Modelling future irrigation demand at a statewide level: lessons from Florida USA

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Abstract

Water resource managers must consider supply constraints, planning horizons, climatic trends and competing uses to understand where water will be needed most in the future. Agricultural water demand is an important consideration, with Australian agriculture consuming 10,730,000 ML of water in 2014. While models exist to predict water use for individual farms, predicting future agricultural water use in Australia at the state or national level is more challenging. The Balmoral Group developed a model to predict agricultural water demand for the entire state of Florida, USA as part of the Florida Statewide Agricultural Irrigation Demand (FSAID) project. Balmoral prepared a Statewide, property-level geodatabase of irrigated agricultural lands using aerial imagery, permit information, and computation of the Normalized Difference Vegetation Index. Water applied for irrigation was estimated using an econometric model based on the water use of 3,200 farms over three years, and the demand for irrigation water for a range of biophysical and economic factors relevant to each farm. The coefficients in the model were used to populate water use for the remaining farms across the State using spatially specific, farm-level data. Special situation water-uses such as frost protection, fertigation and crop establishment water for annuals were evaluated before preparing agricultural acreage projections and associated water requirements. Future projections of irrigated area and water use were estimated using auto-regressive forecasts of landuse change and net crop prices. A similar approach could be applied here in Australia to help plan for and manage the future demand for agricultural water.

Keywords

GIS, Modelling, Water, Agriculture, Water use, Land use, Demand, Forecasts

Introduction

Florida is the southern-most state on the east coast of the USA and faces long-term water security issues in support of its growing economy. In recent decades, local water suppliers have been caught-up in legal conflicts with other suppliers within the same county, between counties and with other states. Florida is heavily populated, with areas of dense urban development neighbouring large natural water bodies and agricultural lands. Irrigated agriculture in Florida uses 40% of total water demand (Marella 2014). In recognition of this large consumptive footprint and amid heightened water scarcity, The Balmoral Group recently developed a model to predict agricultural water demand across the entire state. Balmoral analysed various datasets to collate a property-level geodatabase comprising landuse, soil type, rainfall, evapotranspiration (ET) and irrigation infrastructure. The Balmoral Group combined this geodatabase with hydrological and econometric modelling, to estimate the potential future demand for irrigation and changes in landuse in response to a range of physical and economic variables.

Florida legislature recently adopted new provisions that required the Florida Department of Agriculture and Consumer Services (FDACS) to develop geographically specific agricultural water use estimates incorporating metered and other data over a 20-year forecast, for the entire state. In the past, Florida's five water management districts (WMDs) used their own individual models to estimate agricultural water use separately for each region. As a result, statewide estimation was fraught with inconsistency. For example, a crop in one district might be estimated to require 70 percent more water than the same crop half a mile away but in another district. To overcome this inconsistency, The Balmoral Group was tasked with estimating agricultural water use for all the farms across the state using a consistent approach. This is the Florida Statewide Agricultural Irrigation Demand (FSAID) project.

Methods

The Balmoral Group's estimates were completed in a three-step process. First, a dataset of all agricultural lands was prepared in a geographic information system (GIS), with irrigated lands identified. Second, water use estimates were developed at the farm level using an econometric model that linked current and historical biophysical factors, irrigation water use data and crop prices. Third, revenue and input cost projections, along with long-term climatic trends were incorporated into the model to predict future water use. Auto-regressive techniques were used to identify areas of growing and declining irrigated acreage, to generate projected irrigation areas and water use.

Develop Agricultural and Irrigated Lands Geodatabases

GIS databases of all agricultural lands in Florida, including irrigated lands, were needed as a first step in the FSAID project. The benefit of a geodatabase with individual fields is that it can be utilized at any scale, facilitating refinements to reflect temporal changes and controlling for crop differences. An Irrigated Lands Geodatabase (ILG) was populated for 2015 conditions using data from a number of sources. Agricultural areas were identified as irrigated or non-irrigated through automated and manual processes. GIS was used to visually review and compare various sources: aerial photography (NAIP and Google Earth), the USDA's Cropland Data Layer (CDL) , and permit data (to extract crop type, irrigation system, and irrigated area). The output was the classification of field geometry, crop type and irrigation system. The resulting GIS mapped an estimated 0.7 million hectares of irrigated land in 2015, and about 3.6 million hectares of agricultural land in total (see Figure 1).

Irrigation Estimates

After identifying current irrigated and non-irrigated agricultural lands, The Balmoral Group then estimated farm-level water use. About one-third of farms in Florida report metered water-use data to their local Water Management District. Data was obtained for a total of 3,200 farms across districts for three full years, which allowed a comparison of irrigation practices under a variety of climatic and market conditions. Demand for irrigation water was then modelled with a regression equation that linked total annual water use to biophysical and economic factors relevant to each farm (Table 1). The model included variables such as crop mix, field size, type of irrigation equipment used, soil type, weather conditions and evapotranspiration (ET). The modelled water use was a good fit compared to estimates obtained by other agencies. The coefficients in the model were then used to populate water use for the remaining farms across the ILG using spatially specific farm-level data.

Table 1. Regression Variables

Variable	Measure; all at farm field level
NP	Crop-specific annual revenue; using 70 crops aggregated into 9 crop categories
Soils	Soil type, aggregated into 8 broad soil categories
PERIRR	Percentage of permitted acreage that is irrigated
IRR	Type of irrigation system
FF	Variable to account for freeze protection
L	Vector of location attributes; e.g. latitude/longitude and Water Management District
RF	Mean annual rainfall, based on nearest rain station
ET	Evapotranspiration, based on satellite data

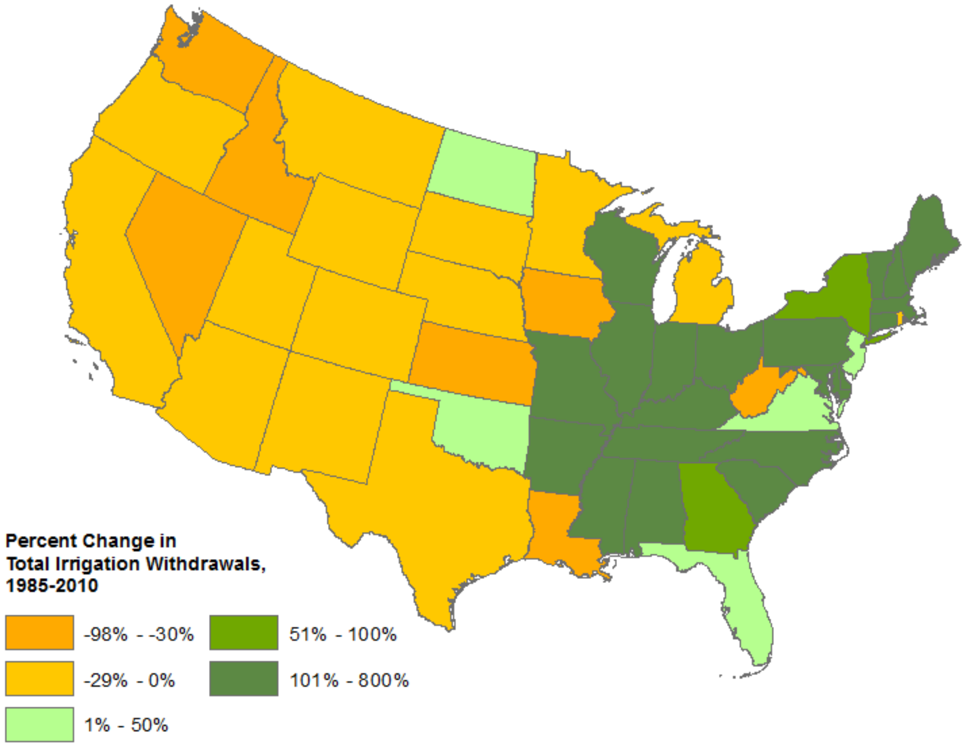
The model estimated that on average, agricultural lands are irrigated at about 406mm/year. Historic estimates of Florida irrigation, as prepared by Water Management Districts, reported demand of about 533mm/year. The model developed from metered data estimated that farmers were actually using about 24% less water overall than was previously thought.

Agricultural Acreage Projections and Associated Water Requirements

With estimates of current water demand in hand, the next challenge was to project irrigation behaviour 20 years into the future in a rapidly urbanising state. The State required forecasts of both water use and its spatial location. Data was analysed to project trends in the future need for water; with behaviour – a central theme of the study – defined by needs. Agriculture is an inherently risky operation, and the behaviour of farm managers takes account of a variety of risks including prices, the cost of labour and weather. Previous econometric modelling has identified spatially-varying trends in behaviour including irrigation intensity, crop mix changes, and land use conversion.

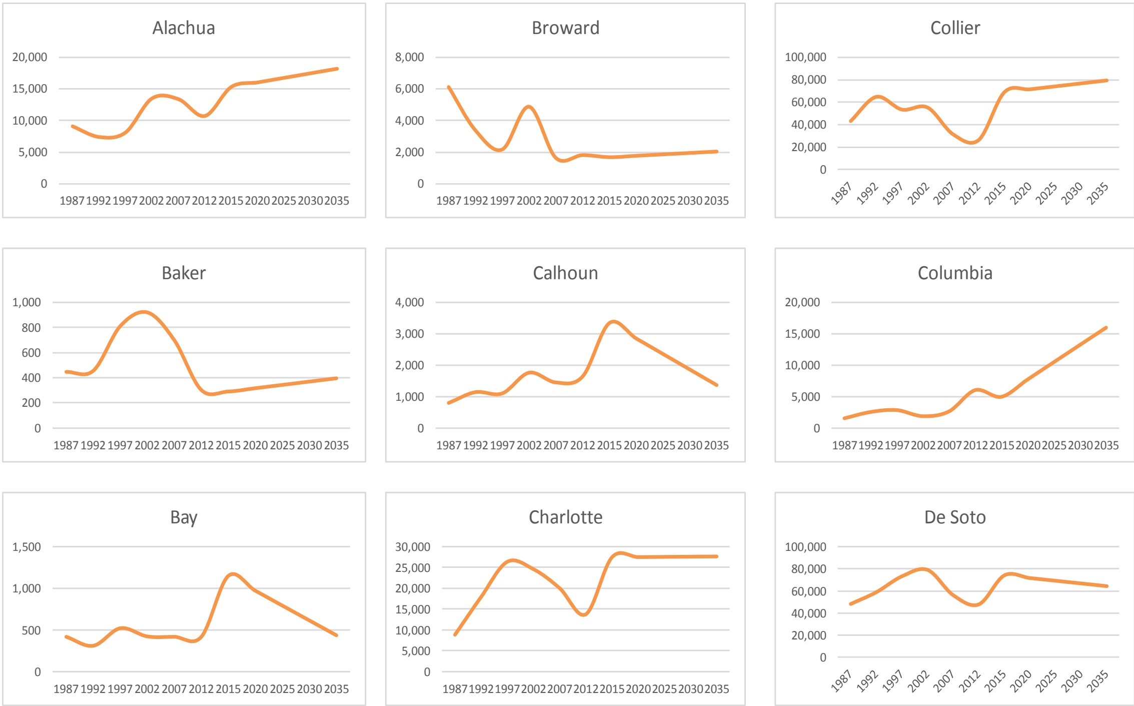
The Balmoral Group developed projections for future agricultural water use in five-year increments for the next 20 years. Future scenarios were modelled using two parallel threads of information: future crop revenue expectations, and long-term trends in land use change. Land use change was tackled first. In some parts of the state, such as the metro Miami area, there is likely to be less agricultural land in twenty years. Whilst in others, such as the northern parts of the state, there are substantial tracts of agricultural land that are currently not irrigated. Irrigation practices in western U.S. states (e.g. Texas and California) have shown evidence of migrating eastward over the past 30 years (Figure 2). Some areas of Florida that have traditionally been dry-land farming have seen new operators install sophisticated irrigation systems, and harvest two or more crops in fields that were historically single crops.

Figure 2. Irrigation Withdrawals, 1985 - 2010



Using agricultural census data that is collected every five years, analysis was conducted at the county level to identify long-term trends in the share of agricultural land that is irrigated. This is distinct from total agricultural land, which is generally declining. Techniques were applied to detect the best-fitting trends to estimate how much agricultural land would be likely to be irrigated in each county twenty years from now. Areas where irrigation was projected to be added or removed were identified in GIS using an automated process developed with R script. Figure 3 shows long-term irrigation trends for selected counties based on activity since 1987.

Figure 3. Selected long-term county trends, Irrigated area



Once the areas identified for likely future irrigation were identified, future water use was estimated. Long-term projections of crop prices were used to estimate future returns by crop type. The econometric model was fitted using long-term average weather trends (rainfall, ET, temperature) and projected revenues, to simulate future climatic conditions and crop returns. Crop mixes have been observed to shift over time as growers respond to farm subsidies, market conditions and structural agronomic changes. In areas projected to be newly irrigated, crop area and water use were estimated by assigning crop mixes supported by local soil conditions and using the irrigation equipment that is prevalent in the local vicinity.

Results

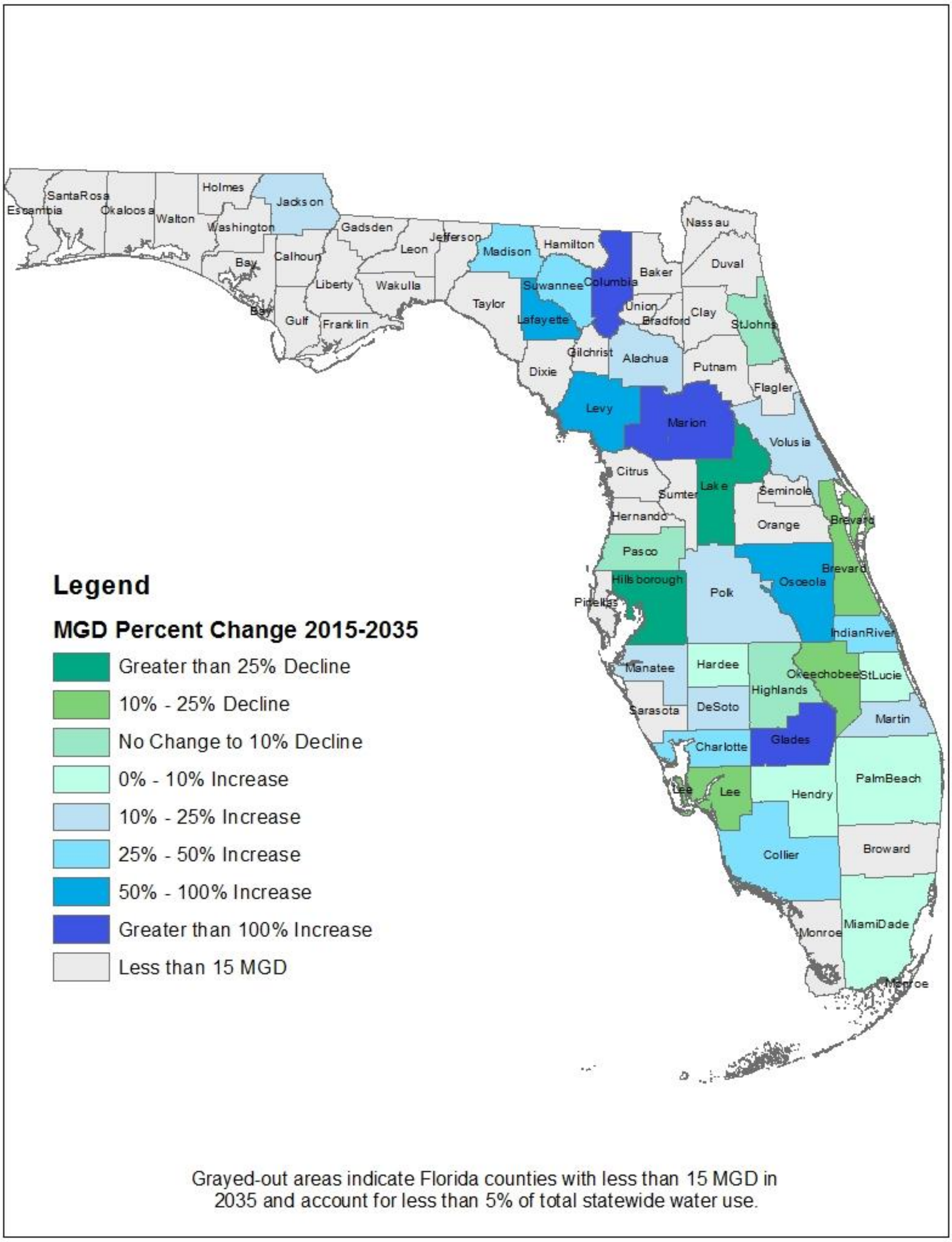
Table 3 provides estimates of changing water use by Water Management Districts. For ease of viewing, only three time periods are shown: 2015, 2025 and 2035. While net water use in the state is expected to increase by 17%, some areas are expected to see increases of 40% whilst others will remain relatively flat at 7%. Projected behavioural changes in conservation measures and frost-protection were also forecast and included in the estimates. Overall, increased efficiencies are expected to offset a significant share of the increased demand. Figure 4 shows the relative magnitude of changes across the state in mega-gallons per day (MGD). The results reflect a combination of data-intensive modelling with national and local long-term trends.

Table 3. Projected Water Use and Irrigated Area, 2015 – 2035

Water Management District	2015 Acres	2015 Avg MGD	2025 Acres	2025 Avg MGD	2035 Acres	2035 Avg MGD	2035 Dry MGD	2015 - 2035 Difference	2015 - 2035 % Difference
NWFWMD	56,829	46	61,879	52	66,713	59	67	9,883	17%
SFWMD	1,045,697	1,237	1,085,635	1,263	1,129,211	1,448	1,665	83,514	8%
SJRWMD	177,371	208	168,708	197	157,536	223	256	(19,835)	-11%

SRWMD	123,956	107	142,671	128	162,106	151	174	38,150	31%
SWFWMD	396,459	534	382,800	506	369,888	611	703	(26,571)	-7%
Total	1,800,312	2,132	1,841,693	2,146	1,885,453	2,491	2,865	85,142	5%

Figure 4. Map of Projected Changes in Relative Water Use



Discussion

Going forward, further refinements to the process are currently underway to accommodate projections without the need for intensive farm-level data collection. Sufficient data may have been collected to support Vector Auto Regression methods (VAR) going forward. If so, similar forecasts could be completed with substantially improved accuracy and considerably less modelling time. These and other alternatives are being explored to allow areas with less available data to capitalize on the work completed for this project. To accommodate stakeholder needs for ongoing detailed data availability, projection data by crop, location and time period is fully accessible through an online interface developed at www.fsaid2.com.

The statewide model with property-level data (all of which is maintained in a geodatabase) supports analysis at various scales and enables the results to be distributed spatially. The resulting database supports many applications such as demand projections, spatial identification of agricultural water use (including future scenarios) and the evaluation of groundwater recharge analysis or opportunities to reclaim water, for instance. The data is currently being used to evaluate the costs and benefits of implementing best management practices (BMPs) for nutrient reduction, freeze protection and alternative water supply sources.

The model provides a better understanding of Florida's likely future water scenarios and the exploration of alternative approaches, using the results of this project, are expected to identify opportunities to prepare water use forecasts in areas with less data-rich environments.

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