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A retrospective analysis of program outcomes and lessons learned on implementing first-time wastewater infrastructure in underserved communities in Texas from 1995 through 2017

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ABSTRACT

In Texas, informal settlements called colonias formed from the 1950s to the 1980s without the most basic municipal infrastructure. Federal and Texas agencies authorized about $1 billion for first-time water and wastewater services for about 300,000 residents from 1995 through 2017. The research uses a mix-method approach to assesses at a high level the distribution of funds and outcomes achieved across 31 counties adjacent to the Texas-Mexico border, identifies where needs continue, examines population growth, and compiles programmatic and technical lessons learned. The results show wastewater coverage increased from less than 20% of the colonia population to over 75%. Funds were generally distributed equitably amongst the counties and expected outcomes were achieved. Grant funding was an incentive for cities with more institutional capacity and operational efficiencies to extend service to colonias and provide regional solutions outside city limits. Despite the progress, the most considerable need remains in smaller and more isolated colonias, where overcoming the barriers to service will be costly. Important lessons were learned, such as adopting laws to prevent further proliferation of colonias, the inclusion of household connections within the project ensured customers connected quickly, and regular coordination amongst funding agencies avoided duplication. Unintended consequences included oversized facilities as population growth did not occur as expected. Replacing what is now aging infrastructure requires a strategy and could include a low-cost loan program. Finally, onsite systems are a potential solution for overcoming barriers to service for those isolated colonias.

1. Introduction

Over half the world's population, 4.2 billion, lacks access to adequate sanitation, which is estimated to cause 432,000 diarrheal deaths annually, as well as other diseases (United Nations, 2019). In recognition of this need, its burden on vulnerable communities, and respect for the health and social dignity of families, in 2015 the United Nations included access to sanitation for all by 2030 as part of its agenda for sustainable development (WWAP (United Nations World Water Assessment Programme), 2015 https://sustainabledevelopment.un.org/content/documents/1711Water%20for%20a%20Sustainable%20World.pdf. It is estimated that five years of annual contributions of $53 billion would be sufficient to achieve universal coverage. Unfortunately, this goal is likely not to be met. Funding may be a factor, but other challenges hindering progress are inadequate program design and lack of institutional capacity to implement regional policies related to wastewater infrastructure. Therefore, this paper discusses a retrospective analysis of program outcomes from 1995 through 2017 at the federal and state level to address a similar regional environmental challenge experienced in Texas along the United States-Mexico border. The research includes the application of spatial analysis to evaluate results achieved and the findings include lessons learned from this case study. Both the evaluation tools and lessons learned can be useful for counties and international funding agencies working towards addressing the current environmental challenge of increasing access to sanitation infrastructure.

From the 1950s through the 1980s, in Texas, informal settlements were formed called colonias which in Spanish means neighborhood. These residential areas along the border with the United States (U.S.) and Mexico had about 300,000 residents, most of whom lacked the most basic municipal services (Texas Water Development Board, 1987). About a quarter of the population lacked water and virtually all the colonia residents lacked wastewater collection and treatment. (Olmstead, 2003; Carter and Ortolano, 2004). Texas and federal agencies invested on the order of $1 billion in funding since the mid-1990s through 2017 in water, sewer, and wastewater treatment in the colonias (Texas Water Development Board, 2019; United States Gov-

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ernment Accountability Office, 2017). By 2014, estimates showed that approximately 90% of colonia residents now have water and wastewater (Texas Office of the Secretary of State, 2014).

All levels of government executed a significant effort and achieved building substantial infrastructure over about 25 years. This research seeks to evaluate these infrastructure investment programs based on progress, issues identified by the applicants and program officers, and infrastructure needs. The questions include: (1) How were funds distributed across 31 counties based on need? (2) Were the expected program outcomes achieved? (3) Does there continue to be a need for service? (4) Did the infrastructure promote growth in the colonias? (5) What were the lessons learned from the programs? Since most of the need was in wastewater, the analysis will only focus on wastewater infrastructure. Wastewater projects implemented typically included water infrastructure within the scope where there was none (Texas Water Development Board, 2020). There was no purpose in installing sewer lines if the residents did not have water.

1.1. Background on colonias

In the U.S., urban growth is dominated by sprawl, where a region's population footprint expands outward towards vacant land constrained by competition with agriculture (Giner et al., 2019). Urban sprawl typically consists of suburban middle-class subdivisions that provide communities the opportunity to develop their land-use regulations and a form of local representation, either through homeowners associations and water or school boards (O'Sullivan, 2007). These areas offer residential living close enough to a city to access its amenities while providing newer and larger homes and better-maintained infrastructure.

Along the Texas-Mexico border, colonias represent a different form of urban sprawl, informal settlements without infrastructure. The state defines colonias as "*economically distressed area that often lacks the most basic necessities, such as drinkable water, sewer systems, paved roads, and safe, sanitary housing*" (Texas Commission on Environmental Quality, 2010). In the 1950s, colonias just outside of the city limits provided an opportunity for poor or working-class families to acquire land and housing at affordable prices with little or no down payment, yet still be close to sources of employment (Federal Reserve Bank of Dallas, 1996; Durst, 2017). They are densely populated, legal developments, and typically unincorporated (Federal Reserve Bank of Dallas, 1996; Carter and Ortolano, 2004). Before 2000, many Texas counties lacked appropriate regulation or adequate enforcement to avoid the formation of colonias.

Families of predominantly Hispanic origin would self-build incrementally without basic services (Durst, 2017). Thus many colonia residents had open disposal of untreated wastewater and regular consumption of contaminated water (Soden, 2006). Those residents that lacked access to municipal service depended on either hauled water or shallow wells, typically contaminated with fecal coliform from latrines on the same property (Carter and Ortolano, 2004). There was limited if any disinfection at the wells. Barrels used for hauled water storage were also exposed to contamination. Almost all residents did not have access to sanitation. Residents discharged wastewater into backyards or unpaved roads or relied on latrines or malfunctioning septic tanks (Olmstead, 2003; Carter and Ortolano, 2004).

Living conditions were challenging in the colonias. Without infrastructure, it was difficult for local businesses or any significant source of industry to offer local employment opportunities or become established (Hargrove and Del Rio, 2017). In addition, unemployment ranged between 20 and 60% as compared to the Texas average of 7% (Federal Reserve Bank of Dallas, 1996). Furthermore, residents might travel long distances for clean water, as there were no convenience stores nearby (Hargrove and Del Rio, 2017).

In the 1980s, these communities did not have established local representation, such as utility boards or homeowner associations to develop or manage infrastructure. As a result, two issues existed: a lack of legal jurisdiction and enforcement. Counties in Texas do not have the authority for land use planning. Prior to 1989, counties could not require subdivision rules to prevent land developers from subdividing land and selling lots without infrastructure (Carter and Ortolano, 2004). The absence of city enforcement of land use planning or building codes in colonias located in extraterritorial jurisdictions or by counties in unincorporated areas for construction of residential septic tanks further exacerbated non-compliant growth. The absence of enforcement was compounded by insufficient political clout stemming from geographic remoteness, isolation from state agencies, and lower socioeconomic status (Ward, 1999; Soden, 2006).

During the 1980s, non-governmental organizations (NGOs) and the media published the threat to the health of over 300,000 people in Texas caused by unsanitary conditions (Carter and Ortolano, 2004). Organizations such as the El Paso Inter-Religious Organization and Valley Interfaith advocated action to bring municipal infrastructure to the colonias. In response, the State of Texas began to identify the number and location of the colonias to quantify the need. From 1987 to 2005, the Texas legislature passed at every session legislation to address funding needs, modify land development laws to prevent further proliferation of colonias, and create a system to manage response (Rapier, 2009). Also, in a 1992 survey, Texas Water Development Board (TWDB) quantified the need for water and wastewater infrastructure as $700 million, of which almost 70% was for sewer and wastewater treatment (Texas Water Development Board, 2003). This study served as the basis for funding.

Although unincorporated poor and working-class communities exist across the United States, Texas colonias are the most studied region, probably because of the large number of densely populated and impoverished rural communities (Durst, 2017). Based on the 2010 census, colonias constitute 1.2% of the Texas population. The 31 counties near the Texas-Mexico border represent 10.5% of the population and where over 320,000 people reside in about 2000 colonias (Texas Office of the Attorney General, 2019). Most rural counties have small colonia populations of less than 5000. High colonia concentrations exist in the eight counties of Cameron, El Paso, Hidalgo, Maverick, Starr, San Patricio, Webb, and Zapata (see Fig. 1). Within the 31 counties, these eight counties contain almost 85% of the colonia population. Also, all 31 counties are below the Texas 2015 median household income (MHI) (Texas Demographic Center at University of Texas San Antonio, 2020). Twenty-seven counties fell below 20% of the Texas MHI, which likely means the colonias are even more impoverished. Therefore, substantial subsidies are required for capital investment to build infrastructure.

2. Materials and methods

This research used a mixed-method approach to collect data from relevant agencies to assess the outcome of Texas colonia investments in wastewater systems. The author conducted over 100 interviews and completed two geographically weighted regressions (GWR) on the distribution of funds and expected outcomes. The study period was for colonia residents receiving first-time wastewater service between 1995 through 2017, which is when most programs began to yield results.

The use of geographically weighted regressions can study the potential for relationships in a regression model for extended geographic areas with variability like the Texas-Mexico border (Matthews and Yang, 2012; Wheeler and Páez, 2010). There was no literature found by the authors on the relationship between infrastructure funding, expected outcomes, and baseline needs. This approach is novel and could be used by agencies to evaluate the equitable distribution of funds and associated results.

2.1. Data from relevant agencies

The first three questions related to the distribution of funds based on 1995 need, program outcomes, and continued 2017 need require data on where first-time wastewater service is provided and funding. The appropriate metric can be defined as the ratio of colonia population with

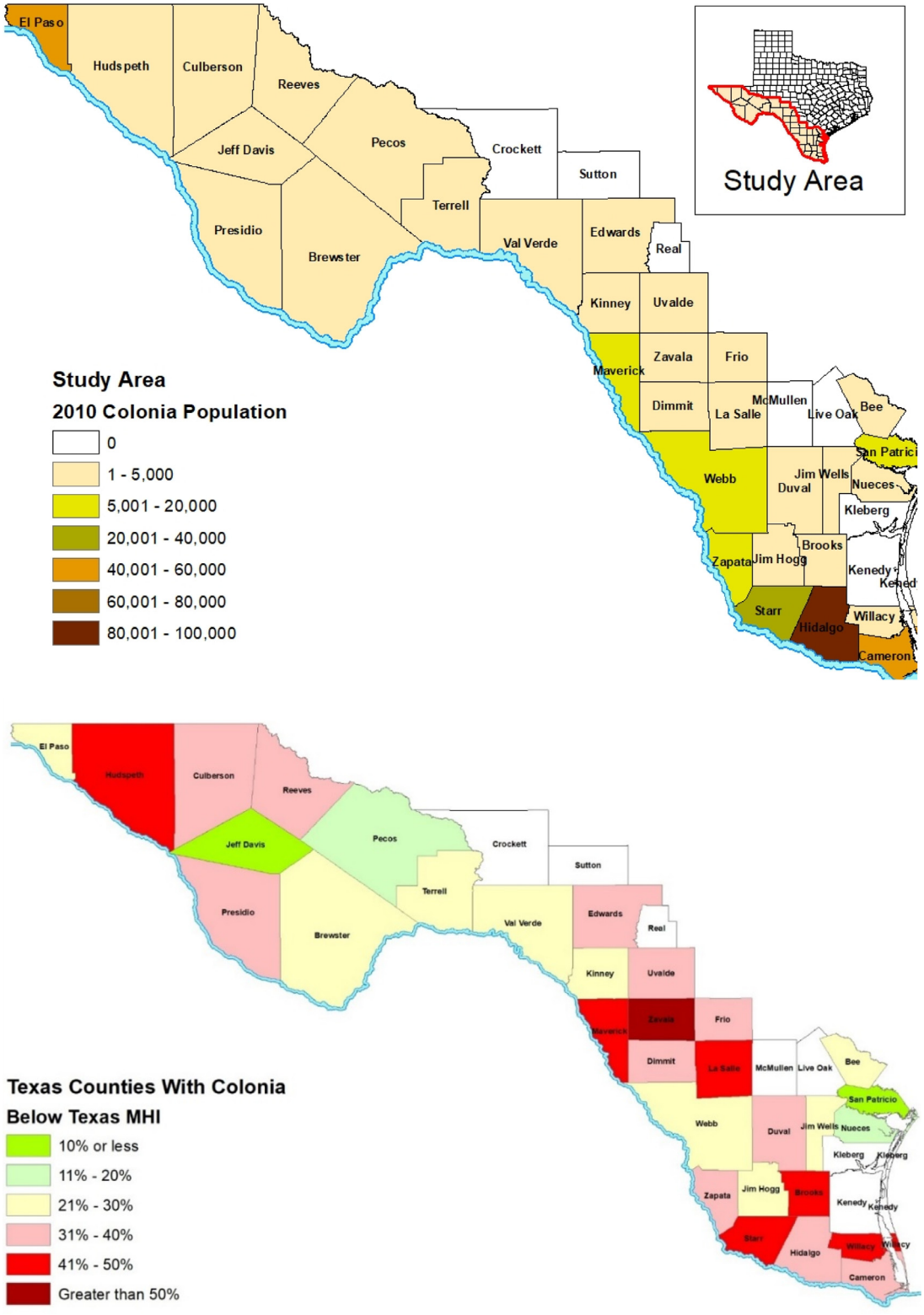

Fig. 1. 2010 colonia population and comparison of 2015 median household income for counties near the Texas-Mexico border. Map in color. Source: (Texas Office of the Attorney General 2019; Texas Demographic Center at University of Texas San Antonio, 2020).

service, also known as wastewater coverage. Wastewater coverage for a county or its colonias population is not available in any report or public sources and is not tracked by Texas or any regulating body. Population data for 2000 and 2010 for each colonia within the study area were available for Texas (Texas Office of the Attorney General, 2019, 2021). The data obtained to calculate wastewater coverage in the colonia population was from publicly available information and interviews with each water utility described in 2.3. Also, the U.S. Department of Agriculture (USDA) funded a needs assessment for some counties within the study area ((Communities Unlimited, and Rural Community Assis-

tance Corporation 2015) and was a valuable tool for cross-referencing some information. The author calculated wastewater coverage for each of the 31 counties for 1995 and 2017 using the following formula:

$$Wastewater\ Coverage = \frac{\text{Colonia Population in County with Service}}{\text{Total Colonia Population in County}} \quad (1)$$

With this information, the author calculated need, or population without wastewater service, for each county using the following formula:

$$Need = Total\ Colonia\ Population\ in\ County - (Total\ Colonia\ Population\ in\ County \times Wastewater\ Coverage) \quad (2)$$

Another metric needed is the distribution of funding amongst the 31 counties for completed wastewater projects. Information on funds allocated by county can be used to evaluate if the counties with a larger unserved population in 1995 received more funding versus counties with fewer unserved. The author aggregated the funds allocated to projects for each county from publicly available reports and data requested through FOIA from the primary funding agencies for 1992 through 2017.[1]

In the 1990s, analysts expected rapid growth in the whole border region, including colonias (Schoolmaster, 1993; Soden, 2006; Parcher and Humberson, 2009). Therefore, a fourth question was added related to growth. Did the colonias grow as expected? The study collected data to analyze the colonia population. Georeferenced shapefiles with boundaries and 2000 and 2010 populations are available for all colonias (Texas Office of the Attorney General, 2019, 2021). Census block data for 2020 was unavailable in July 2021; information at the census block group level for 2019 was used (U.S. Census Bureau American Community Survey Data, 2021). The author used ESRI's ArcGIS GeoErichment method for data apportionment for each colonia and aggregated it to the county level for 2019 (ArcGIS Developers, 2021).[2] The author compared the colonia population aggregated to the county level for 2000, 2010, and 2019 to measure the change.

2.2. Quantitative analysis

The author completed an empirical analysis using the data described in 2.1 to evaluate investment distribution and outcomes achieved amongst the 31 counties. First, for question 1, a simple linear regression estimates the relationship between funding disbursed for projects completed between 1995 through 2017 and the 1995 colonia population without wastewater service (Eq. (3)). Since agencies provide funding on a first-come, first-serve basis and are dependent on utilities of varying size and institutional capacity to submit applications, there is no basis for hypothesizing if those counties with more need in 1995 received increased funding.

$$Y_I = \beta_0 + \beta_1 TRT_c + \in_c \quad (3)$$

$Y_I - Investment\ in\ first-time\ wastwater\ service\ for\ County\ c$ (dependent variable)
$TRT_c - Colonia\ population\ without\ wastewater\ service\ for\ County\ c\ in\ 1995 \beta_1 - Coefficient\ of\ expected\ investment\ per\ unit\ of\ population\ without\ WW\ service$
$\beta_0 - Investment\ at\ zero\ population\ without\ wastewater\ service$
$\in_c$ - Error term

A second multivariate regression for question 2 assesses outcomes achieved (Eq. (4)). It builds on the previous question and estimates the relationship between the 2018 colonia population without wastewater service as a function of investment and need. The independent variables are the investment in infrastructure for completed projects between 1995 through 2017 and the population without wastewater service in 1995. The second variable was added in recognition that the smaller the need, the more ease it can be addressed from a financial and technical perspective. For example, a county with a population without service of more than 80,000 has more difficulties addressing the need than a county with an unserved population of 5000. Like the previous equation, there is no basis for hypothesizing if those counties with more funding and 1995 need had less population in 2018 without wastewater service.

The research used the following model:

$$Y_c = \beta_0 + \beta_1 TRT_c + \beta_2 X_c + \in_c \quad (4)$$

Y_c - $colonia\ population\ without\ wastewater\ service\ for\ County\ c\ in$ 2018
$TRT_c - Investment\ in\ WW\ for\ County\ c$ (dependent variable)
$X_c - colonia\ population\ without\ wastewater\ service\ for\ County\ c\ in$ 1995
$\beta_1 - Coefficient\ of\ expected\ population\ without\ WW\ service\ in$ 2018 $per\ unit\ of\ investment$
$\beta_2 - Coefficient\ of\ expected\ population\ withouth\ WW\ service\ in$ 2018 $per\ unit\ of\ need\ in$ 1995.
$\beta_0 - Population\ without\ wastewater\ service\ with$ zero investment
$\in_c$ - Error term

The funding process and project timing are uncorrelated with the variables considered in the two GWR proposed. Agencies approve funding for project sponsors chiefly on a first-come, first-serve basis. They depend on cities and utilities to submit applications with information that has sufficient development of a project to have cost confidence before funds are approved. Many steps before submission of application need to be completed by the project sponsor, such as: adopting model subdivision rules at the county level; developing eligibility, financial, planning, environmental, and legal documentation; creating a new utility or intergovernmental agreement for receiving service from an existing utility; and engaging stakeholder, among others. Completing these requirements could exceed eight years (Carter and Ortolano, 2004). After funding is approved, the final design, procurement, and construction can be several years more. Also, the capacity of the grant recipients, project size, and county colonia population vary significantly. Finally, the study area is 31 counties, spans over 1000 miles with a varying number of colonias and utilities in each county, and project sponsors with varying institutional capacity ranging from large cities to small water supply corporations.

2.3. Interviews

The author conducted over 100 interviews with utilities in all 31 counties and program managers for USDA, TWDB, and North American Development Bank (NADB) to verify collected data and receive input on lessons learned. Interviews with utilities that received grants confirmed the years funding was received, wastewater projects completed, project costs, colonias served, new household connections, and colonias that continue without service. Also, interviews with utilities that did not receive funding were helpful to identify the colonias with and without service and the year service initiated.

To address question 5 of lessons learned, semi-structured open-ended interviews with utilities covered infrastructure program implementation challenges and lessons learned; colonias served, existing needs, and barriers to service; and observed changes from baseline conditions prior to service such as infill, commercial development. In addition, time was allowed for the interviewee to add any other relevant information. Over a dozen interviews were conducted with six program managers who worked in the funding agencies for over 15 years. The topics covered

[1] Program funding for wastewater projects were allocated by agencies starting in 1992 for those completed by 1995 through 2017.

[2] ArcGIS Pro can enrich polygons with demographic information based on overlays on census geometries and a weighted apportionment. More information one ESRI's ArcGIS GeoEnrichment tool can be found at Data apportionment—ArcGIS REST API | ArcGIS for Developers.

with the agencies interviewed included a program review, process to allocate and disburse funds, agencies' role, institutional capacity of the utilities, barriers associated with continued need, and lessons learned.

3. Results and discussion

The research examines at a high level the distribution of funds, outcomes achieved, where needs continue, population growth, and programmatic and technical lessons learned. The evaluation tools and lessons learned can be helpful for policymakers to evaluate results and create programs that address access to sanitation infrastructure. The results are summarized below.

3.1. Overview of funding

In 1995, it was estimated that about 250,000 people lived in colonias, and approximately 20% had wastewater services. Wastewater coverage varied amongst the 31 counties examined, but only eight counties exceeded 70% of the population with service. The primary funding agencies reported investments of about $626 million for 119 sewer and wastewater treatment projects for first-time wastewater service in the colonias (North American Development Bank, 2020; Texas Department of Agriculture, 2020; Texas Water Development Board, 2020; U.S. Department of Agriculture, 2020). Funding was approved for 28 counties primarily from TWDB, followed by USDA, NADB, and Texas Department of Agriculture (TDA). TWDB provided almost 80%, $480 million, of the total funding for 49 grant recipients in 17 counties. USDA granted over $109 million or almost 15% of the funding for 32 grant recipients in 18 counties. By 2018, approximately 77% of the colonia residents received first-time wastewater service.

The largest tranche of funding was in the early years of the various programs (see Fig. 2). By 2003, the funding agencies approved 85% of the total funding for the study period.[3] After, agencies approved less than $5 million annually in funding. Wastewater coverage grew later as projects were built and residents contracted service with their respective utility for connections.

By 2011 wastewater coverage increases had peaked by then 70% of the colonia population now had service. New wastewater connections each year peaked in 2001 and 2005 and began to taper off by 2011. By the start of 2018, almost 77% of colonia residents had wastewater service. In 15 years, wastewater coverage grew by 50%. In contrast, after 2011, wastewater coverage grew by 7% due to the reduced funding after 2003. Based on agency interviews, federal fund annual appropriations began to decrease around 2004 due to a backlog of projects. The original pool of funds appropriated had been exhausted, was assigned to projects, yet not disbursed due to pending issues in the development phase. As this backlog of projects were completed and a reduced amount of federal funding was received, the decrease in new household connections became evident in the program's later years.

Funding agencies estimate that grants exceed 80% of the project cost and are necessary to make the service affordable. Many utilities could not afford the debt for the capital investment and could not proceed with projects without grants. However, over the years, funding agencies' programs require increasing loans. For example, the USDA program initially funded each project with a 100% grant and then decreased in later years to 75%. TWDB's Economically Distressed Areas Program (EDAP) required that the funding leverage 10% of the loan amount. This requirement was recently increased to 25%.

[3] Approved is defined as when a grant agreement has been signed by the utility and funding agency. For TWDB this called close and is after facility planning is done and environmental clearances complete. USDA defines this as appropriated and occurs after final design is complete.

3.2. Did the funding go to the greatest need?

In 1995, the counties with the largest unserved colonia populations were Hidalgo and El Paso, followed by Cameron, then Maverick and Starr, and finally San Patricio (see Fig. 3). They also generally had the largest county populations in the study area. These six counties are close to 76% of the colonia population reside and contain 85% of the 1995 need. All these counties are located along the border except for San Patricio. Ranking these counties by need, the funding was distributed amongst them in the rank order of 1995 need.

The author applied Eq. (3) in ArcGIS's GWR tool with the data collected for 1995 need and cumulative wastewater funding received by each county. The regression predicts funding for each county based on its 1995 colonia population without wastewater service relative to the 31 counties. The residual indicates how much under or over the predicted funding was received by each county. Fig. 3 illustrates the standardized residuals mapped by county. The greener, the more funding received than expected by the county, and the redder the less funding received than expected.

Twenty-one of the 31 counties received the predicted amount of funding. However, except for San Patricio, all 21 counties had colonia populations of less than 4000 residents without wastewater in 1995. At that time San Patricio had an unserved colonia population of 9600. In contrast, Hidalgo is the county with the largest 1995 colonia population without wastewater, about 85,000, and received less funding than expected. Uvalde, Pecos, Nueces, and Brooks also were slightly underfunded. This is unremarkable as both Uvalde and Pecos received very little funding compared to its need. Although Maverick, El Paso, and Webb received above the predicted amount, Cameron received significantly more than expected.[4] Table 1 highlights those counties that received much more or far less than the predicted amount of funding.

3.3. Where the expected outcomes achieved in wastewater service?

The author applied Eq. (4) in ArcGIS's GWR tool with the data collected for 2017 wastewater coverage, cumulative wastewater funding received by each county, and 1995 wastewater coverage. The regression predicts the 2018 colonia population without wastewater service for each county based on the cumulative investment and the population in 1995 without wastewater service. The residual indicates how much is under or over the predicted 2018 population without service for each county. Fig. 4 illustrates the standardized residuals mapped by county. The bluer, the fewer 2018 colonia residents without service than expected. The redder, the more residents without service than expected.

Twenty-two of the 31 counties achieved the expected outcomes of reducing its unserved colonia population by 2018 based on the funding received and its need in 1995. In the previous analysis, Maverick County received more funds than predicted compared to the other counties yet reduced its unserved population by more than expected. This county achieved one of the most significant increases in wastewater coverage, from 0 to 96%, and with almost $60 million provided first-time service to almost 19,000 colonia residents. Also, in the previous analysis, Hidalgo County received fewer funds than predicted compared to the other counties yet reduced its unserved population in wastewater coverage as expected. Hidalgo received $182 million in investment, provided 70,000 colonia residents with first-time service, and increased wastewater coverage from 3 to 73%. In contrast, El Paso and Cameron counties received more funds than expected, yet their outcomes were less than

[4] Webb county's funding may have exceeded expected funding since one project of approximately $7.0M was for the rehabilitation of an existing wastewater treatment plant for two large colonias that had sewer but inadequate wastewater treatment. No new connections were provided with this service. However, the project was eligible for EDAP funding and therefore was included as part of the funding received by Webb.

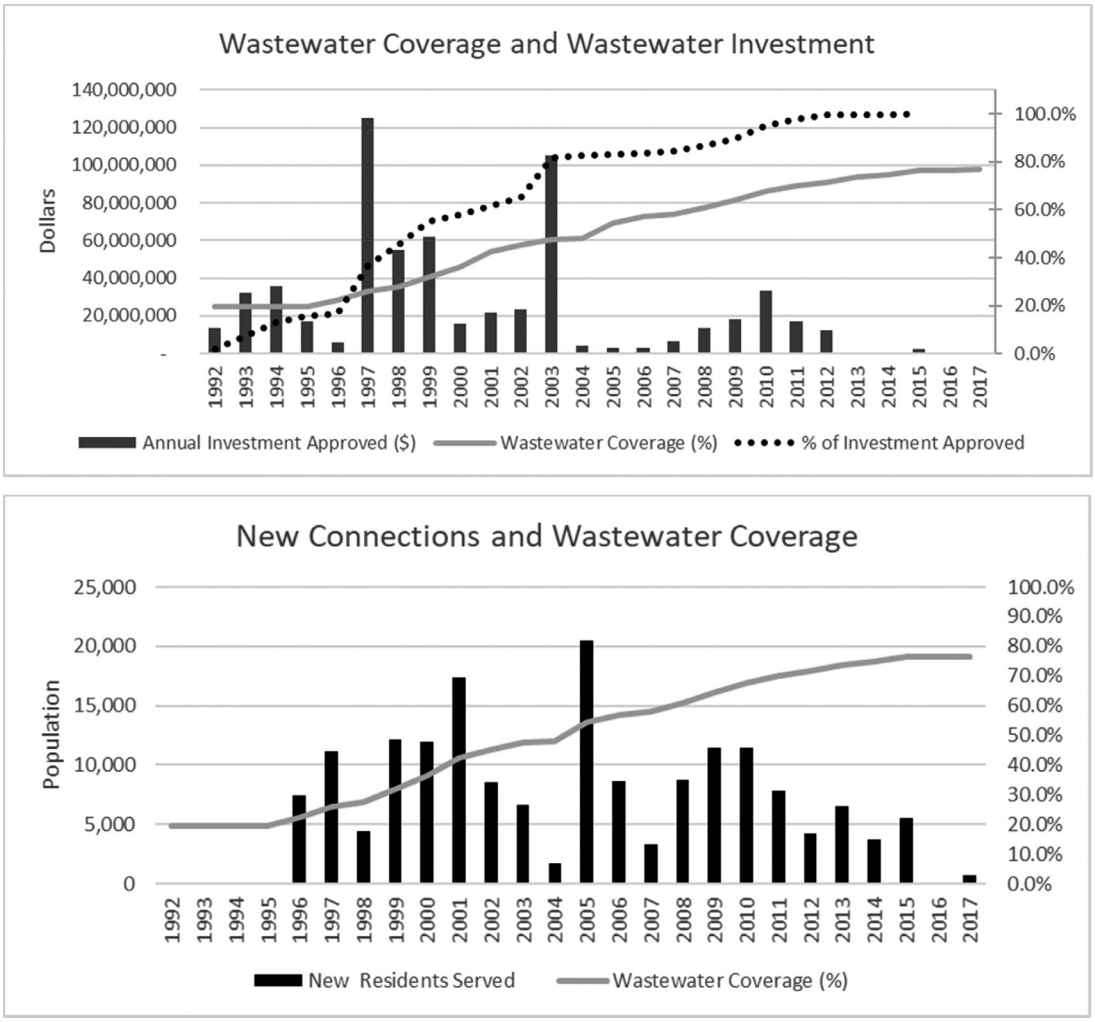

Fig. 2. Wastewater coverage, investment, and new household connections.

Table 1
Investment versus predicted investment based on 1995 need.[6]

County	Investment (Millions)	Estimated 1995 Population No Wastewater	Predicted Investment (Millions)	Standardized Residual
Hidalgo	181.7	84,980	199.2	−3.395153
Uvalde	1.0	2898	10.1	−0.953905
Nueces	0	2229	8.6	−0.89771
Brooks	0	1354	6.5	−0.686503
Pecos	1.04	1246	6.3	−0.550535
El Paso	117.1	46,153	109.8	0.841302
Starr	42.7	12,843	33	1.021624
Maverick	59.94	19,064	47.3	1.33084
Webb	29.9	3783	12.1	1.859177
Cameron	92.7	22,340	54.9	4.014118

expected. El Paso received $117 million, provided 35,000 colonia residents with first-time service, and increased wastewater coverage from 9 to 69%. Cameron received $93 million, provided 19,000 colonia residents with first-time service, and increased wastewater coverage from 33 to 80%.

Table 2 highlights the nine counties with the most significant outcomes based on agency investment and 1995 need. By 2018, these nine counties received 87% of the funding, had 88% of the 1995 unserved colonia population, and achieved 92% of first-time wastewater service outcomes. It is worth noting that funding and wastewater infrastructure do not correspond only to the colonia population but may provide service to other residents.

The EDAP supports economically distressed areas, including neighborhoods not designated as colonias but is below the required income threshold. Therefore, this analysis does not imply any comparative assessment of fund efficiency, as others may have received the benefit. Many reasons can affect costs, such as density of colonias, distance between colonias and from major cities, types of soils, and size of population served. Also, funding is approved based on applications received, which is out of the control of the funding agencies. If utilities chose not to apply for funding, there was little the agencies could do aside from educating them on their opportunities through outreach. Funding agencies were active in communities in disseminating program information.

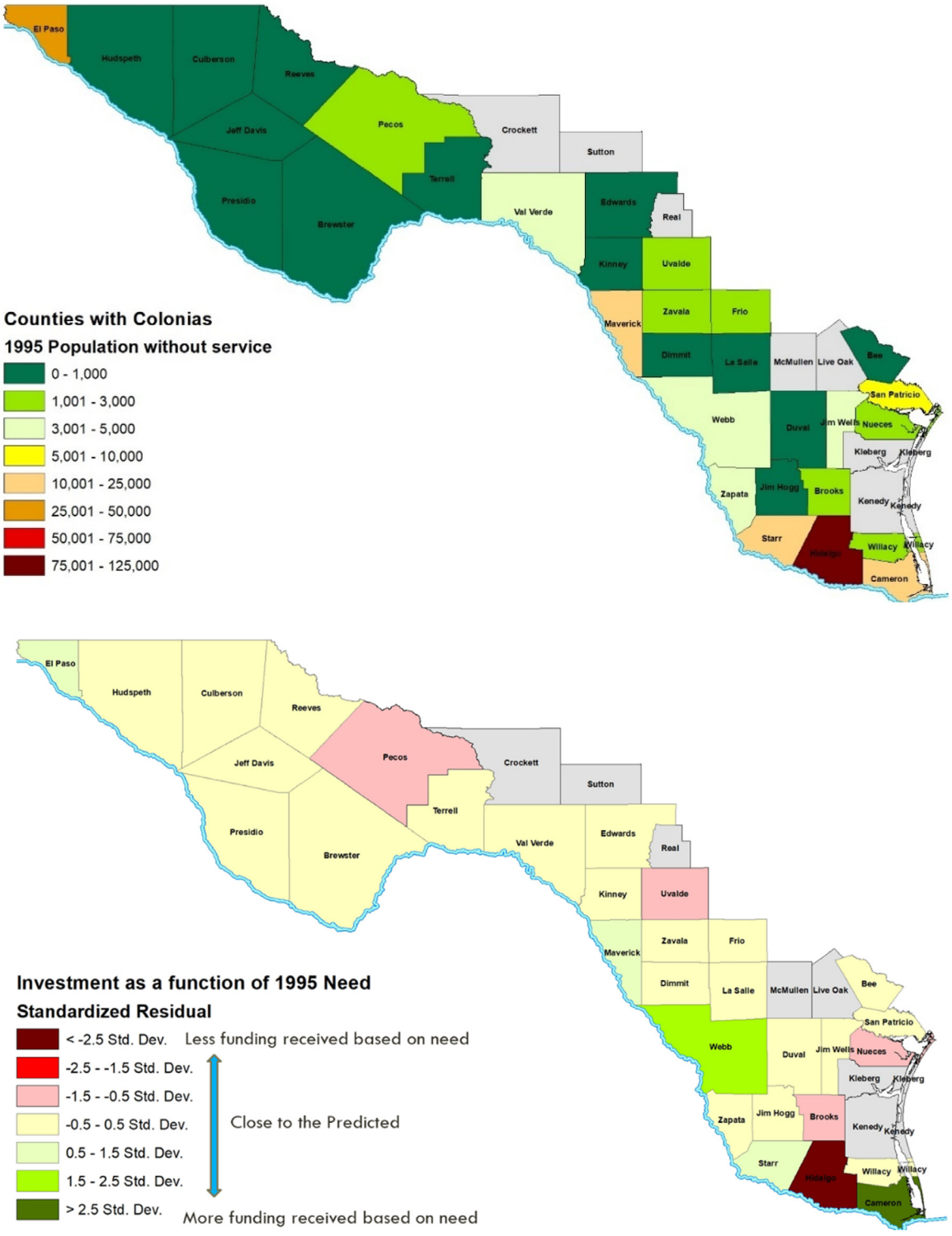

Fig. 3. Colonia population without wastewater service in 1995 and standardized residual of investment as a function of 1995 need. Map in color.

The funding agencies and Texas Secretary of State (SOS) completed extensive outreach campaigns to the communities through their respective call for applications. Based on the interviews, utilities were knowledgeable on TWDB, USDA, TDA, and NADB programs. TWDB and NADB offered initial grant funding for the studies necessary, such as facility plans and environmental assessments, to facilitate the application process since projects that provide first-time service are a priority. However, the funding agencies can only approve funds in response to applications from utilities. Therefore, utilities need to advance their projects before the application process. Those utilities with more institutional capacity realized these tasks more easily as many technical, financial, environmental, and political steps are required to develop infrastructure projects. Therefore, funding tends to be directed towards shovel-ready projects and benefit larger populations.

It is unremarkable that the counties with the larger cities that extended service to the colonias received more funds than expected or

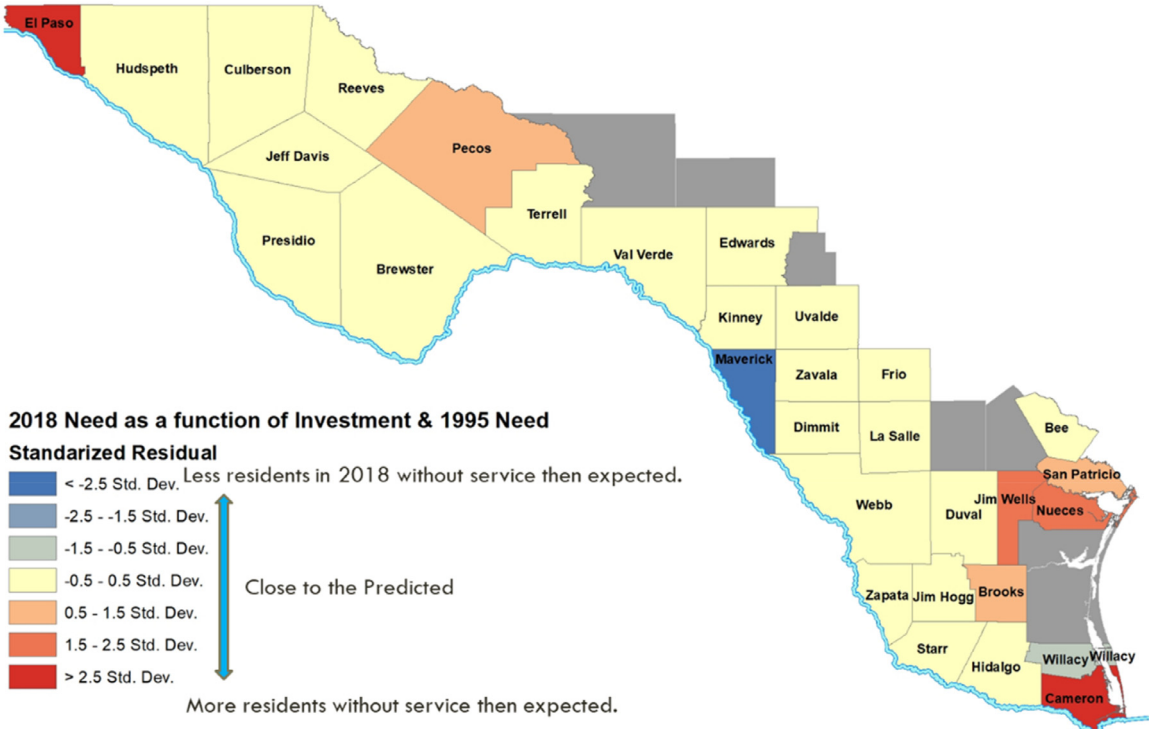

Fig. 4. Standardized residual of 2018 need as a function of investment and 1995 need.[5] The map is in color.

Table 2
Counties with the largest outcomes in serving colonias.

County	Investment (Millions)	1995 Need (population)	WW Coverage 1995	WW Coverage 2018	Estimated New Service (population)
Hidalgo	181.7	84,980	3.1%	73.0%	68,000
El Paso	117.1	46,153	8.5%	68.5%	35,000
Cameron	92.7	22,340	32.3%	79.5%	19,400
Maverick	59.94	19,064	0.0%	96.4%	18,500
Starr	42.8	12,843	6.1%	75.0%	17,000
Webb	29.86	3783	58.5%	85.4%	3700
Val-Verde	8.92	4100	2.8%	75.0%	3600
Willacy	$6.03	2852	0.0%	97.9%	2900
Zapata	$8.70	3561	62.2%	89.7%	2900
Sum	547.757	199,675			171,000
% of Total	87.4%	88.4%			91.6%

Source: Wastewater coverage calculated by the author. Data from TWDB, TDA, USDA, NADB, and OAG.

had differing outcomes. For example, El Paso, Maverick, Webb, and Cameron counties contain the cities of El Paso, Eagle Pass, Laredo, and Brownsville, respectively. These cities have utilities with much expertise to extend wastewater service and much political will to solve issues outside of the city with grant funding. Many of these cities also have multiple goals in providing service to their constituency. Consequently, projects for colonias also included the city's needs as well (Rapier, 2009). For example, El Paso, Eagle Pass, Laredo, Pharr, and Brownsville, to name a few, have wastewater treatment plants that provide service to both in-city and colonia residents. Although funding agencies have a process to divide the costs between in-city and out-of-city needs, water consumption and consequent wastewater discharge can differ between colonias and city residents. This may not have been considered in the division of costs and should be further studied. Even so, grant funds may be the carrot to enable major cities to extend services to colonias and simultaneously capture the benefits of regionalization, such as reduced per capita operation and maintenance costs and increased institutional capacity.

In contrast, in Hidalgo County, the sheer size of the colonia population and the number of colonias may have slowed the funding process. For example, the Agua Special Utility District utility in Hidalgo received almost $45 million to address most of its remaining needs. This project is ongoing and not included in this analysis since it is not complete. However, it is an example of utility capacity affecting funding. In addition, another utility provided service to this area that was subsequently disbanded. Agua SUD was then created. This process took years and delayed funding that was initially approved in the early 2000s.

This analysis is intended to be a high-level analysis of the allocation of funds for wastewater infrastructure and expected outcomes. Thus, there is an opportunity to identify and study the many variables that affect funding and outcomes. The variables could be technical, social science, environmental, or others and could include water consumption patterns, water quality, regionalization, utility capacity, population density, proximity to cities, household income, political will, to name a few.

3.4. Where does the need continue?

By 2018, 77% of the Texas colonia population had wastewater service, which grew over less than 25 years almost 57%, an additional 200,000 plus residents. Based on U.S. Environmental Protection Agency's (EPA) wastewater flow estimates, over 10 million gallons per day of raw sewage are now treated versus discharged into the ground-

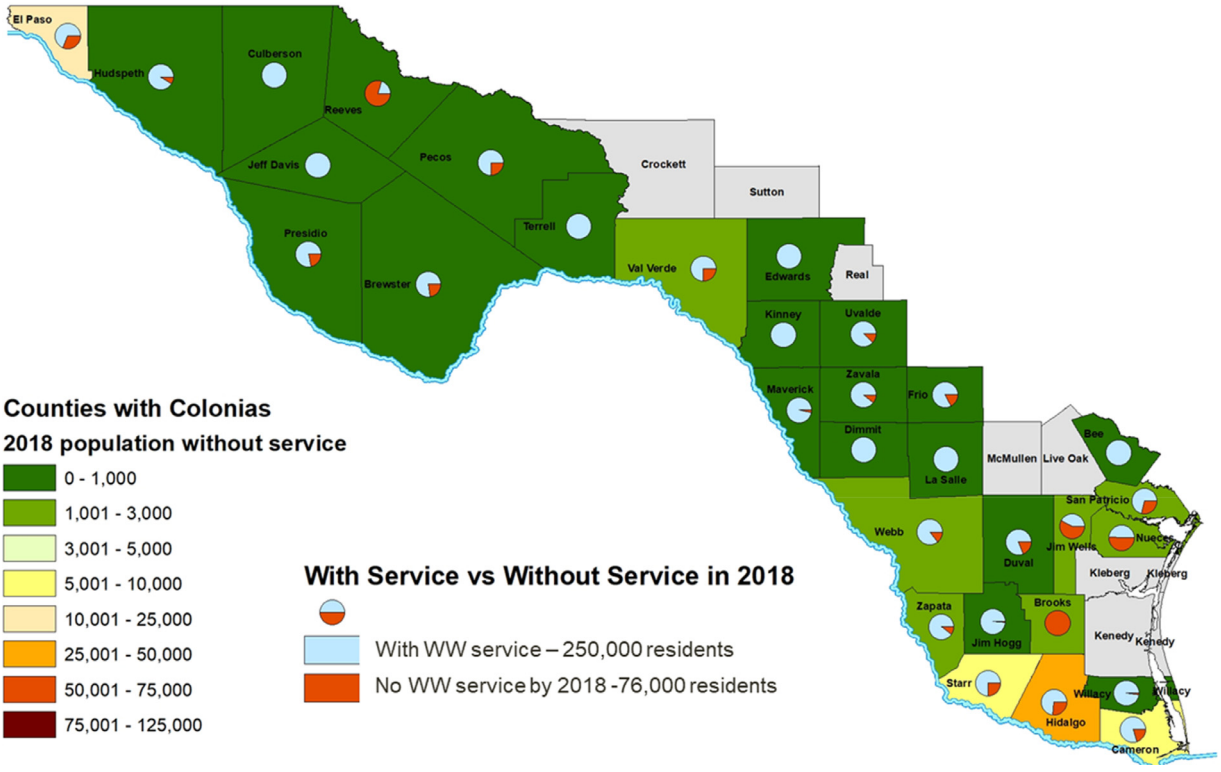

Fig. 5. Colonia population without wastewater service, 2018. Map in color.

water through failing or nonexistent onsite systems (U.S. Environmental Protection Agency, 2002). Hidalgo and El Paso continue as of 2018 as the counties with the largest populations without wastewater service, with approximately 25,000 and 18,000 residents, respectively (see Fig. 5). Cameron and Starr follow this with approximately 8000 and 6000 residents unserved. Thus, as of 2018, less than 80,000 colonia residents do not have wastewater service. Maverick County had the largest increase in wastewater coverage, 96%, followed by Val-Verde, Hidalgo, and Starr with approximately 70%, then El Paso by 60%, and Cameron by 47%. It is worth noting that after 2018, TWDB EDAP funded projects that were in construction during this research and will address much of the pending need.

The interviewees coincided that much of the remaining need will continue mainly in very small isolated colonias where providing service may be costly due to the distance or not within any utility jurisdiction. Fig. 5 also shows by county the proportion of service and without service. Some rural counties continue to have higher percentages of colonia population without wastewater services, such as Reeves, Jim Wells, Nueces, and Brooks, which are all less than 3000. Addressing wastewater needs will be challenging as they tend to be dispersed and have significant barriers for service, which can be costly to eliminate.

3.5. *Did the infrastructure promote growth?*

Growth is a valuable metric because decisions are made regarding infrastructure based on an assumption of above-average growth. The elapsed time between when an agency approves funding and when a water or wastewater system is built can be ten years (Carter and Ortolano, 2004). During that development time, engineers often size the project scope on a population projection of 20 years, so infrastructure capacity is larger than its user base. Otherwise, there are risks of initiating infrastructure operations years later that are too small for the population. A larger projected population means increased construction and operation and maintenance costs for the bigger infrastructure. Also, financial proformas use an inflated population to distribute capital and operation and maintenance costs amongst the residents, which is the basis for a rate structure. If the infrastructure size is larger than needed, operating costs are also higher. If the community does not grow as expected, there may not be sufficient users to support the cost of the infrastructure. Also, oversized wastewater infrastructure can lead to operational challenges because it functions based on a minimum flow and chemistry, such as organic load.

The overall colonia population grew from about 280,000 in 2000 to 322,000 in 2010 (Texas Office of the Attorney General, 2019, 2021). Generally, it remained the same by 2019, with an estimated population of 325,000 residents. Between 2000 and 2010, the colonia population grew overall 13.9% and almost all the border counties grew more than 10% during the ten years. However, the 31 counties in the study area grew by almost 20%, and Texas about 21% during the same period (Texas Demographic Center at University of Texas San Antonio, 2020). The 2019 data supports that most counties either declined in colonia population or grew less than 5% over nine years (see Fig. 6). However, Texas grew over 15% during the same period (Texas Demographic Center at University of Texas San Antonio, 2020).

Literature on the U.S. Mexico border coincides that rapid growth, higher than the rest of the country or Mexico, was expected as a result of the passage of the North American Trade Agreement in 1993 would further stimulate that growth (Schoolmaster, 1993) (Soden, 2006) (Parcher and Humberson, 2009). In addition, some analysts expected that the growth of a county or nearby city would spill over into the colonias. Therefore, design and financing decisions for wastewater infrastructure for colonias were made based on the assumption of growth. Based on interviews, agencies allowed utilities to use a 20-year growth projection to define the project scope. More recently, this has been replaced with a rule of thumb of 30% increased capacity above current needs.

In effect, modest growth occurred as infrastructure was implemented and subsided after it was completed. By 2011, much of the infrastructure was completed and 70% of colonia residents had wastewater service. This coincides with the utility interviews where many,

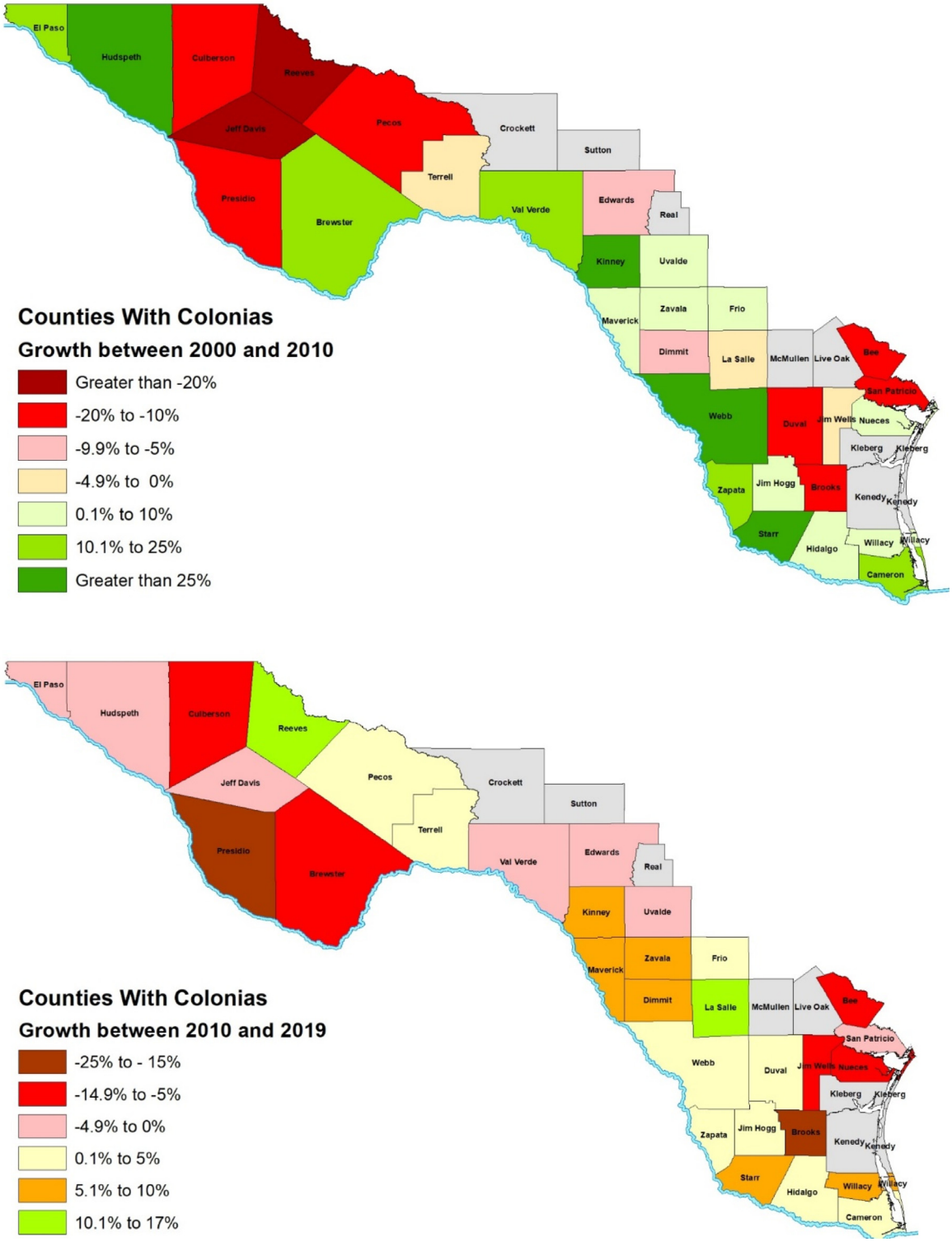

Fig. 6. Growth in colonia population by county, 2000–2010 and 2010–2019. Map in color.

especially in rural areas, reported no permanent growth. Temporary growth associated with fracking had subsided, and workers left and took their trailers or stopped renting hotel space. Further study may explain growth patterns. Some colonias may have grown substantially, as others may have decreased sufficiently to offset any growth overall. For example, colonias closer to cities could have grown as the cities grew in their direction, while more rural colonias experienced a decline.

3.6. What were the lessons learned from program implementation?

Based on about 70 in-depth interviews with funding agencies and utilities and the analysis completed, elements of EDAP and related that worked well were: (1) requiring that counties adopt model subdivision rules; (2) inclusion of wastewater household connections; (3) heavy involvement with project sponsors and coordination amongst funding agencies, (4) documenting a baseline along and tracking results every

few years, and (5) including a prioritization process to expedite funding and maximize benefit. Interviews also identified actions that could further strengthen a program, including: (1) adjusting the assumptions of growth in technical design; (2) follow-up with the project sponsors after project implementation; (3) creating a repair and replacement program, and; (4) identifying potential barriers to service.

Funding agencies required counties where colonias existed to adopt model subdivision rules (MSR) before utilities could receive funding. MSR's prevented the further proliferation of colonia conditions in unincorporated communities where a gap existed in regulation. The MSR requires developers with lots of five acres or less that subdivide land or sell an individual lot include potable water, wastewater treatment, and minimum setbacks for adequate operation of these municipal services. TWDB provides training and assistance to counties on adopting MSR's and includes valuable tools on its website (Texas Water Development Board Model Subdivision Rules (MSR) Training, 2021).

Both TWDB and USDA began their programs in the early 1990s. As those early projects were implemented, it was evident that many families did not have thousands of dollars to connect their homes to the community system. Consequently, changes were made to ensure that the household connections cost to the system was in the grant as part of the project. Through its housing program, USDA funded indoor plumbing, sinks, and bathrooms for significant added benefit. This approach required utilities to outreach throughout the project timeline to residents to budget wastewater connections and contract service. Residents could then take advantage of open trenches during construction to connect their homes, providing cost savings. Connecting residents quickly had both financial and operational benefits. Once residents connected, utilities billed customers monthly, and revenues were received to support plant operations. Wastewater flow would be increased for proper plant operations. Every utility interviewed confirmed that adding household connections to the project was very helpful in the project's success. Colonia residents generally responded positively to the option of wastewater service when the household hookup subsidy was included. They were more likely to connect even though they would be adding wastewater treatment to their bill.

Institutional capacity amongst the utilities varies significantly. Just over half of the projects were for cities that extended service to the colonias. The remaining grantees were utilities created to serve unincorporated areas. All agency interviewees agreed that rural systems tended to be smaller and had more difficulty with the funding process. As part of the TWDB and USDA application process, a financial, managerial, and technical (FMT) evaluation of the utilities was completed to assist the applicant in meeting the program requirements. If an applicant needed any assistance identified in the FMT, staff worked with the entities to access the appropriate training or funding for capacity building. Agency staff could provide utility managers with resources available through NADB TCEQ, or other programs. If an FMT review indicated training was critical, financing could be conditioned upon completion of such training.

Funding agency staff served colonias during the entire process, from project development through construction and start-up. The federal and state programs approved grants for facility planning which led agencies to work closely with utilities over an extended period. Activities included assistance in contracting consultants, attending monthly technical meetings, facilitating the environmental process, helping with the public participation process, and reviewing deliverables. Grant recipients gained much institutional capacity at a very low cost, typically less than $200,000 for the planning study. Ensuring there is sufficient staff to administer the program and provide customized support was critical in achieving results. Utilities expressed in the interviews their appreciation of the support provided during this process. Many were repeat customers of the agencies.

Cost-sharing was common. The agencies coordinated on timing, funding, and project scope, and on occasion, project components were funded by different agencies. For example, one could fund the treatment plant, another the sewer service, and a third the connections even though program requirements could differ across agencies. This symbiotic relationship allowed funds to go further within each agency's limits, reduced duplication, and enhanced a common approach when working with each project sponsor.

TWDB completed a needs assessment in 1992 and revised it in 2003 for tracking which colonias had water and wastewater service over time (Texas Water Development Board, 2003). In 2005 the Texas 79th legislative session established a colonias ombudsmen office in SOS to track and report results from the funding agencies, including USDA, TWDB, TDA, among others (Rapier, 2009). The SOS created a classification system (red, yellow, and green) to report on each colonia every four years producing reports in 2006, 2010, and 2014 tracking progress, including project status, funding, and population benefited. This information was helpful for the agencies to identify areas of need. In addition, SOS designated several ombudspersons staff throughout the region to assist and educate communities on the various programs and MSR requirements (E. Caballero, former SOS staff member, phone interview, March 2021). No report was produced in 2018 since the Texas legislature cut funding in 2017 for the ombudsmen program. Facilitation from the ombudspersons in the field was helpful to those utilities with less institutional capacity and colonias that were more difficult to serve.

Infrastructure programs authorized most of their funds based on a first-come, first-serve basis. As funding declined, programs evolved to include a prioritization process based on population served, income, project readiness, among other factors. Program managers agreed on the benefit of adding environmental objectives to reduce untreated wastewater discharge more quickly. Reducing the unliquidated obligation (unspent federal funding authorized for projects) gave the U.S. Congress confidence to continue appropriating funds for NADB and USDA. Finally, agencies managed grants for technical assistance (planning through design) and construction as two pools of funds, which assisted in more efficiently disbursing funds.

Utility interviews disclosed opportunities to strengthen the funding programs: reducing the planning horizon; subsequent community follow-up; creating a small loan program for aging infrastructure and; addressing continuing barriers to service. Many utilities reported that colonias had not grown as expected and facilities were oversized despite their modular design. NADB had completed retrospective closeouts on projects after almost ten years and documented limited growth in several communities, especially rural ones. Many utility managers confirmed the lack of growth based on solicited new connections, which were few each year. Also, most interviewees lived in the communities and saw little to no growth both in population and commercial development.

Engineers use a 20-year planning horizon and typically design modular facilities, one for existing demand by the time the facility is built and a second for the future. In the colonias, county growth rates were used to population projections for the design of the infrastructure. As discussed previously, this growth did not occur as expected. Most utility managers, where a nearby city did not provide wastewater treatment service, reported only using the first module of the community's plant a decade later. Consequently, these utilities experienced operational issues early on with the wastewater treatment plant due to the unexpected low flows, particularly if mechanized. However, all had resolved the issue over time. Those utilities with lagoon systems rarely discharged as permitted, meaning there was insufficient wastewater flow, evaporating before reaching its discharge point. Another comment received from the interviewees was that water systems required additional flushing for aged water due to low water consumption; otherwise, water quality issues would persist.

One way to prevent oversizing facilities is to use a shorter planning horizon, such as ten years, or a smaller growth rate, especially for more rural areas where growth is less predictable. Such revisions to planning could be an opportunity to further spread funding, build smaller projects more quickly, and follow up with the community a few years later to re-

assess their needs. Also, wastewater flows are typically related to socioeconomic status in residential areas whereby poorer communities, such as the colonias, have lower per capita wastewater flow rates and more variability in the hydraulic loading (Geyer and Lentz, 1966; Imam and Elnakar, 2014). Completing a closeout after three years of operation would be an opportunity to track growth, assess flow rates, and glean other lessons learned. This is a practice NADB implemented to assess if environmental objectives were achieved (North American Development Bank, 2018).

Many of the utilities interviewed stated that they were happy to receive a "shiny new system" but were now concerned about asset management after over a decade of use. The original proforma required for project funding projected operation and maintenance costs and repair and replacement costs. However, after a decade, initial wastewater flows for a user base were now obsolete and had not been updated. All utility interviewees agreed that a small, low-interest loan program without the bond issuance costs would help repair and replace equipment such as lift stations, blowers, and belt presses. Many of the utilities had well-established relationships with TWDB and regarded them as long-term partners. Therefore, default risks will likely be low. Replacing equipment will have the added benefit of improved energy efficiency as technology advances. Also, the equipment selected can be the appropriate size for the population. Both activities will reduce energy consumption. Energy and labor are the most significant operational expenses. Therefore, reducing operational expenses would be helpful, especially for smaller utilities. A low-interest repair and replacement loan program should include technical assistance grants and a website with tools and training on asset management.

Both program managers and utility interviewees agreed that Texas has provided water and wastewater service to most colonias. One program manager expressed, "all the low-hanging fruit and the next level up has been done." Areas that remain without service and are not in the current pipeline of projects are generally too isolated and costly to connect to a centralized system. Onsite systems could provide a solution but require a robust county monitoring program with access to affordable maintenance options. This program should include a permit application process, which is required in Texas, and inspections every two years where residents provide proof of maintenance. Utilities generally responded favorably to the idea of onsite systems as a possible solution.

Conclusion

Over 25 years, Texas provided wastewater for approximately 200,000 residents primarily through grant funding from EPA, USDA, TWDB, TDA, and NADB. Approximately $626 million was provided for 119 projects across 27 counties. About 300,000 residents lived in colonias and wastewater, and coverage increased from 20% in 1995 to 77% by 2018. Many of these programs were developed in the early 1990s, deployed quickly to address a pressing need, and successfully achieved the objective of providing service to many colonia residents in a relatively short amount of time. Over 200,000 colonia residents received wastewater service, but outcomes progressively diminished as grant funding decreased. The programs worked cohesively across all four agencies towards a common mission: affordable access to water and wastewater service access.

This research uses both qualitative and quantitative techniques to assess at a high-level fund distribution from four agencies and outcomes in colonias across 31 counties. The research also describes locations where the need continues and what managers and utilities believe are programmatic and technical lessons learned. The funds were generally distributed equitably amongst the counties with smaller populations. Most counties received an adequate amount of funding as compared to others. Counties with the larger cities that extended service for the colonias received more funds relative to need as both city and colonia needs were met. Many important political decisions need to be made for a city to serve outside its city limits. Grant funds may be an incentive to enable major cities to extend services to colonias and simultaneously capture the benefits of regionalization, such as reduced per capita operation and maintenance costs and increased institutional capacity.

By 2018 the expected reduction in need was achieved in most counties based on original need and the funding received. As of 2021, the most significant need continues in the smaller, more isolated colonias, where overcoming the barriers to service will be costly because of distance and lack of institutional capacity. Both utility managers and program managers reported enhanced outcomes when funding agencies grew a utility's institutional capacity, timely disbursement of funds, ensured household connections were completed quickly, and tracked progress. One unintended consequence was oversized facilities as population growth did not result as projected in rural colonias. A current challenge is how to fund the replacement of aging infrastructure for small utilities.

While water and sanitation may have reached almost 99% of the population in the United States, increased access to water and sanitation continues to be a sustainable development objective goal six worldwide (Wescoat et al., 2007). Research on Texas colonias can be helpful to countries in transition working to meet the United Nations Sustainable Development Goal 6, increased access to water and sanitation.

Limitations

The findings in this study may not be generalizable to other areas. The Texas-Mexico border area is unique in many ways. The sample size of 32 counties is not representative of Texas or the United States or of sufficient size to conclude any causal effect. The colonia population is an estimate based on census data for 2000 and 2010, and the American Community Survey for 2019. These are approximations and could be further improved with household surveys in those periods.

Findings suggest the need for additional research centered on further exploration of the impact of infrastructure funding and development and how that was influenced by economic, migration, perceived opportunity, cultural, and social factors going back to the 1990s. Initially, having the right vocal sponsor may have helped put some projects in the funding pipeline and not others. Such variables were not considered in this study.

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Declaration of Competing Interest

The primary author has no competing financial interests but has personal relationships with some of the utilities and program managers interviewed. This did not influence the research, interpretation of the data, or results of the analysis. After finishing this research, she was employed as the Commissioner of the International Boundary and Water Commission (IBWC). The views expressed in this research do not necessarily represent the views of the IBWC or the U.S. federal government.

The second author is a current employee of the Texas Water Development Board but has no influence or is involved in the areas of the agency responsible for funding any of the water or wastewater infrastructure evaluated in this research. This did not influence the research, interpretation of the data, or results of the analysis.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.envc.2021.100342.

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