Uses of Viewshed Analysis Models in Planning and Neighborhood Preservation

Monique de los Rios-Urban
Robert Chasan

Abstract

In the last fifty years, numerous urban areas in western states have experienced rapid peripheral growth. This shift in development often leaves behind depressed urban cores and struggling first-tier suburbs. In some cities, original residential developments in mature neighborhoods have been able to maintain the integrity of their characteristics and, through preservation efforts, have emerged as strong trend reversal agents. These neighborhoods help sustain entire areas, attracting new infill activity that is necessary for solid urban revitalization.

Among the difficulties with development within or adjacent to historically significant neighborhoods is the impact on the existing urban fabric. Height and massing of new buildings in proximity to these areas may block views, impede access or introduce aesthetic components that are incompatible with the preserved area. This study describes the development of an ArcView-based multiple viewshed model as part of a municipal effort to help a specific cluster of neighborhoods analyze the qualitative and quantitative impacts of changes to its building height restrictions.

Background

Scottsdale, Arizona, located directly to the east of the state's capital, Phoenix, is a dynamic, vibrant desert city that appeals not only to tourists but also to residents of this burgeoning metropolitan area. During the last decade alone, the City has welcomed 58,000 new residents – a 36% increase – to its 185 square miles. A high percentage of this new population, and related development activity, has settled in the northern sections of the City, where the unique Sonoran Desert character has been generally preserved through regulatory zoning practices.

This rapid urbanization rate has presented city officials with enormous challenges in striving to maintain a balance between preserving natural land characteristics and ownership rights to develop. Typical northern Scottsdale residential subdivisions are low-density, high-end and often rural in character. In contrast, the more established southern area of Scottsdale, annexed from Maricopa County in the late 1950's and 1960's, was developed by a number of merchant home builders who catered to the housing needs of a Post-War worker population. The result was a homogeneous housing stock comprised of solid mid-century ranch style structures in tree-lined residential neighborhoods, not unlike most subdivisions planned and built in the 1950's throughout the southwestern United States.

The downtown Scottsdale core, located within the southern section of the city, provides an eclectic mix of southwestern and contemporary art galleries, specialty retail, upscale dining, hotels, active nightlife and museums. A number of original residential neighborhoods located in the vicinity of the densifying downtown core are experiencing the pressures associated with the higher densities and mix of uses that typically accompany increased land values. In addition, several of these 1950's single story subdivisions are experiencing the residential "tear-down and rebuild" phenomenon which in most cases fundamentally alters the original scale and character of established neighborhoods.

Neighborhood Context

The neighborhood at issue in this paper (Figure 1), which will be referred to as "Neighborhood A" due to active litigation, is a clear example of a typical mature neighborhood experiencing increasing development pressures. What differentiates this neighborhood from comparable areas in south Scottsdale is that residents decided to take action and control their future. The area includes three homogeneous subdivisions and is one of the oldest residential neighborhoods of its size. As with most subdivisions in southern Scottsdale, the area was platted between 1954 and 1967, and built between 1955 and 1962. It encompasses approximately 362 single-family residential units on 109 acres. The general land elevation for these plats averages 20 to 30 feet higher than the surrounding residential areas. Developer D.D. Castleberry built the majority of these semi-custom ranch style homes, adapting them to the original topography and maintaining the native desert vegetation.

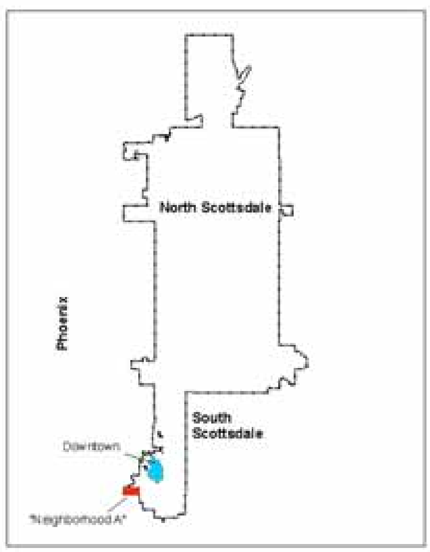

Figure 1. Context Map

Located a mere 3000 feet from the rugged, red sandstone of Barnes Butte in Papago Park to the south and 2.65 miles from internationally known Camelback Mountain to the north, the views of these mountains from "Neighborhood A" are remarkable. (Fig. 2)

Augmenting the scenic backdrop are Castleberry's uniquely Arizonan, low profile home designs. Castleberry, who realized the aesthetic value of the mountain views, ensured that every home site would enjoy a unique vantage point as well as privacy. Homes were originally built single-story with a low and unobtrusive roofline that helps define the profile and scale of the neighborhood. This residential area was considered unique even at the time of its original development due to its large sized parcels, street cross section and rural character .

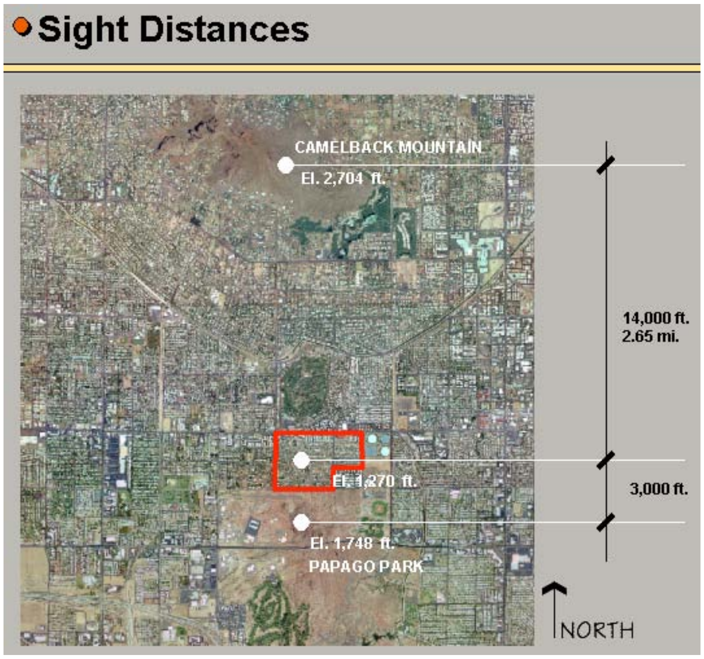

Figure 2. Sight Distances to Mountains

Conditions, Covenants and Restrictions (CC&Rs) were in place in one of the three subdivisions from the onset, restricting building development to 16 feet for building height. However, the homes were kept between 12 and 14 feet. It should be noted that these subdivisions are zoned R1-10, which allows residential building heights up to 30 feet. The deed restrictions expired during the 1990's and all subdivisions are currently under no private regulatory provisions.

Preservation Priorities

In July of 1987, a group of residents interested in preserving the character of the neighborhood formed an association representing about 300 homes. The "Neighborhood A" Neighborhood Association has been active at various times over the past decade and a half. It sponsors events and currently has a very active Neighborhood Watch Program. It is important to note that the Association is not a formal incorporated homeowners association, but that it operates with voluntary membership and involvement of its own residents. In 2001, "Neighborhood A" area residents contacted City of Scottsdale Planning staff with questions and concerns regarding recent development activity adjacent to their neighborhood. After meetings with neighborhood representatives, a survey questionnaire was developed and mailed to all residents in the area.

The principal issues identified by the questionnaire respondents were:

- Character preservation
- Neighborhood traffic (speeding and cut-through)
- Septic tank or sewer conversion
- Burial of power and telephone lines along alleys

Citizens expressed interest in pursuing a neighborhood plan and asked staff to follow up with informational meetings regarding the issues that emerged from the survey questionnaire. The number one priority identified was the preservation of mountain views and privacy. Residents of the area expressed a strong interest in limiting building heights. Because there are no active CC&Rs in the area, the neighborhood leaders identified the Planned Residential Development (PRD) zoning overlay as a preferred option.

Policy Decisions

The City of Scottsdale Zoning Ordinance contemplates a PRD as an option that allows the modification of certain development standards in a residential District without changing the underlying district regulations. The City Council considers a self-imposed PRD Overlay when a significant majority of the residents agree to the rezoning. A working group of neighbors organized a petition campaign and after a few months gathered signatures from neighbors representing 86% of the land area. In late 2003 the Planning Commission and City Council approved this zoning action and imposed the R1-10 PRD Overlay for the "Neighborhood A" area. This PRD specifically restricts building heights to one story with a maximum height of 16 feet.

The Multi-Viewshed Analysis

To assist in the determination of a maximum building height for the area, a multi-viewshed analysis developed specifically for this project by the City's GIS division was applied. Results of this analysis were presented to the neighborhood and were instrumental in the decision making process.

The multi-viewshed analysis was created to quickly provide the constituents with quantitative results based on an easy to understand numeric analysis. In essence, the question "What happens to my view of these important landmarks when all my neighbors raise their roofs to the maximum allowed and I don't?", was programmed into the computer. This question was then asked of the computer for each allowable structure and the results averaged together (arithmetic mean).

This analysis is a very simplified model of the real-world and includes only the most basic of variables – ground elevation based on USGS digital elevation models (DEM) and building roofprint outlines with their approximate highest elevations above ground level derived from full-color orthorectified 6" pixel resolution aerial photography. The observer for each iteration of the viewshed analysis was assumed to be 5' above ground level at the center of the observer's transparent building. Not included were such variables as fences, trees and other vegetation, window placements and changes in ground elevation too subtle to appear in the relatively coarse, 33 meter square cell resolution elevation models. (The City of Scottsdale does have a data warehouse containing custom-made elevation models for the City based on 1', 2', and 3'-5' contour elevations, depending on location, however Camelback Mountain and Barnes Butte are outside the city limits. Rather than mix elevation data from both the City and the USGS, the decision was made to accept the lower resolution of the USGS DEM in order to hold that variable constant.)

Previously acquired USGS "Paradise Valley" and "Tempe" DEMs were converted to ESRI GRID format, mosaicked together, and reprojected to Arizona State Plane Central Zone, NAD1983 coordinates in ERDAS Imagine. The GRID was then resampled to 10' square cell resolution to provide for a more "granular" analysis. Resampling the GRID to an even finer cell size, e.g. 1' square, would reduce the distortion of the house shapes when cast to GRID format (see below), but the potential increase in processing time would have increased significantly.

Once the basic elevation GRID was created, it was decided to perform the multi-viewshed analysis in ESRI's ArcView 3.2a with the Spatial Analyst and 3D Analyst extensions. ArcView is a stable, well known GIS platform that includes the built-in Avenue programming language. Avenue is a high-level object oriented scripting language that permits the modeler to perform many complex operations with a minimum of programming requests.

In ArcView 3.2a, Camelback Mountain and Barnes Butte were identified and two polygons were drawn around each feature to divide the analysis into four zones: Camelback Top, Camelback Bottom, Papago Top, and Papago Bottom.

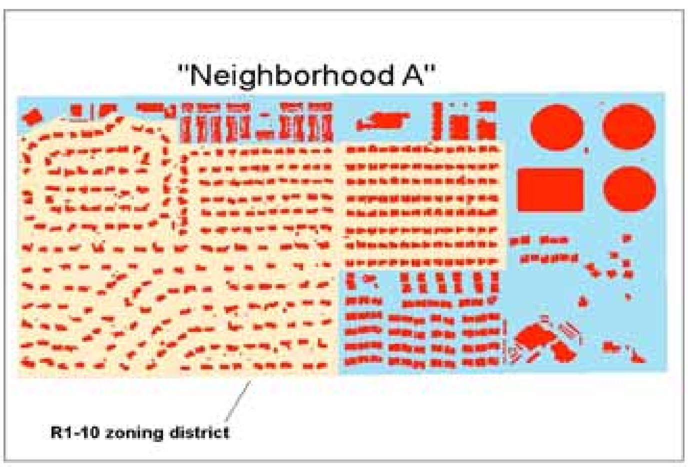

Figure 3. Roofprints within Study Area

Seven hundred fifty two roofprint outlines were identified in the greater "Neighborhood A" area. (Fig. 3) Of those, 511 were found to be in the R1-10 district at issue. Within this district, 362 buildings with a roofprint outline area of 2000 square feet or greater were considered residences subject to a potential height increase.

An Avenue script (Appendix 1) was written to execute the model. Five theoretical maximum roof elevations were tested: 16', 18', 20', 25' and 30'. Aside from some initialization code, the script is a simple loop within a loop. The outer loop determines the maximum elevation being tested. Within this, a tabulation table for each maximum elevation is created. The inner loop performs the analysis for each of the 362 eligible roofprints within that maximum elevation. Within the inner loop, all eligible roofprints are assigned the maximum elevation. The current observer roofprint is assigned a value of zero. All other roofprints retain their original, constant elevations. A point representing the observer is created at the center of the zero roofprint. The roofprints are cast into a GRID and that GRID is added to the ground elevation GRID. The summed GRID represents the ground elevation with buildings. The viewshed analysis is performed. A new record is added to the tabulation table and for each of the mountain zones the sum of cells viewed is added to the table.

The Avenue script ran on an Intel Pentium 4 based 1-gigahertz Compaq DeskPro EN computer with 1 gigabyte of RAM. The operating system was Windows NT. The total run time was 30 hours. Liberal use of Avenue's *PurgeObjects* method was employed to eliminate the danger of abnormal program termination caused by using such a large number of GRIDs. The A*nalysisEnvironment* object was employed to reduce the GRID area being processed and consequently keep processing to a minimum, but it is unknown if any of this had an effect on the length of the processing time.

At the conclusion of the run, the tabulation tables were imported into Microsoft Excel for the calculation of the arithmetic means.

Note: If a similar analysis were to be performed today, the authors would make two changes to the methodology described above. 1) Use ArcObjects and VB6 or VB.NET to write the program and create a compiled executable module for faster processing. 2) Rather than use the older style USGS DEMs, download the elevation data from the USGS National Elevation Dataset Seamless Data Distribution System at http://seamless.usgs.gov/. In any case, with today's all-around faster computers, one could expect the analysis to run in a fraction of the time.

Analysis of Results

The unsurprising results of the analysis (Tables 1 – 4) indicate that, with the exception of Papago Bottom, when the roofs are raised fewer people can see the landmarks and they see less of them. The case of Papago Bottom appears to be that when the roofs are raised, fewer people can see it, but those with views retain very good views.

Despite the inherent simplification and potential inaccuracies of such a model for the results of any particular building, the authors feel that it is reasonable to assume that the relatively large number of processed shapes attenuates the effects of individual errors from skewing the average.

Conclusion

The case of the “Neighborhood A” area illustrates how the strategic use of quantitative GIS analytical techniques can inform the decision making process. The transparent and comprehensive nature of the analysis facilitated discussions that ultimately led to unprecedented levels of consensus within the neighborhood setting. Through this action, the Scottsdale City Council supported the determination of this neighborhood that reaffirming residential character preservation is important not only to its residents but to the City as a whole. As significant development impacts continue to alter the integrity of older neighborhoods, this case exemplifies the commitment to preserving those neighborhoods - the building blocks of a community.

Tables

Elevation	# Houses Seeing CamelBack Top	% of Possible 362 Buildings	Of Those Seeing Camelback Top, Avg. Number of Cells Seen	% Seen Relative to 16'
16'	345	95.30%	2237	100.00%
18'	331	91.40%	1878	84.00%
20'	320	88.40%	1569	70.10%
25'	281	77.60%	1188	53.10%
30'	246	68.00%	1032	46.10%

Table 1. Results for Camelback Top zone

Elevation	# Houses Seeing CamelBack Bottom	% of Possible 362 Buildings	Of Those Seeing Camelback Bottom, Avg. Number of Cells Seen	% Seen Relative to 16'
16'	353	97.50%	2525	100.00%
18'	345	95.30%	1996	79.00%
20'	335	92.50%	1668	66.00%
25'	273	75.40%	1354	53.60%
30'	240	66.30%	1157	45.80%

Table 2. Results for Camelback Bottom zone

Elevation	# Houses Seeing Papago Top	% of Possible 362 Buildings	Of Those Seeing Papago Top, Avg. Number of Cells Seen	% Seen Relative to 16'
16'	345	95.30%	271	100.00%
18'	333	92.00%	239	88.40%
20'	323	89.20%	211	78.00%
25'	254	70.20%	196	72.40%
30'	222	61.30%	177	65.50%

Table 3. Results for Papago Top zone

Elevation	# Houses Seeing Papago Bottom	% of Possible 362 Buildings	Of those seeing Papago Bottom, Avg. Number of Cells Seen	% seen relative to 16'
16'	306	84.50%	440	100.00%
18'	273	75.40%	433	98.30%
20'	244	67.40%	293	66.70%
25'	205	56.60%	433	98.50%
30'	174	48.10%	461	104.80%

Table 4. Results for Papago Bottom zone

Appendix 1 -- Program Code

```
'Multiviewshed Analysis.ave
'copyright 2002, Robert Chasan, City of Scottsdale, Arizona

'--------------------------------------------------------------------------
'Initialization section
'--------------------------------------------------------------------------
av.purgeobjects
theview = av.finddoc("view1")

'get all the roofs
all_roofs = theview.findtheme("Roofprints.shp").getftab
roof_shape = all_roofs.findfield("shape")
roof_extrude = all_roofs.findfield("extrude")
roof_id = all_roofs.findfield("fid_1")
full_extent = theview.findtheme("Roofprints.shp").returnextent

'get the zoning area of interest
analysisarea = theview.findtheme("R1-10 Zone").getftab
thearea = analysisarea.returnvalue(analysisarea.findfield("shape"),0)

'get the bare ground elevation grid
elevations = theview.findtheme("BaseElevation")
elev_only_grid = elevations.getgrid

'create a zeroed out grid for later on
zerogrid = elev_only_grid - elev_only_grid

'get the shapes that delineate the upper and lower zones
'of the Papago Butte and Camelback Mountain.
'these could also have been done from a single shape file
Papago_Lower = theview.findtheme("Papago_Lower.shp").getftab
Lower_Papago = Papago_Lower.returnvalue(Papago_Lower.findfield("shape"),0)
Papago_Lower = nil
Papago_Upper = theview.findtheme("Papago_Upper.shp").getftab
Upper_Papago = Papago_Upper.returnvalue(Papago_Upper.findfield("shape"),0)
Papago_Upper = nil
Cback_Lower = theview.findtheme("Cback_Lower.shp").getftab
Lower_Cback = Cback_Lower.returnvalue(Cback_Lower.findfield("shape"),0)
Cback_Lower = nil
Cback_Upper = theview.findtheme("Cback_Upper.shp").getftab
Upper_Cback = Cback_Upper.returnvalue(Cback_Upper.findfield("shape"),0)
Cback_Upper = nil
av.purgeobjects

'create a list of shapes to be used for the visibility cell count later on
ShapeList = list.make
shapelist.add(Upper_Cback)
shapelist.add(Lower_Cback)
shapelist.add(Upper_Papago)
shapelist.add(Lower_Papago)

'set the Analysis Environment in the hopes of reducing processing time
analysisEnv = theView.GetExtension( AnalysisEnvironment )
analysisEnv.setmask(elevations)
analysisEnv.setcellsize(#ANALYSISENV_VALUE  ,10)
analysisEnv.setextent(#ANALYSISENV_VALUE ,elev_only_grid.getextent)
Grid.SetAnalysisExtent(#GRID_ENVTYPE_VALUE, elev_only_grid.getextent)
Grid.SetAnalysisCellSize(#GRID_ENVTYPE_VALUE ,10)

'set the selection bitmap so that we only process
'buildings with a roofprint polygon of 2000 sq ft or greater
all_roofs.selectbypolygon(thearea,#vtab_seltype_new)
all_roofs.updateselection
for each rec in all_roofs.getselection
  if (all_roofs.returnvalue(roof_shape,rec).returnarea < 2000) then
```

```
    all_roofs.getselection.clear(rec)
    all_roofs.updateselection
  end
end

'take the full_extent rect and remove any area that includes a building
'add the now "holey" polygon to the roofs ftab with a zero extrude value
for each rec in all_roofs
  full_extent = full_extent.returndifference(all_roofs.returnvalue(roof_shape,rec))
end
all_roofs.seteditable(true)
recno = all_roofs.addrecord
all_roofs.setvalue(roof_shape,recno,full_extent)
all_roofs.setvalue(roof_extrude,recno,0)
all_roofs.seteditable(false)

'this is the master bitmap that will be used to reset the all_roofs
'bitmap at the beginning of each iteration of the inner loop
extrude_bitmap = bitmap.make(all_roofs.getnumrecords)
extrude_bitmap.or(all_roofs.getselection)

'---------------------------------------------------------------------------
'End of Initialization Section
'---------------------------------------------------------------------------
'---------------------------------------------------------------------------
'Processing section
'---------------------------------------------------------------------------
for each extrude in {16, 18, 20, 25, 30}      'extrude represents the max bldg heights
  'create a tabulation table for the extrusion height being tested
  tabulate = vtab.makenew(("f:\vshed\"+extrude.asstring).asfilename,dbase)
  tabulate.seteditable(true)
  fid = field.make("fid",#field_decimal,4,0)
  ctop_count = field.make("ctop_cnt",#field_decimal,10,0)
  cbot_count = field.make("cbot_cnt",#field_decimal,10,0)
  ptop_count = field.make("ptop_cnt",#field_decimal,10,0)
  pbot_count = field.make("Pbot_cnt",#field_decimal,10,0)
  tabulate.addfields({fid,ctop_count,cbot_count,ptop_count,pbot_count})
  tabulate.seteditable(false)

  'create a list of thefields that will be used in the tabulations later on
  TabulateFields = list.make
  TabulateFields.add(ctop_count)
  TabulateFields.add(cbot_count)
  TabulateFields.add(ptop_count)
  TabulateFields.add(pbot_count)

  'set the selection set to all appropriate houses in the zone
  all_roofs.getselection.clearall
  all_roofs.updateselection
  all_roofs.getselection.or(extrude_bitmap)
  all_roofs.updateselection

  for each rec in all_roofs.getselection 'establish the max heights
    all_roofs.seteditable(true)
    all_roofs.calculate(extrude.asstring,roof_extrude)
    all_roofs.setvalue(roof_extrude,rec,0)
    all_roofs.seteditable(false)
    all_roofs.getselection.clearall
    all_roofs.updateselection

    'create the observer point
    pt = ftab.makenew("f:\vshed\pt_temp.shp".asfilename,point)
    pt.seteditable(true)
    offseta = field.make("offseta",#field_decimal,5,0)
    pt.addfields({offseta})
    pt.seteditable(false)
    pt_shape = pt.findfield("shape")
    pt.seteditable(true)
    recno = pt.addrecord
    pt.setvalue(pt_shape,recno,all_roofs.returnvalue(all_roofs.findfield("shape"),rec).returncenter)
```

```
    pt.setvalue(offseta,recno,5)  'make the observer height a constant 5'
    pt.seteditable(false)

    'convert the houses to grid format and add that grid to the base elevation grid
    mhg = grid.makefromftab(all_roofs,prj.makenull,roof_extrude,{10,elev_only_grid.getextent})
    mhg_with_zero = mhg.merge({zerogrid})
    elevation_with_houses = elev_only_grid+mhg_with_zero
    mhg = nil
    mhg_with_zero = nil
    av.purgeobjects

    'perform viewshed analysis
    vis = elevation_with_houses.visibility(pt,prj.makenull,true)
    elevation_with_houses = nil
    av.purgeobjects

    'add a new record to the tabulation table
    'insert the house id value into the new tabulation record
    'tabulate count of cells in each mountain zone that are visible to observer
    tabulate.seteditable(true)
    recno = tabulate.addrecord
    fid1 = all_roofs.returnvalue(roof_id,rec)
    tabulate.setvalue(fid,recno,fid1)
    for each x in 0 .. ShapeList.count-1
      theextract = vis.extractbypolygon(ShapeList.get(x),prj.makenull,false)
      thevtab = theextract.getvtab  'get the vtab of the extracted grid
      expr = "([value] = 1)"  'query string for visibility extractions
      thevtab.query(expr,thevtab.getselection,#vtab_seltype_new)
      thevtab.updateselection
      thecount = thevtab.findfield("count")
      for each sel in thevtab.getselection  'there will not be more that one selected rec
        tabulate.setvalue(TabulateFields.get(x),recno,thevtab.returnvalue(thecount,sel))
        tabulate.flush
      end
      thevtab = nil
      theextract = nil
      av.purgeobjects
    end
    tabulate.seteditable(false)

    vis = nil
    av.purgeobjects
    all_roofs.getselection.or(extrude_bitmap)
    all_roofs.updateselection
  end
  av.purgeobjects
end
system.beep
msgbox.info("End of MultiViewshed Analysis","!")
```

Author Information:

Monique de los Rios-Urban
Senior Planner
City of Scottsdale
Planning and Development Systems
7506 E. Indian School Rd
Scottsdale, Arizona 85251
Ph: (480) 312-7898
Fax: (480) 312-7314

Robert Chasan
Geographer / GIS Analyst
City of Scottsdale
Geographic Information Systems
3629 N. Drinkwater Blvd
Scottsdale, Arizona 85251
Ph: (480) 312-4128
Fax: (480) 312-4129