Application of Aerial Photography and GIS Techniques in the Development of a Historical Perspective of Environmental Hazards at the Rural-Urban Fringe

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Abstract
A multi-date land-use/land-cover inventory of a 155 sq km area of the western rural-urban fringe of Phoenix, Arizona was undertaken as one part of the State of Arizona's response to reported incidence of disease in the area. This study was designed to gain a historical perspective of changing land use within the rural-urban fringe as a means of acquiring insight into the nature of present and potential environmental hazards within these dynamic areas. A land-use classification scheme was developed to emphasize activities which may have released hazardous substances into the environment. Land use was mapped by interpretation of panchromatic aerial photographs for seven dates over a 32-year period between 1954 and 1985. Land-use overlays were digitized and entered in a geographic information system (GIS) to facilitate multitemporal comparisons and integration with other data sets. Geographic data summaries of land use over the 32-year span of this study revealed that agricultural lands decreased from 74 percent in 1954 to 28 percent in 1985. Residential (9 to 31 percent) and industrial/commercial land use (5 to 19 percent) increased steadily throughout the study period. Multitemporal analysis also indicated that waste-disposal land use increased significantly during the study period from 1.4 percent to 4.5 percent in 1985. Spatial and historical analysis of known and possible landfills revealed that many abandoned areas have reverted to urban undeveloped, riverwash and riparian, and public land. These may present an environmental risk.

Introduction
The rural-urban fringe has undergone considerable study during the past century as urbanization has generated significant and often rapid changes in land use (e.g., Pryor, 1971). These changes have often created a variety of environmental problems associated with increasing population, competition for available land and water resources, and the necessity for industrial and municipal waste disposal. Gaining a historical perspective of changing land use within the rural-urban fringe should therefore provide significant insight into the nature of environmental hazards (past and future) within these dynamic areas. This study developed a unique data set derived from historical aerial photography to evaluate the relationship between land use and environmental hazards for a portion of the rural-urban fringe of Phoenix, Arizona.

In 1987, concern was raised over a reported high incidence of childhood leukemia concentrated in a residential neighborhood of Phoenix, Arizona (Greene, 1987). It was suggested that the incidence of illness might have been produced by prolonged exposure to hazardous substances in the environment that may have been introduced by past agricultural, industrial, and/or waste disposal activities.

As part of the response of the Arizona Department of Environmental Quality (ADEQ), the Arizona Remote Sensing Center (ARSC) was requested to map land use within a 155-sq-km area of Phoenix, Arizona at seven points in time between 1954 and 1985. This effort was part of a larger ADEQ environmental quality and health risk assessment study. Land-use/land-cover maps were produced by interpretation of historical aerial photographs. Land-use classes included agricultural, industrial, residential, commercial, public, and waste treatment and disposal.

The historical land-use information was utilized to address the relationships between environmental hazards and changing land use as the study region changed from predominately agricultural to urban land uses. Three pertinent questions concerning this relationship were addressed: (1) how did the total area apportioned to waste disposal change during urbanization; (2) what types of land use were converted to waste disposal and what was their fate; and (3) how appropriate were these areas for waste disposal. By providing the answers to these questions for the study area, we can acquire a better perspective on environmental dangers associated with urbanization at the rural-urban fringe.

The Study Area
The 60-square-mile (155-sq-km) study area selected by the ADEQ (Figure 1) is in western Phoenix and is bounded by Camelback Road on the north, 19th Avenue on the east, the Salt River on the south, and 83rd Avenue on the west. Phoe-

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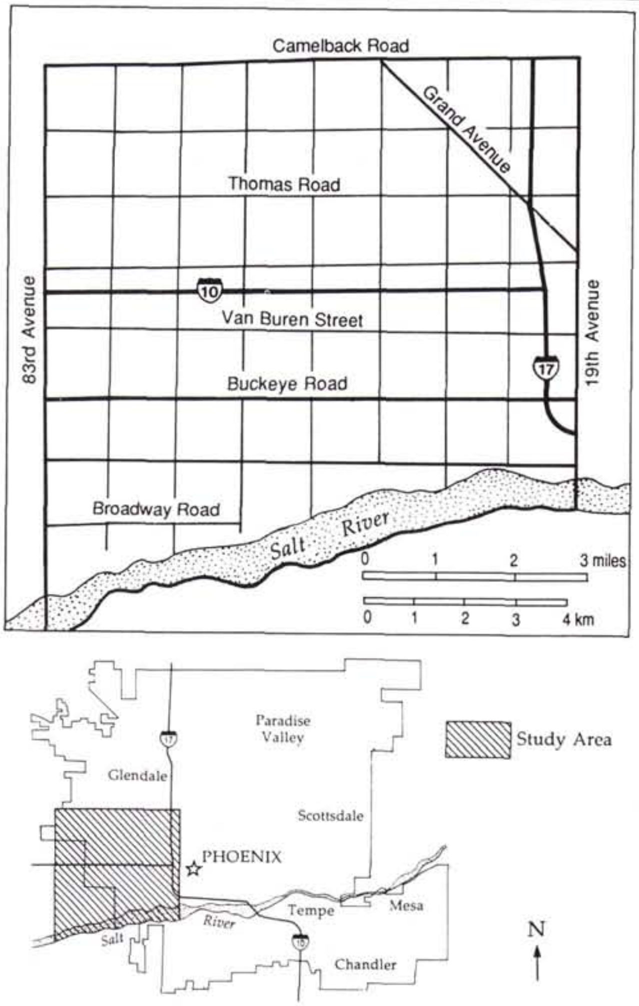

Figure 1. Location map of the west Phoenix study area.

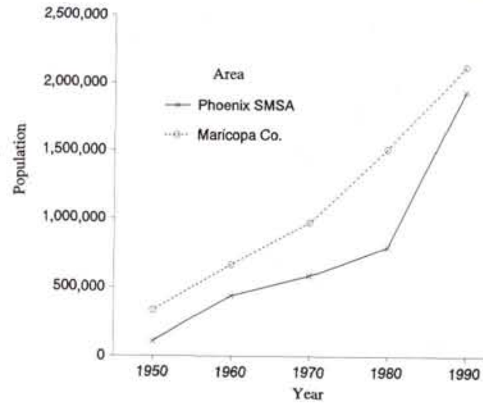

Figure 2. Line graph of Phoenix area population growth 1950-1990.

nix, and this region in particular, has experienced rapid and continuing urbanization, with the population growing from 106,818 in 1950 to 1,935,145 in 1990 (Figure 2).

This portion of central Maricopa County, Arizona, is characterized by broad featureless valleys between north-south trending mountain ranges. All the valleys have a southward gradient and are well drained, with the water table in most areas below 60 m. The climate of the area is desert, with very high temperatures from May through September and with mild winters. There are two separate rainy seasons (November-March and July-September), but rainfall averages just over 18 cm per year.

The landscape in the study area is essentially flat except for the topographic break associated with the Salt River Channel at the southern end of the area. The Salt River is an ephemeral stream which flows only during the rainy seasons. The area is covered by the Gilman-Estrella-Avondale soil association (Hartman, 1977). This association is formed in recent alluvium and is found on the broad, level valley plains and low stream terraces. The association consists primarily of loams and clay loams. The majority of the study site is covered by the Gilman soil series which is 150 cm or more of loam or very fine sandy loam that may be thinly stratified with coarser or finer textured layers. The Estrella soil series are loams or very fine sandy loams 50 to 100 cm deep over an older clay loam soil. Avondale soils have a dark-colored clay loam surface layer above a loam or very fine sandy loam. Torrifluvent soils, which are frequently flooded soils recently deposited by intermittent streams, characterize the present channel of the Salt River. They contain almost no organic matter, are primarily sandy, and may be 5 to 80 percent gravel and cobbles.

Natural vegetation supported by the soils in the area comprises creosote bush, cactus, annual native and exotic grasses, and some mesquite and paloverde trees. The predominant irrigated crops include cotton, alfalfa, small grains, safflower, sugar beets, grapes, citrus, and vegetables.

Analysis Methods

Aerial Photo Interpretation

Aerial photographs have frequently been used to produce historical land-use maps to monitor urban development (Wagner, 1963; Baker *et al.*, 1979; Adeniyi, 1980; Jensen and Toll, 1982; Treitz *et al.*, 1992). These studies have demonstrated that large-scale aerial photography (e.g., 1:10,000) can be utilized to accurately map land use within the four-tiered classification scheme proposed by Anderson *et al.* (1976). This study employed standard aerial reconnaissance and photogrammetric techniques augmented by collateral material (USGS topographic maps, EPA photography, and reports) as well as field checks to delineate land use. Panchromatic aerial photography at nominal scales between 1:8,000 and 1:21,000 were acquired for seven time periods between 1954 and 1985 (Table 1).

Mapping was done manually on clear acetate overlays on the aerial photography and then was transferred to a base map using a Kargl reflecting projector (optical pantograph). The base map was a photo mylar made from four U.S. Geological Survey 7.5-minute, 1:24,000-scale topographic maps (U.S.G.S., 1952; 1957; 1964). Stereoscopic analysis was used to assist interpretation of excavated lands. Wherever uncertainty existed as to the correct classification of an area, the site was visited to determine proper classification. The interpretation process used a conservative approach with regard to the ultimate use of the data (environmental analysis). Areas which had some characteristics of two mapping classes

TABLE 1. AERIAL PHOTOGRAPHY UTILIZED IN THE PROJECT

Date	Original Scale	Print Scale	Source
14 Jan 54	1:20,000	1:8,000	ASCS
27 Jan 54	1:20,000	1:8,000	ASCS
01 Jan 58	1:20,000	1:8,000	ASCS
29 Jan 64	1:20,000	1:8,000	ASCS
19 Jan 70	1:20,000	1:8,000	ASCS
26 Jan 70	1:20,000	1:8,000	ASCS
29 Jan 70	1:20,000	1:8,000	ASCS
11 May 76	1:60,000	1:12,000	ADOT
17 May 81	1:60,000	1:8,300	ASCS
03 Nov 85	1:48,000	1:21,000	ADOT

Sources:
ASCS: U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service, Salt Lake City, Utah.
ADOT: Arizona Department of Transportation, Phoenix, Arizona.

and/or those with uncertain image characteristic were placed in the more restrictive or sensitive class. This methodology would therefore avoid disregarding areas of potential environmental significance.

Interpretation of Environmentally Significant Land-Use Classes

Historical aerial photography is increasingly being used for analysis of industrial and public solid and liquid waste disposal/holding facilities (Garofalo and Wobber, 1974; Erb *et al.*, 1981; Lyon, 1982; Lyon, 1987; Shelton, 1984; Barnaba *et al.*, 1991). Historical photography is especially useful in the location of inactive or "abandoned" sites or, in many cases, sites that have been buried and subsequently developed (Evans and Mata, 1984). These areas are no longer active but may represent a real threat to public health and safety due to the potentially toxic nature of the waste deposited in them.

Of particular significance for the interpretation of environmentally sensitive land-use classes during this study was the publication, *Remote Sensing Investigation Solid/Liquid Waste Disposal Sites,* by the U.S. Environmental Protection Agency National Enforcement Investigations Center (EPA, 1989). This aerial survey covered parts of our study area and provided large-scale, panoramic, high-resolution oblique aerial photography taken from a light aircraft using a hand-held 70-mm camera with true color and color-infrared films. In addition, the report *Aerial Photographic Analysis of the Fowler Industrial Area, Phoenix, Arizona,* EPA Environmental Monitoring Systems Laboratory, Las Vegas (EPA, 1987), was a useful reference for the recognition and interpretation of solid and liquid waste disposal sites. This study analyzed seven selected dates of aerial photography to monitor physical conditions and activities at 12 industrial sites within the study area that could lead to groundwater contamination.

These two documents assisted in expansion of the scope of interpreted industrial land-use classes and were used to train interpreters to recognize significant indications[1] of storage, spillage, and disposal sites for solid and liquid waste materials.

Land-Use Classification Scheme

The land-use classification scheme utilized in our work was developed specifically to meet the needs of the project and consisted of 27 categories within eight major classes of land use (Table 2). Land-use/land-cover classification units consisted of Levels II, III, and IV of the four-level classification hierarchy proposed by Anderson *et al.* (1976). Agricultural land was classified at the second level, residential land at the third level, and industrial and waste disposal at the fourth level. The minimum mapping unit size was 2.3 hectares, with exceptions being made for excavated land in which mapping units of less than 0.4 hectares were delineated.

[1]Indication is defined as a particular observation derived from interpretation of aerial photographs with respect to spatial or spectral characteristics.

TABLE 2. LAND-USE CLASSIFICATION SCHEME AND CODES

200 Agriculture
21 Irrigated Field Crops
22 Irrigated Tree Crops
231 Confined Animal Feeding Operations
232 Confined Animal Feeding with Sewage Lagoons

110 Residential
111 Single Family Low Density
112 Multi-family High Density
113 Mobile Homes and Trailers

120 Commercial
121 Retail
122 Wholesale/Warehouses

130 Industrial
132 Salvage Yards
134 Other Industrial
1311 Industrial with Known On Site Waste Disposal[1]
1312 Industrial with Interpreted On Site Disposal[2]

140 Transportation
141 Interstate Highway
1441 Cropduster Air Fields

170 Public
171 Schools
172 Parks
173 Hospitals
174 Cemeteries
175 Churches
176 Miscellaneous Public Lands

177 Waste Disposal
1771 Municipal Sewage Treatment
1772 Known Landfills and Dump Sites[3]
1773 Possible Landfills and Dump Sites[4]

Miscellaneous
510 Riverwash and Riparian
750 Excavated Land
191 Urban Undeveloped

[1] Previously documented in EPA reports (EPA, 1980, 1987).
[2] Sites photointerpreted based on characteristics (texture, pattern, association) that correspond to mapping unit 1311.
[3] Previously documented in EPA reports (EPA, 1980,1987).
[4] Sites have been photointerpreted based on characteristics (excavations, debris mounds, vehicle tracks, recently exposed soil, ground staining) similar to mapping unit 1772.

Map Digitizing and Database Development

Each land-use map was manually digitized using ARC/INFO[2] software on a minicomputer. All maps were registered to USGS township, range, and section (TRS) digital data obtained from the Arizona Land Resource Information System (ALRIS) library at the Arizona State Lands Department using ARC/INFO's snapping environment settings. At the conclusion of the study, digital land-use data were provided to the ADEQ and

[2]Trade names are included for the benefit of the reader and do not imply an endorsement of the product by the University of Arizona.

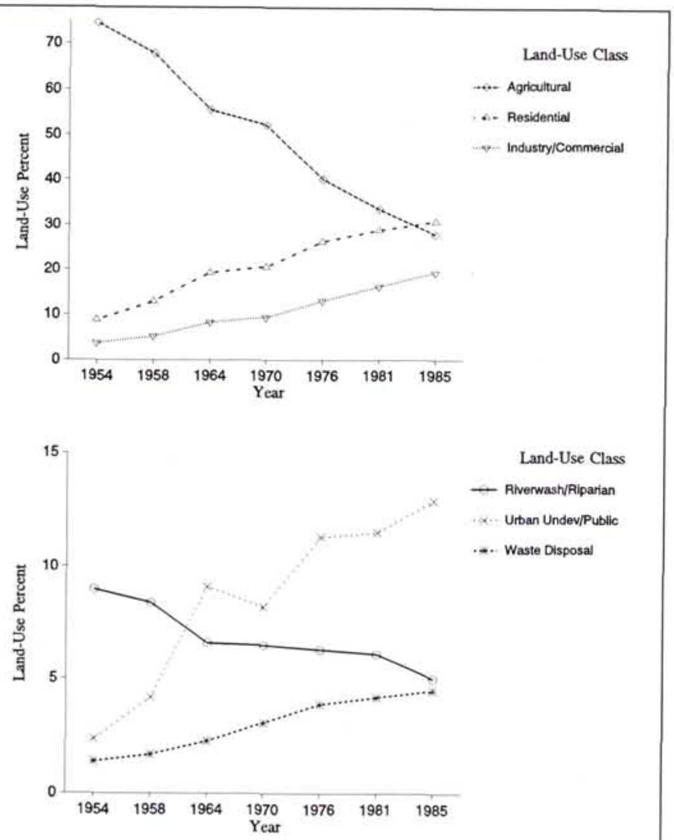

Figure 3. General land-use change 1954-1985.

the Arizona State Lands Department where it is available for continued applied research efforts.

Results

General Land-Use Change

The rural-urban fringe of west Phoenix underwent significant change during the 32 years covered by this study (Figure 3). The study area was predominantly rural in 1954 with over 74 percent of the area in irrigated crops, 9 percent residential, 4 percent industrial/commercial, 2 percent public and urban undeveloped land, and 9 percent riverwash/riparian. By 1985, the study area had become mostly residential and industrial with irrigated agricultural lands decreasing to 28 percent, residential housing increasing to 31 percent, total industrial/commercial land uses increasing to 19 percent, public and urban undeveloped land increasing to 13 percent, and riverwash/riparian areas decreasing to 5 percent.

Specific changes in general land-use categories serve to characterize the geographic nature of the area. Irrigated agricultural lands declined steadily throughout the study period from 74 percent in 1954 to 28 percent in 1985. Orchards were always of minor extent (35 hectares in 1954) and were completely removed between 1970 and 1976. Low density residential housing now predominates in the area. It represented over 94 percent of the 9 percent residential land use in 1954. By 1985, 31 percent of the area was residential, with 27 percent low density residential and 3 percent high density residential. Mobile homes represented less than one percent of the area throughout the study period. In 1954 the industrial/commercial land-use grouping was predominately industrial land, while by 1985 commercial land use had grown to 5.5 percent and industrial utilization had grown to over 13 percent of the area.

Waste Disposal Change Analysis

Seven of the original 27 land-use classes were segregated on the basis of their potential environmental impact (Table 3). These classes were municipal sewage treatment areas, known and possible landfills, industrial sites with known or possible waste disposal activities (combining two classes), feedlots with sewage lagoons, and cropduster airfields.

Municipal sewage treatment increased within the study period from 0.2 percent in 1954 to 0.9 percent in 1985. Known landfill sites were not present in the study area until 1970 but increased rapidly to 0.5 percent of the area in 1985. Sites identified as having strong evidence for burial of waste (possible landfill) reached a peak in 1970 and constituted 0.3 percent of the area by 1985. Thus, a total of approximately 125 hectares was classified as known or possible landfill sites in 1985. Industrial areas with known or possible waste disposal activities on-site increased from just over 1.0 percent in 1954 (~163 hectares) to over 2.5 percent (400 hectares) of the study area in 1985. Total waste disposal land use increased from 1.4 percent in 1954 to 4.5 percent in 1985.

All industrial with waste disposal and waste disposal classes (except cropduster airfields) showed a steady increase in area with time except for one class. The one anomaly in the data is the 1976 peak in the total area interpreted as possible landfill and dump sites (Figure 4). These areas are sites of possible unregulated and illegal waste disposal, and their decline after 1976 may be related to increased environmental regulations implemented in the 1970s. Areas in this class reached a maximum in 1976 at 79 hectares and subsequently decreased to 52 hectares in 1981.

Using the spatial analysis capabilities of the GIS, we examined the history of the known landfill and possible landfill classes. Figure 5 presents these changes for these two classes with 1976 as the base year. This year was selected for analysis because the possible landfill class reached a significant peak in 1976. The analysis therefore represents only the minimum of areas that have converted from landfill to other land uses. Comparing the areas mapped as known landfill in 1976 with the 1954 land-use map, we see that 58 percent of what was to become known landfill began in the riverwash/riparian class, 39 percent in irrigated agriculture, and 2 percent in previously excavated land. One hundred percent of the known landfill areas in 1976 remained landfill through 1985. A more complex change history is evident for the possible landfill and dump class.

TABLE 3. HISTORICAL WASTE DISPOSAL LAND USE PERCENT OF TOTAL AREA

Waste Disposal Land-Use	1954	1958	1964	1970	1976	1981	1985
Municipal Sewage Treatment	0.18	0.19	0.59	0.66	0.64	0.68	0.91
Known Landfill	0	0	0	0.05	0.30	0.44	0.46
Possible Landfill	0.03	0	0.05	0.21	0.50	0.33	0.34
Industrial Waste Disposal (known or possible)	1.03	1.18	1.45	1.96	2.19	2.45	2.53
Feedlot with Sewage Lagoons	0.10	0.20	0.16	0.17	0.19	0.22	0.19
Cropduster Airfields	0.08	0.08	0.03	0.03	0.03	0.03	0.03
Totals:	1.42	1.65	2.28	3.08	3.85	4.15	4.46

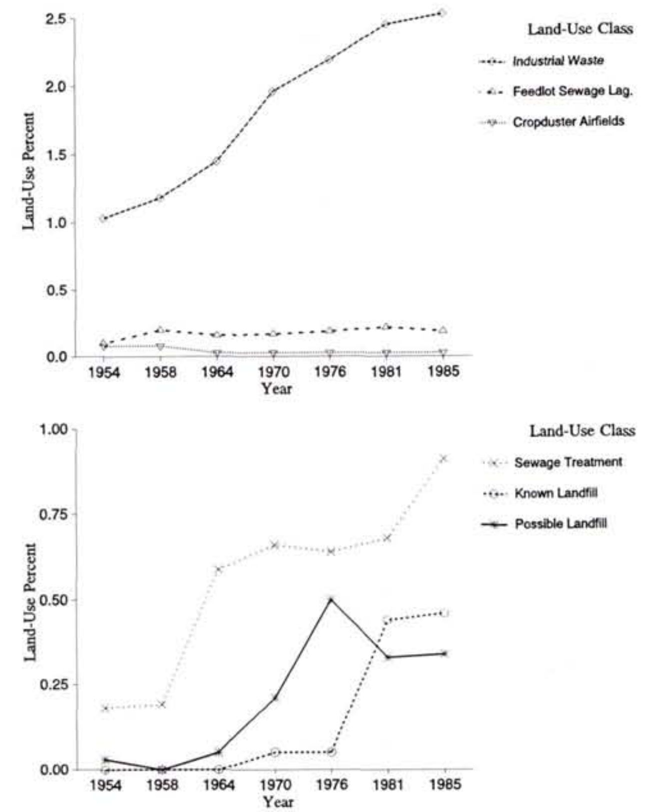

Figure 4. Waste disposal land-use change 1954-1985.

Analysis revealed that 80 percent of the possible landfill areas began as riverwash/riparian areas in 1954, 15 percent previously excavated land, 3 percent irrigated agriculture, 1 percent urban undeveloped land, and 1 percent possible landfill. In 1985 only 37 percent of these areas remained unchanged while 21 percent are now classified as urban undeveloped land, 14 percent riverwash/riparian, 13 percent public land, 7 percent salvage yards, 6 percent excavated land, and 2 percent municipal sewage treatment areas. These results demonstrate that significant areas of historical dumping may currently, or sometime in the future, expose an unsuspecting population to environmental hazards.

Environmental Implications of Waste Disposal Sites

Our historical analysis has demonstrated that the majority of landfills and dump sites in the study area have been located along the Salt River. The extremely coarse textured soils (torrifluvents) of these sites are poorly suited for waste disposal due to high percolation rates through the soil. Moreover, periodic flood events of the Salt River (e.g., floods of 1980 and 1993) further enhance waste movement and exposure. In addition, we performed a topological comparison of the known and possible waste disposal classes in 1976 with the digital Soil Conservation Service soils map (Hartman, 1977). This analysis indicated that the majority of sites were located on soils with moderate to severe limitation ratings for waste disposal and had a high leach potential rating for pesticides. Thus, not only have abandoned waste disposal sites been converted to public, urban undeveloped, and industrial land-uses, but also their original location was not optimally suited to the prevention of groundwater contamination.

Conclusions

Previous research has clearly demonstrated the value of air photo interpretation in the spatial location of waste disposal sites within the framework of changing patterns of urban land use and population density. In the context of a case study of the rural-urban fringe of Phoenix, Arizona, we have attempted to demonstrate how historical land-use information can be coupled with information on waste disposal using GIS technology to gain a unique perspective on environmental risk.

Results of our analysis reveal that increasing industrialization and urban population growth has accelerated the generation of solid and liquid wastes in the Phoenix area. While agricultural land use steadily declined over the period from 1954 to 1985, residential, industrial, and waste disposal land use increased significantly, with the total waste disposal land-use classes increasing from 1.4 percent in 1954 to 4.5 percent in 1985. Spatial and historical analysis of these areas revealed that the majority of waste disposal classes were located in close proximity to the Salt River. Currently abandoned possible waste disposal sites have reverted to a variety of land uses which may ultimately present an environmental risk to the population. Spatial analysis also revealed that the

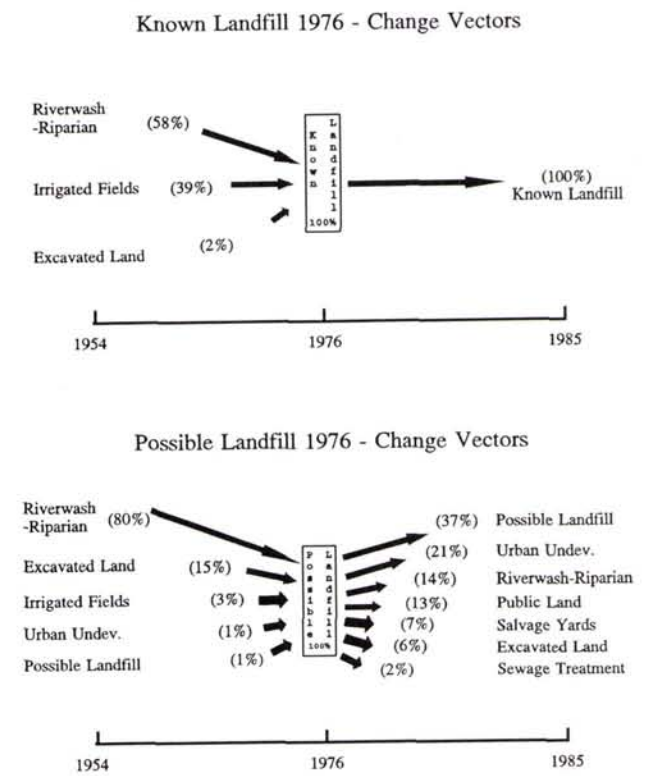

Figure 5. Historical change vectors of the Known and Possible Landfill classes. The figure provides information on areas that were mapped as Known or Possible Landfill in 1976 with regard to what the land use of these areas was in 1954 and what it became in 1985.

original siting of many of these waste disposal areas was at inappropriate locations or on unsuitable soils. Implementing the study within the framework of a GIS facilitated the monitoring of the location and subsequent development of environmentally sensitive land-use classes. The geographic database established by this study can serve as a framework for future detailed environmental and public health investigations in Phoenix, Arizona.

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References

Adeniyi, P.O., 1980. Land-Use Change Analysis Using Sequential Aerial Photography and Computer Techniques, *Photogrammetric Engineering & Remote Sensing,* 46(1):1447–1464.

Anderson, J., E. Hardy, J. Roach, and R. Witmer, 1976. *A Land-Use and Land Cover Classification System for Use with Remote Sensor Data,* U.S. Geological Survey Professional Paper 964, U.S. Geological Survey, Washington, D.C., 28 p.

Baker, D.B., J. DeSteiguer, D. Grant, and M. Newton, 1979. Land-Use/ Land-Cover Mapping from Aerial Photographs, *Photogrammetric Engineering & Remote Sensing,* 45(5):661–668.

Barnaba E.M., W.R. Philipson, A.W. Ingram, and J. Pim, 1991. The Use of Aerial Photographs in County Inventories of Waste-Disposal Sites, *Photogrammetric Engineering & Remote Sensing,* 57(10): 1289–1296.

Environmental Protection Agency, 1980. *Remote Sensing Investigation Solid/Liquid Waste Disposal Sites,* Volume I, National Enforcement Investigation Center, Denver.

——, 1987. *Aerial Photographic Analysis of the Fowler Industrial Area,* Phoenix, Arizona, Environmental Monitoring Systems Laboratory, Las Vegas, Nevada.

Erb, T., W.R. Philipson, W.L. Teng, and T. Liang, 1981. Analysis of Landfills with Historical Airphotos, *Photogrammetric Engineering & Remote Sensing,* 47(9):1361–1369.

Evans, B.M., and L. Mata, 1984. Aerial Photographic Analysis of Hazardous Waste Disposal Sites, *Hazardous Waste and Environmental Emergencies,* Hazardous Materials Control Research Institute, Maryland.

Garofalo, D., and F. Wobber, 1974. Solid Waste and Remote Sensing, *Photogrammetric Engineering,* 40(1):45–59.

Glass, G.E., J. Morgan, D. Johnson, P. Noy, E. Israel, and B. Schwartz, 1992. Infectious Disease Epidemiology and GIS: A Case Study of Lyme Disease, *Geo Info Systems,* 2(10):65–69.

Greene, T., 1987. On the West Side, They Die Young, *New Times,* Vol. 18, No. 24, Phoenix, Arizona.

Hartman, G., 1977. *Soil Survey of Maricopa County, Arizona, Central Part,* U.S. Department of Agriculture Soil Conservation Service Report, Phoenix, Arizona, 117 p.

Jensen, J.R., and D.L. Toll, 1982. Detecting Residential Land-Use Development at the Urban Fringe, *Photogrammetric Engineering & Remote Sensing,* 48(4):629–643.

Lyon, J.G., 1982. Use of Aerial Photography and Remote Sensing in the Management of Hazardous Wastes, *Hazardous Waste Management for the 80's* (T. Sweeney, H. Bhatt, R. Sykes, and O. Sproul, editors), Ann Arbor Science Inc., Ann Arbor, Michigan, pp. 163–172.

——, 1987. Use of Maps, Aerial Photographs, and Other Remote Sensor Data for Practical Evaluations of Hazardous Waste Sites, *Photogrammetric Engineering & Remote Sensing,* 53(5):515–519.

Mack, C., C. Hutchinson, J. Walsh, and S. Kimesy, 1989. *West Phoenix Historic Land Use Mapping, 1954 - 1985,* Arizona Remote Sensing Center Final Report, Office of Arid Lands Studies, University of Arizona, Tucson, Arizona, 10 p.

Philipson, W.R., E.M. Barnaba, A. Ingram, and V.L. Williams, 1988. Land-Cover Monitoring with SPOT for Landfill Investigations, *Photogrammetric Engineering & Remote Sensing,* 54(2):223–228.

Pryor, R.J., 1971. Defining the Rural-Urban Fringe, *Internal Structure of the City* (L.S. Bourne, editor), Oxford University Press, New York, N.Y., pp. 59–127.

Shelton, G.A., 1984. Hazardous Waste Site Characterization Using Remote Sensing: an EPA Office View, *Hazardous Waste Management for the 80's* (T. Sweeney, H. Bhatt, R. Sykes, and O. Sproul, editors), Ann Arbor Science Inc., Ann Arbor, Michigan.

Stohr, C., W.J. Su, P.B. DuMontelle, and R.A. Griffin, 1987. Remote Sensing Investigations at a Hazardous-Waste Landfill, *Photogrammetric Engineering & Remote Sensing,* 53(11):1555–1563.

Treitz, P.M., P. Howarth, and P. Gong, 1992. Application of Satellite and GIS Technologies for Land-Cover and Land-Use Mapping at the Rural-Urban Fringe: A Case Study, *Photogrammetric Engineering & Remote Sensing,* 58(4):439–448.

Wagner, R.R., 1963. Using Aerial Photos to Measure Changes in Land Around Highway Interchanges, *Photogrammetric Engineering,* 27: 645–649.

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