Preliminary Assessment of Increased Natural Recharge Resulting from Urbanization and Stormwater Retention within the City of Chandler

M. Milczarek[1], A. Graham[1], J. Harding[1], D. Toy[2],

The City of Chandler captures all stormwater runoff in drywells and retention basins, from which it either evaporates or infiltrates. The portion that infiltrates does so through either irrigated turfgrass, gravel mulch, or drywells, thus a significant portion of stormwater runoff may ultimately result in groundwater recharge. A preliminary evaluation was conducted to estimate the amount of groundwater recharge resulting from engineered stormwater capture and retention, and from direct precipitation on irrigated turfgrass and agriculture, in the City of Chandler.

Historic precipitation records were analyzed to determine the precipitation characteristics of dry, average, and wet years. These data were combined with land use and surface cover data to generate estimates of stormwater runoff within Chandler city limits for different storm intensities during dry, average, and wet years. The fraction of runoff that evaporates was then estimated, and the remainder of runoff was assumed to infiltrate into groundwater through drywells and retention basins. Deep percolation resulting from direct infiltration through turfgrass and agriculture was also estimated.

Study findings include:

1. Estimated pre-development groundwater recharge rates were negligible (less than 191 acre-feet per year).
2. More than 3,800 drywells exist within the City of Chandler, along with an estimated 1,400 acres of stormwater retention basins.
3. An estimated 3,700 to 4,800 acre-feet of stormwater runoff reaches retention basins and drywells during an average year. Estimated dry and wet year runoff volumes are 1,500 and 10,900 acre-feet, respectively.
4. An average of 2,100 to 3,100 acre-feet of water per year are estimated to recharge in Chandler drywells and stormwater retention basins. Estimated dry and wet year recharge volumes are 770 and 8,700 acre-feet, respectively.
5. An estimated 1,290 acre-feet per year of groundwater recharge is estimated to result from direct precipitation on turfgrass and agricultural lands.
6. An average of 3,900 to 4,600 acre-feet per year of total potential groundwater recharge is estimated to occur. Estimated dry and wet year total potential groundwater recharge volumes are 1,400 and 10,930 acre-feet, respectively.

[1] GeoSystems Analysis, Inc., 2015 North Forbes Blvd, Suite 105, Tucson AZ 85745
[2] City of Chandler Municipal Utilities Department, 975 E. Armstrong Way, Building L, Chandler, AZ 85249

Introduction

Estimating groundwater recharge rates is becoming more important to communities in the arid Southwest as they develop assured water supplies and meet safe-yield goals for groundwater resources. Natural groundwater recharge in the Southwest is believed to occur primarily in mountain front areas and in ephemeral stream channels, with negligible groundwater recharge occurring in inter-channel areas (Scanlon, et al, 1999, Scanlon et al., 2003). Urbanization causes increased stormwater runoff due to the increase in impervious surfaces. The increased runoff routed into channels, retention basins, and drywells may increase local groundwater recharge.

The City of Chandler contains and controls all stormwater runoff within its boundaries through the use of drywells and retention basins. Increased groundwater recharge resulting from urbanization and these methods of stormwater control represents a potential additional source of assured water supply. In addition, groundwater recharge from precipitation falling on irrigated turf-grass and agricultural areas may be a significant resource.

Groundwater Recharge and Effects of Urbanization in the Southwest

Groundwater recharge is defined as water that penetrates the land surface into the subsurface (infiltration), moves through the zone of evapotranspiration into the deeper unsaturated or vadose zone (deep percolation), and reaches an aquifer. In natural settings, recharge by deep percolation occurs in three principle ways: a) through soils and the vadose zone in inter-drainage areas; b) through streambeds, and c) through localized concentrations of water (i.e. basins) in the absence of well-defined channels (Lerner et al., 1990). The relative importance of each of these recharge pathways is the subject of ongoing research, but recharge appears to correlate strongly to local geology and geomorphology, and climate and weather patterns.

Several authors have shown that very little (less than one percent of annual precipitation) groundwater recharge occurs in arid environments (Allison et al., 1994, Gee and Hillel, 1988; Gee et al., 1993). Scanlon et al. (1999) found that in the Chihuahan desert, groundwater recharge rates in ephemeral stream channels and localized depressions were several orders of magnitude greater than recharge rates in inter-channel areas. Most recently, Scanlon et al. (2003) proposed that in the Chihuahuan and Amargosa deserts and in the High Plains, recharge rates in interdrainage areas are negligible, and upward drying trends have been occurring for several thousand years. Pool (2004), in a study of ephemeral stream channel recharge in southeastern Arizona, found that annual stream flow volumes and estimated recharge rates increased three- to four-fold from 1933 to 1999. Although the majority of the increase was believed to be due to the increased frequency of El Niño years and associated increased stormwater runoff, greater relative increases in recharge were also observed in urbanized versus non-urbanized watersheds.

Urbanization can increase the recharge that occurs through ephemeral channels because interdrainage areas are sealed off by impermeable surfaces such as parking lots, roads, and buildings. The impermeable surfaces cause a greater fraction of precipitation to become stormwater runoff captured in drainages, retention basins and drywells. Most importantly, runoff may result from precipitation events that would not have generated runoff under pre-urbanized conditions. For example, urbanization in Los Angeles County has resulted in a tenfold increase in runoff over the last several decades (LASGRWC, 2003). GSA (2004) examined the potential for enhancing groundwater recharge rates through stormwater capture in the Upper San Pedro Basin in southeastern Arizona. Surface water modeling predictions suggested that urbanization could result in a two- to four- fold increase in stormwater runoff and a 500 percent increase in infiltration volumes over pre-urbanized values. The higher increases in runoff observed in Los Angeles County as compared with modeled results for the Upper San Pedro Basin may be attributed to greater urbanization and concrete lining of flood control channels in Los Angeles County.

Finally the presence of turfgrass and agriculture may also increase groundwater recharge from precipitation. Turfgrass and agriculture are normally irrigated at rates exceeding the evapotranspirative demand to account minimize salt accumulation in the root zone, therefore a portion of the precipitation that infiltrates into these areas will also percolate into groundwater.

Estimated Pre-human Groundwater Recharge within Chandler

Other than costly and time-consuming direct in-situ measurements, no reliable methods exist to estimate natural groundwater recharge rates in small inter-basin semi-arid settings such as Chandler. Most approaches either rely on empirical relationships (i.e. Maxey-Eakin, 1949) or require calibration of basin-scale groundwater flow models. Two methods, the U.S. Geological Survey's Regional Aquifer Systems Analysis (Anderson et al., 1992) and the Arizona Department of Water Resources Salt River Valley (ADWR-SRV) Groundwater Flow Model (Correll and Corkhill, 1994), were applied to the City of Chandler.

The RASA study (Anderson et al., 1992) identifies mountain front recharge as a major component of recharge in the hydrologic basins of southeastern Arizona. The authors caution against using the estimation equation for small watersheds where estimated mountain front recharge is less than 1000 acre-feet per annum (afa). Nonetheless, applying the equation to The City of Chandler watershed, with a total area of 39,000 acres and an average annual precipitation of 8.3 inches, yields a recharge rate of 49 afa.

The ADWR-SRV model includes defines the major groundwater recharge components of the pre-development (circa 1900) hydrologic system as perennial and ephemeral stream channel infiltration and mountain front recharge (Corell and Corkhill, 1994). The natural recharge estimated for the entire 2,240 square-mile SRV study area was 108,000 afa, or 0.075 afa per acre. However, the absence of perennial and large ephemeral stream channels within the Chandler city limits (Reynolds, 2004) suggests that it is unlikely that predevelopment recharge rates were this high in that area. If the perennial and ephemeral stream channel components are removed from the SRV model estimates, the result is an average recharge rate of 0.005 afa per acre, equivalent to 191 afa within Chandler. As only two small contributing mountain front areas exist near Chandler, this value likely includes groundwater recharge occurring from stormwater runoff into small ephemeral drainages within Chandler.

Study Approach

Storm water runoff and groundwater recharge were estimated as follows. National Weather Service (NWS) precipitation data from the Chandler and surrounding communities were used to determine the intensity and frequency of storms, and characteristics of wet, dry, and normal precipitation years for the Chandler area. Two approaches were then taken to defined land surface characteristics for estimating stormwater runoff coefficients: a) land surface cover, and; b) land use classification. These estimates were based on GIS land use data combined with aerial photos. Runoff from storms during wet, dry and normal years then was predicted using the Soil Conservation Service - Curve Number (SCS-CN) method. Finally, groundwater recharge was estimated to equal the fraction of captured runoff that does not evaporate, and the amount of deep percolation occurring from direct precipitation onto turf grass and agricultural land.

Precipitation Analysis

Stormwater runoff and subsequent groundwater recharge is directly dependent on precipitation intensity and frequency. Regional climate studies show a sustained drought occurred in the Chandler area in the 1950s, part of a multidecadal dry period spanning 1947 to 1976 with the wettest periods in the past century occurring between 1925 to 1946 and 1977 to 1998 (McPhee et al., 2004). It is expected that precipitation and stormwater runoff during wet years will substantially increase the amount of potential recharge above a “normal” or dry (drought) years.

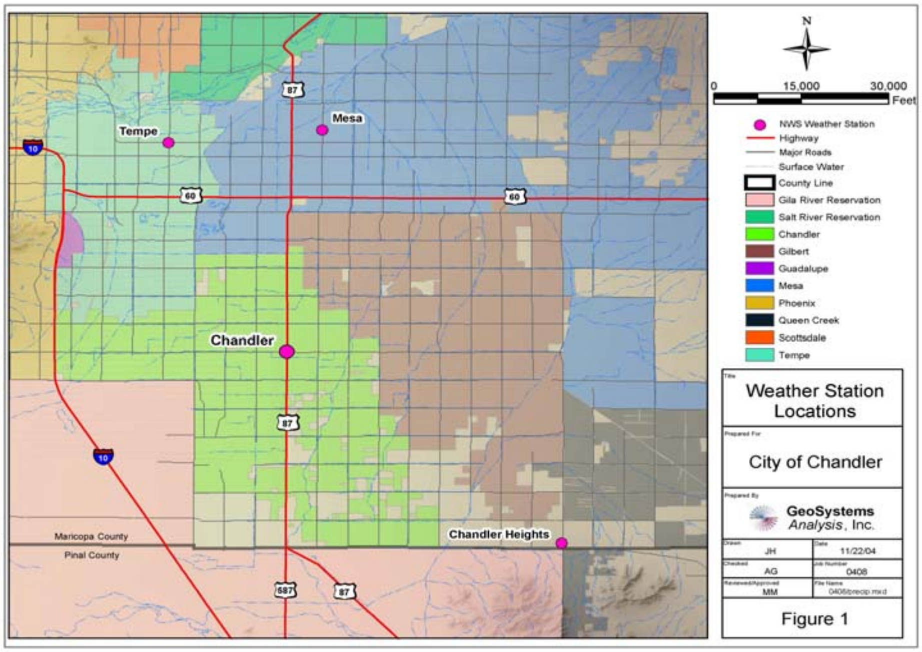

Figure 1. Location of NWS weather stations in the Chandler area.

To characterize daily precipitation intensity and frequency patterns, daily precipitation data from NWS weather stations within a 16 mile radius of downtown Chandler (Figure 1) were analyzed to account for spatial variability and to obtain more than 100 years of daily precipitation data. Except for the period 1896-1904 when only one data set was available, at least two daily precipitation values were averaged for each day to determine: 1) the number of storms per year in the 0.4 to 0.6 inch, 0.6 to 0.8 inch, 0.8 to 1.0 inch, and greater than 1.0 inch; 2) the average precipitation for each precipitation range; and 3) the average number of storm events in each precipitation range for dry, normal, and wet years.

Based on the historical record, the average annual precipitation from the daily average of the four Chandler area stations was 8.3 inches per year, with approximately 12% of the years being dry and 11% being wet. This roughly corresponds to eight normal, one dry and one wet year per every ten year period. Each precipitation year during the period of record was then classified as dry, normal, or wet. Normal years were defined as those when the annual precipitation was within one standard deviation (3.16 inches) of the mean.

Dry and wet years were defined as years having annual precipitation less or greater than one standard deviation from the mean, respectively. Figure 2 shows annual precipitation and the dry, normal, and wet years for the Chandler area.

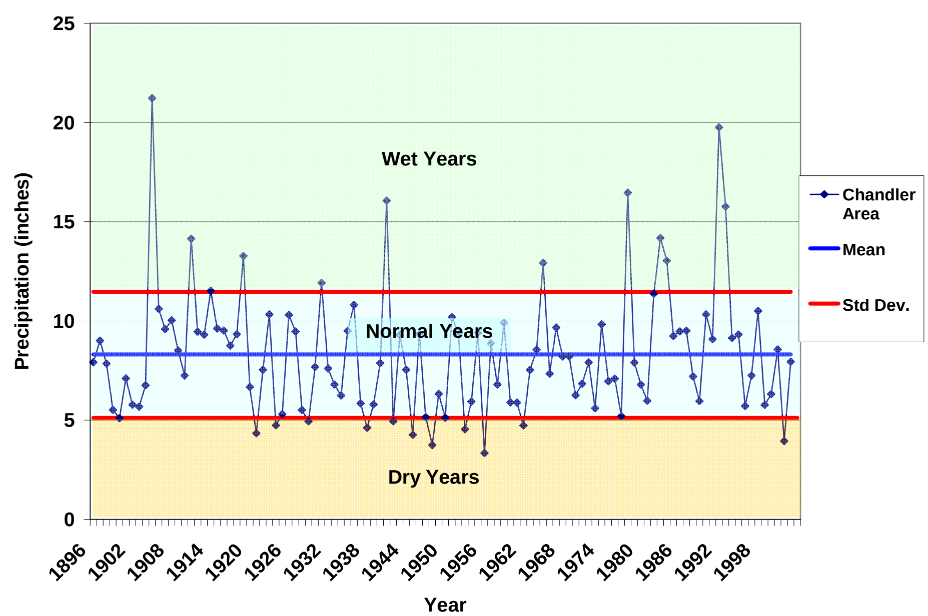

Figure 2. Annual precipitation characteristics for Chandler stations.

Table 1. Average cumulative precipitation per event, average number of events per year and percent of total annual precipitation for each precipitation range (average of four stations)

Precipitation Range (inches)	0 - 0.2	0.2 – 0.4	0.4 - 0.6	0.6 - 0.8	0.8 - 1.0	Above 1.0
	Average precipitation per event (inches)					
Dry Year	0.07	0.29	0.48	0.70	0.90	1.46
Normal Year	0.08	0.29	0.49	0.69	0.91	1.36
Wet Year	0.08	0.30	0.50	0.70	0.90	1.43
	Average number of events per year					
Dry Year	17.4	4.5	1.5	0.5	0.3	0.3
Normal Year	20.1	6.1	2.9	1.6	0.9	1.0
Wet Year	27.1	8.9	5.2	2.8	1.8	3.0
	Percent of total annual precipitation					
Dry Year	29 percent	30 percent	16 percent	8 percent	7 percent	10 percent
Normal Year	19 percent	23 percent	18 percent	14 percent	10 percent	16 percent
Wet Year	14 percent	17 percent	17 percent	13 percent	10 percent	28 percent

Dry, normal, and wet precipitation years were further characterized by taking the weighted average (based on years in record) of the number of storms in each precipitation range and the average total precipitation per storm event (Table 1). The number of events per precipitation range decreases with increasing precipitation intensity. Moreover, the increase in average number of events per year between the dry, normal and wet years is most significant for the larger precipitation ranges.

Stormwater Runoff Analysis

Methods to estimate stormwater runoff from various surfaces rely on estimates of the surface roughness and permeability. These values are derived directly from knowledge of a particular land surface, or indirectly from land use classification data. Two approaches were taken to define land surfaces in Chandler: land surface cover (i.e. impervious, turfgrass), and land use classification (i.e. zoning type). In the land surface cover approach, the land surface was divided into six cover categories, for which runoff curve numbers were estimated using the SCS method (SCS, 1986). In the land use classification approach, the land was divided into ten land use categories based on available land use data to estimate the extent and distribution of various surface types. A single composite runoff curve number (SCS, 1986) was then used to describe runoff from the mix of surfaces within each land use category.

The various land surface covers were estimated using city, county and state geographic information system (GIS) land use data and aerial photos. The accuracy of this approach was somewhat limited by the fact that the actual land use, determined from the aerial photos, did not always agree with the GIS-listed land use which includes intended as well as actual land use. Additionally spatial errors in the GIS plots can cause errors in surface cover estimates. Likewise, errors in the land use category approach can occur when actual land use does not agree with current zoning specifications.

Land Surface Cover Approach

The first approach used to derive land surface data for stormwater runoff modeling was to determine the extent of various surface covers in the city, and to model runoff from each surface type as a continuous, homogenous surface. For this approach, all surface area in the city was classified as impervious, turfgrass, agriculture, vacant, water, or other. Estimated surface areas and assigned curve numbers for each of the land surface covers is shown in Table 2.

Table 2. Estimated land cover percentages

Land Cover	SCS Curve Number	Total Surface Area (Acres)	Percent of Total
Impervious	98	11300	28 percent
Turf	66	4900	13 percent
Agriculture	75	7100	18 percent
Vacant	80	5500	15 percent
Water	N/A	400	1 percent
Other	85	9800	25 percent
Chandler Total		**39000**	**100 percent**

Impervious Surface Analysis. The percent impervious surface was estimated by three different methods: a) City land use classification and aerial photos; b) the Arizona Impervious Surface Area (AZ ISA) GIS data layer (ADWR 2001), and c) previously published ADWR land use categories (ADWR 1991). For the City land use classification approach, aerial photos were analyzed and test sections were selected for each of Chandler's 43 land use categories to estimate the amount of roads, sidewalks, and rooftops. The percent impervious surface area in each land use category was then estimated by scaling the fraction of impervious surface observed in each test section to the total surface area of that category. Using this method, the total impervious surface cover in Chandler was estimated to be 11,300 acres. The AZ ISA data provides estimated ranges of percent impervious surface on a 1-km grid from satellite data (Figure 3). Using this method, the impervious surface in Chandler was estimated to be 10,500 acres. The third estimate of impervious surface cover for Chandler was made by combining the 43 Chandler land use categories were into the 12 ADWR land use categories specified in ADWR (1991), and then using the ADWR land use-impervious surface relationship to estimate the total impervious surface for Chandler as 8,100 acres.

The land surface cover classification estimate of 11,300 acres of impervious surface area (Table 3) using Chandler GIS and aerial photography data is believed to be the most reliable estimate because it is the most direct, current, and site-specific. The ADWR estimates are based on Phoenix land use characteristics in the early 1990s, which may not accurately reflect the current land use in Chandler. The AZ ISA data are more current and generally agree (within 7 percent) with Chandler land use classification estimate.

Turfgrass Analysis. Estimates of turfgrass cover for Chandler were made using aerial photos combined with City land use GIS data. One test section was chosen for each of Chandler's 43 land use categories and the percent impervious surface area in each land use category was estimated by scaling the fraction of impervious surface observed in each test section to the total surface area of that category. Using this method, turfgrass cover was estimated to be 4,900 acres (Table 3). Because of potential error, turfgrass below trees and rooflines was not estimated; consequently, the turfgrass value is considered conservative.

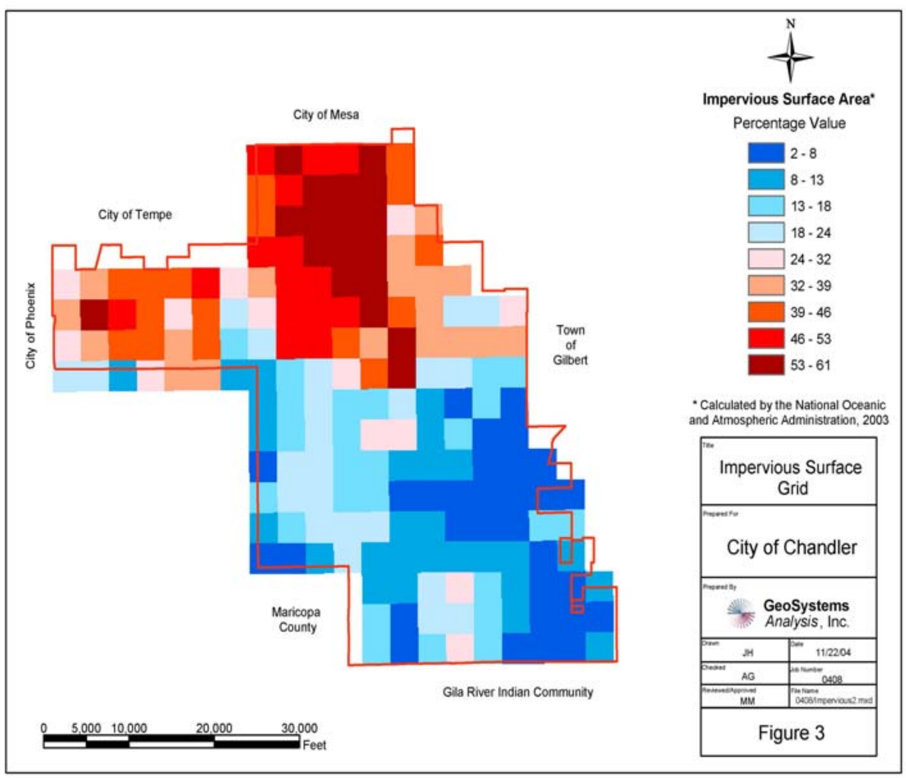

Figure 3. Impervious surface area map generated from AZ ISA map (ADWR 2004).

Agricultural and Vacant Land. Estimates of agricultural and vacant land cover for Chandler were made using Chandler GIS vacant and agricultural land use estimates and subtracting the estimates of impervious and turfgrass surface area within these land uses. City land use estimates for agricultural and vacant land are estimated to be approximately 7,240 and 5,670 acres, respectively. Impervious surface areas were estimated to be 140 and 170 acres for agriculture and vacant land. Therefore, the agricultural and vacant land surface cover in Chandler was estimated to be 7,100 and 5,500 acres (Table 2).

Other. Surface area that does not fall into the impervious, turf, agriculture, water, or vacant categories make up 9,800 acres, or 25 percent of total (Table 2). This is land situated between buildings, pavement and turfgrass. For runoff estimation purposes, this land was assumed to be sparsely vegetated. The ADWR (1991) study of land cover in the Phoenix area found that, on average, sparse vegetative cover made up 23 percent of the total land cover, comparable to the findings here.

Land Use Classification Approach

The second approach to determine land use data for runoff modeling was to combine Chandler's 43 land use classifications into ten broad classifications based on ADWR's (1991) study of drywell recharge in Phoenix. All City land was grouped into the following general land use classifications:

- Single Family Residential:
- Multi Family Residential:
- Commercial
- Industrial and Airports
- Schools, Churches, Hospitals
- Infrastructure
- Parks, Golf Courses
- Agriculture
- Water
- Desert, Vacant Land

The surface area for each of the ten land use categories was determined by summing the areas of the land use classifications within each category. Table 3 shows the total surface area and percent of total land for each category. These total surface areas were then combined with composite runoff values from the literature to model runoff.

Table 3. Estimated land use category percentages

Land Use	SCS Curve Number	Estimated Surface Area (Acres)	Percent of Total
Single Family Residential	91	13,500	35 percent
Multi-Family Residential	94	1,500	4 percent
Commercial	96	2,000	5 percent
Industrial, Airports	92	2,300	6 percent
Schools, Churches and Hospitals	92	1,200	3 percent
Infrastructure	98	1,900	5 percent
Parks, Golf Courses	78	3,300	9 percent
Agriculture	75	7,200	19 percent
Desert, Vacant Land	80	5,700	15 percent
Chandler Total		**38,600**	**100 percent**

Drywell Analysis

Drywells are used extensively in Chandler's storm water management system. In commercial, industrial, school, church, and hospital areas, drywells are often directly connected to impervious surfaces, whereas in residential areas, drywells are more typically associated with stormwater retention basins. In both cases, the drywells disposal of stormwater runoff by routing it to higher permeability soils in the subsurface.

Table 4. Drywells by study land use classification

Land Use	City Drywell Count	Percent of City Drywells	Estimated Total Drywells**
Single Family Residential*	795	41 percent	1548
Multi Family Residential*	241	12 percent	470
Commercial	280	14 percent	545
Industrial and Airports	52	3 percent	101
Schools, Churches, Hospitals*	263	14 percent	512
Infrastructure	54	3 percent	105
Parks, Golf Courses	55	3 percent	107
Agriculture	8	0 percent	16
Water	58	3 percent	113
Desert, Vacant Land	126	7 percent	245
Total	**1932**	**100 percent**	**3763**

*Includes passive open spaces
**Assumes all drywells follow a similar land use classification as Chandler verified drywells

The ADEQ Drywell Registration Database and Chandler drywell GIS layers were combined with aerial photos to determine drywell characteristics. The ADEQ database contains almost twice as many drywells as the Chandler database, however, the latter have been ground-truthed. So, the ADEQ data was assumed to be more accurate with respect to the total number of drywells, and Chandler data were assumed to be more accurate regarding location. Therefore, the number of drywells per land use category was estimated by multiplying the percent of drywells per land use (from Chandler data) by the total number of drywells in the ADEQ data. These estimates were then combined into the ten ADWR land use categories (Table 4).

The Chandler drywell data shows that most drywells are located in stormwater retention basins (Figure 4). Stormwater retention basins are required to be constructed such that the water depth resulting from a 100-year, two-hour storm is limited to a maximum of three feet and the percolation rates are sufficient to drain the basin in less than thirty-six hours. These basins are typically planted with turf grass and irrigated. For vacant land and agricultural areas, it was assumed that retention basins are on-site, non-irrigated, and have native vegetation.

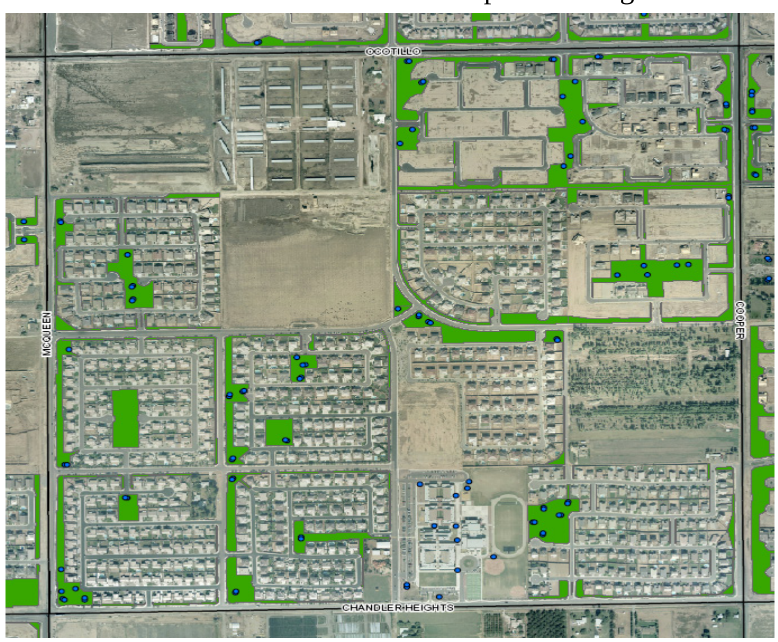

Figure 4. Example of drywell association with retention basins

Stormwater Runoff Estimates

In estimating stormwater runoff from precipitation and land surface cover data, the following assumptions were made:

1) All runoff is retained in either retention basins or drywells within Chandler.
2) Water that would be pumped from the older retention basins in downtown Chandler only collects during large storms, and is an insignificant percent of the total surface water runoff budget.
3) On average, precipitation is uniformly distributed throughout Chandler, and can be classified as described.
4) The Soil Survey for Eastern Maricopa County (SCS, 1974) is adequate for estimating soil types within Chandler.
5) Land cover and land use types discussed above were used.

Stormwater runoff depth from the land surface cover and the land use category estimates was calculated for each of the average storm events per precipitation range using the SCS-CN method (SCS, 1986). Depending on the CN, initial abstractions range from 0.04 to 0.82, below which no runoff is predicted. Estimated storm water runoff volumes were then calculated by multiplying the estimated runoff depth by the number of precipitation events per precipitation range per year. Runoff volumes from all storms for dry, normal, and wet years were then combined for an annual total runoff volume for dry, normal and wet years for land surface cover and land use.

Table 5. Estimated annual runoff volumes by surface cover type

Surface Cover	Curve Number	Initial abstraction (inches)	Dry	Normal	Wet
			Runoff (afa)		
Impervious	98	0.04	1870	4130	8800
Turf	71	0.82	20	40	140
Agriculture	81	0.47	30	70	230
Vacant	87	0.30	40	120	360
Other	96	0.08	170	480	1350
Total Runoff			**2130**	**4840**	**10880**
Total Precipitation			**13550**	**24810**	**47200**
Percent of Precipitation to Runoff			**16 percent**	**20 percent**	**23 percent**

Depending on the precipitation year and the method, estimates of total runoff range from 1,500 to 10,900 afa. Table 5 shows the estimated annual runoff volumes for the surface cover type approach. Runoff as a fraction of precipitation increases from dry to wet years resulting in almost a five-fold increase in runoff. The land use category estimates were consistently less than the surface cover type runoff estimated volumes, though the variance decreased with increasing precipitation (Tables 5 and 6). Table 6 also shows the estimated annual runoff volumes by precipitation range for the land use category method. Approximately half the predicted stormwater runoff occurs from precipitation events greater than 1 inch per day, with over 90 percent of the predicted runoff occurring from events greater than 0.4 inches per day.

Table 6. Estimated annual runoff volumes by precipitation range for land use categories

Precipitation Year	Precipitation Range (inches)						
	0 – 0.2	0.2 - 0.4	0.4 – 0.6	0.6 – 0.8	0.8 – 1.0	Above 1.0	TOTAL
Runoff (afa)							
Dry	6	196	265	211	235	531	**1500**
Normal	7	274	572	664	633	1525	**3690**
Wet	11	411	1060	1187	1271	5121	**9070**
Runoff as Percent of Precipitation							
Dry	0 percent	14 percent	18 percent	15 percent	16 percent	37 percent	**11 percent**
Normal	0 percent	7 percent	16 percent	18 percent	17 percent	41 percent	**15 percent**
Wet	0 percent	5 percent	12 percent	13 percent	14 percent	57 percent	**19 percent**

The SCS-CN method is generally considered appropriate to model storms greater than 0.5 inches per day (SCS, 1986). Estimated runoff values from all precipitation events in the Chandler area smaller than 0.5 inches per day ranged from 12 to 25 percent, consequently, the error associated with using the SCS-CN method in this range is low. The primary source of error is the assigned curve number: relatively small changes in the curve number could result in an approximately 25 percent or greater decrease or increase in predicted runoff.

Groundwater Recharge Estimates

Runoff flowing to retention basins and drywells will either evaporate/evapotranspire or infiltrate into the soil. Captured stormwater entering drywells contributes directly to groundwater recharge as it bypasses the root zone of most plants, and is unlikely to evapotranspire. Water infiltrating into surface soils of retention basins may either evapotranspire or recharge to groundwater. Finally, a fraction of the precipitation that does not run off and instead directly infiltrates through turf-grass and agriculture soils will recharge as a result of irrigation in excess of the evapotranspirative plant needs.

The two different runoff estimation methods require different recharge estimates. The land surface cover approach does not identify the runoff source or capture areas, consequently the amount of recharge can only be approximated using a global factor. Conversely, the land use categories are amenable to deriving different recharge estimates for each of the categories.

Groundwater Recharge from Surface Cover Approach

In-situ monitoring in stormwater retention basins in southeastern Arizona over a three year period in indicated that 36 percent, 43 percent, and 80 percent of stormwater runoff became groundwater recharge in dry, normal, and wet years, respectively (GSA, 2004). The referenced study area receives approximately 75 percent more precipitation (at 14.8 inches per year) than the Chandler area. However, Chandler retention basins contain drywells and are irrigated, maintaining high moisture contents that facilitate recharge. Therefore, these recharge values are considered to provide a conservative estimate of groundwater recharge rates in Chandler retention basins.

Potential groundwater recharge from land surface cover runoff were estimated by multiplying the recharge factors of 36, 43, and 80 percent by predicted runoff for dry, normal, and wet years, respectively. Groundwater recharge rates determined by this method ranged from 770 to 8,700 afa depending on the precipitation year (Table 7). Over ten years (8 normal, 1 dry, 1 wet), the average estimated groundwater recharge from stormwater capture is approximately 2,610 afa.

Groundwater Recharge from Land Use Category Approach

Recharge in the Land Use Category approach was estimated by grouping the ten land use categories into three general categories, each with its own assumptions for estimating potential recharge:

Single Family Residential, Multi Family Residential, School, Hospitals, Churches, and Park Land Use:

- All stormwater runoff reports to retention basins containing drywells in open passive space.
- The depth of stormwater reporting to the basins is calculated from the total stormwater runoff volume divided by retention basin area.
- Average pan evaporation rate for Chandler is 0.3 inches per day (NOAA, 1983).
- Stormwater runoff collected in the retention basins drains within two days before the next irrigation and is subject to 0.6 inches of evaporation (0.3 inches per day).
- Evapotranspiration is negligible because retention basins are landscaped with turfgrass irrigated on average every 48 hours (Capps, 2004).

Commercial, Infrastructure, and Industrial Land Use Categories:

- Runoff from all surfaces reports directly to drywells and is recharged to groundwater.

Agriculture and Vacant Land Use Categories:

- Runoff from all surfaces reports to retention basins without drywells or irrigation. The majority of runoff is lost to evapotranspiration and groundwater recharge is negligible.

Table 7. Estimated groundwater recharge summary

Source	Dry Year	Normal Year	Wet Year
	Estimated Groundwater Recharge (afa)		
Land Surface Cover Estimates	770	2080	8700
Land Use Category Estimates	1150	3050	7610
Agriculture and Turf grass Deep Percolation	690	1250	2230
Total Land Cover Type Estimate (afa)	**1460**	**3330**	**10930**
Land Cover Type Estimate 10 Year Average (afa)	**3900**		
Total Land Use Category Estimate (afa)	**1840**	**4300**	**9830**
Land Use Category Estimate 10 Year Average (afa)	**4610**		

For the land use category method, stormwater runoff is estimated to contribute from 1150 to 7,610 afa to potential groundwater recharge depending on the precipitation year (Table 7). Over ten years (8 normal, 1 dry, 1 wet), the average estimated groundwater recharge rate from storm water runoff is approximately 3,320 afa. The variance from dry to wet years in the land use category recharge estimates is less than the surface cover recharge estimates, and the ten-year average is greater.

Groundwater Recharge from Precipitation Directly Infiltrating into Turfgrass and Agricultural Land

Precipitation that does not result in stormwater runoff either evaporates or infiltrates into the soil profile. Most precipitation infiltrating into natural southwestern deserts returns to the atmosphere through evapotranspiration. However, in irrigated agriculture and turfgrass areas, the soil profile is maintained at high moisture content, and irrigation is supplied in excess of plant consumptive use in order to prevent the buildup of salinity in the soil. Consequently, groundwater recharge will occur from a portion of precipitation infiltrating into turfgrass and agriculture land. To estimate recharge from precipitation infiltrating into turfgrass and agriculture areas, it was assumed that a minimum leaching factor of 20 percent is required to reduce root zone salinity below adverse levels (Ayers and Westcot, 1989, Turgeon, 1999).

Under these assumptions, and depending on the precipitation year, estimated potential recharge from direct precipitation infiltrating into turf grass and agriculture ranges from 690 to 2,230 afa (Table 7). Over 10 years (8 normal, 1 dry, 1 wet), the average estimated potential recharge rate is approximately 1,290 afa.

Conclusions

This study provides a preliminary assessment of the potential increase in groundwater recharge that has resulted from urbanization and stormwater retention in the City of Chandler. Pre-human recharge rates for Chandler were estimated to be 191 afa. Groundwater recharge estimates using two different approaches indicate that the amount of estimated recharge is strongly influenced by the assignment of surface cover and land use characteristics and the incidence of above average precipitation (wet years). These groundwater recharge estimates indicate that urbanization, stormwater retention and the use of irrigated turfgrass has potentially increased groundwater recharge rates by as much as 3900 to 4600 afa over an average ten year period within the City of Chandler.

The estimated potential groundwater recharge rates should only be considered a first approximation. A conservative set of assumptions have been followed in order to minimize positive bias in the runoff assumptions and deep percolation estimates in irrigated lands. Errors that could increase the amount of estimated groundwater recharge include greater stormwater runoff than estimated, the existence of drywells and irrigated retention basins that capture runoff from vacant and agricultural land, and lower irrigation efficiencies (higher leaching factors). Errors that could decrease the amount of estimated groundwater recharge include lower drywell efficiency in commercial, industrial, and infrastructure areas, and higher evaporation and evapotransipiration in retention basins.

References

ADWR, See Arizona Department of Water Resources.

Arizona Department of Water Resources, 1991. "Drywell Recharge and Contaminant Loading in Metropolitan Phoenix, Arizona", prepared under Grant #G-009562-1 for the U.S. EPA.

Arizona Department of Water Resources, 2001. Arizona Impervious Surface Area. GIS data layer. Phoenix, Arizona.

Allison, G.B., G.W. Gee, and S.W. Tyler, 1994. Vadose-zone techniques for estimating recharge in arid and semi-arid regions, Soil Soc. Amer. J. 58:6-14.

Anderson, T.W., F.W. Freethy, and P. Tucci, 1992. Geohydrology and water resources of alluvial basins in South-central Arizona and parts of adjacent states, Regional Aquifer-System Analysis- Southwest alluvial basins, AZ and Adj. States, U.S. Geol. Surv. Prof Paper 1406-B, 67 p.

Ayers, R.S., and D.W. Westcot, 1989. Water Quality for Agriculture: Food and Agriculture Organization Drainage Paper, 29 Rev.1. 174 pp.

Capps, Gregg, 2004. Water Resource Manager, City of Chandler. Personal Communication.

Corell, S. W., E. Corkhill, 1994. A regional groundwater flow model of the Salt River Valley-Phase II. Arizona Department of Water Resources, Hydrology Div., Modeling Report No. 8. 92 p.

Gee, G.W. and D. Hillel, 1988. Groundwater Recharge in Arid Regions: Review and Critique of Estimation Methods. J. Hydrol. Proc., 2:255-266.

Gee, G.W., P.J. Wierenga, B.J. Andraski, M.H. Young, M.J. Fayer, and ML. Rockhold, 1993. Variations in water balance and recharge at three western desert sites, Soil Sci. Soc. Amer. J. 58:63-72.

GeoSystems Analysis, Inc., 2004. Project SP-0011 Storm water recharge feasibility analysis. Prepared for the Upper San Pedro Partnership.

LASGRWC. See Los Angeles and San Gabriel Rivers Watershed Council.

Lerner, D.N., A. Issar and I. Simmers, 1990. Groundwater recharge; a guide to understanding and estimating natural recharge. International Contributions to Hydrogeology vol. 8. Heise, Hannover, FRG. 345 pp.

Los Angeles and San Gabriel Rivers Watershed Council, 2003. Water augmentation study Phase II Annual Monitoring Report. 58 pp.

McPhee, J., A. Comrie and G. Garfin. 2004. Drought and Climate in Arizona: Top Ten Question & Answers. Climate Assessment Project for the Southwest (CLIMAS). Tucson, AZ.

Maxey, G.B., and T.E. Eakin, 1949, Ground water in White River Valley, White pine, Nye, and Lincoln Counties, Nevada: Nevada State Engineer, Water Resources Bulletin 8.

National Oceanic and Atmospheric Administration (NOAA), 1982. Technical Report NWS 33, Evaporation Atlas for the Contiguous 48 United States, National Weather Service, NOAA, Washington, D.C.

Pool, D.R., 2004. Variations in climate and natural recharge in Southeastern Arizona. Water Res. Res. Submitted.

Scanlon, B. R., Langford, R. P., and Goldsmith, R. S., 1999. Relationship between geomorphic settings and unsaturated flow in an arid setting: Water Resources Research, v. 35, no. 4, p. 983–999

Scanlon, B. R., Keese, K., Reedy, R. C., Simunek, J., and Andraski, B. J., 2003. Variations in flow and transport in thick desert vadose zones in response to paleoclimatic forcing (0–90 kyr): field measurements, modeling, and uncertainties: Water Resources Research, v. 39, No. 7, p. 1179

SCS. See Soil Conservation Service

Soil Conservation Service, 1986, Urban Hydrology for Small Watersheds, Technical Release 55, 2nd ed., U.S. Dept. Agriculture, NTIS PB87-101580, Springfield, Virginia, June.

Soil Conservation Service, 1974, Soil Survey: Eastern Maricopa and Northern Pinal Counties Area, Arizona. United States Department of Agriculture.

Turgeon, A.F. 1999. Turfgrass Management, 5th Edition. Prentice Hall. 392 pp.