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Hassayampa River Study Assessing Low Impact Development for Stormwater Management



Cover Photo: Hassayampa River Valley (Reclamation Resource Assistant Intern Chloe Killian)

Final Report

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Hassayampa River Study Assessing Low Impact Development for Stormwater Management

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Mission Statements

The U.S. Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its trust responsibilities or special commitments to American Indians, Alaska Natives, Native Hawaiians, and affiliated Island Communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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- Mark Frago, FCDMC
- Peter Acton, JE Fuller

Disclaimer

The information being offered herein represents the opinion of the author(s). It has not been formally disseminated by the U.S. Bureau of Reclamation. It does not represent and should not be construed to represent Reclamation's determination or policy.

Acronyms and Abbreviations

ADWR	Arizona Department of Water Resources
AMA	Active Management Area
Amsl	Above mean sea level
ASCO	Arizona State Climate Office
AGWA	Automated Geospatial Watershed Assessment
BTM	Benefit Transfer Method
CSI	Conventional Stormwater Infrastructure
CMP	Community Master Plan
DDMSW	Drainage Design Management System for Windows
DEM	Digital elevation model
DOI	U.S. Department of the Interior
e.g.	for example
EPA	U.S. Environmental Protection Agency
°F	Fahrenheit
FAC	Federal Acquisitions Circular
FCDMC	Flood Control District of Maricopa County
FEMA	U.S. Federal Emergency Management Agency
GIS	Geographical Information System
GSI	Green Stormwater Infrastructure
HEC-1	Hydrologic Engineering Center 1, U.S. Army Corps of Engineers
HUC	Hydrologic Unit Code (USGS)
K2	Kinematic Runoff and Erosion Hydrologic model
LID	Low Impact Development
MAF	million acre-feet
MPC	Master Planned Communities
NED	National Elevation Dataset
NOCD	Number of Check Dams
OM&R	Operations, Maintenance and Replacement
O&M	Operations and Maintenance
PCSWMM	Personal Computer Storm Water Management Model
PXAO	Phoenix Area Office
Reclamation	U.S. Bureau of Reclamation
ROW	Right-of-way
SV ADMP	Sun Valley Area Drainage Master Plan
SWAT	Soil and Water Assessment Tool
TSC	Technical Service Center
USGS	U.S. Geological Survey
WSRV	West Salt River Valley

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1 Introduction

1.1 Background

The Hassayampa River Study - Assessing Low Impact Development for Stormwater Management study (Study), investigated and compared the impacts of theoretical use of Low Impact Development (LID) and conventional stormwater infrastructure (CSI) to manage stormwater in a regional watershed and hypothetical development within the City of Buckeye, Arizona (Buckeye). The study area is on an alluvial fan on the west side of the White Tank Mountains in an area where residential development is expected ([Figure 1](#)). The Study also assessed LID Operations and Maintenance (O&M) practices and costs, completed an economic analysis of LID and CSI, developed a Buckeye LID design manual, and a high-level conceptual water budget.

Green Stormwater Infrastructure (GSI) is defined by the Environmental Protection Agency (EPA) as a range of nature-based solutions used to manage, harvest and reuse stormwater. LID is a type of GSI that uses site-specific designs and a series of nature-based engineering and development features that work within the natural landscape to minimize impervious built infrastructure to manage stormwater runoff near its source (EPA, 2023). LID has been shown to reduce flood risk and urban heat, increase infiltration and ecosystem services and improve air and stormwater quality (USBR, 2020) and promote distributive infiltration in the built watershed. LID may be used in Smart Growth, Green Building, and assist in Clean Water Act compliance.

Traditionally, Conventional Stormwater Infrastructure (CSI) have been used to manage stormwater by consolidating flows into one or more wide, man-made, straight impervious channels to convey water away from developed areas. CSI uses engineered systems of storm drains, pipes, and ditches to convey stormwater flows to retention basins or natural drainages where erosion may be exacerbated. CSI stormwater management practices may modify and reduce natural distributive infiltration and groundwater recharge by concentrating and conveying stormflows into channelized systems that convey stormwater away from developed areas or into stormwater basins.

Arizona is currently in a long-term drought. State, county, and city governments in the arid west seek to optimize management of local water resources. The ongoing drought escalated awareness and magnified the need for innovative water management approaches. The use of nature-based stormwater management practices has increasingly drawn interest as a forward-thinking solution to potentially augment community water supplies in the arid southwest.

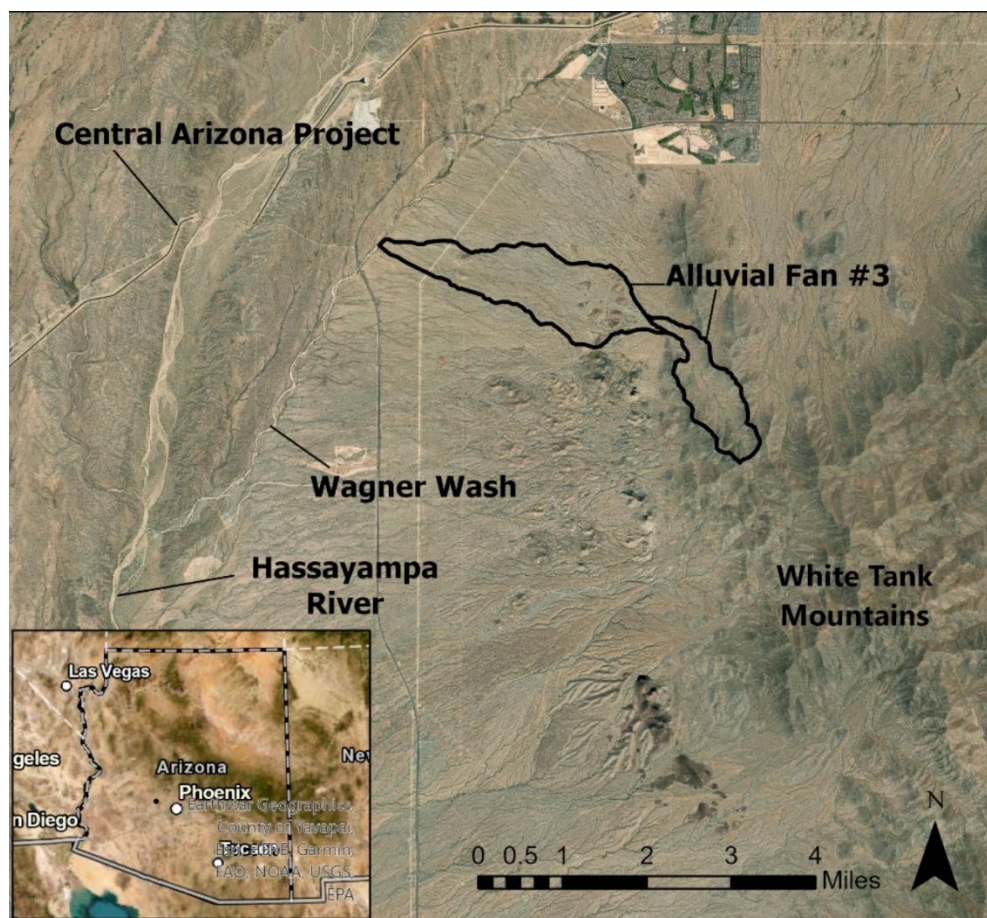


Figure 1. Study Area

Current stormwater management trends indicate that local communities and non-municipal entities in Arizona may implement new or expand their current use of GSI/LID. Buckeye, like other communities, is interested in identifying, understanding, and potentially implementing nature-based stormwater management.

Buckeye is identified as one of the fastest growing municipalities in Arizona, and in the entire United States (U.S.). According to the U.S. Census Bureau, Buckeye's population grew from approximately 50,000 residents in 2010 to over 90,000 in 2020. In May 2020, Buckeye was identified as the 2nd fastest growing city in the U.S. Planned development in Buckeye is projected to support a buildout population of over 1.5 million and would result in Buckeye being the second largest city in Arizona after the City of Phoenix. As such, Buckeye is proactively exploring management strategies to help support water demands associated with the anticipated growth.

Buckeye's General Plan – Imagine Buckeye 2040 supports plans for an innovative, healthy, and resilient community while being good stewards of its natural resources, open spaces, and overall quality of life (Buckeye, 2022). Prior to the financial crisis in 2007 and 2008 and the subsequent Great Recession, the City of Buckeye had approved 26 Community Master Plans (CMPs). Although development slowed during the recession, new construction in the region is underway. This Study assesses the use of LID to manage stormwater while respecting the existing CMP entitlement

designations. This Study designed a hypothetical development within a portion of the 2005 Sun Valley Villages I and II CMP (Carter & Burgess Inc. 2005) that was used for surface water modeling of theoretical GSI and CSI for stormwater management.

In June 2023, the Arizona Department of Water Resources (ADWR) published the Groundwater Flow Model of the Phoenix Active Management Area (AMA). Buckeye is located within the Phoenix AMA. The ADWR model results show that over 100 years, the total demand in the Phoenix AMA is about 140-million acre-feet (MAF) and that there is an unmet demand of 4.9 MAF (ADWR, 2023). In 100-years, the depth to groundwater along the edges of the Phoenix AMA may reach 1,000 feet below land surface or bedrock. In Buckeye, there are sufficient water supplies available for existing residences and current residential construction and development that have approved and assured water allotments however, there is uncertainty about the availability of water for future development.

1.2 Study Authority, Duration, and Funding

This Study is conducted pursuant to the Act of Congress approved June 17, 1902 (32 Stat. 388), and acts amendatory thereof or supplementary thereto, all of which are commonly known and referred to as Reclamation Law, the Act of March 4, 1921, referred to as the Contributed Funds Act, and Public Law 115-31, and the Consolidated Appropriations Act of 2017.

The Bureau of Reclamation and the City of Buckeye entered into an agreement for this Study on November 25, 2020.

Funding consists of 50 percent federal and 50 percent non-federal cost share. The total estimated cost of this Study is approximately \$540,000 with Reclamation contributing \$270,000 and Buckeye contributing a minimum of \$270,000 through cash and in-kind services.

1.2.1 Partners, Participants, and Contributions

Reclamation and Buckeye partnered on this Study. Partner roles are shown in [Table 1](#). Study planning, oversight and tasks were completed by a Study Team consisting of representatives from Reclamation, Buckeye, the U.S. Geological Survey (USGS), Flood Control District of Maricopa County (FCDMC), and Buckeye's contractors Logan Simpson Design Inc., and Kimley-Horn. Members of the Study Team and task contributions are shown in [Table 2](#).

Table 1. Study cost share partners and roles

Bureau of Reclamation (Reclamation)
Study Manager. Provide Study task oversight. Compile and review data and information, coordinate and organize meetings, prepare summary reports. Use Geographic Information System (GIS) to depict Study Area, provide Study maps and information for analyses. Prepare and run surface water flow model. Prepare final report.

Bureau of Reclamation (Reclamation)
City of Buckeye
Study Partner. Assist with collaborative Study process. Compile and review data and information. Attend meetings. Assist with report preparation. Provide review and approval of Study tasks and work products.

Table 2. Study participants and contributions

City of Buckeye		
Name	Title	Task(s)
Adam Copeland	Deputy Director of Planning	Study Team. Provide assistance, reviews and approvals.
Amy Murray	Environmental Compliance Officer - Stormwater	Study Team. Provide assistance, reviews and approvals.
Bobby Anastov	Environmental Manager, Water Resources	Study Team. Provide assistance, reviews and approvals.
Denise Garcia	Project Engineer	Study Team. Provide assistance, reviews and approvals.
Hobart "Bart" Wingard	Principal Planner	Study Team. Provide assistance, reviews and approvals.
Josh Ford	Project Engineer	Study Team. Provide assistance, reviews and approvals.
Mariah Cathey	Water Resource Specialist	Study Team. Provide assistance, reviews and approvals.
Robert Eroh	Project Engineer	Study Team. Provide assistance, reviews and approvals.
Robert van den Akker	Environmental Manager, Public Works	Study Team. Study Lead for Buckeye. Provide assistance, reviews and approvals.
Robert Wisener	Conservation and Project Manager	Study Team. Provide assistance, reviews and approvals.
Scott Lowe	Public Works Director	Study Team. Provide assistance, reviews and approvals.
Terry Lowe	Water Resources Director	Study Team. Provide assistance, reviews and approvals.
FCDMC		
Name	Title	Task(s)
Lynndsay O'Neill	Senior Planner, Planning Branch	Study Team, BOR/FCDMC model subgroup.
Mark Frago	Project Manager, Planning Branch	Study Team, BOR/FCDMC model subgroup.
Nicholas Balik	Water Resources and Conservation Planner	Study Team, BOR/FCDMC model subgroup.

Logan Simpson		
Name	Title	Task(s)
Trace Baker	Senior Associate	Buckeye contractor. Complete LID Operations and Maintenance Assessment, prepare report.
Wayne Colebank	Principal/Landscape Architect	Buckeye contractor. Oversight LID Operations and Maintenance Assessment.
Reclamation		
Name	Title	Task(s)
Deborah Tosline	Hydrologist	Study Manager. Coordination with Study Team. Oversight, planning and execution of Study tasks.
Edward St. Pierre	Water Resource Specialist	Study Team. Assist with Study Interim and Economic Analysis report preparation.
Jasmine "Chloe" Killian	Resource Assistant Intern Direct Hire Authority Program	Study Team. Complete Economic Analysis of GSI, CSI, and Technical Memorandum.
John Rasmussen	Program Manager, Water Resources	Study Team. Lead on conceptual water budget.
Kelleen Lanagan	Physical Scientist, Applied Hydrology	Study Team. Model Subgroup. Develop and run surface water model, prepare report.
Lindsay Bearup	Civil Engineer (Hydrologic), Applied Hydrology	Study Team. Model Subgroup. Develop and run surface water model, prepare report.
Lisa Rivera	Natural Resource Specialist	Study Team. Lead O&M Assessment. Assist with economic analysis, LID design manual and report preparation.
Valerie Swick	Planner, Water Resources	Study Team. Lead on surface water model. Design and develop hypothetical developments, report preparation.
USGS		
Name	Title	Task(s)
Laura Norman	Supervisory Research Physical Scientist	Study Team. Model Subgroup. Design and develop surface water model for regional watershed.

1.3 Study Area

The Study area is approximately 30 miles west of downtown Phoenix and is located on alluvial fans on the west side of the White Tank Mountains in Buckeye, Arizona, ([Figure 1](#)). Buckeye currently encompasses 392 square miles with a planning area of over 600 square miles. This Study assessed stormwater management within Alluvial Fan No. 3 (Fan No. 3) designated by the FCDMC in the

2006 Sun Valley Area Drainage Master Plan (SV ADMP) (JE Fuller Hydrology and Geomorphology et al., 2006).

The Study area is located within the Sonoran Desert, in a predominantly shrubland ecosystem. Topographic relief within the Lower Hassayampa Sub-Basin region ranges from about 700 feet above mean sea level (amsl) to about 4,000 feet amsl (Brown and Caldwell, 2010). Buckeye has an arid/semi-arid climate, with an average annual precipitation in the Study area of about 6.02 over 37 years (FCDMC, 2023). The seasonal precipitation pattern is bi-modal, with precipitation occurring during the winter months (December through March) and during the monsoon season (June through September).

Arizona has been in a long-term drought since 1994 (ASCO, 2023). While variable precipitation is normal in the Study area, drought is indicated by a string of dry years with occasional interspersed wet years. Weather information collected from 1997 through 2022 at the FCDMC Buckeye FRS No. 1 weather station, show an all-time high of 123 Fahrenheit (°F) and low of 20 °F. (FCDMC, 2023).

At the time of this report, existing development in the Study area is concentrated in the area north of Fan No. 3. Land within the study area is primarily undeveloped, however, new development is currently in various stages of permitting and infrastructure planning for construction.

1.4 Research Questions

This Study assesses the effectiveness and costs of theoretical stormwater management using GSI and CSI alternatives in a regional watershed and in a hypothetical development:

- GSI alternative
 - GSI regional watershed scenario
 - GSI hypothetical development scenario
- CSI alternative
 - Conventional regional watershed scenario
 - Conventional hypothetical development scenario

The Study attempted to answer the following questions:

1. *Does GSI reduce stormflow peaks and promote distributive infiltration in a regional watershed?*
2. *Does GSI reduce stormflow peaks and promote distributive infiltration in a hypothetical development?*
3. *How do installation, O&M, and replacement costs for GSI compare to costs for CSI ?*
4. *How does the use of GSI and CSI impact infiltration in the study area?*

1.5 Stakeholder Meetings

Three stakeholder meetings were conducted during the duration of the Study. The initial meeting introduced the Study, the interim meeting summarized work completed to date and introduced the final tasks, and the final meeting summarized the results of the remaining tasks. Copies of each of the stakeholder presentations are provided in [Appendix 1](#).

1.5.1 Initial Stakeholder Meeting

The initial stakeholder meeting occurred in August 2021. There were 36 attendees including Study partners and representatives from Maricopa County Parks and Recreation Department, the Bureau of Land Management, the White Tank Mountains Conservancy, Central Arizona Conservation Alliance, The Nature Conservancy, Arizona Department of Transportation, Arizona State Land Department, Arizona State University, Global Water Resources, George Cairo Engineering, WVSU Holdings, Arizona Public Service, and the Lower Gila River Water Association.

During the initial stakeholder meeting Low Impact Development (LID) and Green Stormwater Infrastructure (GSI) were defined. An overview of the Study was provided including Study area selection, data compilation, and use of the FCDMC SV ADMP data and information. Study tasks were introduced including development of the GSI and CSI model scenarios and surface water model. Planning was described for the LID Operation and Maintenance (O&M) assessment, the Buckeye LID Design Manual, an economic analysis and a conceptual groundwater model to assess groundwater recharge associated with LID.

Copies of the initial stakeholder meeting agenda, presentation, and a list of attendees are provided in [Appendix 1](#).

1.5.2 Interim Stakeholder Meeting

The interim stakeholder meeting was held in January 2023. There were 50 attendees including Study partners and representation from the Arizona Department of Transportation, Arizona Department of Water Resources, Arizona Department of Environmental Quality, Arizona State University, Salt River Pima-Maricopa Indian Community, Bureau of Land Management, City of Buckeye, Reclamation, Environmental Protection Agency, Federal Emergency Management Agency, FCDMC and Baker Contracting, LLC.

The interim stakeholder meeting provided information regarding development of the surface water models to assess the hydrologic impacts of theoretical stormwater management scenarios. Results from the LID O&M assessment were presented. Status updates were given for the Buckeye LID Design Manual, an economic analysis of GSI and CSI scenarios, and potential preparation of a high-level conceptual water budget.

Copies of the interim stakeholder meeting agenda, presentation, and a list of attendees are provided in [Appendix 1](#).

1.5.3 Final Stakeholder Meeting

The final stakeholder meeting was held in December 2023. There were 36 attendees including Study partners and representation from the Arizona Commercial Real Estate Community, Arizona Department of Environmental Quality, Arizona Department of Water Resources, Arizona Municipal Water Users Association, ASU Sustainable Cities Network, Center for the Future of Arizona, City of Buckeye, Flood Control District of Maricopa County, Gila River Indian Community, Maricopa County Parks and Recreation, and the U.S. Geological Survey.

During the final meeting a brief overview of the Study was provided. Status updates were presented including surface water model results for the GSI and CSI model scenarios. Draft results of the economic analysis and Buckeye's LID Design Manual were provided. It was stated that the high-level conceptual water budget task would not be completed due to lack of resources.

Copies of the final stakeholder meeting agenda, presentation, and a list of attendees are provided in [Appendix 1](#).

2 Tasks

Study tasks included: data compilation, preparation of GSI and CSI hypothetical development designs, surface water model development, infiltration testing, LID O&M assessment, an economic analysis, development of Buckeye's LID Design Manual and preparation of the final report.

2.1 Data Compilation

Existing data and information compiled during development of the surface water models included: GIS layers and maps, aerial photography, historic flood and hazard reports, streets and transportation infrastructure, zoning information, storm drain as-built plans, land use data, wildlife corridor information, CMP descriptions and maps and weather and soils data.

FCDMC's 2006 SV ADMP identified boundaries for alluvial fans located on the west side of the White Tank Mountains and modeled the CSI regional stormwater management alternatives for select fans. At the time of this report the FCDMC has updated the SV ADMP regional stormwater management alternatives and developed a new surface water model for the region. FCDMC provided model files and pertinent GIS files and reports from both the 2006 and current SV ADMP investigations.

Buckeye provided GIS files and references including standards and criteria from their Storm Water Drainage System Design Manual (Buckeye Public Works Department, 2012), Street Planning and Design Criteria (Buckeye, 2007) and a Community Master Plan for Sun Valley Villages I & II (Carter & Burgess Inc., 2005), a proposed development within the Study area.

The Buckeye Storm Water Drainage System Design Manual (Buckeye, 2007) was used as guidance when modeling the theoretical GSI and CSI alternatives. GSI stormwater management regulations were not available.

The LID O&M assessment conducted a reference search for GSI and LID implemented in the arid southwest.

Unit costs taken from the 2006 SV ADMP and a local drainage study by the City of Phoenix (JE Fuller, 2018) were used to develop an economic analysis of theoretical GSI and CSI features modeled in the Study.

2.2 GSI/LID and CSI features

In preparation for the surface water modeling task, GSI and CSI feature types were selected for theoretical stormwater management scenarios in a regional aquifer and in a hypothetical development. The FCDMC 2006 SV ADMP contains design dimensions, diagrams, and unit costs for a variety of CSI stormwater management features including gabions which were used as drop structures to slow stormflow velocities within walled-levee stormwater corridors. Gabions were used as GSI/LID to slow and infiltrate stormflows from the top to the bottom of select drainages within the regional watershed and in the hypothetical development. Gabions are a type of rock detention structure, composed primarily of rock material and are installed to *detain* water for a short period of time rather than *retain* water permanently (Norman 2020).

2.2.1 GSI/LID features

Gabion features were selected by the Surface Water Modeling team and approved by the Study Team for use in the GSI/LID alternative to theoretically manage stormflows in the regional watershed and in the hypothetical development. Culverts were required at each GSI channel road crossing.

A gabion consists of a wire-mesh basket or box filled with rock, broken concrete or other debris installed within a drainage channel to slow water flows. Gabions are tied into the channel sides and bottom to minimize erosion around the structure. Gabions are designed as flow through structures intended to slow water flows (*detain*).

Culverts were required at each GSI channel road crossing. Concrete box culverts with wing-walls were selected for channel road crossings. A culvert is a structure that conveys and maintains water flows under a road or bridge in a natural channel or a drainage canal.

The number of theoretical gabions used in the GSI regional watershed and hypothetical development scenarios were estimated using the Number of Check Dams (NOCD) formula (Soil Management of India, 2023):

$$\text{Number of Check Dams} = \frac{L(S_i - S_e)}{h}$$

Where:

L: Length of swale (m)

Si: Initial existing slope of ratio of the swale (rise/run)

Se: Desired effective slope of the enhanced swale (between 0.005 – 0.01, rise/run)

h: The average effective height of the check dams in m (excluding foundations)

The dimensions of the theoretical gabion installations used in the GSI regional watershed scenario were taken from the 2006 SV ADMP for drop structures. Gabion dimensions are 3-foot-high, 1-foot thick, and average widths were based on digitized channel widths.

Based on the NOCD formula, theoretical GSI were applied consistently within select channels in the regional watershed from the top of the watershed to an outfall at Wagner Wash and in retained channels in the hypothetical development.

2.2.2 CSI features

The CSI regional watershed scenario uses features reported in FCDMC's 2006 SV ADMP for the Wagner Sub-area Step 2 – Alternative B4-3 recommended alternative (JE Fuller, 2006). This alternative applies a detention basin, a dike, walled-levee corridors, and gabion drop structures to manage stormwater.

The CSI hypothetical development scenario uses *retention* basins, drainage easements, gabion drop structures (*detention* structures), and culvert crossings to manage stormwater.

Detention basins are excavated areas used to temporarily store and release surface water. Dikes consist of small earthen structures installed to prevent surface water breakouts at strategic locations outside of walled-levee corridors. Constructed drainage easements are used to convey stormwater away from property. Gabions drop structures limit channel erosion.

Retention basins are excavated areas used to permanently store surface water flows for infiltration. Walled-levee corridors consist of single or multiple walls, typically concrete, used to control lateral movement of surface water flows.

2.3 Surface Water Model

2.3.1 Model Area

The FCDMC 2006 SV ADMP identified 24 alluvial fans on the west side of the White Tank mountains. Under the current SV ADMP update, FCDMC selected eight alluvial fans for further analysis in areas of projected development to identify regional flood hazard mitigation alternatives ([Figure 2](#)). This Study assesses the use of GSI and CSI for stormwater management within Fan No. 3 ([Figure 1](#)).

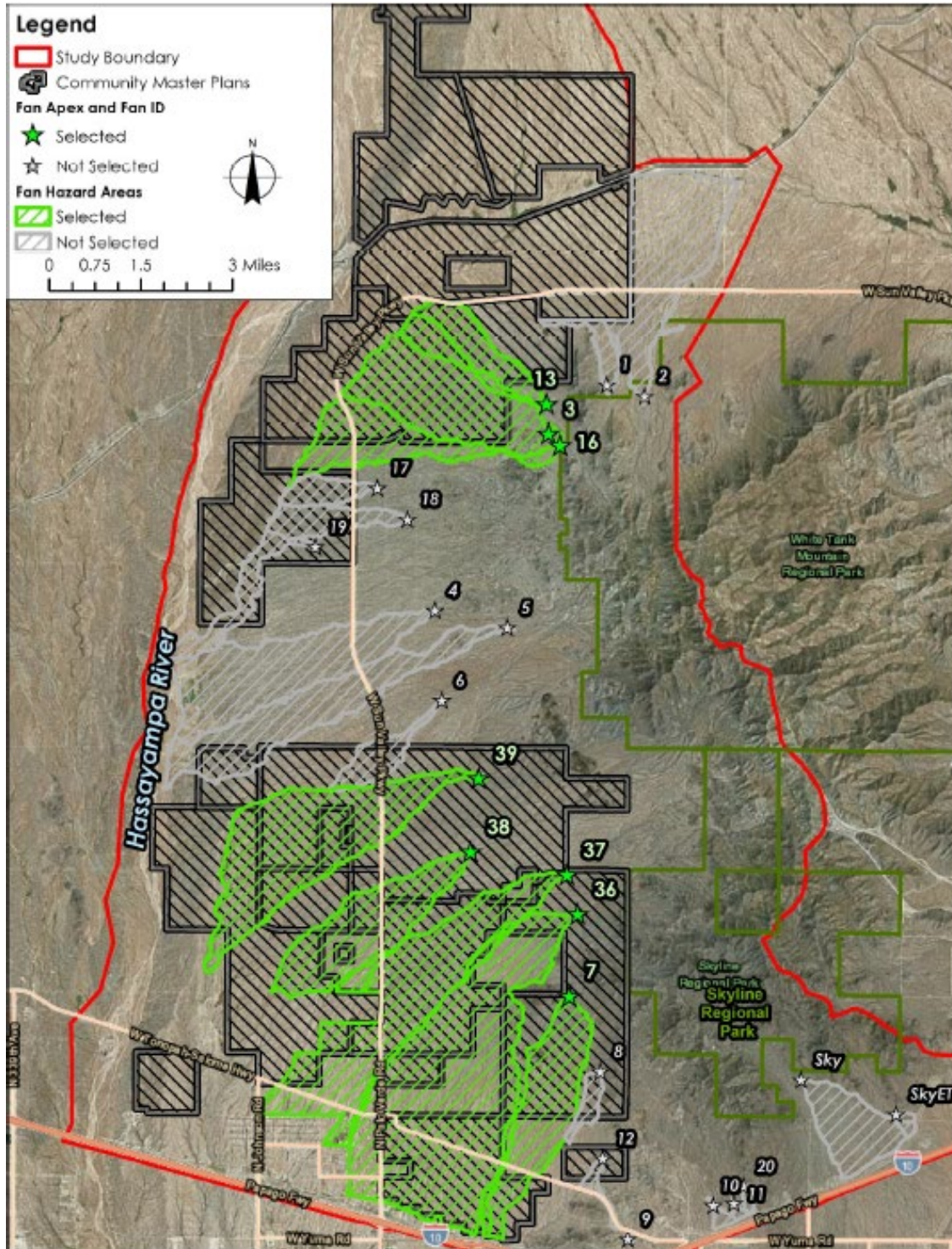


Figure 2. FCDMC SV ADMPU Alluvial Fans Selected for Further Study (JE Fuller, 2022)

The FCDMC divided the SV ADMP study area into geographic sub-areas and developed a series of independent FLO-2D sub-models, labeled A to L, for each sub-area ([Figure 3](#)). Fan No. 3 is in FCDMC's Submodels A and C (JE Fuller, 2022).

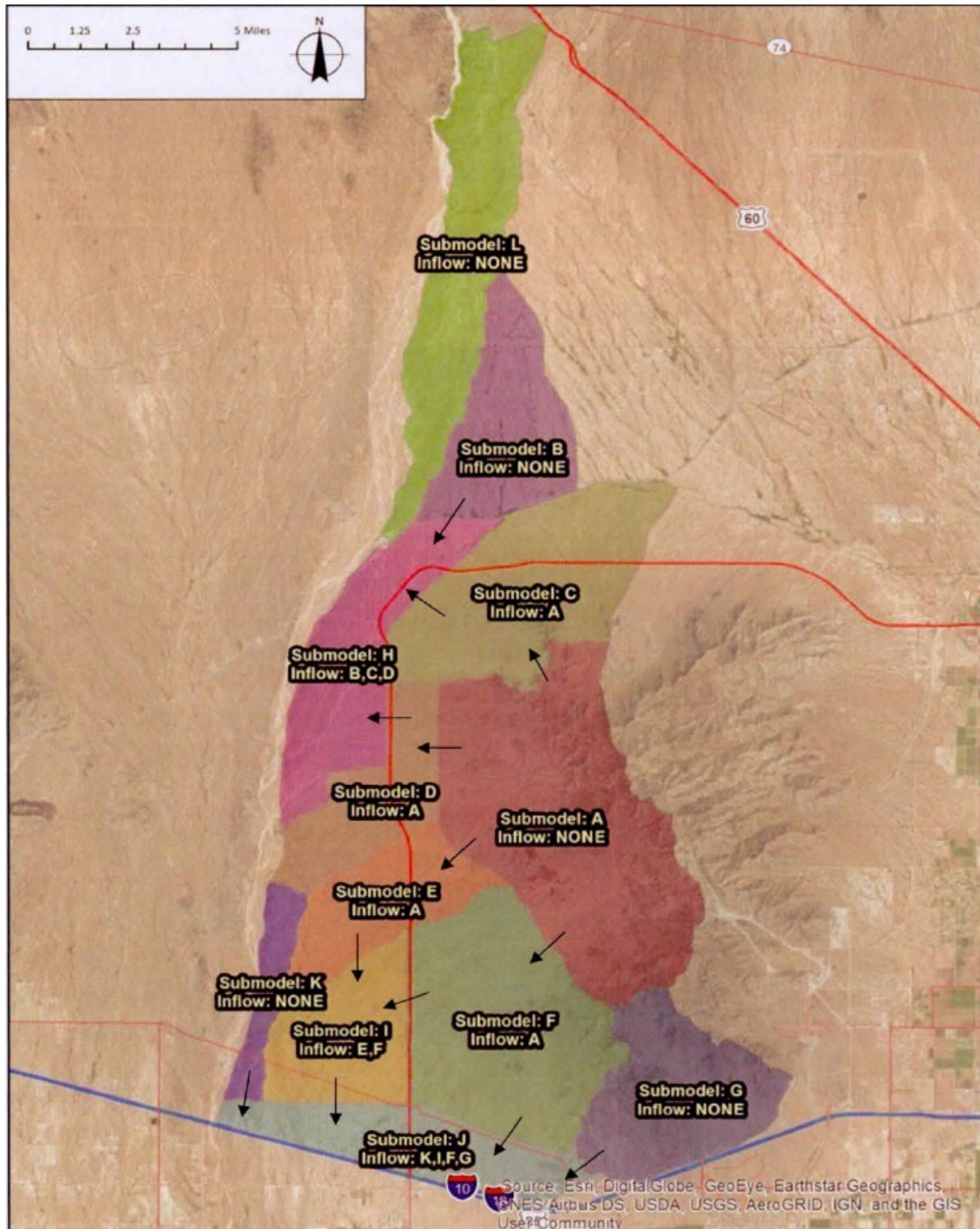


Figure 3. FCDMC SV ADMP FLO-2D Sub-Model Boundaries (JE Fuller, 2020)

The Study area is within the Wagner Wash sub-watershed which drains an area of approximately 183 square miles in central Arizona. Wagner Wash is tributary to the Hassayampa River within the Lower Gila-Agua Fria Basin, USGS HUC 6, and Lower Gila Sub-Region of the Lower Colorado Region ([Figure 4](#)).



Figure 4. USGS Lower Gila-Agua Fria HUC 6

Alluvial fans are formed when fast moving water flows onto flatter terrain and deposits sediments developing a fan-shaped landform at the base of a steep slope. Alluvial fans consist of recent geologic deposits comprised of coarse grained, unsorted, and unconsolidated sediments. Surface water drainage channels are located throughout the topography of the alluvial fan surface.

The Study Team selected Fan No. 3 for theoretical application of GSI and CSI in the regional watershed and in a hypothetical development for the following reasons:

- An existing Community Master Plan (CMP) showing natural channels and roads was available for proposed Sun Valley Villages I and II developments (Carter & Burgess Inc., 2005).
- The CMP preliminary residential development plat could be used to develop hypothetical development designs.
- Fan No. 3 is a less complex fan system with fewer distributary channels in the upstream portion of the watershed and only two channel breakouts below the apex of Fan No. 3.
- The Fan No. 3 Wagner Wash outfall is well defined.
- At the time of this report the regional watershed in Fan No. 3 is undeveloped.

2.3.2 Model Development

This Study developed surface water models to assess the effectiveness of theoretical GSI and CSI installations to manage stormflows in a regional watershed and within a hypothetical development on Fan No. 3. The term “scenario” is used to describe the individual surface water models developed for the GSI and CSI alternatives ([Table 3](#)). Model results from the 2006 SV ADMP were used for the CSI regional watershed scenario. The USGS developed the GSI regional watershed scenario model using a 5m resolution digital elevation model to coincide with the watershed boundary found in the modeling from the 2006 SV ADMP. Reclamation’s Denver TSC developed the GSI and CSI hypothetical development scenario models.

Table 3. GSI and CSI Modeling Scenarios

Modeling Scenarios	Model Development
GSI Regional Watershed	USGS
GSI Hypothetical Development	TSC
CSI Regional Watershed	FCDMC, 2006 SV ADMP
CSI Hypothetical Development	TSC

This Study used the 100-year, 6-hour storm event for all model scenarios based on the FCDMC SV ADMP FLO-2D baseline model results showed that the 100-year, 6-hour storm event produced a higher peak flow compared to the 100-year, 24-hour storm event.

Buckeye requires that residential developments retain the volume of stormwater generated from the 100-year, 2-hour storm which approximates the excess volume of runoff being generated by the development.

The United States Geological Survey (USGS) used the Automated Geospatial Watershed Assessment (AGWA) tool, a geographic information systems (GIS) interface designed to help manage and analyze watershed water quantity and quality (Kepner et al. 2009; Goodrich et al. 2012).

AGWA uses standardized spatial data sets readily available online and is designed to investigate the hydrologic impacts of land cover/land use change in small watersheds to basin-scale studies. AGWA data can be used to develop input parameter files for two watershed runoff and erosion models: the Kinematic Runoff and Erosion (K2) hydrologic model and the Soil and Water Assessment Tool (SWAT) to evaluate the effectiveness of theoretical application of GSI for stormwater management in the regional watershed in Fan No. 3. The K2 model was used for comparing event-based iterations.

FCDMC modeled the 2006 SV ADMP Fan No. 3 alternative using the one-dimensional lump-sum HEC-1 hydrologic model developed by the U.S. Army Corps of Engineers, Hydrologic Engineering Center. The FCDMC is updating the SV ADMP surface water model from a HEC-1 model to a two-dimensional grid-based FLO-2D model. At the time of this Study the SV ADMP FLO-2D baseline model is complete, but the Fan No. 3 stormwater management alternative designs and modeling are not complete. This Study used data and information from the FCDMC 2006 SV ADMP HEC-1 model for the CSI regional watershed scenario model results.

Reclamation's Denver Technical Services Center used data and information from the FCDMC SV ADMP FLO-2D baseline model to develop the Personal Computer Stormwater Management Model (PCSWMM) for the GSI and CSI hypothetical development scenarios. PCSWMM is a GIS-based interface and toolset that works with the EPA's Storm Water Management Model (Rossman & Huber, 2016). PCSWMM is a spatial decision support software used for wastewater, watershed, and stormwater management. PCSWMM uses datasets including stormflow, topography, land use, land cover, soils, and weather to develop a realistic hypothetical stormwater runoff analysis. PCSWMM provides unique 1D and 2D integrated modeling capabilities as well as packages to quickly implement LID features.

The 2005 Sun Valley Villages I and II CMP (Carter & Burgess Inc. 2005) were used as a guide to develop the GSI and CSI hypothetical development scenarios for modeling. The hypothetical development designs include low and medium density residential lots, parks, roads, public lands, open spaces and GSI or CSI stormwater infrastructure.

Baseline models showing the natural channel conditions were prepared for the GSI and CSI hypothetical developments ([Figure 5](#)). The GSI hypothetical development retained natural channels with flow rates greater than 20 cubic feet per second (cfs) during a 100-year, 6-hour storm event. All natural channels were eliminated in the CSI hypothetical development and replaced with drainage easements and retention basins.

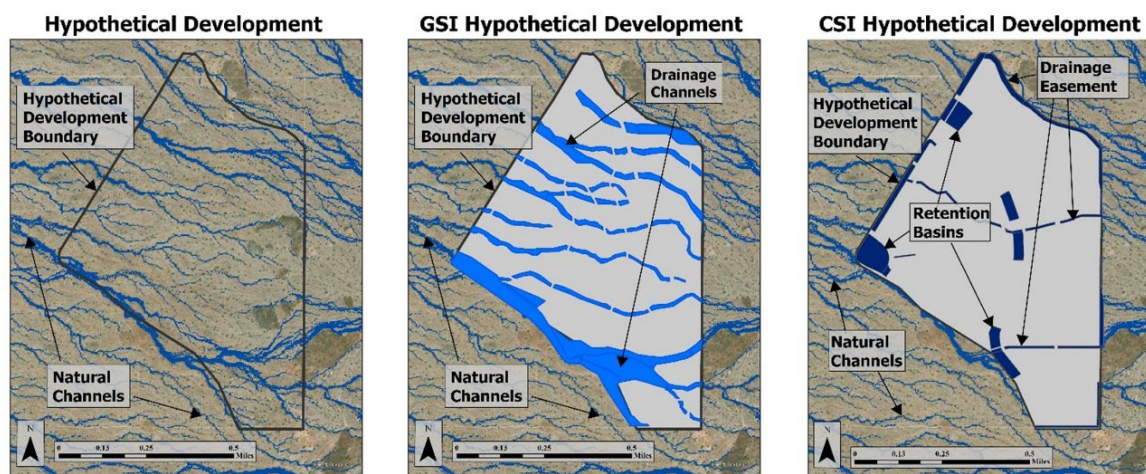


Figure 5. Natural Channels and the GSI and CSI Hypothetical Developments

This Study represents a theoretical analysis of stormwater management in a hypothetical development. The Study area is in a region identified as a high hazard area by the Federal Emergency Management Agency (FEMA). Coordination between the developer, FCDMC, Buckeye, and FEMA would need to occur to revise the high hazard designation. A technical analysis would need to be conducted as identified in FEMA's Letter of Map Revision process to show that the high hazard area has been mitigated.

2.3.3 Model Scenarios Comparisons

Individual models were developed for each scenario. The primary differences between the models for the regional watershed and the hypothetical development scenarios are described below.

GSI and CSI Regional Watershed Scenarios

The GSI regional watershed scenario applies gabions in select drainages from the top of the watershed to the outfall in Wagner Wash. The GSI gabions are designed to slow and reduce the volume and flow rate of stormwater close to its source. Slowing stormflows throughout the channel bottom promotes distributive infiltration of stormwater similar to natural conditions, enhances infiltration and reduces erosion and sediment transport. GSI are typically implemented to manage small to medium storms (Norman et al., 2010).

The CSI regional watershed scenario collects stormwater from the upstream portion of the regional watershed in a detention basin at the Fan No. 3 apex. The detention basin releases stormwater into a walled-levee corridor that conveys stormflows to the Wagner Wash outfall. The CSI method uses intermittent drop structures to periodically slow stormflows, however fast flowing stormwater is conveyed out of the local hydrologic system and is less likely to infiltrate. CSI is typically implemented to manage large storms.

GSI and CSI Hypothetical Development Scenarios

The GSI hypothetical development retains nine natural channels. Theoretical gabions are installed within the natural channels to manage stormwater flows within the development. To minimize developable lot losses, the lot sizes of the GSI hypothetical development were reconfigured to accommodate the nine natural channels retained in the GSI scenario. The GSI medium density lots are about 12 percent smaller and the GSI low density lots are about 15 percent smaller than the CSI medium and low-density lots respectively. Retaining nine natural drainages in the GSI hypothetical development results in smaller lot sizes however the GSI hypothetical development scenario has 58 percent more open space than the CSI hypothetical development scenario ([Table 4](#)).

The GSI hypothetical development design consists of 302 medium and 230 low density lots and 107 acres of open space ([Table 4](#)). The average lot size in the medium density portion of the GSI hypothetical development is 6,173 square feet (sq ft) and 15,299 sq ft in the low-density portion.

The CSI hypothetical development design consists of 306 medium and 241 low density lots and 75 acres of open space ([Table 4](#)). The average lot size in the medium density portion of the CSI development is 7,014 sq ft and are 17,997 sq ft in the low-density portion of the CSI development.

Details for the hypothetical development designs are provided in [Appendix 2](#).

Table 4. GSI and CSI Hypothetical Development Lot Sizes and Number of Lots

		Alternatives	
		Green Stormwater Infrastructure	Conventional Stormwater Infrastructure
Hypothetical Development	Medium Density	Number of Lots: 302 Average Lot Size: 6,173 sq ft Open Space*: 34.62 acres	Number of Lots: 305 Average Lot Size: 7,012 sq ft Open Space*: 17.21 acres
	Low Density	Number of Lots: 230 Average Lot Size: 15,300 sq ft Open Space*: 72.44 acres	Number of Lots: 241 Average Lot Size: 1800 sq ft Open Space*: 46.15 acres
	Total	Number of Lots: 532 Open Space*: 107.05 acres 39% Open Space**	Number of Lots: 546 Open Space*: 63.36 acres 23% Open Space**

* Open Space does not include the area around the school.

** The gross development area is ~287.94 acres. The school is ~10.32 acres, leaving ~ 277.62 acres for the total development area.

2.3.4 Model Runs

This Study assesses the effectiveness of using theoretical GSI and CSI to manage stormwater using four unique models. Model runs were completed for each alternative scenario:

- GSI alternative
 - GSI regional watershed scenario
 - GSI hypothetical development scenario
- CSI alternative
 - CSI regional watershed scenario
 - CSI hypothetical development scenario

GSI Regional Watershed Scenario

The GSI regional watershed scenario applied 569 theoretical gabion installations from the highest elevation of select channels in Fan No. 3 to an outfall at Wagner Wash ([Figure 6](#)). Culverts are not required in the GSI regional watershed scenario because at the time of this analysis there are no roads that require culvert crossings. The GSI features modeled in the GSI regional watershed scenario are provided in [Table 5](#).

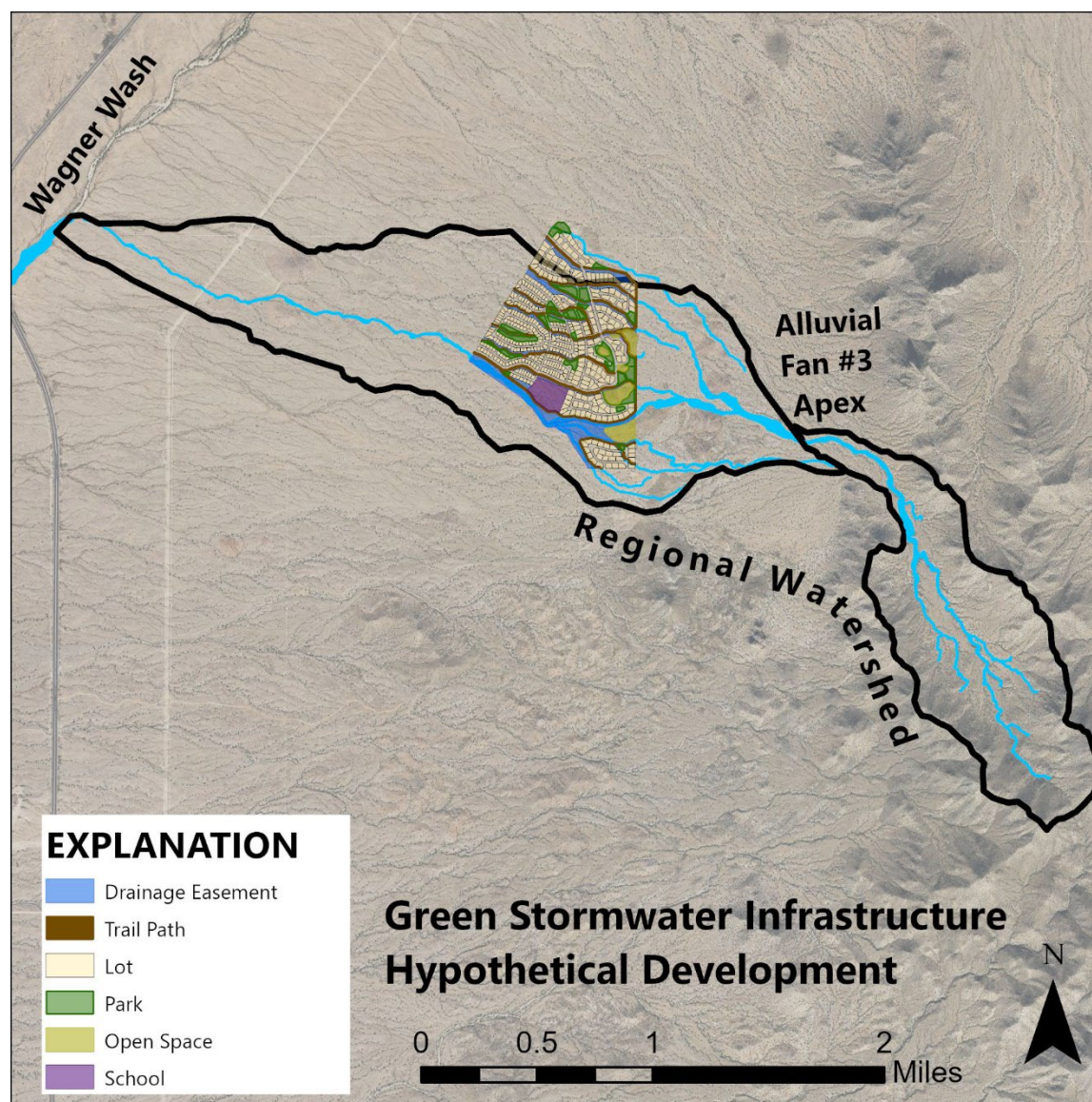


Figure 6. GSI Regional Watershed Scenario

The USGS developed the GSI regional watershed scenario model and completed three model runs: baseline (no gabions), with Gabions (Light) and with Gabions (Heavy). The Gabion (Light) model run applied 478 gabions and the Gabion (Heavy) run applied 569 gabions to selected channels within the regional watershed in Fan No. 3. Details of the GSI regional watershed modeling are in the USGS modeling report provided in [Appendix 3](#).

GSI Hypothetical Development Scenario

The GSI hypothetical development scenario retains 9 natural channels, applies 248 gabion installations and 28 culvert crossings ([Table 5](#)). The GSI hypothetical development design is shown in [Figure 7](#).

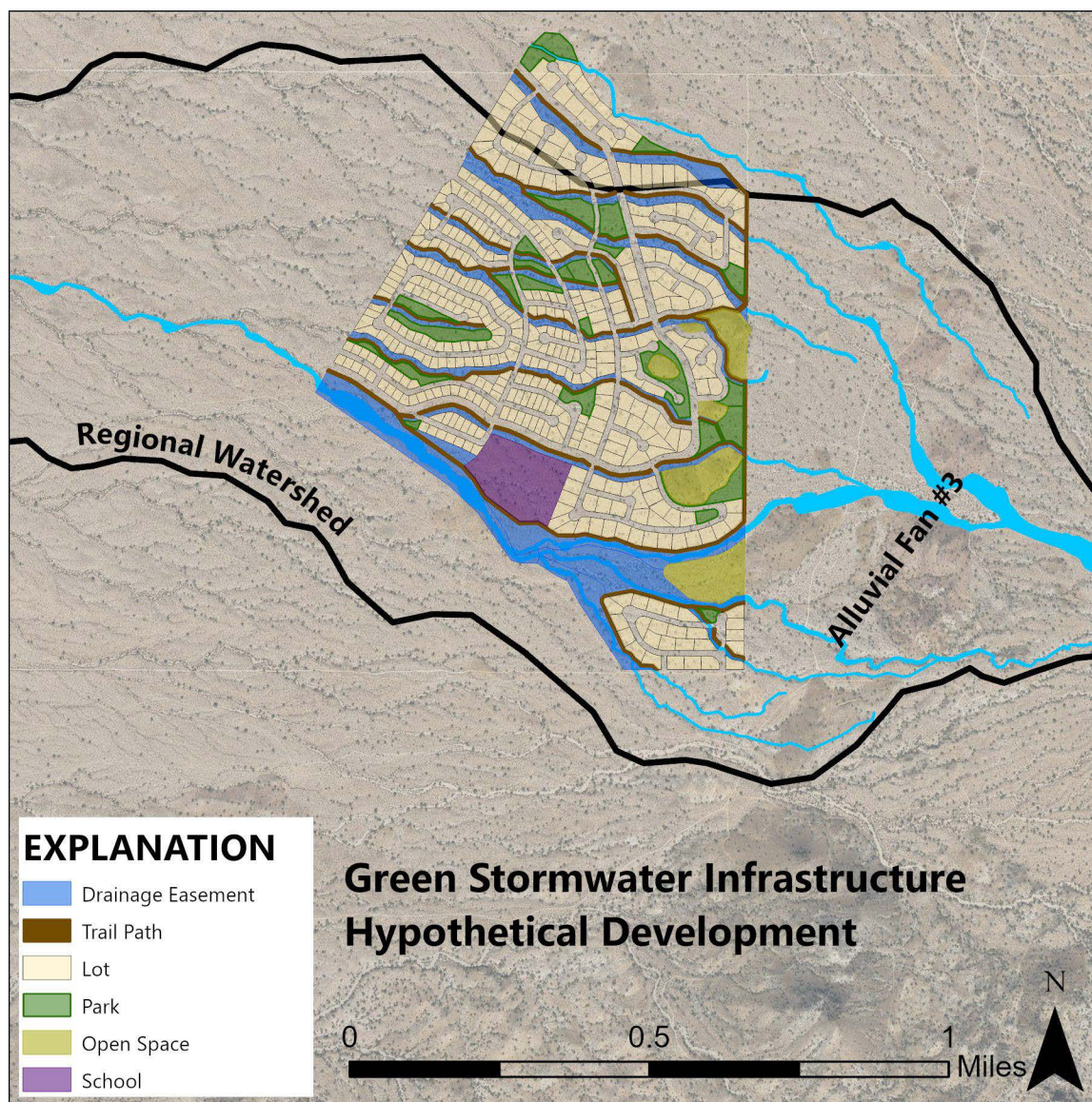


Figure 7. GSI Hypothetical Development Scenario

The TSC developed the GSI hypothetical development scenario model using PCSWMM. Two model runs were completed. The first model run applied 223 theoretical gabions within the retained channels. Based on the model results, the number of theoretical gabions were modified to provide model stability and to slow stormwater flows in high flow areas. The second model run applied 204 theoretical gabions. Details of the GSI hypothetical development modeling are in the TSC modeling report provided in Appendix 4.

CSI Regional Watershed Scenario

The CSI regional watershed scenario ([Figure 8](#)) uses the FCDMC 2006 SV ADMP stormwater infrastructure design for the Wagner Sub-area Step 2 – Alternative B4-3. The CSI scenario is

comprised of one detention basin at the fan apex, one dike, 19 gabion drop structures and a 2.5 mile walled-levee corridor from the Fan No. 3 apex to Wagner Wash ([Table 5](#)).

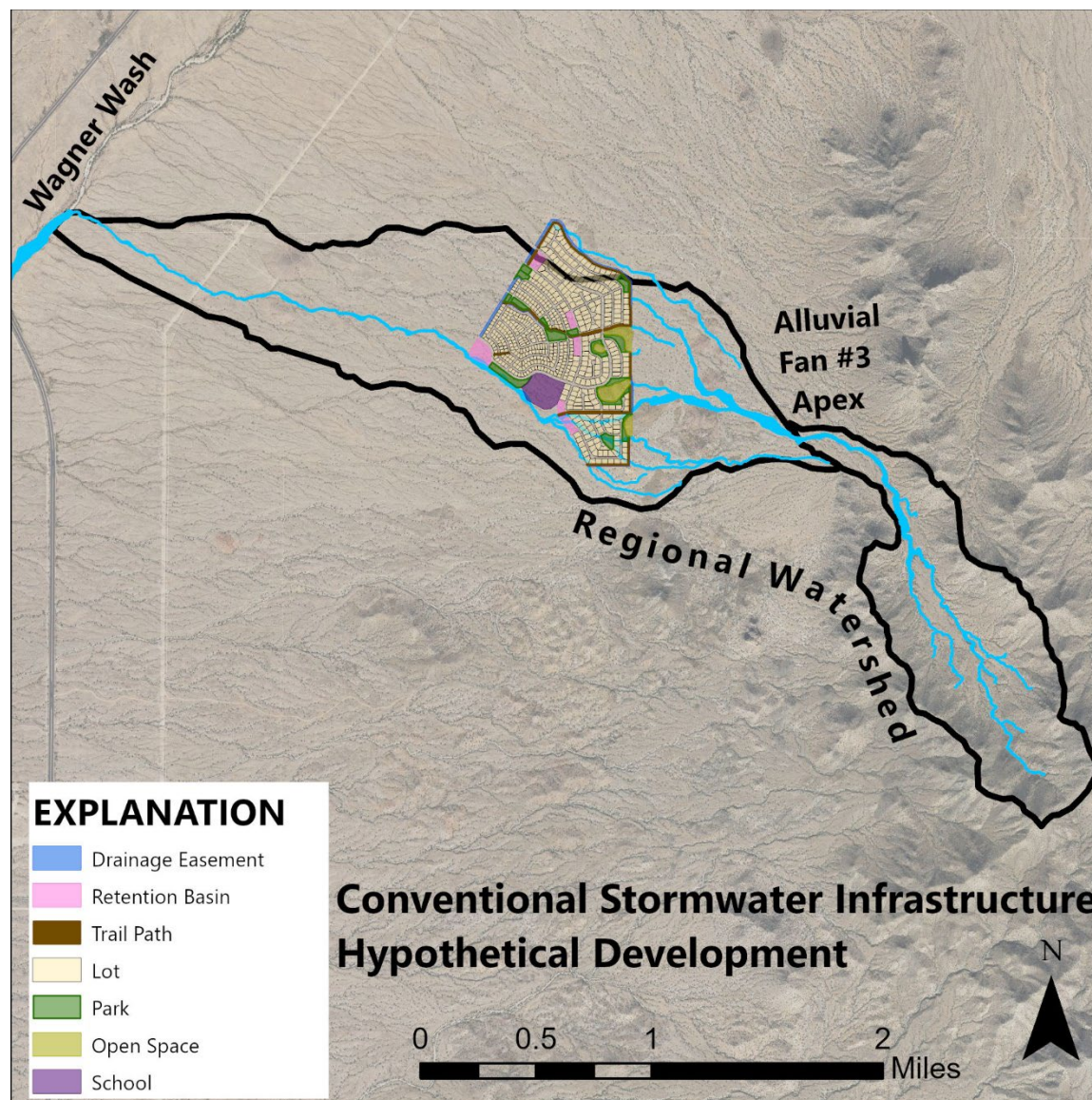


Figure 8. CSI Regional Watershed Scenario

The results for the FCDMC 2006 SV ADMP HEC-1 Fan No. 3 Wagner Sub-area Step 2 – Alternative B4-3 modeling are used directly in this Study as the CSI regional watershed scenario model results.

CSI Hypothetical Development Scenario

The CSI hypothetical development scenario design was based on Buckeye's Storm Water Drainage System Design Manual, 2007 (Buckeye, 2007) and the CMP for the Sun Valley Villages I & II (Carter & Burgess, 2005).

The CSI hypothetical development ([Figure 9](#)) applies five retention basins, 10 drainage easements, nine gabion drop structures, and 12 culvert road crossings for stormwater management ([Table 5](#)). Details of the CSI hypothetical development modeling are in the TSC modeling report provided in [Appendix 4](#).

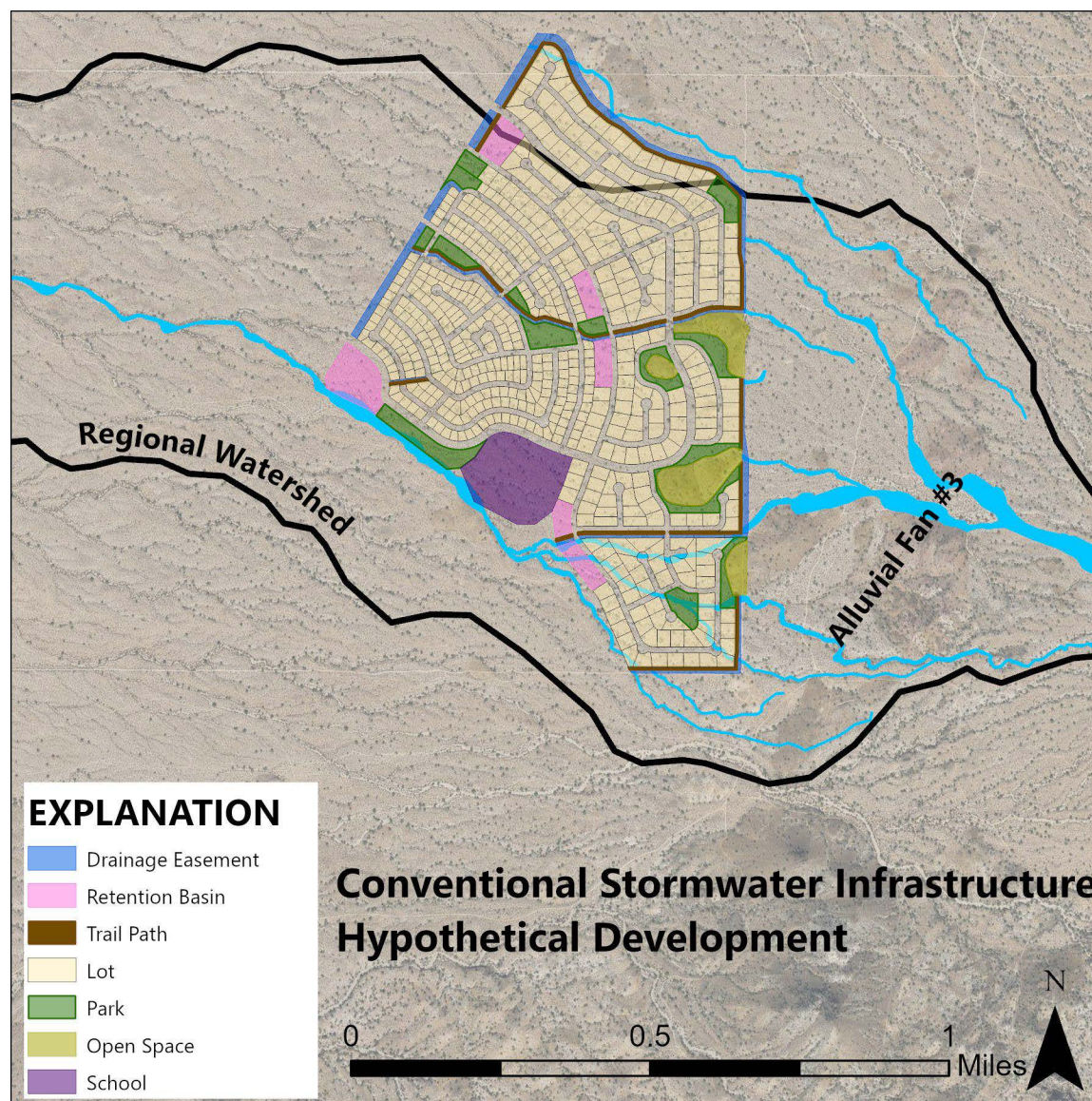


Figure 9. CSI Hypothetical Development Scenario

The CSI hypothetical development design was modeled in PCSWMM. One model run was completed to assess the effectiveness of theoretical CSI within the hypothetical development.

Table 5. GSI and CSI Scenario Designs

Scenario		Final Model Scenarios	
		Green Stormwater Infrastructure	Conventional Stormwater Infrastructure
	Regional Watershed	569 Gabions 0 Culverts	1 Dike 1 Detention Basin 2.5 Miles of Walled-Levee Corridors 19 Gabions 0 Culverts
	Hypothetical Development	9 Natural Channels 209 Gabions 28 Culverts	0 Natural Channels 5 Retention Basins 10 Drainage Easements 9 Gabions 12 Culverts

2.3.5 Model Results

GSI Regional Watershed Scenario

Scenarios were created to consider installing gabions into the regional subwatershed around the study area. Three total model iterations, baseline (undeveloped natural or pre-development), with gabions (Light) and with more gabions (Heavy), were imported into the Automated Geospatial Watershed Assessment (AGWA) tool and a GIS interface. The results of these three model iterations were differenced to visualize how the wetland impacts of gabions installed therein would influence the hydrology of the watershed using riverscape channels that were digitized.

GSI regional watershed modeling indicated that the addition of gabions reduces runoff volume outflow for the event-based storm and increases the sub-surface infiltration, especially notable in the planes (vs. channels). Peak flowrate and peak discharges were reduced from the baseline in the gabions (Light) and gabions (Heavy) model iterations. The GSI regional watershed modeling showed that the addition of gabions has the potential to reduce erosion and sediment transport. In [Table 6](#), the total volume of water for each scenario for precipitation (rainfall), infiltration (in plane and channel model elements), interception, and runoff (outflow), with model numerical error (volume in – volume out – storage) equal <1 percent. Detailed modeling results for the GSI regional watershed scenario are in the USGS modeling report provided in [Appendix 3](#).

Table 6. Distribution of water predicted throughout the watershed in baseline vs. Gabions scenarios Light and Heavy (Norman & Petrakis, 2024)

	Baseline (in)	Gabions, Light (in)	Gabions, Heavy (in)
Rainfall	3.18	3.18	3.18
Plane Infiltration	1.42	1.45	1.46
Channel Infiltration	0.56	0.57	0.57
Interception	0.03	0.03	0.03
Outflow	1.15	1.11	1.10

GSI Hypothetical Development Scenario

In the GSI hypothetical development simulations, gabions decreased the outflow from the development for the 100-year 6-hour storm in channels with low peak flow (< 200 cfs) and adequate channel depth and geometry to install enough gabions in areas that capture development flows. Gabions alone were not enough to reduce flows from the developed area to below pre-development flows. Gabions were also effective in reducing flows in some channels to below the 5 ft/s safety threshold used in this study. Gabions were more effective in reducing both peak outflows and peak velocities in simulations of smaller storms (10-year 6-hour and 2-year 6-hour). [Table 6](#) provides a summary of peak flow reductions as a percent of flow. For more details on the results of the GSI hypothetical development modeling, see [Appendix 4](#).

Table 7. Percent (%) peak outflow reduction for each drainage easement (DE)

Drainage Easement	# of Gabions	100 Year Storm	10 Year Storm	2 Year Storm
DE 0	0	0	0	0
DE 1	0	0	0	0
DE 2	64	-2	19	32
DE 3	15	3	13	14
DE 4	39	5	7	9
DE 5	17	-1	-1	0
DE 6	36	4	1	2
DE 8	38	-4	10	16

Adding gabions upstream of the development, as simulated by the regional watershed model described above, provided additional reductions as described in the GSI Regional Watershed Scenario section. This was most effective at reducing flows in the largest channel (DE8) where the most structures were installed.

CSI Regional Watershed Scenario

The 2006 SV ADMP HEC-1 model results calculated a peak inflow to the detention basin at Fan No. 3 of 835 cubic feet per second (cfs) with a design peak outflow of 75 cfs released from the detention basin into the walled-levee corridor and 1,512 cfs at the Wagner Wash outfall for the 100-year 6-hour storm.

CSI Hypothetical Development Scenario

The CSI hypothetical development simulations routed the increased runoff from impervious surfaces through drainage easements in and around the development. CSI development included five retention basins in the development and one regional retention basin to retain and slow storm water. These simulated basins effectively reduced total flows out the development to below pre-development outflows, but required disturbance to channels within the development to route flows to these larger, more centralized features, as well as disturbance to the area upstream of the development to reduce high flows coming into the development.

2.3.6 Model Results GSI versus CSI Comparisons

Comparison of GSI and CSI Regional Watershed Model Results

Simulated CSI features effectively reduced post-development flows to pre-development levels, consistent with their traditional design and application. However, gabions as the only low impact treatment did not reduce flows from the GSI development to pre-development flows. In addition, except for in the 2-year 6-hour storm case, gabions alone could not reduce the flows to acceptable safety standards of less than 5 ft/s. Because gabions alone could not reduce flows to the pre-development condition and velocities to meet safety standards, additional treatment, would be necessary in or above the development to achieve desired flows.

[Table 7](#) is a comparison of the two models. Although the flows are different because of the two different models, focus was placed on the percent reduction that each infrastructure makes. The FCDMC alternative has a larger reduction at the apex, but the overall reduction of flows at Wagner Wash is not as significant.

Table 8. GSI and CSI Regional Watershed Model Results Comparison

Location	K2 Model			FDC 2006 HEC-1 Model		
	Natural Conditions (cfs)	Max Gabions (cfs)	% Reduction	Natural Conditions (cfs)	Full Treatment (cfs)	% Reduction
Apex #3	2,439	2,329	4.5%	835	75	90%
Wagner Wash	3,124	2,789	10.7%	1,455	1,512	-3.9%

Comparison of GSI and CSI Hypothetical Developments

Gabions were able to decrease the outflow in some drainage easements, such as in DE 3, DE 4, and DE 6. Outflows increased slightly in DE 2 and DE 5. However, the differences in DE 2 and DE 5 were within the modelled percent error. Gabions alone were not enough to achieve pre-development flows discharging from the drainage easements. CSI discharges more water to DE 2 than under pre-development condition, the overall flows out of the development are less than pre-development. [Table 8](#) shows the simulated peak outflows from the 100-year 6-hour storm.

Table 9. Simulated development peak outflows (cfs) from the 100-year 6-hour storm

Drainage Easement	Pre-Development	GSI			CSI
		No Treatment	No Upstream Treatment	Full Treatment	
DE 0	61.8	85.8	85.8	85.8	
DE 1	21.7	38.5	38.4	38.4	
DE 2	196.1	262.8	267.2	270.4	206.4
DE 3	46.5	59.3	57.8	57.8	
DE 4	102	158.3	150.5	150.7	
DE 5	50.4	67.4	67.8	67.8	
DE 6	72.6	127	122.4	122.4	
DE 8	1254.6	1258.9	1314.8	1230.3	304.1

2.4 Infiltration Tests

Buckeye hired contractor Matrix New World Engineering to conduct infiltration sampling. Infiltration samples were collected from Fan No. 3 at nine locations, the apex, between the apex and the hypothetical development and within the hypothetical development ([Figure 10](#)).

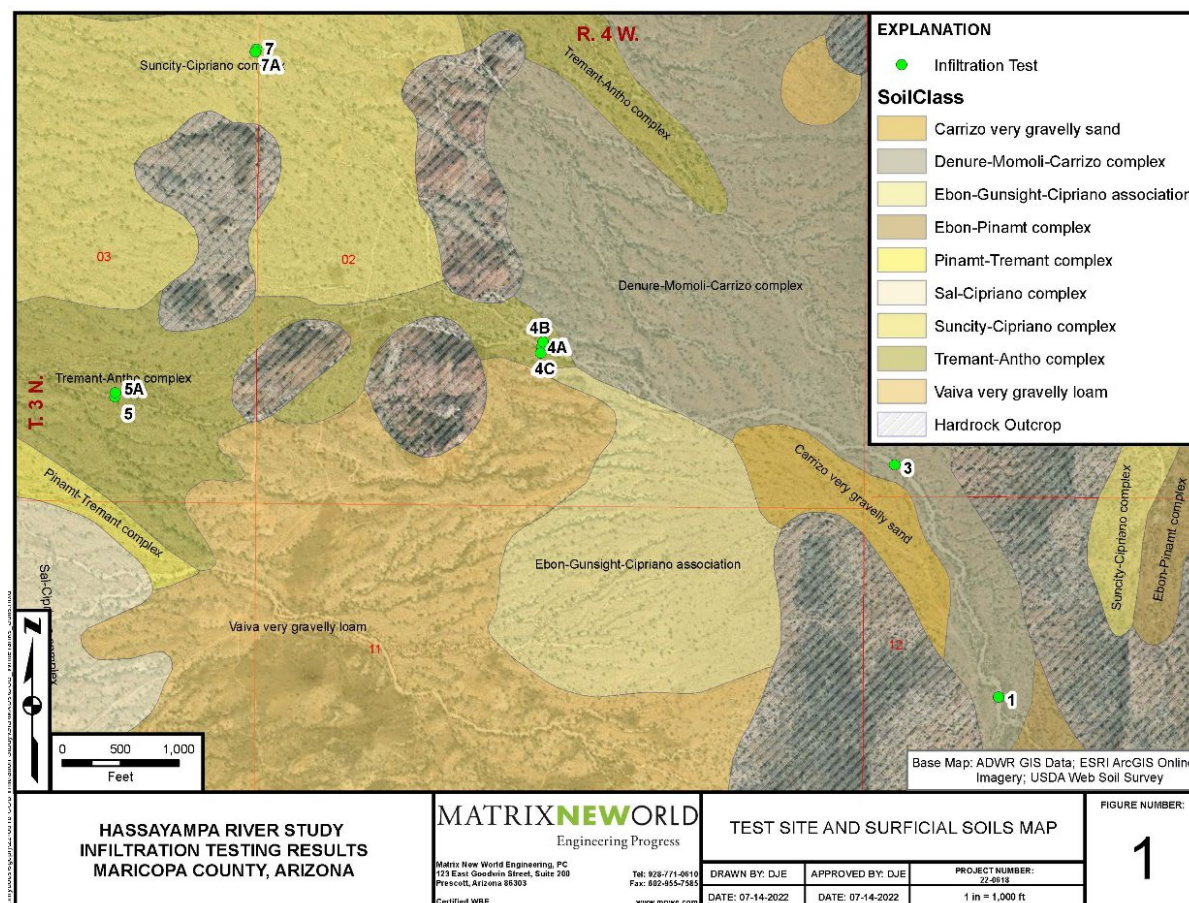


Figure 10. Soil Infiltration Sample Locations (Easthouse, 2022)

A site visit was conducted on June 1, 2022, with Buckeye, Reclamation and Matrix New World staff to assess site access and identify sample locations (Figure 10). On June 8, 2022, nine infiltration samples were collected from six sites within the channel bottom and three sites located on the adjacent terraces (Easthouse, 2022). Infiltration testing was conducted using the single-ring infiltrometer method described by Bouwer et al (1999). The results show that the channel bottom soils are predominately well graded sand and well graded sand with gravel with infiltration rates ranging from 16.45 feet per day (ft/day) to 58.65 ft/day. The stream terrace test site soils are clayey sand and well graded sand with clay with infiltration rates ranging from 0.58 ft/day to 3.78 ft/day (Figure 10). Test sites located in the channel were found to have high to very high permeability due to the predominance of coarse grained, unconsolidated deposits of sand and gravel. Test sites located on stream terraces were found to have low to moderate permeability due to the presence of clay and/or cemented material below 6-inches. Infiltration results vary within the channel and on the terraces due to variations in soil conditions at each test site location and small test samples. The infiltration sample results were integrated into the surface water modeling analyses and are included as Appendix 5.

Table 10. Soil infiltration test results. (Easthouse, D. 2022)

Soil Test Number	Soil Test Location	Soil Type	Hydraulic Conductivity (ft/day)
1	Channel bottom	Well graded sand	16.45
3	Channel bottom	Well graded sand with gravel – bedrock at 18 inches	44.37
4A	Channel bottom	Well graded sand with gravel	58.65
4B	Channel bottom	Well graded sand with gravel	51.51
4C	Terrace	Well graded sand with clay	3.78
5	Channel bottom	Well graded sand with gravel	57.90
5A	Terrace	Clayey sand	.58
7	Channel bottom	Well graded sand	28.93
7A	Terrace	Well graded sand with clay	3.35

2.5 LID O&M Assessment

There is limited information available regarding O&M practices and costs for installed GSI/LID. Prior to considering broad scale LID installations for stormwater management, it is important to understand O&M requirements and costs.

The GSI/LID O&M assessment tasks included:

- A reference search to identify O&M data and information for installed LID in central Arizona and nearby arid lands.
- Identification of entities with LID installations and potential interviewees.
- Development of interview questions and a script to promote consistency during interviews.
- Analysis, interpretation, and summary of interview results.
- Preparation of a final report.

In August 2021, Buckeye entered into a professional service agreement with Logan Simpson, Design, Inc. to complete the LID O&M assessment. Reclamation collaborated with Buckeye to oversee the LID O&M Assessment task to develop a scope of work, conduct a reference review, identify sub-tasks and timeframes, approve work products and provide general task review and oversight.

The LID O&M Team completed a reference search for O&M requirements and costs for entities with existing LID installations in central Arizona and nearby arid environments. The literature review located 87 potentially useful journal articles, online publications, websites, and doctoral dissertations. Nineteen published LID handbooks and manuals were identified. The reference search results were used to identify potential entities for interviews.

Identifying interviewees and scheduling interviews was an iterative process. All potential contacts were tracked in a spreadsheet. After identifying an entity with LID installations, a cold call was made where the interviewer described LID features and inquired about LID use at the entity. The results of the cold call directed the interviewer to continue to identify a potential interviewee or to eliminate the entity from the interview process. When a potential interviewee was identified, a pre-interview meeting was scheduled. During the pre-interview meeting the interviewer inquired about LID implementation and O&M practices and costs. When a potential interviewee was selected for a

formal interview, an interview was scheduled, and a list of interview questions was provided to the interviewee prior to the formal interview.

Although the O&M assessment methodology was simple, task implementation took time and required overcoming challenges such as limited knowledge, lack of recordkeeping and staff turnover. 25 entities were contacted, 20 entities responded, and seven formal interviews were conducted with five local communities and two non-municipal entities.

The results of the LID O&M assessment showed that at the time of the interviews, there was little to no data or information available regarding O&M practices and costs from the entities interviewed. Entities were not monitoring, specifically maintaining, or recording costs for LID O&M. Some interviewees described LID general O&M practices, but entities were not specifically tracking O&M practices and costs at the feature level. The assessment found that typically, LID installations are integrated with CSI stormwater management systems. LID O&M practices and costs are combined with CSI and/or landscaping O&M. Most often, LID specific O&M and landscaping practices were not followed, and instead conventional O&M was practiced. LID O&M costs were not specifically tracked or separated from overall costs and were not known. Qualitative information on O&M practices and costs were summarized.

Entities are beginning to identify specific LID O&M requirements and establish methods to record and monitor costs. For example, the City of Tucson and FCDMC are identifying standardized LID O&M practices for maintenance workers and plan on recording and monitoring LID O&M costs.

The GSI/LID O&M assessment final report summarizes the process and results and provides details about the interview questions, interview script, and interview responses. Documentation for the assessment is provided in the final report completed in December 2022 titled “Low Impact Development Operations and Maintenance Assessment” ([Appendix 6](#)).

2.6 Economic Analysis of Green and Conventional Stormwater Infrastructure

There is limited cost benefit information for GSI implementation in arid environments. The economics analysis assessed capital costs; operations, maintenance, and replacement costs (OM&R); and ecosystem services benefits of theoretical GSI and CSI implementation under four scenarios over a 100-year period in Fan No. 3:

- GSI alternative
 - GSI regional watershed scenario
 - GSI hypothetical development scenario
- CSI alternative
 - CSI regional watershed scenario
 - CSI hypothetical development scenario

The theoretical GSI and CSI designs for each scenario were used to develop costs and benefits during this analysis. Unit costs for all GSI and CSI features, except culverts were developed using the FCDMC 2006 SV ADMP, from a nearby drainage study conducted by the City of Phoenix (JE Fuller, 2018) and Federal Prevailing wages as defined by Davis-Bacon Act¹.

2.6.1 Cost Estimating – Capital Costs and OM&R

Cost estimates were developed in accordance with Reclamation Manual Policy and Directives and Standards – Project Planning and Facility Operations, Maintenance, and Rehabilitation (FAC) P09, FAC 09-01, and FAC 09-03.

Capital costs account for initial or one-time costs to complete construction. Contingency costs account for uncertainty in mobilization, design, and procurement. Operation costs are applied equally to the same features with varying sizes and are assumed to include labor and materials. Maintenance costs are assumed to be any repairs or upkeep that require labor and material to ensure the stormwater systems function as intended. Replacement costs are assumed for 40 percent of the GSI and CSI at 50 years. All costs are indexed to April 2022 dollars.

In this estimate, final values are conveyed using net present value, also called net present worth. The net present value is calculated using a discount rate of 2.25 percent per year over the entire Study life or Study period. All costs are indexed to April 2022 dollars. Costs were increased by three percent per year up to 2020 and increased by five percent per year from April 2020 to April 2022.

Hypothetical Development

The 100-year capital costs for stormwater management in the GSI hypothetical development scenario are \$6,200,000. The 100-year OM&R costs for the GSI hypothetical development scenario are \$12,650,000. The 100-year capital costs for stormwater management in the CSI hypothetical development scenario are \$4,900,000. The 100-year OM&R costs for the CSI hypothetical development scenario are \$6,810,000.

Capital costs for the GSI hypothetical development scenario are 23 percent, or 1.2 times higher than the capital costs for the CSI hypothetical development because there are 133 percent more culverts required in the GSI development. GSI OM&R costs for the hypothetical development are 76 percent more than the CSI OM&R costs in the hypothetical development due to the greater number of culverts required in the GSI development.

¹ “The Davis–Bacon Act of 1931 is a United States federal law that establishes the requirement for paying the local prevailing wages on public works projects for laborers and mechanics. It applies to “contractors and subcontractors performing on federally funded or assisted contracts in excess of \$2,000 for the construction, alteration, or repair (including painting and decorating) of public buildings or public works.”

Regional Watershed

The 100-year capital costs for the regional watershed stormwater management GSI scenario are \$1,700,000. The 100-year OM&R costs for the GSI regional watershed scenario are \$480,000. The 100-year capital costs for the regional watershed stormwater management CSI scenario are \$14,000,000. The 100-year OM&R costs for the CSI regional watershed scenario are \$6,620,000.

Capital costs for the GSI regional watershed scenario are 87 percent of, or about eight times lower than the CSI regional watershed scenario. The OM&R for the GSI regional watershed is nearly 14 times lower than the CSI regional watershed scenario.

2.6.2 Ecosystem Services Benefits Analysis

This Study assesses ecosystem services benefits for the GSI and CSI stormwater management scenarios for a 100-year life-cycle. Limited information is available regarding the ecosystem services benefits of using GSI and CSI in arid environments. Ecosystem services are the many and varied benefits derived from the natural environment that maintain health, food production, and flood control. These direct and indirect contributions of natural systems enhance the well-being of humans and wildlife.

Methods that measure ecosystem services benefits to humans for particular ecosystems have been established by ecosystem-focused research. Ecosystem services information may be used to assess impacts of decision scenarios in regional settings. The U.S. Environmental Protection Agency states that ecosystem services enhance environmental management, informs urban design, and contributes to community vitality, economic health, and livability (US EPA, 2022).

There are many types of ecosystem services. This Study only estimated those ecosystem services that could be quantified:

- air quality
- climate stability
- disaster risk reduction
- recreation
- soil retention
- water storage

2.6.3 Benefit Estimating Methodology

Benefit estimates for the GSI and CSI were developed using the capital and OM&R cost savings and an ecosystem services assessment for each GSI and CSI scenario.

Ecosystem services benefits for this Study were determined using the reference titled, *Value of Ecosystem Services in Lower Sabino Creek* (Chadsey and Mojica, 2016) which measured ecosystem services in Tucson, AZ, by land type.

The benefit transfer method (BTM) was used to estimate economic values for ecosystem services. The BTM transfers information available from studies completed in one location or context to another (Organisation for Economic Development, 2005). The Lower Sabino Creek study used information from other studies to develop their BTM and the estimates were found to be applicable and used in this analysis. BTM may be assessed as a unit value transfer or a function transfer.

The BTM assesses ecosystem services benefits based on acreage. Acreage for ecosystem services benefits for each GSI and CSI scenario was digitized using GIS software ArcGIS Pro.

2.6.4 Cost and Benefit Estimate Assumptions

The following assumptions were used in the economics analysis:

- The GSI and CSI scenarios are equally effective at reducing stormflow peaks. Stormflow reduction was not included in the benefits analysis.
- Gabion installation can increase vegetation health up to 3 miles (5 km downstream (or 1 km upstream)) from each structure, despite drought conditions (Norman et al., 2014; Wilson and Norman, 2018). Increased vegetation was not included in the benefits analysis.
- The GSI regional watershed scenario applies theoretical gabion installations from the top of the watershed to an outfall in Wagner Wash. All GSI channel acreage plus channel acreage for 3 miles of Wagner Wash downstream from the last gabion installation were used to calculate shrubland ecosystem services benefits for GSI regional watershed scenario.
- The GSI hypothetical development scenario applies theoretical gabion installations throughout nine retained natural channels. All channel acreage was used to calculate ecosystem services benefits.
- Under the CSI regional watershed scenario shrubland ecosystem services are only accrued in the vicinity of intermittently installed gabions where stormwater may infiltrate. CSI regional watershed scenario benefits were determined for the fraction of the channel acreage where gabions slow stormflows allowing infiltration.

Limitations of using the BTM method include:

- There is limited information available for ecosystem services for varying land types and the per acre value may vary as the available acres decrease.
- Values for ecosystem services were approximated so that the monetary values could be refined and updated in the future as more data is gathered.
- Ecosystems are unique and estimated benefits may not respond as expected.

The final Technical Memorandum titled “Economic Analysis of Green and Conventional Stormwater Infrastructure” is provided in [Appendix 7](#).

2.6.5 Cost Benefit Results

Regional watershed GSI and CSI

The GSI regional watershed scenario consists of 144 acres of shrubland ecosystem services resulting in an estimated \$3,185,323 in present value benefits. The CSI regional watershed scenario consists of 16 acres of shrubland ecosystem services resulting in \$346,849 in estimated present value benefits. Over 100 years, the GSI regional watershed scenario could provide \$2,838,474 more shrubland ecosystem services value than the CSI regional watershed scenario.

Hypothetical Development GSI and CSI

The GSI hypothetical development scenario consists of 14 acres of shrubland ecosystem services resulting in an estimated \$306,303 in present value benefits. The CSI hypothetical development scenario consists of 9.4 acres of shrubland ecosystem services resulting in \$210,886 in estimated present value benefits. Over one-hundred years, the GSI hypothetical development scenario could provide \$95,417 more shrubland ecosystem services value than the CSI hypothetical development scenario.

2.7 Buckeye LID Manual – Engineering Design Standards

Buckeye prepared a Low Impact Development Design Manual to aid in development and implementation of LID for stormwater management in the region. The handbook details LID specifications including long-term life cycle maintenance and cost estimates for LID infrastructure. The LID Design Manual will serve as an Engineering Standard and as a guide for the proper operations and maintenance of LID features.

Development of the LID Design Manual included:

- Compile and review existing Arizona LID manuals
- Compile LID OM&R data and information from concurrent tasks and reference searches
- Compile and review infiltration data from concurrent tasks and other sources
- Identify best management practices for site selection, design, installation, and OM&R
- Prepare Buckeye LID design manual

Buckeye utilized locally published LID manuals to adopt LID solutions specific to their unique environmental and site conditions. The forthcoming Buckeye LID Design Manual will be made available to developers as guidance for nature-based alternatives for stormwater management to protect and enhance regional ecosystem services. The LID Design Manual is anticipated to be completed before the end of 2024.

2.8 Conceptual Water Budget

Initially this Study included a conceptual groundwater modeling task to assess potential changes to mountain front recharge associated with using GSI and CSI for stormwater management. However,

due to increased costs associated with the Covid-19 pandemic, the groundwater modeling task was replaced with proposed development of a conceptual water budget which also was not completed due to time and budget constraints. Modeling results may be used by others to assess how GSI and CSI used in a hypothetical development and in the regional watershed to manage stormwater impact infiltration and groundwater recharge.

Distributive mountain front recharge occurs when stormwater flows within alluvial fan drainage channels and as sheet flow across slopes of undeveloped land. Development decreases permeable surfaces inhibiting stormwater infiltration. CSI consolidates flows and conveys stormwater away from developed areas for storage in retention basins or to be discharged at outfalls. GSI slows flows and allows for distributive infiltration of stormwater within channels and close to its source.

Study data and information that may be used to develop a conceptual water budget include:

- Existing and inferred baseline infiltration rates
- Surface water modeling results for GSI infiltration rates for the hypothetical development and regional watershed scenarios
- Surface water modeling results for CSI infiltration rates for the hypothetical development and regional watershed scenarios
- Local precipitation
- Local groundwater pumping data
- Local streamflow

A conceptual water budget may be used to assess the differences in runoff and infiltration values for the GSI and CSI alternatives.

3 Conclusions

3.1 GSI/LID and CSI Features

Treatment with gabions alone in the GSI regional watershed scenario decreased peak discharge and delayed water in 2-year 6-hour storm case, but could not reduce the flows to acceptable safety standards of less than 5 ft/s. With a large cost savings over CSI features detailed in FCDMC's 2006 SV ADMP, additional GSI features could be added to achieve desired velocities and flows while staying below the high costs of conventional infrastructure. The FCDMC alternative has a larger reduction at the apex than the GSI regional watershed scenario presented in this study, but the overall reduction of flows at Wagner Wash is not as significant.

Similar to the GSI regional watershed scenario, gabions were simulated in channels for the GSI hypothetical development scenario. The 100-year 6-hour storm iteration produced unsafe flow conditions in channels that would be incorporated into the hypothetical developments in both

scenarios. However, when gabions are installed on the landscape, peak discharge is reduced, but streamflow will remain elevated for a longer period. This results in increased vegetation which slows discharge velocity over time. The GSI hypothetical development scenario did not account for growing vegetation in the natural channels that could reduce velocities and flows. Research has shown that repeated installation of GSI features results in ecosystem services benefits that extend up to 3 miles (5 kilometers) downstream from the last applied gabion (Norman, L., et al., 2018).

The detention basin, dikes, walled-levee corridors, and gabion drop structures reported in FCDMC's 2006 SV ADMP to manage stormwater prove effective in the CSI regional watershed scenario (JE Fuller, 2006). The dikes are proposed to be small earthen structures protected by riprap where necessary. FCDMC identified an important, but small breakout located about 2,200 feet upstream of the proposed on-line detention basin The Fan System 3. The dike design includes a short earth structure with 6:1 side slopes and riprap bank adjacent to the dike. Drainage easements and retention basins based on Drainage Policies and Standards from Maricopa County, AZ (2018) were applied for the CSI hypothetical development scenario to route the increased runoff from impervious surfaces through drainage easements in and around the development.

Modeling results found that conventional drainage easements and retention basins alone could not prevent unsafe flows. Velocities in some channels were so large that the flow velocities were not reduced enough to meet safety standards for the 100-year 6-hour storm in the CSI hypothetical development scenario. Drainage easements could be treated to slow flow by resizing channels or incorporating additional in-stream structures that would increase overall costs. Details of the CSI hypothetical development modeling are in the TSC modeling report provided in [Appendix 4](#).

3.2 Surface Water Model

Using gabions as Natural Infrastructure in Dryland Streams (NIDS) can turn arid arroyos into soil-water-carbon sinks, like wetlands (Norman et al, 2022). One way to quantify their potential effect of slowing the flow and increasing the recharge for planning purposes is by modifying land cover inputs to watershed models. The Automated Geospatial Watershed Assessment (AGWA) tool was used to implement the kinematic runoff and erosion model (K2) to simulate the effects of hypothetical gabion NIDS on flood hydrographs and sediment yield, related to stormwater runoff (Goodrich et al. 2012). The model predicted changes are very small in a percentage change standpoint because the application was for a single event to be compared with other event-based simulations; additional sediment trapping would be expected to occur over time, until the height of the gabion is reached. Hypothetical installation in the upper watershed cause the K2 model to estimate decreased peak discharge, that also delays water (detains) by 1-2 minutes, which could allow for increased infiltration.

Stormwater Management Results

This Study assesses stormwater management for theoretical implementation of GSI and CSI in the regional watershed and in hypothetical developments.

For the regional watershed, the kinematic runoff and erosion (K2) watershed model was used to examine a 100-year, 6-hour event, and determine the effects of gabions on processes of surface

runoff and sediment yield. [Table 11](#) is a comparison of the K2 model and the HEC-1 model used in the FCDMC 2006 SV ADMP Fan No. 3 alternative. Focus was placed on the percent reduction that each infrastructure makes. While the flows are different because of the two different models, the FCDMC alternative has a larger reduction at the apex, but the overall reduction of flows at Wagner Wash is not as significant.

Table 11. GSI and CSI Regional Watershed Model Results Comparison

Location	K2 Model			FDC 2006 HEC-1 Model		
	Natural Conditions (cfs)	Max Gabions (cfs)	% Reduction	Natural Conditions (cfs)	Full Treatment (cfs)	% Reduction
Apex #3	2,439	2,329	4.5%	835	75	90%
Wagner Wash	3,124	2,789	10.7%	1,455	1,512	-3.9%

Theoretical GSI are installed within natural channels in the regional watershed to slow storm flows from the top of the watershed to an outflow in Wagner Wash. The GSI alternative provides a 4.5 percent reduction near the apex and a 10.7 percent reduction for a 100-year, 6-hour storm event at the Wagner Wash outfall. The CSI alternative uses a detention basin near the apex to capture stormflows upstream from the hypothetical development and slowly releases the detained water to the channelized drainage to the Wagner Wash outflow. The differences between the theoretical GSI and CSI installations make it challenging to compare the stormflow reductions, especially at the apex. Stormflows are managed at the apex upstream of the hypothetical development to protect life and property.

This Study used the 100-year storm event for surface water modeling because the FCDMC analyzed the SV ADMP Fan No. 3 alternatives using a 100-year event. In the hypothetical development scenarios, the outflows between the two different treatments were modeled and compared. Model results show that the 100-year 6-hour storm produced unsafe flow conditions in channels that would be incorporated into the hypothetical developments even before development and increasing impervious surface runoff is incorporated.

The development parameters used in the GSI hypothetical development were designed to route the increased runoff from impervious surfaces through natural channels in the development. In this Study theoretical GSI are installed within natural channels in the hypothetical development. Gabions were simulated in channels that were greater than 1 ft deep and in the full treatment scenario, the inflows were modified into the hypothetical development based on the results from the USGS K2 model. The same development parameters as in the CSI development ([Table 12](#)) but reweighted them based on the new development and configuration of the subcatchments.

Table 12. Simulated development peak outflows (cfs) from the 100-year 6-hour storm

Development feature	Impervious area (%)	Overland Manning's n	Depression storage (in)
Drainage Easement	0	0.13	0.25
Lot	40	0.12	0.07

Open space	0	0.13	0.25
Park	0	0.13	0.25
Retention basin	0	0.13	0.25
Road	100	0.011	0.07
School	20	0.08	0.07
Trail Path	0	0.13	0.25

GSI stormwater management for a 100-year, 6-hour storm would require GSI treatment at the lot level and inclusion of detention basins for storage and infiltration during large storm events. Nine natural channels were retained in the GSI hypothetical development. Linear parks were situated adjacent to the channels; however, the linear parks were not designed to take overflows from the natural channels during large storm events. Installing detention basins or swales within the linear parks adjacent to the natural channels would improve GSI stormwater management during a 100-year storm event.

A holistic GSI development would include treatment at the lot level and in right-of ways in addition to channel treatments. This Study modeled the use of theoretical GSI solely within the channels and references model results of GSI used for lot treatments in the Reclamation study titled: Identifying Key Areas in The City of Phoenix for Infiltration and Retention Using Low Impact Development (aka LID Floodplain). In that study, surface water modeling using PCSWMM was completed to assess changes in stormwater flow volumes following theoretical implementation of LID within each land use type for three LID application rate scenarios ([Table 13](#)).

Table 13. LID Floodplain PCSWMM model results

LID Floodplain Participation and Outflow Results			
Participation	25%	50%	100%
Outflow Reduction	16%	29%	55%

The LID Floodplain study model results showed that at LID implementation at 100 percent of lots there was a 55 percent stormflow volume reduction and a six percent peak flow reduction within the stormwater catchment (storm events modeled - Flood Control District's Jackson Street at 7th Ave. Gauge, 29 Year Continuous Precipitation from February 1, 1991 through January 1, 2020 Provides a variety of storms and ambient conditions).

In this Study, model results show that the streets and residences in the GSI hypothetical development increase the impervious surfaces and stormwater runoff by an average of 41 percent from pre-development to full GSI treatment for a 100-year, 6-hour storm. Implementation of theoretical GSI in the hypothetical development did not or only minimally reduce stormflow volumes for a 100-year, 6-hour storm. Based on these results, it would be insufficient to implement GSI solely in channels in a residential development to manage stormwater flows for a 100-year, 6-hour storm ([Table 14](#)).

Table 14. Simulated development peak outflows (cfs) from the 100-year 6-hour storm

Drainage Easement	Pre-Development	GSI			CSI
		No Treatment	No Upstream Treatment	Full Treatment	
DE 0	61.8	85.8	85.8	85.8	
DE 1	21.7	38.5	38.4	38.4	
DE 2	196.1	262.8	267.2	270.4	206.4
DE 3	46.5	59.3	57.8	57.8	
DE 4	102	158.3	150.5	150.7	
DE 5	50.4	67.4	67.8	67.8	
DE 6	72.6	127	122.4	122.4	
DE 8	1,254.6	1,258.9	1,314.8	1,230.3	304.1

Implementing GSI at the lot level and installing detention basins in linear parks adjacent to natural channels in the GSI hypothetical development would significantly improve stormwater management in the GSI hypothetical development during a 100-year, 6-hour storm. This Study also modeled implementation of GSI in channels in the hypothetical development for the 10-year storm reduced outflows from zero to 19 percent and for a 2-year storm reduced outflows from zero to 32 percent for a 2-year storm (refer to table percent (%) peak outflow reduction for each DE).

As highlighted in the LID Floodplain study, minimizing stormwater runoff at the lot level is crucial in managing stormflows in a development. Combining treatments at the lot level, in ROWs and in natural channels would be an optimum design for managing stormwater in a development. Model results showed installing gabions reduced the flows between GSI treatment and no upstream treatment in some channels.

However, gabions as the only low impact treatment did not reduce flows from the GSI development to predevelopment flows. In addition, except for in the 2-year 6-hour storm case, gabions alone could not reduce the flows to acceptable safety standards of less than 5 ft/s. To assess the ability of GSI to manage large storm events, it is important to model the use of GSI at the lot level, in ROWs as well as in natural channels. Stormwater management results can be found in the TSC modeling report provided in [Appendix 4](#).

3.3 LID O&M Assessment

Use of GSI in arid lands is a burgeoning field. There is limited information available regarding the cost to maintain LID features. As part of this Study, a report was produced that identified and interviewed entities with LID installations. At the time of the assessment, O&M practices for LID features were not established and no LID O&M costs were available.

The interview results indicated that limited quantitative data regarding LID O&M practices and costs are available. The conclusions of that report had to be based on anecdotal and qualitative information obtained during the interviews. More details of the LID O&M assessment can be found in the Low Impact Development Operations and Maintenance Assessment Final Report, [Appendix 6](#).

3.4 Infiltration Analysis

An infiltration analysis was planned as part of development of a conceptual groundwater model and subsequently a conceptual water budget. As a result of Covid there were insufficient resources to complete a conceptual water budget. Information from this study may be used to analyze changes to natural infiltration when GSI and CSI are used for stormwater management.

GSI regional watershed model found that the addition of gabions reduced runoff volume outflow for the event-based storm and increased sub-surface infiltration. Given multiple events of monsoon rainfall, increased infiltration and storage upstream could saturate conditions over time, supporting a slow release of excess in the channel that would continue dampening effect on peak flow (Norman et al., 2016). This estimated increase in infiltration comes at the reduction in stream discharge associated with wetlands in the same locations. Infiltration model results for the GSI regional watershed scenario are in the USGS modeling report provided in [Appendix 3](#).

Infiltration testing results from the Study area gathered by Matrix New World staff were used in the surface water modeling analyses. However, only infiltration outputs in the pre-development, no treatment, and no upstream treatment scenarios were compared because the CSI and GSI full treatment scenarios have different and smaller model domains. The TSC modeling report found that much of the model domain was unaffected by the development and the overall average infiltration of the entire model scenario may not have been sensitive enough to pick up a difference that the development gabions make in the GSI scenario. Detailed infiltration results can be found in the TSC modeling report provided in [Appendix 4](#) and Hassayampa River Study Infiltration Testing Results in [Appendix 5](#).

3.5 Economic Analysis and Ecosystem Services

Theoretical designs of GSI and CSI applied within a hypothetical development and the regional watershed for a 100-year, 6-hour storm event were used to develop capital and OM&R costs and to quantify the value of any associated shrubland ecosystem services benefits.

Capital costs for the GSI regional watershed scenario are about 12 percent of the capital costs for the CSI regional watershed scenario. Capital costs for the GSI scenario for the hypothetical development are about 17 percent higher than the capital costs for the CSI hypothetical development due to having 28 culvert installations under the GSI scenario versus 12 culvert installations under the CSI scenario.

OM&R costs for the GSI regional watershed scenario are about seven percent of the OM&R costs for the conventional scenario in the regional watershed. OM&R costs are 26 percent higher in the GSI hypothetical development scenario than the CSI hypothetical development scenario due to the larger number of culvert crossings required in the GSI hypothetical development versus the CSI hypothetical development.

Total benefits for the GSI and CSI scenarios were determined by adding the capital and OM&R cost savings to the shrubland ecosystem services benefit values for each scenario. Over the 100-year

Study period the capital and OM&R and shrubland ecosystem services for the GSI alternative exceed those associated with the CSI alternative.

Stormflow reduction was not included in the benefits analysis but should be an important consideration. Had the GSI hypothetical development scenario been modeled so that the channels overflowed into adjacent parks and the water was stored in parks for infiltration, these potential benefits could have been accounted for. Installing detention basins in linear parks adjacent to natural channels in the GSI hypothetical development would significantly improve stormwater management and lead to increased benefits.

3.6 Other Conclusions

The GSI and CSI hypothetical developments were designed to maximize the number of developable lots. The GSI retains nine natural channels, as a result there are fewer lots. The GSI hypothetical development contains 530 lots and has 107 acres of open space. The CSI hypothetical development contains 546 lots and has 63 acres of open space. There is a 2.9 percent reduction in the number of lots in the GSI scenario over the CSI scenario, however the GSI hypothetical development contains 58 percent more open space than the CSI scenario. Although there are fewer lots in the GSI hypothetical development than the CSI hypothetical development the GSI hypothetical development provides increased ecosystem services increasing their value similar to residential lots adjacent to golf courses.

GSI increases ecosystem services over CSI. Both GSI and CSI would be used to manage stormwater to protect life and property, however GSI enhances ecosystem services benefits that CSI does not including, supporting native vegetation, infiltrating water close to its source. Increased vegetation reduces urban heat, and air and stormwater pollution and improves environmental conditions in urban areas (LID Floodplain Study, 2022).

To successfully utilize GSI in a residential development, GSI would need to be implemented throughout a development to adequately manage 100-year storms. This may be easily addressed with infiltration basins situated on every residential lot to capture stormwater runoff from the lots impervious surfaces including roof systems and driveways. This would dramatically reduce street runoff and the need for large concrete infrastructure projects.

4 Lessons Learned

- The GSI hypothetical development retained nine natural channels that are located adjacent to linear parks. The nine natural channels should have been designed to convey excess stormwater into adjacent linear parks for storage during high-flow storm events.
- Linear parks in the GSI hypothetical developments should have been designed to accept excess flow from adjacent natural channels during high-flow storm events.
- GSI used in natural channels in the hypothetical development is insufficient to manage large storm flows and must be augmented by use of GSI at the lot level and by incorporating

infiltration basins in linear parks adjacent to the natural channels. Minimizing runoff from individual lots is crucial to stormwater management.

- Comparing isolated installations of GSI features (solely within channels) to CSI to manage a 100-year storm event is not reasonable. However holistic use of GSI throughout a development may adequately manage 100-year storms. Using the results of this Study and the LID Floodplain a meta-analysis or a new analysis may be conducted to assess the potential for holistic GSI installations to manage a 100-year event. GSI greatly enhances ecosystem services benefits and the environmental benefits of a holistic GSI development would be tremendous. Holistic GSI implementation in a development may be easily addressed by installing infiltration basins on every residential lot to capture stormwater from impervious surfaces including roof systems and driveways and keep this runoff off of the streets reducing the need for large scale CSI systems.

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Appendices

Appendix 1.	Stakeholder Meetings
Appendix 2.	Technical Memorandum: Creating the Hypothetical Developments downstream of Fan Apex #3
Appendix 3.	Case Study Using KINEROS2 (K2) Model to Assess Potential Hydrologic and Geomorphic Effects of Installing Gabions in a Developing Subwatershed near Buckeye, Arizona, USA
Appendix 4.	Hassayampa River Study: Modeling Low Impact Development for Stormwater Management
Appendix 5.	Hassayampa River Study: Infiltration Testing Results
Appendix 6.	Low Impact Development Operations and Maintenance Assessment
Appendix 7.	Hassayampa River Study: Economic Analysis of Green and Conventional Stormwater Infrastructure