# Forecasting Future Population and Resource Demands using GIS

Steve Rossi, City of Phoenix
Ray Quay, City of Phoenix
Michael LaBianca, HDR

## Abstract

The future isn't always what we plan for. This presentation will focus on how GIS was used to help the City of Phoenix develop a strategic water supply and water infrastructure master plan by examining the potential impacts of alternative land use scenarios on water supply and water infrastructure needs. The alternative land use scenarios that were modeled were developed based on hypothetical future headlines, like Valley Manufacturing Moves Overseas, Climate Changes Affect Tourism and In-Migration. For each headline, changes in economic, demographic and technological trends were identified and translated into land use impacts. GIS was used to develop alternative growth, population and employment scenarios for each alternative future from which water demand and the locations for the alternative water infrastructure could be projected. The presentation will include a discussion of how these land uses were modeled, the findings, and methodology for integration into the water models.

## Introduction

The City of Phoenix Water Resources Department's implementation of Geographic Information Systems (GIS) to develop alternative land use scenarios as part of its 2005 Water Resources Plan Update, and the update of water and wastewater infrastructure master plans provides an ideal case study for this discussion of applying GIS technology to water resources planning.

With their capacity to consider numerous factors at once, GIS-based models are being used to address increasingly complex issues. For example, they have become valuable analysis tools for addressing regional planning issues such as resource planning, land use, socioeconomic projections, air quality and transportation—all of which have a spatial component.

According to a survey of planning agencies conducted in 2004, nearly 88 percent of municipalities surveyed reported they used GIS (Simpson, 2004). The City of Phoenix is no exception with a robust system that is used by nearly all of the City's departments.

## Background

This project was prepared in response to a need for a more dynamic method of re-evaluating water resource availability over a 50-year planning horizon. At the heart of the 2005 Water Resources Plan Update and infrastructure master plan updates is a need to account for uncertainty in both growth projections and drought impacts to Phoenix over that timeframe.

In its broadest sense, drought can be caused by seasonal or multi-year weather conditions as well as long-term climatic cycles. The effect of a given drought on a water utility is based on the relative dependency on supplies that are prone to drought impacts—such as surface water—and the degree of available reservoir storage.

Arizona's key watersheds have experienced low runoff conditions for the past nine years. During this time, we have considered that the current drought potentially could continue

for multiple decades. The prospects of droughts of this magnitude have not been considered in any great detail in past plans.

It should be noted that Arizona's wet 2004/2005 winter season does not necessarily portend an end to the decade-long drought that has affected the Southwest. Periods of normal to elevated precipitation can span weeks to years and are typical of multi-year drought periods. While improving the immediate water supply, a wet period in a longer-term drought pattern may hinder appropriate planning because it provides false assurance that a drought has subsided. Also, while Arizona's reservoirs have rebounded from years of depletion, reservoirs on the Colorado River system remain very low and will take several above-normal runoff years to recover.

Over the past two decades, the City strengthened its diverse portfolio of water supplies through acquisition of additional water supplies and implementation of conservation programs. The City established and routinely updates water resource plans, conservation plans and drought management plans to consider recent trends and projections, and to guide decision making by the utility in these areas. The development of the 2005 Water Resources Plan Update will help determine future directions to account for both long-term drought and changes to current growth projections.

**Phoenix**

Phoenix covers more than 514 square miles and has a population of nearly 1.5 million, making it the fifth largest city in the country (Phoenix, 2005a). Precipitation in the Phoenix area is less than eight inches annually (Arizona, 2005). Major sources of water supply include the Colorado River and Arizona's Salt and Verde Rivers. These sources serve nearly 90 percent of Phoenix's water demands. Groundwater and reclaimed water meet the remaining demands.

For the past 50 years, water supply has not been a major limiting factor to urban growth in the western United States. However, nine years of drought within the Colorado River watershed causes concern that the river's storage systems will not be able to meet the

urban water demands of the 25 million people it serves today. Thus, the need to understand the resource limits of western water supplies is now critical. Unfortunately, the complexity and uncertainty of the natural and political processes driving water supply make it difficult to determine and explain these limits. Phoenix is using an aggregated probabilistic scenario planning approach to distill the complexity and uncertainty and identify the key strategic factors and critical scenarios decision makers should focus on.

Phoenix's water resource planning involves managing a complex portfolio of dynamic water resources to meet current and future demands from a rapidly growing population. These resources each present a unique set of geographic, temporal and operative restrictions affected by a broad set of factors, many with a high degree of uncertainty:

- Climate/Drought — Tree ring studies reveal that droughts on the Colorado, Salt and Verde rivers are more severe than droughts observed over the past 100 years. Simultaneous drought also is more frequent than previously thought. There also is some concern that climate change will negatively impact water supply in the future, even in non-drought years.
- Environmental Pressures — A desire to use existing water resources for enhancement of environmental benefits is growing and intertwined with issues regarding health of the watersheds that generate our water supplies. Compliance with the Endangered Species Act may have many positive environmental benefits but may also have negative impacts on the ability to use existing resources or on the acquisition of future supplies. These issues touch both Salt River Project (SRP) and Central Arizona Project (CAP) supplies.
- Colorado River Supplies — The Secretary of the Interior has broad authority to declare shortages, but no criteria exist. The Secretary is allowing Colorado River water users to come up with shortage criteria, and discussions are underway between the seven Colorado River states to come up with them. Projections for future river flows and reservoir storage levels are being made to support these efforts but many assumptions and uncertainties are inherent in these projections. These projections suggest that 2010–2012 may be the earliest time for a shortage based upon historic records of low river flow periods set against current reservoir

levels. Actual river flow could be less. The Secretary may decide to protect water levels at Lake Mead or Lake Powell and declare a shortage sooner than the hydrologic models predict. Issues for how shortages will flow to water users within Arizona also are being discussed within the State. While large quantities of CAP water have been banked to make up for shortage reductions in CAP water for municipal users planning, efforts to recover this water have been slow to develop.

- SRP Supplies — Though SRP's allocation was reduced in 2003 and 2004 due to low reservoir conditions, the City was largely unaffected by that reduction. However, deeper cuts in future years could create deficits in the areas eligible to receive this water.
- Regional Growth and Demand — Growth will put pressure on existing resources like CAP and create increasing competition for water supplies. The Central Arizona Groundwater Replenishment District facilitates growth in areas largely dependent upon groundwater by replenishing pumped groundwater. Historically, the CAGRD has used excess CAP water to accomplish that goal but will be seeking more firm supplies to allow continued growth over the next 10 years.
- Groundwater Availability and Quality — Much of the groundwater underlying Phoenix, especially within the boundaries of SRP, needs additional treatment to meet potable standards. Cleanup efforts for groundwater with industrial contamination have lagged because of lack of state funding. SRP's water supply during drought is largely groundwater, and its pumping capacity has been decreasing as more agricultural land urbanizes.
- Financial — Protection against continued drought may require acquisition of additional water supplies and infrastructure, including drilling additional wells. Treatment of groundwater that does not meet potable standards also may be part of the equation. Financial resources will be needed to accomplish these goals. Demand management resulting in significant reductions of potable water also can have negative impact on revenue.
- Regional Context — Entities surrounding Phoenix generally rely on the same sources of water as Phoenix, but variations in specific amounts and specific

sources exist. As a result, differences between cities' ability to deal with drought will surface if the drought worsens or continues.

The intent of Phoenix's approach is to reduce the complexity and uncertainty of drought, growth and demand to a small number of strategic factors. For example, it is anticipated that regardless of the wide array of surface water management polices tested, long-term drought scenarios will reveal that cities in Arizona need a greater reliance on ground water than currently planned. To implement this aggregated scenario planning analysis, Phoenix developed a model that assesses impacts on its water delivery system based on multiple water supply, growth and user demand scenarios.

Phoenix's analysis focuses on three areas of uncertainty: management of regional water supply during long-term drought; growth and the factors that may influence growth over the next 50 years; and demand and potential changes in residential, commercial and industrial demand over 50 years. Of these factors, growth and demand both have explicit spatial characteristics, thus, the model was developed with a spatial component. GIS technology was crucial to not only develop the inputs to the model but also assess the model results. This article examines the process of creating growth scenarios.

The City of Phoenix began using GIS in 1991 with passage of a bond funding GIS data conversion and creation of both maintenance and automated mapping applications. Initially, street, parcel, water, sewer, zoning and political data layers were converted. Since 1997, the City's GIS program has expanded to other departments in City government (Dillon, 2005) and is now used for a variety of applications.

Water resource planning traditionally has been based on the General Plan[1], which describes the future land uses for a planning area. Land uses describing the intensity and

[1] The General Plan is an expression of long-term community intentions regarding the future development and physical form of the City. It contains maps, goals, objectives and policies that are used to coordinate and implement land use decisions with other decisions about infrastructure, parks, recreation and open space, city services, housing supply and affordability, and public resources such as air and water.

density of development are the principle drivers of water demand. Future land use provides a window on future water demand. Historical water demand for specific land use categories can be calculated and applied to future growth.

Because Arizona is growing rapidly, the General Plan and other plans are amended regularly. Additionally, other key New Economy[2], demographic and infrastructure trends will influence the rate of future population growth and land use in the city. The most significant of these include the approval of additional and substantial funding for public transportation (light rail and bus rapid transit), genomics research, expansion and decentralization of the state university system, and a re-emergence of the central city as a residential and business center for the city and valley.

The existing, long-standing land use paradigm of separate districts for work, commerce and living is shifting. *Mixed-use*—describing an intense area of activity which may include single-family and multi-family residential development, retail, office and industry all within the same block, often within the same building or complex—is becoming a more common land use. The instability of oil prices, transportation problems and economic cycles all influence land use decisions on a daily basis. To address the uncertainty of development patterns and the resultant demand for water services, the City added alternative land use scenarios to the variables of supply and demand. Developing alternative land use scenarios allowed the Phoenix Water Services Department to develop assumptions that could be monitored and explore the resultant water demand based upon these scenarios.

**Process**

The intent of the overall planning process was to determine spatial impacts of a wide range of scenarios incorporating various surface water shortage conditions and growth projections. The City has historically evaluated supply availability using just the General

[2] The "New Economy" can be defined as the series of changes in the economic landscape that resulted from industry's massive investment in new information and communication technologies over the past 10 years or so. These technologies include computers, software and telecommunications equipment and are broadly based on the "general purpose technology" of the microchip.

Plan-based growth projections and has spatially divided the city into two areas based on water right appurtenance For the 2005 Water Resources Plan Update, the city was divided into 12 “demand zones,” which allows for a more refined means of projecting spatial impacts of these varying conditions. The process ultimately generates monthly water supply deficits for each zone in five-year increments (2005-2055). The process accounts for water infrastructure conditions (access to water treatment plants, transmission mains, wells, etc.) in evaluating potential shortfalls in each zone. The results are expected to be utilized in the City’s Water and Wastewater Infrastructure Master Plan updates, which are being developed concurrently.

A key component in the process was determining the impact of varying growth projections on water demands through development of “alternative general plans” (i.e. variations of the Phoenix General Plan). An array of alternative demand scenarios was considered. After comparing the demand levels generated by these alternative scenarios, several were removed from consideration due to similar results. Three alternative scenarios, along with the base (General Plan) scenario, were moved forward. Each scenario was further modified to include moderate and aggressive conservation levels. Thus, 12 scenarios (four land use and three “rate of use” variations) now factor into development of the Water Resources Plan.

The Maricopa Association of Governments (MAG), the metropolitan planning organization (MPO) for the Phoenix metropolitan area, is responsible for regional land use, transportation and air quality modeling. MAG assisted the City of Phoenix by developing land use and socioeconomic projections based on the scenarios developed for this project. MAG typically considers the Phoenix General Plan in its population projections.

In this process, MAG was responsible for taking the alternative land use plans and assumptions regarding Phoenix’s share of growth, Maricopa County and Phoenix (population) control totals, and other factors and converting them into land use and population projections for the water demand zones. The output from the MAG process

included the number of single-family and multi-family dwelling units and the projected acreage for various non-residential land use categories (retail/office, industrial, commercial, public). Projected "unit demand" factors were developed by the City's Finance Department based on historic information from the water billing system. The Finance Department then generated monthly demand projections for each zone.

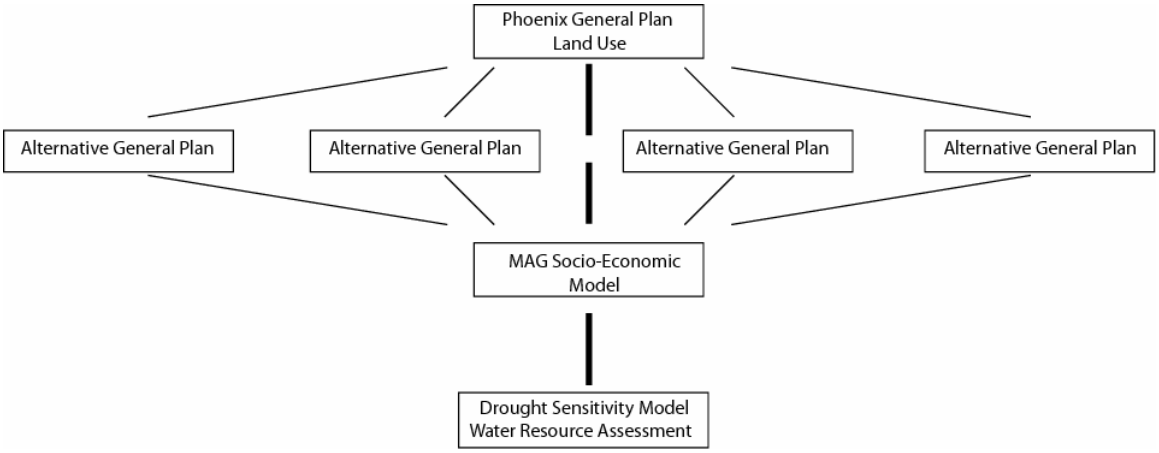


**Figure 1 Flow chart depicting the process by which the water demand results were developed. The MAG land use model converted the land use scenarios and assumptions into socio-economic projections for five-year increments through the planning horizon.**

## Scenario Development Process Summary

Development of the scenarios used to project future land use alternatives for the city included four steps: 1) Identification of Future Trends, 2) Assessment of Future Trends, 3) Formation of Future Scenarios, and 4) Future Scenario Land Use Mapping and Growth Projections. Each step is described briefly here.

1. Identification of Future Trends

Future land use scenarios were developed with assistance from a number of City of Phoenix Departments, including the Water Services, Planning, Finance and Economic Development, as well as members of the consultant team assisting with development of the Plan. To identify and assess future trends, research was presented in the form of hypothetical future newspaper headlines at a meeting of representatives from Planning, Utilities Accounting, Finance, Water Services, and Economic Development, as well as project consultants. Participants were allowed to add headlines, and, following a

discussion meeting, participants prioritized the headlines by voting on those believed to have the highest likelihood of occurrence.

2. Assessment of Future Trends

The group then discussed some of the infrastructure and physical trends they believed might be associated with those headlines. Additional research on these trends was used to create five future scenarios that became the basis for the future land use assumptions.

Meeting participants were asked to describe what impact the believed the headlines would have on the development pattern, nodes of development, employment, housing and infrastructure of the city. This information was summarized and augmented by additional trends research, specific change factors such as redevelopment, future development patterns and land use intensities, and then densities were developed.

3. Formation of Future Scenarios

Headlines and influences then were grouped into five overall land use scenarios. The results were incorporated into a matrix that included identification of specific influences that could cause it to occur, trends to watch to ascertain if the scenario was likely, and social (employment, housing) and physical (infrastructure, land use and development) impacts that likely would manifest if the scenario were to occur (from the assessment exercise with City staff). The five general scenarios are listed in the table below.

1. Very Slow Growth — Growth of Phoenix is held at 1-2 percent annually with the existing General Plan defining the land uses.
2. Dispersed Poly-nucleated City — Factors such as a new regional airport and new employment centers located along transportation corridors create a multiple-nuclei city form.
3. Strong Central City — Downtown becomes the premiere valley business location with employment and residential intensities increasing.
4. Resort Mecca — Resort development adjacent to open space areas affects land pattern in northern and southern areas of the city.

5. Transportation Influenced — The light rail system is developed beyond the currently planned system.

Moving forward, two scenarios ("Very Slow Growth" and "Resort Mecca") were dropped when socioeconomic modeling revealed they showed little variation from the base case.

4. Future Land Use Mapping and Growth Projections

The land use ramifications of each scenario described above were identified using aerial maps of the city, the current General Plan and other information relevant to that scenario.

**Use of GIS**

The conversion of information described into a spatial component began with the City of Phoenix General Plan. Within ArcGIS, the Phoenix General Plan was modified to reflect each scenario. This process resulted in modified General Plan shape-files that could be fed into the MAG model to develop demand projections.

In developing the alternative General Plans, numerous data sets were used. Aerial imagery provided a snapshot of development on the ground, allowing planners the ability to "relate" to nodes and development patterns they would build on in developing the scenarios. Plots were created for the entire city, with aerials underlying important information such as the current General Plan (displayed as a percent transparent to see what is happening "on-the-ground").

**Very Slow Growth**

One of the components MAG uses to augment the general plans in the socioeconomic modeling is a development database. In creating this scenario, the development database was reviewed, and, based on the assumptions of the scenario, development areas of the city were prioritized. Based on infrastructure and other factors, certain areas of the city would develop only after "more ripe" areas were built out. The ability to overlay multiple datasets in GIS allowed the planners to make these decisions quickly.

**Dispersed Poly-nucleated City**

In this scenario, more than 33,000 acres of change were applied to the current Phoenix General Plan. Research on changes in the spatial distribution of employment resulted in land use changes to specific employment centers, spawning creation of significant nodes of employment and changes to residential and retail development dispersed from the city center. One of the more significant areas of change was the application of large areas of mixed-use development.

The mixed-use category "denotes areas where developments combining a mix of land use types (residential, commercial, employment and business park) may take place. Use of the mixed-use designation is intended to minimize the impacts traditionally associated with growth by providing housing, shopping and employment opportunities together in the same area." (Peoria General Plan, 2004)

The Phoenix General Plan does not indicate the ratio of uses (residential, commercial, employment and business park) in the mixed-use land use description. MAG developed percentage breakdowns of the mixed-use categories by working with City of Phoenix planners to develop ratios based on the geographical area in which the mixed-use occurs. This information was applied to the mixed-use areas through a linked table that provided a one-to-many relationship based on a unique identifier in the mixed-use polygon field. In creating new mixed-use areas, planners applied their best estimate of the mix of development and provided the breakdown of uses as described above.

**Strong Central City**

In developing the Strong Central City, various development plans currently being discussed were digitized from various sources and integrated into the land use plan. The ease of quickly creating these polygons in GIS aided development of the scenarios.

**Resort Mecca**

Digital elevation models were used to assist with formation of conservation areas for the Resort Mecca scenario. Using elevation as a proxy for open space preservation, areas above 1,800 feet were identified. Overlaying these areas with developed areas and land ownership files available through Arizona's State Land Development Department, aggressive conservation areas were created. Additionally, by buffering floodways one-half mile, additional potential conservation areas were quickly identified. These assumptions led to identification of approximately 80,000 acres of change areas. Resort development adjacent to open space areas affects land patterns in northern and southern areas of the city.

**Transportation Influenced**

For the transit scenario, various proposals to extend the planned Minimum Operating System were incorporated into the land use plan. For this scenario, land uses were modified within one-quarter mile of the proposed rail lines, increasing the intensity and density of land uses. Land uses also were intensified within a buffered distance of one-half mile surrounding the 47 proposed light rail stations. This scenario envisioned 100 percent redevelopment around the transit stations. MAG's existing land use coverage was compared to the General Plan. Redevelopment consisted of changing all existing land use polygons in the buffered areas to be consistent with the General Plan.

**Results and Conclusions**

The process has yielded valuable information to further consider in the city's water acquisition, conservation and infrastructure planning efforts. A key objective currently under development is the optimal degree of redundancy needed in water supplies and infrastructure to address foreseeable system shortfalls.

As expected, the shortfalls vary tremendously depending on the scenario. Under normal conditions and with moderate conservation, current supplies will be sufficient through at least 2025. With a moderate drought and higher-density development (e.g. the Transit scenario), shortages—more severe in some zones than others—begin to develop in the

2015–2020 time frame. The City currently is determining strategies for addressing these shortfalls and the relative costs involved. It is expected that the ultimate direction regarding water supply acquisition and infrastructure enhancements will focus largely on the next 10–20 years and be tempered by means of recovering costs for these improvements.

References

Arizona, Office of the State Climatologist. *Phoenix, Arizona Normals, Means, And Extremes*. [database online]. http://www.wrcc.dri.edu/cgi-bin/clilcd.pl?az23183 (Accessed May 25, 2005).

Dillon, Deborah and Lemar, Shea. "Using Mapping to Solve Community Problems." ArcUser. 2005. ESRI. http://www.esri.com/news/arcuser/0700/auth.html: 2005-04-14

Phoenix. 2005a. "Community Trends and Profile." http://www.ci.phoenix.az.us/CITYGOV/stats.html. Accessed May 25, 2005.

Phoenix. 2005b. http://phoenix.gov/WATER/drtintro.html . Accessed May 23, 2005. Phoenix Water Services Department: Phoenix AZ, 2000

Simpson, David M. 2004. The Use of Technology by Planning Agencies in the U.S.: A National Benchmarking Survey. University of Lousiville, Department of Urban and Public Affairs: Lousiville, KY.

Walker, Kelly. "City of Phoenix General Plan: City of Phoenix." ESRI, Map Book Gallery Volume 16. ESRI. http://www.esri.com/mapmuseum/mapbook_gallery/volume16/local2.html. Accessed May 25, 2005.

Authors

Steve Rossi, Principal Water Resources Planner
City of Phoenix Water Services Department
200 W. Washington 9th Floor Phoenix, AZ 85003
Office: (602) 495-3669
Fax: (602) 495-5542
steve.rossi@phoenix.gov

Ray Quay, Assistant Director - Water Resource & Development Planning
City of Phoenix Water Services Department
200 W. Washington 9th Floor Phoenix, AZ 85003
Office: (602) 495-3669
Fax: (602) 495-5542
ray.quay@phoenix.gov

Michael LaBianca, Planner
HDR Engineering, Inc.
3200 E Camelback Road
Phoenix, AZ 85018
(602) 522-7700 phone
(602) 522-7707 fax
michael.labianca@hdrinc.com

**APPENDIX A**

**Phoenix Water Analysis – Scenario Analysis**

**MAG Socioeconomic Modeling Data Needs**

This is a synopsis of the modeling information used by the Maricopa Association of Governments in developing the socioeconomic projections for the water demand model.

**Time Periods:**

2010, 2020, 2025, 2030, 2040, 2055

**Control Totals:**

- For Maricopa County and Phoenix Demand Zones for each year in the scenarios. Control totals for the following – housing units (single/multi family) or population in households (single/multi family), and total employment.

**Description:**

Description of the changes in the scenario from the Base and Interim Projections indicating:

- Changes in control totals and build out. How do the changes in Phoenix MPA impact the County?
- General areas where changes will be seen and timelines associated with the changes.
- Impacts of the scenario on the existing known developments in the area of impact.
- Discussion of accessibility changes.
- Discussion of employment changes (i.e changes in retail, industrial, office, public and other employment sectors for each scenario).

**Data/Land use/GIS files:**

- All GIS coverages in Stateplane NAD 83 (international feet).
- Base GIS file of Phoenix General Plan with MAG land use code.
- MAG land use codes used in the Interim Projections are attached.
- Coverage indicating General Plan land use changes required for the scenario.
- Land use coverage with MAG land use code, target dwelling units density (for residential) and employment density or sq. ft (for non residential uses).

- In cases where land use is mixed use or planned development, percent split of land uses and associated densities using MAG land use codes.
- In cases where areas are being redeveloped, GIS coverage indicating redevelopment zones along with a start year for redevelopment. The model is allowed to rebuild the existing land use only in redevelopment areas.
- Impacts of the scenario on the existing know developments in the area of impact.
- List of data fields for the land use changes GIS file (at a polygon level):
    - Polygon ID (unique for each polygon in the coverage)
    - Land use description (if new land use)
    - MAG Land use code (from land use code list attached)
    - Target dwelling unit density (for residential and mixed use only)
    - Non-residential sq. ft
    - For mixed use – Land use code 1
    - For Mixed use - % for Land use code 1
    - For mixed use – Land use code 2
    - For Mixed use - % for Land use code 2
    - For mixed use – Land use code 3
    - For Mixed use - % for Land use code 3
    - For mixed use – Land use code 4
    - For Mixed use - % for Land use code 4
    - For mixed use – Land use code 5
    - For Mixed use - % for Land use code 5
- List of data fields for the land use changes GIS file (at quarter section level):
    - Redevelopment Flag (1 indicates this is a redevelopment area)
    - Year (when is the change expected to start)