Solving Flooding Challenges with Green Stormwater Infrastructure in the Airport Wash Area

Prepared for Ward 1, City of Tucson

By Watershed Management Group

In collaboration with Pima County Regional Flood Control District

May 20th, 2015

Executive Summary

Neighborhoods throughout Tucson are challenged by aging stormwater infrastructure or a lack thereof. Even in small rain events streets, homes, and community centers become flooded with polluted stormwater. Residents in the area south of Airport Wash are significantly impacted by impassable or dangerously flooded roads, damage to roads and buildings, and pollution in their washes and rivers as well as the pollution remaining when the water recedes.

On behalf of the City of Tucson's Ward 1 Office, Watershed Management Group (WMG) worked with the Pima County Regional Flood Control District (PCRFCD) to understand the potential for Green Stormwater Infrastructure (GSI) to cost effectively address flooding and water quality challenges. A holistic Cost Benefit Analysis (CBA) was utilized to assess the full range of benefits that would be experienced if GSI were implemented throughout the area south of the Airport Wash. Flooding and GSI retention were assessed using a 2-dimensional hydrologic and hydraulic model in three watersheds that drain directly into the Santa Cruz River: Valencia, El Vado, and the Santa Clara. Conditions resulting from frequent small events as well as an infrequent extreme storm event were modeled for existing conditions and two GSI scenarios. WMG utilized ESRI ArcGIS to map potential GSI infrastructure for homes, rights-of-way (ROW), and streets, as well as commercial properties, schools, churches, other community nodes, and their associated parking lots.

Results from modeling show GSI can have a significant impact on both large and small storm events. GSI resulted in reducing the 100-year 3-hour event peaks by 24%, 19% and 10% in the Valencia, El Vado, and Santa Clara watersheds respectively. GSI implemented throughout these watersheds in our 25-year scenario will result in over $2.5 million dollars of annual community benefits as a result of flood reductions, water conservation, property value increases, reduced urban heat island impacts, improved stormwater quality, reduced heating and cooling needs, air quality improvements, and the energy associated with pumping CAP water and groundwater in Tucson. Residential rain gardens, curb cut rain gardens, and Green Street features have benefit/cost ratios greater than 1 showing that benefits outweigh the costs by 4.4, 2.7, and 2.1 for those features respectively. Rain garden retrofits have a benefit/ratio of 0.5 due to the high cost of asphalt demolition and concrete curbing. Research suggests that GSI is efficient at removing and treating pollutants in stormwater such as suspended solids, nutrients, heavy metals, hydrocarbons, and pathogenic bacteria. GSI can therefore help Tucson and Pima County reduce runoff concentrations for two problematic pollutants for the region: *E. coli* and copper.

Recognizing that one approach will not solve the flooding and stormwater quality challenges faced by residents in the area south of Airport Wash, GSI presents an approach with significant community benefits that is low cost and can be implemented immediately in combination with large-scale projects being planned by PCRFCD. New policies to promote GSI will be necessary to achieve the scenarios presented in this report. A dedicated GSI fund is essential for long-term targeted implementation and maintenance of new GSI systems. Every dollar the community invests in a GSI fund will create 2 to 4 dollars of community benefits in return.

Contents

Acknowledgements

The region has many notable resources that will be leveraged for successful implementation of the recommendations in this report. These resources include:

- City of Tucson's Water Harvesting Rebates, Commercial Rainwater Harvesting ordinance, and Green Streets Policy
- PCRFCD's Low Impact Development and Green Infrastructure Guidance Manual
- Pima Association of Government's (PAG) Green Infrastructure Prioritization Tool
- PCRFCD & PAG's Evaluation of GI/LID Benefits in the Pima County Environment[1]

This report contains many assumptions and novel research. The authors made their best attempts to provide accuracy and transparency while utilizing best practices and current knowledge. Suggestions or comments can be directed to Kieran Sikdar, Program Manager, Watershed Management Group, at ksikdar@watershedmg.org.

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[1] Impact Infrastructure, Stantec, 2014. Evaluation of GSI/LID Benefits in the Pima County Environment.

Introduction

Flooding presents a major challenge for the residents in the area south of Airport Wash. Damage to roads, homes, and community centers is a common occurrence even with smaller rain events due to underperformance of existing infrastructure. This study seeks to understand the potential for Green Stormwater Infrastructure (GSI) to cost effectively mitigate flooding challenges and improve water quality for the Airport Wash area. The following were completed to achieve these goals:

- Assessment of existing conditions
- Identification of opportunities for implementation of GSI across the watershed
- Analysis of estimated flooding reduction resulting from the implementation of GSI practices
- Analysis of additional benefits of GSI features
- Cost estimate for design and implementation of GSI features
- Suggested steps for management and policy to support implementation of GSI features

Existing Conditions Assessment

The Airport Wash area within Tucson, Arizona is significantly impacted by flooding due to stormwater runoff. Several community resources are regularly flooded such as the Hope United Methodist Church and Marshall Home for Men Care. The neighborhood has recently been studied to determine traditional infrastructure, also known as grey infrastructure, measures that can be implemented to manage stormwater runoff and ease this flooding.[2] WMG examined the area south of Airport Wash to determine opportunities for and benefits of implementing green infrastructure throughout this frequently flooded neighborhood.

The study area consists of three watersheds: Valencia, El Vado, and Santa Clara (Figure 1). Each watershed drains west to the Santa Cruz River. Some basin characteristics are described in Table 1.

Table 1. Watershed Characteristics

Watershed Name	Drainage Area (sq. mi.)	Impervious Cover (%)	Land Owners/ Uses
Valencia	1.45	54	Residential with some land owned by Pima County and City of Tucson.
El Vado	2.00	42	Residential & Tucson International Airport
Santa Clara	0.39	39	Residential & Tohono O'odham Indian Reservation

Understanding the neighborhood conditions throughout the project area, as well as around important community centers, was critical to understanding the extent of flooding challenges. A variety of methods were utilized to evaluate the existing conditions of the project area to understand how water flows throughout the urban watershed and to create the foundation for evaluating GSI opportunities. Google Earth, Maps, and Street View were utilized to conduct a desktop assessment of the project area. Site visits were performed to verify desktop observations.

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[2] CMG Drainage Engineering and Kimley-Horn and Associates, Inc. Summary Report Airport Wash (South) Basin Management Study, October 2014.

Public engagement and input was sought throughout the process. On June 25, 2014, WMG, Tucson Water, and PAG informed community members of the benefits of GSI, the water harvesting rebate program, and local GSI programs and grant opportunities. Existing conditions were presented by PCRFCD and their consultant, CMG Drainage. In partnership with Ward 1, WMG reached out to the neighborhood associations within the project area through the Southside Neighborhood Association Presidential Partnership (SNAPP) which represents the leadership of all the neighborhood associations in the project region. WMG presented the project goals, scope, and timeline and distributed our *Green Infrastructure for Southwestern Neighborhoods* manual to share designs and best practices with residents. Final results of the project have been shared with City of Tucson Ward 1 Office, Tucson Department of Transportation, and other stakeholders. Additional meetings will be held with community stakeholders to gather support and feedback.

PCRFCD had a FLO-2D model of existing conditions in this neighborhood created to inform them where flooding issues are most prevalent in the area south of Airport Wash. This model is detailed in the Valencia, El Vado, & Santa Clara Washes Hydrology & Hydraulics Report.[3] The model area is shown in Figure 1. This model provided existing conditions of flooding throughout the model area for small events, the half inch 1-hour and 2-year 1-hour storms, and a large event, the 100-year 3-hour storm. The maximum flood depth experienced during the 2-year storm and the trouble areas identified by the community members during the public engagement meetings are shown in Figure 2.

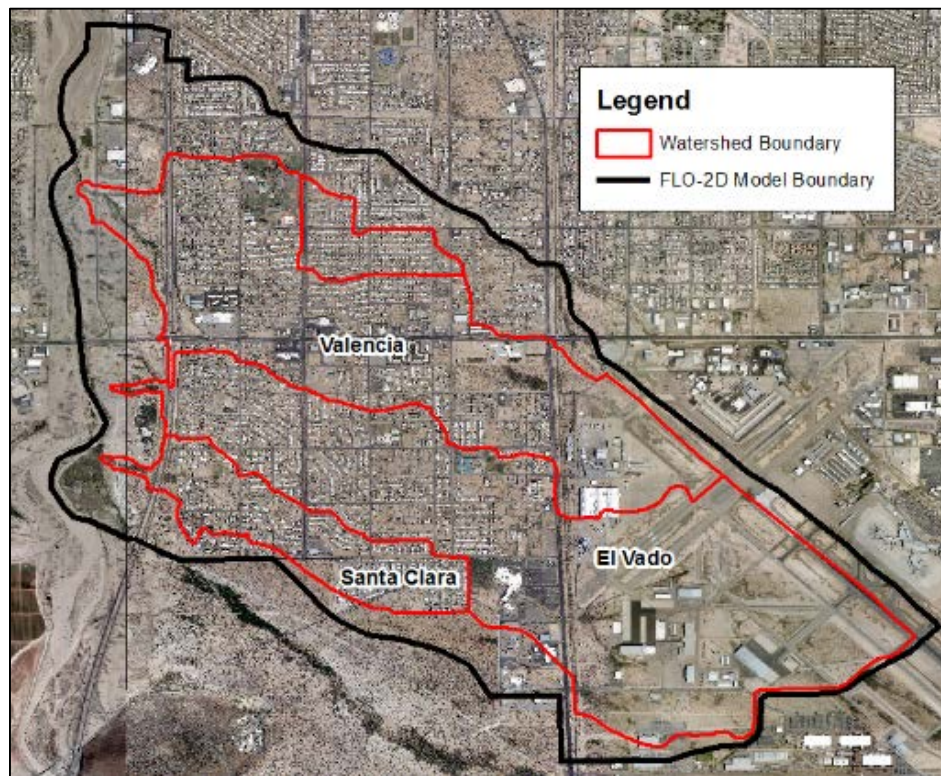*Figure 1. FLO-2D Model Area and watershed boundaries*

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[3] CMG Drainage Engineering. Valencia, El Vado, & Santa Clara Washes Hydrology & Hydraulics Report, May 2014.
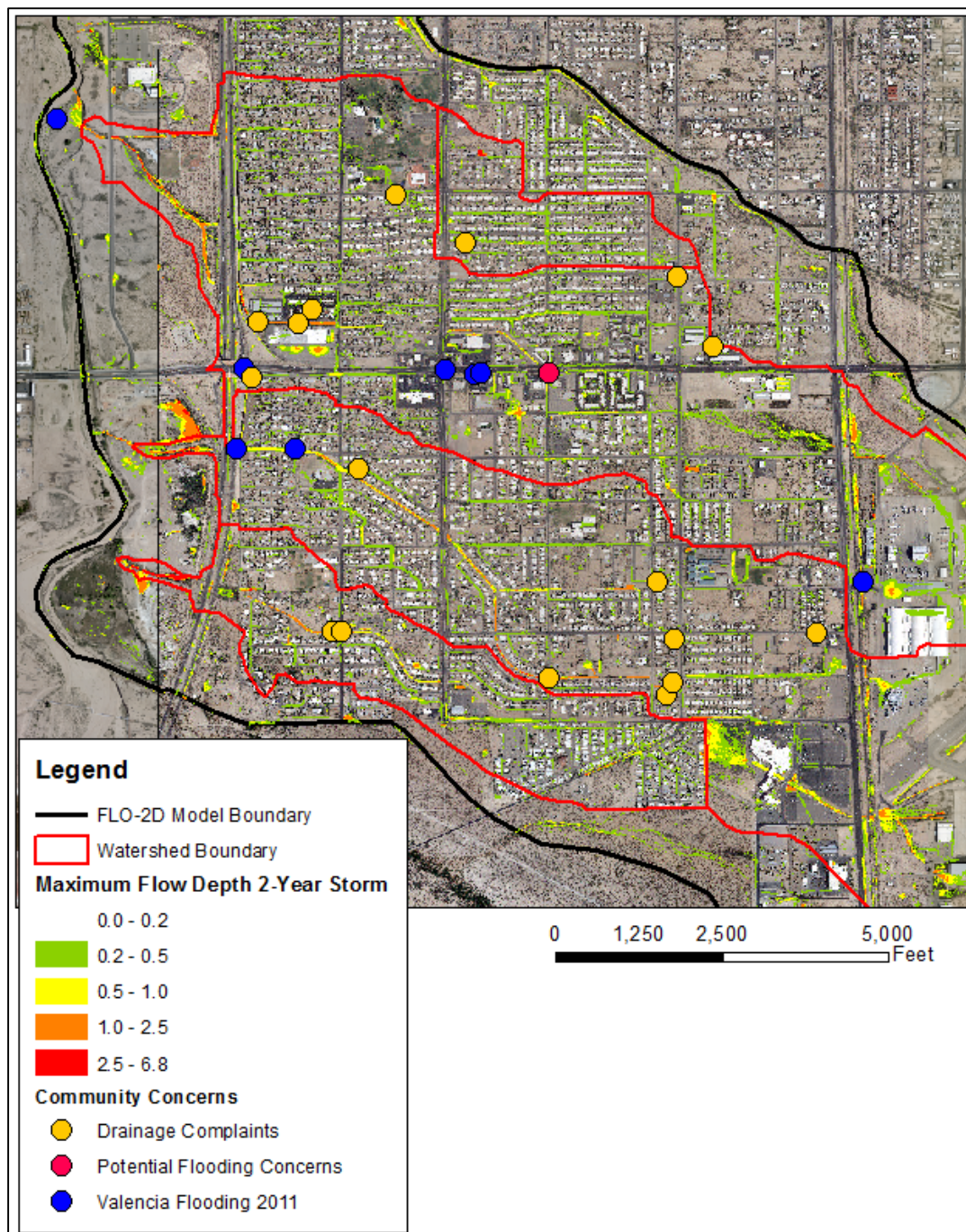
Figure 2. Documented community concerns and 2-year 1-hour maximum flow depths.

Green Stormwater Infrastructure Opportunity Identification

Recognizing the importance of cost effective stormwater management, the use of GSI has been steadily increasing in the Tucson region. The benefits of GSI are widely recognized and local programs are in place to encourage and sometimes require their implementation. Tucson recently adopted Green Streets Active Practice Guidelines that require new construction and reconstruction of streets to incorporate GSI.

Based on the implementation of GSI that could be accomplished within the next 10 to 25 years, two GSI scenarios were developed. The focus of this study was the use of water-harvesting basin designs for residential and commercial properties, ROWs, streets, and community centers such as schools, parks, and churches. Examples of these GSI are shown in Figure 3 through Figure 7.

Figure 3. Residential: Rain gardens that harvest runoff from roofs and adjacent landscape.

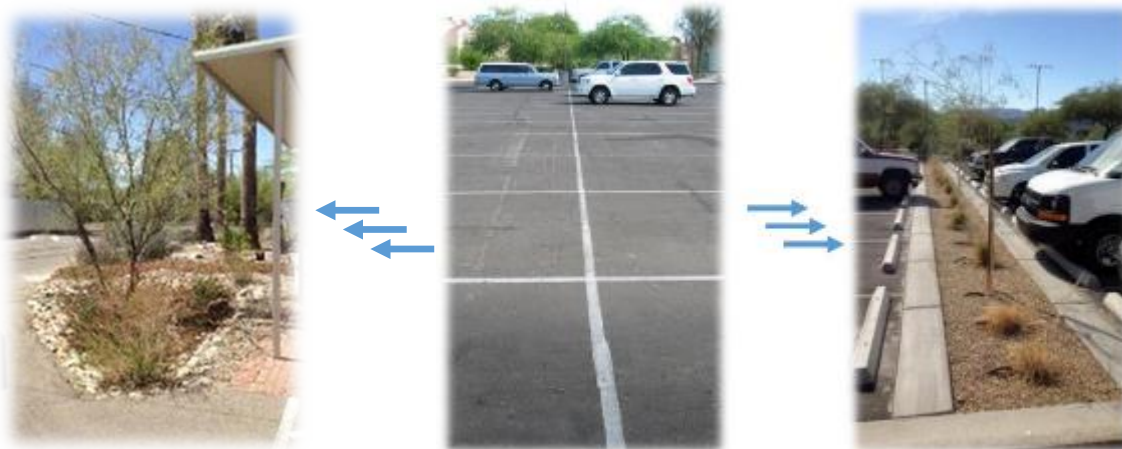*Figure 4. ROW: Rain gardens behind the curb with curb cut inlets to harvest water from the street*

Figure 5. Commercial: Rain garden retrofits to harvest from commercial buildings and parking lots, which often include conversion of excess impervious surfaces to water-harvesting basins.

Figure 6. Street: Asphalt removal for creation of in-street basins to narrow roads, slow traffic, and harvest street runoff.

Figure 7. Green Streets: Streetside ROW rain gardens designed according to Active Practice Guidelines.

The two GSI scenarios were developed in ArcGIS and incorporated into the previously mentioned FLO-2D model. Polygons were used to delineate basins of reasonable size and location throughout the model area. A summary of the 10% GSI Scenario and the 25% GSI Scenario is provided in the table below.

Table 2. Description of GSI Scenario Delineation.

	10% GSI Scenario	**25% GSI Scenario***
Residential	10% (420) of parcels with GSI features including ROW GSI features in front of parcels where possible.	25% (1,050) of parcels with GSI features including ROW GSI features in front of parcels where possible.
Streets	12.5% of streets near community nodes, in areas of severe flooding, and where traffic calming needs were perceived.	All major arterial streets and streets affected by construction of the grey infrastructure alternatives will contain at least the first flush volume of runoff.
Commercial and Community Centers	Parking lots that were older and would soon require repair, and in areas surrounding commercial properties where GSI would make sense.	Parking lots and open spaces were delineated for all community centers and commercial parcels that experience flooding.
Basin Depth	0.5 feet	1 foot

* All features included in the 10% GSI Scenario are also included in this scenario with an increased depth.

The 10% GSI scenario consisted of the following parameters:

- Rainwater-harvesting basins were delineated within 10% of randomly selected residential parcels in the study area. Within each of the 420 individual properties about one-third of all available landscape area was dedicated to a rainwater-harvesting basin.

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- Where possible, ROW GSI features were delineated in front of the selected 10% of residential properties either behind the curb or in-street depending on which was most appropriate based on apparent constraints. Constraints considered included the presence of utilities, street width, number of lanes of traffic, and the space between the curb and the sidewalk.

- Additional ROW and in-street GSI features were delineated for 12.5% of the streets in the project area. Rather than being selected randomly, the 12.5% of streets selected was based on a number of factors including proximity to community centers such as parks, schools, and churches, as well as areas of severe flooding and streets where traffic calming is most needed.

- The parking lots of commercial properties and community centers were also delineated based on opportunity. These were primarily retrofits to older parking lots that would soon require repair or areas surrounding commercial properties where GSI would make sense.

- All features were assigned a conservative retention depth of 0.5 feet.

Figure 8. Example of Delineated Residential and ROW Basins.

The 25% GSI Scenario was developed based on the following parameters:

- All features in the 10% GSI Scenario were included in this scenario with an increased depth of 1 foot. This depth accounts for the City of Tucson design standard basin ponding depth of 8 inches and expected infiltration rates based on local soil conditions.

- An additional 630 residential parcels were delineated, bringing the total residential incorporation of GSI to 25%. Rather than random selection, the additional parcels were concentrated in the middle of the watershed where the maximum water depth during the 2-year flood event was above 0.5 feet.

- Where possible, ROW features were delineated in front of selected 25% of residential properties either behind the curb or in-street depending on which was most appropriate based on apparent constraints.

- Additional ROW and in-street features were delineated along arterial streets and streets targeted for construction in the proposed grey infrastructure alternatives report[4]. Arterial streets included Valencia Road, Nogales Highway, 12th Avenue, and 6th Avenue. Sufficient capacity was delineated to contain at least the first flush volume, 0.5" of rainfall, in accordance with the City of Tucson Green Streets Active Practice Guidelines.

- All community nodes (churches, schools, and parks) in the model area were delineated to collect stormwater runoff in parking lots and in open spaces available on the properties.

- Commercial properties that experience water depths above 0.5 feet in the existing conditions for a 2-year storm event had basins delineated to collect stormwater runoff in parking lots and in open spaces on the properties as shown in Figure 9 below.

Figure 9. Example of GSI features in parking lots and open space at a school. Black lines represent flow lines in the flow accumulation layer.

- The retention depth for all GSI features in this scenario was set to 1 foot. This accounts for the 8" standard depth of GSI infrastructure and a moderate infiltration rate within basins. See the Modeling Methodology section for more specific information.

All of the features delineated were informed by both the FLO-2D model of existing conditions and a flow accumulation layer created based on the 2008 bare earth LiDAR provided by PAG. The FLO-2D model results include a maximum flow depth that occurred during each simulation which indicates where water collects during each storm event. The flow accumulation layer helped inform where features would be most effective by indicating flow paths throughout the study area. The flow accumulation layer was created using Arc Hydro tools, an extension of ArcGIS.

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[4] An Alternatives Analysis Report is included as Appendix B of CMG Drainage Engineering and Kimley-Horn and Associates, Inc. Summary Report Airport Wash (South) Basin Management Study, October 2014.

Results

Flooding

Modeling Methodology

The development of the FLO-2D model is detailed in the Valencia, El Vado, & Santa Clara Washes Hydrology & Hydraulics Report (2014).[5] The existing conditions and GSI scenarios were run by PCRFCD from January to April 2015. This modeling effort was intended to determine the impact of the GSI scenarios on both small and large flood events, specifically the half inch 1-hour storm, the 1.15 inch 2-year 1-hour storm, and the 3.21 inch 100-year 3-hour storm event. The small events occur more frequently and can indicate the impact of GSI on nuisance flooding and water quality concerns. The large event was assessed in order to determine the effect of GSI on the proposed grey infrastructure alternatives. The precipitation, inflow hydrograph, rain loss, manning's roughness, physical structures, and other features of the model are described in detail in the Hydrology & Hydraulics Report.[6] The FLO-2D model had 15' grid cells. This high resolution facilitated understanding the impact of small-scale, decentralized GSI. A summary table of model parameters from this report is reproduced in Table 3.

In order to incorporate GSI features into the existing model, the method recommended by FLO-2D is to adjust the TOL values in the model. The FLO-2D Data Input Manual defines TOL as surface detention, the minimum value of the flow depth for flood routing.[7] This means that the cells delineated as GSI are assigned a depth (0.5 ft. in the 10% scenario and 1 ft. in the 25% scenario) and until that depth is exceeded that cell will not share flow with adjoining model cells. Essentially, water is ponded on a cell up to the TOL value before any water flows off. In the existing conditions model simulations, the surface detention (TOL) depth for all model cells is 0.004 feet which is equal to 14.9 Ac-Ft of storage. This TOL value is also utilized by the Maricopa County Flood Control District to provide a conservative estimate of the amount of water stored throughout the watershed based on existing soil and vegetation. In the 10% and 25% GSI Scenarios, this storage was increased as a result of GSI to 45.3 Ac-Ft and 176.9 Ac-Ft of storage, respectively. No other model parameters were changed to represent the GSI in the simulation.

The only model parameter available to incorporate GSI into the existing model was TOL. It would have been too time intensive to change the elevations, infiltration, or roughness of cells throughout the model area. This method has limitations and the GSI scenarios took these limitations into account. For example, since infiltration within GSI model cells was not increased the TOL depths were increased in the 25% GSI Scenario to hold water that would realistically be infiltrated during the model simulation time. Also, while a street to be resurfaced would be graded to direct flow into landscaped areas, without the ability to adjust the DEM of the model, some GSI street features were sized to fit the ROW and then moved into the flow path. These modifications were made carefully but will have unquantified impacts on the accuracy of the results. It is recommended that future studies change more of the model parameters to reflect actual conditions within the GSI model cells.

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[5] CMG Drainage Engineering, Valencia, El Vado, & Santa Clara Washes Hydrology & Hydraulics Report. May 2014.

[6] Same as above.

[7] FLO-2D reference manuals are available online: http://www.flo-2d.com/download/

Table 3. FLO-2D Model Parameters Summary Table taken from Valencia, El Vado, & Santa Clara Washes Hydrology & Hydraulics Report (2014).

FLO-2D Model Parameters	Description
FLO-2D Study Area	• Approximately 5.84 square miles. See previous paragraph and Figure 2 for details.
Grid Size	• 15 ft grid. The FLO-2D model has total 723,403 grids.
Topographic Data and Aerial Photos	• 2008 PAG bear earth LIDAR data and 2008 1-ft aerial photos.
Storm Frequencies Evaluated	• 100-year rainfall event.
Rainfall Data (RAIN.DAT)	• 100-year NOAA 14 (upper 90%) rainfall depths for 1-hour and 3-hour storms are 2.75" and 3.21", respectively. • 3-hour Type II and 1-hour local rainfall distributions were applied. • No Aerial reduction factor.
Inflow Hydrographs (INFLOW.DAT)	• Breakout flow from Hughes Wash (provided by KHA) for 3-hour storm event. • No breakout flow was modeled for 1-hour storm event.
Infiltration (INFIL.DAT)	• Used the SCS Curve Number method. • SCS Curve Numbers were obtained from hydrologic soils, impervious cover densities, vegetation covers. • Curve Number for paved streets and large paved parking lots is 98.
Manning's Roughness Coefficient	• Manning's roughness coefficients follow guidance in FLO-2D Reference Manuals. • Manning's roughness coefficient for streets was singled out and was assigned as 0.02. • Manning's roughness coefficient for residential backyards is 0.2. • Depth varied roughness coefficient switch is "ON" • Manning's roughness coefficient for shallow flow is 0.13.
Limiting Froude Number (FPFROUDE.DAT)	• Limiting Froude Number on paved streets (not STREET component) is 1.2. • Limiting Froude Number for all other areas utilized global limiting Froude Number of 0.95 (in CONT.DAT).
Hydraulic Structures (HYSTRUC.DAT)	• Drainage structures on TIA properties. • Drainage structures downstream TIA properties. • Catch basins on streets.
WALLS (LEVEE.DAT)	• On 12th Avenue, between Mossman Rd and Calle Alvord, in the vicinity of Catch Basin 12_CB9.
Floodplain Area and Width Reduction (ARF.DAT)	• Buildings were coded for runoff blockage. • A block wall south east of the Los Reales Road and 6th Avenue intersection was coded.
Channels	• No channel component were provided. Channels are well represented by the 15-ft grids.

Rainfall was modeled in FLO-2D with the rain event occurring over the entire model area. Three storms were considered in the model:

1. Half inch 1-Hour Storm Event – Also known as the "first flush" event, equivalent to the 85th percentile storm event. Simulations were run for 4 hours.

Studies show that GSI, specifically bioretention, can treat pollutants in stormwater. The "first flush" of rainwater on urban surfaces is considered to contain the majority of pollutants in stormwater runoff. This first flush of rain collects the dust, debris, oils, etc. that collect on surfaces between rain events.

    2.   1.15 inch, 2-Year 1-Hour – Simulations were run for 4 hours.

Nuisance flooding is defined as flooding that is sufficient to inconvenience people by saturating lawns, flooding sidewalks, and potentially overtopping low street curbs. These events occur frequently enough to be a nuisance. While nuisance floods are not defined by the 2-year flow event, this small flood event was selected to provide insight into the potential impact GSI can have on nuisance floods in this study.

    3.   3.21 inch, 100-Year 3-Hour – Simulations were run for 24 hours.

Traditional stormwater infrastructure is sized to mitigate flooding during large, extreme events such as the 100-year event. These events are, by definition, infrequent. This study will investigate the impact GSI can have on these large, infrequent events in addition to the smaller, more frequent events.

The 1-hour storm event consists solely of a 1-hour storm rainfall over the model area, while the 3-hour storm event includes a 3-hour storm rainfall and a flow hydrograph coming in upstream of the model.[8] The former represents higher intensity monsoon-type storms that may pose higher flooding hazards in the area, while the latter represents longer duration winter rain events.[9] For the half inch and 2-year storm events three model simulations were run: existing conditions, 10% GSI Scenario, and the 25% GSI Scenario. Since the 100-year storm event models took approximately 48 hours to simulate, only existing conditions and 25% GSI Scenario simulations were run.

Model Results

Flood risk reduction is one of many benefits of GSI. Stormwater runoff that is routed to or intercepted by GSI is retained on site. This retained water no longer makes it downstream and can decrease flood depths at downstream locations. The FLO-2D model of the Airport Wash area provides insight into how much of an impact GSI can have on flooding. Table 4 compares the total volumes of water entering and leaving the model and reports the volume of water stored in model cells due to TOL values.

Table 4 shows that in every flood event the amount of water stored in the floodplain increases with the amount of GSI. Also, in every flood event the amount of water flowing out of the model decreases as GSI increases. The 25% GSI Scenario reduced the total water flowing from the model by 18%, 37%, and 13% for the half inch, 2-Year, and 100-year events respectively. These results show that GSI can have a significant impact on nuisance flood events such as the 2-year storm. The effect of GSI on the amount of water leaving the model is also evident in the outflow hydrographs (Figure 10) for each of the three main watersheds shown in Figure 1.

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[8] CMG Drainage Engineering, Valencia, El Vado, & Santa Clara Washes Hydrology & Hydraulics Report. May 2014.
[9] Same as above.

Table 4. Model Total Volume Results Summary (All volumes in acre-feet).

Storm Event	Description	Existing Condition Results	10% GSI Scenario Results	25% GSI Scenario Results
Half Inch	Total Inflow	155.6		
	Overland Storage Due to TOL	11.0	14.0	17.1
	Total Outflow	1.7	1.5	1.4
2-Year	Total Inflow	357.8		
	Overland Storage Due to TOL	13.7	24.4	43.0
	Total Outflow	40.1	34.1	25.3
100-Year	Total Inflow	1,057.7		
	Overland Storage Due to TOL	13.7	-	93.5
	Total Outflow	591.6	-	516.1

Note that some hydrographs from the model results appear truncated. As the model simulation took hours to run, the half inch and 2-year storm simulations were run for 4 hours while the 100-year storm was run for 24 hours. While this length was sufficient in most cases to capture the peak of the storms, any future model simulations will be run for a longer period. There was no outflow at the watershed outlets within the model simulation time for the half inch storm.
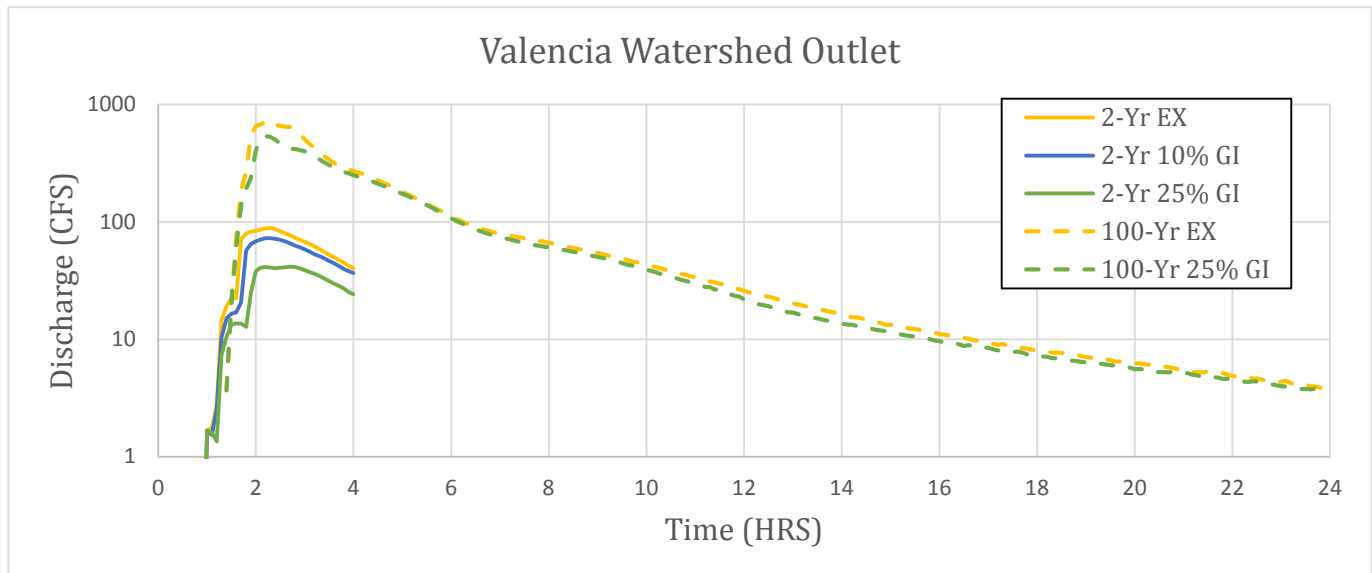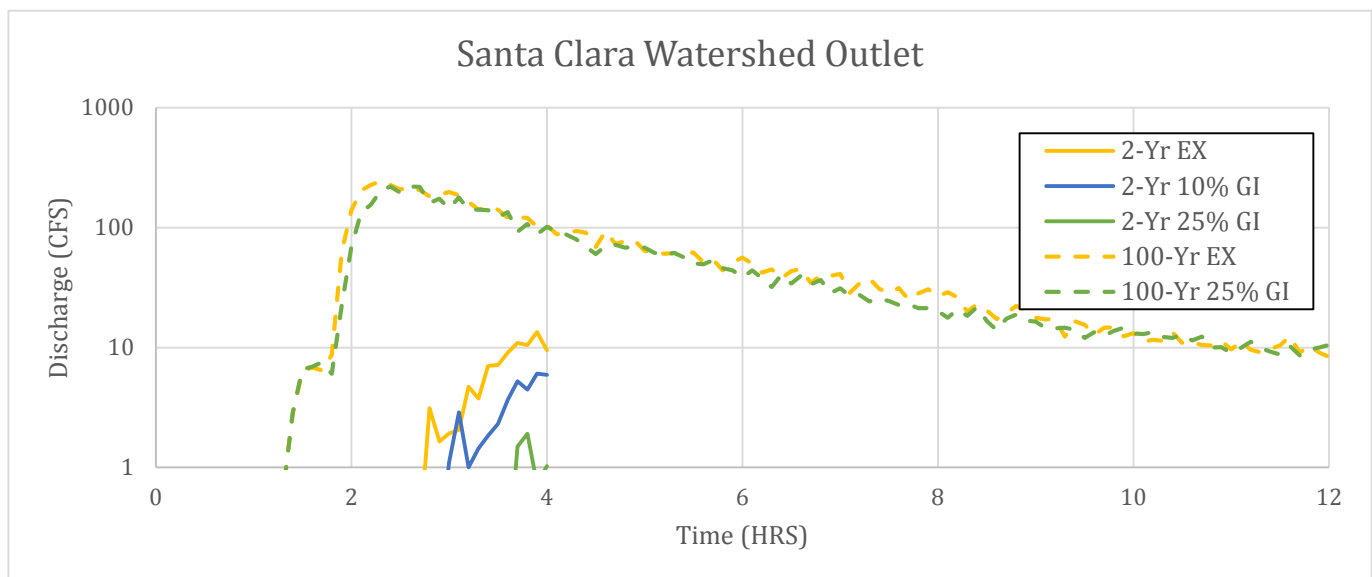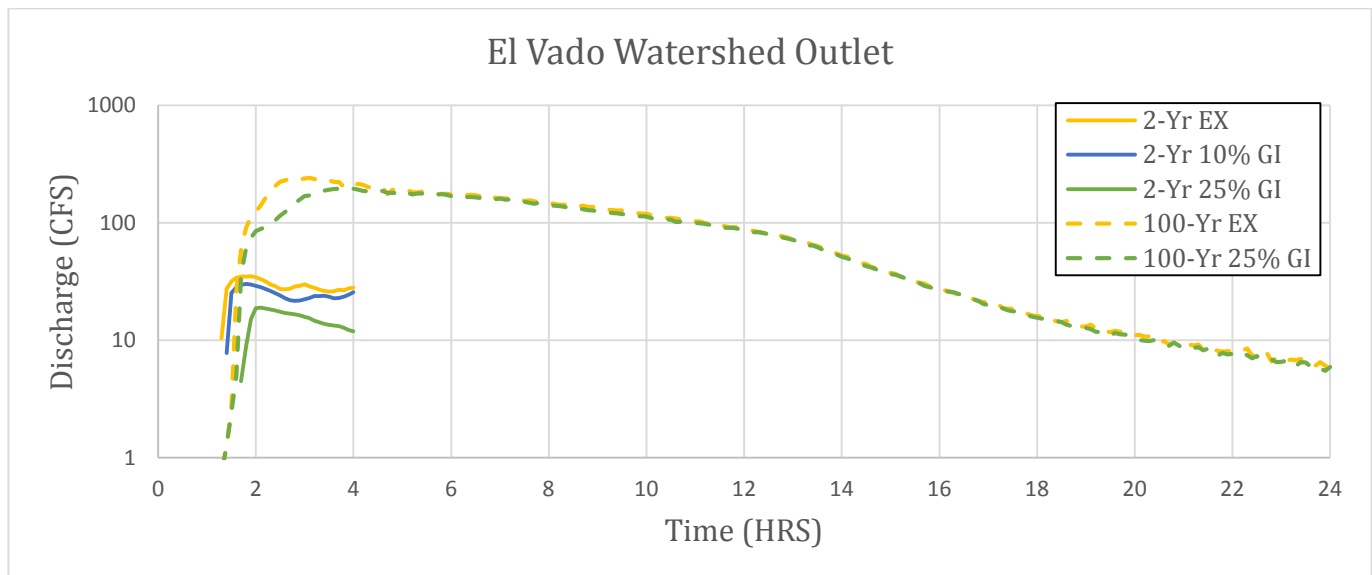
Figure 10. Outflow hydrographs from the Valencia (top), El Vado (middle), and Santa Clara (bottom) Watersheds from the 100-year 3-hour and 2-year 1-hour storm event with and without GSI. There was no outflow from any watershed in the half inch 1-hour modeling results. The y-axis is plotted on a logarithmic scale.

Figure 10 shows that for the 2-year and 100-year floods the peak flow is lower in all 3 watersheds in the simulations that include GSI compared to the existing conditions. The magnitude of the peak reduction for each watershed and each scenario is summarized in Table 5

Implementing GSI within the Valencia Watershed would decrease the peak of the 100-year extreme flood by 24%. Similarly, in all three watersheds for both the 2-year and 100-year flood events peak discharges are decreased by at least 10%. GSI within the Santa Clara Watershed decreased the peak flow by 86% during the 2-year storm, creating a hydrograph that is only briefly above 1CFS, as shown in Figure 10.

Table 5. Watershed Peak Flow Reductions.

	Valencia	El Vado	Santa Clara
100-Year 25% GSI	24%	19%	10%
2-Year 10% GSI	18%	14%	55%
2-Year 25% GSI	53%	46%	86%

In terms of individual neighborhoods, the Hope United Methodist Church has experienced severe flooding in recent rain events. Figure 11 shows the 100-year maximum flow depth at existing conditions and the difference between existing conditions and the 25% GSI Scenario. The average maximum depth on this lot during the 100-year flood with existing conditions is 0.5ft, which was reduced to 0.3ft in the 25% GSI Scenario.
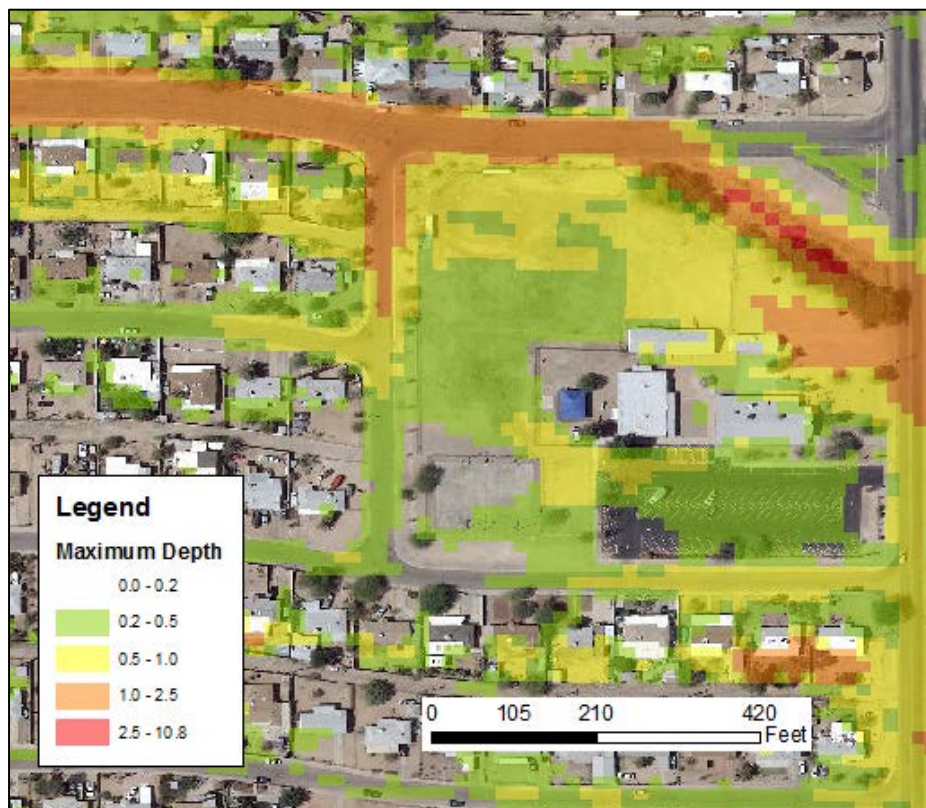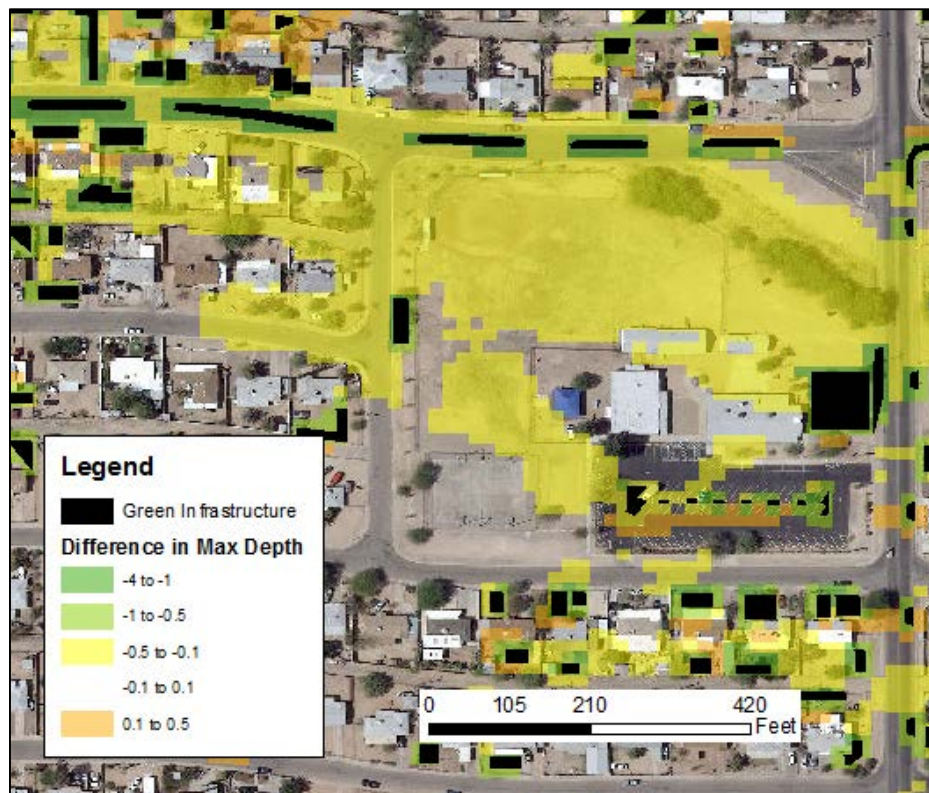
Figure 11. Hope Methodist Church 100-year flooding (top) existing conditions max depth and (bottom) the difference between maximum depths reached in the 25% GSI Scenario and existing conditions.

Note that there are some increases in flow depth in the difference plot. This is due to the method that GSI was implemented in the model. By increasing the TOL depth without lowering the DEM where a rainwater-harvesting basin is proposed, the water that would be stored in a basin is held on the surface, creating a pillar of water in that model cell and slightly increasing the water depths in cells upstream. Throughout all simulations, no increase in maximum depth exceeded the GSI TOL values (0.5 ft. for the 10% scenario and 1 ft. for the 25% scenario).

Figures 11 through 14 depict model results of areas with documented drainage complaints and known flooding within the model. A brief description of each location is included.
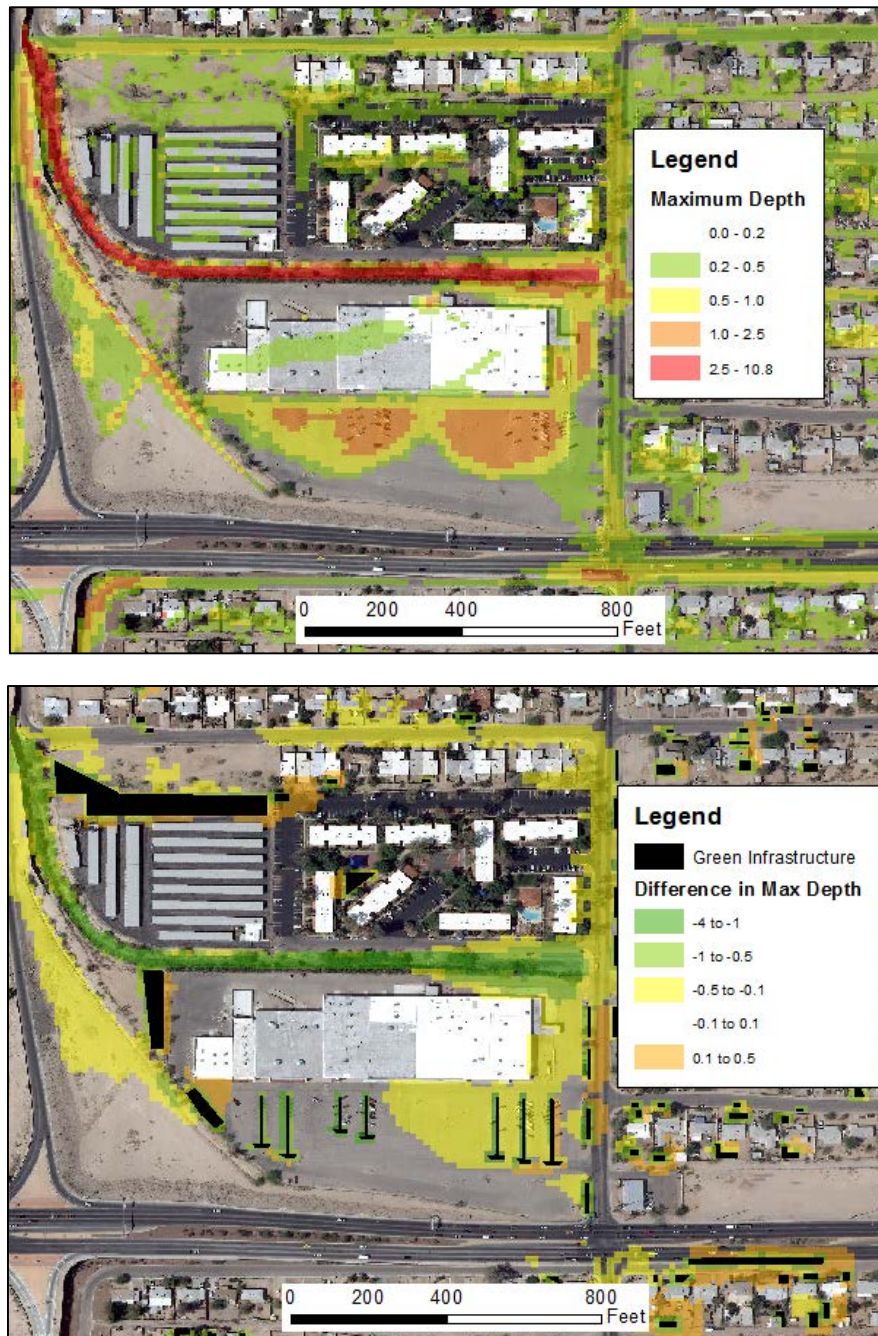
Figure 12. Commercial lot, apartment complex, and school just east of Interstate 19 showing 100-year flooding (top) existing conditions max depth and (bottom) the difference between maximum depths reached in the 25% GSI Scenario and existing conditions.
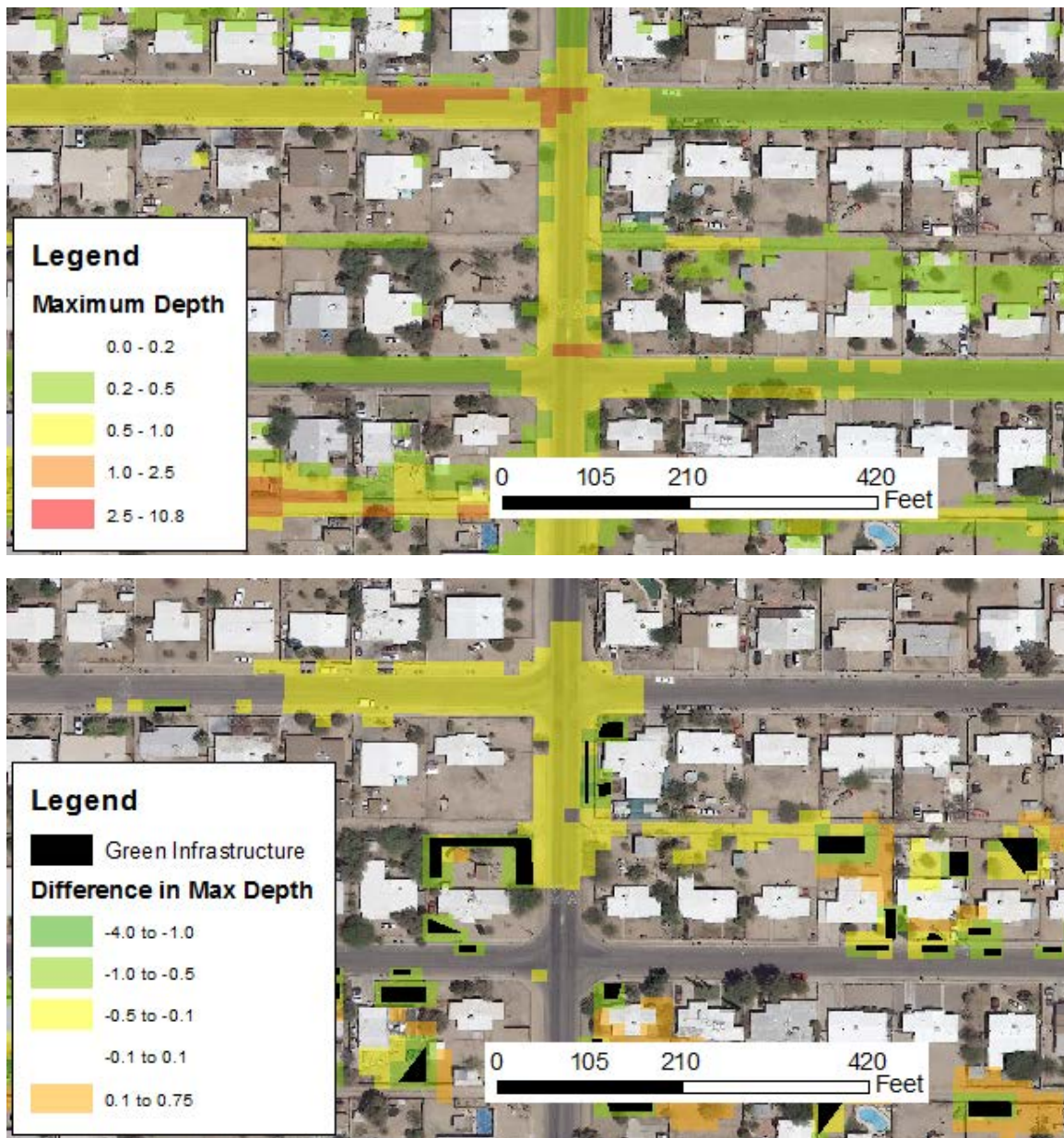
Figure 13. Residential area in the middle of Valencia watershed depicting 100-year flooding (top) existing conditions max depth and (bottom) the 25% GSI Scenario maximum depth.

Figure 14. School off Elvira Street in the El Vado watershed showing 100-year flooding (top) existing conditions max depth and (bottom) the difference between maximum depths reached in the 25% GSI Scenario and existing conditions.
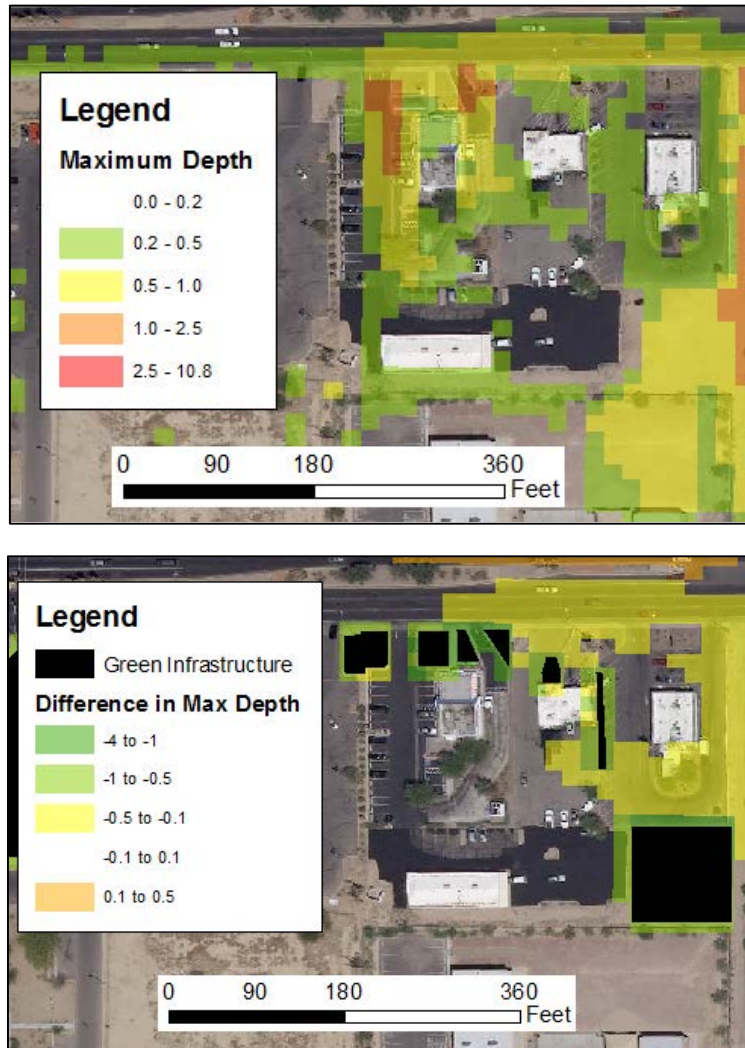
Figure 15. Commercial lot and Valencia Road with 100-year flooding (top) existing conditions max depth and (bottom) the difference between maximum depths reached in the 25% GSI Scenario and existing conditions.
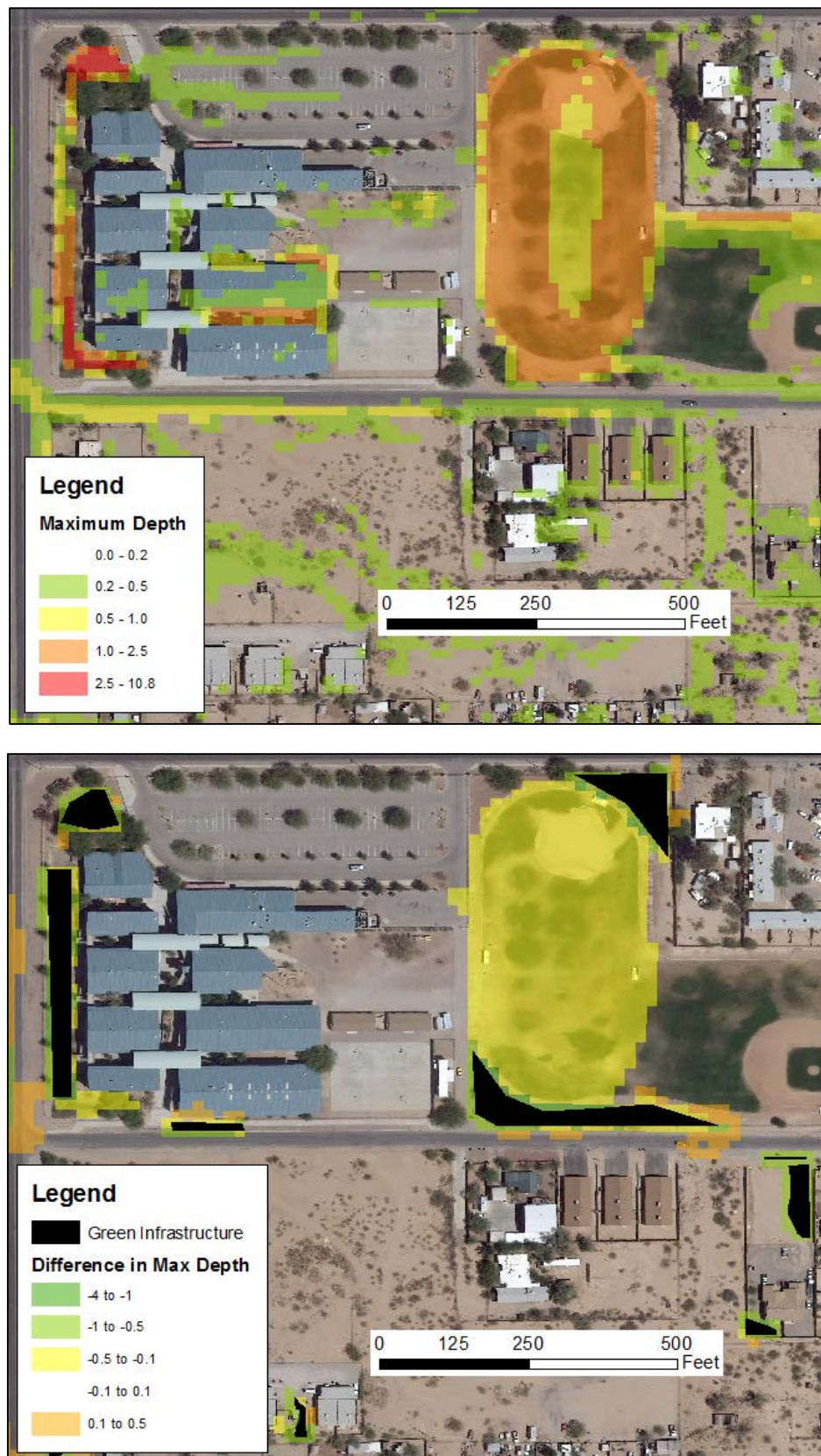
Grey Infrastructure Capacity Analysis

Although grey infrastructure and GSI studies for the Airport Wash area were conducted separately, these practices can work together to save money and resources. As shown in Table 5, strategically locating GSI throughout the watershed can have a significant impact on the volume of water at locations downstream. Since the dimensions and design of grey infrastructure practices are based on peak flow numbers, implementing GSI can affect the dimensions of grey infrastructure.

In addition to the watershed outlet hydrographs shown in Figure 10, there are 64 cross sections configured to export hydrograph data during the model simulations. These cross sections are mostly located around the grey infrastructure alternatives proposed by CMG Drainage. As an example, the proposed sizing of grey infrastructure surrounding the Hope United Methodist Church

was examined.[10] This area, proposed grey infrastructure, and the cross sections where hydrographs are available are shown in Figure 16.

Figure 16. Hope United Methodist Church proposed grey infrastructure (purple) with model cross section locations shown in orange.

Hydrographs for this area are provided in Figure 17 and show that peak flows are reduced by at least 20% for each of the four cross sections shown in Figure 16. Currently, the El Vado Wash crosses on top of S Santa Clara Avenue and exits on to W Medina (also Calle Medina) Road. The 100-year flow on W Medina Road (cross section 36) is reduced by 41% in the 25% GSI Scenario. The Alternatives Report for grey infrastructure calls for the basin on church property to be 6 feet deep and have a ponding depth of 4.1 feet. Based on the modeling results for the 100-year flood and the reductions in flow shown in Figure 17, this basin volume could be decreased, saving construction cost. The proposed basin would require 18,000 cubic yards (CY) of excavation at a cost of $7/CY.[11] A conservative 15% reduction in the volume to be excavated would result in savings of $18,900. The box culvert proposed to pass El Vado Wash underneath S Santa Clara Avenue is a 2-cell 10'x4' RCBC and the outlet for the basin is proposed as a 12' x 3' concrete arch storm drain under Calle Sevilla. Given the 20% decrease in peak flow and volume retention observed in the GSI modeling, these structures could be oversized in a GSI scenario. The 2-cell 10'x4' RCBC is listed in the cost estimates as $700/linear foot (LF) while all other RCBC proposed (including the 12'x3' concrete arch proposed in EV5) cost $500/LF. While a culvert capacity analysis would need to verify that this culvert could in fact be downsized, the potential cost savings of reducing the size of the 10'x4' RCBC's to either a 14'x4' or two 7'x4' would total $17,000 out of $155,560 construction sub-total for EV7.

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[10] Alternatives EV5 and EV7 from CMG Drainage Engineering and Kimley-Horn and Associates, Inc. Summary Report Airport Wash (South) Basin Management Study, October 2014.

[11] The Alternatives Analysis Report is Appendix B of CMG Drainage Engineering and Kimley-Horn and Associates, Inc. Summary Report Airport Wash (South) Basin Management Study, October 2014.

These potential savings, totaling $35,000, are sufficient to cover the capital expenditures for about 202 CY of rain garden based on the unit cost of $0.86/gallon of capacity. In the 25% GSI Scenario, there are 775 GSI model cells upstream of this basin that collected 0.2 feet of water or more in the 100-year event, detaining 5,316 CY of water. While the unit capital costs for GSI based only on volume are larger than for grey infrastructure, there are numerous other benefits that provide a positive Benefit Cost Ratio while conventional flood and stormwater infrastructure typically only mitigate flood risks.
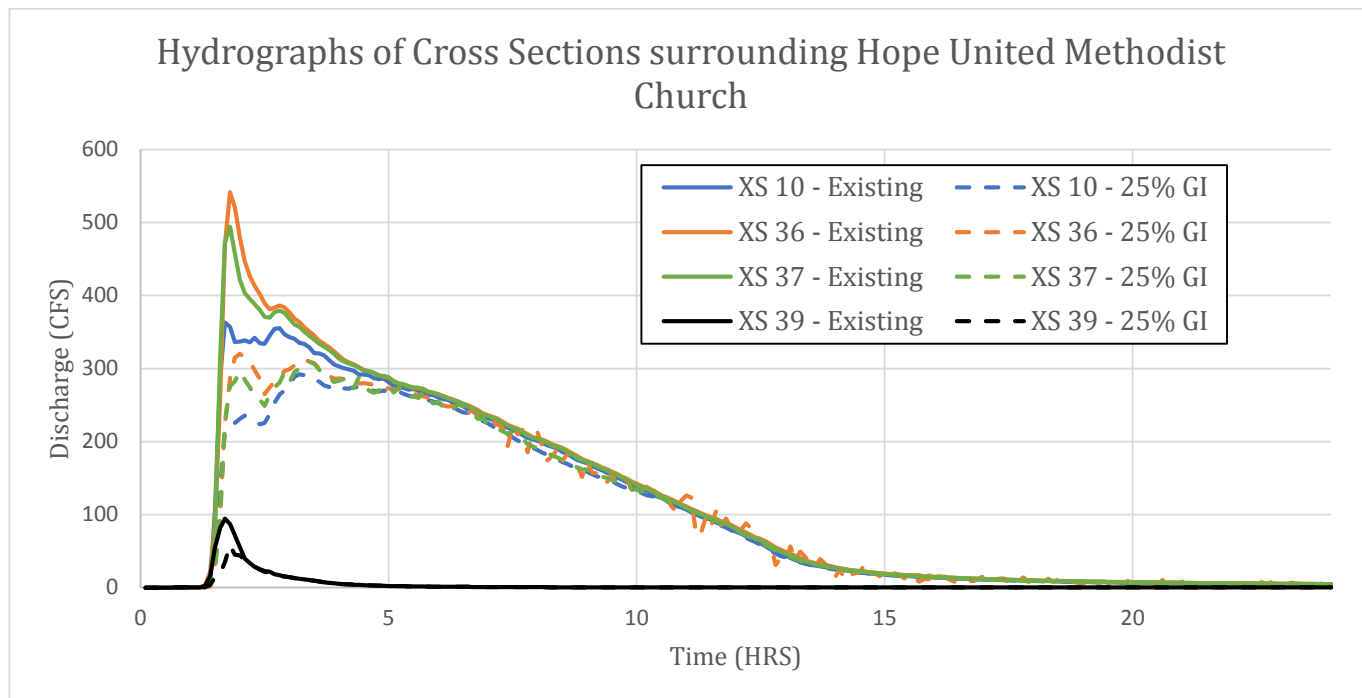
Figure 17. Hydrographs around the Hope United Methodist Church comparing the 100-year event existing conditions to the 25% GSI Scenario. Cross-section IDs are provided in Figure .

In the Valencia Watershed, there is a grey infrastructure detention basin proposed at the corner of S 6th Avenue and W Medina Road (Figure 18). A cross section at the corner of S 6th Avenue and W Medina Road indicates that the 25% GSI Scenario would lead to a 13% reduction in peak flow during the 100-year event.

Figure 18. Alternative V2 specifications. Image from the Alternatives Analysis Report (2014).

With a 13% peak flow reduction, it is plausible that the volume of the basin or the size of the 24"
RCP storm drain under S 6th Avenue could be reduced. The cost estimate for the V2 alternative
indicates that 730 LF of 24" RCP is needed at a cost of $70/LF. Alternatively, an 18" RCP would cost
$65/LF and save approximately $3,650. The proposed basin would require 36,000 CY of excavation
at a cost of $5/CY. At this rate, a 10% reduction in the size of the basin would save $18,000. These
potential savings are sufficient to cover the capital expenditures for about 125 CY of rain garden. In
the 25% GSI Scenario, there are 421 GSI model cells upstream of this basin detaining 3,376 CY of
water.

Water Quality
GSI implemented at a broad scale has the potential to reduce stormwater pollution from the "First
Flush" or the first half inch of rain that liberates the oils, grease, animal feces, brake dust, metals,
and sediment that accumulate on our roofs and streets in between storm events. Water quality can
be improved in the arid southwest through the use of water-harvesting basins. These features
provide flood control benefits as well as water quality improvements by slowing, spreading, and

sinking water into the landscape where soil, plant, and microbial interactions process pollutants. It is essential that water-harvesting basins utilize organic mulch and are planted with grasses, ground covers, shrubs, and trees to support the ecological and physical processes for pollutant reduction. Research specific to the southwest from Davis et al.[12] and Pavao-Zuckerman[13] show that appropriately designed GSI features positively impact the following water quality parameters: suspended solids, nitrogen, phosphorus, heavy metals (copper, lead, zinc and cadmium), hydrocarbons, and pathogenic bacteria.

Although stormwater quality testing is very costly and was not a part of the scope of this work, WMG approximated water quality benefits based on existing GSI research and input from professionals throughout the region. The Pima County Annual Report from the Arizona Pollutant Discharge Elimination System published in October 2013 indicates that runoff from Pima County is high in *E. coli* and dissolved copper.[14] Table 6 shows the hypothetical reductions in both *E. coli* and dissolved copper based on documented removal efficiencies for GSI features.

The October 2013 Pima County Annual Report included four sampling events at five sampling locations. The primary land use for each sample site varied and not every site was sampled during all four sampling events. The values reported in Table 6 are the median value for each contaminant from these sampling events.

No studies were found that report the removal efficiencies of GSI in the arid southwest. A published review of existing research on rain garden performance indicates that field studies in North Carolina showed a 70% removal rate for *E. Coli* and fecal coliform while a laboratory test saw an average removal rate of 91.6%.[13] The same paper indicated that removal rates for heavy metals are high as well, citing a study of parking lot features at the University of Maryland that experienced 57% removal rates for dissolved copper.[14]

Table 6. Potential Water Quality Improvements in Pima County due to GSI.

	Units	SWQS	Initial Concentration[15]	Removal Efficiency	Outflow Concentration
E. Coli	MPN*	126	1,789	70%[16]	537
Dissolved Copper	μg/L	16	20	57%[17]	8.5

* MPN = Most probable number per 100 mL of stormwater

Actual removal efficiencies of pollutants will depend on a variety of factors (e.g. soil characteristics, climate, GSI design, etc.), but Table 6 shows that Pima County could use GSI to comply with surface water quality standards (SWQS).

[12] Davis, A.P., Hunt, W.F., Traver, R.G., and M. Clar. Bioretention Technology: Overview of Current Practice and Future Needs. Journal of Environmental Engineering, Vol. 135, No. 3, March 1, 2009.

[13] Pavao-Zuckerman, M. Soil's Role in Processing Pollutants: Case Studies of Green Infrastructure and Carbon Sequestration. Webinar presented Jan 24, 2013. http://watershedmg.org/webinars/soils

[14] Water and Stormwater Division, Pima County, AZ. October 2013. 16th Annual Report Arizona Pollutant Discharge Elimination System Stormwater Discharge Permit No. AZ000002 Pima County.

[15] Median concentration of samples collected at 5 sites during 4 sample events. From the 16th Annual Report Arizona Pollutant Discharge Elimination System, Pima County, October 2013.

[16] Davis, A.P., Hunt, W.F., Traver, R.G., and M. Clar. Bioretention Technology: Overview of Current Practice and Future Needs. Journal of Environmental Engineering, Vol. 135, No. 3, March 1, 2009.

[17] Davis, A.P. Field Performance of Bioretention: Water Quality. Environmental Engineering Science, Vol. 24, No. 8, October 19, 2007.

The 25% GSI Scenario in the Airport Wash could remove 264 billion MPN of *E. Coli* and 240g of dissolved copper during the half inch storm. This approximation is based on the amount of water retained in the FLO-2D model simulations (Table 4), the initial pollutant concentrations in Pima County, and hypothetical removal efficiencies of bioretention basins (Table 6).

Cost Benefit Analysis

GSI provides a range of benefits to communities beyond stormwater management. A cost benefit analysis (CBA) was conducted to capture the relevant economic values for GSI in the arid southwest. PAG and PCRFCD with cooperation from City of Tucson customized the available CBA research for use in the arid southwest.[18] WMG has utilized this research in combination with i-Tree[19] and other research to create a simplified GSI CBA tool to quickly assess economic values of GSI across the project area based on basin capacity and number of trees.

The values accounted for in this study are divided into two categories: direct and indirect economic values. Direct economic values have a market value that benefits the property owner, community, or local government such as utility costs or maintenance reductions. Indirect economic values are not currently reflected by local or regional markets but can be estimated through related costs to society. For example, extreme temperatures as a result of the urban heat island effect result in medical costs that are borne typically by elderly populations. By reducing the risk of stress through GSI, it is possible to reduce the occurrence of heat stress related costs. A breakdown of the direct and indirect economic values that are included in the CBA are listed below.

Direct economic values:

- Water conservation
- Air quality improvement
- Energy savings
- Reduced street maintenance from shaded pavement
- Stormwater runoff reduction
- Property value increases
- Avoided grey infrastructure

Indirect economic values (has a market value not directly tied to GSI):
- Social value of water conservation
- Greenhouse gas emissions reductions
- Flood risk reduction
- Energy for CAP & groundwater pumping
- Stormwater pollution reduction
- Urban heat island effect reduction

There are other benefits created by GSI such as traffic calming, habitat creation, and others. However, additional research is needed before financial values can be utilized in cost benefit analyses with confidence. All Net Present Values (NPV) are calculated with a discount rate of 6.5% over 40 years to accurately reflect the long-term benefits of GSI and to be consistent with the Impact Infrastructure report and other infrastructure cost benefit analyses.

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[18] Impact Infrastructure, Stantec, 2014. Evaluation of GSI/LID Benefits in the Pima County Environment.
[19] I-Tree Streets. https://www.i-Treetools.org/

Four main practices were evaluated through in this CBA: Rain gardens, rain gardens with curb cuts, rain garden retrofits, and Green Streets water-harvesting features. Rain gardens harvest water from the adjacent landscape and/or roof area. Rain gardens with curb cuts harvest water from streets and parking lots. Rain garden retrofits involve removing impervious surfaces such as concrete and asphalt and replacing them with a rain garden in-street or in parking lots. Green Streets features are rain gardens with curb cuts implemented along major roadways that include additional design and implementation labor to meet the Green Streets Active Practice Guidelines.

Below is a graphical and tabular summary of a CBA for a residential water-harvesting basin. The direct cumulative net benefit has a breakeven period of about 8 years and a net present value of $3,400. This is based on the direct economic values listed above. The benefits of GSI are based on the inputs of the number and average size of trees planted, area of water-harvesting basins, and volume of water-harvesting basins.
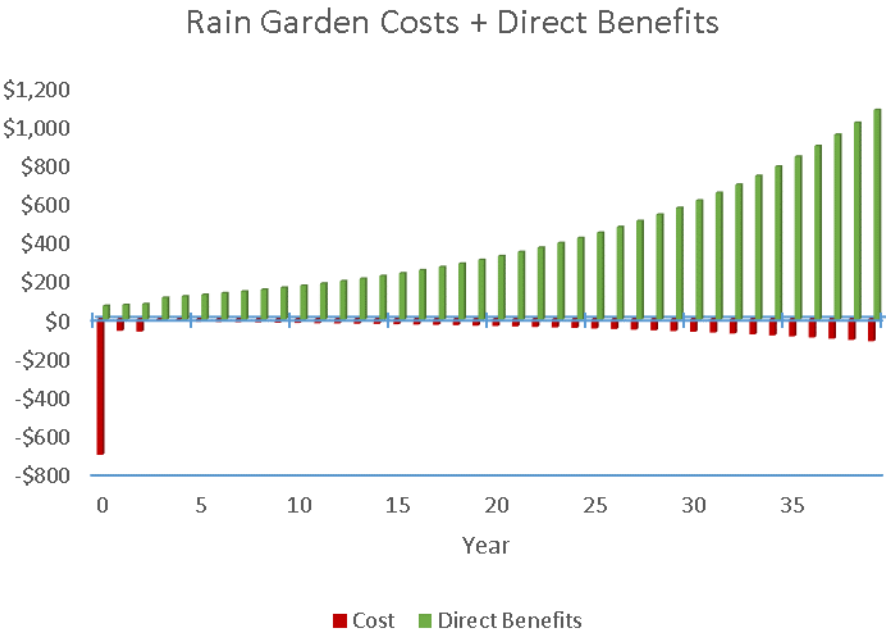

Figure 19. Costs and direct benefits for a 100 square foot rain garden. Net present value is $2,100.
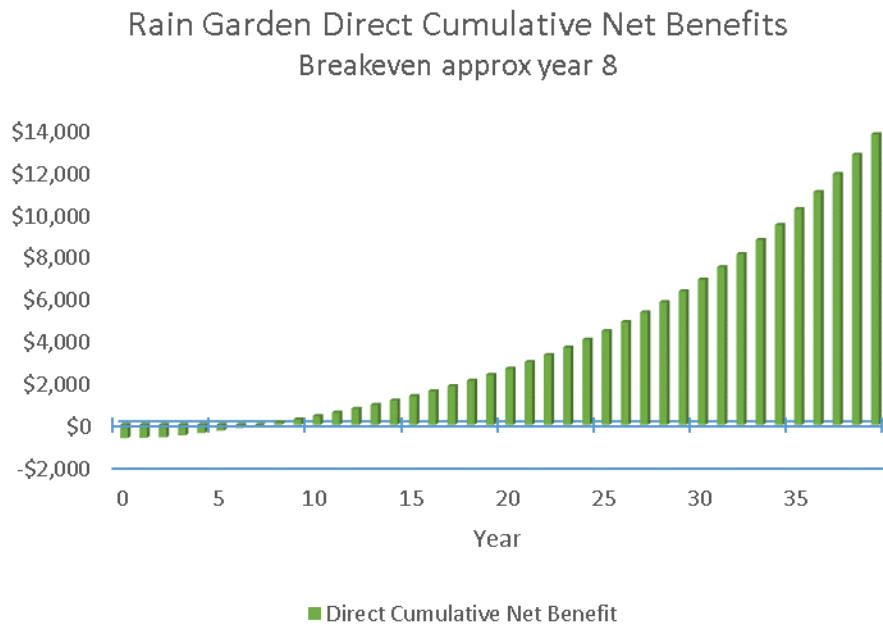
Figure 20. Direct cumulative net benefits (benefits – costs + benefits from previous year) of a 100 square foot rain garden
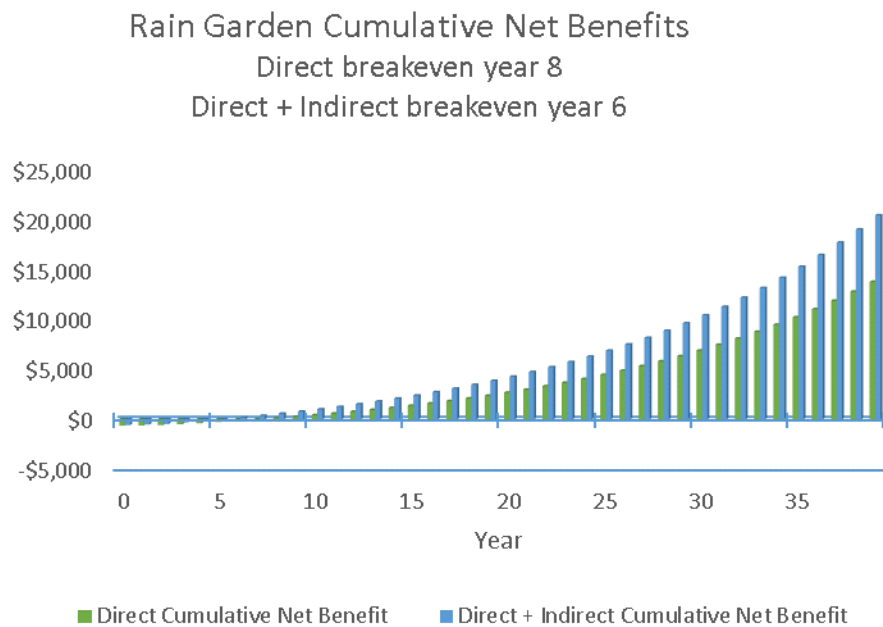

Figure 21. Direct + Indirect benefit comparison for a 100 square foot rain garden. Direct + Indirect net present value is $3,500.

Table 7. Summary of inputs (grey) and annual benefits (green = direct, blue = indirect) from CBA for the different scenarios analyzed

Scenario	Rain Garden	Rain Garden w/Curb cut	Rain Garden Retrofit	Green Streets
Trees #	2	2	3	2
Basin Area (sf)	100	100	160	100
Water Conservation	$25.92	$25.92	$41.47	$25.92
Air Quality Improvement	$15.80	$15.80	$25.28	$15.80
Heating & Cooling	$14.62	$14.62	$23.40	$14.62
Street Maintenance	$8.80	$8.80	$14.08	$8.80
Stormwater Runoff Reduction	$4.05	$4.05	$6.48	$4.05
Grey Infrastructure Avoided	$0.56	$0.56	$0.90	$0.56
Property Value	$0.33	$0.33	$0.52	$0.33
Social Value of Water Conservation	$23.58	$23.58	$37.73	$23.58
Greenhouse gas emissions reductions	$13.36	$13.36	$21.38	$13.36
Flood Risk Reduction	$1.15	$1.15	$1.84	$1.15
CAP & Groundwater pumping	$0.82	$0.82	$1.32	$0.82
Stormwater Pollution Reduction	$0.70	$0.70	$1.11	$0.70
Urban Heat Island effect reductions	$0.36	$0.36	$0.58	$0.36

Assumptions:

Table 8. Detailed cost data utilized for the CBA analysis based on WMG experience, i-Tree, and professionals designing, installing, and maintaining GSI

Capital costs	Rain Garden	Rain Garden w/Curb cut	Rain Garden Retrofit	Green Streets
Per unit area (square feet)	*100*	*100*	*160*	*100*
Labor	$250	$300	$5,000	$500
Design	$50	$100	$2,000	$250
Plants	$75	$75	$350	$75
Rock	$40	$50	$200	$50
Mulch	$30	$30	$150	$30
Excavation & hauling	$200	$250	$2,500	$400
Irrigation labor + parts		$75	$250	$150
Permit Fees		$75	$150	$75
Curb cut		$175		$150
Utility marking		$50		$50
Demo & Concrete			$4,500	
Total Capital Costs	$645	$1,180	$15,100	$1,730

Annual Maintenance				
Green waste disposal	$2.54	$2.54	$2.54	$2.54
Pruning	$1.00	$1.00	$1.00	$1.00
Irrigation	$51.84	$51.84	$82.95	$51.84
Sediment removal		$5.00	$5.00	$5.00

Table 9. Summary of entire project area analysis results

Entire Project Area Results	Rain Garden	Rain Garden w/Curb cut	Rain Garden Retrofit	Green Streets
25% GSI Area (Sq. Ft)	3,043,398	66,122	400,524	130,049
# features	30,434	661	2,503	1,300
Costs	($33,409,303)	($1,182,192)	($40,658,423)	($2,996,760)
Benefits	$147,141,770	$3,244,221	$19,364,480	$6,287,579
Benefit/Cost ratio	$4.40	$2.74	$0.48	$2.10
Payback Period (yrs.)	6	8	30	10
Total Net Benefit	**$113,732,467**	**$2,062,029**	**-$21,293,942**	**$3,290,818**
Annualized Net Benefit	$2,843,312	$51,551	-$532,349	$82,270

The results in Table 9 show great positive economic benefits for GSI features besides those that require asphalt demolition and concrete curbing (rain garden retrofit). GSI for redevelopment shows great promise given the results above for rain gardens, curb cuts, and green streets features. Benefit cost ratios will only improve with new development as a result of little to no additional cost required to design and implement GSI. In many cases, GSI can save money relative to traditional infrastructure solutions.[20]

GSI vs. Grey Infrastructure

Utilizing flood risk reduction benefits from the BCE, the construction costs determined by CMG in the Alternatives Analysis report[21] as well operations and maintenance costs estimated by the BCE tool for the grey infrastructure features, a cost benefit analysis resulted in a benefit/cost ratio of $0.01. For every dollar invested in grey infrastructure, $0.01 of flood risk reduction value is created based on the BCE. This value is likely underestimated given the design intent of the BCE tool. However, other studies show single use grey infrastructure have benefit cost ratios less than 1 depending on the type of infrastructure and the benefits captured in the analysis[22]. This means for every dollar invested less than one dollar of value is created, and if other alternatives exist that have benefit cost ratios greater than one they should be selected. Benefit/cost ratios do improve significantly when multiple benefits are created by infrastructure features as seen by larger GSI ratios. However, in some cases, even large detention structures with multiple benefits estimated can still have benefit/cost ratios less than 1.[23]

A 2nd order polynomial regression reveals the relationship between detention basin capital costs + present value operations and maintenance (O&M) cost and capacity in the Pima County Alternatives Analysis. This regression model reveals that based on capital and O&M costs, decentralized GSI is more cost effective than detention structures smaller than 2.5 acre-feet based on the rain garden cost of $0.85/gal.

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[20] U.S. EPA. Costs of Low Impact Development: LID Saves Money and Protects Your Community's Resources.
[21] Appendix B of CMG Drainage Engineering and Kimley-Horn and Associates, Inc. Summary Report Airport Wash (South) Basin Management Study, October 2014
[22] Hawley, K., Moench, M., and L. Sabbag. Understanding the Economics of Flood Risk Reduction.
[23] Lee, N. Benefit/Cost Analysis for Colusa Basin Drainage District Integrated Watershed Management Plan Feasibility Study.

Detention Basin Construction & O&M Cost Trends

The chart plots Construction + PV O&M Costs (y-axis, from $- to $6,000,000) against Basin Capacity (Acre-feet) (x-axis, 0 to 35) with fitted trendline:

$$y = -1524x^2 + 185687x + 764836$$
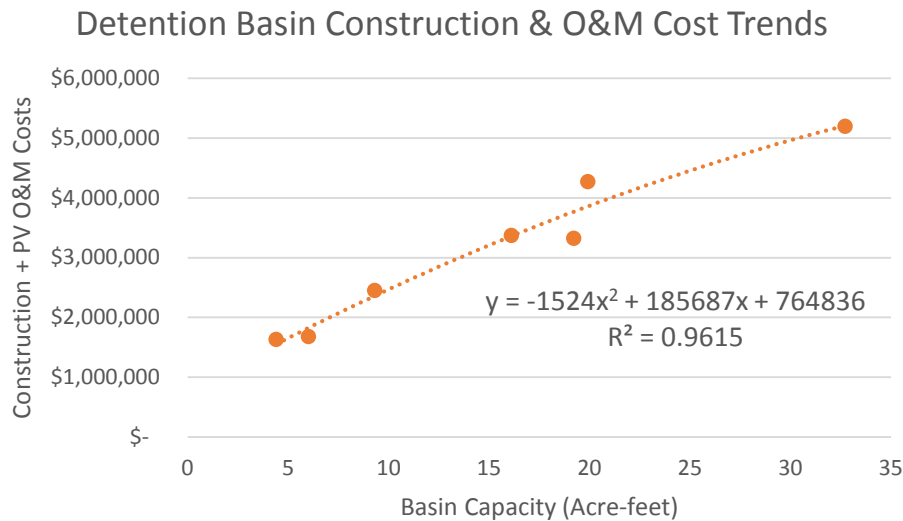$$R^2 = 0.9615$$

Figure 22. Cost trends for detention basin features proposed for the Airport Wash area.

Additional study is needed to accurately assess and compare the costs and benefits of large grey infrastructure with decentralized GSI. Based on this initial analysis, the range of benefits created by GSI outweigh the benefits created by grey infrastructure. However, both are needed to address the flooding challenges in the Airport Wash area.

Detailed Benefit Description

Below is a detailed summary of economic values calculated for GSI. For additional details on the research that supports these costs see the footnotes, i-Tree references, and the 'Evaluation of GI/LID Benefits in the Pima County Environment' report.[24]

Direct Benefits

Water Conservation – Water demand during establishment for rain gardens was based on low water use plants[25] for two native trees, four grasses, two groundcover plants, and two shrubs for every 100 square feet of basin area. It is assumed that GSI has similar irrigation efficiencies as flood irrigation. Flood irrigation efficiencies range from 40-85%[26]. A conservative value of 50% is used here. Irrigation demand is reduced by 50% for commercial properties and Greens Streets projects based on City of Tucson Green Streets Active Practice Guideline requirements. It is assumed that irrigation to GSI is discontinued after the first three years of plant establishment.

Air Quality Improvement – Air quality benefits are calculated in the BCE as the sum of reduced emissions of air pollutants from power-generating plants and the value of pollutant uptake from trees.

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[24] Impact Infrastructure, Stantec, 2014. Evaluation of GSI/LID Benefits in the Pima County Environment.
[25] Tucson Water. Harvesting Rainwater: Guide to Water-Efficient Landscaping.
[26] Howell, T.A. Irrigation Efficiency. Encyclopedia of Water Science. United States Department of Agriculture.

Energy Savings – Energy savings are based on reduction in air-conditioning and heating bills as a result of tree shade. This value is calculated using the method described by McPherson et al.,[27] which uses a typical single-family residence to model energy simulations.

Reduced Street Maintenance – Shade created by trees installed with GSI extends the life of asphalt pavement, reducing the maintenance required. As shown by McPherson & Muchnick,[28] significant financial savings can occur from pavement shading.

Stormwater Runoff Reduction – This number is calculated as the value of rainfall intercepted by urban trees. McPherson et al. used Glendale, Arizona's cost for retention/detention basins to determine the value of water collected and stored by trees.

Property Values – Property value increases occur as a result of local environmental attributes. Studies show that each large front yard tree is associated with a 0.88% increase in property value.[29] The Business Case Evaluator (BCE)[30] uses local property values and applies research values to estimate the increase in property value due to Low Impact Development (LID) projects. The BCE tool was used to define a relationship between water-harvesting basin dimensions and benefit value.

Avoided Grey Infrastructure – Potential savings are realized in large-scale flood mitigation infrastructure if GSI retention is taken into account in sizing detention basins, storm drains, or culverts. Values used in the CBA are based on the cost estimates of proposed grey infrastructure alternatives for the Airport Wash area and conservative estimates of savings.

Indirect Benefits

Social Value of Water Conservation – The indirect cost of water is determined by the cost of water extraction and purification from alternative water sources. This represents the cost to provide water if a Central Arizona Project shortage is declared and new sources of water are accessed. The cost of water from alternative sources was found in "Arizona's Next Century: A Strategic Vision for Water Supply Sustainability." It was assumed that the cheapest sources would be used first.

Greenhouse Gas Emissions Reduction – The carbon reduction value from the BCE was calculated by subtracting the carbon emissions emitted during construction from the total benefits of decreased energy use in lifetime maintenance for the project and the carbon sequestration as a result of tree plantings. The average value for carbon emissions utilized based on BCE research is $50/metric ton.

Flood Risk Reduction – The flood risk reduction value is based on water that is retained by water-harvesting basins. The BCE [31] models rainfall in Tucson over the next 100 years to determine a rainfall model that is used to determine flood damages that are mitigated by the reduced runoff volume associated with active and passive rainwater harvesting.

[27] McPherson, E.G., J.R. Simpson, P.J. Peper, S.E. Maco, Q. Xiao, and E. Mulrean. Desert Southwest Tree Guide: Benefits, Costs, and Strategic Planting. Arizona Community Tree Council: Phoenix, Ariz., 2004.
[28] McPherson, E.G., and Muchnick, J. Effects of Street Tree Shade on Asphalt Concrete Pavement Performance. Journal of Arboriculture, Vol. 31, No. 6, November 2005.
[29] Anderson, L.M. and Cordell, H.K. Influence of Trees on Residential Property Values in Athens, Georgia (U.S.A.): A Survey based on Actual Sales Prices. Landscape and Urban Planning, Vol. 15, 1988.
[30] Parker, J. and Meyers, R. (2015). Business Case Evaluator A Value and Risk Based Enhancement to Envision User & Documentation Manual. Impact Infrastructure.
[31] Business Case Evaluator. http://www.impactinfrastructure.com/businesscaseevaluator/

CAP and Groundwater Pumping – In Tucson, we receive about 20% of our water from groundwater sources and 80% from the Central Arizona Project (CAP). The energy used to source and treat one gallon of water from each of these sources is 0.0139 kWh for CAP water and 0.0013 kWh for groundwater.[32] The average cost for 1 kWh of energy in Tucson is $0.0969.[33] This number was used to determine the value of water-harvesting features that require no additional energy input.

Stormwater Pollution Reduction – Water-harvesting basins and tree plantings provide the service of removing pollutants and heavy metals from runoff and treating them through natural filtration. There are regions in the southwest that have a stormwater utility fee that provides incentives for GSI implementation to meet stormwater management needs. Property owners who implement GSI have reduced utility fees as a means to incentivize GSI. These fee reductions for GSI represent the best local approximation of the economic benefits of stormwater pollution reduction from GSI. Costs are based on Oro Valley's fee structure of $2.90 per equivalent residential unit. [34]

Urban Heat Island – The urban heat island effect occurs in urban areas where temperature is often higher than that of surrounding rural areas. This is due to the density of impervious surfaces and lack of trees in urban areas, which allows heat to be stored and slowly released, keeping the surrounding air hotter for longer. This value was calculated based on the mitigation of deaths associated with heat stress related illnesses as calculated in the BCE. A benefit number can be calculated to express the value of GSI in the urban landscape based on the estimated value of a statistical life.[35]

Priority Project Identification

The location of GSI features were selected based on their proximity to important community resources such as schools, churches, or other community centers and the need for traffic calming. These project areas were then prioritized based on drainage complaints, GSI feature performance, and high flood risks in order to maximize the community benefits created.

1. **Community drainage complaints** were collected in a point file by CMG.[36] While the model simulates conditions, the experience and input of watershed residents was given high importance when identifying priority areas. There were 29 drainage complaint points in the shapefile from CMG. The complaints within close proximity were grouped as shown in Figure 23. There were six areas identified with more than one noted complaint, these are summarized in Table 10.

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[32] Energy Costs of Water (ECW) – U.S. Units: http://www.harvestingrainwater.com/water-energy-carbon-nexus/#Energy Costs of Water
[33] SW energy: http://www.swenergy.org/publications/factsheets/az-factsheet.pdf
[34] Oro Valley Storm Water Utility Service Fee Proposal: https://wrrc.arizona.edu/publications/water-harvesting/oro-valley-storm-water-utility-service-fee-proposal
[35] Impact Infrastructure, Stantec, 2014. Evaluation of GI/LID Benefits in the Pima County Environment, p. 29.
[36] CMG Drainage Engineering and Kimley Horn. Existing Conditions Report: Airport Wash (South) Basin Management Study. October 2014.
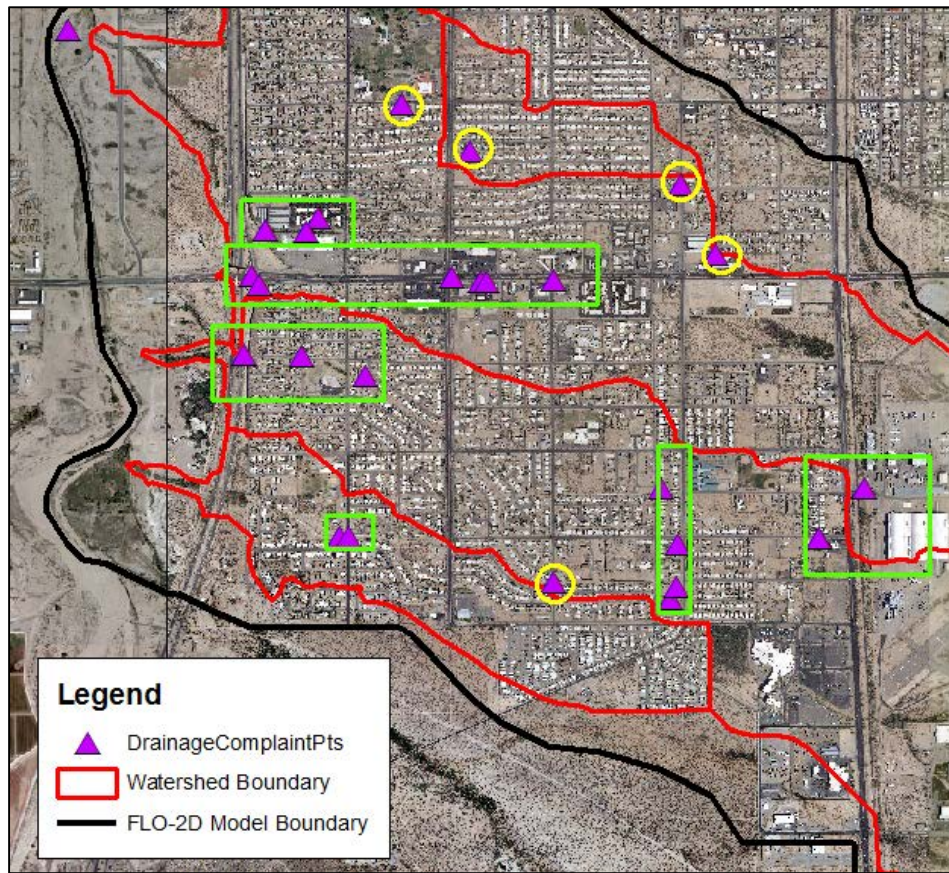
Figure 23. Drainage Complaints. Drainage complaints that were grouped are depicted by a green box while isolated drainage complaints are depicted with yellow circles.

Table 10. Drainage Complaint Critical Areas.

Number of Complaints	Area Description
7	Along Valencia Road
4	Between S Missiondale Rd and 6th Ave in the El Vado Watershed
3	Near Hope United Methodist Church
3	Around Southgate Academy, north of Valencia Road
2	Where Santa Clara Wash passes under Santa Clara Ave
2	Near the Pima County Community College

2. **GSI feature performance** was determined for the nuisance flooding events, the 2-year, and half inch storm simulations. GSI performance was evaluated based on the depth of water retained during the simulations. Cells that retained more than 0.2 and 0.5 feet of water during the half-inch and 2-year events, respectively, were considered effective. Approximately 5% of the GSI feature model cells from the 25% GSI Scenario retained 0.2 feet or more of water during the half inch storm event. Approximately 10% of the GSI model cells

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from the 25% GSI Scenario retained 0.5 feet or more of water during the 2-year storm. The location of these cells was used to create a heat map (Figure 24) using the kernel density function in ArcGIS. Higher values indicate a higher concentration of GSI model cells considered effective.
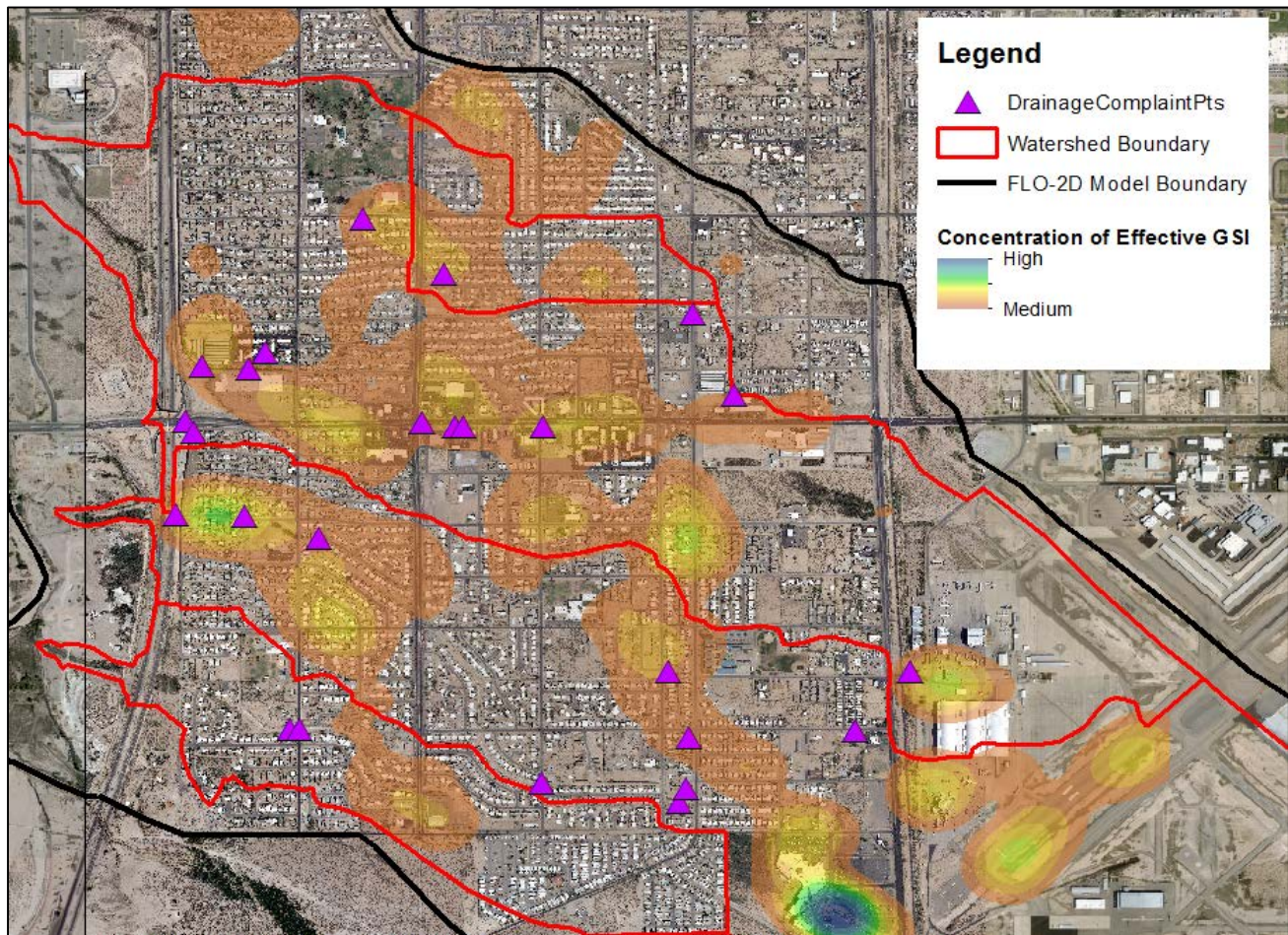

Figure 24. GSI Performance. The more green/blue the color, the higher concentration of GSI cells that detained significant flow during the half inch and 2-year storms.

Since the smaller events occur more frequently than the extreme 100-year event, Figure 24 shows the location of GSI features that will have a more noticeable local impact for the residents who install them and their neighbors.

The highest concentration of effective GSI was at the casino just west of Nogales Highway, intercepting airport runoff. As the casino is upstream in the El Vado watershed and intercepts significant flow from the airport runways, multiple GSI features were delineated on the property, including in a wash running through the parking lot and between the casino buildings. This resulted in the highest concentration of effective GSI cells. The next highest concentration occurred just west, and downstream of Hope Church where water from the El Vado Wash flows on W Medina Road. There are multiple areas in yellow and orange shown in Figure 24 that also indicate where the delineated GSI features were effective in retaining runoff.

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3. **High flood risk** as shown in the existing conditions model results was also considered. Figure 25 shows the model area with the drainage complaint groupings, the heat map of effective GSI, and model cells with significant flooding depths (shown in black). Significant flooding depths were considered from the 100-year and 2-year storm events. Maximum flood depths of greater than 1 foot during the 100-year storm and depths greater than 0.5 feet during the 2-year storm were considered significant.
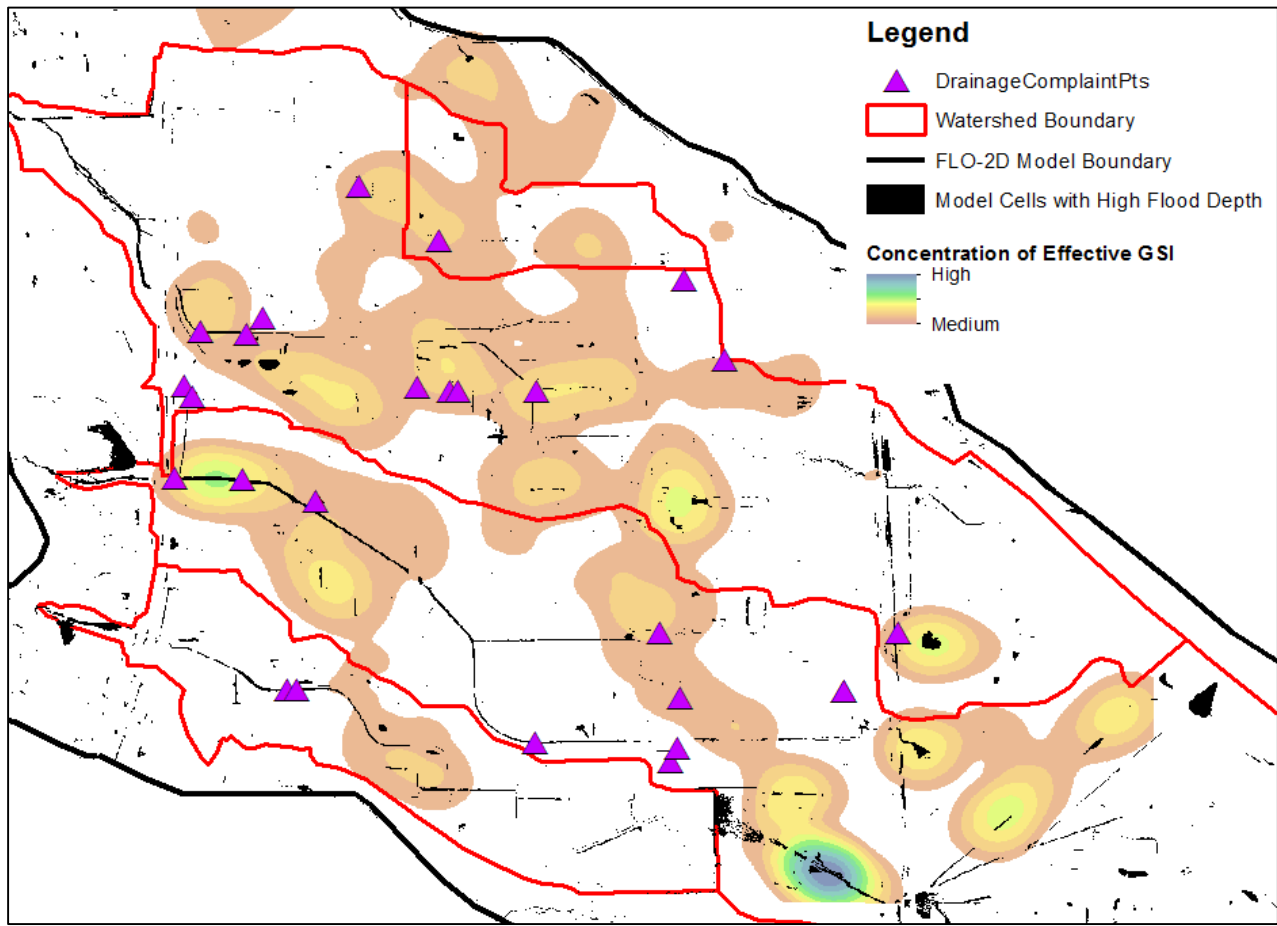

Figure 25. High Flooding Depths during the 100-year and 2-year storm events.

While some overlap is expected between high flood risk areas in the model simulations and drainage complaints, including them both ensures that high risk areas are not missed.

Priority Project Areas:

Based on these three parameters, the following list of five areas within the project area is recommended for immediate focus.

1. The area around Hope United Methodist Church.

While the model results show that some of the most effective GSI features were along W Medina Road west of the church, it is recommended to reduce the amount of water getting to W Medina and the church. This will help reduce the flood risk for these areas and decrease the likelihood of GSI placed along W Medina being overwhelmed in a flood. It is recommended to focus on the area immediately east and upstream of the church where the residential parcels flow into the El Vado

Wash (Figure 26). The GSI efficiency in this neighborhood indicate the potential to directly reduce the amount of water in El Vado Wash available to flood the church and W Medina. GSI implemented in this area would have a noticeable local impact as there are locations with high flood depths.

Utilizing residential and in-street GSI upstream of the church can cost effectively mitigate flooding impacts by also creating community benefits from shade and neighborhood beautification. This area could be redeveloped with GSI with seed funding from grants, private funders, and the Tucson Water Rainwater Harvesting Rebate Level 1 (Passive Systems) to demonstrate the effectiveness of GSI to mitigate flooding, promote water conservation, and improve neighborhood quality of life. Demonstration results should support the development of longer-term funding sources like a municipal GSI fund.
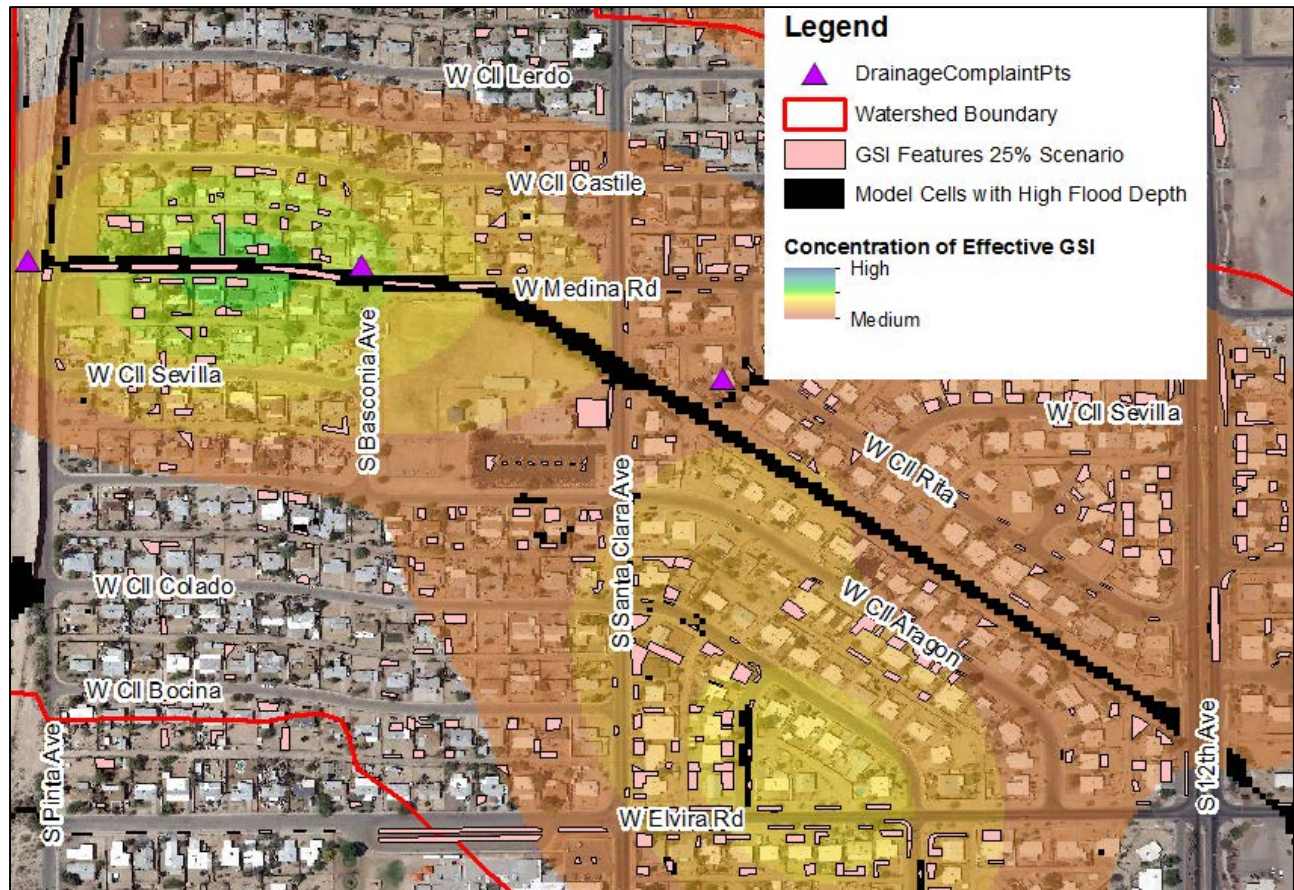

Figure 26. Area around Hope United Methodist Church.

2. Pima County Community College and Tucson International Airport

Pima Community College flooding can be mitigated through the use of GSI to reduce impervious surfaces leading to high flow events. Photographs from the 2011 flooding event depict this area flooded with up to 2 feet of water. The GSI implemented in this area of the model (Figure 27) were highly effective at capturing water. Given the documented flooding in this area and its location upstream in the Valencia and El Vado watersheds, water retained in this area would have a high local and downstream impact. To alleviate concerns of attracting birds and other airplane hazards in close proximity to the airport runways, the GSI could be designed as wide, shallow basins without trees or other tall vegetation. Closer to campus buildings, narrower and deeper basins can be designed within the more constrained space to allow for vehicle and pedestrian pathways while still

accomplishing flood mitigation objectives. The Aviation campus provides an excellent opportunity to create a living lab of aviation redesign for GSI. The features delineated in the modeling scenario are shown in Figure 27
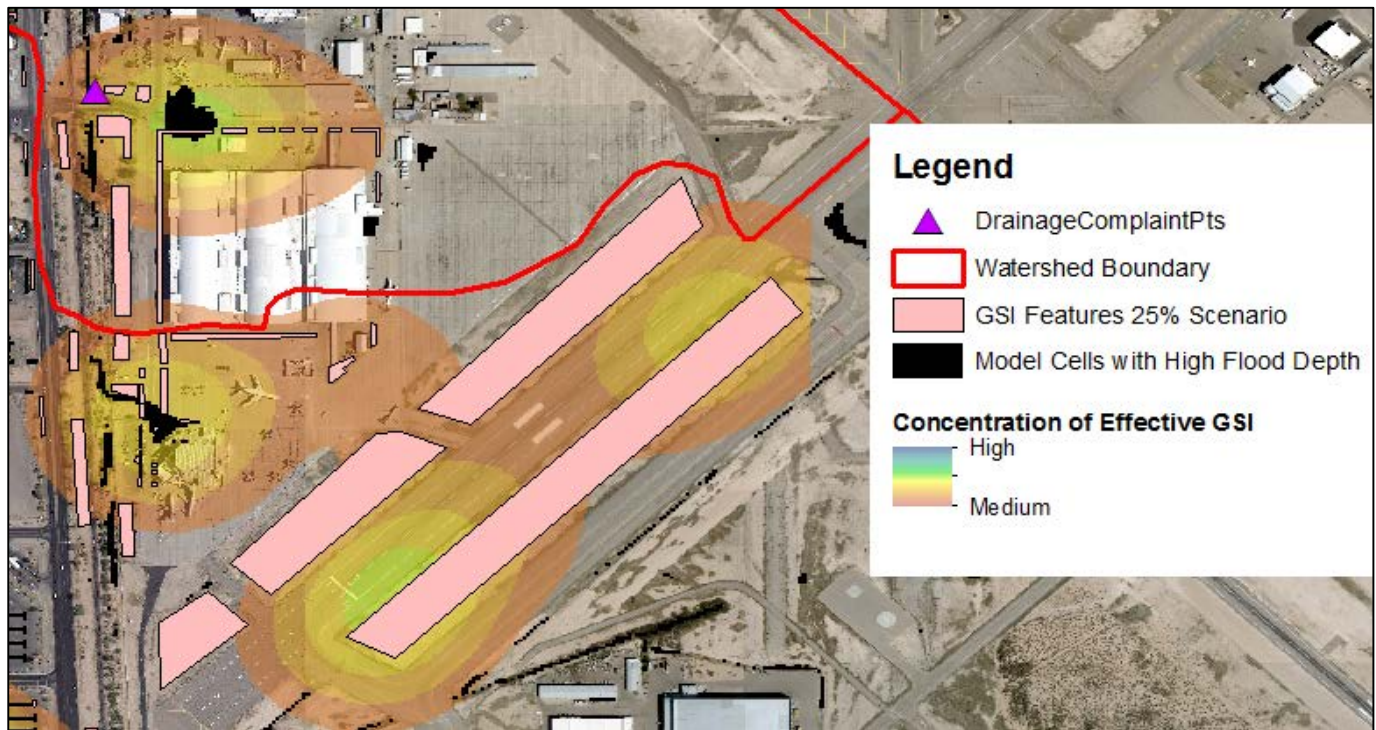

Figure 27. Community College and Airport.

3. Vicinity of S 6th Avenue and W Medina Road

This neighborhood, shown in Figure 28, shows some isolated high flood depths on residential parcels and drains to Valencia Road. Valencia Road has the highest collection of drainage complaints in the area and the neighborhood with S 6th Avenue and W Medina Road at its center is one of the largest concentrations of effective GSI.
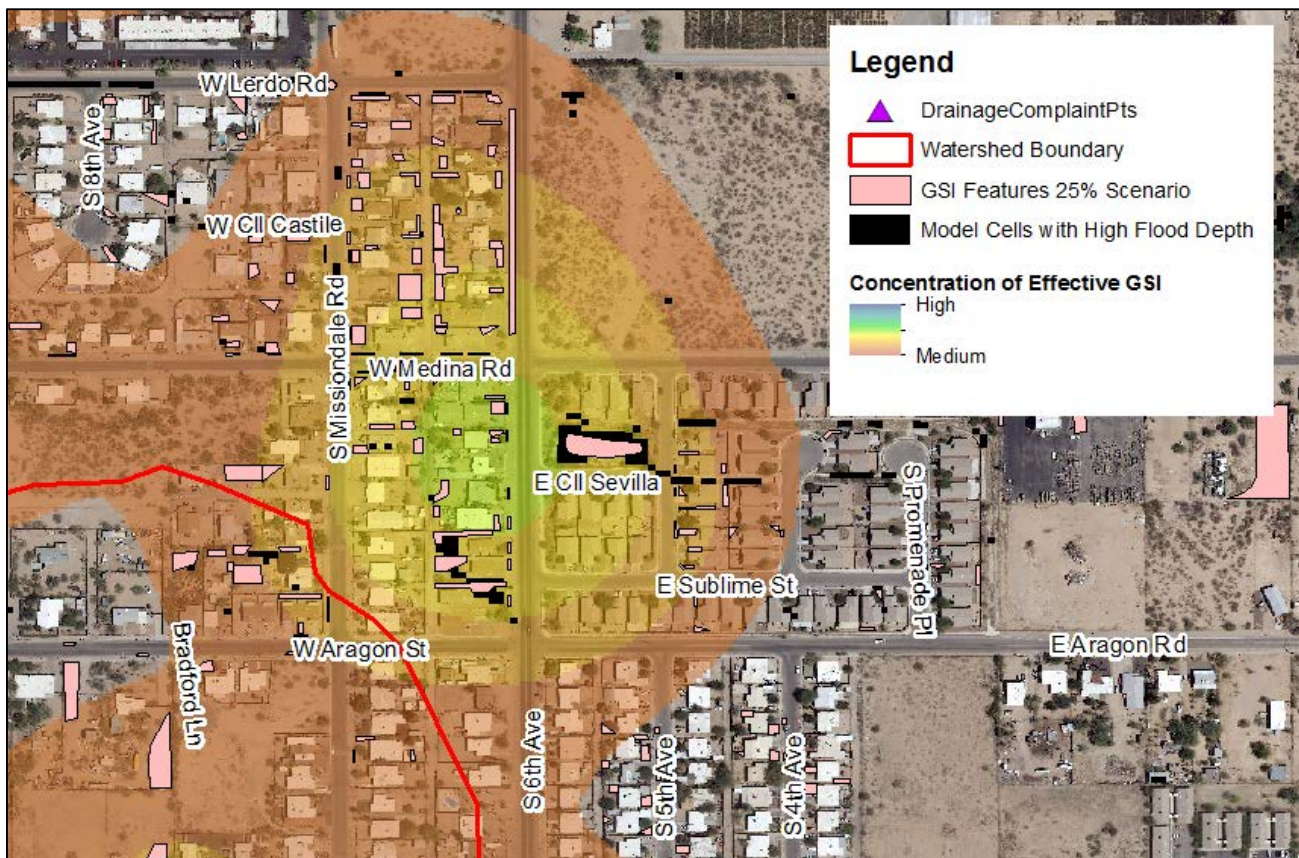
Figure 28. Residences in the Valencia Watershed near W Medina Rd.

4. Along Valencia Road

Although there is limited downstream impact for GSI implemented along Valencia Road, there is a high local impact. GSI in this area would have high visibility as the road is the main thoroughfare through the model area with multiple businesses and restaurants. The efficient GSI in the 25% GSI Scenario are shown in Figure 29 and include features along Valencia Road, in the Food City and McDonald's parking area, in the county public library, and two churches. Valencia Road should be redeveloped to comply with Tucson's Green Streets Active Practice Guidelines, and the businesses, residences, and community centers along the road should be targeted for short-term GSI implementation.
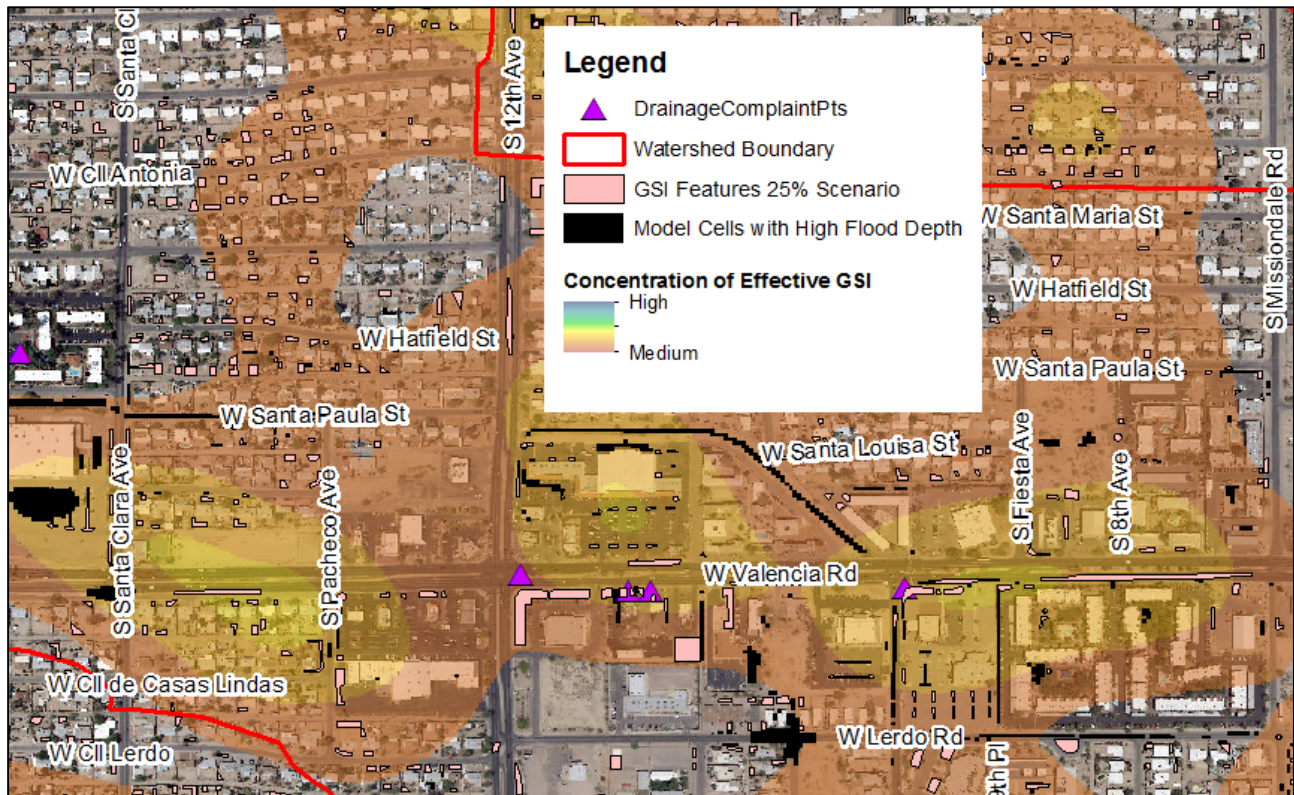
Figure 29. Valencia Road. Figure shows GSI efficiency (yellow/orange), high max flow depths (black), and the location of 25% scenario GSI (pink).

5. El Vado Watershed between S Missiondale Road and S 6th Avenue

There were four drainage complaints in the residential blocks between S Missiondale Road and S 6th Avenue, spanning the El Vado Watershed from north to south (Figure 23). The modeling of existing conditions shows that the average and maximum water depth on one representative block in this area are 0.1 and 0.8 feet, respectively, during the 2-year storm. For the same representative block, residents would be under an average and maximum water depth of 0.5 and 1.5 feet during the 100-year event, respectively. GSI implemented on these parcels would help keep water out of these homes and reduce stormwater volumes downstream at Hope Church. GSI throughout this area would have a high downstream impact but the parcels with higher flood depths and greater GSI efficiency can be targeted for initial action. The areas with good GSI efficiency are shown in Figure 30.
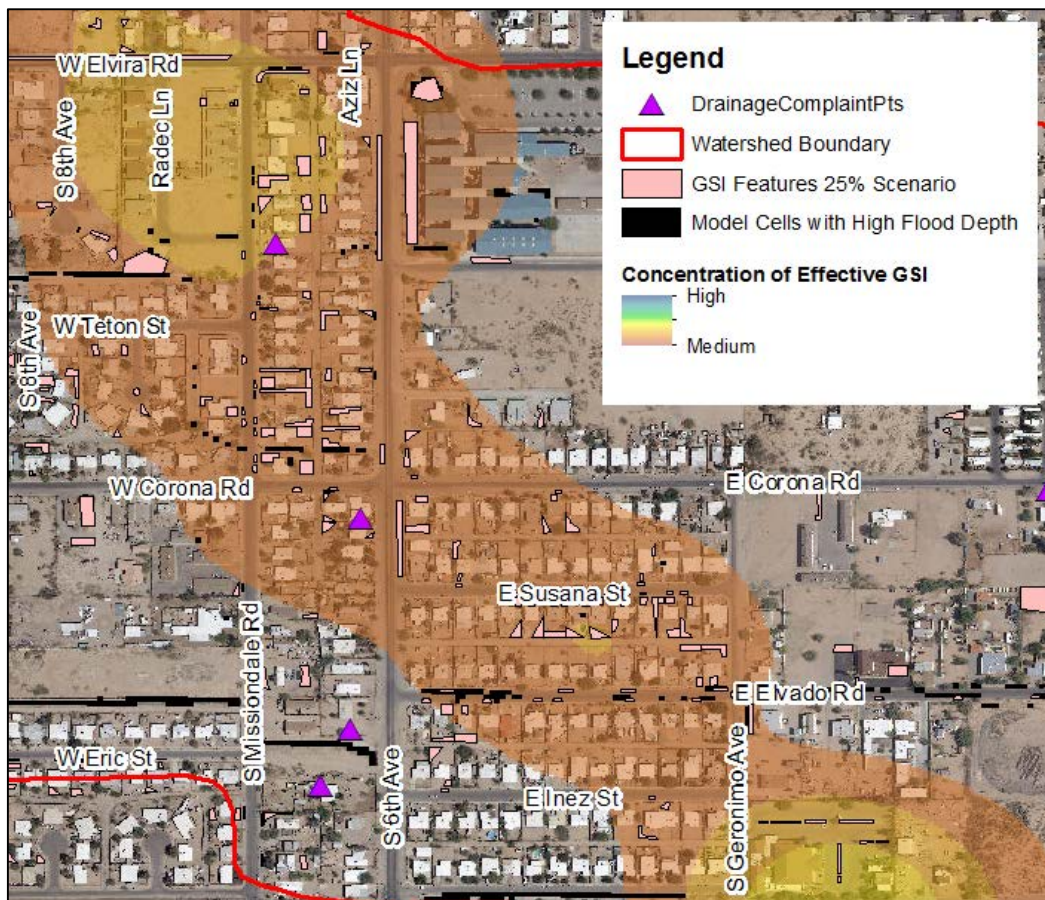
Figure 30. Missiondale Road. Figure shows GSI efficiency (yellow/orange), high max flow depths (black), and the location of 25% scenario GSI (pink).

Management and Policy Implications

Although GSI has been demonstrated by various projects throughout the community at residential, commercial, and community sites, and neighborhood to arterial roadways, it has not been integrated into the core planning processes for Tucson. Below are recommendations to increase adoption and utilization of GSI in the Tucson region.

Short-Term Approaches (present to 2+ years)

1) Maintain City of Tucson Commercial Rainwater Harvesting ordinance. This ordinance has begun the slow transformation of new or redeveloped commercial sites to begin integrating GSI components. The ordinance should be reviewed to assess effectiveness from both a stormwater and a water conservation perspective.

    a. Development of GSI best practice guidelines will help inform landscape development to better address water quality and urban heat island issues.

    b. Current maintenance practices are detrimental to GSI. A GSI maintenance plan incorporating GSI best practices should be developed to ensure the site can achieve and exceed stated infrastructure performance goals as the site matures.

2) Maintain City of Tucson's Green Streets Active Practice Guidelines. This policy is critical to ensure future roadway projects integrate GSI starting at the initial planning stages. Periodic review of this policy is needed to ensure its effectiveness over time.

3) Maintain and improve passive rainwater-harvesting incentive programs. The Tucson Water Rainwater Harvesting Rebate program is critical to raise awareness and incentivize the effectiveness of rain gardens for personal and community benefits. This rebate is currently the only incentive for individual property owners in the City of Tucson to implement systems that have both a water conservation and stormwater reduction potential among myriad other benefits. Metro Water also has an incentive program for water harvesting for its customers.

4) Develop neighborhood-scale demonstrations in targeted areas recommended in the Project Priority Identification section. Identify funding and develop GSI projects around and upstream of community centers such as schools, churches, and parks currently experiencing flooding to optimize benefits.

5) Valencia Road is slated to be redeveloped through the Regional Transit Authority and as such will be subject to the Green Streets Active Practice Guideline policy. Effective engagement of water-harvesting professionals with this process will ensure appropriate design and placement of water-harvesting features in the landscape to achieve verifiable benefits.

6) Develop a GIS-based GSI opportunity prioritization tool. A GIS-based tool could assist with GSI project identification and targeted outreach for the region.

Placement of GSI affects the stormwater and flood mitigation effectiveness of the feature. Identifying opportunities, assessing the effectiveness, and prioritizing development of GSI features can be automated given high-quality elevation data available. In retrofit scenarios GSI features should be placed in locations where water naturally collects.

Identifying these locations can be accomplished by utilizing a GIS-based flow accumulation analysis or by selecting grid cells modeled with a significant maximum flow depth. All of these methods require high-quality digital elevation models (DEM) that will depict realistic flow lines. For urban areas, the resolution must be fine enough to capture flow constraining features such as street curbs or a ground-based effort should verify flow paths.

The first round of selected site opportunities can be further filtered utilizing additional data layer information (e.g. utility location, street widths, etc.) or overlaid with community needs (e.g. PAG's Shade Map Prioritization Tool). In addition, the automatic selection of potential GSI locations would need to be examined for practicality (e.g. availability of land, utility constraints, property ownership, etc.). This could also be automated if there is a spatial layer to define desired or undesired land types or features. For example, the potential GSI locations could be refined to only include points on residential parcels with soils suitable for infiltration or refined to not include points on top of river or wash lines.

Medium-Term Approaches (2 to 5 years)

7) Develop a City of Tucson Green Infrastructure Fund. It is critical that a sustained financing mechanism(s) is created to a) implement and care for GSI along ROWs to ensure infrastructure performance and b) incentivize private property retrofits. This "Green

Infrastructure Fund" could be developed and administered similarly to the "Water Conservation Fund" administered by Tucson Water with an advisory committee. Alternatively, a municipal stormwater utility could be developed. However, based on other stormwater utility examples, it may require a more expansive scope thus reducing the funding effectiveness to focus on GSI.

Long-Term Approaches (5+ years)

8) Scale the GSI-based scenario assessments to include arroyo and floodplain enhancements. Floodplain connection of arroyos is critical to dissipate energy, reduce flood peaks, filter non-point source pollutants, and support xeric-riparian vegetation. Due to hydraulic modeling and budget constraints, the potential stormwater benefits of arroyo and floodplain enhancements could not be assessed at this time. Several opportunities were identified to restore floodplain connection to urban drainage ways to further reduce downstream flood risks.

Conclusions

Hydraulic modeling and cost benefit results highlight the need for taking a different approach to stormwater management. The following are the resulting conclusions based on the study results:

- GSI can have a noticeable difference on the flood volumes and peak flood flows in extreme storm events
- Even a low adoption rate, ~10%, can address nuisance flood flows
- Investment in GSI has a strong community payback
- Long-term sustained funding is critical to increase adoption in already developed urban areas

Pima County has made great strides in moving forward new development regulations and guidelines to utilize green stormwater infrastructure. However, retrofitting developed urban areas needs to be made a priority to address myriad community issues. This study demonstrates the potential of GSI to provide a community payback and validates the necessity of making that investment now.

Next Steps

In order to continue the advancement of implementation of GSI, the following are next steps that need to be addressed:

- Refine assumptions by field tests for infiltration
- Quantify the benefits of understory plant function and appropriate rain garden care
- Quantify urban habitat and tourism economic value created
- Quantify water quality impacts for GSI neighborhood-scale demonstration projects
- Develop funding scenarios for GSI fund
- Build capacity for GSI fund implementation
- Study flooding and CBA of arroyo and floodplain enhancements
- Investigate the potential for enhanced aquifer recharge through natural channel design projects along urban washes