Pima County Ecological Monitoring Program
Landscape Pattern Monitoring Protocol

March 2020

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Cover photo: National Land Cover for the conterminous United States – NLCD program.

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Definitions
Throughout the development of Pima County’s Multi-species Conservation Plan (MSCP), monitoring landscape-level parameters of land use and land cover was considered a top priority (RECON Environmental Inc. 2007). Landscape pattern is a broad category describing the spatial configuration and extent of land-cover and land-use parameters. Land cover is the observed biophysical state of the earth’s surface and immediate subsurface; it can be categorized into types of natural vegetation (e.g., forest and grassland) and human uses such as urban development, agricultural fields, mine sites, and roads. Land use can involve both the manner that land is manipulated and the intent of that manipulation.

Purpose
The purpose of this protocol is to describe the objectives and tools which are proposed for use in Pima County MSCP’s Ecological Monitoring Program (EMP) for detecting and interpreting changes in patterns of land use and land cover over the thirty-year term of Pima County’s Section 10 (incidental take) permit. This report responds to the commitments in the MSCP (2016) approved by U. S. Fish and Wildlife Service and builds on previous work of Fonseca et. al. (2009). It attempts to complement the NPScape monitoring effort (Monahan et al. 2012) for the National Park System units in our area.

Objectives
MSCP Objectives for Landscape Pattern Monitoring
Landscape Pattern is one of the five ecological monitoring elements of the Pima County Multi-species Conservation Plan (the other elements being: single-species, habitat, threats, and climate monitoring). Of the five, it is the broadest in extent. Monitoring changes in landscape patterns, including land cover and land use, will help explain observed changes in the habitats used by species covered by the MSCP and anticipate future threats.

MSCP objectives for the Landscape Pattern element fall into two categories: retrospective and prospective analyses.

Retrospective:
1. Document changes in the type and location of land cover conversion activities that have occurred during each reporting period, including updating the built environment GIS layer used as a reference for mitigation of County activities under the permit.

Prospective
2. Forecast extent and location of potential future development that may result in land cover changes.

Changes in land cover and land use may affect the long-term viability of many of the covered species. Measures of fragmentation of habitat, independent of land cover and land use, can be analyzed at the landscape level or inferred using results from both retrospective and prospective monitoring.

Landscape pattern monitoring results will also provide a useful regional context to supplement the evaluation of permit-related activities every ten years as described in Chapter 9 of the MSCP. We anticipate developing a separate statement with the Science and Technical Advisory
Team (STAT) to guide all of the analyses that will be brought to be bear on the decennial review of the Section 10 permit, separately from this document.

Additional Objectives in Relation to Changed Circumstances

Changed circumstances are “changes in circumstances affecting a species or geographic area covered by a Habitat Conservation Plan (HCP) that can reasonably be anticipated by Plan developers and the [USFWS] and that can be planned for” (50 CFR §17.3). Table 7.1 of the MSCP lists identifiable changed circumstances for the County’s permit, and describes potential responses that Pima County may take. Many of the changed circumstances are related to activities of others that could affect species or their habitats covered by the MSCP, for which no response would be needed.

Much of Table 7.1 is evaluated and discussed with USFWS annually, but in the 2016 MSCP Annual Report, we proposed to integrate the reporting frequency for several changed circumstance scenarios with landscape pattern monitoring techniques. These select circumstances are shown below in Table 1. The reporting frequency for changed circumstances that will be addressed through landscape pattern monitoring varies as shown below.

Table 1. Changed Circumstances addressed through Landscape Pattern Element (abstracted from Pima County MSCP Annual Report 2016, Table 6).

<table>
<thead>
<tr>
<th>Circumstance</th>
<th>Minimum reporting frequency</th>
<th>Reporting mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Arizona Project recharge creates aquatic habitat, and expands riparian habitat.</td>
<td>5 years</td>
<td>Landscape pattern analysis in eastern Pima County</td>
</tr>
<tr>
<td>Land is graded on County-held grazing leases, County conservation easements, or County-owned mitigation lands for infrastructure or other developments beyond County’s control (e.g., condemnation)</td>
<td>5 years for landscape pattern, otherwise as data become available</td>
<td>Landscape pattern in eastern Pima County, supplemented with biennial inspection reports, threats monitoring at site level</td>
</tr>
<tr>
<td>Conversion of desert, riparian areas, or grasslands to agriculture in Permit Area or on adjacent tribal lands.</td>
<td>5 years</td>
<td>Landscape pattern monitoring in Pima County</td>
</tr>
<tr>
<td>Conversion of desert, riparian, or grasslands to development due to Federal projects or federally authorized projects of others in the Permit area or on adjacent tribal lands.</td>
<td>10 years</td>
<td>Landscape pattern monitoring in Pima County</td>
</tr>
<tr>
<td>New roads or utilities established in CLS outside Preserves.</td>
<td>5 years</td>
<td>Landscape pattern monitoring in Pima County excluding tribal lands</td>
</tr>
<tr>
<td>Reduction in effluent discharge from County treatment facility (below permit issuance baseline) contributes to die-offs of riparian forest and elimination of aquatic vegetation along the Santa Cruz River in Pima County</td>
<td>Discharge annually; Vegetation as new products become available</td>
<td>Annually report change in effluent discharges; examine vegetation using Landscape Pattern monitoring</td>
</tr>
<tr>
<td>Wildland fire exceeding 1,000 acres in size occurring inside or outside County preserve network. Not all County preserves are affected at same time, but at least one is.</td>
<td>5 years</td>
<td>Landscape pattern monitoring in Pima County, excluding tribal lands</td>
</tr>
</tbody>
</table>
Protocols presented in this document integrate detection of these changed circumstances primarily with retrospective land cover analysis using the National Land Cover Dataset (NLCD) and other sources of information.

**Area of Analysis**

In general, we prefer to analyze landscape change in Pima County across jurisdictions, where data and analytical resources are available. In some cases, the analysis may be restricted to a smaller area, for instance to satisfy one of the above changed circumstances, or to use high-resolution data sources that do not extend more broadly over Pima County (see Table 1). The permit area is much smaller than Pima County and shrinks with time as areas are annexed. The permitted activities primarily affect eastern Pima County and a small area around Ajo, Arizona. The permit area does not extend onto the Tohono O’odham Nation or other tribal or federal lands.

**Permit Baseline**

The Section 10 permit was signed in July 2016. The monitoring plan itself has a five-year period for initiation. In general, the baseline or reference conditions for monitoring landscape pattern will be defined based on imagery analyses selected as close to July 2016 as possible. Successive-year analyses such as those supporting the decennial permit review will also be used to establish trends over time.

**Component Monitoring Protocols**

**Protocol Summary**

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Frequency</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Built environment</td>
<td>Updated as CIP projects occur</td>
<td>Establish new reference layer for more accurate baseline; Maintain reference layer for determining when County projects require mitigation.</td>
</tr>
<tr>
<td>National Land Cover Dataset (NLCD)</td>
<td>As NLCD products are released</td>
<td>Detect changes in regional land cover and land use using 2016 baseline to understand trends; monitor and report certain changed circumstances</td>
</tr>
<tr>
<td>Large wildland fire impacts</td>
<td>5 years</td>
<td>Detect changes in land cover on County preserves that may be related to fires exceeding 1000 acres in size for changed circumstances affecting covered species</td>
</tr>
<tr>
<td>Effluent-reduction analysis for Santa Cruz River</td>
<td>5 years</td>
<td>Detect changes in aquatic or riparian habitat for covered species and evaluate in relation to effluent discharge and other factors</td>
</tr>
<tr>
<td>Regional road network</td>
<td>5 years</td>
<td>Detect changes from 2016 baseline that may shape future land use or fragment habitat in CLS for decennial review</td>
</tr>
<tr>
<td>Sewer analysis</td>
<td>5 years</td>
<td>Establish 2016 baseline; detect changes that may shape future land use patterns or fragment habitat in CLS for decennial review</td>
</tr>
<tr>
<td>Future development</td>
<td>≤10 years</td>
<td>Project how and where future development may affect land cover that support the habitat of covered species for decennial review</td>
</tr>
</tbody>
</table>
Built Environment Analysis

The built environment GIS layer serves one main purpose: to serve as the basis for determining when County construction projects (defined in the MSCP as Capital Improvement Projects or CIP) require mitigation. It is NOT used to track other types of urban growth.

When the permit was issued, Pima County created the geographic information system (GIS) layer known as CIPBUILT to determine when Capital Improvement Projects performed by Pima County require mitigation (Figure 1). This layer is continuously edited as CIP projects are completed and after permit issuance become finalized. In other words, each new CIP project redefines the built environment representation against which new CIP projects are measured, to prevent double mitigation. CIPBUILT is stored as GIS layer in Pima County’s central GIS library.

Like every representation of reality, this layer imperfectly represents the actual distribution of developed areas in 2016 when the permit was issued. Most of the work to represent the built environment was done by the Pima Association of Governments and represented in an earlier layer, BLT_2008, prepared eight years before the permit was issued. In addition, the effort did not finely resolve certain land use categories.

As noted in the 2016 and 2017 MSCP Annual Reports, accounting for certain types of CIP projects has been difficult because the original layer from which CIPBUILT was derived (BLT_2008) did not account accurately for the pre-permit parks and landfills where the County continues to do work. As documented in the 2017 Annual report, USFWS authorized an update to CIPBUILT to account for landfills that were in existence at permit baseline, but a similar exercise has not been performed for parks which may have varying compositions of sod, hardscape, natural vegetation, and other land covers but that are otherwise primarily managed for human use and recreation, rather than natural resources.

We seek USFWS permission to perform a similar update to CIPBUILT for parks using a detailed classification of imagery dated 2015 to distinguish between natural cover and areas where the ground has been disturbed and cover is largely managed for visual or recreational purposes. Parks are often a mix of natural and developed areas. In 2017, for instance, the lining of an existing pond at Agua Caliente affected an already developed area that was not reflected in the CIPBUILT layer. We can anticipate this being a recurring issue in the use of the CIPBUILT layer if not otherwise corrected.
Figure 1. CIPBUILT indicates built up areas and is used to determine whether new capital improvements covered under the permit require mitigation.
When we have permission, we will revise the CIPBUILT layer to identify areas of natural cover in parks that had been converted to either ponded water, impervious cover, structures, irrigated land (turf) by 2015, when the PAG imagery used for the raster classification called LULC18 was collected and analyzed. Figure 2 provides an example where substantial areas of irrigated turf and ponded water in a golf course are adjacent to natural open space vegetation. This example highlights the level of detail provided by the LULC18 classification and its proposed use for improving the classification of the built environment in park lands.

In general, the LULC18 classification is very good at discriminating changes in land cover, but including the barren/bedrock land cover classification may introduce some inaccuracies because it can conflate areas of natural open ground (bare dirt or bedrock) with some types of human-altered land covers such as bladed ground. As an example, in Figure 2 the poorly irrigated turf sport field in the lower right part of the image is incorrectly classified as barren/bedrock. Since there are natural land covers types described by barren/bedrock throughout many of the scrub lands in the permit area, inclusion of barren/bedrock would pose problems. Our proposal to exclude the land cover category barren-bedrock from the built environment is conservative, in that it will not capture poorly irrigated turf such as the ball field in the southern part of the figure.

NLCD Landscape Pattern Analysis
The National Land Cover Dataset is derived from LANDSAT satellite data, and is intended to provide reliable information on the Nation’s land cover and land use change (Yang et al, 2018). The National Park Service has chosen the NLCD for most of its land cover and land use monitoring, and has published detailed instructions for its use (available at irma.nps.gov). The scale of this product is typically 30-meter resolution. The NLCD has been supported by
consistent funding, and iterative updates are then provided at no cost to the public, every five years or so.

The primary purpose of using the NLCD for the EMP, as proposed by Fonseca (2008), is to analyze gross changes in regional land cover that may be responsible for long-term trends in covered species distributions or population trends. The NLCD will also be used to analyze for and report changed circumstances as noted in Table 1 and discussed below.

The NLCD has been used successfully in the detection of land cover change in Arizona (Kepner et al. 2000), and Pima County (Fonseca 2008). More recently, Shrestha et al. (2012) found that 80% of the “developed, low intensity” and 66% of “open space, very low intensity” areas were correctly classified near Phoenix. In arid regions, NLCD is quite successful in detecting this otherwise difficult land use. In Pima County, Fonseca (2008) and Fonseca et al. (2009) found the NLCD was useful in detecting land cover removal due to dirt road construction in areas of lot splitting.

Grassland classification has been thought to be a notable weakness of the previous iterations of the NLCD (Xian, et al. 2015). Estimates of grassland or other herbaceous cover varied greatly between NLCD 2011 and Wallace et al. (2011) for the Cienega Creek watershed (Powell 2015). Importantly for Pima County’s work, the 2016 NLCD dataset now includes improved shrub and grass mapping for southern Arizona and New Mexico, as well as large parts of the western United States (Young 2017). Most of Pima County falls in the shrub and grass categories of NLCD, but there are major areas of evergreen forest, agriculture and developed lands (Fonseca et al., 2009).

**NLCD 2016** has just been released (June 2019). Land cover and imperviousness products are available for seven product dates between 2001 and 2016. Land cover and imperviousness products are now spatially and temporally consistent among the various years that NLCD has existed, permitting trend analysis. The 2016 release provides separate fractional vegetation products for download, and these can be incorporated into the land cover for improved accuracy.

Economic and land use changes are important drivers that are expected to change landscape pattern over the term of the permit. The NLCD’s change detection products will be used to provide unique information on the conversion of natural land cover types by mining, urban expansion, and agricultural activities within and outside the permit area. This analysis will provide information about trends in these land-use activities, which can affect habitat conditions for covered species.

For our first five-year review period, we will retrospectively evaluate changes in all of the Anderson Level 1 and 2 categories of the NLCD (Table 3) that occurred from 2006 to 2016. This analysis will help us understand and interpret trends that led up to the NLCD 2016 baseline, and inform interpretation of subsequent changes that affect the NLCD 2016 baseline for the first decennial review.
Table 3. Anderson Level 1 (number in first column) and 2 (value in second column) Land Cover Classes in NLCD 2016.

11. Water  
12. Perennial Ice Snow (not in Pima County)  
21. Developed, Open Space  
22. Developed, Low Intensity  
23. Developed, Medium Intensity  
24. Developed High Intensity  
31. Bare Rock/Sand/Clay  
41. Deciduous Forest  
42. Evergreen Forest  
43. Mixed Forest  
52. Shrub/Scrub  
71. Grasslands/Herbaceous  
81. Pasture/Hay  
82. Cultivated Crops  
90. Woody Wetlands  
95. Emergent Herbaceous Wetlands

After the initial five-year review, Pima County will specifically report observed changes using the change detection datasets provided by NLCD. If these are not available at five-year intervals, Pima County may at our discretion use other products rather than wait for another release. In reporting results, we will use the NLCD’s categories of land use or land cover (see Table 4) whenever possible, guided by NPS protocols available at irma.nps.gov. If similar regional analyses are available from NPS for the area near Saguaro National Park, we will compare our results to theirs.

Of particular interest is the robustness of any emerging trends in grassland/herbaceous class over time. We will look for further research by others that will elucidate the accuracy of the NLCD classification and trends, and if possible, bring local ancillary data, such as those from Santa Rita Experimental Range, into an evaluation of long-term trends.
### Table 4. Reporting Metrics Using NLCD Land Cover Product

<table>
<thead>
<tr>
<th>Purpose</th>
<th>NLCD-derived Metric and Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>Describe existing land cover</td>
<td>Total area of Level 2 Land Cover class in acres by type and percent area for Pima County for baseline and year of analysis (Table); map of Eastern Pima County and Western Pima County at Level 2</td>
</tr>
<tr>
<td>( \Delta ) Land Cover</td>
<td>Table of total areal change (-/+ ) for each Level 2 land cover class from 2016 baseline to year of analysis in Pima County; supporting map showing dominant changes</td>
</tr>
<tr>
<td>Conversion of desert, riparian areas, or grasslands to agriculture in Permit area or on adjacent tribal lands (changed circumstance)</td>
<td>Table of acreage lost from 2016 baseline Level 1 Shrubland, Grassland, or Wetland (Woody and Emergent) to any type of Developed or Barren class; a sample is then spot-checked with high-resolution aerial photographs to determine if change occurred</td>
</tr>
<tr>
<td>Agriculture (changed circumstance)</td>
<td>Map of change from 2016 baseline any Level 1 natural land-cover type except Barren to Pasture or Cropland in Permit Area or tribal lands; these are then verified with high-resolution aerial photographs to determine if change occurred</td>
</tr>
<tr>
<td>Wildland Fire (changed circumstance)</td>
<td>Conversions at Level 1 within areas of previous fires on County mitigation properties (see protocol below)</td>
</tr>
<tr>
<td>New roads or utility incursions in CLS, outside Preserves (changed circumstance)</td>
<td>Map showing conversions to Level 1 Barren or Developed in CLS outside Preserves that have been verified with street network or other ancillary data</td>
</tr>
<tr>
<td>Federally authorized project incursion (changed circumstance)</td>
<td>Map showing locations of conversions from Level 1 natural land cover types to Agriculture, Barren, Urban or Open Water; verified with high-resolution aerial photographic or other evidence</td>
</tr>
<tr>
<td>CAP recharge creates aquatic habitat or expanded riparian habitat (changed circumstance)</td>
<td>Map showing locations of conversion from a Level 1 non-water cover type to a wetlands cover type near CAP recharge areas; verified with high-resolution aerial photographic evidence</td>
</tr>
</tbody>
</table>

### Wildland Fire Analysis

The monitoring objective is to detect large fires that cause long-lasting alterations of habitat for covered species in County preserves. If there is a wildland fire meeting the size and proximity criteria, it will be reported as a potential changed circumstance, subject to later analysis for habitat alteration. The distribution of fires and their long-term effects on distribution of broad classes of vegetation community structure will thus be available in the decennial review.

Pima County will screen for wildland fires exceeding 1,000 acres in size that have occurred inside or outside the County preserve network using fire perimeters reported to the MTBS (Monitoring Trends in Burn Severity) multiagency program (MTBS 2017). The GeoMAC (Geospatial Multi-Agency Coordination) Wildland Fire Support will not be consulted because it is not comprehensive.

Figure 3 compares the two databases for the period 2000 to 2016. Most fires before the permit was issued occurred on lands outside the County preserve network. Many fires in Pima County were not reported by GeoMAC, and our comparative analysis showed that every fire that was on GeoMAC was also on MTBS. A record of pre-permit polygons from both MTBS and
GeoMAC will be maintained to support decennial analysis. The pre-permit baseline for this effort will include MTBS perimeters for fires that either occurred within Pima County or had part of their perimeter located within a four-mile buffer from Pima County dating back to 1984. It will reside in Pima County’s GIS library as a shapefile and as an Enterprise Geodatabase feature class showing the number of times a given polygon has burned between 1984 and 2016.

Figure 3. Fire perimeters from the period 2000 to 2016 from two different data sources. MTBS seems to report fires more reliably than GeoMAC in Pima County.

MTBS provides data on fire perimeters of 1,000 acres or greater, including prescribed fires (MTBS 2017). It seems that there is a lag time of about 18 months for successive years’ release of data (e.g. the 2016 data were released on August 3, 2018). MTBS data are also free and consistent over time, since they are based on Landsat imagery. There is a high likelihood that this program will be maintained in the future, making it useful for the Landscape Pattern Monitoring element of the EMP. If MTBS is not continued, then Pima County will rely on GeoMAC or another federal successor program.

MTBS will be queried every five years to identify the location of new (post-permit) fire perimeters relative to County preserves. Additionally, any large fires that occur on County preserves would likely be reported in that particular year’s MSCP annual report to the USFWS. If direct mortality of covered species or impacts to covered species habitats due to wildfire has been verified by field observations, we will also advise USFWS of this in our reporting of the changed circumstance in the County preserve or preserves.

Assuming there is no direct observation supporting mortality of covered species, we will review evidence for long-lasting habitat impacts. If MSCP mitigation land or potential mitigation lands are affected and the total acreage of the fire appears to exceed 1000 acres in size, an analysis of land cover impacts will be performed using remote sensing products described below, when those are made available. Because some fires will not result in vegetation or soil changes that
are apparent or persistent enough to be considered a change in land cover by remote sensing, it is not anticipated that a changed circumstance will be confirmed each time a County mitigation property is burned.

The fire effects occurring on MSCP mitigation land or potential mitigation land will be analyzed and reported using MTBS. The MTBS dataset is developed by first compiling fire occurrence data from federal and state land management agencies in order to identify candidate fires. For fire events that meet MTBS’ 1,000-acre minimum, corresponding Landsat scenes are selected based upon the reported location and ignition date. Pre- and post-fire scenes are then evaluated. The burned area boundary is delineated manually by an analyst who looks for any detectable fire area based on the base reflectance imagery as well as the differenced Normalized Burn Ratio (dNBR) and relativized dNBR (RdNBR) burn severity values derived from the prefire and postfire scenes. Thus the perimeters will be different and presumably more accurate than the GeoMAC-derived perimeters which are not estimated in this manner. The MTBS program also publishes burn severity data for each fire.

The perimeter data from MTBS will be used in conjunction with changes in NCLD Land Cover to evaluate significant changes in vegetation structure during ensuing years. A gross change in NLCD Level 1 classification for any portion of the total burn polygon area, such as a conversion of woodland to grassland or grassland to bare ground, will be evaluated for a potential changed circumstance if it persists for five years or longer. Changes will be evaluated in light of the ecological site state-and-transition models for the locations, and their effects on covered species. Pima County will discuss any potential changed circumstances with USFWS in the context of covered species distributions and habitat impacts to determine whether an actual changed circumstance has occurred.

If a new post-fire NLCD Land Cover product is not available at each five-year review period, then LANDFIRE data may be used. A significant change in the overall composition of the Existing Vegetation Types (EVT_Order in LANDFIRE) for any portion of the burn polygon will be considered a potential changed circumstance warranting further discussion with USFWS. In the first five-year reporting period (2021), if neither product is available, we will examine pre-permit fires located in the MSCP mitigation properties (mainly Sands/Clyne Ranch) to see if previous fires have caused persistent effects to the 2016 baseline.

**Effluent-reduction Vegetation Analysis along the Santa Cruz River**

The objective of this analysis is to detect certain changes in vegetation related to decreased discharge of treated sewage (effluent) discharged downstream of the Agua Nueva wastewater treatment facility. The effluent discharge helps to support some of the most extensive riparian vegetation and the longest and largest perennial flows of water in the permit area. Extensive upgrades to the County’s sewage treatment facilities were completed before the Section 10 permit was issued, resulting in a higher quality of effluent discharge, and changes in the ratio of discharges at the two treatment facilities.

In 2019, City of Tucson began diverting their effluent from Agua Nueva to a discharge location downtown. This discharge is not a County action and is not part of this monitoring protocol. However, any uses or diversions from the Agua Nueva or Tres Rios facilities by effluent owners have the potential to reduce effluent discharge to the Lower Santa Cruz River. Continued
discharges of effluent to the river depend on actions by various entities, principally City of Tucson and U. S. Bureau of Reclamation.

The drivers of vegetation structure and composition along the effluent-dependent Santa Cruz River are flood-related erosion and deposition, discharge of effluent, groundwater pumping and land use history (particularly mechanical disturbance) (Pima County Regional Flood Control District 2013). In the absence of disturbances such as erosion, dredging or other mechanical disturbance, floodplain sand and gravel bars become progressively more stabilized by vegetation. Such vegetation can be important for covered species such as Abert’s towhee and Bell’s vireo, though the text of the changed circumstance points to riparian forests that might eventually serve as habitat for covered species such as the cuckoo, and aquatic covered species such as Gila topminnow, which were detected and reported to USFWS in 2017.

Pima County will use information from Pima County’s Effluent Generation Report to identify and report post-2016 reductions in effluent discharge from County treatment facilities to the Santa Cruz River on an annual basis. Calendar year 2016 provides a cumulative permit issuance baseline discharge of 41,789.42 acre-feet from the treatment facilities (33,678.13 from Tres Rios, and 8111.29 from Agua Nueva).

Effluent reductions have occurred since the permit was issued. We know that the effluent discharged to the Santa Cruz River was reduced at both Agua Nueva and Tres Rios in 2017, to 39,590.10 acre-feet. For example, there were 67 dry days at Trico Road (a location downstream of both water treatment facilities) in water-year 2016 versus 109 days for water-year 2017 (the 2016 water year ended September 30). The Regional Flood Control District (Pima County 2017) identified no change in June base flow length for flow downstream of Agua Nueva, and a reduction in flow length downstream of Tres Rios. These reductions may have reduced available habitat for the Gila topminnow in the Tres Rios reach (downstream of Ina Road).

One explanation for the reduction of discharge since 2016 (the permit baseline) is that total inflows of untreated sewage diminished by about a thousand acre-feet (Pima County 2017). This explains about half of the reduced discharge. Water-efficient appliances installed by consumers and businesses are thought to be responsible for the observed long-term trend in reduced indoor consumption of water, and hence sewage production (Mayer 2017). When the decline in water consumption and sewage inflows first began, the reductions upended expectations that sewage volumes would always expand with population growth. Now the question is when this trend of diminishing inflows tied to increasing appliance efficiency will end. Other factors such as diversion of flows to constructed recharge or reclaimed water lines also reduce the discharge to the river.

Effluent discharge has decreased, and will probably continue to do so, but this does not mean a changed circumstance has occurred for vegetation according to the terms in Table 7.1 of the MSCP. If effluent discharge continues to decline, we will evaluate aerial photographic imagery against a baseline to interpret whether riparian forest loss has occurred, and whether this can be linked to reduction of effluent discharge that occurred after 2016.

Vegetation loss can result from other factors such as channel-bed clearing, removal of vegetation, increased infiltration rates, or decreases in natural runoff due to recent floods or drought. A combination of factors will be likely sources of increases or decreases in vegetative
cover classes along the Santa Cruz River. Pima County will report a changed circumstance when a decrease in area of riparian forest below the baseline is thought to be primarily driven by reduced discharges at the two County treatment facilities, rather than flood flows or other factors.

The NLCD 2016 was tested as a baseline for land cover class change from or to emergent herbaceous wetland, water and woody wetlands along the Santa Cruz River from Grant to Trico Roads. Although previous testing of 2011 and earlier NLCD datasets detected subtle changes in woody wetlands (Fonseca 2008, 2009), NLCD 2016 proved to be insensitive to many obvious reductions in water and woody wetlands based on comparison with high-resolution aerial imagery collected by Pima Association of Governments for similar time frames, at least for the time period 2011 to 2016. Thus, 2016 NLCD will not be used as a baseline to evaluate the changed circumstance.

We also evaluated the LANDFIRE Existing Vegetation Type dataset as a baseline for the effluent-dependent Santa Cruz River downstream of Agua Nueva. The North American Warm Desert Riparian Forest and Woodland class name in LANDFIRE EVT appeared to capture this type in the Cienega Creek Natural Preserve, but the vegetation classes along the effluent-dependent Santa Cruz River were classified as herbaceous or shrub, and appeared relatively insensitive to forest or woodland types. This data source was therefore rejected for a baseline.

In 2018, Pima County Regional Flood Control District and the Chesapeake Conservancy (Chesapeake) team classified imagery and LiDAR from 2015 and 2016 into a GIS layer known as LULC2018. The classification uses the following land cover classes: water, trees/shrubs, irrigated lands, desert, barren-bedrock, impervious, structures, and roads. We will use the tree/shrub class as our baseline for interpreting vegetation changes along the Santa Cruz River, and then evaluated changes based on successive PAG or other aerial imagery posted to PimaMaps. If RFCD elects to repeat their land use/land cover analysis based on Chesapeake’s algorithms (Allenby and Phelan, no date), we will report changes from that source as well, when it becomes available.

Changes in Regional Road Networks

The primary purpose of regional road network analysis is to detect changes relative to fragmentation of the Maevan Marie Behan Conservation Lands System by major roads, and to consider the trajectory of potential urban growth during the decennial review. This protocol will not be used to determine changed circumstances relating to grading of roads inside Preserves. The latter will be addressed at a more granular level through biennial inspections, threats monitoring and ongoing ranch road inventories and reported at a gross level through the NLCD analyses.

Changes in the regional road network will be identified for Pima County every three to five years (Table 5). The 2021 analysis will use 2016 as a baseline. Figure 4 presents the baseline road network for 2016. The baseline road network consists of data layers maintained by Pima County, supplemented with information from other sources. At present, our baseline will use the layers Street Network (stnetall) and Street Miscellaneous (stmisc). Street Network is maintained daily; Street Miscellaneous is maintained whenever there is a change or addition to unnamed streets in Pima County.
### Table 5. Road Network Analyses for Pima County MSCP

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incursion of new roads into the Maeveen Marie Behan Conservation Lands System, relative to unincorporated and incorporated areas</td>
<td>The CLS guidelines are intended to minimize post-permit incursions into the CLS, but land-use authority of Pima County applies mainly in unincorporated Pima County</td>
</tr>
<tr>
<td>Location of post-permit CIP road projects relative to the Maeveen Marie Behan Conservation Lands System</td>
<td>The permit authorizes road work undertaken by Pima County in areas outside its land-use authority</td>
</tr>
<tr>
<td>Paving of unpaved roads since permit baseline, intersected with County Preserves and MSCP Restricted Covenants</td>
<td>The permit authorizes road paving by Pima County, but MSCP RCs forbid it except in limited circumstances.</td>
</tr>
</tbody>
</table>

To support the decennial review, analyses of core NPScape metrics (NPS 2013) such as road density, distance from roads, and roadless areas will also be considered by Pima County at its discretion, and with input from the STAT.

![Figure 4. The 2016 baseline for the road network in Pima County, Arizona is comprised of two different GIS layers (stnetall and stmisc).](image)

**Figure 4.** The 2016 baseline for the road network in Pima County, Arizona is comprised of two different GIS layers (stnetall and stmisc).

**Changes in Sewer Networks**

The primary purpose of sewer network analysis is to detect changes relative to intensification of land use in the Maeveen Marie Behan Conservation Lands System (CLS) during the decennial review. Sewered areas support much higher density development than do unsewered areas. To the extent that the County Board of Supervisors keeps the sewer system out of the CLS via exercise of its discretion during land-use planning authorities, the fragmentation of the reserve design will be minimized. Thus, the results will be useful for both retrospective as well as prospective views of land-use change in relation to Pima County’s strategic investments in important urban infrastructure.
**Retrospective analyses**
Pima County IT maintains the [sanitary sewer network](#) (wwm_sn) on a daily basis at a scale of 1:200. A copy of the 2016 sanitary sewer network ([ssn_cl](#)) has been created and archived. This is represented in Figure 5, relative to the CLS. Figure 6 shows development of the sewer network over time. The sewer baseline does not include systems owned by other entities such as Marana or those operated by private entities (Robert Shay, RWRD personal communication, Dec 2018). Incursions of the CLS by these authorities are beyond discretion of the Board. Abandoned portions of the sewer system are also not included in the baseline.

The baseline shapefile [ssn_cl](#) will be intersected with the current County sewer network every three to five years, and any post-permit incursions into the Maeveen Marie Behan Conservation Lands System will be reported retrospectively.

**Prospective analyses**
For the prospective analysis, the current [Pima County RWRD Service Area](#) (GIS layer [sewr_bnd](#)) will be intersected with the CLS. This shapefile is not maintained every year, as it changes slowly. The scale is also coarser, 1:24,000. Post-permit incursions of the RWRD Service Area into the CLS will be reported for decennial analyses. Changes in County sewer service area will also be compared at five-year intervals in between the decennial reviews.
Figure 5. Area enclosed by the purple line (sewr_bnd) represents the sewer service area baseline in 2016 (ssn_cl). Red lines show the sewers within the service area as of 2016. Principal incursions in the CLS (light and dark green) are in the Corona De Tucson area, and the Tortolita piedmont.
Figure 6. Sewer development prior to issuance of the Section 10 permit, 1900-2015 (map from Pima County 2016).
Future Development

The purpose of forecasting the location and extent of future development is to understand how future development may affect land cover that may support the habitat of covered species. This look at the direction of change will help inform the decennial reviews, including outside peer review.

Pima County will either use 1) population density projections and transportation plans provided by Pima Association of Governments (PAG) or 2) an updated land use model to measure and forecast development-related activities for the decennial analyses. Pima County’s Comprehensive Land Use Plan growth areas will also be depicted relative to the CLS and analyzed relative to species PCAs. Other supplemental analyses will be at Pima County’s discretion.

The baseline for population density distribution is provided by the 2045 PAG Regional Mobility and Accessibility Plan (RMAP). The RMAP was adopted by the regional governments on May 26, 2016. Existing and projected population densities for 2045 are shown below (Figure 7). For the most part, future patterns of growth are similar with a significant increase in density in the urban core, and large increases in population density near Houghton Road projected in the City of Tucson’s Houghton Area and Esmond Station Plans. PAG is planning to complete the next update of the RMAP by 2020, and again in 2024 per federal regulations.

The update cycle begins with state population projections. The Arizona Department of Administration has recently updated population estimates for each county through 2055. The state projects a population of 1.28 million by 2055 for Pima County. This is a significant decrease of 250,000 from the future population projection used to develop PAG’s 2045 RMAP. PAG’s Population Technical Subcommittee is evaluating how population growth may be distributed across the county’s landscape using updated information about land use, employment and demographics. PAG’s modeling group will develop a revised scenario of changes in land use and regional development patterns to inform recommendations for addressing future transportation needs.

In developing the currently adopted 2045 RMAP, PAG considered three different future land use scenarios arranged along a continuum from lowest to highest density. Each of the scenarios considered the same number of future jobs and population, but evaluated different patterns of their distribution. New land developed varied from 98 to 315 square miles. The official growth scenario chosen is based on the general and comprehensive plans of each jurisdiction in Pima County adopted as of 2013. Under this scenario, an additional 234 square miles would come under development, including some portions of biological core management area lands (CLS land category with high biological value) south of the Interstate 10 along the axis of Houghton and Sahuarita Roads (Figure 9; lower right portion).
The 2020 effort will be an update to the 2016 RMAP and will not undergo the extensive scenario modeling that PAG conducted as part of the 2016 adopted RMAP. The official growth scenario that we will use for this update will again reflect the adopted general and comprehensive plans of each jurisdiction in Pima County current as of 2017.

As part of the project selection and analysis phase of the 2016 RMAP, PAG mapped the list of preferred projects to be included and superimposed the project map over the regional biological resources identified in the Sonoran Desert Conservation Plan (see Figure 8 below). Of particular concern is the Sonoran Corridor State Route 410 through Pima Pineapple Cactus habitat, since most of the route is new, but it has the advantage of being located entirely out of the CLS. The other plans that affect CLS are for improvements to existing roadways in the CLS, in particular the Sandario Road through the Tucson Mitigation Corridor, and the roadways in the Rocking K Valley.
Figure 8. Location of projects relative to Maeveen Marie Behan Conservation Lands System categories (categories combined; gray-green color) and wildlife corridors (yellow checks). Map by PAG.
In addition, the proposed Interstate 11 has the potential to affect human population distribution, and alter wildlife connectivity. A Tier 1 Environmental Impact Statement (EIS) released early in 2019 recommends an alignment to bypass long-haul truck traffic around Tucson, but doing so could greatly affect the trajectory of future development along its path. The proposed alignment runs through State trust land west from Interstate 10 along the south boundary of the San Xavier District and north more or less along the Sandario Road parkway alignment shown on the RMAP figure. It cuts through the Tucson Mitigation Corridor, which was secured as mitigation for the wildlife connectivity impacts caused by the Central Arizona Project for Saguaro National Park and Tucson Mountain Park. An alternative alignment runs along the existing Interstate Highway 10, and this would not affect regional wildlife connectivity.

Figure 8 also reflects a general location for the future Sonoran Corridor that is consistent with the Congressional designation of the Sonoran Corridor as a High Priority Corridor on the National Highway System. No specific alignment was selected as part of the RMAP process so as not to bias the outcome of the current Tier 1 Environmental Impact Statement (EIS) process being conducted by ADOT. The study, which should conclude in 2020 will identify a single Preferred Alternative Corridor that is expected to be 2000 feet in width. The future roadway alignment would then be located within that 2000 feet as determined by additional studies and design work, either as a whole or in separate projects. More information on the Tier 1 EIS can be found on ADOT’s website [https://www.azdot.gov/planning/transportation-studies/sonoran-corridor-tier-1-environmental-impact-statement/overview](https://www.azdot.gov/planning/transportation-studies/sonoran-corridor-tier-1-environmental-impact-statement/overview).

Every ten years or so, Pima County is required to complete a revision of its Comprehensive Land Use Plan per state statute. As part of this plan, the County must identify to the state areas that it wishes to target for growth or re-development. Pima Prospers, which was completed in 2015, is the baseline for the Section 10 permit, but was not included in the 2016 RMAP. Figure 9 summarizes the areas where Pima County is focusing investments in infrastructure that are intended to foster growth or re-development. All areas are outside the CLS except for a portion of biological core and certain Important Riparian Areas southwest of Tucson. Avoidance and minimization of IRAs is accomplished through the Floodplain and Erosion Hazard Management Ordinance and the Floodprone Acquisition Program. Pima County also purchased and restricted some parts of the biological core management unit lands from development.
Figure 9. Growth areas (red) identified in Pima County’s Comprehensive Land Use Plan relative to the Maeveen Marie Behan Conservation Lands System categories and incorporated boundaries.
Literature Cited


