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Development of a brownfield inventory for prioritizing funding outreach in Tucson, Arizona

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ABSTRACT

Fear of liability from the 1980 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund) has prompted developers to build preferentially upon undeveloped green space rather than potentially contaminated former industrial sites, leading to urban sprawl in the suburban areas while blighted properties in the urban core remain vacant. A brownfield is defined as a property in which the presence or potential presence of a hazardous substance or contaminant poses a barrier to development. Agencies often create brownfield inventories by performing a site suitability analysis, using distinguishing features such as ecologically and culturally significant areas or neighborhoods that need revitalizing. Pima County, Arizona and the Sonora Environmental Research Institute, Inc. (SERI) developed a brownfield inventory of the large, industrial area directly to the west of Davis-Monthan Air Force Base. Because the brownfield target area has few residential neighborhoods and lacks the distinguishing features usually used in a brownfield site suitability analysis, the county and SERI used the official tax assessor database and 11 federal, state and county environmental databases to develop a brownfield inventory. The goal of the project was to prioritize properties that stood to benefit from the grant funding. The final brownfield inventory contained 531 parcels.

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brownfield; urban planning;
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1. Introduction

The United States Environmental Protection Agency (USEPA) defines a brownfield as a property in which “the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant” (USEPA 2021a). The definition of brownfield includes sites contaminated with petroleum and petroleum products (USEPA 2021b), even though these compounds are excluded from the legal definition of “hazardous substance” (USEPA 2009). The American economy has changed from traditional heavy manufacturing to the knowledge and service industries, causing many companies to close their manufacturing facilities. Companies have left behind abandoned industrial sites which are difficult to redevelop because of actual or perceived contamination (Collaton and Bartsch 1996; Leigh and Coffin 2000). Industrial processes that may produce environmental contamination include petroleum refining; paint manufacture; chemical and fertilizer production; tanneries; and meat processing. Facilities that may generate contamination range in size from dry cleaners and gas stations to large industrial complexes (Leigh and Coffin 2000). Former industrial facilities, fuel stations, and dry cleaners are among the most common types of brownfields in both urban and rural areas (Muse 2015).

Liability from the 1980 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund) is a major reason why brownfield sites are less attractive to developers (Alberini et al. 2005; Attoh-Okine and Gibbons 2001; Coffin and Shepherd 1998). CERCLA’s requirement of joint and several liability means that any owner or user of a property is potentially responsible for the total cost of the cleanup, even if they did not cause the contamination (Coffin and Shepherd 1998; Collaton and Bartsch 1996; Tzoumis and Driehorst 2016). Potential responsible parties include the buyer of a contaminated property as well as transporters, disposal companies, and even organizations or companies that have only disposed of a small amount of waste at a facility (Tzoumis and Driehorst 2016). It can be very difficult for developers to obtain financing for the cleanup, renovation and development of brownfield properties, because Superfund liability has caused banks to refuse to grant loans (Weintraub 1995; Collaton and Bartsch 1996), a practice Collaton and Bartsch (1996) call “brown-lining”. Fear of Superfund liability has prompted developers to build preferentially upon undeveloped green space, leading to urban sprawl in the suburban areas of cities while blighted parcels in the urban core remain vacant (Coffin and Shepherd 1998; Dasgupta

and Tam 2009; Leigh and Coffin 2000; Horsch, Milmed, and Plante 1996; Muse 2015; Tzoumis and Driehorst 2016).

The 2002 Small Business Liability Relief and Brownfields Revitalization Act, or Brownfield Law (Pub. L. No. 107-118), grants liability relief from CERCLA to “bona fide prospective purchasers of contaminated properties”. To qualify for this exemption, a bona fide prospective purchaser must conduct “all appropriate inquiries” through an environmental audit (Forte 2007). The Brownfield Law also protects purchasers of contiguous property from CERCLA liability, again provided that the purchaser also conducts “all appropriate inquiries” and that no contamination is discovered. During a Phase I environmental audit, the auditor will inspect the facility; interview past and present landowners and operators; and review federal, state, and local government records. If potential contamination issues are discovered, a Phase II audit will collect samples of site materials, soil and groundwater samples for analysis (Vaidya 2015). A Phase I audit typically costs \$2000–\$3000 (US dollars). The price of a Phase II audit depends upon the complexity of the facility, and may range from \$6000–\$25,000. Because these costs may be prohibitive for small business

owners, the Brownfield Law provides funding to state and local government agencies to conduct environmental audits and remediate contaminated properties (Dahlquist and Barzal 2003).

In 2015, Pima County, Arizona obtained brownfield funding for the large industrial area directly west of the Davis-Monthan Air Force Base in Tucson, Arizona (Figure 1). The entire brownfield target area contains 13,886 parcels and has a total area of approximately 35.7 square miles (92.5 km²). It includes unincorporated Pima County and City of Tucson properties as well as the Tucson International Airport. This study focuses on the 5672 parcels under Pima County jurisdiction, an area of approximately 11.3 square miles (29.4 km²). Our study area is larger than Paterson, New Jersey (8.7 square miles; Ferdinand and Yu 2016), and the total brownfield area is larger than New Haven, Connecticut (20.12 square miles; Chrysochoou et al. 2012).

Forty eight percent of the land in the brownfield target area was vacant (Table 1). The prevalence of wildcat dumping, scrap yards, and abandoned buildings meant that a large number of properties met the brownfield criteria of abandonment and real or perceived contamination. To best allocate the funding

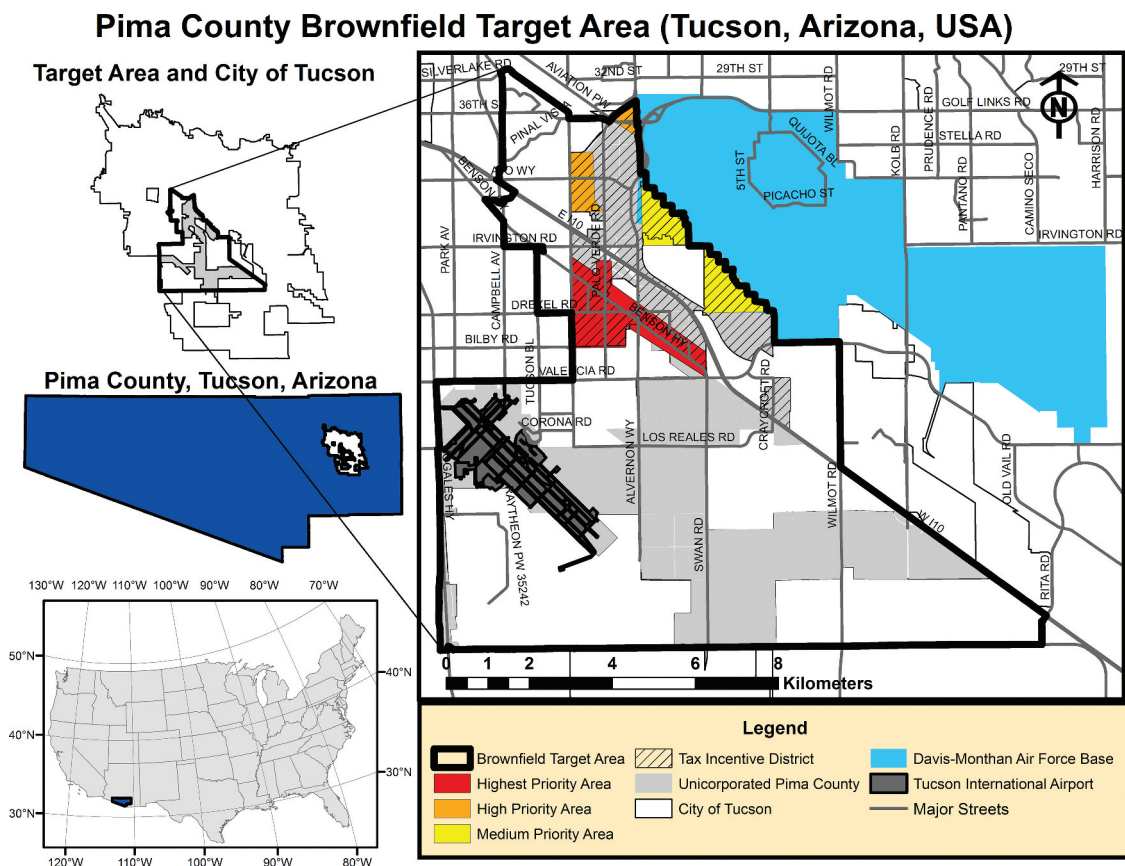


Figure 1. The brownfield target area (which includes Tucson International Airport), and county development priorities within the tax incentive district. The infill incentive district was created by an overlay of Arizona revised statutes requirements on a census 2010 block group scale. The goal of an infill incentive district program is to develop a “menu” of incentives, both regulatory and financial, that will bolster infill development and revitalization. The brownfields project is considered as one of the financial “menu” items under the infill incentive program.

Table 1. Zoning in the brownfield target area, which was calculated using a Geographic Information System (GIS) and the official Pima County tax assessor database. This table includes the entire brownfield target area, which contains both unincorporated Pima County and City of Tucson parcels.

Type	Parcels	Acreage	%Total Area
Commercial (includes auto repair, salvage, scrap metal, scrap and landscaping yards, auto wrecking yard, trailer parks)	805	4848	21%
Industrial (includes warehousing, quarrying/processing for mines, manufacturing, etc.)	847	2282	10%
Misc (includes parks, military sanitary, common areas, public school, rail property, etc.)	66	1420	6%
Unused/vacant (includes previously industrial, residential, and commercial property)	1129	11,036	48%
Residential	11,010	2730	12%
Utility/Agriculture (gas, sanitary, and water facilities)	28	532	2%

for environmental audits and remediation, Pima County collaborated with the Sonora Environmental Research Institute, Inc. (SERI) to create an inventory of high priority sites in the brownfield target area, using an Esri Geographic Information System (GIS). The first goal for the site suitability analysis was to identify properties with the highest potential or perceived potential for contamination, using federal, state, and county environmental datasets. Properties receiving brownfield funding also needed to reflect the development priorities outlined in the 2015 Pima County Comprehensive Plan update (Figure 1). Finally, to generate good will among the community and encourage land owner participation, the county wanted to identify properties that stood to benefit from the grant, such as properties already for sale or rent.

2. Research methodology

A site suitability analysis is the process of determining the fitness of a given tract of land for a defined use (Abdullahi and Pradhan 2016; Steiner, McSherry, and Cohen 2000; Malczewski 2004). Agencies typically use distinguishing features such as endangered species; natural areas; surface water; or culturally sensitive areas to select brownfield properties suitable for redevelopment (Muse 2015; Chrysochoou et al. 2012). US Census demographic data is an important data source for selecting brownfield sites from neighborhoods that need revitalizing (Chrysochoou et al. 2012). Performing a site suitability analysis was challenging, because of the study area's large size and lack of distinguishing features that are usually used in brownfield suitability analyses. US Census data was also of limited utility in this highly industrial area because the brownfield target area has few residential neighborhoods.

To create a brownfield inventory, we performed a GIS site suitability analysis following the general protocol of Coffin (2003) as well as previous work by SERI (2010). Coffin created a brownfield inventory using official tax assessors records; USEPA environmental datasets; and other state and local environmental datasets. SERI created a hazard score for businesses based on environmental and health risks, which was then used to develop neighborhood risk maps using GIS (SERI, 2010). We clipped the official tax assessor database to contain only parcels in the brownfield target area. The official tax assessor database uses the Arizona HARN State Plane Central Projected Coordinate System. Its underlying projection is Universal Transverse Mercator (UTM), and its geographic coordinate system is the 1983 North American Datum (NAD83). We converted 11 federal, state and county environmental datasets into the same spatial format; mapped the data to the parcels in the official tax assessor database; and developed a potential contamination risk score for each parcel. We further refined the brownfield inventory with Pima County development priorities and interested landowners who had properties for sale or lease.

2.1. Mapping environmental data to the brownfield target area

The federal, state and county environmental datasets we used are listed in Table 2, and are described in detail in the next section. We obtained six datasets online, and Pima County furnished the team with 5 datasets in Excel format. Data from web sites lacking the capability to export the data were pasted manually into Excel. To convert information into a spatial format, it is essential to know the datum, a reference point on the earth where position measurements are made (Featherstone and Vanicek 1999). The World Geodetic System 1984 (WGS84) datum and NAD83 are both commonly used in the United States. There is a difference of approximately 1–2 m between WGS84 and NAD83. Through sophisticated survey techniques, Arizona and other states have adjusted NAD83 to create High Accuracy Reference Networks (HARN; Esri 2021). For the four Pima County datasets with an unknown datum, we assumed a datum of WGS84 because this datum is usually used for Global Positioning Systems (GPS), which county staff use when measuring the coordinates in the field.

For environmental datasets with geographic coordinates, we used the Esri Convert Coordinate Notation tool, which assumes a datum of WGS84, to convert the datasets into a spatial format. To link each point to the correct parcel in the tax assessor database, we used the Esri Spatial Join tool. (The stormwater dataset actually had a datum of NAD83, but the 1–2 m difference was not significant for this study.) Unfortunately, the

Table 2. Environmental datasets used in this study. The following abbreviations are used in this table: United States Environmental Protection Agency (USEPA); Arizona Department of Environmental Quality (ADEQ); Pima County Regional Wastewater Reclamation Department (PCRW); Pima County Department of Environmental Quality (PDEQ); and Pima Development Services Department (PDS). The latitude and longitude fields of the stormwater permit database contained degrees, minutes and seconds in single fields. We converted them to decimal degrees using the following formula: (degrees/3600) + (minutes/60 + seconds).

Dataset	Source	Original Format	Years Data	Original Projection	Key Field	No. Records
Resource Conservation and Recover Act	USEPA	Online ^a	1984–1/7/2017	WGS84	Address	259
Toxic Release Inventory	USEPA	Online ^a	1987–1/7/2017	WGS84	Address	39
Toxic Substances Control Act	USEPA	Online ^a	1976–1/7/2017	WGS84	Address	5
Surface water discharge permits	USEPA	Online ^a	1972–1/7/2017	WGS84	Address	4
Stormwater discharge permits	ADEQ	Online ^b	2008–1/4/2017	NAD83	Coordinates	164
Industrial wastewater permits	PCRW	Excel	Current permits	Unknown	Address	514
Industrial wastewater violations	PCRW	Excel	2008–1/18/2017	Unknown	Address	63
Air quality permits	PDEQ	Online ^c	Current permits	Unknown	Address	57
Underground storage tanks	PDEQ	Excel	1/1/1950–8/18/2006	Unknown	Address	134
Environmental Notices of Violation	PDEQ	Excel	2010–1/13/17	WGS84	Coordinates	3002
Building code violations	PDS	Excel	1992–10/5/16	WGS84	Address	67

^a<https://www.epa.gov/nepa/nepassist>.

^bhttps://legacy.azdeq.gov/databases/azpdessearch_drupal.html.

^chttp://webcms.pima.gov/government/environmental_quality/air.

geographic coordinates of the USEPA databases were not useful, because they landed on streets rather than the parcels. Instead, we mapped the street addresses using the Pima County online composite address locator, and joined the points to the tax assessor database with the Esri Spatial Join tool. This method was also used for the environmental databases that lacked geographic coordinates. Our workflow is illustrated in Figure 2.

2.2. Description of the environmental datasets used in this study

This section describes the landmark legislation which led to the creation of the environmental datasets used in this study. An understanding of these laws is critical to estimating the level of environmental risk posed by each of the 11 datasets (see Table 2).

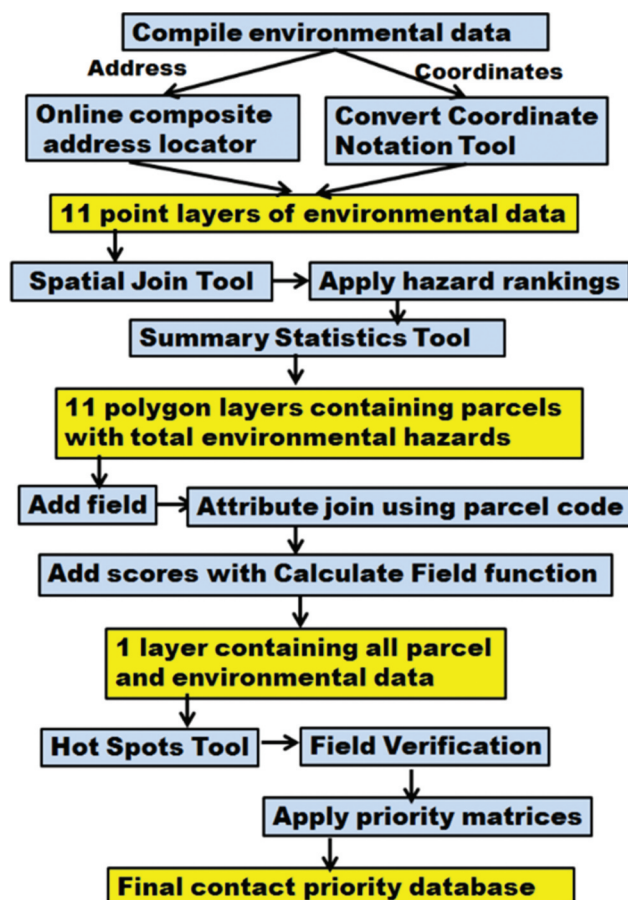


Figure 2. Workflow for the brownfield project. Yellow boxes represent databases, and blue boxes represent tools and procedures. We used a one to many relationships for the spatial and attribute joins. All tools are from Esri GIS Desktop 10.8.1.

2.2.1. The 1972 Clean Water Act (CWA)

This study uses four datasets related to the Clean Water Act. CWA established the National Pollutant Discharge Elimination System (NPDES) to regulate the discharge of pollutants into surface waterways (USEPA 2021c). Facilities that discharge directly into surface waters are required to obtain an NPDES permit. The brownfield target area does not actually contain any free flowing surface water, but a few facilities have NPDES permits to discharge into drainage channels called washes. Industrial sources and construction projects that generate stormwater runoff are also required obtain a NPDES permit (USEPA 2021d). In Arizona, the stormwater permitting program is administered by the Arizona Department of Environmental Quality (ADEQ).

CWA also established limits on the amounts of chemicals that a facility can discharge into a publically owned sewer treatment system. The law requires facilities to pre-treat their wastewater, and obtain a permit to discharge it into the sewer system (USEPA 2021e). The Pima County Industrial Wastewater Control Division of the Regional Wastewater Reclamation Department is responsible for administering the pre-treatment program in the brownfield target area. They provided the team with Excel files containing information on regional wastewater permit holders and wastewater permit violations.

2.2.2. The 1976 Resource Conservation and Recovery Act (RCRA)

The Resource Conservation and Recovery Act governs the handling and disposal of hazardous waste (USEPA 2021f). RCRA classifies facilities into one of three categories according to how much hazardous waste the facility generates monthly: very small quantity generator, small quantity generator, and large quantity generator (USEPA 2021g). The RCRA database also includes many facilities that lack a generator classification, because they no longer generate significant quantities of hazardous waste (USEPA 2021h). We included these facilities in our brownfield inventory, because hazardous waste discharges can remain in the environment for a long time (GSG Consultants 2005).

2.2.3. The 1970 Clean Air Act (CAA) and the 1990 Clean Air Act Amendments (CAAA)

The Clean Air Act established national ambient air quality standards for six “criteria” pollutants that are harmful to human health and welfare: lead, carbon monoxide, nitrogen oxides, ozone, sulfur dioxide, and particulate matter. The law also regulates the emission of 187 “hazardous air pollutants” that are known or suspected to cause health effects such as cancer or birth defects. Facilities that discharge criteria pollutants or hazardous air

pollutants into the atmosphere must obtain a permit (USEPA 2021i). The type of air quality permit depends upon the amount of pollutants a facility emits. Class I facilities emit 100 tons per year (tpy) of any criteria air pollutant excluding lead; 10 tpy of any single hazardous air pollutant; or 25 tpy of a combination of hazardous air pollutants; or 5 tpy of lead. Class II permits are issued to sources that do not qualify for Class I permits, but have the potential to emit “significant quantities of regulated air pollutants” (ADEQ 2021). In Pima County, the Department of Environmental Quality (PDEQ) administers the Clean Air Act permitting program.

2.2.4. The 1986 Emergency Planning and Community Right-to-Know Act (EPCRA)

The Right-to-Know Act was designed to help communities plan for emergencies such as chemical spills. The law requires facilities to report on their use, storage, and release of chemicals (USEPA 2021j). The Toxic Release Inventory (TRI) lists facility reports of environmental releases of hazardous chemicals (USEPA 2021k).

2.2.5. The 1988 CERCLA Underground Storage Tank (UST) regulations

Under the authority of the Superfund law, the USEPA has promulgated regulations for underground storage tanks containing petroleum products or hazardous substances. The regulations include requirements for leak detection, leak prevention, as well as remediation requirements for leaking underground storage tanks (USEPA 2021l). In Arizona, ADEQ administers this program. PDEQ provided us with an Excel spreadsheet of underground storage tanks for the entire state of Arizona, and we manually selected tanks in the brownfield target area. We confined our analysis to tanks that were currently in use, because contamination from leaks is remediated when an underground storage tank is removed.

2.2.6. Pima County environmental and building code violations

PDEQ is responsible for investigating violations for environmental permitting programs such as stormwater and air quality, as well as other environmental violations such as leaking sewage, wildcat dumping, gray water discharge, and asbestos. PDEQ provided us with an Excel file containing their environmental Notices of Violation. The Pima County Development Services provided us with data on building code violations such as dilapidated buildings and unpermitted structures. The building code violations were included to address the subjective perception of contamination, even though they did not necessarily indicate actual contamination.

Table 3. Relative scoring matrix for potential environmental risk. Fields with no parameters are labeled NA.

Parameter	0	1	2	4	6	8	12
Building code violations	Code violations only	Violations older than 2010	Violations newer than 2010	NA	NA	NA	NA
Environmental Notice of Violations	NA	Older than 2016 (overrules other scores)	Permit related violations	Stormwater runoff violations	Wastewater, hazards, env. nuisances, gray water violations, asbestos	Sewage and septic violations	NA
TRI	NA	Newer than 1990 or persistence >8	NA	NA	In EPA database	NA	NA
Air Permits	NA	NA	NA	Class III CESAQ	Class II SQG, Transporter, Permit in Progress	Class I LQG, Transfer Facility, Used Oil Permitted	NA
RCRA	NA	NA	Generator type not listed	NA	NA	Permitted	NA
IWC	NA	NA	NA	NA	NA	Permitted	NA
Surface discharge & TSCA	NA	NA	NA	NA	NA	Double-walled or blank construction field	Single-walled tank
Tanks	NA	NA	NA	Single-walled piping (additional score)	NA	NA	NA
IWC Violations	NA	NA	NA	Paperwork violations	Oil & grease, pH, chloromethane, or bromoethane exceedances	Copper, zinc, mercury, sulfide, carbon disulfide exceedances (persistence, toxicity)	NA
Stormwater discharge permits	NA	NA	Outside 1 mile radius, but intersects study area wash	Inside study area	NA	NA	NA

2.2.7. The 1976 and 2016 Toxic Substances Control Act (TSCA)

The Toxic Substances Control Act regulates the use of new and existing chemicals. The law “provides EPA with authority to require reporting, record-keeping and testing requirements, and restrictions relating to chemical substances and/or mixtures. Certain substances are generally excluded from TSCA, including, among others, food, drugs, cosmetics and pesticides.” The law also requires the USEPA to maintain a TSCA inventory (USEPA 2021m).

2.3. Developing potential risk scores

The 11 environmental datasets represent varying degrees of potential risk from environmental contamination. For example, older, single-walled tanks with a single-walled piping system pose a high risk of potential contamination from leaks, while small quantity generator facilities may pose less of a potential contamination risk because they generate less hazardous waste. It is important to remember that this analysis identifies the potential or perceived risk of contamination rather than the actual environmental contamination, which is only detectable with air, soil, and groundwater sampling. For example, environmental sampling may uncover no contamination at a RCRA large quantity generator facility that is diligent in preventing environmental releases. But significant contamination can be found at a facility that no longer handles hazardous waste, because many chemicals may persist in the environment for a long time. Contamination may come from previous uses of a property or even from fill (GSG Consultants 2005). Usually environmental sampling is performed during a Phase II assessment after a Phase I audit uncovers potential contamination issues (Vaidya 2015).

We created a relative scoring system for each type of potential environmental risk, based upon the team’s expert opinion (Table 3). RCRA large quantity generator status, single walled tanks, and industrial wastewater violations were scored highly. PDEQ environmental notice of violations were scored relative to their severity and potential for contamination. For example, sewage and septic leaks were considered higher risk than gray water discharges and trash buildup. Facilities with only an environmental violation were given a score of zero if the violation occurred before 2016, and facilities with only a building code violation were also given a score of zero. The Esri Summary Statistics tool was used to compute the total score for each parcel in the study area. The result was 11 tables, each with a single score for each parcel. These results were then combined into a final table with 11 score fields (one per dataset), which were summed using the Calculate Field function (see Figure 2 for workflow).

2.4 Field verification

Given the large number of vacant properties with previous industrial use, many properties in the 29.4 km² study area had the potential to qualify for brownfield funding. Many studies use remote sensing and image classification to map out potential brownfield areas. However, the spatial and temporal scales of most multispectral, publicly available imagery lacks the resolution to detect perception-based indicators of contamination such as wildcat dumping and trash buildup. In addition, the spectral signature of certain properties such as abandoned gas stations or dilapidated structures might not differentiate sufficiently from other built up land, and the distinction was important. Aerial photographs have greater resolution, but available county photos would have been at least a year old. There was no money in the budget to commission new aerial photographs.

We needed to verify the subjective conditions of “perceived contamination” and “interested owners” for the parcels in our potential environmental risk inventory by observing them in the field. The brownfield funding was a voluntary program, and participation was required in order to renew each cycle. Therefore, it was important to identify not only the potential for contamination, but also properties that were inhibited by the perception and stood to benefit from the program. These properties would serve to sow trust and therefore greater participation in the community. These factors and specific criteria ultimately are not measureable on imagery, or simply occur on a smaller scale and change more quickly than would be detectable. Field staff therefore looked for junkyards, dilapidated structures, wildcat dumping, apparent abandonment, and visible evidence of contamination such as paint cans, tire piles, and chemical containers. Because the program was voluntary and the county was looking for interested landowners, field staff also recorded the information on for rent and for sale properties.

Parcels were identified in the field using the mobile version of Pima County’s PimaMaps service, an online web-map containing data from the county GIS library. For each property, the parcel number(s) were recorded, along with other attributes including the date visited, search area, vacancy, realty information, contact information, apparent use, and photograph number(s). Observations were limited to what could

Table 4. The total risk score matrix, which combines the potential environmental risk with the observed field risk.

		Potential Environmental Risk			
		0–5	6–10	11–20	21+
Observed Field Risk	Low	Low	Medium	High	High
	Medium	Medium	Medium	High	High
	High	High	High	High	Very High
	Very High	High	Very High	Very High	Very High

be ascertained of the property without trespassing, and no environmental testing was performed. The fieldwork was completed in approximately three weeks, and field staff observed approximately 7500 parcels within the priority areas.

Parcels were ranked using a subjective scale from low to very high perceived environmental contamination risk. The field observations were incorporated into the brownfield inventory using Structured Query Language (SQL) queries based on a matrix (Table 4). An additional matrix (Table 5) was used to delineate priority contact lists for direct business contact. Parcels that were observed to be vacant or for sale were given higher contact priority, because these parcels would be more likely to have interested landowners. High contact priority was given to parcels with high potential contamination scores; parcels likely to re-develop; and property owners who had expressed interest. Parcels falling within other county development initiatives, such as Infill Development Zones were also elevated to a higher priority status.

3. Results and discussion

The tax incentive district (see Figure 1) consists mostly of small parcels, while the southern half of the brownfield target area contains fewer, but much larger parcels. Aside from an obvious area of high potential contamination risk centered at Tucson International Airport, the potential environmental risk scores throughout the brownfield target area are fairly similar (Figure 3). To guide our field verification, we performed a spatial clustering analysis in the point data using the Esri Optimized Hot Spots tool (Figure 4). This tool uses the Getis-Ord Gi* statistical test (Drake et al. 2015) to calculate areas of statistically significant clustering. A Gi_Bin value of ± 3 is statistically significant with 99% confidence; ± 2 is statistically significant with 95% confidence; and ± 1 is statistically significant

Table 5. The contact priority matrix, which combines the total environmental risk score with availability, vacancy, and landowner interest.

		Vacancy, Availability and Landowner Interest					
		None	Vacant	Available	Vacant & Available	Interested Owner	Interested, Vacant & Available
Environmental Risk	Low	None	Low	Medium	Medium	Medium	High
	Medium	Low	Medium	High	High	High	Very High
	High	High	High	Very High	Very High	Very High	Very High
	Very High	High	Very High	Very High	Very High	Very High	Very High

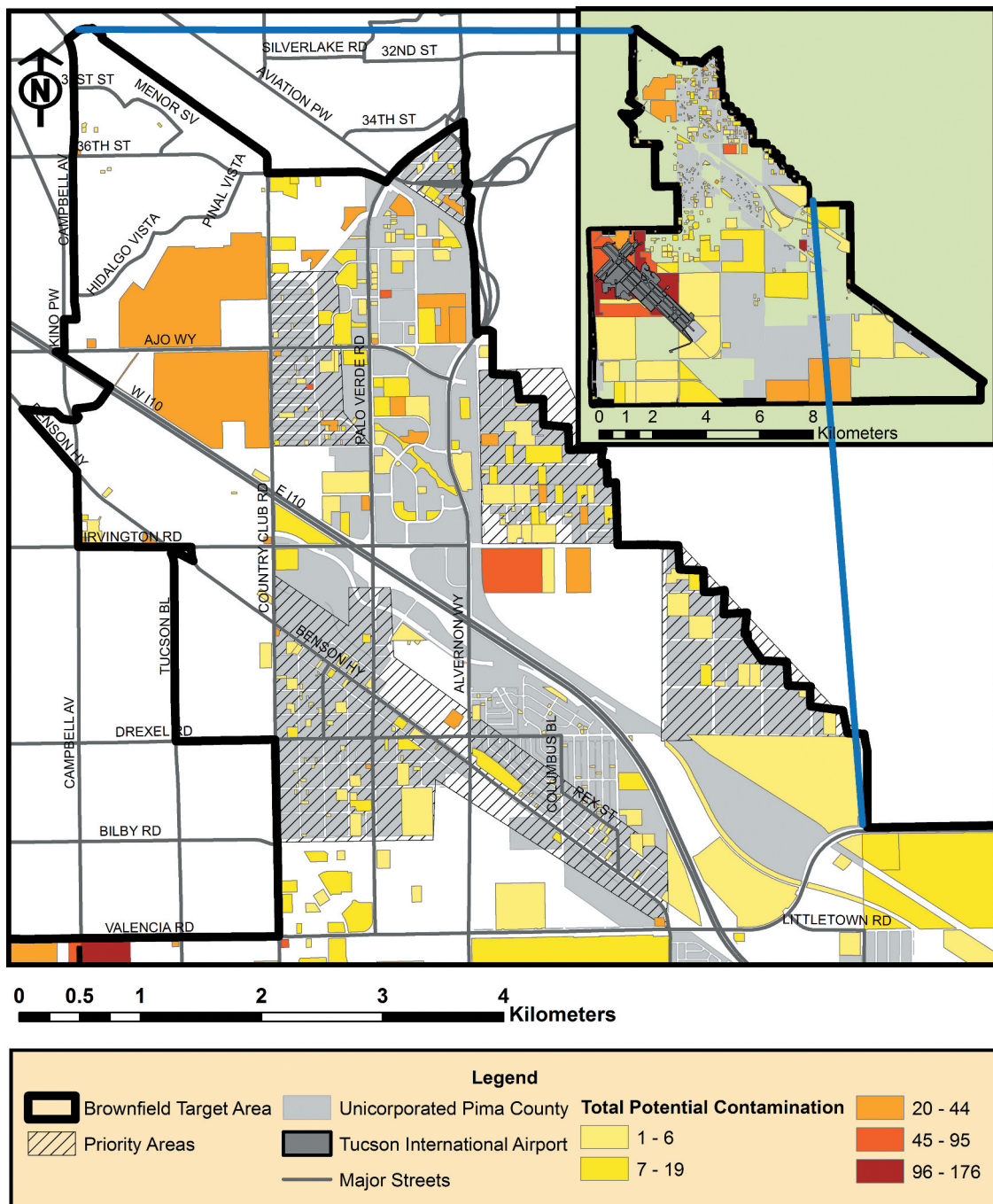


Figure 3. Total potential contamination risk of brownfield parcels under Pima County jurisdiction.

with 90% confidence. Our final field verification plan, which was guided by the results of the hot spot analysis, is shown in Figure 5.

An appropriate scale must be identified for calculating clusters, because data that is clustered on a small scale may be considered dispersed on a larger scale. The Optimized Hot Spot tool is designed to select a scale for datasets that do not have an obvious scale. The tool employs the Global Moran's I statistic at multiple scales to measure the intensity of clustering at each scale. If this method does not produce a clear "peak" in intensity, the tool will use a scale equal to an average distance that yields k neighbors for each feature. We ran the Optimized Hot Spot tool using three

scales within the brownfield target area, as summarized in Table 6. The first scale included data points that fell within 1.5 miles of the brownfield target area, to account for edge effects. The second scale included both City of Tucson and Pima County properties within the brownfield target area. The scale that we used in our final map of hot and cold spots of potential contamination (Figure 4) only included Pima County parcels, and excluded City of Tucson parcels because of jurisdiction issues.

The un-weighted hot spot analysis shows a statistically significant spatial clusters distribution of facilities that pose at least some risk of potential or perceived environmental contamination. The infill

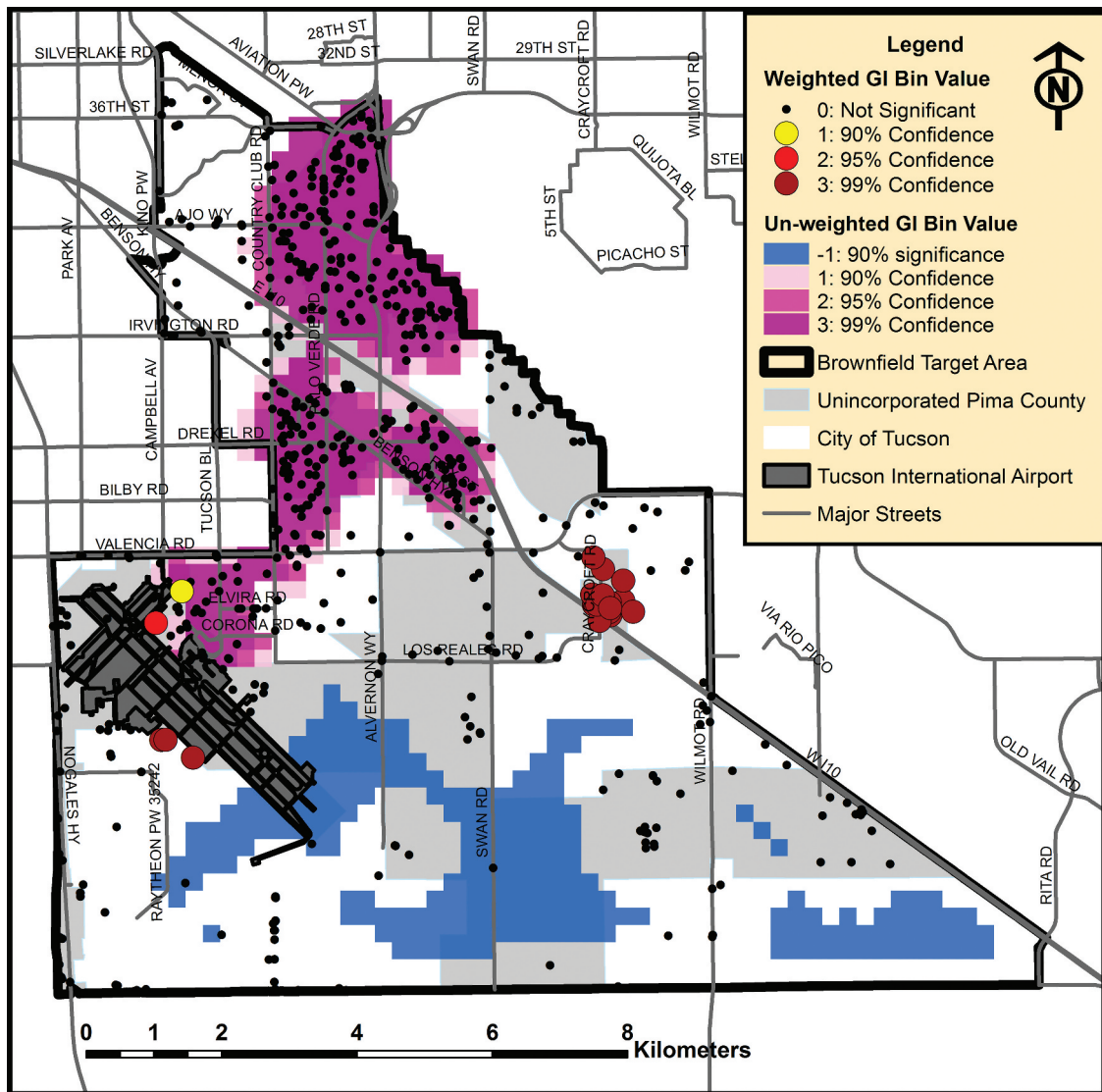


Figure 4. Weighted and un-weighted Optimized Hot Spot analysis of parcels with at least some degree of perceived or potential environmental risk. The northern part of the study contains more parcels (hot spots) than the less developed southern portion of the target area (cold spots). The weighted analysis shows clusters of points with hot spots of higher potential environmental risk.

incentive district contains a large hot spot, and a large cold spot is located in the southern portion of the brownfield target area, where facilities are larger and more widespread. When the tool is weighted with the potential environment risk score, points of hot spots are evident in the eastern half of Area 7 and near Tucson International Airport. Given the prevalence of wildcat dumping, scrap yards, and vacant parcels within the infill incentive district, there are a large number of parcels that meet the legal brownfield criteria of abandonment and perceived or potential environmental risk.

Applying the additional criteria of county development priorities, availability, vacancy, and landowner interest narrowed the potential environmental risk inventory to a more manageable list of landowners for the county to contact: 28 very high contact priority; 129 high priority; and 132 medium priority (Figure 6). Most of the very high and high priority parcels are located in the infill incentive district, especially along

the boundary with Davis-Monthan Air Force Base. Eight properties from Area 7 (see Figure 5), which were flagged in the weighted hot spot analysis, are also given very high priority in this inventory. Several large parcels south of the infill incentive district are also included in the high and very high priority lists. Their large size and proximity to Tucson International Airport have the potential to make them attractive to developers.

Developing a brownfield inventory can be challenging, because it is necessary to consider many environmental, economic and social factors when choosing sites (Aktas, Bartholomew, and Church 2017; Brill 2009). The 29.4 km² study area is three times larger than the entire city of Paterson, NJ, (Ferdinand and Yu 2016). Yet it has few residential neighborhoods and a complete lack of distinguishing features such as surface waters, cultural areas or natural areas. Unlike many brownfield redevelopment projects which focus on one property (Brill 2009), a substantial

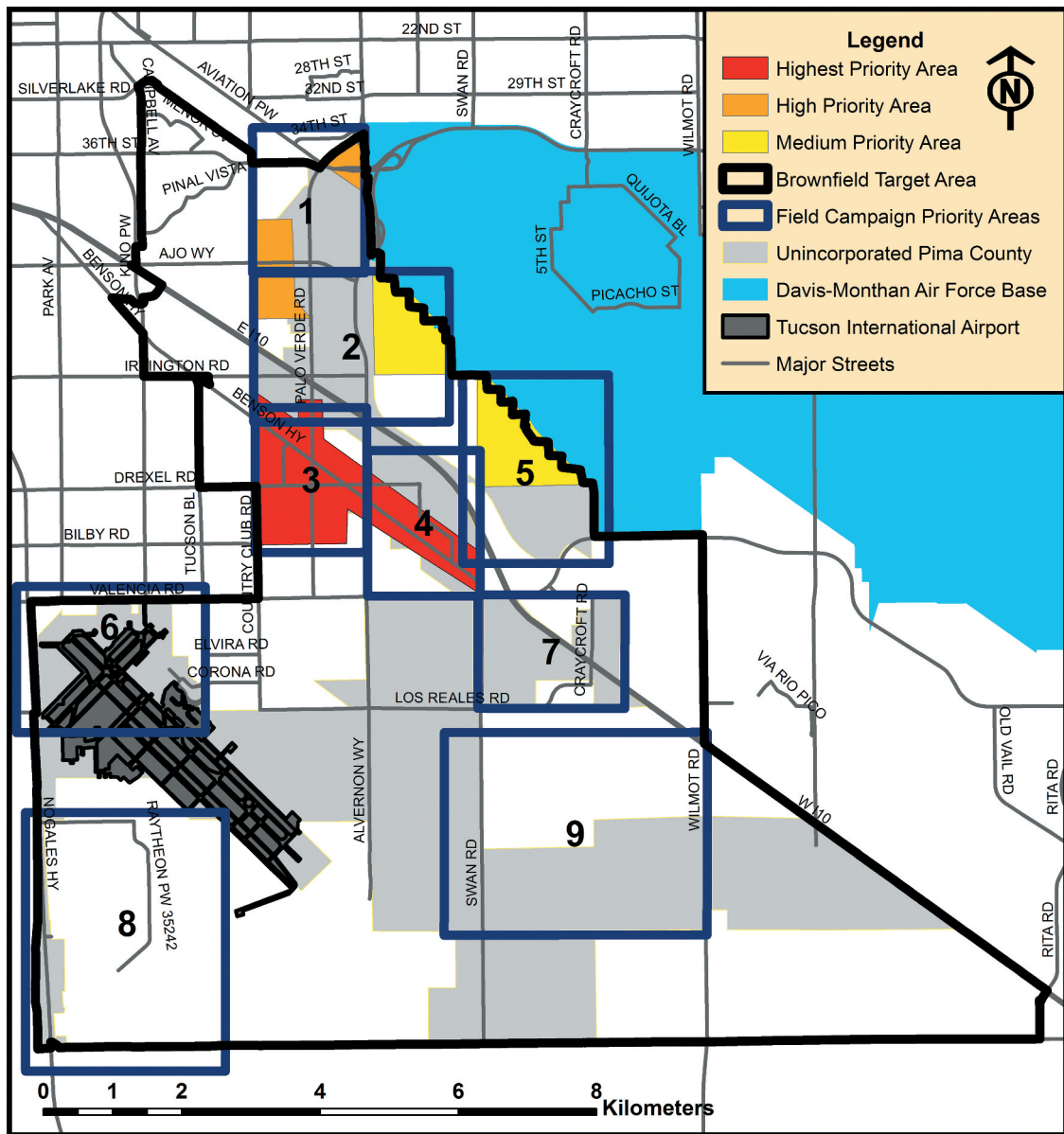


Figure 5. Priority search areas for the field observations. The field team did not enter Air Force land during field observations. Field staff also did not evaluate the high potential contamination area within Tucson International Airport (Area 6) because this area was covered by another project.

Table 6. Optimal distances for clustering analysis was performed using ESRI’s Optimized Hot Spots tool. The weighted analyses were performed using the total potential environmental risk.

Analysis	Weighted	Optimal Distance	Number Significant Parcels
1.5 miles buffer to study area.	No	3073	53
	Yes	2423	177
Entire brownfield area. Grid cell size: 834.000 feet	No	2799	514
	Yes	2389	32
Unincorporated Pima County. Grid cell size: 792.000 feet	No	2998	491
	Yes	2436	55

number of properties in the large brownfield target area were likely to meet the legal definition of a brownfield. To create a brownfield inventory, we

performed a site suitability analysis using 11 Federal, state and county environmental datasets. Converting the datasets into a spatial format proved to be challenging, because some of the datasets were not available in a spatial format, and the datum of four county datasets was unknown.

The USEPA (2021a) estimates that there are more than 450,000 brownfields in the U.S. Cleaning up contaminated sites protects human health and the environment (Amekudzi, Attoh-Okine, and Laha 1997; Bacot and O’Dell 2006). Redevelopment of brownfields is essential to enhance sustainable urban development, protect greenfields, and reduce urban sprawl (Abdullahi and Pradhan 2016; Amekudzi, Attoh-Okine, and Laha 1997). Redevelopment also uses existing civil infrastructure while creating new jobs and tax revenues (Amekudzi, Attoh-Okine, and

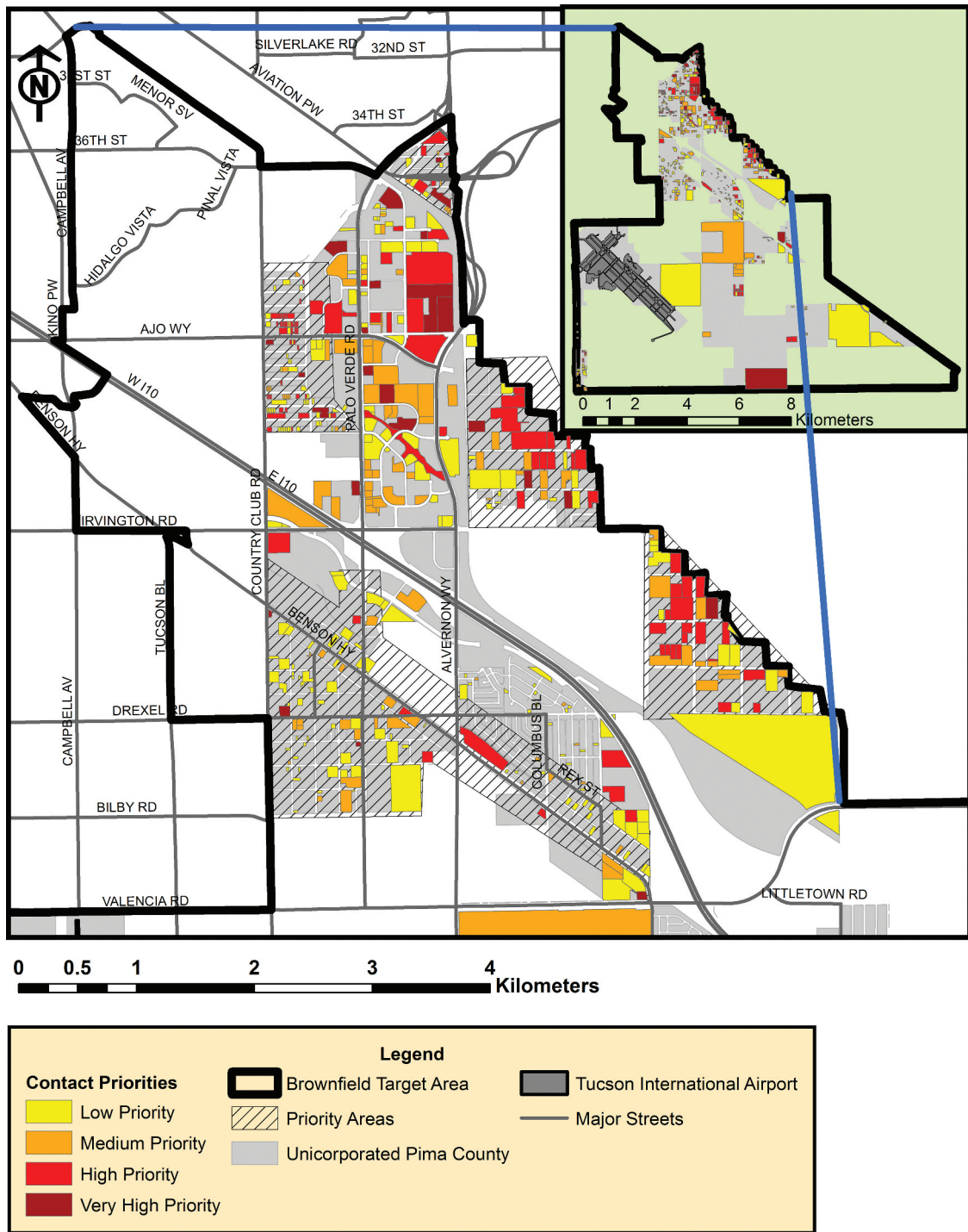


Figure 6. Contact priority inventory, based upon an analysis of potential environmental risk, field observations, and Pima County redevelopment priorities.

Laha 1997). Creating a brownfield inventory using GIS is an excellent method for selecting candidate properties, so that brownfield redevelopment supports sustainable development and revitalizes neighborhoods. GIS has the capability to integrate quantitative environmental datasets with subjective information such as development goals and field observations of blighted neighborhoods. The brownfield inventory created through this project will help the county allocate scarce funding, and will also be useful for informing future revitalization projects in the area.

USEPA data datasets from landmark environmental laws such as the Clean Water Act have been generated since the 1970s, and are now easily accessible through the Web. This study is a good example of how it is possible to generate useful spatial information from publicly available datasets that are not necessarily in a spatial format. Researchers are also using other public datasets to answer research questions and inform policy decisions. Lauko et al. (2020) used Google Street view photographs to estimate the green space under the forest canopy in Milwaukee County,

Wisconsin, USA. Lock and Pettit (2020) analyzed tweets to learn more about how the public views public transportation in Sydney, Australia.

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Data availability statement

Information about SERI publications can be found at <https://seriaz.org/about/publications-presentations/>. The data for SERI and Pima County Brownfields assessment paper are also available upon request. Please contact seri@seriaz.org.

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