it})(1 - ratio_{it}) / A_{itc} \qquad (6)$$

where $CRPP_{it}$ is the payment for conservation reserve programs and $A_{itc}$ is the total acres of

cropland in county $i$ at time $t$. The exclusion of payment for conservation reserve programs

follows Lubowski, et al. (2008) and the reason to do so is because we set CRP as one of the

choice options for crop land use.

Because sales of livestock products were not spilt by pasture- or rangeland, we do

additional calculations to get approximated net return per acre for pasture- and rangeland.

First, we calculate per acre sales of livestock products, $s_{it}$:

$$s_{it} = \frac{S_{itl}}{A_{itp} + A_{itr}}$$

where $A_{itp}$ and $A_{itr}$ are total acres of pasture- and rangeland in county $i$ at time t, respectively.

The per acre net return for pastureland, $NR_{itp}$, is written as follows:

$$NR_{itp} = \frac{s_{it}(1 - ratio_{it})}{\sum_{n=1}^{4} \varphi_n ALCC_{itpn}} \qquad (7)$$

where $ALCC_{itpn}$ is the total acres of pastureland in $n^{th}$ land capability class (LCC). In the NRI

data, LCC is classified from one to eight, but we grouped them into four assuming that the

neighboring class has the similar soil characteristics and the higher number indicates the worse

soil quality for crop production. $\varphi_n$ is the percent allowable use of forage production for each

pastureland LCC group. According to Holechek (1988), we assume a higher $\varphi$ for a lower LCC

group. Specifically, we assume $\varphi$ equals to 0.7, 0.6, 0.5 and 0.4 for land capacity category from

one to four, respectively.

Similarly, the per acre net return for rangeland, $NR_{itr}$, is written as,

$$NR_{itr} = \frac{S_{it}}{\sum_{n=1}^{4} \vartheta_n ALCC_{itrn}} \qquad (8)$$

where $ALCC_{itrn}$ is the total acres of rangeland in $n^{th}$ land capability class (LCC) and $\vartheta_n$ is the

percent allowable use of forage production for each pastureland LCC group. Here, we assume

$\varphi$ equals 0.5, 0.4, 0.3 and 0.2 for land capacity category from one to four, respectively.

The difference between (7) and (8) is we assume there is no production cost associated

with livestock production in rangeland, and that rangeland is less productive than pastureland

with a lower livestock-stocking rate (Lubowski, et al., 2006, Lubowski, et al., 2008).

**4.2.2 Urban Returns**

Following Lubowski, et al. (2006) , we construct county-specific estimates for the average price

per acre of recently developed land which serves as a proxy for urban net returns. Data on

property value, including land and structures, is taken from the US Census' Public Use

Microdata Samples (PUMS 5% sample). For 2000, the PUMS survey was conducted as part of

the decennial census. In 2005, the US Census began implementation of the annual PUMS survey as part of the American Community Survey.

The PUMS data is reported at the Public Use Microdata Area (PUMA) geographic unit. PUMA boundaries lie completely within state boundaries; however, their overlaps with county boundaries vary across the country. In some cases, multiple PUMAs will be contained within a single county, while other PUMAs may have multiple counties falling within a single PUMA. We scaled the PUMS data accordingly using neighbor relationships derived within a GIS to estimate the county-level sales price of recently developed homes.

County sales price is the weighted average of the PUMS property value, where the weight is the area of overlap between county and PUMA boundary. This scaling introduced some measurement error when the PUMA boundary was large relative to the county boundary. This is particularly acute in the western US because there are large areas of open space with very little population from which to survey households.[4]

Because we are interested in the value of land, not the total price of the property, we use the average cost of new home construction to back out the price of land. The cost of new home construction is taken from the US Census' Survey of Construction (SOC) microdata files. The SOC is a national-level survey of new house construction, including data on house price, lot price, and lot size. The SOC data is reported at the Census division level with an indicator of whether the observation was within a metropolitan statistical area.

Per acre net returns to urban land in county $i$ at time $t$, $NR_{itu}$, are calculated as follows:

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[4] If the measurement error is correlated with the size of the PUMA, it may be appropriate to scale the weights with the size of the county. Where-by larger PUMAs are given a systematically lower property value relative to smaller PUMAs.

$$NR_{itu} = \frac{SP_{it} * LS_{dt}}{LA_{dt}}$$

where $SP_{it}$ is the sales price; $LS_{dt}$ is the average lot share in division $d$ at time $t$ and $LA_{dt}$ is

the average lot size in acres in division $d$. Lot share is calculated from SOC as sales price of the

lot divided by the total sales price including the house. Dividing by average lot size converts the

measure to a per acre value. Multiplying $NR_{itu}$ by an assumed discount rate of 5% annualizes

the net returns measure.

*4.3 Climate Data*

Historical climate observations from 1950-2011 were obtained by aggregating the 4-km spatial

resolution surface meteorological datasets from Abatzoglou (2013) to the county level. For

agricultural production, we use the standard agronomic approach to convert daily

temperatures into degree-days using a base temperature of 8C and upper threshold of 32C,

which represents heating units and is an important indicator to capture the nonlinear effect of

temperature on crop yields (Schlenker, et al., 2005, Schlenker and Roberts, 2009). In addition to

growing season degree-days and precipitation, we calculate the index of precipitation intensity,

defined as a fraction of total precipitation results from daily precipitation amounts exceeding

the 95th percentile of the climatological distribution for wet days (Tebaldi, et al., 2006). We

also construct a drought index based on values of the Palmer Drought Severity Index (PDSI).

Specifically, we define drought index equals one if PDSI less than -2, otherwise zero.

Following recent research showing importance of uncertainty in climate change

projections (Asseng, et al., 2013, Dell, et al., 2014, Rötter, 2014), we use a suite of downscaled

climate model projections and two Representative Concentration Pathways (RCPs) from the

Coupled Model Intercomparison Project Phase 5 (CMIP5). Daily projections from 20 CMIP5

climate projection models was statistically downscaled using the Multivariate Adaptive

Constructed Analogs method (Abatzoglou and Brown, 2012) to 4-km resolution using the same

dataset used in our historical analysis. Downscaling was completed for both historical periods

(1950-2005) and future periods for two emission scenarios, i.e., RCP4.5 and 8.5, from 2006 to

2100. Degree-days, precipitation intensity and drought index were calculated following the

same procedure as previously mentioned.

As examples, Figure 1 shows the changes in annual precipitation and mean temperature

from 2070-2099 relative to the base period from 1976-2005, for assemble of 20 GCMs from the

CMIP5 under the RCP8.5 emission scenario. In the western U.S., most counties will have

increased precipitation, however, coastal areas in Northern California and eastern of New

Mexico and Colorado will have decreased precipitation. Regarding changes in mean

temperature, all western U.S. will be warming by the end of the 21st century and big increase in

mean temperature in inland Pacific Northwest.

4.4 Summary statistics

Table 3 shows the summary statistics of variable used in the land-use models as well as the

Hedonic Models for the Western U.S. In 2002, the mean annualize net return of cropland,

pastureland, rangeland, forestland and urban land are $42, $1, $13,$25, and $3988 per acre. All

land use net returns increased in 2007 except forestland, partly because of impact of

globalization with a world of timber surpluses and increasing competition(Franklin and Johnson,

2004). The average annual net returns of crop-, pasture- and rangeland are higher than the

annualized ones, ranging from $71, $8 and $26 per acre.

**5. Estimation Results**

In this part, we first interpret estimation results from the conditional logit model for land in starting use of crop, pasture, and range, and then discuss results from the hedonic model on net returns of crop, pasture, range, and urban. We also discuss the robustness of results from alternative model specifications.

5.1 Model specifications

Table 4 shows estimation results of the land-use model. We specified three functional forms: one is the full model with net returns, land quality categories and interaction terms, the second model is the constrained model without land quality variables and their interaction terms with urban net return for the choice of urban; the third model is also the constrained model without land quality variables. Across all three specifications, estimates are consistent. We choose model 3 as an example to interpret.

Table 4 shows marginal effects of the hedonic model for crop-, pasture- and rangeland, respectively. Following previous literature (Burke, et al., 2015, Mendelsohn, et al., 1994), we have estimates from two specifications, with and without weighted OLS. For most significant variables, estimates are consistent across two specifications. However, we focus on the model with weighed OLS because it is model suggested in previous literature.

5.2 Estimates of land-use models

For most land uses, the estimation results are consistent with profit-maximizing behavior. In most cases of three equations (starting use in cropland, pastureland and rangeland), the transition-specific constant terms are negative and significantly, suggesting that conversion costs deter conversions out of the starting use. Similarly, coefficients on crop and urban net

returns variables are positive and significantly, indicating that higher returns to a given use, while controlling returns to other sues constant, will encourage conversion to that use.[5]

Coefficients on the land quality interaction terms are statistically significant, which indicates that pastureland tends to be more profitable than cropland on low quality land. On the lowest quality lands, crop returns have a diminished effect on the probability that land remains in crop.

5.3 Estimates of Hedonic net return models

As expected, increase in mean precipitation will increase crop- and pasture-land net returns, but the magnitude with pastureland net return is smaller than that of cropland net return. Precipitation is beneficial for plat growing at a certain level and then be harmful. However, at the mean, the marginal effect is positive. Similarly, degree-days with optimal temperature for crop production would increase cropland net return but it is statistically insignificant. While pastureland net return is reduced because of increased degree-days. One explanation is because of the competition for land use when temperature is good for crop production, and farmers would like to put more land in crop production from crop-mix.

**6. Future Land Use Changes**

In this part, we predicted future land-use change without and with incorporating future climate change. For both cases, we use net returns and initial land-use status from the 2007 NRI. According to Lewis and Plantinga (2007) and Lawler, et al. (2014), we generate the land-use transition matrix using estimated parameters from equation (4). When equation (4) was estimated at the economic and plot-level variables, we get a transition probability matrix ( $P_{jt}$ )

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[5] The exception is pastureland and rangeland net returns, which are negative. One explanation is that rangeland and pastureland are not the choices that farmers want to make, most of the time, they have to put land in grazing because of bad land qualities.

for each NRI plot $j$ at time $t$ . We then define the vector $A_{jt}$ as acres in each of the six land

uses in NRI plot $j$ in time $t = 2007$ . Then we can calculate the acres in each land use in $N$

time-step:

$$A_{jt+N} = A_{jt} \times P_{jt}^N$$

Because the transition land-use matrix was for a 5-year interval, each period is 5-year in

length to correspond to the time-step in the NRI data. Please note that for those land-use

choices that are not been modeled, such as forest and CRP, we use the simple transition matrix

from the historical period from 2007 to 2012. Because we did not observe urban land

converting to other uses, the associated transition probabilities for land beginning in urban use

always equal zero. In addition, we assume public land stays the same.

6.1 Future land-use change without climate change

Figure 2 shows the future land-use change from 2007 to 2057 assuming the land-use

transition matrix is static over time. However, it is updated according to landowner's

expectation of land-use net returns once we include climate effects on land-use net returns,

which we will discuss later. Nevertheless, we find cropland, forestland and CRP land are all

declining over time, while pastureland, rangeland and urban land are increasing. Among all

changes, we predict a big urban expansion with expenses of crop and CRP land. This is because

of projected increase in population in the following 50 years, which put more demand for urban

development. For example, population in California is around 38 million in the 2013 estimates,

but by 2050, it is projected to be 50 million. The big increase in population will demand more

land for housing and urban development.  The decline in crop and CRP land is partly due to

drought effects on the estimated land-use transition matrix and it carries over to the future (NOAA 2012).

**7. Conclusion**

In this paper, we use econometric analysis to estimate the effects of climate change on land-use changes on private land between urban, cropland, pasture, Conservation Reserve Program (CRP) land, rangeland and forest land use and land cover. We use the most recently plot-level land-use data from NRI for western U.S. Our estimation results of the land-use model are consistent to economic theory as well as to previous literature that we have positive coefficients on crop and urban land use net returns and negative coefficients on the transition costs. We also find that crop and pasture land use net returns increase as the mean precipitation increase and pastureland net return is reduced if growing season degree-days are increased, suggesting the substation effects between crop and pasture land use when the temperature is optimal for plant growing. When predict into the future, we find the expansion of urban land with expenses of crop and CRP land, which reflects the increase in projected population in the western U.S. as well as the effects from the observed drought in this region.

So far, we have not presented any results on future climate effects on land uses because we are still working on it and will update before the meeting. Nevertheless, this study has important implications for climate mitigation policy and ecosystem management. For example, future land-use change could be integrated to the InVEST ecosystem service model to evaluate changes in food production, timber production, carbon storage and sequestration and habitat. In addition, climate mitigation policies could be directly evaluated in the model.

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**Table 1 Changes in Major Non-Federal Land Uses between 2002 and 2007 in Eleven States from National Resources Inventory (NRI) (in 100 acres)**

| Land use in 2002 | Cropland | Pastureland | Rangeland | Forest land | Urban land | CRP | 2002 total |
|---|---|---|---|---|---|---|---|
| Cropland | 502738 | 12246 | 3732 | 5* | 2759 | 8479 | 529959 |
| | (94.86) | (2.31) | (0.70) | (0) | (0.52) | (1.60) | (100) |
| Pastureland | 6124 | 100767 | 3986 | 418* | 803 | 536* | 112634 |
| | (5.44) | (89.46) | (3.54) | (0.37) | (0.71) | (0.48) | (100) |
| Rangeland | 2858 | 767* | 2201796 | 531* | 5281 | 119* | 2211352 |
| | (0.13) | (0.03) | (99.57) | (0.02) | (0.24) | (0.01) | (100) |
| Forest land | 29* | 66* | 2345 | 551390 | 1114 | 0* | 554944 |
| | (0.01) | (0.01) | (0.42) | (99.36) | (0.20) | (0) | (100) |
| Urban land | 54* | 7* | 138 | 31* | 119920 | 0* | 120150 |
| | (0.04) | (0.01) | (0.11) | (0.03) | (99.81) | (0) | (100) |
| CRP | 1955 | 1059 | 781 | 0* | 0* | 87466 | 91261 |
| | (2.14) | (1.16) | (0.86) | (0) | (0) | (95.84) | (100) |
| 2007 total | 513646 | 114862 | 2208695 | 538073 | 131238 | 96574 | 3603088 |
| | (14.26) | (3.19) | (61.30) | (14.93) | (3.64) | (2.68) | (100) |

Note: percentages are presented in parentheses. "*" indicates numbers of plots are less than 30. Totals include only lands which remained non-federal and in the six listed uses between 2002 and 2007. Read the table horizontally to see how land that was under a particular land use in 2002 (row heading) was subsequently allocated in terms of land use in 2007 (column heading). Read the table vertically to see how land that that was in a particular land use in 2007 (column heading) was previously allocated in terms of land use in 2002 (row heading).

**Table 2 Changes in Major Non-Federal Land Uses between 2007 and 2012 in Eleven States from National Resources Inventory (NRI) (in 100 acres)**

| Land use in 2007 | Cropland | Pastureland | Rangeland | Forest land | Urban land | CRP | 2007 total |
|---|---|---|---|---|---|---|---|
| Cropland | 502593 | 7260 | 433* | 50* | 1233 | 2077 | 513646 |
|  | (97.85) | (1.41) | (0.08) | (0.01) | (0.24) | (0.40) | (100) |
| Pastureland | 3420 | 110259 | 713 | 111* | 358 | 1* | 114862 |
|  | (2.98) | (95.99) | (0.62) | (0.10) | (0.31) | (0) | (100) |
| Rangeland | 2341 | 1209* | 2201860 | 1066* | 2202 | 17* | 2208695 |
|  | (0.11) | (0.05) | (99.69) | (0.05) | (0.10) | (0) | (100) |
| Forest land | 3* | 31* | 476* | 537001 | 562 | 0* | 538073 |
|  | (0) | (0.01) | (0.09) | (99.80) | (0.10) | (0) | (100) |
| Urban land | 40* | 13* | 110 | 35* | 131040 | 0* | 131238 |
|  | (0.03) | (0.01) | (0.08) | (0.03) | (99.85) | (0) | (100) |
| CRP | 11882 | 9411 | 149* | 0* | 0* | 75132 | 96574 |
|  | (12.30) | (9.74) | (0.15) | (0) | (0) | (77.80) | (100) |
| 2012 total | 520589 | 128441 | 2206009 | 538970 | 135776 | 77227 | 3607012 |
|  | (14.43) | (3.56) | (61.16) | (14.94) | (3.76) | (2.14) | (100) |

Note: percentages are presented in parentheses. "*" indicates numbers of plots are less than 30. Totals include only lands which remained non-federal and in the six listed uses between 2007 and 2012. Read the table horizontally to see how land that was under a particular land use in 2007 (row heading) was subsequently allocated in terms of land use in 2012 (column heading). Read the table vertically to see how land that that was in a particular land use in 2012 (column heading) was previously allocated in terms of land use in 2007 (row heading).

Table 3 Summary Statistics

| Variable | Observations | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| ***Variables for land-use models*** | | | | | |
| Annualized forestland net return, 2002 | 312 | 25.92 | 70.20 | -231.75 | 468.41 |
| Annualized urban land net return, 2002 | 404 | 3988.46 | 2792.97 | 933.43 | 20199.58 |
| Annualized cropland net return, 2002 | 374 | 41.57 | 477.80 | -1803.76 | 3858.76 |
| Annualized pastureland net return, 2002 | 356 | 1.03 | 13.47 | -49.74 | 234.98 |
| Annualized rangeland net return, 2002 | 373 | 12.80 | 75.03 | 0 | 1070.74 |
| LCC1, 2002 | 1,362,936 | 0.16 | 0.37 | 0 | 1 |
| LCC2, 2002 | 1,362,936 | 0.22 | 0.41 | 0 | 1 |
| LCC3, 2002 | 1,362,936 | 0.10 | 0.30 | 0 | 1 |
| LCC4, 2002 | 1,362,936 | 0.10 | 0.30 | 0 | 1 |
| Forestland net return, 2007 | 303 | 19.57 | 63.02 | -240.94 | 399 |
| Urban land net return, 2007 | 396 | 6200.80 | 3116.44 | 1908.91 | 18807.46 |
| Cropland net return, 2007 | 362 | 65.71 | 496.98 | -1534.30 | 3195.24 |
| Pastureland net return, 2007 | 349 | 1.81 | 23.33 | -120.48 | 313.62 |
| Rangeland net return, 2007 | 369 | 15.65 | 87.40 | 0 | 1103 |
| LCC1, 2007 | 1,362,936 | 0.16 | 0.36 | 0 | 1 |
| LCC2, 2007 | 1,362,936 | 0.21 | 0.40 | 0 | 1 |
| LCC3, 2007 | 1,362,936 | 0.10 | 0.30 | 0 | 1 |
| LCC4, 2007 | 1,362,936 | 0.09 | 0.29 | 0 | 1 |
| ***Variables for Hedonic models*** | | | | | |
| Mean cropland net returns ($/acre) | 97,104 | 71.33 | 245.85 | -1237.57 | 3034.90 |
| Mean pastureland net returns($/acre) | 96,417 | 7.72 | 43.17 | -139.17 | 768.88 |
| Mean rangeland net returns($/acre) | 35,505 | 25.69 | 114.92 | 0.00 | 1709.37 |
| Mean cropland acres (100) | 100,389 | 796.09 | 807.39 | 0.00 | 8848.52 |
| Mean pastureland acres(100) | 100,389 | 323.46 | 315.65 | 0.00 | 2444.67 |
| Mean rangeland acres(100) | 100,389 | 565.64 | 1522.85 | 0.00 | 17125.14 |
| Mean precipitation(10cm) | 101,869 | 5.44 | 1.67 | 0.00 | 10.43 |
| Mean degree-days (1000) | 101,869 | 2.16 | 0.66 | 0.00 | 3.72 |
| Mean per capita income ($) | 97,134 | 12481.48 | 2641.89 | 5348.30 | 38508.68 |
| Mean population density (persons/100 square miles) | 97,134 | 1.67 | 11.37 | 0.00 | 446.74 |

| | | | | | |
|---|---|---|---|---|---|
| Share of LCC1 in cropland | 98,902 | 0.45 | 0.26 | 0 | 1 |
| Share of LCC2 in cropland | 98,902 | 0.44 | 0.24 | 0 | 1 |
| Share of LCC3 in cropland | 98,902 | 0.08 | 0.13 | 0 | 1 |
| Share of LCC4 in cropland | 98,902 | 0.03 | 0.08 | 0 | 1 |
| Share of irrigated cropland | 98,176 | 0.15 | 0.26 | 0 | 0.99 |
| Irrigated cropland X precipitation | 98,011 | 0.59 | 1.12 | 0 | 9.22 |
| Irrigated cropland X degree-days | 98,011 | 0.30 | 0.56 | 0 | 3.58 |
| Share of LCC1 in pastureland | 98,063 | 0.30 | 0.24 | 0 | 1 |
| Share of LCC2 in pastureland | 98,063 | 0.47 | 0.23 | 0 | 1 |
| Share of LCC3 in pastureland | 98,063 | 0.16 | 0.17 | 0 | 1 |
| Share of LCC4 in pastureland | 98,063 | 0.08 | 0.13 | 0 | 1 |
| Share of irrigated pastureland | 97,639 | 0.20 | 0.30 | 0 | 1.00 |
| Irrigated pastureland X precipitation | 12,812 | 1.21 | 0.80 | 0 | 3.55 |
| Irrigated pasture X degree-days | 12,812 | 0.83 | 0.68 | 0 | 3.60 |
| Share of LCC1 in rangeland | 35,703 | 0.11 | 0.16 | 0 | 1 |
| Share of LCC2 in rangeland | 35,703 | 0.35 | 0.23 | 0 | 1 |
| Share of LCC3 in rangeland | 35,703 | 0.30 | 0.19 | 0 | 1 |
| Share of LCC4 in rangeland | 35,703 | 0.24 | 0.23 | 0 | 1 |

Note: variables for the Hedonic models are aggregated over 1969 to 2011.

Table 4 Estimation Results of land-use Changes

| Land in starting use | Crop Land | | | Range Land | | | Pasture Land | | |
|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (1) | (2) | (3) | (1) | (2) | (3) |
| CropNR | 0.8475*** | 0.6368*** | 1.3064*** | 0.3692 | 0.6941** | 0.7628*** | 0.4639*** | 0.4634*** | 0.5540*** |
| | (0.2013) | (0.2018) | (0.1714) | (0.2940) | (0.2781) | (0.2709) | (0.1207) | (0.1206) | (0.1227) |
| CropNRXLLC2 | -0.5414** | -0.2824 | -0.9220*** | | | | | | |
| | (0.2392) | (0.2392) | (0.2113) | | | | | | |
| CropNRXLLC3 | -0.2144 | 0.0134 | -1.0538*** | | | | | | |
| | (0.3794) | (0.3790) | (0.3665) | | | | | | |
| CropNRXLLC4 | -0.1547 | -0.0715 | -1.5026*** | | | | | | |
| | (0.3243) | (0.3178) | (0.2517) | | | | | | |
| CropNRX(LCC3+LCC4) | | | | 0.2319 | -0.2785 | -0.3707 | 1.2446*** | 1.2483*** | 0.7517*** |
| | | | | (0.3481) | (0.3320) | (0.3233) | (0.3149) | (0.3139) | (0.2861) |
| Pasture constant | -4.5808*** | -4.6160*** | -3.8811*** | | | | 2.9425*** | 2.9416*** | 3.1265*** |
| | (0.1032) | (0.1042) | (0.0327) | | | | (0.0467) | (0.0461) | (0.0412) |
| PastureNR | 5.1843*** | 5.2211*** | 2.1911 | | | | -17.7007* | -17.7022* | -22.2024** |
| | (1.4546) | (1.4555) | (1.4927) | | | | (9.5700) | (9.5698) | (9.7864) |
| LCC2 | 0.6258*** | 0.6651*** | | | | | | | |

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| | (0.1109) | (0.1119) | | | | | | | |
| LCC3 | 1.4517*** | 1.4886*** | | | | | | | |
| | (0.1283) | (0.1292) | | | | | | | |
| LCC4 | 1.7961*** | 1.8011*** | | | | | | | |
| | (0.1634) | (0.1644) | | | | | | | |
| LCC3+LCC4 | | | | | | | 0.6598*** | 0.6641*** | |
| | | | | | | | (0.0995) | (0.0942) | |
| PastureNRXLCC2 | -4.6716** | -4.6970** | -1.9965 | | | | | | |
| | (1.8905) | (1.8906) | (1.9109) | | | | | | |
| PastureNRXLCC3 | -14.2230 | -14.2282 | -5.9288 | | | | | | |
| | (8.6860) | (8.6644) | (6.7147) | | | | | | |
| PastureNRXLCC4 | -6.0218 | -6.2606 | 1.6199 | | | | | | |
| | (9.5775) | (9.7947) | (7.4076) | | | | | | |
| PastureNRX(LCC3+LCC4) | | | | | | | 10.2463 | 10.2480 | 16.3805 |
| | | | | | | | (10.5941) | (10.5940) | (10.8029) |
| Range constant | -5.8750*** | -5.9071*** | -5.2375*** | 5.9906*** | 6.6490*** | 6.7982*** | -0.7497*** | -0.7506*** | -0.5711*** |
| | (0.2023) | (0.2029) | (0.0733) | (0.1389) | (0.1403) | (0.0935) | (0.0867) | (0.0864) | (0.0705) |
| RangeNR | -8.7653 | -8.9667 | -21.5812 | -5.9088 | -5.8710 | -6.2170 | -52.7567** | -52.7622** | -53.8650** |
| | (9.7216) | (9.8175) | (17.2923) | (4.5159) | (4.5307) | (4.4799) | (24.5921) | (24.5941) | (24.4184) |
| LCC2 | 0.1720 | 0.2064 | | | | | | | |
| | (0.2301) | (0.2306) | | | | | | | |
| LCC3 | 1.6873*** | 1.7209*** | | | | | | | |
| | (0.2588) | (0.2592) | | | | | | | |

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| LCC4 | 2.6808*** | 2.6850*** | | | | | | | |
| | (0.2621) | (0.2628) | | | | | | | |
| LCC3+LCC4 | | | | 1.1885*** | 0.1917 | | 0.6422*** | 0.6465*** | |
| | | | | (0.1877) | (0.1372) | | (0.1537) | (0.1504) | |
| RangeNRXLCC2 | -120.6612* | -119.0919* | -236.9636*** | | | | | | |
| | (63.0058) | (62.8943) | (79.0625) | | | | | | |
| RangeNRXLCC3 | -397.0864* | -396.5080* | -23.0216 | | | | | | |
| | (232.6408) | (232.6061) | (87.9734) | | | | | | |
| RangeNRXLCC4 | -107.6978 | -109.6463 | 21.1574 | | | | | | |
| | (93.3438) | (93.9996) | (24.1790) | | | | | | |
| RangeNRX(LCC3+LCC4) | | | | 2.0039 | 1.8573 | 2.3588 | 49.8857** | 49.8914** | 51.0401** |
| | | | | (5.2295) | (5.2391) | (5.1947) | (24.7285) | (24.7306) | (24.4924) |
| Urban constant | -4.8691*** | -5.5389*** | -5.5424*** | -1.5408*** | 0.0217 | 0.0178 | -2.6464*** | -2.6562*** | -2.6869*** |
| | (0.1733) | (0.1339) | (0.1335) | (0.3033) | (0.1696) | (0.1697) | (0.2440) | (0.2330) | (0.2337) |
| UrbanNR | 0.0004 | 0.0045 | 0.0056 | 0.0300*** | 0.0292*** | 0.0294*** | 0.0405*** | 0.0406*** | 0.0430*** |
| | (0.0083) | (0.0079) | (0.0079) | (0.0082) | (0.0081) | (0.0081) | (0.0129) | (0.0128) | (0.0129) |
| LCC2 | -0.9622*** | | | | | | | | |
| | (0.1539) | | | | | | | | |

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| LCC3 | -0.9868*** | | | | | | | | |
| | (0.3096) | | | | | | | | |
| LCC4 | 0.6350** | | | | | | | | |
| | (0.2712) | | | | | | | | |
| LCC3+LCC4 | | | | 2.0537*** | | | -0.0398 | | |
| | | | | (0.3131) | | | (0.2979) | | |
| CRP constant | -4.9105*** | -4.9453*** | -4.4868*** | | | | | | |
| | (0.1186) | (0.1195) | (0.0431) | | | | | | |
| LCC2 | 0.4966*** | 0.5356*** | | | | | | | |
| | (0.1287) | (0.1295) | | | | | | | |
| LCC3 | 0.6608*** | 0.6974*** | | | | | | | |
| | (0.1759) | (0.1765) | | | | | | | |
| LCC4 | -0.2010 | -0.1967 | | | | | | | |
| | (0.3936) | (0.3940) | | | | | | | |
| N | 273895 | 273895 | 273895 | 322233 | 322233 | 322233 | 61488 | 61488 | 61488 |

Note: Standard errors are in parentheses; *p<0.1; **p<0.05; ***p<0.01.

Table 5 Marginal effects of Hedonic model regression of crop, pasture and rangeland net returns

| | Cropland Net Return | Pastureland Net Return | Rangeland Net Return | Cropland Net Return | Pastureland Net Return | Rangeland Net Return |
|---|---|---|---|---|---|---|
| | (1) | (1) | (1) | (2) | (2) | (2) |
| Mean precipitation | 25.4656*** | 3.6734*** | 12.1245*** | 15.8759*** | 0.7124*** | 0.2391 |
| | (4.9462) | (0.9051) | (3.5882) | (3.3297) | (0.1498) | (0.1470) |
| Mean degree-days | -2.0898 | -3.9133* | -19.1119** | 5.0952 | -0.9463*** | 0.4630 |
| | (8.7665) | 2.0168 | (8.4990) | (5.0482) | (0.3274) | (0.4573) |
| Irrigation share | -0.6326 | 14.7474* | | -64.41698** | 8.2682*** | |
| | (41.5813) | (8.8345) | | (29.2854) | (2.2813) | |
| Population density | 7.5677 | -1.4662 | 12.5471* | 2.7750 | -0.6834** | -0.1147 |
| | (6.0382) | (1.2919) | (6.2569) | (4.1213) | (0.3167) | (0.2768) |
| Per capita income | 0.0081*** | 0.0003 | -0.0007 | 0.0126*** | 0.0002** | 0.0002*** |
| | (0.0026) | (0.0004) | (0.0011) | (0.0027) | (0.0001) | (0.0001) |
| LCC2 | -23.1986 | -12.2032** | 75.8993 | -74.0818*** | -4.5826*** | 0.2397 |
| | (22.7308) | (5.3803) | (49.6936) | (14.4566) | (1.1442) | (2.4151) |
| LCC3 | -23.6182 | -18.0293*** | 36.2049 | -63.5739* | -6.2709*** | -0.0357 |
| | (65.3819) | (6.2500) | (47.2784) | (32.4438) | (1.2563) | (2.2326) |
| LCC4 | -179.2358** | -13.3254 | 19.9008 | 77.0646 | -5.2453*** | -1.6806 |
| | (85.4902) | (9.4842) | (38.8574) | (134.7472) | (1.4932) | (1.9692) |
| Constant | 15.5740 | -26.3874* | -14.7207 | -157.3424** | -3.1776 | -3.9907 |
| | (96.1796) | (13.9342) | (57.9682) | (69.2538) | (2.2294) | (3.8831) |
| Weighted OLS | N | N | N | Y | Y | Y |
| $R^2$ | 0.30 | 0.08 | 0.07 | 0.49 | 0.03 | 0.01 |
| N | 93984 | 93502 | 35406 | 93984 | 93502 | 35406 |

Note: Standard errors are in parentheses; *p<0.1; **p<0.05; ***p<0.01. Marginal effects of climate variables are conditional on the mean of irrigation rate, and marginal effects of irrigation shares are conditional on mean precipitation and mean degree-days.
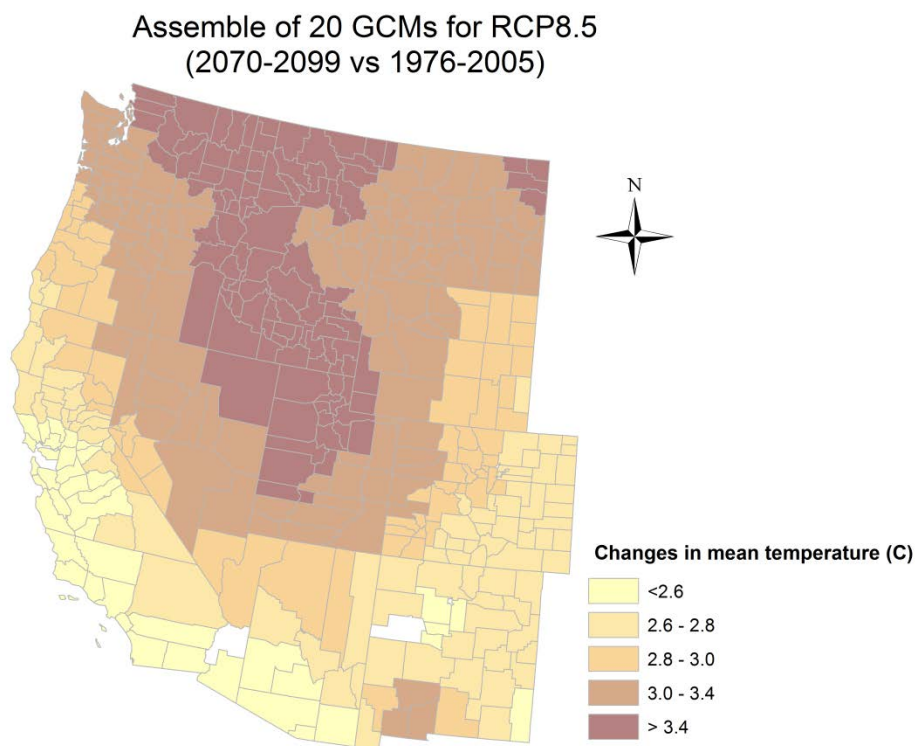
## Assemble of 20 GCMs for RCP8.5
## (2070-2099 vs 1976-2005)

**Changes in precipitation (cm)**

| | |
|---|---|
| | <-2.5 |
| | -2.5 - 0 |
| | 0 - 2.5 |
| | 2.5 - 5 |
| | >5 |

## Assemble of 20 GCMs for RCP8.5
## (2070-2099 vs 1976-2005)

**Changes in mean temperature (C)**

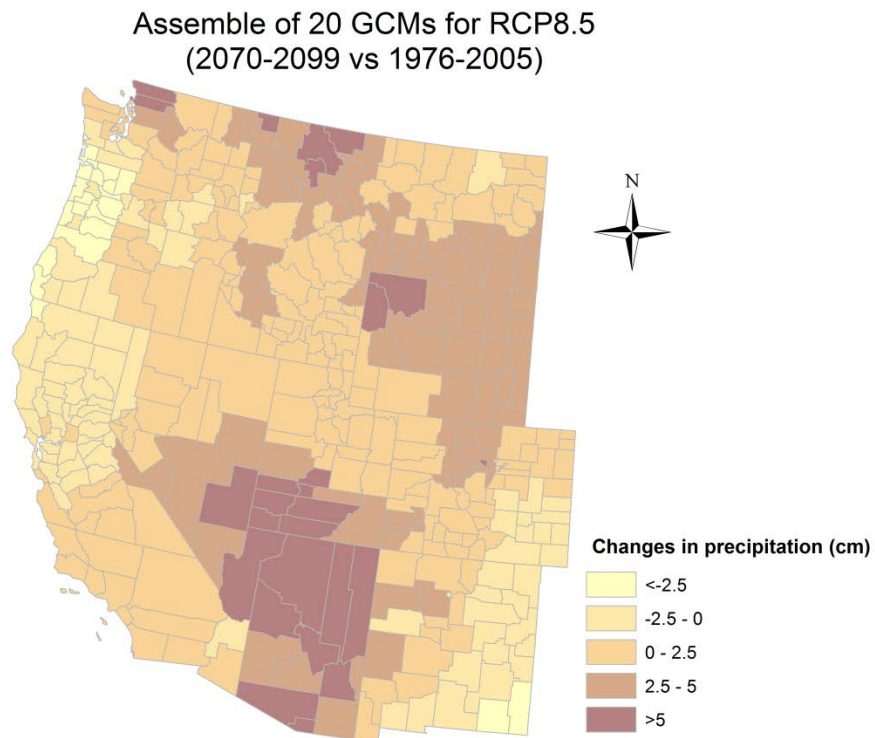| | |
|---|---|
| | <2.6 |
| | 2.6 - 2.8 |
| | 2.8 - 3.0 |
| | 3.0 - 3.4 |
| | > 3.4 |

Figure 1 Change in precipitation and mean temperature from 2070-2099 relative the baseline period 1976-2005
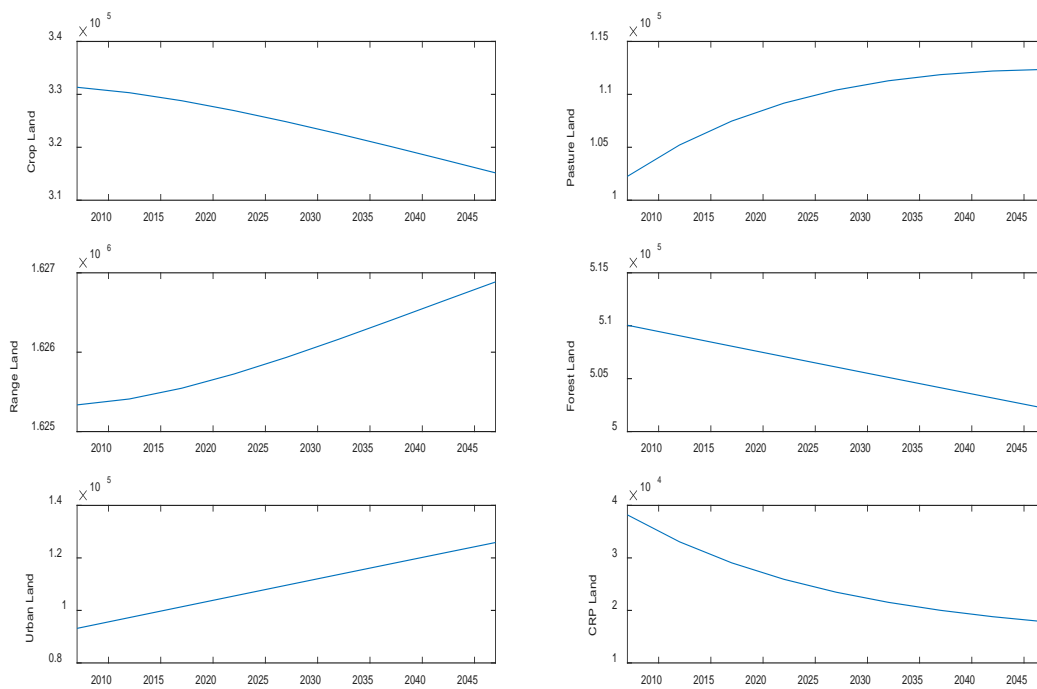
Figure 2 Land-use changes (100 acres) from 2007 to 2057 without climate change