2010

# Estimated area of impervious parking surfaces and the potential groundwater recharge increase through permeable pavement retrofit in the Chino Basin

Zablon Afera Adane

# ESTIMATED AREA OF IMPERVIOUS PARKING SURFACES AND THE POTENTIAL GROUNDWATER RECHARGE INCREASE THROUGH PERMEABLE PAVEMENT RETROFIT IN THE CHINO BASIN

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A Project

Presented to the

Faculty of

California State University,

San Bernardino

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In Partial Fulfillment

of the Requirements for the Degree

Master of Science

in

Environmental Sciences

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by

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September 2010

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## ABSTRACT

California recently declared a state of emergency over drought following three years of below average rain and snowfall. The state has had pronounced water problems over the past few decades as its population increases and its scarce water resources are subsequently more and more depleted. There is a consensus among many involved in water supply in California for finding new sources of water, conservation, and increasing recharge to replenish the groundwater with surface water that would have been lost to run off. Studies of the adjudicated Chino Basin show that land use and drainage decisions have resulted in significant reduction in groundwater recharge. The area within the adjudicated Chino Basin has been progressively transformed from a predominantly agricultural zone to an urbanized area with minimal agricultural activity. The impervious asphalt and concrete associated with urbanization are contributing factors to increased storm-water runoff and reduced rainwater infiltration and recharge to groundwater. This urbanization in the Chino Basin has declined stormwater recharge by 14,000 acre-ft per year with a probable reduction of approximately 30,000 acre-ft per year in the upper watershed. This study investigates the amount of stormwater that could potentially be reinvested as groundwater recharge by simply transforming selected impermeable parking lots of the commercial, industrial and institutional sectors into pervious pavement that allow water to infiltrate rather than be lost as urban runoff. Assuming appropriate selection of materials, successful installation, and long term maintenance of permeable pavements, this project estimates that on average 7,421 acre-feet/year (~2,418,000,000 gallons) of precipitation may be harvested for potential groundwater recharge. These estimates of potential annual rainwater recharge bear directly upon public water policy and are hoped to guide policy makers in the design of ordinances to install permeable paving in the selected commercial, industrial and public parcels of the Chino Basin.

## ACKNOWLEDGMENTS

I would like to express my deepest gratitude to the members of my graduate committee, Dr. Erik Melchiorre, Dr. Joan Fryxell, and Ms. Susan Longville for their continuous support and guidance. I would also like to acknowledge Mr. Mark Wildermuth and Dr. Jeffrey Hwang of Wildermuth Environmental, Watermaster Ken Manning of the Chino Basin for providing me with resources I needed to conduct the research, and Ms. Lisa Pierce and Mr. Aaron Fergeolle for their help in the GIS aspect of the research.

Finally, I would like to thank my entire family for their continuous help and encouragement. I dedicate this paper to my father Dej. Afera Y. Adane and mother Yeromnesh Belete without whom none of this would have been possible. For all those who have their hands in this paper, thank you.

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# CHAPTER ONE

# INTRODUCTION AND BACKGROUND

## Introduction

The Chino Basin is one of twenty adjudicated groundwater basins in California (State of California, 2004). The majority of the Basin is in San Bernardino and Riverside Counties, and is located approximately 50 miles east of Los Angeles (Figures 1 and 2). In terms of its storage capacity, the Basin is amongst the largest in Southern California. It contains approximately 5,000,000 acre-feet of water and can store an additional 1,000,000 acre-feet (Wildermuth Environmental, Inc., 2001; Chino Basin Watermaster (CBWM) Website).

The Chino Basin spans over nearly 235 square miles of the upper Santa Ana Watershed. Although the Basin is also located within Los Angeles and Riverside counties in Southern California, approximately 80% of the Basin lies within San Bernardino County (Wildermuth Environmental, Inc., 2001; CBWM). The Chino Basin shares boundaries with a number of Southern California basins and the San Gabriel Mountains (See Figure 2). Some of the boundaries shared by the Chino Basin and its surrounding are briefly described below.

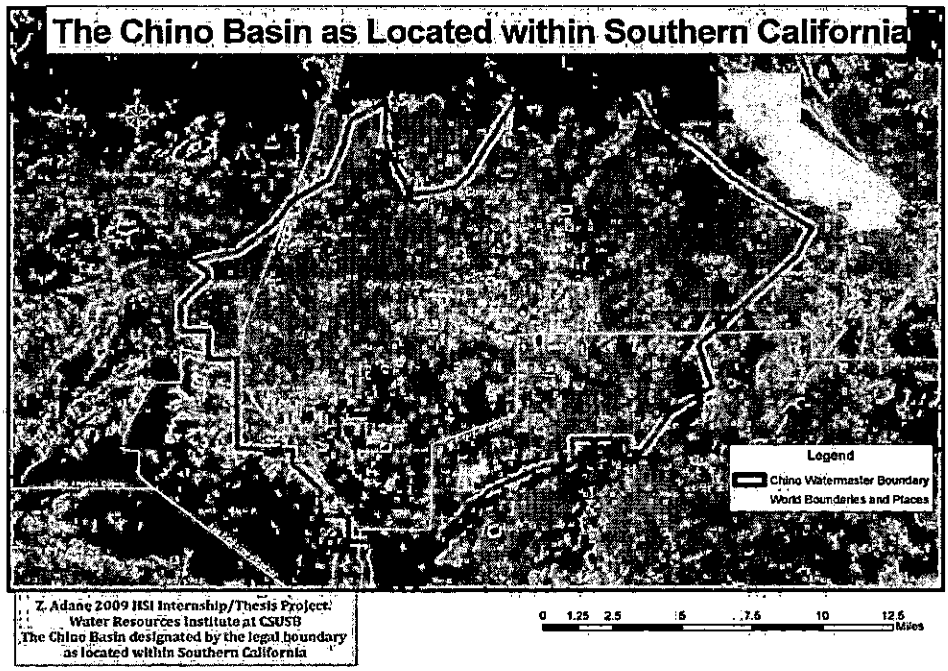


**Figure 1.** The Chino Basin as Located within Southern California.

Adane Z. *Impervious Surfaces and Permeable Pavement Retrofitting in the Chino Basin*. Water Resources Institute Internship/Thesis Project. California State University, San Bernardino, 2009.

The northern boundary of the Chino Basin is shared with the Cucamonga Basin and the San Gabriel Mountains while Temescal Basin shares the Basin's southern end. The Chino Basin is also bound to both Chino and Puente Hills

Basins in the Southwest side of its hydrologic boundary. Similarly, San Jose Hills, Pomona, and Claremont basins share the Basin's northwest hydrologic boundary. The Rialto and Colton Basins border the eastern portion of the Chino Basin (Wildermuth Environmental, Inc., 2001; CBWM).

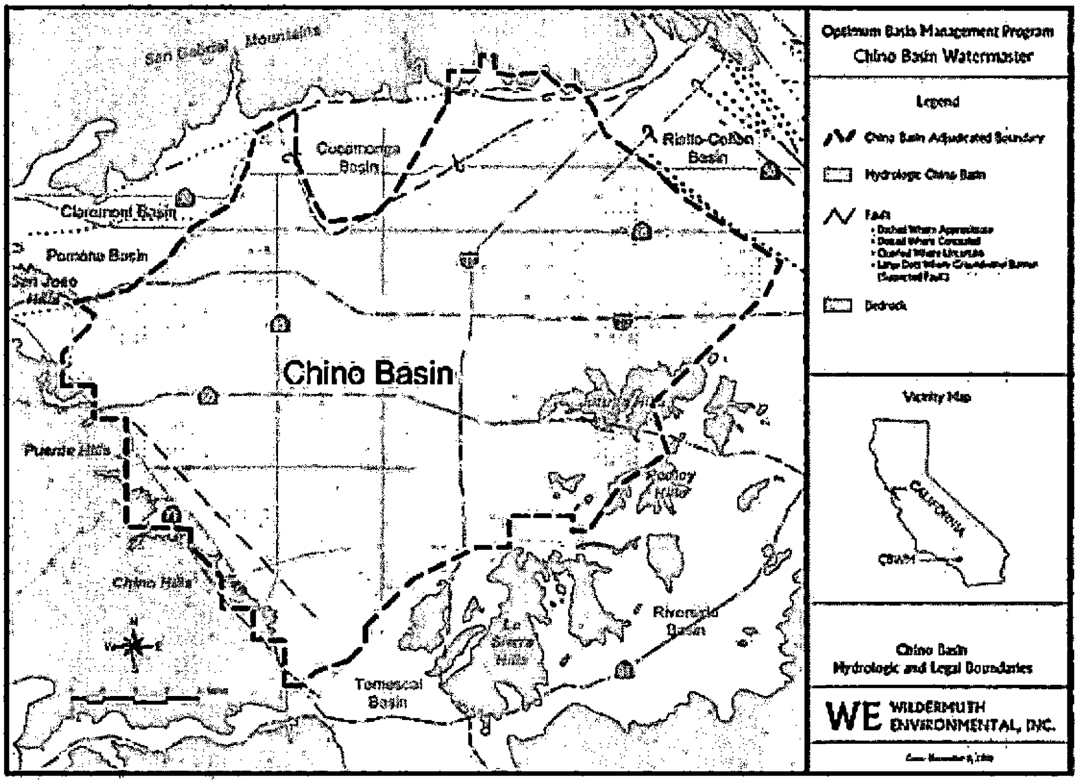


**Figure 2.** The Legal and Hydrological Boundaries of Chino Basin.

Wildermuth Environmental, Inc. *Optimum Basin Management Program Phase II Report*. Prepared for Chino Basin Watermaster, August 1999; p. 2.

The Chino Basin uses the Santa Ana River as its main drainage pathway. The Santa Ana River originates from the San Bernardino Mountains and flows across the Santa Ana watershed to its final destination in the Pacific Ocean (Wildermuth Environmental, Inc., 2001). Along its path, the River enters the Chino Basin at the Riverside Narrows and flows to the Prado Flood Control Reservoir to be discharged at the Prado Dam. The Basin is also intersected by a few seasonal and year-round streams including Chino, San Antonio, Cucamonga, Deer, Day, Etiwanda, and San Sevaine Creeks (Wildermuth Environmental, Inc., 2001).

The Chino Basin is experiencing a rapid growth population trend. In 2001, the population of the Chino Basin was approximately 1.2 million that span over the above mentioned three Southern California counties. The population of the Basin is expected to exceed 1.6 million by the year 2020 (Wildermuth Environmental, Inc., 2001; CBWM). It is obvious that the demand for water from the Chino Basin will continue to rise. Therefore, conservation and efficient use of the Basin's water resources is imperative to accommodate the water demands of its future residents.

In the 1970s, the Chino Basin encountered heavy water production while its water supply and quality were diminishing. Water users of the Chino Basin comprised of different groups were concerned with the trend and planned to take action (Wildermuth Environmental, Inc., 1999; CBWM). In 1975, several water users of the Basin and the State of California began to research water rights allocation concerns within the Basin. During a following period of negotiations, three categories of water users that included agriculture users, industrial users, and water municipalities emerged. Agricultural users, dairy farmers, and the State of California made up the "Agriculture Pool" while the industrial users comprised of the "Non-Agricultural Pool". Water municipalities and other local water agencies were grouped as the "Appropriative Pool" (Wildermuth Environmental, Inc., 1999; CBWM).

In 1975, many from the aforementioned water user groups filed suit in California State Superior Court of San Bernardino County to resolve the problem of water rights allocation in the Chino Basin. Three years later, the court reached a judgment in "Chino Basin Municipal Water District v. City of Chino et al." establishing the Watermaster of the Basin and allocating water rights (Wildermuth

Environmental, Inc., 2001; CBWM). This judgment adjudicated all groundwater rights in the Chino Basin and contains resolutions for water allocation issues for those with water rights and/or who rely on the Basin for their water supply. The Watermaster assigned by the court plans, manages, and implements all the necessary operations of the Basin. The judgment of 1978 established the safe yield of the Chino Basin to be 145,000 acre-feet of water per year (Wildermuth Environmental, Inc., 2001; CBWM). This initial safe yield was divided among the three water user groups based on their water needs. The Agricultural Pool was allocated 82,800 acre-feet per year, 7,366 acre-feet per year for the Non-Agricultural Pool, and 54,834 acre feet of water per year for the Appropriative Pool (Wildermuth Environmental, Inc., 2001; CBWM).

## Geology of the Chino Basin and Its Surroundings

Chino Basin was formed when a geological depression was filled by erosion materials of the Chino Hills, Puente Hills, and the San Gabriel Mountains (Wildermuth Environmental, Inc., 1999). The San Bernardino Mountains consist of the highest point in Southern California. Mount San Gorgonio of these mountains reaches 11, 502 feet in elevation and is the southern-most point in California showing signs of past glaciations (Cramer and others, 2007). The bottom of the Chino basin is comprised of impermeable sedimentary and igneous rocks and serves as the base of the Basin's freshwater aquifer. It is overlain by older alluvium of the Pleistocene Epoch top-layered by younger alluvium of the Holocene Epoch. The top-layer (younger) alluvium can be up to 100 feet thick near as it approaches the mountains (Wildermuth Environmental, Inc., 1999). Because the younger alluvium is located on top of the older alluvium, it is far above the saturation zone. Water wells in this region need to be drilled past the young alluvium layer and well into the older alluvium (approximately 500 feet on average) for any meaningful water yield (Wildermuth Environmental, Inc., 1999). Well capacities in the Chino Basin generally range between 500 and 1,500 gallons per minute (gpm). Modern test pumps performed in the Basin have demonstrated well capacities exceeding 4,000 gpm (Wildermuth Environmental, Inc., 1999). Assuming proper maintenance that include proper long term natural and artificial recharge plans, the Basin has an enormous well production potential to meet its water supply demand.

Faults have significant contribution in the formation of the Chino Basin as well as the constraints and direction of groundwater flow. The Chino Basin is bounded by the same fault system as that uplifted the surrounding mountains (Wildermuth Environmental, Inc., 1999). The location of the faults and groundwater barriers in the freshwater aquifer base of the Basin are displayed in Figure 2. These faults and groundwater barriers provide the external boundaries of the Basin. The magnitude and direction of groundwater flow is also influenced by the presence and location of these faults (Wildermuth Environmental, Inc., 1999). It should be noted that the adjudicated boundaries of the Chino Basin vary from the hydrological boundaries (see Figure 2).

## The Water Cycle and Its Major Components

The water cycle, which is interchangeably known as the hydrologic cycle, describes a constant circulation of water from bodies of water to the atmosphere, surface, and subsurface of earth. This cycle includes evaporation and transpiration, condensation, precipitation, runoff, infiltration. While all the processes are obviously important and significant when discussing water resources and other aspects of the environment, the scope of this thesis project mainly gravitates towards precipitation, runoff and the infiltration processes of the hydrologic cycle. The water cycle accounts for the entire volume of water present on earth; however only a fraction, approximately 1%, of the total volume of water actually passes through the cycle annually (Manning, 1997). "Only about 5 of every 100,000 gallons of the total supply are in motion at any one time and the turnover rate of an individual particle of water in the atmosphere probably averages about 8 to 10 days" (Manning, 1997).

The oceans contain most of the water (salt water) and the polar ice accounts for most of the freshwater on earth. Groundwater contains less than 1% (approximately 0.61%) of the total supply of freshwater which is a testament to its value as a resource (Manning, 1997). Although groundwater accounts for a very low percentage of the total volume of freshwater, it is about 200 times the volume of annual flow of all the rivers in the world (Manning, 1997). The zone of saturation is present in the water table underneath earth's surface; and once volume of water in the water cycle infiltrates this zone, it becomes groundwater (Manning, 1997). Groundwater is a relatively stable process of the hydrologic cycle as it stays underground for millions of years. Its introduction back into the water cycle includes flowing into the ocean and upward springs to the surface (Manning, 1997). As can be seen in Figure 3, processes such as evapotranspiration can draw groundwater into the hydrologic cycle once plant roots and the unsaturated zone extract water from the groundwater table. Artificial drafting via well pumping can also reintroduce groundwater to the mobile hydrologic cycle.

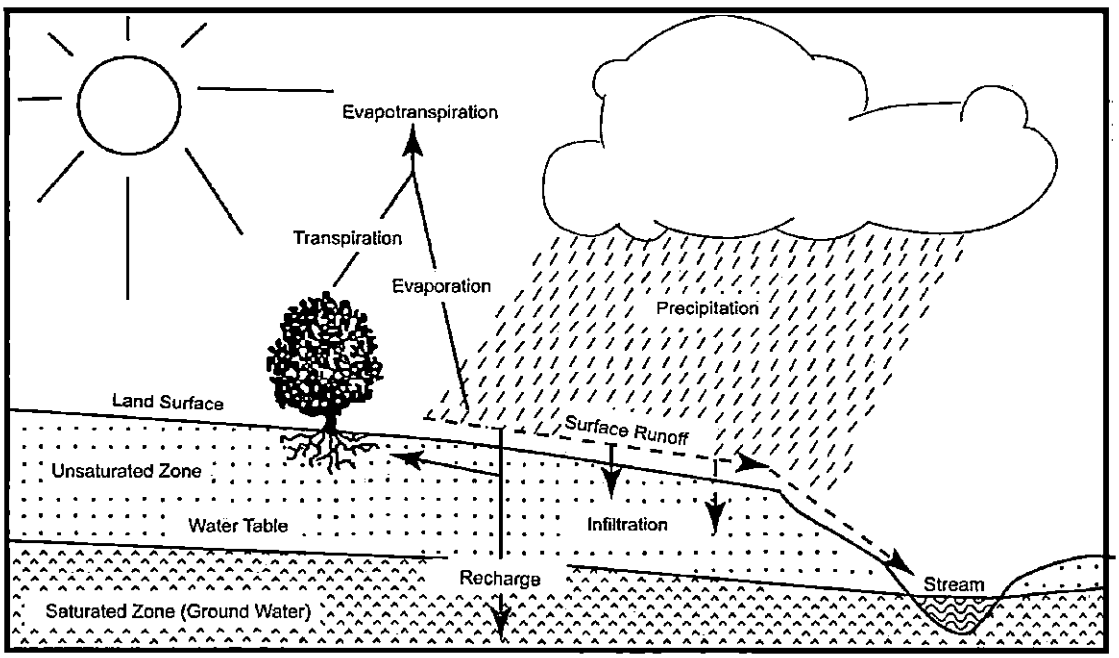


**Figure 3.** The Water Cycle Displaying the Major Components of the Process Including Precipitation, Runoff, and Infiltration.

Charles, E., Behroozi, C., Schooley, J., and Hoffman, J. *A Method for Evaluating Groundwater Recharge Areas in New Jersey*. New Jersey Geological Survey Report, GSR-32, 1993; P. 4.

One of the water cycle processes that are directly linked to the scope of this study is runoff. Runoff is part of the water cycle where water flows in streams, tributaries, rivers, and land. The process of runoff comprises of many integral processes starting from precipitation and is directly influenced by climate, topography and drainage characteristics of the area. Climate and weather conditions determine the volume of water that is supplied through snow and rainfall (Manning, 1997).

The volume of water returned to the atmosphere via evaporation or transpiration is also determined by the climate and the availability of vegetation in the region. Daily moisture patterns, types of storm and precipitation, duration and intensity of such events as well as the distribution over the region affect the magnitude of runoff and are greatly affected by climate (Manning, 1997). On site physical conditions of a region such as its topography, geology, availability or lack of vegetation, as well as soil type tremendously affect runoff (Manning, 1997). In essence, the magnitude of evapotranspiration due to climate and vegetation affects the proportion of precipitation that will be discharged as runoff. Although runoff is natural in rivers and across lands, human alteration of streams through diversions, deforestation of vegetated lands, and construction of buildings and pavements affect the occurrence and severity of runoff (Manning, 1997). Under natural conditions, floods occur when a stream or river does not have the capacity to contain the volume of rainfall and/or snowmelt runoff rushing into its banks (Manning, 1997). The physical conditions such as elevation discussed above as well as climate conditions such as intensity and duration of precipitation also affect runoff and the severity of floods.

As mentioned above, human activities and land use changes of natural makeup have a direct effect on the storage and eventual discharge of precipitation as runoff. In naturally vacant areas where vegetation is present, water collected from precipitation is stored in the soil, plants, and local surface depressions (Konrad, 2003). When these depressions are at their maximum saturation level, the water will gradually flow as runoff through the soil. In comparison, developed areas with significant amount of impervious pavements and structures have minimum ability to retain precipitation (Konrad, 2003). Moreover, vegetations and natural geological formations are removed during grading for construction of structures and access roads, further reducing the components that retain water for a slow percolation (Konrad, 2003). Impermeable modifications reduce the infiltration rate of precipitation into the ground and increase the speed of runoff in concrete channels and local streams. Escalated concrete channelization increases velocity of flow; and depending on the impermeability of the structure, it can reduce or entirely obstruct any infiltration (Konrad, 2003). The construction of impermeable surfaces and concrete channeling are important in urban settings however there are unwanted results. The consequences of urban development include increased peak discharge and frequency of floods as well as loss of water infiltration to the ground (Konrad, 2003).

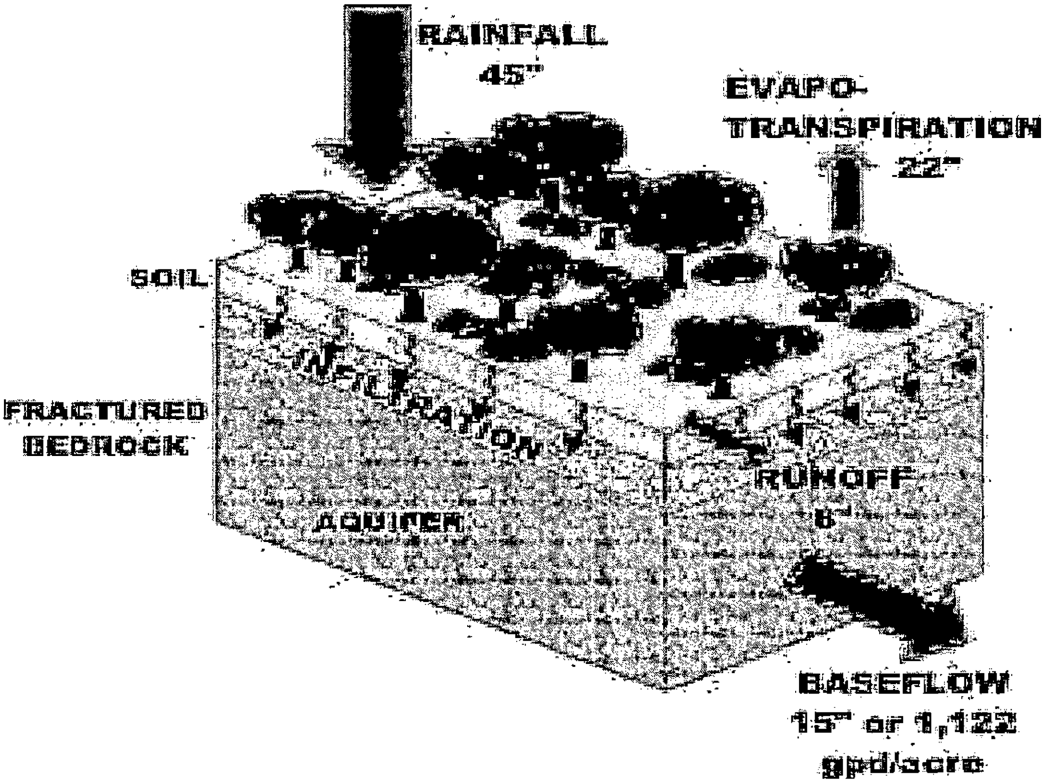


**Figure 4.** Annual Water Cycle for an Average Year Where There is Little or No Alteration Due to Urbanization.

Cahill Associates and Environmental Consultants. *The Sustainable Stormwater Management and Use of Porous Pavements: The Design and Construction of Pervious Pavements*. Powerpoint Presentation, Oregon State University, 6 February 2006.

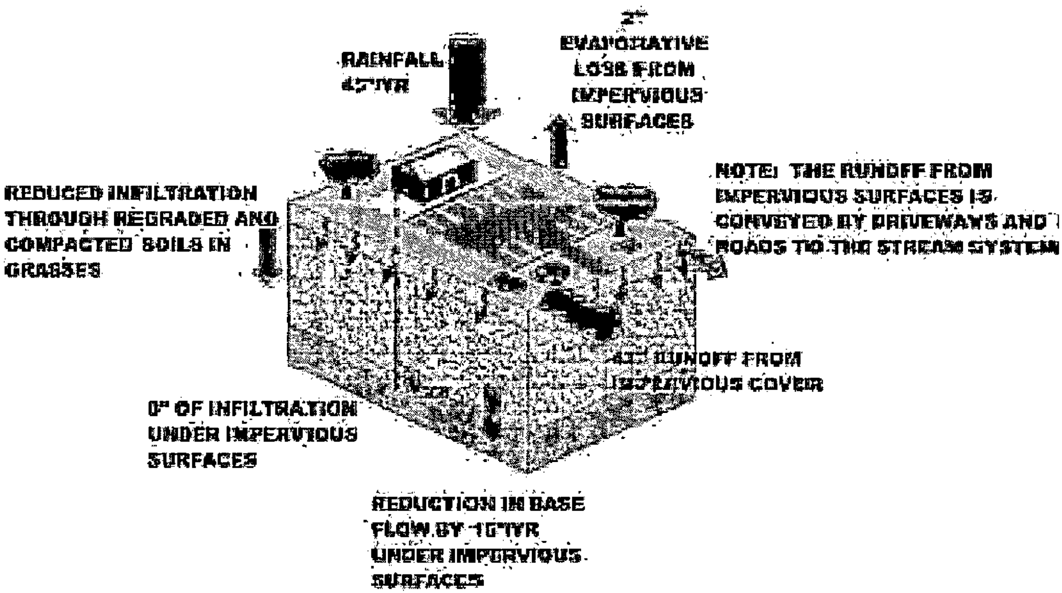


**Figure 5.** Annual Water Cycle for an Average Year Where Significant Alteration Occurred Due to Urbanization.

Cahill Associates and Environmental Consultants. *The Sustainable Stormwater Management and Use of Porous Pavements: The Design and Construction of Pervious Pavements*. Powerpoint Presentation, Oregon State University, 6 February 2006.

## Climate and Precipitation Characteristics of the Chino Basin

The Inland Empire region where Chino Basin is located experiences a semi-arid Mediterranean climate known for its hot, dry summers and cool, wet winters (Cramer and others, 2007). The majority of the rainfall occurs between September and April with alternating intense storms and dry periods. The region also experiences very low relative humidity throughout the year (Cramer and others, 2007). As can be deduced from Figure 3, the average precipitation (rainfall) of the Chino Basin and its surrounding between 1985 and 2005 was nearly 17 inches annually (Metropolitan Water District, 2007). The Chino Basin groundwater is significantly dependent on the natural recharge it receives from this relatively short season of precipitation. The Basin also receives further infiltration from the surrounding mountains as well as from the Santa Ana River (Wildermuth Environmental Inc., 2005). "Other sources of groundwater recharge include underflow from the saturated sediments and fractures within the bounding mountains and hills; recharge of storm water, imported water, and recycled water at spreading grounds; and underflow from seepage across faults. Sources of discharge include groundwater production, rising water within Prado Basin where groundwater that is near or at the ground surface, and underflow to adjacent basins" (Wildermuth Environmental, Inc., 2005). A high evapotranspiration rate is also observed in this area due to a combination of local winds and warm temperature. For example, the precipitation level in the proximal City of Riverside is approximately 9 - 11 inches per year, however, the evapotranspiration rates are between 55 and 60 inches, requiring water to be imported in to this area (Cramer and others, 2007). The fiscal precipitation year was selected for reporting, as it most closely captures the water year in this part of Southern California.

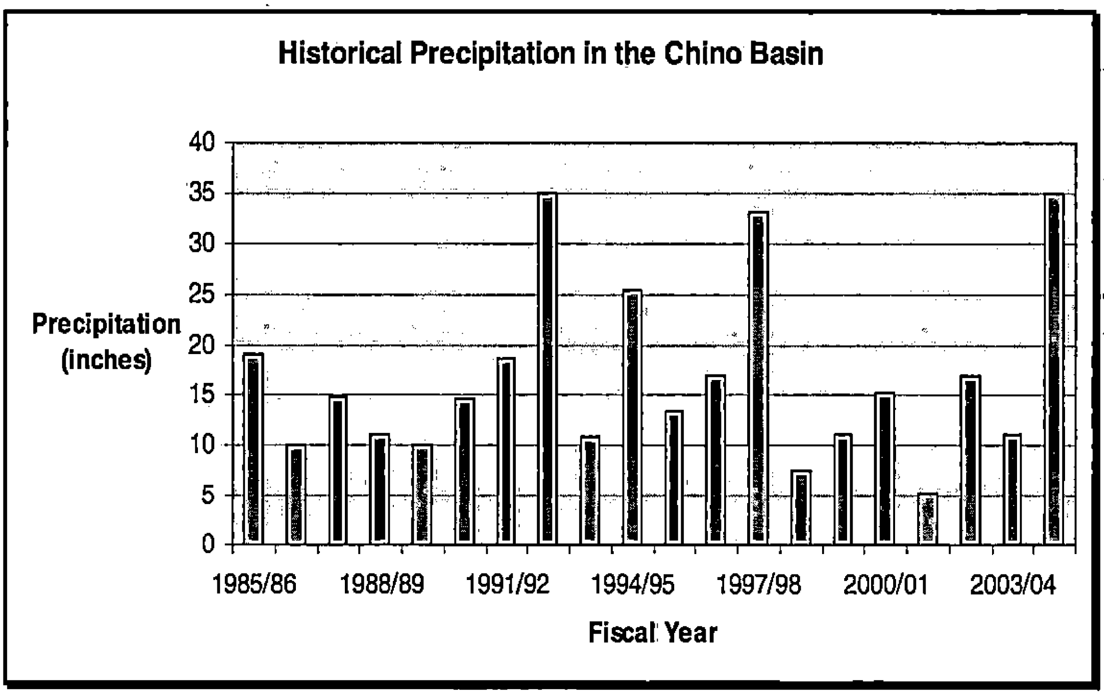


**Figure 6.** Historical Precipitation in the Chino Basin from Fiscal Year 1985 to 2005.

Data Source: Metropolitan Water District of Southern California. *Groundwater Assessment Study. Groundwater Basin Reports: Inland Empire Basins*. 2007.

The most annual rainfall occurred in the 1997/98, 1992/93 and 2004/05 fiscal years at approximately 33, 35, and 35 inches, respectively. The Basin experienced its lowest precipitation of this 20 year timeline in the 2001/02 fiscal year at a little over 5 inches of rainfall.

## The History of Urbanization in the Chino Basin

A series of land use maps developed by Wildermuth Environmental, Inc. are used below to illustrate the history of urbanization in the Chino Basin.

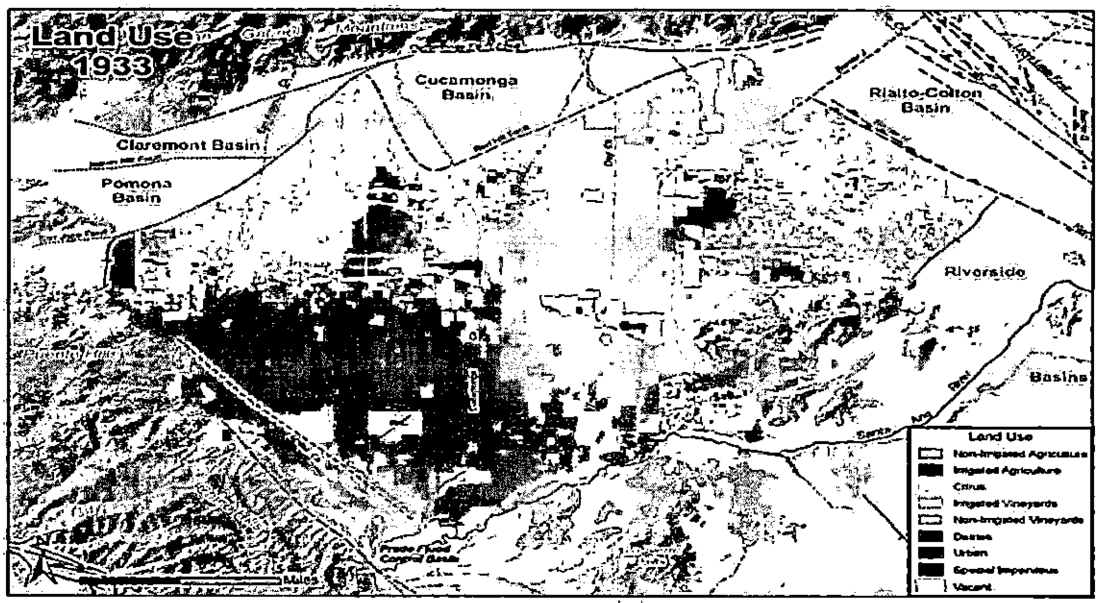


**Figure 7.** 1933 Urbanization Map of the Chino Basin.

Wildermuth M. *Declining Rainwater Recharge in the Chino Basin: Implications for the Watershed and Beyond.* Power Point Presentation. Chino Basin Watermaster, 29 January 2009.

In 1933, the basin was almost completely used for agriculture related uses. Irrigated and non-irrigated agriculture cover the majority of the basin. A significant area of the basin is covered by growing citrus. The urban land use designated is very minimal and the special impervious land uses represented are almost negligible.

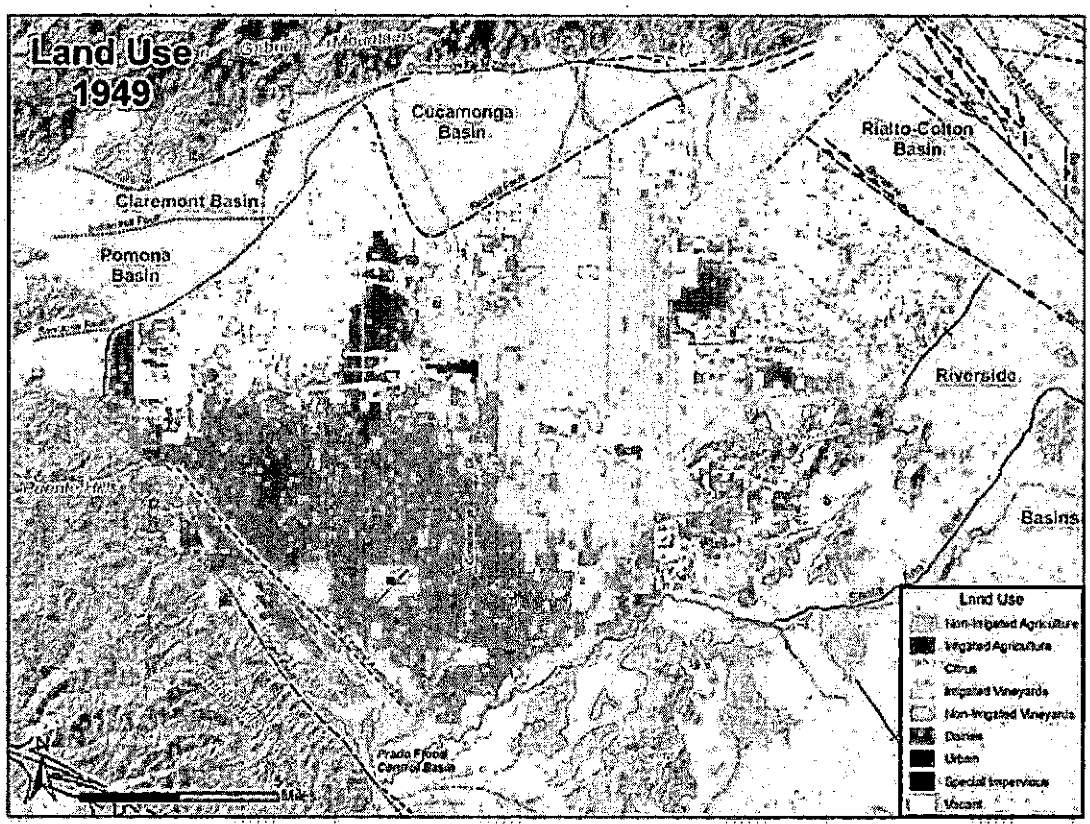


**Figure 8.** 1949 Urbanization Map of the Chino Basin.

Wildermuth M. *Declining Rainwater Recharge in the Chino Basin: Implications for the Watershed and Beyond.* Power Point Presentation. Chino Basin Watermaster, 29 January 2009.

The 1949 urbanization map displays virtually no changes from the 1933 in the amount of land covered by each land use. The majority of the Basin was used for citrus, irrigated, and non-irrigated agriculture along with scattered vineyards.

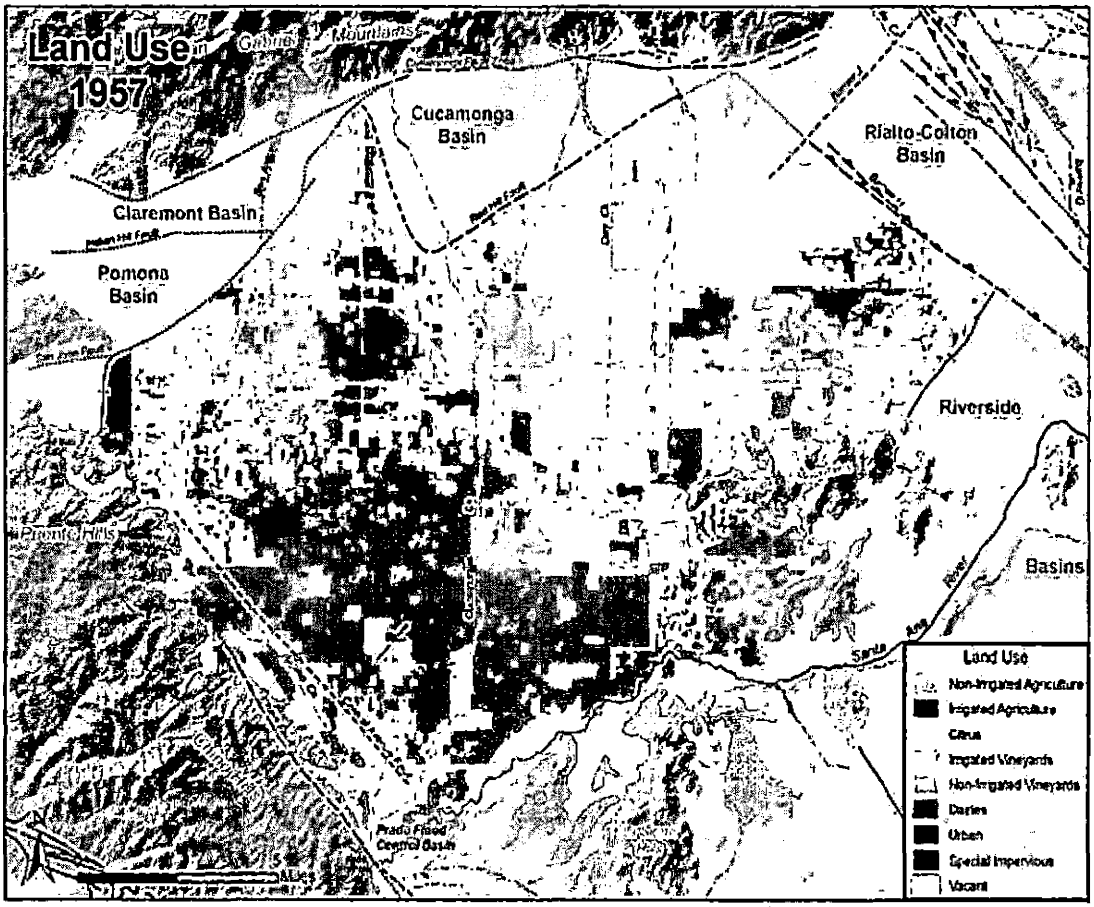


**Figure 9.** 1957 Urbanization Map of the Chino Basin.

Wildermuth M. *Declining Rainwater Recharge in the Chino Basin: Implications for the Watershed and Beyond*. Power Point Presentation. Chino Basin Watermaster, 29 January 2009.

By 1957, there are significant changes in the land use coverage of the Chino basin. The irrigated field crops have remained intact and unchanged while the non-irrigated field crops have significantly diminished over the past eight years. Irrigated and non-irrigated vineyards represented in shades of pink are expanding and dairies are being introduced into the Basin. Urban areas have also expanded slightly as compared to the 1933 and 1949 maps.

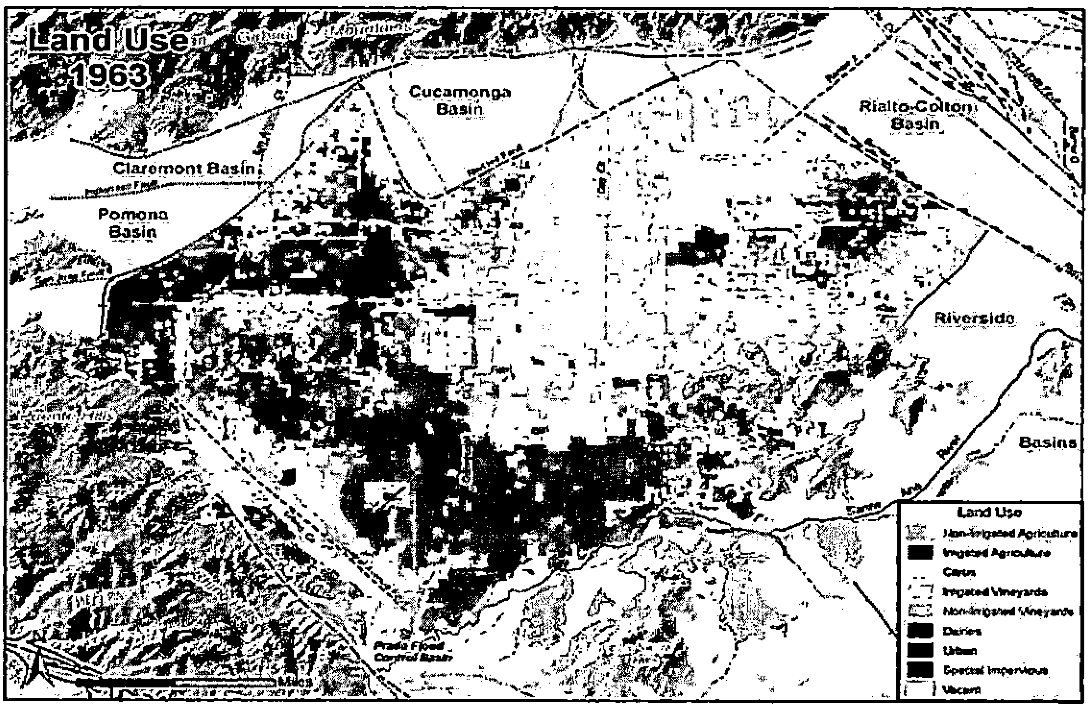


**Figure 10.** 1963 Urbanization Map of the Chino Basin.

Wildermuth M. *Declining Rainwater Recharge in the Chino Basin: Implications for the Watershed and Beyond.* Power Point Presentation. Chino Basin Watermaster, 29 January 2009.

By 1963, the irrigated field crops remain viable while the non-irrigated field crops are again significantly reduced as compared to the 1957 map. The vineyards and dairies continue to expand throughout the Basin. Urban areas and the amount of impervious surfaces have expanded significantly from the previous maps. The urbanization noticeably replaces the Pomona and Claremont areas predominantly used as citrus land uses.

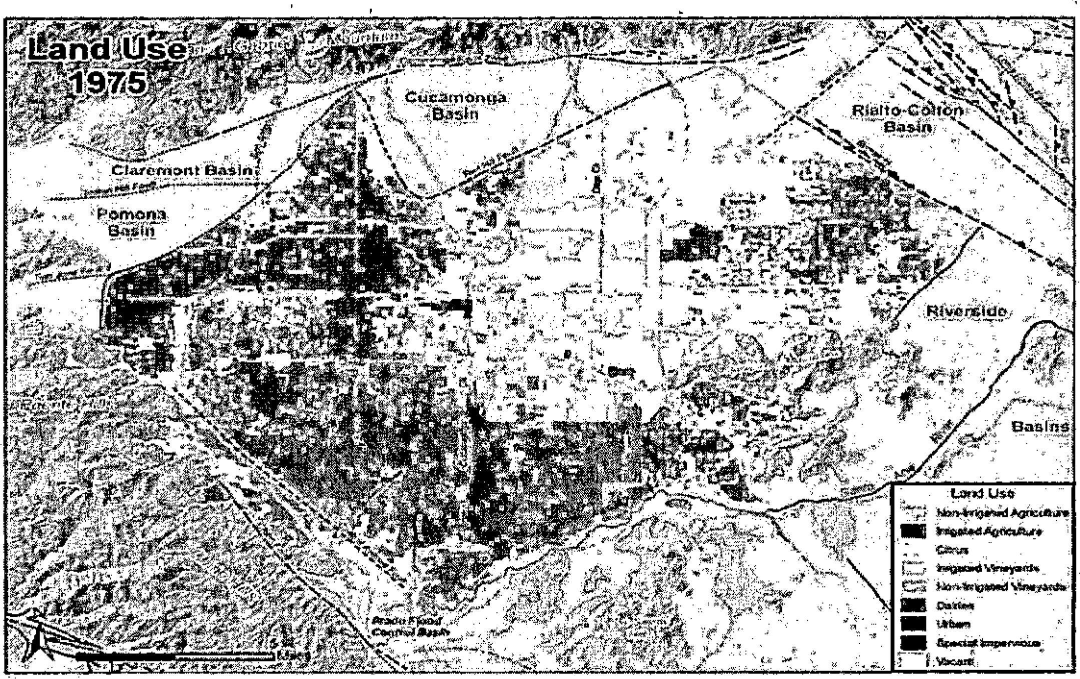


**Figure 11.** 1975 Urbanization Map of the Chino Basin.

Wildermuth M. *Declining Rainwater Recharge in the Chino Basin: Implications for the Watershed and Beyond.* Power Point Presentation. Chino Basin Watermaster, 29 January 2009.

By 1975, there is still a significant area devoted to irrigated field crops, however the non-irrigated agriculture field crops designated have almost disappeared from the Basin. The vineyards that had been expanding are now declining. During this time, dairies continue to expand in the Basin. The urbanized area of the Chino Basin is still growing but at a slightly slower rate than the prior period.

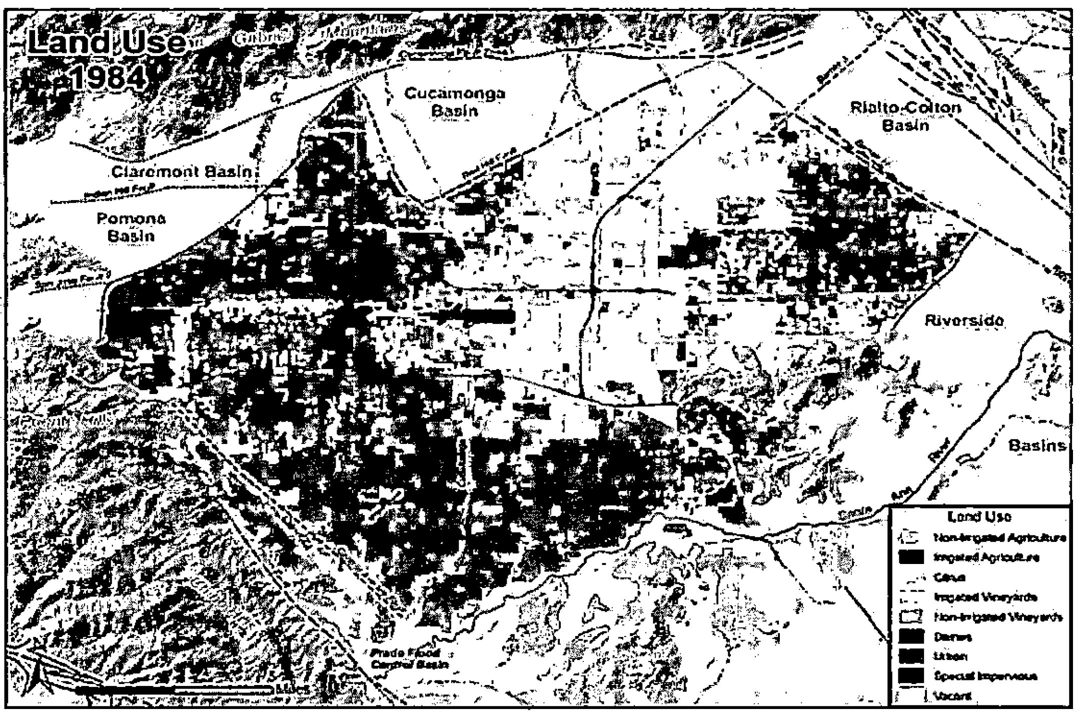


**Figure 12.** 1984 Urbanization Map of the Chino Basin.

Wildermuth M. *Declining Rainwater Recharge in the Chino Basin: Implications for the Watershed and Beyond*. Power Point Presentation. Chino Basin Watermaster, 29 January 2009.

The Urbanized area of the basin is substantially greater than the prior periods. The rest of the land uses have maintained their trend from their previous land coverage. Although the irrigated and non-irrigated agricultural land uses have drastically decreased, the area of land allotted for vineyards is still substantial. Dairies are still expanding in the Chino Hills and Ontario areas in place of irrigated agriculture.

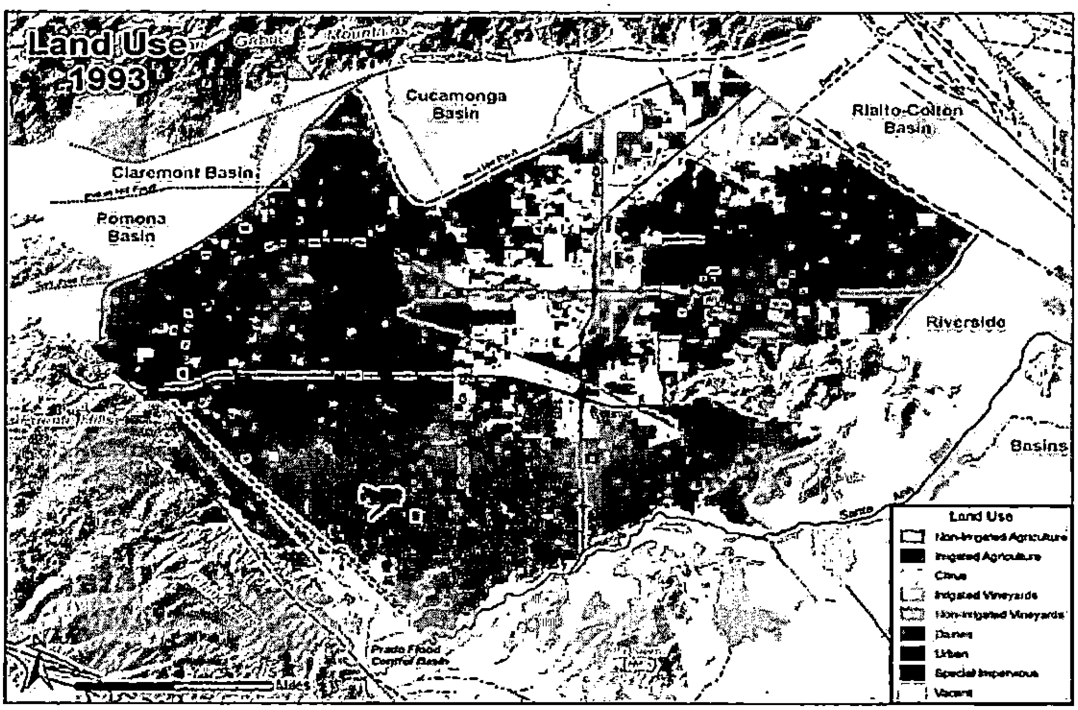


**Figure 13.** 1993 Urbanization Map of the Chino Basin.

Wildermuth M. *Declining Rainwater Recharge in the Chino Basin: Implications for the Watershed and Beyond.* Power Point Presentation. Chino Basin Watermaster, 29 January 2009.

The urbanization map illustrates that the amount of urbanized area in the Chino Basin is significantly greater than prior periods and dominates land coverage over the other land uses. The special impervious that are associated with roads, transportation highways, concrete channels, and other land uses also show substantial growth compared to prior periods. During this period, dairies and vineyards are still viable.

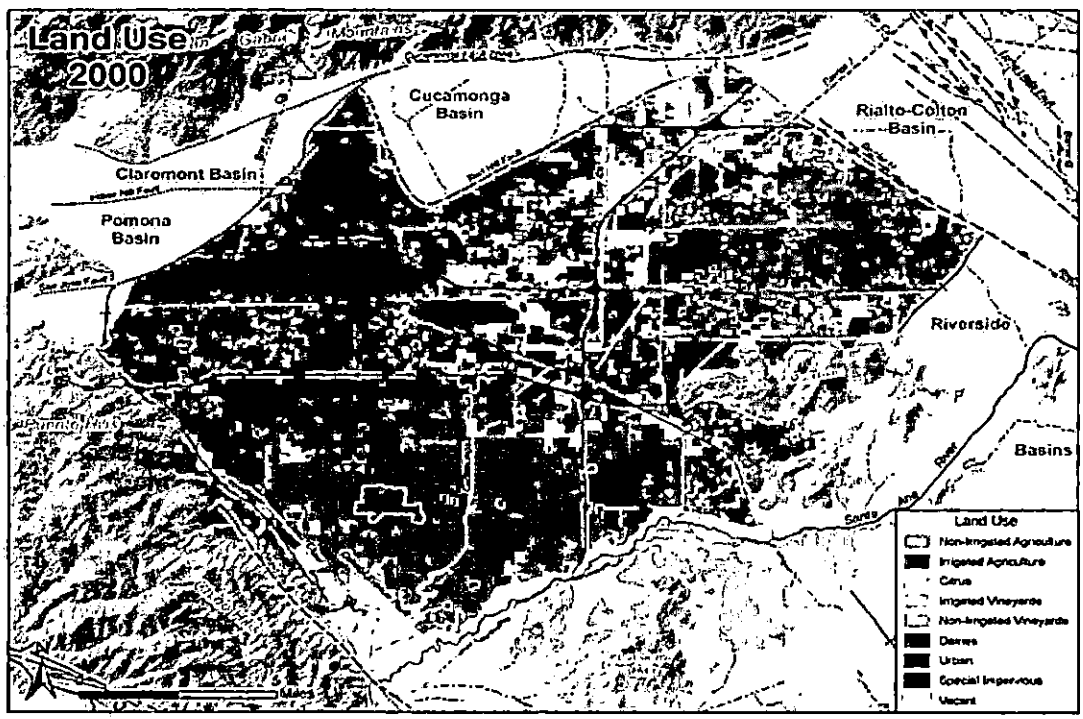


**Figure 14.** 2000 Urbanization Map of the Chino Basin.

Wildermuth M. *Declining Rainwater Recharge in the Chino Basin: Implications for the Watershed and Beyond*. Power Point Presentation. Chino Basin Watermaster, 29 January 2009.

By the year 2000, the Chino basin is completely different as compared to the 1933 urbanization map. The non-irrigated crop fields have almost completely disappeared. The irrigated crop fields are substantially reduced and limited to the south-western part of the basin. The vineyards have almost disappeared and are replaced with urbanized land uses. The dairy farms are still viable co-existing with the irrigated field crops along the Ontario and Chino areas. The urbanized areas are tremendously greater than the prior periods, even when compared to the 1984 and 1993 maps.

## Introduction to Permeable Pavements

Permeable pavement is a particularly simple and effective mechanism to address important natural resources issues and support environmentally sustainable growth. This pavement type allows water to infiltrate while providing dense surface for walking, driving and other activities (Tennis and others, 2004; National Ready Mixed Concrete Association (NRMCA) Website). It serves a great purpose in groundwater recharge by capturing and permeating water to seep into the ground while simultaneously reducing stormwater runoff. The use of permeable pavements is one of the Best Management Practices (BMPs) recommended by the U.S Environmental Protection Agency for managing stromwater runoff on a local and regional scale (Tennis and others, 2004; NRMCA). It is also encouraged for permeable pavements to be used in combination with other smart growth BMPs such as reduction of parking spaces and mixing of land uses (Nisenson, 2005). This pavement technology also helps in sustainable land management by reducing the need for stormwater management structures such as culverts, swales, and retention ponds designed and constructed to temporarily store stormwater runoff in the events of heavy precipitation (Tennis and others, 2004; NRMCA).

## Currently Available Permeable Pavement Types

There are about nine permeable pavement types commercially available for application. Some of the most common of these pavements and their brief descriptions are covered below.

### Pervious Concrete

Pervious concrete is a one of the permeable pavements that are commercially available. The strength of the material allows for a wide range of uses. As a result, it is vastly utilized as a green replacement for impermeable surfaces. Pervious concrete has similar material content as standard Portland Cement but with reduced fine aggregate and high stiffness designed for its porous characteristics (American Concrete Institute (ACI) Committee 522, 2006).

Limited amounts of water and cementing materials are applied to form an adhesive coating formula around aggregate ingredients. In order to create void content within the pervious concrete mix, fine materials such as sand are used at a minimum or completely avoided (Tennis and others, 2004). Permeable and interconnected voids that permeate water are formed using sufficient amount of adhesive to coat and join the aggregate material in this type of pavement. The mixture of open graded ingredients containing Portland Cement, coarsely graded aggregates, adhesive materials and water will yield a hard material with interconnected pores that are between 2 to 8 mm in size and will be able to drain water through the pavement material (ACI Concrete 522, 2006). The void content can range between 18 to 35% with compressive strength of 400 to 4000 psi (ACI Concrete 522, 2006). Pervious concrete will be able to drain water at a rate that ranges between 2 and 18 gallons per minute per square feet (81 to 730 L/min/$m^2$) (ACI Committee 522, 2006).

**Figure 15.** Pervious Concrete Installed in Lincoln, Nebraska.

City of Lincoln Watershed Management: Education. *Pervious Concrete*. Accessed 8 July, 2010.

http://www.lincoln.ne.gov/city/pworks/watrshed/educate/pervious/

While the reduction of fine materials such as sediments increases porosity, it may also reduce strength compared to traditional pavements. However, sufficient strength and durability can be achieved for many applications. Pervious concrete can be used for many pavement functions, however, its primary use is in sidewalk, parking lot, and driveways pavement (Tennis and others, 2004; NRMCA).

Porous Asphalt

Porous asphalt is a bituminous (pitch-black) permeable paving material with all of the structural characteristics of conventional impervious asphalt (Cahill and others, 2003). However, like the above discussed pervious concrete, this pavement type contains very minimal amount of fine particles such as sands. The omission of these fine materials allows water to drain through the pavement. Uniformly graded stone aggregates are placed beneath this pavement to provide void space of approximately 40% (Cahill and others, 2003). The relatively high void percentage is designed to allow rainfall that falls directly onto the pavement as well as inflow from surrounding impervious surfaces to readily infiltrate to the ground (Cahill and others, 2003).

During a storm event, runoff that drains through the permeable asphalt is temporarily held in the stone aggregates as it slowly infiltrates to the underlying soil blanket. The stone aggregate bed is separated from the soil blanket by geotextile filter preventing the downward movement of sediments and fine materials along with the draining stormwater (see Figure 16).

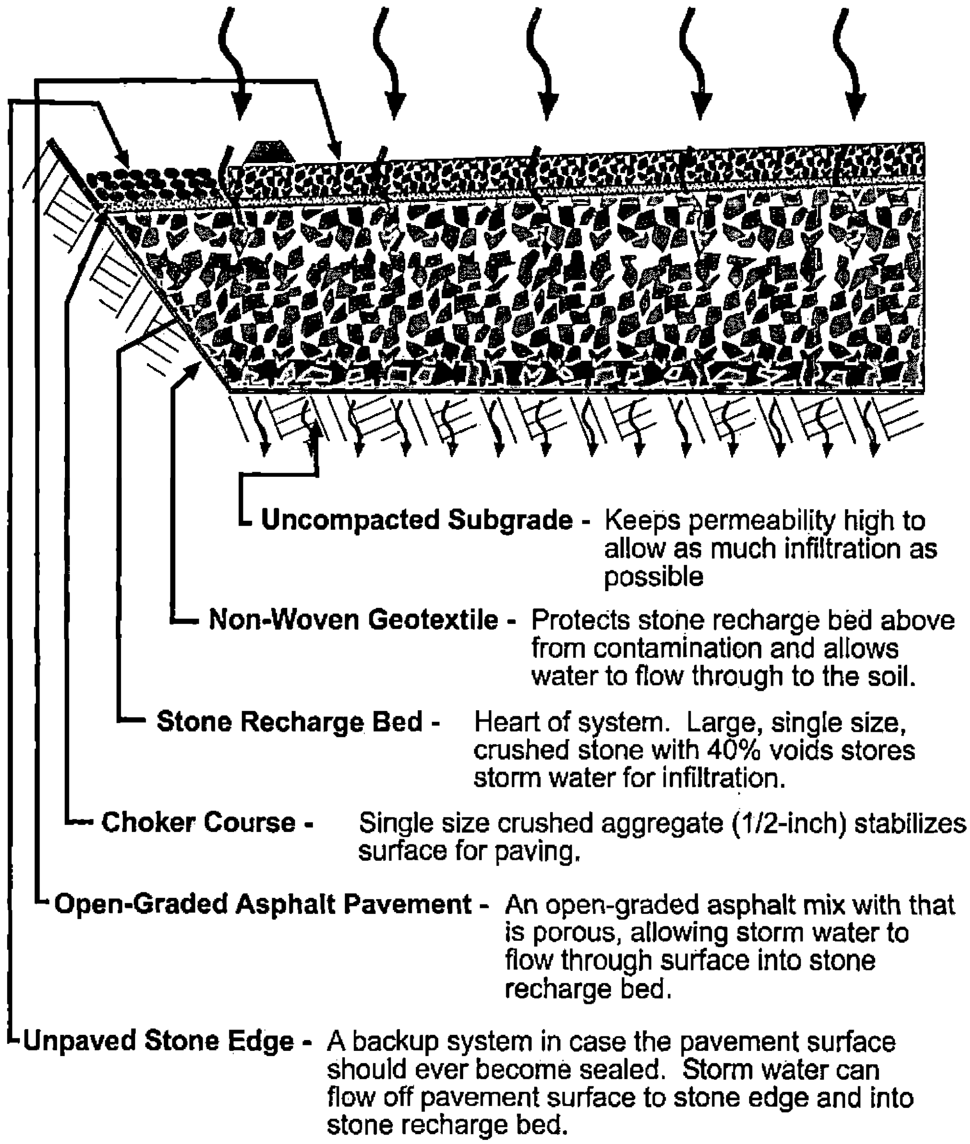


**Figure 16.** Cross-Section of Porous Asphalt Pavement with Subsurface Recharge Bed.

National Asphalt Pavement Association. *Innovative Stormwater Management: Porous Asphalt Pavement with Subsurface Recharge Bed.* Accessed 8 July 2010.

http://www.hotmix.org/PDFs/Poster for MBC.pdf

The subsurface stone aggregate bed is either designed as a storage and infiltration structure or as a temporary retention basin, depending on site conditions and application objective. Porous asphalt pavement is particularly suited for parking lots and can also be used for play courts and pathways. Porous asphalts carefully designed with site conditions in mind can outlast conventional impervious pavement types in both aspects of stormwater management and durability (Cahill and others, 2003). Other permeable pavement types use similar materials and structural arrangement in their installations.

Pervious Pavers

Pervious Pavers are generally made of pre-cast concrete, bricks, stones, or cobbles. They have interlocking designs for both aesthetics and permeability. They are then placed in hard, defined frame set on top of fine material bed made of sand or other sediments (American Concrete Institute, 2006). The gaps between these pervious pavers are filled with sand or gravel to allow water drain through the material and the subsurface to gradually percolate to the ground. Some pavers contain small structural voids in the pavement surface to boost permeability and infiltration. Pervious pavers are commercially available in different shapes, sizes, colors, textures and can be constructed to support heavy weights (American Concrete Institute, 2006).

**Figure 17.** Pervious Pavers Installed in San Diego, California Demonstration Site.

Cahill Associates and Environmental Consultants. *The Sustainable Stormwater Management and Use of Porous Pavements: The Design and Construction of Pervious Pavements.* Powerpoint Presentation, Oregon State University, 6 February 2006.

These qualities and the durability of pervious pavers have made them a logical replacement for asphalts and conventional pavement for parking lots, roads and sidewalks. Fine sediments may clog the small structural voids within this type of permeable pavements and can reduce drainage capacity. It should be noted that most permeable pavement types including pervious pavers are subject to debris accumulation over time and need to be inspected and cleaned (hosed) regularly depending on traffic frequency and local site conditions (American Concrete Institute, 2006).

Other permeable pavement methods that are not discussed above are also commercially available such as reinforced turf, gravel filled cells, single sized aggregates, and open jointed blocks. These pavement types are not discussed in detail because they are generally used for driveways rather than permeable parking lot retrofit. It is important to understand the site conditions, the climate, and traffic frequency as well as other important parameters in order to select the right type of permeable pavement and design application prior to constructing these pavements.

## Collective Advantages of Pervious Pavements

1. Urban cities in the U.S. typically have ambient air temperatures 2 to 8 °F higher than the surrounding rural areas with the built up area being 2 to 4 °F higher than the unpaved surroundings (Ferguson,

2005). The highest temperature is usually observed where both the pavement and the buildings contribute to the temperature effect. This is called the urban "heat island" effect because urban temperature contour maps, much like elevation maps, of urban areas appear as an island of warmth (Ferguson, 2005). On larger temperature maps, a whole city can be seen as an island in cooler surrounding of suburbanized lands. "Pavements contribute at least just as much as buildings to heat-island formation because pavements have high thermal inertia at the ground surface" (Ferguson, 2005). This excess heat can be an advantage to cold cities but for places like Chino Basin with warm conditions, it is clearly undesirable.

The light colored construction materials such as concrete pavements absorbs less heat from solar radiation than darker pavements materials like asphalt, and the relatively open pore structure of pervious concrete stores less heat, helping to lower heat island effects in urban areas (Tennis and others, 2004). Porous pavements with grass components such as geo-cells and concrete grids can help to significantly reduce the heat-island effect (Tennis and others, 2004).

Plants and vegetation near parking lots and sidewalks provide shelter from the heat and produce a cooling effect in the surrounding, further helping reduce heat island effects. Pervious pavements are also ideal for protecting trees in a paved environment (Tennis and others, 2004). Various plant species struggle to grow in urban settings paved by conventional impervious pavements because the access to air and water is not readily available to the roots. Pervious pavements, sidewalks or driveways allow nearby plants more air and water supply while still serving their purpose as hard surface pavements (Tennis and others, 2004). Pervious pavements also offer a practical solution for green and sustainable builders to plan and manifest green scenery in parking lots and paved urban areas.

2. High traffic frequency is not ideal for pervious pavements. However, pervious pavement surfaces can improve safety during storm events by avoiding puddle from forming, perched water splashing, and hydroplaning by providing more friction to vehicles

(Tennis and others, 2004). Both conventional dense pavements and porous pavements provide such friction in dry weather. However, during rainstorm events, a thin cover of water over impervious pavement surfaces prevents the tires having a strong traction causing skidding due to spilled petroleum and lubricants of vehicles on the pavements (Tennis and others, 2004). Porous pavements also remove car oil and water spills directly beneath to the drainage system reducing perching and increasing friction of the surface. "The friction coefficient value of dense asphalt in wet conditions is a fourth of its dry-weather while porous pavement retains their dry-weather friction value" (Ferguson, 2005).

3. Stormwater runoff rate reduction in impervious surfaces replaced with permeable pavement is considerable. One of the main contributions of these pavements is a significant reduction of runoff rate and stormwater volume from that of hard surfaces (Dinz, 1980). If the pavement type and infiltration structures are designed properly, it is possible to temporarily detain the runoff and discharge it at a rate slow enough to prevent flooding while allowing

more time for infiltration (Dinz, 1980). Groundwater recharge with porous pavements is imperative especially in water deficient areas such as the Chino Basin. Impermeable paving may prevent recharge to a local aquifer and thereby further reducing its safe yield.

4. Erosion protection from uphill and channel flows is another attribute of permeable pavements. "Because impervious areas generate higher rates of runoff than pervious areas, the erosive capacity of the flow is also increased by its increased depth of flow and velocities" (Dinz, 1980). As a result, such flows downstream from impervious areas are subject to further removal of soils and other loose materials. However, porous pavement installations would drastically reduce runoff volume through infiltration. Such absorption is instrumental in soil protection from erosion (Dinz, 1980).

5. Permeable pavements can provide water quality enhancement from areas that have the potential of being contaminated. "By capturing the initial runoff (flush) of rainfall and allowing it to percolate into the ground, soil chemistry and biology can then

"treat" the water by removal or degradation of some contaminants" (Tennis and others, 2004). Discussion of the water quality issues are beyond the scope of this study, however the average contaminant removal efficiencies of porous pavements can be seen on Table 1. Porous pavements remove suspended solids, organic carbon, and metals at high efficiency rate of approximately 90%. Other water contaminants such as Nitrogen, Phosphorous, and Ammonia are also removed at a significant rate. Thus, stormwater retention areas may be reduced or eliminated, allowing increased land use. Furthermore, by collecting rainfall and allowing it to infiltrate, groundwater recharge is increased, peak water flow through drainage channels is reduced, and flooding is minimized. In fact, the EPA named pervious pavements as a Best Management Practice (BMP) for stormwater pollution prevention because they allow fluids to percolate into the soil (Cahill and others, 2005). Although permeable pavements can help mitigate some water contaminants, they should not be used as a sole mechanism to address water quality issues. The water quality shortcomings of permeable pavement will be briefly discussed in the next section focusing on disadvantages of permeable pavement.

**Table 1.** The Average Contaminant Removal Efficiency Rate of the Best Management Practices Type of Porous Pavements.

| | Infiltration BMP Type | | | | |
|---|---|---|---|---|---|
| **Water Quality Parameters** | **Trench 1** | **Trench 2** | **Porous Paving Type 1** | **Porous Paving Type 2** | **Average Removal Efficiency** |
| TSS[1] | 90 | - | 95 | 89 | 91 |
| TP[2] | 90 | 68 | 71 | 65 | 66 |
| TN[3] | 60 | - | - | 83 | 72 |
| TOC[4] | 90 | - | - | 82 | 86 |
| Pb | - | - | 50 | 98 | 74 |
| Zn | - | - | 62 | 99 | 81 |
| Metals | 90 | - | - | - | 90 |
| Bacteria | 90 | - | - | - | 90 |
| BOD[5] | 75 | - | - | - | 75 |
| Cd | - | - | 33 | - | 33 |
| Cu | - | - | 42 | - | 42 |
| TKN[6] | - | 53 | - | - | 53 |
| Nitrate | - | 27 | - | - | 27 |
| Ammonia | - | 81 | - | - | 81 |

Cahill T., Adams M., and Marm C. *Stormwater Management with Porous Pavements*. 2005, p. 18.

[1] Total Suspended Solids
[2] Total Phosphorus
[3] Total Nitrogen
[4] Total Organic Carbon
[5] Biochemical Oxygen Demand
[6] Total Kjeldhal Nitrogen

6. Porous pavements have a significantly lower life-cycle cost than their impervious counterparts. Although the initial cost of pervious installation may be slightly higher, it saves money in the long run due to its superior durability and strength. It requires fewer repairs than asphalt, and has a longer overall lifespan as well (NRMCA). For example, Pervious concrete is economical in that it minimizes the need for runoff retainers, reducing property costs. There is very little overproduction since it is usually made directly on-site, and it can be recycled once it has reached the end of its pavement life-cycle. Thus, permeable pavements are widely known as the lowest life-cycle cost option available for paving (NRMCA). The need for curbs and storm sewer installation or expansion may also be avoided since sewer line overload is further mitigated with the use of porous pavements (Dinz, 1980).

Pervious concrete is also a robust and highly enduring material. Parking parcels properly designed and installed will last 20-40 years with minimal or no maintenance (Tennis and others, 2004; NRMCA). As opposed to impervious asphalt, the unfastening of surface aggregates occurs only in the early weeks once the concrete is put in place. This phenomenon can be abated with proper grading and compaction approaches (Tennis and others, 2004). Pervious concrete mixes are designed with minimal amounts of water and therefore have high dependable and stiff consistency. The shrinkage associated with pavement drying happens when pervious concrete is used than conventional pavements (Tennis and others, 2004). This permits many pervious pavements to be installed without any cracks, preventing temperature effects commonly observed in dense pavements (Tennis and others, 2004). Such durability makes permeable pavements more cost effective than conventional dense pavements from a life-cycle cost perspective.

## Disadvantages of Permeable Pavements

Permeable pavements have some surmountable problems that can be overcome by paying attention to the special conditions and details of a location during installation and proper care and maintenance afterwards.

1. One of the most often voiced concerns of permeable pavements is vulnerability to clogging. Clogging

generally occurs due to operation and construction scheduling problems (Dinz, 1980). For instance, debris of construction materials or local erosions on completed pavements may clog pores and reduce permeability. This can be corrected with proper construction scheduling to prevent debris of materials that can cause clogging of the pavement pores (Dinz, 1980). If a spill occurs, immediate vacuuming and de-clogging with pressure washers will restore pavement permeability to near pre-spill infiltration efficiency. However, if the pores are clogged and dirt is compacted in by traffic deep in these pavement structures, drilling holes may be necessary to recover prior permeability rates (Dinz, 1980).

2. Pervious pavements are not capable of sufficient infiltration when snow accumulated on the surface begins to melt and/or when it rains on a frozen surface (Dinz, 1980). Although this problem is less likely to happen in the Chino Basin due to its warm climate, there are design considerations that can increase infiltration and reduce freeze-thawing effect.

3. Pervious pavements have less strength than impervious surfaces and can only tolerate a lower traffic load. However, they can be designed to withstand strengths well beyond 3,000 psi, pressure equivalent to that exerted by a fire truck (Tennis and others, 2004; NRMCA). More durability and strength can be achieved with provisional mix of materials, structural designs, and layering methods (Tennis and others, 2004; NRMCA). The ingredient for strong and enduring pavements is utilizing materials such as silica fume (a byproduct of producing silicon metal or ferrosilicon alloys), fly ash, and blast furnace slag (Tennis and others, 2004; NRMCA). All of the above materials increase durability of the pavements but also decrease permeability. Pavement strength can also be maximized by installing sub-grade levels of coarse and/or fine aggregates beneath the pavements (Tennis and others, 2004).
4. The cost of installation of porous pavements may be slightly higher than conventional pavements. However, as discussed in the above section; if the overall life-cycle cost that includes repair, installation of drainages and other related costs of traditional

pavements are considered, the cost of installing porous pavements is significantly lower.

5. Permeable pavements provide a significant reduction of water contaminants such as metals, suspended solids and bacteria. Yet, they do not provide adequate removal of some water contaminants such as nitrates (see Table 1). Water quality mitigation should be considered a bonus attribute of installing permeable pavements, not as a primary objective. Water quality concerns should be addressed with other mitigation measures which are beyond the scope of this study.

The negative aspects of porous pavements discussed above are not at all insurmountable in most instances. Also, the advantages of their installation far outweigh the real or perceived disadvantages of permeable pavements.

# CHAPTER TWO

# STATEMENT OF PROBLEM

## Introduction

The area within the adjudicated Chino basin has become progressively urbanized. As shown in figures 7 through 14, the basin has been altered between 1933 and 1990 from a predominantly agricultural land uses to a completely urbanized area. The urbanization of the basin increases its impervious surfaces due to the need for buildings, roads, driveways and parking lots. Such developments reduce the infiltration of surface water to recharge groundwater and increases stormwater runoff from these impervious surfaces. "The volume of water not captured for recharge in the Basin during the period of October 1977 and September 1999 averaged approximately 41,000 acre-feet per year (acre-ft/yr) and ranges from a low of 2,000 acre-ft/yr to a high of about 174,000 acre-ft/yr" (Wildermuth Environmental, Inc., 2001). The volume of stormwater produced in the basin has increased since 1999 and will clearly increase substantially in the future as the remaining undeveloped (vacant) and agricultural crop fields are converted to developed, urbanized land uses that are impervious to infiltration.

## Statement of Problem

This research project focuses on the potential amount of rainwater that can be captured and introduced to the Chino Basin groundwater by pervious pavement retrofit of the existing commercial, industrial, and institutional parcels. The scope of the research includes quantifying the amount of land covered by each of the three sectors and the amount of stormwater associated with land uses. The amount of precipitation and the magnitude of stormwater runoff associated with the impervious surfaces of the three categories will also be quantified. Subsequently, the quantity of rainwater that can be captured from land use surfaces ideal for permeable pavement retrofit will be determined. Assuming appropriate installation and maintenance of the pervious pavement surfaces, the quantity of water captured by the retrofitting effort will be the potential amount of stormwater captured that can be used to recharge the basin's groundwater.

# CHAPTER THREE

# METHODS

## Introduction

The projected impervious surface areas were obtained, and in some instances calculated, using the 2006 Geographic Information System (GIS) data layer made available by San Bernardino Associated Governments (SANBAG). The information was then used to obtain a list of urban land uses that are present within the Chino Basin. The land uses that are relevant for this particular study are selected from the list of urban land uses. The impervious surface area of the selected land uses is then estimated and is used to calculate the estimated impervious surface parking area with pervious pavement retrofit potential. The potential groundwater recharge is calculated from an unpublished data set (Appendix c) provided by Wildermuth Environmental, Inc., that contains precipitation and stormwater runoff values for the Chino Basin between the years of 1950 and 2006. Many assumptions were made in the estimation of the impervious area, including the impervious coefficients of some land uses and the association of precipitation and runoff to particular land use parcels. The following subsections demonstrate the detailed methods on how the potential groundwater water recharge from the retrofitting of pervious pavement was generated for the Chino Basin.

## Selection of Land Uses of Interest

A significant portion of this project was conducted by utilizing GIS. In order to prepare a GIS layer for the existing commercial, industrial and institutional parcels within the Chino Basin boundary, the 2006 land use data and designation made available by San Bernardino Associated Governments was utilized. The land use summary provided 56 types of land uses of which approximately 20 land uses of interest were extracted. The land uses of interest were selected based on conventional reasoning as to the possible applicability of their parking spaces for permeable pavement (Table 3). Land uses with significant amount of impervious pavement parking lots were omitted if they do not fit into the above three categories of commercial, industrial and institutional. A land parcel meeting the above qualification can also be omitted if it seems unreasonable for its parking spaces to be converted into permeable pavement and still perform their function under their normal traffic frequency. Other land parcels such as non-irrigated cropland were entirely excluded because they do not have any conventional impervious parking spaces. A simple addition of the area of individual land parcels provides the total area of land use in each of the three categories. Subsequently, the amount of impervious surface within the selected land uses in the Chino Basin is calculated by the summing the three categories. The acreage applied for this research is entirely based on the data extracted from the SANBAG database.

## Quantifying Impervious Surfaces

One of the most crucial concerns in the discussion over impervious surfaces is simply the mechanism for measuring and quantifying impervious surfaces with any justifiable accuracy. To date, there is no standardized methodology used as metric for impervious surfaces. There are a few varying methods that include statistical enumerations, demographical data, and arduous mapping of surface cover characteristics utilizing high spatial resolution aerial imagery (Slonecker and others, 2001). Impervious surfaces have shown the ability to indicate water quality and other regional environmental conditions. Therefore, the methods employed to estimate impervious surface coverage needs an intense and close examination. In addition, the capacity of the measurement to indicate errors, in depth understanding of the methods, and precisions of calculating impervious surfaces coverage are crucial (Tiley and Slonecker, 2006).

Although the consequences of land use alteration, population density, and impervious surfaces on water quality have been generally known for a while, a fundamental difficulty exists in measuring the specific coverage magnitudes and distribution of various types of impervious surfaces. Precise and justifiable measurements of impervious coverage have been intangible as well as time and resource consuming (Tiley and Slonecker, 2006). The need for quantifying the area of impervious surfaces is mainly a mapping issue. Hence, the resolution for this concern will be found in mapping; by evaluating individual and collective applications and methods of quantifying impervious surfaces. There are currently a few practical application methods, such as statistical estimates, spectral reflectance methods, and GIS algorithms to determine the extent of imperviousness (Tiley and Slonecker, 2006).

As mentioned previously, impervious surfaces can serve as a possible indicator of water quality deterioration. As a result, research studies began to assess and evaluate several of these statistical, demographical, and land use mapping methods in order to quantify the total impervious area (TIA) of specific locations (Tiley and Slonecker, 2006). These emerging mapping application methods, however, had not been properly evaluated for precision and accuracy of the metric. In addition, in academic publications and other scholastic discussions, road surface coverage has often been presented as the main concern of impervious surfaces (Tiley and Slonecker, 2006). This, however, is not the case as buildings, parking lots and driveways account for a substantial portion of imperviousness.

An imperviousness study used data collected via high-resolution mapping to evaluate other TIA estimation methods of pre-designated control sites to assess their accuracy. The three methods evaluated were, sub-pixel mapping of impervious area, land use coefficients, and land cover coefficients. The first method tested for precision was sub-pixel mapping. "Sub-pixel estimates of impervious areas are derived from advanced image processing techniques using Landsat Thematic Mapper 30-meter multi-spectral and high-resolution digital orthophoto quarter quads. The result obtained is a percentage of impervious area within each 30-meter pixel" (Tiley and Slonecker, 2006). Sub-pixel imperviousness estimates for many U.S regions are made available by USGS and U.S. EPA National Land Cover Data (NLCD) set. These data sets are a dependable, rational, and expedient method of estimating TIA. The assessment of sub-pixel estimating method showed a persistent underestimation of TIA that is typically within 10 percent of the actual measurement of the control sites (Tiley and Slonecker, 2006). The imperviousness of one of the control sites (a watershed), however, was underestimated by more than 40 percent. This substantial estimation error is possibly due to (coniferous) tree cover in this watershed site that shades the spectral reflectance of impervious surfaces beneath the vegetation (Tiley and Slonecker, 2006).

The second application evaluated, the land-use coefficient method, is commonly used in impervious surfaces and other land use type estimations. "The method is based on multiplying the area of each vector-based land use polygon by a predetermined coefficient that represents the average amount of impervious area for that particular land use class" (Tiley and Slonecker, 2006). The study concluded from evaluation in four watershed sites that the TIA estimates from the land-use coefficient method were typically within 7 percent of the result obtained from the high-resolution mapping (Tiley and Slonecker, 2006). In comparison with the first method, the land use coefficient provides a more accurate method for estimating TIA for watersheds.

The third method tested, the land cover method, includes producing TIA estimates from existing land cover data in a raster data model collected from satellite-based image processing methods such as GIS (Tiley and Slonecker, 2006). "Land cover data, like land use, is a thematic representation of surface phenomenon, but is based on the environmental cover or spectral reflectance properties of the surface instead of on an anthropogenic-based utilization of land" (Tiley and Slonecker, 2006). In other words, land cover commonly provides less detail about the specific uses of that parcel than "land use" data used in the land use coefficient method. More importantly, it is mapped on a raster-based GIS model as opposed to vector-based data model of the second method. "The land cover method offers the advantage of a national, thematically consistent and regularly updated data set from which many other spatial relationships, such as impervious surfaces, can be derived on a consistent, national basis" (Tiley and Slonecker, 2006).

**Table 2.** Land Uses and Impervious Surfaces Coefficients.

| Land Use Classes | Land Use Code | Impervious Coefficients |
|---|---|---|
| Open Urban Land | 10 | 0.086 |
| Residential – 2 Acre Lot | 11 | 0.106 |
| Residential – 1 Acre Lot | 12 | 0.143 |
| Residential – 0.5 Acre Lot | 13 | 0.212 |
| Residential – 0.25 Acre Lot | 14 | 0.278 |
| Residential – 0.125 Acre Lot | 15 | 0.326 |
| Townhome Residential | 16 | 0.409 |
| Multifamily Residential | 17 | 0.444 |
| Agriculture | 20 | 0.019 |
| Institutional | 30 | 0.344 |
| Churches | 31 | 0.399 |
| Schools | 32 | 0.303 |
| Municipal | 33 | 0.354 |
| Golf Courses | 34 | 0.050 |
| Cemeteries | 35 | 0.083 |
| Parks | 36 | 0.125 |
| Light Industrial | 40 | 0.534 |
| Commercial | 50 | 0.722 |

Tiley, J.S and Slonecker, E.T. *Quantifying the Components of Impervious Surfaces*. U.S. Geological Survey, Open-File Report 2007-1008. 2006; P. 17.

Two estimation methods were used to quantify TIA from National Land Cover Data (NLCD). These methods use different coefficients based on land cover types to calculate a percentage of impervious area for each individual pixel. The outcome of the evaluations indicated that the land-cover coefficient method achieved an average of 96 percent precision when compared to the values obtained from high-resolution mapping data (Tiley and Slonecker, 2006). The database made available by SANBAG for this particular study on the Chino Basin is raster-based GIS for land use and coefficients need to be applied to estimate impervious surfaces.

In this research project, the utilization of high resolution data set of the Chino Basin and identify each parcel and its impervious surface area would have been ideal prior to finding the total amount of area that is impervious. However, this method would obviously require significant allocation of time and resources than was available and is highly labor intensive.

For the purposes of this research and the scope of the study, it was optimal to use the 2006 GIS data layer made available by the San Bernardino Associated Governments (SANBAG) which is generated by the third method of TIA estimation. In this method, the land cover is not particularly well detailed in regards to land use data but maps its data on a raster-based GIS model derived from the satellite imagery data available for San Bernardino and surrounding counties.

## Quantifying Impervious Parking Spaces

The primary focus of this research project was to identify and estimate the potential groundwater recharge that can be gained by retrofitting conventional impervious parking and driveway spaces into permeable parking and driveway lots. Therefore, quantifying the amount of impervious area associated with parking spaces to a reasonable accuracy is imperative. The quantification of impervious parking spaces however is not a straight forward process because parking spacing depends on many factors.

The county of San Bernardino Land Use Services Department and Planning Division provides ordinances that dictate the building to parking space ratio for some of the land uses and further sets general guidelines as to the appropriate number of spaces for specific land uses. The parking and loading regulations included within the administrative guidelines of San Bernardino County are not set in terms of building footprint to parking space ratio. In fact, most of the parking space rules are quite dependant on the number of occupants of the location, that is, the number of parking spaces for a hospital is dependent on the number of patient beds and staff while a university relies on its number of students and staff to determine its number of parking spaces.

The San Bernardino parking ordinances, should they provide adequate information, would have been another ideal path to proceed to calculate the impervious surface area specifically attributed to parking spaces of the selected land uses (see Appendix a). This method is obviously time, labor and resource intensive without a guarantee that it would provide a reasonably accurate estimate for two reasons. The first reason is that the parking ordinances are not complete and they are quite often merely guidelines and recommendations. The second reason, the more important of the two, is that there will be a need to quantify every single building within each land use in the Chino Basin. Mapping out every single building to find out the building footprint ratio to parking spaces or even taking a sample of similar buildings to reach a multiplier coefficient is time consuming and simply not very productive.

For the purpose of this research project, values and estimation found in an impervious surface reduction literature prepared for the City of Olympia were used to estimate the area for parking associated with a building perimeter. On average parking lots of residential areas accounted for less than 10% of a residential land use while parking lots accounted for roughly 53% of the impervious surfaces of a commercial building (City Olympia, 2006). The impervious surface reduction study for the City of Olympia further evaluates impermeable surfaces with respect to their effectiveness at producing runoff. For instance, a residential roof may be similar in size to a commercial building, however given the presence of permeable landscaping around the residential roof and the presence of impervious surface around the commercial roof make it much more effective at producing runoff.

An estimated coverage for commercial and industrial parking/driveways is 53% of the impervious surface. The study in City of Olympia included 13% pervious for lawn/landscaping conditions. Therefore, the value used to represent parking lot percentage in Chino Basin is adjusted to reflect this difference by dividing 53% by the remaining 87% (100 - 13)%. The result is approximately 61% of an impervious surface of any land use.

In order to determine the ratio of impervious surface of a land use, the San Bernardino County Flood Control Hydrology Manual (SBCFCH) (Appendix b) was utilized. The manual recommends that 40%, 90%, and 90% values be used as impervious surface ratios for schools, commercial and industrial land uses, respectively. The manual does not designate any ratio or coefficient for the imperviousness of governmental land uses. For the scope of this study, 40% was utilized for all public and governmental facilities. The value from Tiley and Slonecker and Capiella and Brown (Table 2) assigns a slightly higher ratio of impervious surfaces of institutional land uses than value given for schools by the SBCFCH; therefore, the 40% ratio is within reason. The final parking lot impervious surface area is calculated as follows.

$$P_A = [L_A] \times [I_C] \times [P_R]$$

Where:

$P_A$ = Area of parking lot and driveways (acres)

$L_A$ = Area of land use (acres)

$I_C$ = Impervious surface coefficient

$P_R$ = Ratio of parking to impervious surfaces

It should be noted that the values used to reach the estimated numbers and conclusions do not account for the importance of soil type, slope, and the effectiveness of the subsurface. The values for parking lot and driveways will be provided in later tables.

## Runoff and Precipitation Data Modeling

A hydrologic subarea boundary consisting summarized runoff/rainfall was provided by Wildermuth Environmental (Appendix c). The summarized data contains annual average rainfall and average runoff from impervious areas in the Chino Basin. The data were obtained utilizing Wildermuth's runoff/rainfall simulation model for Chino Basin. In order to generate runoff data, Wildermuth Environmental, Inc. used daily rainfall data from 24 stations around the Chino Basin for the period of October 1, 1949 to December 31, 2001 and also radar data from January 1, 2002 to September 30, 2007. Daily runoff has been generated from 156 sub-drainage areas in the surface modeling area boundary and then summarized for annual runoff average. The runoff is expressed in acre-ft/acre for each sub-drainage area. All the summarized runoff and rainfall data displaying average, minimum, and maximum values is attached in Appendix c.

The hydrologic shapefile provided by Wildermuth Environmental, Inc. can be overlaid with the selected commercial, industrial and institutional (CII) land uses to display the area of a specific land use and its location within the Wildermuth assigned sub-drainage polygons. The assigned polygons contain an average rainfall and runoff data for parcels within their boundaries. The average annual runoff from impervious areas derived from averaging the runoff values of the sub-drainages in the Chino Basin is approximately 1.03 acre-ft per acre per year. The averaged runoff minimum and maximum values are approximately 0.11 and 2.7 acre-ft per acre, respectively. It should be noted that not all sub-drainage polygons are used to produce this average. Some of the sub-drainage areas were outside of the legal and hydrologic boundary of the Chino Basin and are subsequently omitted. Approximately 50 subdrainage areas outside of the boundaries of Chino Basin were left out of the calculations. However, the precipitation rates of these subdrainage polygons were comparative to those in the Basin and would not have altered the results significantly. aUtilizing this runoff estimated average, the runoff generated from the impervious parking lot portion of the land uses is calculated by simply multiplying the runoff average (acre-ft/acre per year) by the building parking lot and driveway areas (acres) as follow.

$$R_P = [P_A] \times [R_{AV}]$$

Where:

$R_P$ = Recharge potential (acres-ft/year)

$P_A$ = Area of parking lot (acres)

$R_{AV}$ = Runoff average (acres-ft/acre*year)

The sum of the runoff calculations of each land use are summarized in their specific land use CII category. The calculations assume average rainfall and runoff will occur within the polygon where the parking lot is located. The potential rainfall groundwater recharge should retrofitting of impervious surfaces be applied assumes a complete and comprehensive installation of appropriate permeable pavement type, method and materials for the soil, slope, climate and other important conditions of each location. The values for stormwater runoff from parking lot and driveways will be provided in later tables.

CHAPTER FOUR

RESULTS AND DISCUSSION

## Results

The results of the subdivisions of the three categories displayed can be seen below in Table 3.

**Table 3.** The Land Uses of Interest in the Chino Basin as Categorized within the Commercial, Industrial and Institutional Sectors.

| | **Commercial** | **Industrial** | **Institutional** |
|---|---|---|---|
| 1. | Commercial & Recreational | Maintenance yards | College and Univ. |
| 2. | Commercial storage | Mixed commerc. & indust. | Elementary schools |
| 3. | Modern strip | | Government offices |
| 4. | Older strip | | Junior highs schools |
| 5. | Park and ride | | Public facilities |
| 6. | Retail centers | | Police and sheriff |
| 7. | | | Public parking |
| 8. | | | Religious centers |
| 9. | | | Senior high schools |
| 10. | | | Trade schools |

The majority (ten) of the land use types selected within the Chino Basin are categorized in the Institutional sector while the Commercial sector contains about a third (six) of the number of land uses within the boundary. The industrial sector contains only two of the land use types including the mixed commercial and industrial land parcels.

The results of the GIS layer prepared for the existing commercial, industrial and institutional parcels in the Chino Basin included the 18 types of land uses that are within the three categories. The latest data from the 2006 Land Use files provided by SANBAG displayed varying sizes and locations of land uses in the Chino Basin boundary.

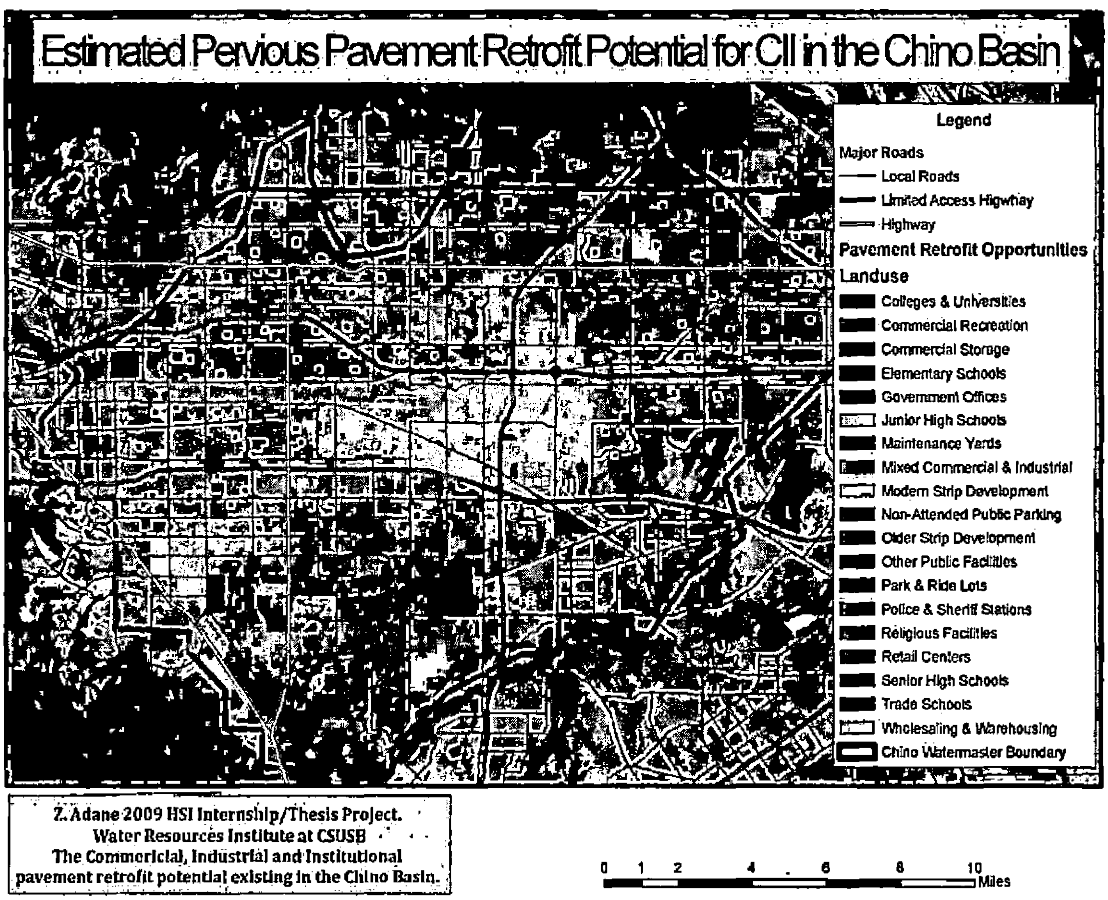


**Figure 18.** Estimated Potential Commercial, Industrial, and Institutional Land Uses for Pervious Pavement Retrofit in the Chino Basin.

The individual land parcels are merged with other land parcels of the same land use within proximity to display a solid block for each land use as designated by varying colors as seen in Figure 18. The majority of the land uses are scattered within the Basin's boundary while the Wholesale and Warehousing land parcels as designated contain a significant portion of the impervious surface present in the Chino Basin with potential for parking lot permeable pavement retrofit. Many of the land parcels are spread across the Basin and are not able to form a visible solid block of individual land uses; however, retail centers, schools, old and modern strips, and wholesale and warehouses visibly cover a significant amount of area of impervious surfaces. It should be recognized that the extent of imperviousness in this region is obviously greater than what is indicated in this figure. Although the study is limited to impervious surfaces of the above mentioned three categories, it can acknowledge the enormous presence of imperviousness associated with residential areas, roads, and CII parcels considered unsuitable for permeable retrofit.

The result of the total area occupied by each of the land uses as well as the impervious ratios and acres of impervious surfaces occupied by parking and driveways are displayed in the tables below.

**Table 4.** Total Area of Commercial, Industrial and Institutional Sectors Estimated for Potential Permeable Pavement in the Chino Basin.

| Types of Commercial, Industrial and Institutional (CII) Parcels Existing in Chino Basin | Total Acres | Impervious Coefficients | Ratio of Parking & Driveways of Impervious | Acres of Impervious Parking & Driveways | % of Total Impervious Parking & Driveways |
|---|---|---|---|---|---|
| Colleges & Universities | 186.16 | 0.40 | 0.61 | 45.42 | |
| Commercial Recreation | 737.20 | 0.90 | 0.61 | 404.72 | |
| Commercial Storage | 191.76 | 0.90 | 0.61 | 105.28 | |
| Elementary Schools | 1,142.28 | 0.40 | 0.61 | 278.72 | |
| Government Offices | 180.82 | 0.40 | 0.61 | 44.12 | |
| Junior High Schools | 548.77 | 0.40 | 0.61 | 133.90 | |
| Maintenance Yards | 81.23 | 0.90 | 0.61 | 44.60 | |
| Mixed Commer. & Industrial | 260.21 | 0.90 | 0.61 | 142.86 | |
| [redacted] | | | | | |
| Non-Attended Public Parking | 56.93 | 0.90 | 0.61 | 31.25 | |
| Older Strip Development | 176.90 | 0.90 | 0.61 | 97.12 | |
| Other Public Facilities | 59.51 | 0.40 | 0.61 | 32.67 | |
| Park & Ride Lots | 26.67 | 0.90 | 0.61 | 14.64 | |
| Police & Sheriff Stations | 14.13 | 0.40 | 0.61 | 3.45 | |
| Religious Facilities | 658.66 | 0.40 | 0.61 | 160.71 | |
| [redacted] | | | | | |
| Senior High Schools | 1,130.95 | 0.40 | 0.61 | 275.95 | |
| Trade Schools | 44.07 | 0.40 | 0.61 | 10.75 | |
| [redacted] | | | | | |
| **Total** | **15,293.94** | | | **7,205.09** | [redacted] |

The results for the amount of total land use acreage and impermeable parking pavement within each land use in the Chino Basin for the three categories of commercial, industrial and institutional can be seen in Table 4. An estimated total of 15,293 acres of parcels was identified in the Basin. The area covered by impervious parking lot and driveways was approximately 7,205 acres which is approximately 47% of the entire impervious surface area associated with the selected land uses of the Chino Basin.

Table 4 shows that four land uses dominate the Chino Basin. Elementary schools occupy approximately 1,142 acres of land in the Basin. Approximately 279 acres of the area of elementary schools is impervious parking lot and driveways. Modern strip development consists of approximately 1,611 acres of land in the Chino Basin and approximately 885 acres of this area is associated with impervious parking and driveways. Retail centers occupy slightly higher amount of land than modern strips at approximately 1,666 acres of land. Impervious parking and driveways consist of roughly 915 acres of the total 1,666 acres of retail centers present in the Basin. Warehouse and wholesaling is by a large margin the dominant land use in the Basin and accounts for a massive 6,520 acres of land, approximately 3,579 of the impervious surface total acreage is used as parking lots and driveways. Although the rest of the land uses combined account for a significant percentage of the impervious surface of the Basin, each of the land uses individually contain a relatively small amount of land in comparison with the four land uses of the Chino Basin discussed above.

**Table 5.** Total Area of Impervious Parking and Driveways of Commercial, Industrial, and Institutional Land Categories in the Chino Basin.

| Category of Impervious Parking and Driveways | Commercial | Industrial | Institutional | Total |
|---|---|---|---|---|
| Area ( Acres) | 5,985.14 | 187.46 | 1,032.49 | 7,205.09 |
| ~ % of Total | 83.1 | 2.6 | 14.3 | 100.00 |

The selected commercial land uses account for 5,985 acres which is approximately 83% of the Basin's total impervious surfaces associated with parking lot and driveways. Wholesale and warehousing land uses contain approximately 60% of impervious parking and driveways of the commercial sector and 50% of the entire impervious surfaces of the Chino Basin.

The industrial sector of the Chino basin contains less than 3% of the total impermeable pavement for parking and driveways of the selected land uses. This land category mainly consists of maintenance yards and mixed commercial and industrial parcels. Even with the inclusion of all mixed commercial and industrial land uses, which could also be placed in the commercial category, the estimated value indicates that only minimal amount of impervious surface is available from this land use category for retrofit.

The institutional sector of Chino basin includes schools, government infrastructure, and religious centers. The institutional land uses account for approximately 14% of the entire impermeable parking lots and driveways of the Chino Basin. The area of land used for schools makes up for 72% of the institutional sector and slightly more than 10% of the entire impervious parking lot and driveways of Chino Basin. While the school parcels dominate the institutional sector, governmental institutions and religious centers cover significant portions of the remaining acreage.

The individual land uses and their respective acreage of impervious parking lot and driveways are represented in the following Figure 19. As shown below, many of the land uses within the three categories occupy a very small amount of the Chino Basin area of impermeable surfaces. The land uses that were quite visible in Figure 18 are obviously well represented in Figure 19 including commercial recreation, elementary schools, modern strip developments, and most notably wholesale and warehousing with 6,520 acres of land, of which 3,579 acres are attributed to impervious parking lots and driveways. Retail centers and modern strip Developments are the second and third dominant land uses with approximately 1,667 and 1,612 acres of land, of which approximately 885 acres and 915 acres are associated with impervious parking lots and driveways, respectively.

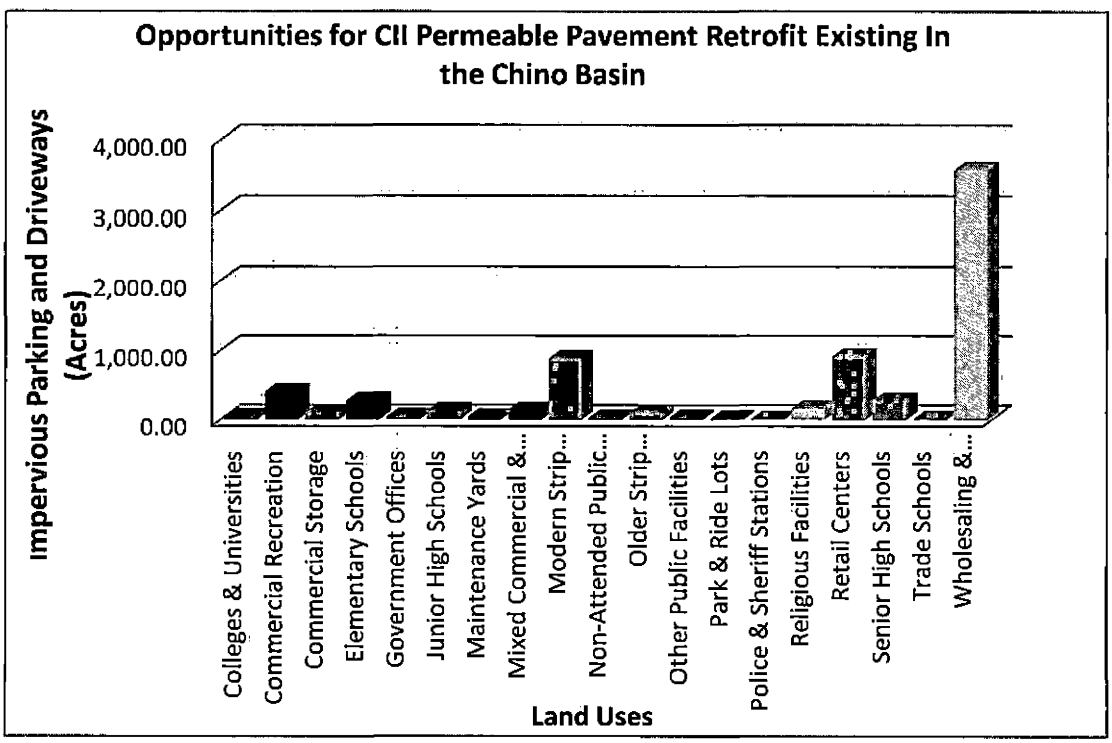


**Figure 19.** Opportunities for Permeable Pavement Retrofit in Existing Commercial, Industrial, and Institutional Land Uses for the Service Area of Chino Basin.

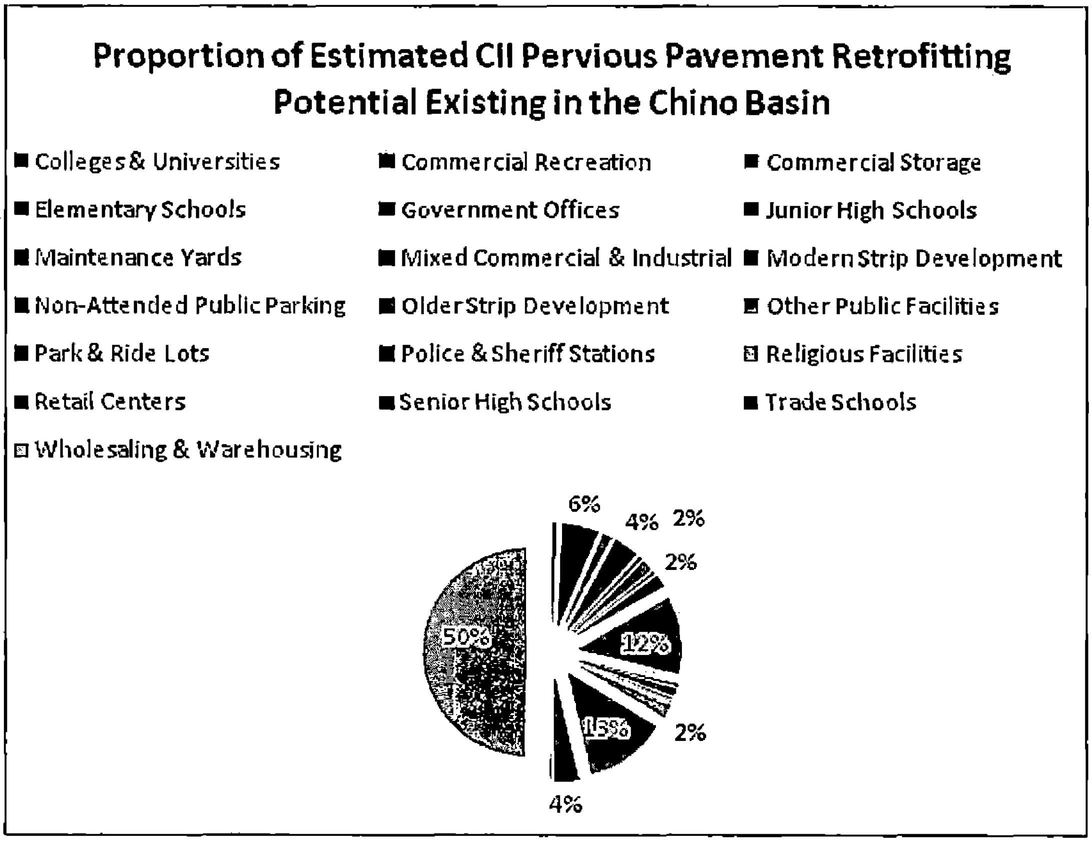


**Figure 20.** Proportion of Estimated Pavement Retrofit Potential of Commercial, Industrial, and Institutional Land Uses.

Figure 20 shows the proportions of impervious parking lot and driveways occupied by each land uses. Wholesale and warehousing occupies approximately 50% of the entire retrofitting potential of the Basin while commercial storage and retail centers cover significant portion of the Basin at approximately 12% and 13%, respectively. Most of the remaining land uses such as government offices and commercial storage cover less than 2% of the impervious parking lot and driveways each although they occupy approximately 25% of the permeable retrofit potential of the Chino Basin.

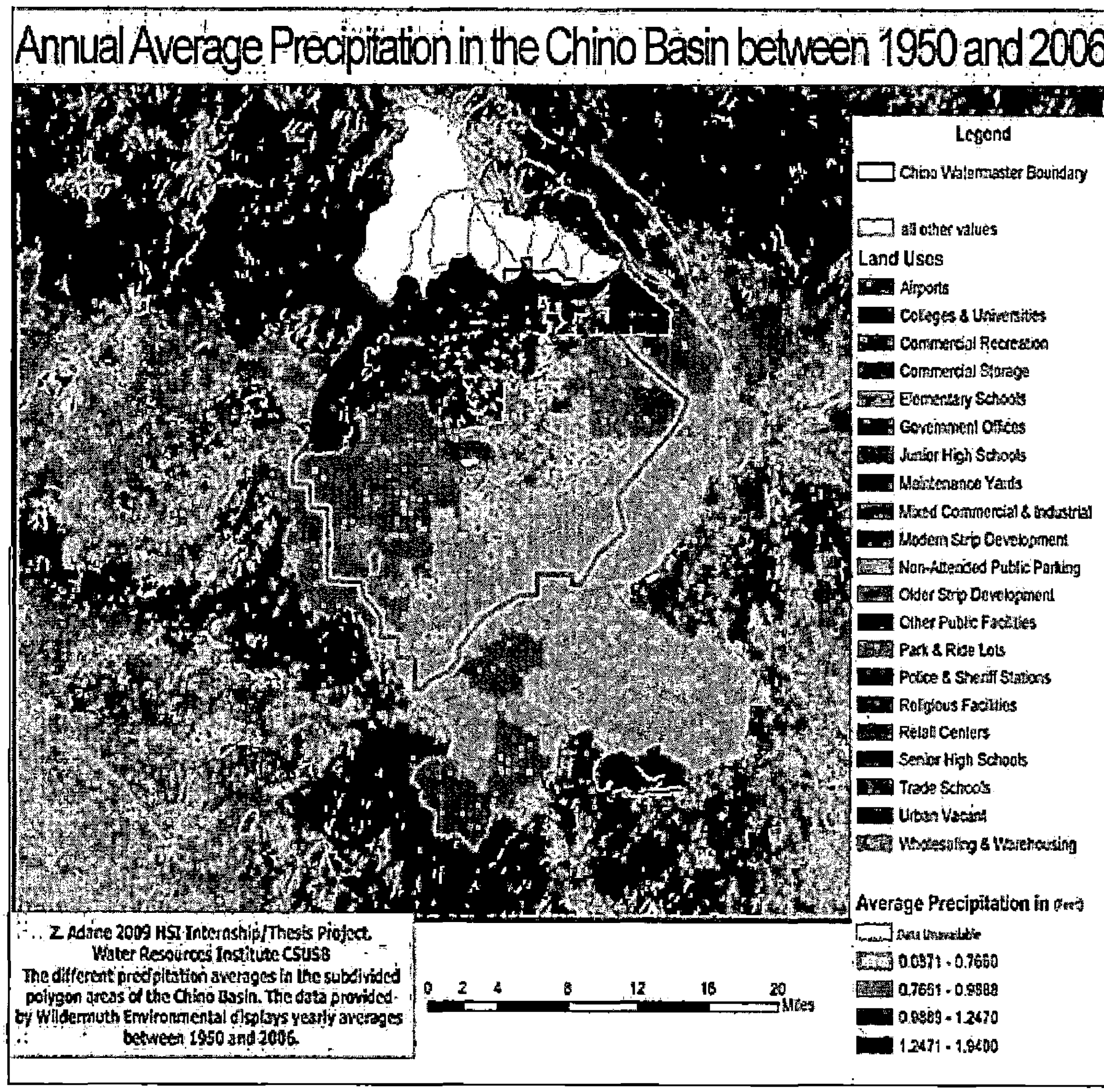


**Figure 21.** Average Precipitations of Different Sub-Drainage Polygons within the Chino Basin between 1950 and 2006.

Chino Basin is subdivided into many polygons in order to obtain more accurate values for precipitation and runoff annual averages. A land parcel located within a specific polygon is given the precipitation and runoff average of that polygon. As Figure 21 illustrates, the basin is divided into five regions of annual runoff averages. The yellow region of the map located at the base of the San Gabriel Mountains does not have any precipitation and runoff value available but it is irrelevant since it is outside of the Chino Basin legal and hydrology boundary.

The majority of the Basin's precipitation falls between 0.766 feet (9.19 inches) and 1.940 feet (23.28 inches) per year as designated by the shades of green and blue. These values are consistent with the Metropolitan Water District data (see Figure 6). In addition, the 20 year historical data indicates the average precipitation for this region to be nearly 17 inches and maximum rainfall observed is approximately 35 inches. The northern part of the Basin represented in the shades of blue experiences heavier average annual precipitation than the rest of the area. The urban developments are visibly concentrated in the northern half of the Chino Basin which receives more precipitation; hence, more likely to experience heavier stormwater runoff due to its impervious surfaces.

**Table 6.** Total Estimated Area of Commercial, Industrial, and Institutional Land Use Impervious Surfaces and Annual Expected Runoff Averages.

| Types of Commercial, Industrial, and Institutional (CII) Parcels Existing in Chino Basin | Total Acres in Parcel | Impervious Coefficients | % of Parking & Drwys of Impervious | Acres of Impervious Parking & Drwys | Annual Runoff Average (Acre-ft/acre) | Average Runoff from Parcels (Acre-ft/ acre/yr) | % of Total |
|---|---|---|---|---|---|---|---|
| Colleges & Universities | 186.16 | 0.40 | 0.61 | 45.42 | 1.03 | 46.78 | |
| Commercial Recreation | 737.20 | 0.90 | 0.61 | 404.72 | 1.03 | 416.86 | |
| Commercial Storage | 191.76 | 0.90 | 0.61 | 105.28 | 1.03 | 108.44 | |
| Elementary Schools | 1,142.28 | 0.40 | 0.61 | 278.72 | 1.03 | 287.08 | |
| Government Offices | 180.82 | 0.40 | 0.61 | 44.12 | 1.03 | 45.44 | |
| Junior High Schools | 548.77 | 0.40 | 0.61 | 133.90 | 1.03 | 137.92 | |
| Maintenance Yards | 81.23 | 0.90 | 0.61 | 44.60 | 1.03 | 45.94 | |
| Mixed Commercial & Industrial | 260.21 | 0.90 | 0.61 | 142.86 | 1.03 | 147.15 | |
| [redacted] | | | | | | | |
| Non-Attended Public Parking | 56.93 | 0.90 | 0.61 | 31.25 | 1.03 | 32.19 | |
| Older Strip Development | 176.90 | 0.90 | 0.61 | 97.12 | 1.03 | 100.03 | |
| Other Public Facilities | 59.51 | 0.40 | 0.61 | 32.67 | 1.03 | 33.65 | |
| Park & Ride Lots | 26.67 | 0.90 | 0.61 | 14.64 | 1.03 | 15.08 | |
| Police & Sheriff Stations | 14.13 | 0.40 | 0.61 | 3.45 | 1.03 | 3.55 | |
| Religious Facilities | 658.66 | 0.40 | 0.61 | 160.71 | 1.03 | 165.53 | |
| [redacted] | | | | | | | |
| Senior High Schools | 1,130.95 | 0.40 | 0.61 | 275.95 | 1.03 | 284.23 | |
| Trade Schools | 44.07 | 0.40 | 0.61 | 10.75 | 1.03 | 11.07 | |
| [redacted] | | | | | | | |
| **TOTAL AREA ESTIMATED WITH POTENTIAL FOR PERVIOUS PAVEMENT RETROFIT** | | | | 7,205.09 | | 7,421.24 | [redacted] |

Table 6 shows the combination of estimated land coverage with potential for pervious pavement retrofit and the volume of stormwater that can potentially be captured by applying permeable pavement for each of the land uses. An average value of 1.03 acre-ft/acre per year was used to calculate the average runoff from parking and driveways of each parcel. This value was obtained by averaging the precipitation values of 104 of the total 156 subdrainage polygons which are directly located within the Chino Basin (see Appendix c). Since the runoff average (1.03 acre-ft/acre per year) is equivalent to 1 acre-ft/acre per year, the land use areas and the runoff have similar numerical values. On average, approximately 7,421 acre-ft of stormwater runoff was produced from 7,205 acre feet of impervious parking lots and driveways from the selected commercial, industrial and institutional land uses of the Chino Basin.

As was the case for the impervious surface coverage, modern strip developments, retail centers, and Wholesale and Warehousing produce the most runoff at approximately 911, 942, and 3,687 acres-ft of stormwater per year, respectively. These three land uses combined account for nearly 75 percent of the total stormwater runoff generated by the impervious surfaces while the rest of the land uses combined produce the remaining volume of runoff.

**Table 7.** Total Stormwater Runoff Generated from Impervious Parking and Driveways of Commercial, Industrial, and Institutional Land Categories in the Chino Basin.

| Category of Impervious Parking and Driveways | Commercial | Industrial | Institutional | Total |
|---|---|---|---|---|
| Annual Runoff Average in Acre-ft/year | 6,180.14 | 193.09 | 1047.44 | 7,421.24 |
| ~ % of Total | 83.3 | 2.6 | 14.1 | 100.00 |

The above table shows that approximately 6,180 acre-ft of urban stormwater runoff is generated by impervious parking lots and driveways of commercial land uses per year. The commercial sector produces most of this runoff because it accounts for most of the impervious surface acreage through modern strip developments, retail centers, and more importantly wholesale and warehousing. Wholesale and warehousing alone accounts approximately 61 percent of stormwater runoff produced by the commercial sector. The other two land uses generate nearly 30 percent of the commercial runoff while the rest of the land uses of the commercial category produce approximately 10 percent of the runoff. As expected, the industrial sector of the selected land uses produces the least runoff of 193 acres-ft per year while the institutional land uses account for approximately 1,047 acre-ft (14%) of urban stormwater runoff.

**Table 8.** Total Estimated Area of Commercial, Industrial, and Institutional Land Use Impervious Surfaces and Annual Minimum Expected Runoff Averages.

| Types of Commercial, Industrial, and Institutional (CII) Parcels Built Out in Chino Basin | Total Acres in Parcels | Acres of Impervious Parking & driveways | Averaged Annual Runoff Minimum in Acre-Ft/Acre | Averaged Minimum Runoff From Parking and Driveways in Acre-Ft/Year |
|---|---|---|---|---|
| Colleges & Universities | 186.16 | 45.42 | 0.11 | 5.00 |
| Commercial Recreation | 737.20 | 404.72 | 0.11 | 44.52 |
| Commercial Storage | 191.76 | 105.28 | 0.11 | 11.58 |
| Elementary Schools | 1,142.28 | 278.72 | 0.11 | 30.66 |
| Government Offices | 180.82 | 44.12 | 0.11 | 4.85 |
| Junior High Schools | 548.77 | 133.90 | 0.11 | 14.73 |
| Maintenance Yards | 81.23 | 44.60 | 0.11 | 4.91 |
| Mixed Commercial & Industrial | 260.21 | 142.86 | 0.11 | 15.70 |
| [redacted] | | | | |
| Non-Attended Public Parking | 56.93 | 31.25 | 0.11 | 3.44 |
| Older Strip Development | 176.90 | 97.12 | 0.11 | 10.68 |
| Other Public Facilities | 59.51 | 32.67 | 0.11 | 3.59 |
| Park & Ride Lots | 26.67 | 14.64 | 0.11 | 1.61 |
| Police & Sheriff Stations | 14.13 | 3.45 | 0.11 | 0.38 |
| Religious Facilities | 658.66 | 160.71 | 0.11 | 17.68 |
| [redacted] | | | | |
| Senior High Schools | 1,130.95 | 275.95 | 0.11 | 30.35 |
| Trade Schools | 44.07 | 10.75 | 0.11 | 1.18 |
| [redacted] | | | | |
| Total | 15,293.94 | 7,205.09 | | 792.54 |

Table 8 shows the estimated area coverage with potential for pervious pavement retrofit and the volume of stormwater that can potentially be captured by applying permeable pavement for each of the land uses during a historically low precipitation year. An average value of 0.11 acre-ft/acre per year was used to calculate the average minimum runoff from parking and driveways of each parcel. This value was also obtained by averaging the 104 of the total 156 polygons that are located within the Chino Basin hydrological boundary. During a low precipitation year, approximately 793 acre-ft of stormwater runoff can be captured from 7,205 acres of impervious parking lots and driveways. The percentage of the total stormwater runoff generated by the land uses is proportional to Table 6.

**Table 9.** Total Estimated Area of Commercial, Industrial, and Institutional Land Use Impervious Surfaces and Annual Expected Maximum Runoff Averages.

| Types of Commercial, Industrial, and Institutional (CII) Parcels Built Out in Chino Basin | Total Acres in Parcels | Acres of Impervious Parking & driveways | Averaged Annual Runoff Maximum in Acre-Ft/Acre | Averaged Maximum Runoff From Parking and Driveways in Acre-Ft/Year |
|---|---|---|---|---|
| Colleges & Universities | 186.16 | 45.42 | 2.70 | 122.63 |
| Commercial Recreation | 737.20 | 404.72 | 2.70 | 1,092.74 |
| Commercial Storage | 191.76 | 105.28 | 2.70 | 284.26 |
| Elementary Schools | 1,142.28 | 278.72 | 2.70 | 752.54 |
| Government Offices | 180.82 | 44.12 | 2.70 | 119.12 |
| Junior High Schools | 548.77 | 133.90 | 2.70 | 361.53 |
| Maintenance Yards | 81.23 | 44.60 | 2.70 | 120.42 |
| Mixed Commer. & Industrial | 260.21 | 142.86 | 2.70 | 385.72 |
| [redacted] | | | | |
| Non-Attended Pub. Parking | 56.93 | 31.25 | 2.70 | 84.38 |
| Older Strip Development | 176.90 | 97.12 | 2.70 | 262.22 |
| Other Public Facilities | 59.51 | 32.67 | 2.70 | 88.21 |
| Park & Ride Lots | 26.67 | 14.64 | 2.70 | 39.53 |
| Police & Sheriff Stations | 14.13 | 3.45 | 2.70 | 9.32 |
| Religious Facilities | 658.66 | 160.71 | 2.70 | 433.92 |
| [redacted] | | | | |
| Senior High Schools | 1,130.95 | 275.95 | 2.70 | 745.07 |
| Trade Schools | 44.07 | 10.75 | 2.70 | 29.03 |
| [redacted] | | | | |
| **Total** | 15,293.94 | 7,205.09 | | 19,453.75 |

Table 9 shows the estimated area coverage with potential for pervious pavement retrofit and the volume of stormwater that can potentially be captured by applying permeable pavement for each of the land uses during a historically high precipitation year. An average value of 2.7 acre-ft/acre per year was used to calculate the average maximum runoff from parking and driveways of each land use.

If the Basin experiences such high rate of rainfall, a permeable retrofit can potentially infiltrate nearly 19,500 acre-ft of water from these selected land uses per year.

## Discussion

The findings in this research project suggest that there currently exists a significant amount of impervious surfaces in the Chino Basin. More importantly, the study displays the total estimated area of impervious surfaces associated with parking lot and driveways and the total volume of urban stormwater generated in the selected land uses of the commercial, industrial and institutional sectors.

Based on the results, it is apparent that the commercial sector of the Basin has the most potential for permeable retrofit. The selected commercial land uses account for 5,985 acres, approximately 83%, of the Basin's total impervious surfaces associated with parking lot and driveways. Wholesale and warehousing land parcels contain nearly 60% of impervious parking and driveways of the commercial sector and 50% of the total impervious surface area of the Chino Basin. The projected results indicate that the commercial sector produces 6,180 acre-ft of stormwater per year which corresponds approximately 83% of all the land uses considered for this study. The commercial land uses; especially modern strip developments, retail centers and wholesale and warehousing, provide the most promise for permeable retrofit. Based on the results, any retrofitting efforts in the Chino Basin should primarily focus on the commercial land uses.

The industrial sector of the Chino Basin produces less than 3% of the total urban stormwater runoff generated by parking and driveways of the selected land uses. The industrial land uses include maintenance yards and mixed commercial and industrial parcels but do not account for a significant area of impervious surfaces. However, approximately 193 acre-ft of stormwater runoff per year is produced by industrial land uses on an average precipitation year.

The institutional sector of Chino Basin includes schools, government infrastructure, and religious centers. The institutional land uses account for approximately 14% of the entire impermeable parking lots and driveways and the 14% of the urban stormwater runoff these impervious surfaces produce in the Chino Basin. Schools make up 72% of the institutional sector and slightly more than 10% of the entire impervious parking lot and driveways of the Chino Basin. Governmental institutions, religious centers and other public facilities also cover a significant amount of the impervious surfaces of the Basin. Municipalities have direct access and control of the institutional land uses. Therefore, local governments such as San Bernardino County can implement retrofitting efforts in these land uses to increase the Basin's recharge and serve as a leading example to land uses in the commercial and industrial sectors.

# CHAPTER FIVE

# CONCLUSION

## Conclusion

The projected results of this study indicate that there is a large volume of urban stormwater runoff generated by the impervious surfaces of parking lots and driveways in the Chino Basin. A significant volume of stormwater runoff can be reinvested into the ground by ramping up the efforts of permeable retrofitting of parking lots and driveways of commercial, industrial and institutional land parcels. Although pervious retrofit effort should include all parcels with impervious surfaces, there should be special focus on commercial land uses due to the vast acreage they occupy. Modern strip developments, strip centers and wholesale and warehousing account for the majority of the impervious parking lots and driveways as well as stormwater runoff generated each year. Public policy makers should keep in mind the magnitude of these land uses when designing ordinances to install permeable parking lots and driveways.

A study conducted by Wildermuth Environmental for the Chino Basin shows stormwater recharge in the basin declined by 14,000 acre-ft per year with a probable reduction of approximately 30,000 acre-ft per year in the Upper Watershed (Wildermuth Environmental, Inc. Presentation, 2009). The results of this research project indicate more than half of this stormwater recharge decline can be reinvested into the groundwater by retrofitting the selected impermeable parking lots and driveways of the commercial, industrial, and institutional sectors into pervious pavement that allow water to infiltrate rather than be lost as urban stormwater runoff. Residential areas were not considered for this research project, however, including residential parcels in the retrofitting effort will significantly increase the volume of stormwater captured in the Basin and will assist in increasing the Basin's groundwater capacity and reducing water imported.

The urbanization of the Basin increases its impervious surfaces due to the need for buildings, roads, driveways, and parking lots. "The volume of water not captured for recharge in the Chino Basin during the period of October 1977 and September 1999 averaged approximately 41,000 acre-feet per year (acre-ft/yr) and ranges from a low of 2,000 acre-ft/yr to a high of about 174,000 acre-ft/yr" (Wildermuth Environmental, Inc. Report, 2001). Based on the results of this research, the volume of stormwater currently produced from select commercial, industrial, and institutional land uses is approximately 7,421 acre-ft per year and ranges from a low of 793 to a high of 19,454 acre-ft per year depending on the annual precipitation. The volume of stormwater produced will clearly increase substantially in the future as the remaining undeveloped (vacant) and agricultural crop fields are converted to developed, urbanized land uses that are impervious to infiltration.

Although the scope of this study is limited to how much stormwater can be captured by pervious retrofit of the selected land uses, permeable pavements provide many other benefits to the Chino Basin if the retrofitting is implemented. Permeable pavements help alleviate the heat island effect of urban areas. The light colors of permeable pavements reflect sunlight and reduce the temperature compared to the dark asphalts that tend to absorb sunlight and increase ambient temperatures. The designs of permeable pavements are also aesthetically appealing and can work well with landscaping by providing the conditions for planting trees, grass and other plants. Permeable pavement installations also provide puddle, splash and skid reductions for cleaner surrounding and safer traffic conditions. Substantial runoff reduction and erosion control are also important contributions of retrofitting. Water quality is also enhanced by removing chemicals, metals and other contaminants from the urban runoff. Assuming proper maintenance, pervious pavements have significant lower life costs than impervious surfaces.

This study does not account for soil studies and other onsite conditions of any land parcels. It is important to understand the site conditions, the climate and traffic frequency and other important parameters of the parcels in order to select the right type of permeable pavement and design application prior to constructing these structures. Assuming appropriate installation and maintenance of the pervious pavement surfaces, the Chino Basin will benefit from retrofitting by increasing groundwater recharge, aesthetics, erosion control, and water quality while reducing pavement deterioration and life cycle cost. Therefore, the municipalities and local governments should encourage, incentivize and mandate new businesses of the commercial and industrial land owners to install permeable parking lots and driveways. Parking lot and driveway pavements of existing businesses often deteriorate and are subsequently replaced by new but still impervious surfaces. Policy makers should design ordinances that provide pressures and incentives for business to install permeable retrofits. Governments should lead the retrofitting effort by transforming institutional land parcels such as schools and governmental facilities by replacing their parking lots and driveways with pervious pavements.

All public water policies, land use, and drainage decisions that have an effect on the amount of stormwater recharge of the Chino Basin must include mitigation measures to control further increase of urban stormwater runoff. Since further urbanization of undeveloped land is eminent, as the population of Southern California increases, all necessary steps, including the installation of permeable pavement, must be taken to provide an affordable supply of drinking water for current and future generations.

# APPENDIX A

# PARKING AND LOADING REGULATIONS AND ORDINANCES

# OF SAN BERNARDINO COUNTY ADMINISTRATIVE

# DESIGN GUIDELINES

**San Bernardino County Land Use Services Department,**
**Current Planning Division**
**Administrative Guidelines[7]**

## Parking and Loading Regulations

Off-street parking is required for all new uses and changes in use when the occupancy or use is changed to a different use. The parking and loading spaces required by the Development Code, Section 87.0601 et seq, shall be provided on the same site with the main use or building or on a site developed in accordance with a plan approved by the Planning Division or Building Official. Property within the ultimate right-of-way of a street or highway shall not be used to provide required parking or loading facilities.

**Parking Lot Design Requirements:**
1. The parking area shall be designed so that a car entering the parking area shall not be required to enter a street to move from one location to any other location within the parking area or premises.
2. Parking and maneuvering areas shall be so arranged that any vehicle entering a vehicle right-of way (street or road) can do so traveling in a forward direction.
3. Head-in parking shall not be permitted where curbs and gutters do not exist and where vehicular access to the private property is not restricted by barriers.
4. Driveways and parking areas should be clearly defined with physical barriers.
5. Individual parking stalls shall be clearly striped and permanently maintained with double or hairpin lines on the surface.
6. Nonresidential parking areas, which abut residential land use districts, shall be separated
There from by a solid fence or masonry wall six (6) feet in height, measured from finished grade of the parking lot.
7. All parking area lighting shall reflect light and glare away from public thoroughfares and any adjacent residences.
8. All off-street parking facilities shall be designed to limit to private property from street and highways to a minimum number of standard driveways per the County Department of Transportation specifications.

**Dimensions**
1. Each required parking space shall be a minimum of nine (9) feet wide by nineteen (19) feet long, except where compact spaces have been authorized.
2. Compact parking spaces shall be a minimum of even and one-half (7 1/2) feet wide by fifteen (15) feet long. Compact spaces shall be grouped in separate areas. Compact spaces shall be marked and/or posted with signs stating "Compact Cars Only".

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[7] http://www.co.san-bernardino.ca.us/landuseservices/Informational%20Handouts/Administative%20Design%20Guidelines-Jan%202002.pdf

3. One-way access drives leading to aisles within a parking area shall be a minimum 12' wide, and within the aisle as follows:
Parking Stall Angle Minimum Aisle Width
Parallel (0) 12'
1-45 14'
46-60 17'
61-90 24'
4. Two-way aisles and two-way access drives leading to aisles within a parking area shall be a minimum width of twenty-four feet (24').

**Surfacing**
1. In Valley areas, the required parking, loading, and access driveways shall be surfaced with a minimum of two (2) inches of A.C. paving (County Specification No. 39)
2. In Mountain areas, where the property abuts a paved street, the required parking, loading, and access driveways shall be surfaced with a minimum of two (2) inches of road mixed paving (County Specification No. 38).
3. In Desert areas, where the property abuts a paved street, the required parking, loading, and access driveways shall be surfaced with a minimum of two (2) inches of A.C. paving, except as follows:
a. For single-family residential on lots of 18,000 square feet or larger, required parking and driveways shall be dust proofed or fully paved.
b. For commercial, industrial, or institutional uses with no greater than 4,000 square feet of building area in Improvement Level Area 4 or 5, the required off-street access driveways, parking for the disabled, and loading areas shall be surfaced with a minimum of two (2) inches of A.C. paving. The remaining parking areas may be paved or dust-proofed. The non-paved parking shall have a positive barrier to prevent direct access onto the paved road.

**Landscaping**
Landscaping shall be provided for parking lots consistent with the requirements of the Countywide Landscaping Requirements, Parking Lots, as specified on page 16 of these Administrative Design Guidelines.
**Loading**
Every institutional, commercial, industrial or special use shall have one permanently paved and maintained loading space for each 5,000 square feet of building floor area, provided however, that not more than four (4) such spaces shall be required per use. Each space shall be not less than ten (10) feet wide, twenty (20) feet long, and fourteen (14) feet clear in height.

**Parking for the Disabled**
1. Parking spaces for the disabled shall be provided for multifamily residential, commercial, industrial, institutional and public uses as follows:
**Total Number of Number of Parking Spaces Required**
**Parking Spaces For The Disabled**

1 - 25 ....................................................1
26 - 50 ..................................................2
51 - 75 ..................................................3
76 - 100 ................................................4
101 - 150 ..............................................5
151 - 200 ..............................................6
201 - 300 ..............................................7
301 - 400 ..............................................8
401 - 500 ..............................................9
501 - 1000 ............................................2 percent of total
1001 and over............................................. 20 plus 1 for each 100 or fraction thereof over 1001.

2. Each parking space for the disabled shall be a minimum of 14' x 19'. Two adjacent parking spaces for the disabled can be accommodated within a 23' wide area that is lined to provide for a 9' parking area on each side of a 5' loading and unloading area in the center. One in every eight (8) parking spaces for the disabled, but not less than one, shall be served by an access aisle 96 inches wide and shall be designated van accessible. This means that when only one (1) space is required, it shall be seventeen (17) feet wide and outlined to provide a nine (9) foot parking area and an eight (8) foot loading/unloading area on the passenger side. When only two (2) spaces are required, they may be provided within a twenty-six (26) foot-wide area lined to provide a nine (9) foot parking area on each side of an eight (8) foot loading/unloading area in the center. All such spaces may be grouped on one level of a parking structure.

3. Parking spaces for the disabled shall be located as near as practical to a primary entrance to a single building, or shall be located to provide for safety and optimum proximity to the entrances of the greatest incidence of use when more than one (1) building is served by the parking lot. Such spaces shall be located so that a disabled individual is not compelled to wheel or walk behind parked cars other than his own. Pedestrian ways, which are accessible to the physically disabled, shall be provided from each such parking space to related facilities, including curb cuts or ramps as needed. Ramps shall not encroach into any parking space.

**Number of Spaces per Use**

Where two or more uses are located in a single building or on a single lot, required parking shall be provided for each specific use and adding the requirements together.

Business and Commercial Uses:

a. General business, except as herein specified: One (1) parking space for each two hundred (200) square feet of building floor area. A minimum of four (4) parking spaces shall be provided for each use.

b. Amusement enterprises, commercial recreation and similar uses such as shooting ranges, race tracks, miniature golf course, pitch and putt courses, parks and zoos: One (1) parking space for each four (4) persons using or attending the facilities.

c. Automobile sales, boat sales, mobile home sales, retail nurseries and other open uses not in a building or structure: One (1) parking space for each two thousand

(2,000) square feet of open area devoted to display or sales; provided, however, that where such area exceeds ten thousand (10,000) square feet, only one (1) parking space need be provided for each five thousand (5,000) square feet of such area in excess of the first ten thousand (10,000) square feet contained in such area.

d. Bowling alleys and billiard halls: Five (5) parking spaces for each bowling lane and two (2) parking spaces for each billiard table.

e. Chapels and mortuaries: One (1) parking space for each three (3) fixed seats and for every twenty (20) square feet of seating area where there are no fixed seats, all to be within the main chapel, and one (1) parking space for each four hundred (400) square feet of floor area outside the main chapel. Twenty-four (24) linear inches of bench or pew shall be considered a fixed seat.

f. Child care centers: One (1) parking space for each employee or teacher and one (1) parking space for each five (5) children that the facility is designed to accommodate.

g. Children's homes: One and one-half (1½) parking spaces for each employee on the largest shift.

h. Churches: One (1) parking space for each four (4) fixed seats or for every twenty-five (25) square feet of seating area within the main auditorium where there are no fixed seats.

Twenty-four (24) linear inches of bench or pew shall be considered a fixed seat.

i. Dance halls: One (1) parking space for each twenty (20) square feet of dance floor area and one (1) parking space for each three (3) fixed seats and for each twenty (20) square feet of seating area where there are no fixed seats.

j. Golf courses and driving ranges, but not to include miniature golf courses: Four (4) parking spaces per hole on all golf courses and one (1) parking space per tee for driving ranges.

k. Hospital: One (1) parking space for each two (2) patient beds and one (1) parking space for each staff member and employee on the largest shift.

l. Medical offices, clinics, veterinary hospitals: Five (5) parking spaces for each doctor or dentist.

m. Offices, banks, building and loan associations, business and professional uses: One (1) parking space for each two hundred (200) square feet of floor area. A minimum of four (4) such parking spaces shall be provided.

n. Organization camps: One and one-half (1½) parking spaces for each staff member or employee.

o. Restaurants, including drive-ins, cafes, night clubs, taverns and other similar places where food or refreshment are dispensed: One (1) parking space for each three (3) fixed seats and/or for every fifty (50) square feet of floor area where seats may be placed. A minimum of ten (10) parking spaces shall be provided. For food establishments with take-out provisions only: One (1) parking space for each two hundred (200) square feet of building floor area. Additionally, one (1) parking space shall be required for each employee on the largest shift and/or for each vehicle used for delivery purposes, whichever is greater. A minimum of four (4) parking spaces shall be provided for such establishments.

p. Skating rinks, ice or roller: One (1) parking space for each three (3) fixed seats and for each twenty (20) square feet of seating area where there are no fixed seats

and one (1) parking space for each two hundred and fifty (250) square feet of skating area. Twenty-four (24) linear inches of bench shall be considered a fixed seat.
q. Social care facilities: One (1) parking space for each three (3) residents in accordance with the resident capacity of the home as listed on the required license or permit, plus one (1) parking space for each staff member and employee on the largest shift.
r. Commercial swimming pools and swimming schools: One (1) parking space for each five hundred (500) square feet of water surface area. A minimum of ten (10) parking spaces shall be provided.
s. Theaters, auditoriums, stadiums, sport arenas, gymnasiums and similar places of public assembly: One (1) parking space for each four (4) fixed seats and for every twenty-four (24) square feet of seating area where there are no fixed seats.
t. Mini-storage facilities: One (1) parking space for each 200 square feet of office floor area, with a minimum for four (4) parking spaces. If a caretaker's residence is included in the design of the facility, an additional two (2) parking spaces are required. A parking lane shall be provided adjacent to the storage building's openings, which is a minimum of nine (9) feet in width and outlined (painted). This parking lane is for temporary parking only — thirty (30) minutes maximum. This time restriction must be clearly marked with signs. Driveways adjacent to the parking lane shall be a minimum width of fifteen (15) feet for one-way and twenty-four (24) feet for two-way.

**Educational Uses:**
a. Schools, accredited general curriculum, kindergarten through grade nine (9): One (1) parking space for each staff member, faculty member, and employee.
b. Schools, accredited general curriculum, grade ten (10) through twelve (12), colleges and universities, business and professional schools: One (1) parking space for each five (5) students plus one (1) parking space for each staff member, faculty member and employee.
c. Special schools or trade schools: One (1) parking space for each three (3) students plus one (1) parking space for each staff member, faculty member, and employee.

**Industrial Uses:**
Industrial uses of all types, including warehouses or buildings used exclusively for storage purposes, wholesale houses and distributors and public utility facilities including, but not limited to, electric, gas, water, telephone and telegraph facilities not having business offices on the premises: One (1) parking space for each employee on the largest shift or one (1) parking space for each one thousand (1,000) square feet of floor area, whichever is greater, and one (1) parking space for each vehicle operated or kept in connection with the use. For facilities that allocate a portion of the building to office space, one (1) parking space shall be required for each two hundred (200) square feet of office area.

**Residential Uses:**

a. Dwellings, including multiple dwellings. Two (2) parking spaces on the same site with the main building for each dwelling unit. Such parking spaces shall be located to the rear of the front setback line except that in mountain areas the parking spaces may be located within the setback areas. Tandem parking shall be prohibited except in mountain areas.
b. Clubs, conference centers, fraternity and sorority houses, rooming and boarding houses and similar structures having guest rooms: One (1) parking space for each three (3) guest rooms.
In dormitories, each one hundred (100) square feet shall be considered equivalent to a guestroom.
c. Mobile home parks: Two (2) parking spaces (which may be in tandem) on each mobile home lot.
There shall also be established and maintained within each mobile home park one (1) parking space for each ten (10) spaces or fraction thereof within the mobile home park, for visitor use.
d. Motels, hotels, and motor hotels: One (1) parking space for each unit.

**Site Plan Requirements:**
The plot plan or site plan shall show the following:
a. Formula used to calculate the number of spaces required for each use/unit type of surfacing.

b. Directional arrows.

# APPENDIX B

## SAN BERNARDINO COUNTY FLOOD CONTROL HYDROLOGY MANUAL - ACTUAL IMPERVIOUS COVERS FOR DEVELOPED AREAS

# County of San Bernardino Hydrology Manual[8]
# Prepared by: Williamson and Schmid, Civil Engineers, Irvine, California, 1986

## Actual Impervious Area for Developed Areas

ACTUAL IMPERVIOUS COVER

| Land Use (1) | Range-Percent | Recommended Value For Average Conditions-Percent (2) |
|---|---|---|
| Natural or Agriculture | 0 - 0 | 0 |
| Public Park | 10 - 25 | 15 |
| School | 30 - 50 | 40 |
| Single Family Residential: (3) | | |
| 2.5 acre lots | 5 - 15 | 10 |
| 1 acre lots | 10 - 25 | 20 |
| 2 dwellings/acre | 20 - 40 | 30 |
| 3-4 dwellings/acre | 30 - 50 | 40 |
| 5-7 dwellings/acre | 35 - 55 | 50 |
| 8-10 dwellings/acre | 50 - 70 | 60 |
| More than 10 dwellings/acre | 65 - 90 | 80 |
| Multiple Family Residential: | | |
| Condominiums | 45 - 70 | 65 |
| Apartments | 65 - 90 | 80 |
| Mobile Home Park | 60 - 85 | 75 |
| Commercial, Downtown Business or Industrial | 80 - 100 | 90 |

Notes:

1. Land use should be based on ultimate development of the watershed. Long range master plans for the County and incorporated cities should be reviewed to insure reasonable land use assumptions.

2. Recommended values are based on average conditions which may not apply to a particular study area. The percentage impervious may vary greatly even on comparable sized lots due to differences in dwelling size, improvements, etc. Landscape practices should also be considered as it is common in some areas to use ornamental gravels underlain by impervious plastic materials in place of lawns and shrubs. A field investigation of a study area shall always be made, and a review of aerial photos, where available, may assist in estimating the percentage of impervious cover in developed areas.

3. For typical equestrian subdivisions increase impervious area 5 percent over the values recommended in the table above.

**SAN BERNARDINO COUNTY**
HYDROLOGY MANUAL

ACTUAL IMPERVIOUS COVER FOR DEVELOPED AREAS

C-8

Figure C-4

[8] http://www.sbcounty.gov/dpw/floodcontrol/pdf/HydrologyManual.pdf

# APPENDIX C

# CHINO BASIN ANNUAL RAINFALL AND RUNOFF FROM IMPERVIOUS AREA FROM WATER YEAR 1950 TO 2007

**Unpublished Data Provided by Wildermuth Environmental, Inc.**
**Contact: Jeff Hwang, PhD**
**23692 Birtcher Drive Lake Forest, CA 92630**
**(949) 420-3030**
**www.wildermuthenvironmental.com**

**Chino Basin Annual Rainfall and Runoff from Impervious Area**
**From Water Year 1950 to 2007**

| ID | Name | Annual Rainfall (inches) | | | Annual Runoff from Impervious Area (acre-ft/acre) | | |
|---|---|---|---|---|---|---|---|
| | | Min. | Max. | Average | Min. | Max. | Average |
| 1 | HSA02 | 4.30 | 44.10 | 18.64 | 0.18 | 3.03 | 1.15 |
| 2 | HSA02A | 3.90 | 42.10 | 18.32 | 0.17 | 2.87 | 1.16 |
| 3 | HSA02B | 3.90 | 42.10 | 18.32 | 0.17 | 2.87 | 1.16 |
| 4 | HSA03 | 3.60 | 41.70 | 17.74 | 0.12 | 2.88 | 1.07 |
| 5 | HSA04 | 3.90 | 41.60 | 18.09 | 0.15 | 2.87 | 1.11 |
| 6 | HSA04A | 3.20 | 41.80 | 17.36 | 0.10 | 2.92 | 1.09 |
| 7 | HSA05 | 3.30 | 41.80 | 17.47 | 0.11 | 2.90 | 1.07 |
| 8 | HSA06 | 3.20 | 41.80 | 17.36 | 0.10 | 2.92 | 1.09 |
| 9 | HSA07 | 3.20 | 41.80 | 17.36 | 0.10 | 2.92 | 1.09 |
| 10 | HSA08 | 3.10 | 40.30 | 17.10 | 0.10 | 2.75 | 1.04 |
| 11 | HSA08A | 3.20 | 41.80 | 17.36 | 0.10 | 2.92 | 1.09 |
| 12 | HSA08B | 3.00 | 38.30 | 16.48 | 0.09 | 2.50 | 0.98 |
| 13 | HSA09 | 2.80 | 37.30 | 15.83 | 0.08 | 2.47 | 0.95 |
| 14 | HSA09A | 3.20 | 41.80 | 17.36 | 0.10 | 2.92 | 1.09 |
| 15 | HSA09B | 3.10 | 40.80 | 17.18 | 0.10 | 2.79 | 1.05 |
| 16 | HSA10 | 2.90 | 37.90 | 16.24 | 0.09 | 2.48 | 0.96 |
| 17 | HSA10A | 2.80 | 36.70 | 15.54 | 0.08 | 2.37 | 0.92 |
| 18 | HSA14 | 2.50 | 34.70 | 14.21 | 0.07 | 2.16 | 0.85 |
| 19 | HSA15 | 2.50 | 34.70 | 14.21 | 0.07 | 2.16 | 0.85 |
| 20 | HSA16 | 2.50 | 34.70 | 14.22 | 0.07 | 2.16 | 0.85 |
| 21 | HSA17 | 2.50 | 34.70 | 14.21 | 0.07 | 2.16 | 0.85 |
| 22 | HSA18 | 2.80 | 37.10 | 15.70 | 0.08 | 2.48 | 0.96 |
| 23 | HSA19A | 2.60 | 34.70 | 14.49 | 0.07 | 2.19 | 0.86 |
| 24 | HSA19B | 2.50 | 34.70 | 14.21 | 0.07 | 2.16 | 0.85 |
| 25 | HSA20 | 2.60 | 35.00 | 14.67 | 0.07 | 2.21 | 0.87 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 26 | **HSA21** | 2.50 | 34.70 | 14.21 | 0.07 | 2.16 | 0.85 |
| 27 | **HSA22** | 2.50 | 34.70 | 14.21 | 0.07 | 2.16 | 0.85 |
| 28 | **HSA23A** | 2.50 | 33.40 | 14.00 | 0.07 | 2.06 | 0.79 |
| 29 | **HSA23B** | 2.30 | 31.30 | 13.15 | 0.07 | 1.88 | 0.71 |
| 30 | **HSA24** | 2.50 | 34.70 | 14.21 | 0.07 | 2.16 | 0.85 |
| 31 | **HCH01** | 3.90 | 41.60 | 18.15 | 0.15 | 2.87 | 1.12 |
| 32 | **HCH02** | 3.20 | 41.80 | 17.36 | 0.10 | 2.92 | 1.09 |
| 33 | **HCH02A** | 3.20 | 41.80 | 17.36 | 0.10 | 2.92 | 1.09 |
| 34 | **HCH02B** | 3.20 | 41.80 | 17.36 | 0.10 | 2.92 | 1.09 |
| 35 | **HCH03** | 2.90 | 37.60 | 15.93 | 0.09 | 2.47 | 0.93 |
| 36 | **HCH04** | 2.50 | 34.70 | 14.21 | 0.07 | 2.16 | 0.85 |
| 37 | **HCH05** | 2.50 | 34.70 | 14.21 | 0.07 | 2.16 | 0.85 |
| 38 | **HCH06** | 2.40 | 32.30 | 13.47 | 0.07 | 1.95 | 0.73 |
| 39 | **HCC02** | 5.70 | 56.70 | 21.50 | 0.24 | 4.01 | 1.33 |
| 40 | **HCC03** | 6.30 | 62.10 | 21.66 | 0.28 | 4.43 | 1.37 |
| 41 | **HCC04** | 6.10 | 60.00 | 21.17 | 0.26 | 4.27 | 1.31 |
| 42 | **HCC04A** | 6.50 | 63.80 | 21.72 | 0.29 | 4.57 | 1.39 |
| 43 | **HCC04B** | 6.50 | 63.60 | 21.72 | 0.29 | 4.56 | 1.38 |
| 44 | **HCC04C** | 4.40 | 48.00 | 21.12 | 0.16 | 3.32 | 1.31 |
| 45 | **HCC06** | 4.00 | 42.10 | 18.36 | 0.17 | 2.88 | 1.16 |
| 46 | **HCC06A** | 4.70 | 46.80 | 20.69 | 0.18 | 3.23 | 1.25 |
| 47 | **HCC07** | 3.70 | 48.80 | 20.91 | 0.12 | 3.40 | 1.34 |
| 48 | **HCC08** | 3.70 | 42.00 | 18.12 | 0.13 | 2.66 | 1.07 |
| 49 | **HCC09** | 3.40 | 45.80 | 19.48 | 0.11 | 3.10 | 1.20 |
| 50 | **HCC10A** | 2.80 | 37.10 | 15.70 | 0.08 | 2.48 | 0.96 |
| 51 | **HCC10B** | 2.80 | 37.10 | 15.70 | 0.08 | 2.48 | 0.96 |
| 52 | **HCC11A** | 2.80 | 38.00 | 16.08 | 0.08 | 2.50 | 0.97 |
| 53 | **HCC11B** | 2.60 | 33.00 | 14.20 | 0.07 | 2.08 | 0.81 |
| 54 | **HCC11C** | 2.70 | 35.10 | 14.90 | 0.08 | 2.27 | 0.86 |
| 55 | **HCC12** | 2.80 | 37.10 | 15.70 | 0.08 | 2.48 | 0.96 |
| 56 | **HCC13** | 2.10 | 29.30 | 12.37 | 0.06 | 1.77 | 0.69 |
| 57 | **HCC14** | 2.20 | 27.60 | 11.95 | 0.06 | 1.57 | 0.63 |
| 58 | **HCC15** | 2.10 | 28.90 | 12.23 | 0.06 | 1.74 | 0.69 |
| 59 | **HCC16A** | 2.10 | 28.90 | 12.23 | 0.06 | 1.74 | 0.69 |
| 60 | **HCC16B** | 2.20 | 28.90 | 12.18 | 0.06 | 1.71 | 0.67 |
| 61 | **HCC17** | 2.10 | 29.30 | 12.36 | 0.06 | 1.75 | 0.68 |
| 62 | **HDR02** | 3.70 | 48.90 | 20.90 | 0.12 | 3.42 | 1.35 |
| 63 | **HDR03** | 3.70 | 49.00 | 20.90 | 0.12 | 3.43 | 1.35 |
| 64 | **HDR04** | 3.70 | 49.00 | 20.90 | 0.12 | 3.43 | 1.35 |
| 65 | **HDR05A** | 3.70 | 49.00 | 20.90 | 0.12 | 3.43 | 1.35 |
| 66 | **HDR05B** | 3.70 | 49.00 | 20.90 | 0.12 | 3.43 | 1.35 |
| 67 | **HDR05C** | 3.70 | 49.00 | 20.90 | 0.12 | 3.43 | 1.35 |
| 68 | **HDR05D** | 3.70 | 49.00 | 20.90 | 0.12 | 3.43 | 1.35 |
| 69 | **HDR06** | 4.90 | 49.90 | 21.27 | 0.19 | 3.47 | 1.31 |
| 70 | **HDR07** | 3.70 | 49.00 | 20.90 | 0.12 | 3.43 | 1.35 |
| 71 | **HDR08** | 3.70 | 49.00 | 20.90 | 0.12 | 3.43 | 1.35 |
| 72 | **HDR09** | 3.70 | 48.50 | 20.69 | 0.12 | 3.38 | 1.32 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 73 | HDR10A | 2.50 | 29.50 | 13.06 | 0.07 | 1.87 | 0.73 |
| 74 | HDR10B | 2.30 | 26.60 | 11.82 | 0.06 | 1.60 | 0.63 |
| 75 | HDY03 | 3.70 | 49.20 | 21.22 | 0.12 | 3.41 | 1.36 |
| 76 | HDY04 | 3.70 | 49.00 | 20.90 | 0.12 | 3.43 | 1.35 |
| 77 | HDY05 | 3.30 | 42.60 | 18.33 | 0.10 | 2.84 | 1.12 |
| 78 | HDY07 | 3.70 | 49.00 | 20.90 | 0.12 | 3.43 | 1.35 |
| 79 | HDY08 | 3.70 | 49.00 | 20.90 | 0.12 | 3.43 | 1.35 |
| 80 | HDY09 | 3.70 | 48.80 | 20.84 | 0.12 | 3.41 | 1.34 |
| 81 | HDY10 | 3.00 | 35.50 | 15.45 | 0.08 | 2.39 | 0.90 |
| 82 | HDY11 | 2.30 | 26.10 | 11.53 | 0.06 | 1.62 | 0.65 |
| 83 | HDY12 | 2.30 | 26.00 | 11.51 | 0.06 | 1.61 | 0.65 |
| 84 | HDY13 | 2.60 | 30.20 | 12.73 | 0.07 | 2.00 | 0.74 |
| 85 | HDY13A | 2.60 | 30.20 | 12.73 | 0.07 | 2.00 | 0.74 |
| 86 | HDY14 | 2.40 | 27.80 | 12.06 | 0.06 | 1.80 | 0.66 |
| 87 | HDY15 | 2.30 | 26.00 | 11.51 | 0.06 | 1.61 | 0.65 |
| 88 | HDY16 | 2.30 | 26.00 | 11.51 | 0.06 | 1.61 | 0.65 |
| 89 | HDY17 | 2.20 | 27.70 | 11.96 | 0.06 | 1.57 | 0.63 |
| 90 | HET02 | 4.20 | 53.40 | 22.65 | 0.15 | 3.77 | 1.42 |
| 91 | HET02A | 3.70 | 46.50 | 19.36 | 0.12 | 3.24 | 1.17 |
| 92 | HET03 | 3.70 | 48.30 | 20.79 | 0.12 | 3.31 | 1.31 |
| 93 | HET04 | 2.70 | 30.90 | 13.11 | 0.07 | 2.05 | 0.76 |
| 94 | HSS01D | 4.20 | 55.20 | 22.62 | 0.15 | 3.87 | 1.46 |
| 95 | HSS01E | 4.20 | 55.20 | 22.62 | 0.15 | 3.87 | 1.46 |
| 96 | HSS01F | 4.20 | 55.20 | 22.62 | 0.15 | 3.87 | 1.46 |
| 97 | HSS02A | 4.20 | 55.20 | 22.62 | 0.15 | 3.87 | 1.46 |
| 98 | HSS02B | 4.20 | 54.40 | 22.35 | 0.14 | 3.81 | 1.43 |
| 99 | HSS03 | 4.20 | 55.20 | 22.62 | 0.15 | 3.87 | 1.46 |
| 100 | HSS04 | 4.00 | 52.00 | 21.62 | 0.13 | 3.57 | 1.35 |
| 101 | HSS05 | 2.80 | 36.30 | 15.86 | 0.07 | 2.32 | 0.92 |
| 102 | HSS06 | 2.70 | 31.80 | 13.73 | 0.07 | 2.05 | 0.76 |
| 103 | HSS07A | 2.60 | 30.20 | 12.73 | 0.07 | 2.00 | 0.74 |
| 104 | HSS07B | 2.70 | 32.30 | 14.02 | 0.07 | 2.08 | 0.78 |
| 105 | HSS07C | 2.80 | 37.90 | 16.51 | 0.07 | 2.45 | 0.99 |
| 106 | HSS08A | 2.60 | 30.20 | 12.73 | 0.07 | 2.00 | 0.74 |
| 107 | HSS08B | 2.80 | 34.90 | 15.26 | 0.07 | 2.23 | 0.86 |
| 108 | HSS09A | 2.50 | 28.10 | 12.20 | 0.07 | 1.82 | 0.67 |
| 109 | HSS09B | 2.60 | 29.30 | 12.51 | 0.07 | 1.92 | 0.70 |
| 110 | HSS09C | 2.70 | 31.80 | 13.82 | 0.07 | 2.04 | 0.76 |
| 111 | HSS10A | 2.30 | 26.00 | 11.51 | 0.06 | 1.61 | 0.65 |
| 112 | HSS10B | 2.20 | 25.40 | 11.49 | 0.06 | 1.56 | 0.60 |
| 113 | HPR01 | 2.50 | 34.70 | 14.21 | 0.07 | 2.16 | 0.85 |
| 114 | HPR02 | 2.10 | 29.30 | 12.40 | 0.06 | 1.76 | 0.68 |
| 115 | HPR03 | 2.10 | 27.30 | 11.41 | 0.07 | 1.48 | 0.56 |
| 116 | HTE23 | 2.20 | 34.70 | 14.46 | 0.06 | 2.35 | 0.86 |
| 117 | HTE24 | 1.90 | 23.20 | 9.48 | 0.05 | 1.38 | 0.45 |
| 118 | HTE26A | 1.80 | 21.60 | 9.49 | 0.03 | 1.21 | 0.48 |
| 119 | HTE26B | 1.80 | 22.10 | 8.90 | 0.05 | 1.30 | 0.45 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **120** | **HTE27A** | 1.90 | 21.20 | 9.63 | 0.05 | 1.23 | 0.49 |
| **121** | **HTE27B** | 1.90 | 22.20 | 9.89 | 0.06 | 1.24 | 0.52 |
| **122** | **HTE28** | 1.80 | 22.30 | 9.18 | 0.05 | 1.32 | 0.46 |
| **123** | **HTE29** | 2.00 | 25.50 | 10.77 | 0.07 | 1.47 | 0.57 |
| **124** | **HTE30** | 2.20 | 33.50 | 14.05 | 0.06 | 2.17 | 0.79 |
| **125** | **HTE31** | 2.20 | 34.70 | 14.46 | 0.06 | 2.35 | 0.86 |
| **126** | **HTE32** | 2.10 | 31.20 | 13.41 | 0.06 | 1.92 | 0.70 |
| **127** | **HTE33** | 2.00 | 26.10 | 10.93 | 0.07 | 1.52 | 0.58 |
| **128** | **HTE34** | 2.00 | 25.30 | 10.78 | 0.07 | 1.38 | 0.54 |
| **129** | **HLYT05** | 4.20 | 54.50 | 22.37 | 0.14 | 3.79 | 1.43 |
| **130** | **HLYT06A** | 3.40 | 37.00 | 15.84 | 0.10 | 2.46 | 0.95 |
| **131** | **HLYT06B** | 3.40 | 37.00 | 15.84 | 0.10 | 2.46 | 0.95 |
| **132** | **HLYT06C** | 3.40 | 37.00 | 15.84 | 0.10 | 2.46 | 0.95 |
| **133** | **HLYT07** | 3.40 | 36.90 | 15.66 | 0.10 | 2.39 | 0.92 |
| **134** | **HLYT08** | 3.10 | 36.00 | 14.68 | 0.08 | 2.21 | 0.81 |
| **135** | **HLYT09** | 2.60 | 34.80 | 13.37 | 0.06 | 2.21 | 0.76 |
| **136** | **HFRC01A** | 3.60 | 44.70 | 18.98 | 0.11 | 2.83 | 1.10 |
| **137** | **HFRC01B** | 3.00 | 36.30 | 16.33 | 0.08 | 2.31 | 0.94 |
| **138** | **HFRC01C** | 2.80 | 37.90 | 16.51 | 0.07 | 2.45 | 0.99 |
| **139** | **HFRC01D** | 2.90 | 37.30 | 16.40 | 0.07 | 2.40 | 0.97 |
| **140** | **HFRC01E** | 2.80 | 36.20 | 16.04 | 0.07 | 2.34 | 0.92 |
| **141** | **HFRC01F** | 3.10 | 36.50 | 16.16 | 0.09 | 2.27 | 0.92 |
| **142** | **HFRC02** | 2.80 | 35.30 | 13.97 | 0.07 | 2.16 | 0.77 |
| **143** | **HFRC03** | 2.60 | 34.80 | 13.37 | 0.06 | 2.21 | 0.76 |
| **144** | **HFRC07** | 2.50 | 32.90 | 13.20 | 0.06 | 1.95 | 0.68 |
| **145** | **HFRC08** | 2.50 | 31.10 | 14.17 | 0.06 | 1.87 | 0.74 |
| **146** | **HFRC09** | 2.00 | 24.50 | 11.37 | 0.04 | 1.47 | 0.59 |
| **147** | **HFRC10** | 2.00 | 24.30 | 11.35 | 0.04 | 1.47 | 0.60 |
| **148** | **HRV17** | 1.80 | 21.20 | 9.44 | 0.03 | 1.21 | 0.47 |
| **149** | **HRV18A** | 1.80 | 20.90 | 9.52 | 0.04 | 1.22 | 0.47 |
| **150** | **HRV18B** | 1.90 | 21.40 | 10.02 | 0.05 | 1.25 | 0.51 |
| **151** | **HRV19** | 2.00 | 24.10 | 11.23 | 0.04 | 1.46 | 0.60 |
| **152** | **HRV20** | 2.00 | 23.90 | 11.46 | 0.04 | 1.43 | 0.59 |
| **153** | **HRV21** | 2.00 | 24.10 | 11.74 | 0.05 | 1.44 | 0.61 |
| **154** | **HRV22** | 2.00 | 24.00 | 11.77 | 0.05 | 1.46 | 0.64 |
| **155** | **HRV23** | 2.00 | 23.90 | 11.72 | 0.05 | 1.44 | 0.64 |
| **156** | **HRV24** | 1.90 | 22.80 | 10.63 | 0.06 | 1.30 | 0.55 |

APPENDIX D

LAND USES CURRENTLY EXISTING IN THE

CHINO BASIN

**California State University, San Bernardino Water Resources Institute and San Bernardino Associated Governments Land Use GIS Data**

**Table of Attributes of Existing Land Uses in 2006**

**Existing Land Uses**

Airports
Base (built-up area)
Bus Terminals & Yards
Commercial Recreation
Commercial Storage
Communication Facilities
Duplexes, Triplexes, 2 or 3
Electrical Power Facilities
Elementary Schools
Fire Stations
Freeways & Major Roads
Golf Courses
Government Offices
High Density S.F.
Horse Ranches
Improved Flood Waterways
Irrigated Cropland
Junior High Schools
Local Parks & Rec.
Low Den. S.F.
Low-Med. Rise Major Office
Low-Rise Apartments
Low-Rise Apartments, Condos
Maintenance Yards
Major Medical Health Care
Manufacturing, Assembly, Ind.
Med-Rise Apartments, Condos
Mineral Extraction-Other
Mixed Commercial & Industrial
Modern Strip Development
Non-Attended Public Parking
Non-Irrigated Cropland
Nurseries

Older Strip Development
Open Storage
Orchards & Vineyards
Other Open Space & Rec.
Other Public Facilities
Other Special Care Use
Park & Ride Lots
Police & Sheriff Stations
Railroads
Religious Facilities
Retail Centers
Senior High Schools
Special Care Facilities
Trade Schools
Trailer Parks High Den.
Under Construction
Urban Vacant
Vacant Area
Vacant Undifferentiated
Water Storage Facilities
Water Transfer Facilities
Wholesaling & Warehousing

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