AGAINST THE GRAIN

Carving campus corridors through stormwater diversion and capture

2019 EPA Campus Rainworks Challenge
Team M25
University of Arizona

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ABSTRACT:

Located in Tucson, Arizona, the University of Arizona (UA) suffers from the same lack of effective stormwater management that characterizes the city. On campus, storm events result in major flooding occurring along the prominent east-west streets that run through campus, inhibiting north-south pedestrian and bicycle movement. This exacerbates existing pedestrian and bicycle challenges at UA; with an east-west campus orientation, pedestrians and bicycles are forced to weave between buildings, dodge vehicular traffic, and navigate awkward and ill-defined routes to travel north or south across campus. *Against the Grain* carves three north-south corridors across campus that address social and environmental needs by diverting stormwater from major east-west streets into connected north-south basins that accommodate infiltration, decrease reliance on supplemental irrigation, and address flooding issues. The basins line newly defined north-south pedestrian and bicycle corridors that promote connectivity and safety, providing a dense canopy of native shade trees that increase human comfort and define UA as an institution uniquely rooted in the Sonoran Desert. Three context-based typologies along the corridor are presented, illustrating interventions to be incorporated throughout the project. The layering of hydrologic and social functions contributes to the positive impacts and feasibility of *Against the Grain*. At the same time, the relationship between people and water in the Sonoran Desert is strengthened as the notion of water as an urban nuisance is reframed and shown to be a valuable resource that sustains life and enhances social experiences.

INTRODUCTION

A Collaborative Approach: *Against the Grain* is a collaboration between students in three University of Arizona (UA) classes from three different departments. *Landscape Architecture Studio V* (LAR 612) students oversaw plan development and project management, *Ecology of Rainwater Harvesting* (RNR 496B/696B) students conducted soil analysis that guided proposed stormwater harvesting approaches, and *Green Infrastructure* (ENVS 450/550) students conducted financial, maintenance, and hydrologic assessments to inform and support design goals and decisions. Master plan development involved an iterative approach that incorporated feedback and research provided by members of the student team throughout the process, resulting in a plan that is grounded in feasibility and responds to the needs of the UA community and campus (Fig. 1). *Against the Grain* is a masterplan for the University of Arizona (UA) that layers pedestrian and hydrologic functions through the implementation of 3 continuous green infrastructure (GI) corridors.

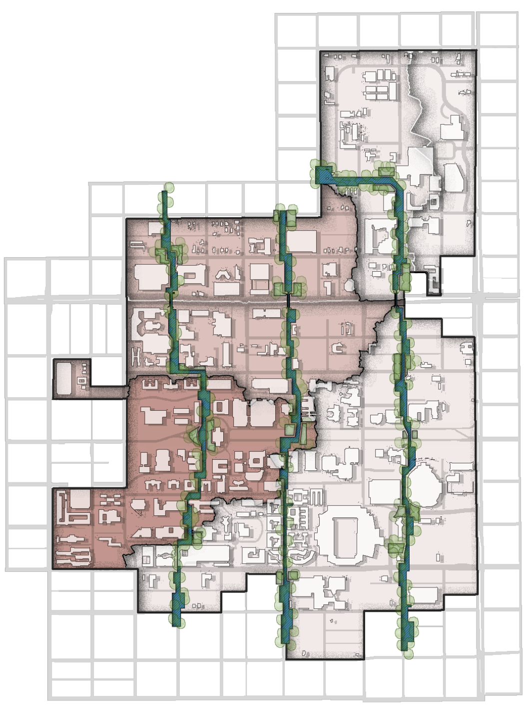

Fig. 1 - Master plan showing sub-watersheds and location of proposed corridors in green.

Climatic Context: The Sonoran Desert stretches from northern Mexico into Arizona and California, with Tucson included towards the eastern edge of its extent. It is a unique biome that features leguminous trees and immediately recognizable columnar cacti found nowhere else on earth. It exhibits bi-modal rainfall patterns, with over half of the average 12 inches of annual precipitation occurring in short, intense storms in the summer monsoon season between July and October (NOAA, 2019). A second, lesser rainy season occurs between December and February, and accounts for the majority of the remaining annual precipitation (NOAA, 2019). The months of April through June exhibit minimal rainfall, with weeks and sometimes months of no precipitation. Because rainfall is limited and the majority of it occurs in short, intense summer storms, effective stormwater management that diverts and captures this flow is crucial for maximizing the use of this precious resource.

Like much of the arid southwest, Tucson is characterized by hot summer temperatures and intense sun, with average daily high temperatures exceeding 90°F from May through September (NOAA, 2019). Shade is critical for comfortable outdoor spaces that limit the negative health impacts of extreme heat.

Effective stormwater management in Tucson and at UA will become more crucial throughout the century as climate change intensifies. It is generally agreed that within the region, average annual temperatures and the number and intensity of extreme heat events will increase, while precipitation is likely to decrease (U.S. Global Change Research Program, 2018). Some climate models indicate an increase in the intensity of short-term precipitation events, especially during the summer monsoon season (U.S. Global Change Research Program, 2018). This is consistent with global climate models that indicate a warmer atmosphere will be capable of supporting individual rainfall events of a greater intensity than was previously possible (Kunkel, 2003). Intensification of extreme rainfall events is an anticipated result of human-caused climate change worldwide. These intense, short-term stormwater runoff events are expected to be amplified in urban areas, which are dominated by impermeable paved surfaces (Luong et al., 2017). This type of flash flooding is even more problematic in the semi-arid and arid urban areas of the Southwest, because the exposed soils that do remain are generally not capable of absorbing rainwater quickly due to their inherent mineral-devoid qualities. Combined, the future climate projection for the urban Southwest translates to a future where drought and extreme heat are the norm, punctuated by occasional excessive rainfall and flash flooding. These occasional extreme precipitation events are not, however, expected to make up for the deficit in moisture. Increased evapotranspiration due to warmer temperatures combined with an overall decrease in annual precipitation will lead to chronic drought conditions (U.S. Global Change Research Program, 2018).

THE SITE

The University of Arizona is comprised of 490 acres located in northwestern Tucson (Fig. 2). It is a Research I level institution, with 45,000 students and 12,000 faculty and staff members. *Against the Grain* considers the entire campus as a site, focusing on the definition, prioritization, and restructuring of existing pedestrian and bicycle routes within the framework of a functional green infrastructure and hydrologic transportation system.

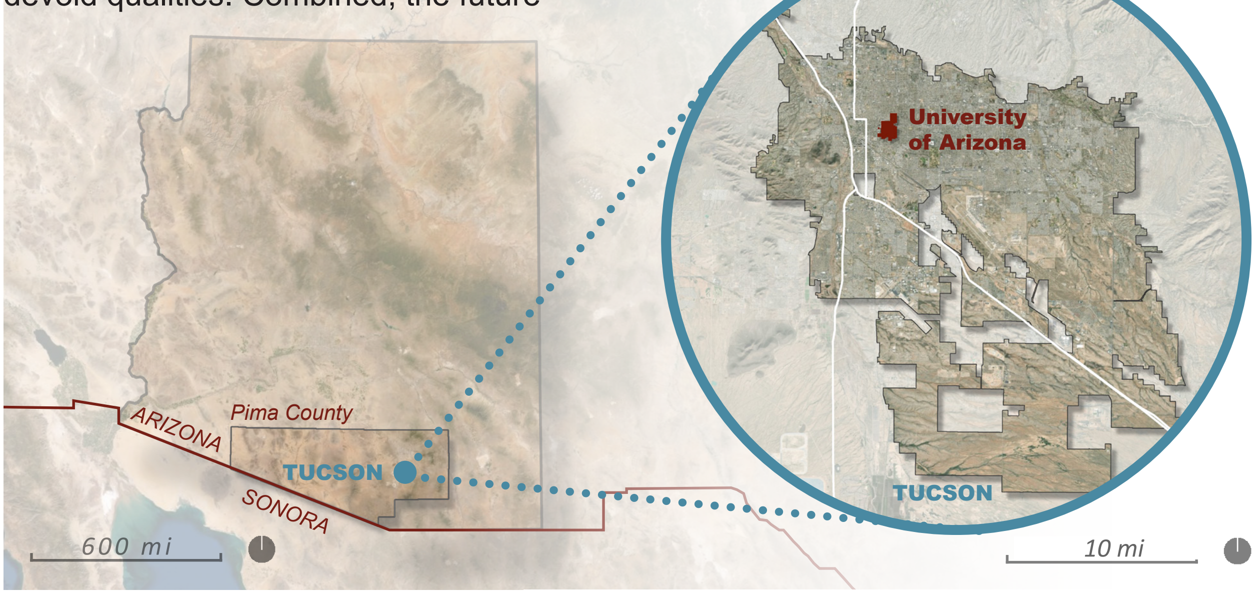

Fig. 2 - Context maps showing location of Tucson and the University of Arizona.

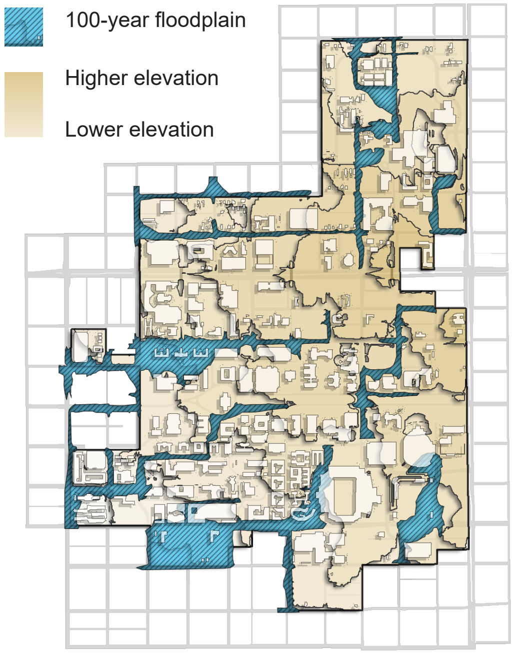

Fig. 3 - Campus topography and flooding.

SITE ASSESSMENT

Hydrology: Today, stormwater management in Tucson and at UA is virtually nonexistent. The city lacks an underground stormwater management system and relies on streets to convey excess stormwater to the nearby Santa Cruz River. Precious rainwater is contaminated as it travels through the streets, causing flooding of important circulation routes. Formerly human infrastructure and daily live was built around water. Now it is now viewed as a nuisance to be removed rapidly from the urban Tucson landscape. In the *2017 UA Stormwater Management Plan*, the 100-year floodplains were identified throughout campus as priority areas for stormwater management (Fig. 3). These areas align with on-campus flooding during lesser rain events, and are targeted for flood management in *Against the Grain*.

To understand the extent of contributing hydrologic areas to the identified flooding issues, we derived the 6 sub-watersheds that make up the campus hydrologic landscape using the ArcGIS Hydrology toolset. These sub-watersheds were based on sub-watersheds identified in the *2009 UA Surface Water Implementation Plan* (UA Campus and Facilities Planning, 2009), but included updates to building footprints and topography. We also derived flow lines across campus using 1' topography lines in ArcGIS to understand the flow path of water to flood-prone areas and where interventions could divert and capture this water. Flow generally occurs from east to west, concentrating along large east-west streets that flow uninterrupted across campus and effectively create small rivers during rain events. This water is transported to the Santa Cruz River, dispersing urban pollutants collected from the streets into the River and landscapes downstream of Tucson.

Circulation Conflicts: UA features a vehicle-oriented campus with prominent east-west streets that inhibit north-south pedestrian and bicycle movement (Fig. 4). Although north-south pedestrian

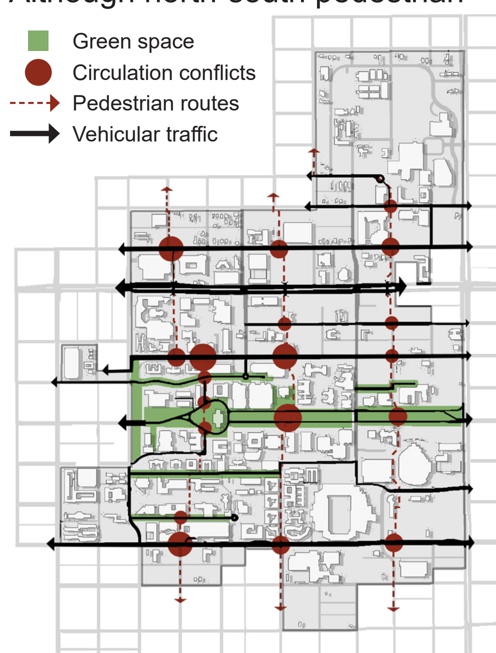

Fig. 4 - Circulation conflicts and connectivity.

and bicycle movement across campus is necessary for students and faculty traveling from home and between classes, these routes are ill-defined, awkward, and relegated to in-between spaces. These routes require street crossings that prioritize perpendicular, east-west vehicular movement and result in uncomfortable and unsafe conditions for crossing pedestrians and bicycles.

A Fragmented Approach: UA's current approach to implementing stormwater management and pedestrian infrastructure is fractured and piecemeal. Because there is no designated funding source for GI and other stormwater management infrastructure, these interventions are typically tacked on to other construction projects as an afterthought. This results in disconnected GI and active stormwater management systems across campus that address site-level stormwater management but lack the broader holistic perspective necessary for watershed management. This fragmented approach to stormwater at UA is mirrored in the implementation of pedestrian and bicycle infrastructure. Throughout campus, sections of functional and financially costly pedestrian and bicycle infrastructure exist. Three underpasses beneath the 7-lane vehicular Speedway Boulevard provide connection between north and central campus, and short sections of comfortable biking paths can be found throughout campus. However, the functionality of these infrastructure fragments is limited, as pedestrians and cyclists are required to navigate awkward, ill-defined, and often vehicle-dominated routes and crossings in between the functional sections of infrastructure. The efficacy of these well-designed fragments of circulation infrastructure could be maximized by implementing functional pedestrian and bicycle routes between them, facilitating movement across campus.

Conflicting Functions: At UA, stormwater is transported along human circulation routes with no designated infrastructure to divert, treat, or allow it to infiltrate. This means that during rain events, already difficult north-south pedestrian movement is further impeded as east-west streets effectively become small rivers. The present circulation system is designed to transport people and vehicles, with water conveyance as an afterthought. Synergistically addressing stormwater management and circulation conflicts in a layered approach could functionally integrate these systems and address human and environmental issues cohesively.

SOLUTION: AGAINST THE GRAIN

Project Goals: The process of watershed analysis - understanding the flows of both water and people - led to a connecting of dots and the incremental development of three goals that guided master plan development:

GOAL I: Get stormwater off the streets and into the landscape

GOAL II: Layer hydrologic interventions with social infrastructure

GOAL III: Devise a solution that is holistic in scale yet grounded in feasibility

Concept - Against the Grain: *Against the Grain* addresses the lack of effective stormwater management at UA by carving three continuous greenways that facilitate the movement of water, pedestrians, and cyclists across campus. The corridors are positioned to interrupt the flow of water along east-west streets and mitigate water accumulation in current flood-prone areas, diverting it into networks of north-south oriented passive basins that slow, capture, and infiltrate the stormwater and irrigate densely planted native vegetation. In addition to stormwater management benefits, the master plan enhances the pedestrian experience. The linear networks of passive basins line the pedestrian and bicycle oriented corridors, providing definition to the routes and a connection to the Sonoran Desert with dense native plantings. The corridors facilitate human movement through existing utilized yet undefined and awkward routes by separating modes of transportation, creating continuous stretches of functional pedestrian and bicycle corridor, connecting fragments of existing pedestrian and bicycle infrastructure, and prioritizing non-vehicular circulation at key areas across campus. *Against the Grain* reframes the current reality of stormwater as a nuisance on campus, taking advantage of this valuable resource to define and enhance public spaces, irrigate native plantings, and reconnect people with the dynamic landscapes and hydrologic processes of the Sonoran Desert.

WATERSHED-SCALE PHASING

The current fractured approach to implementing GI and pedestrian infrastructure is replaced with a phasing plan that addresses stormwater management holistically at a hydrologic scale. By narrowing the geography to the watershed - rather than corridor-by-corridor - the hydrologic impacts of GI interventions can be connected and measurable, while still responsive to opportunity windows for project funding. These phased interventions allow for stand-alone corridors that build upon one another, eventually creating a network of north-south greenways.

The project includes three phases that are defined by the six sub-watershed boundaries that make up the UA campus. Phasing priorities are determined by pedestrian traffic volume (Ayers Saint Gross, 2009), severity of flooding, and characteristics particular to each watershed (Fig. 5). Timeline estimates take into account fundraising and construction.

Phase I: Two Year Timeline

The first phase includes the sub-watershed containing the historic and academic core of campus, which features the highest concentration of activity as well as several significant flooding areas that have been prioritized for flood mitigation in the *2017 Stormwater Management Plan (*UA Risk Management Services, 2017). Additionally, this area is a primary interface with prospective students and the public, so implementation of this phase will have an immediate impact not only on UA faculty and students, but on the public as well. This phase will include construction

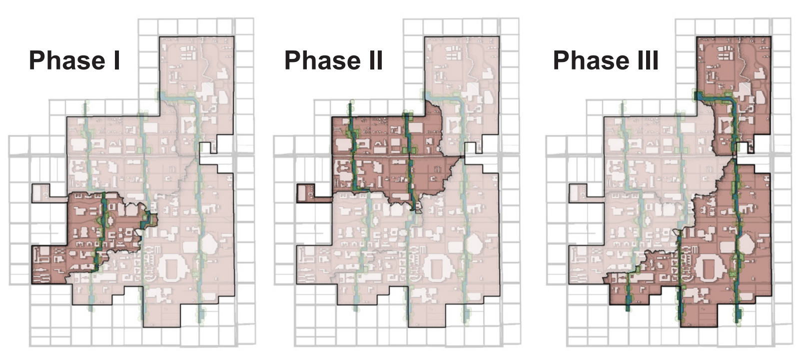

Fig. 5 - Watershed scale phasing plan for Against the Grain.

of the central portion of the western corridor as well as a small section of the central corridor, at the top of the watershed and where high traffic crossings exist at the campus center.

Phase II: Four Year Timeline

The second phase includes the two northwestern sub-watersheds. These watersheds are adjacent to Phase I, allowing Phase II construction to extend the existing pieces of the western and central corridors to the north edge of campus. This facilitates pedestrian and bicycle transportation into campus from the north, where new and future planned housing developments are increasing commuters entering from the north. This phase includes several flooding areas along prominent east-west streets that affect campus and the surrounding neighborhoods.

Phase III: Six Year Timeline

The remaining three watersheds along the eastern edge of campus are addressed in Phase III. This includes the extension of the western and central corridors to the southern edge of campus as well as the construction of the entire eastern corridor. This phase addresses flooding along the southern and northeast sections of campus and connects the Phase I and II corridors to housing to the south of campus. Phase III areas include the medical center in the northeast and the sports district, which are largely separate from and unique in character to the eastern, academic core of campus. Relatively, these portions of campus currently have the most developed fragments of north-south pedestrian infrastructure (wide sidewalks, intermittent plazas, and stretches of streets limited to pedestrian and bike travel only).

TYPOLOGIES

Spaces within the corridors can be categorized into three distinct typologies. Each typology includes interventions that respond to the context, function, and layout of the space and address project goals of diverting and capturing stormwater while enhancing pedestrian and bicycle movement. An example of each typology has been selected and designed for the Phase I watershed to illustrate how the proposed interventions interact with existing features in real spaces. Two features occur in all typologies to create a continuous and well-defined route; these features are the replacement of asphalt and concrete sidewalks with brick-like permeable pavers that align with the aesthetic design standards at UA, and native plantings within the basins that provide a densely shaded corridor that is strongly rooted in the unique ecology that defines the Sonoran Desert.

1. Street Crossings: This typology is about facilitating movement of people and water against the grain. Where proposed corridors intersect existing prominent east-west streets, pedestrian and bicycle safety is prioritized while street flooding is diverted into north-south oriented basins that line the corridors.

Speed tables at pedestrian and bicycle crossings raise the street to curb level, requiring vehicles to slow down while allowing pedestrians and bicycles to cross the street without changing grade. These speed tables also function as water diversion mechanisms, redirecting water flowing through the streets into decorative scuppers built into the sidewalks. The scuppers drain into the vegetated basins that line the corridor, removing stormwater from the flooded streets and dispersing it into the corridor where it is allowed to slow, infiltrate, and irrigate basin vegetation.

2. In Between Buildings: Because UA was not designed to facilitate north-south movement, weaving between narrowly spaced buildings is unavoidable when moving north-south across campus. These narrow, in between spaces form a second typology which defines a large portion of the corridors between street crossings. Taking advantage of space is a necessity in making these areas functional for water capture and pedestrian and bicycle movement.

Pedestrian and bicycle lanes are clearly separated and run along the middle of this typology, flanked on the sides by long linear basins that capture excess run-off from the permeable pavement. Riprap armoring along the steep banks act as erosion control, allowing for basin capacity to be maximized. Adjacent architecture is integrated into the design through the disconnection of downspouts, which funnel roof run-off into the vegetated basins. Check dams are spaced along the basins, slowing the flow of water through the basins and allowing it to infiltrate. Perforated pipes buried beneath the basins allow for additional conveyance of water away from the architecture during heavier storm events.

3. Plazas and Nodes: Plazas, nodes, and other gathering areas comprise the third typology found throughout the corridors. These spaces function as larger patches along the corridor and include additional seating and social spaces not found in the other typologies. The spaces that make up this typology are more unique than the other typologies, and so exact interventions will vary to some extent depending on the space. However, following some guiding principles and incorporating simple interventions that align with the other typologies will ensure these spaces will fit cohesively within the corridor. Existing architecture and built features should be incorporated into the design when appropriate. Hardscape should be replaced with permeable pavement when possible, and excess hardscape should be removed. Basin size and shape should respond to existing conditions and maximize capture. Basins should be connected by perforated pipes beneath the pavement to accommodate basin overflow.

The example space for this typology is a fountain at the western edge of the historic core of campus. Four openings are cut into the fountain, with the fountain transformed into a densely shaded octagonal gathering space that incorporates the existing fountain infrastructure. The central elevated platform in the fountain is maintained and transformed into a native cactus garden which forms the epicenter of the space. The inner concrete sidewalk is removed and replaced with densely planted basins that capture run-off from the surrounding hardscape. Several existing basins are connected to the new basins through perforated pipes that run under the permeable pavement. Benches and seat-walls provide shaded seating adjacent to the basins.

DESIGN PERFORMANCE

To understand the potential hydrologic and ecologic impacts of the design, performance metrics were calculated for the Phase I watershed. Basins were sited along the western corridor in the Phase I watershed as shown in Fig. 6, with performance calculations reflecting the position and size of these basins. Hydrologic performance measurements include peak discharge reduction, time of concentration, and total run-off capture for a 2-year, 24-hr storm using rainfall data from the NOAA Atlas 14 as an input. A soil study conducted for this report informed the decision to focus on passive systems to enhance ecological function. Additional performance metrics include canopy coverage and land cover change. For detailed calculations used to determine performance presented below, see p. 15.

Basin Capacity: Basins were sized and placed for Phase I of the master plan as shown in Fig. 6. Basin volumes were calculated, summed, and compared to the volume of stormwater generated in the sub-watershed in a 2-year, 24-hour storm. Proposed basins were calculated to divert and capture over 40% (4.78 acre feet) of the total 11.79 acre feet of run-off generated in a 2-year 24-hour storm event.

Peak Discharge and Time of Concentration: To determine both the peak discharge and time of concentration, the web interface PC-Hydro model was used. PC-Hydro is a semi-empirical rainfall-runoff model for predicting flood peaks in watersheds under natural and developed hydrological conditions (Arroyo Engineering, 2007). The interface accepts rainfall intensity-depth-duration data directly from the NOAA Atlas 14 upper 90%rainfall (Arroyo Engineering, 2007). Model inputs included soil type, percent imperviousness, and vegetative cover. Impervious coverage for the site was calculated to be 55%, vegetative cover 20%, and soil type D was used based on the Pima County Regional Flood Control soil database. The time of concentration was calculated using an empirical equation that relates it to the physical characteristics of the watershed and rainfall intensity (Arroyo Engineering, 2007). Peak discharge during a 2-year storm event was found to decrease from 163cfs to 132cfs (or by 19%). The time of concentration increased from 14 minutes to 24 minutes (a 71% increase), indicating that water is effectively being slowed and stored onsite.

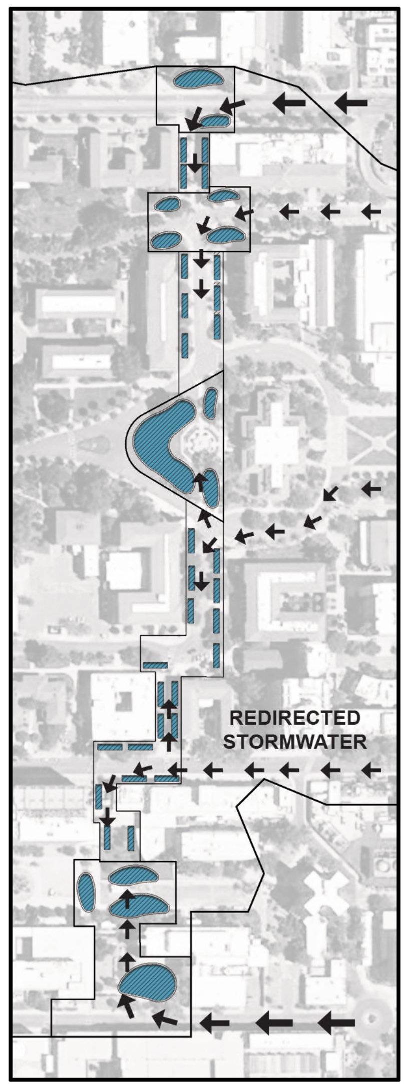

Fig. 6 - Basin locations and stormwater movement in Phase I segment of western corridor.

Land surface coverage: Land surface coverage was calculated for corridor segments in Phase I for both current and proposed conditions. On average, the corridors are 50' wide, with 20% asphalt, 40% concrete, and 40% compacted DG coverage, with two shade trees every 70'. The proposed design doubles the number of shade trees, creating a continuous shaded corridor that shields pedestrians and cyclists from the intense Tucson sun. Impervious surfaces are replaced with permeable pavement (44%) and vegetated, permeable basins (56%).

Ecological Function: To understand the ecological performance of different types of GI installations, we conducted a soil study that compared biological diversity for a passive on-campus GI system (Underwood Garden) comprised of natively vegetated rain gardens, with a more technologically advanced GI system that included native and non-native plantings implemented in engineered soils of the Environment and Natural Resources 2 (ENR2) building's inner courtyards (Figs. 7-8). Higher soil biological diversity is associated with high functioning ecological systems. We found that the Underwood Garden soils had higher microbial diversity than those of ENR2, indicating a passive GI approach with native plants and soils is more ecologically functional than a more technologically advanced approach with non-native plantings.

Findings from the soil analyses informed the decision to focus on passive rainwater harvesting and native plantings in *Against the Grain*, due to their potentially positive impacts on soil health. Xeroriparian vegetation communities, with a palo verde and mesquite canopy will be implemented in open, sunny areas of the corridor. Narrower, in-between buildings spaces feature native sycamores and hackberry, providing a shaded canopy that mimic high desert canyon ecology.

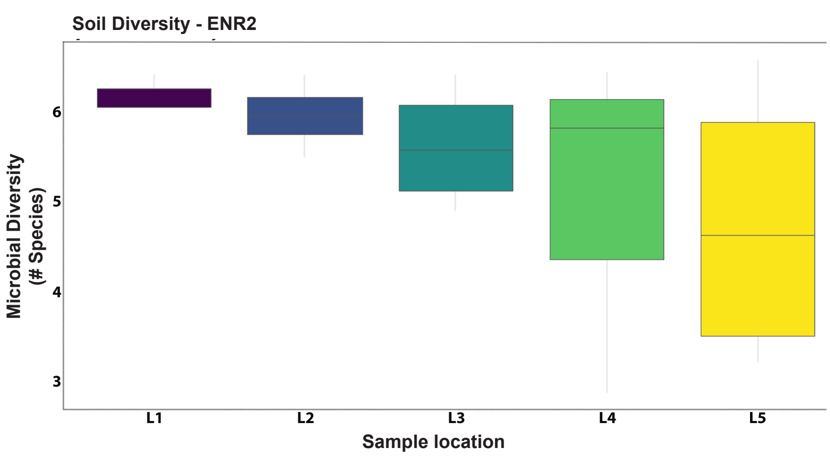

Fig. 7 -Species diversity of soil samples from ENR2 (each sample is taken from a different courtyard level).

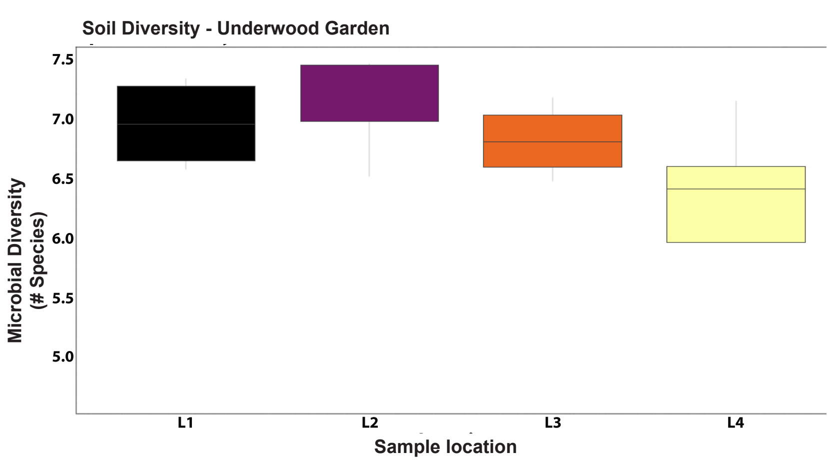

Fig. 8 -Species diversity of soil samples from GI Underwood Garden. L4 represents a control sample from non GI soils.

INTEGRATION WITH EXISTING PLANS

Local & Regional Standards: Linear basin and vegetated swale designs were inspired by and adhere to existing City of Tucson and Pima County Green Infrastructure Standards (Pima County, 2015). These standards inspired the use of pervious pavements and the inclusion of check dams to slow flow along linear basins in proposed typologies. Perforated pipes included in all basins exceed the overflow design standards set forth by the Arizona Department of Water Resources. Dimensions and other basin characteristics were determined based on state standards, with narrow, linear basins featuring riprap armoring to address erosion issues of steeply sloping walls, and depth of these basins limited to 2 feet to avoid safety hazards to pedestrians.

Campus Plans: An updated 2020 master plan for UA is in development through a contract with Ayers Saint Gross Architects (ASG). Conversations with Jack Black, Vice President of the Tempe, Arizona office of ASG reveal that definition of north-south pedestrian and bicycle routes through campus is a primary goal in the plan updates, and ASG is supportive of *Against the Grain*. The need for these routes was first recognized in the 2003 UA Comprehensive Campus Plan and remains an important campus-wide priority (UA, 2003). *Against the Grain* also aligns with issues and goals identified in other UA campus planning documents. Corridors are placed to intercept and divert water from flooding areas prioritized for additional management in the *2009 UA Surface Water Implementation Plan*. Circulation conflicts identified in the *2003 UA Comprehensive Campus Plan* (Fig. 9) are addressed through typology interventions that prioritize pedestrian and bicycle movement and safety.

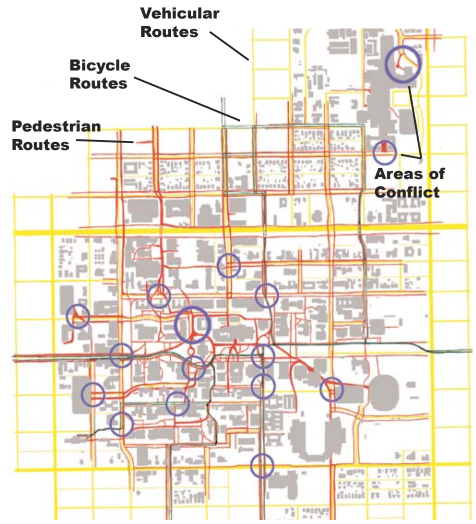

Fig. 9 - Circulation conflict map from the 2003 Comprehensive Campus Plan.

COMMUNITY RELEVANCE

Benefiting Individuals: The majority of the 45,000 students and 12,000 faculty and staff at UA will likely utilize the corridors to reach their offices or travel between classes. Additionally, the eastern corridor aligns with an important route used to access the sports facilities. With 18 home games with an average attendance of 15,000 in the 2019 men's basketball season, and seven home football games with an average attendance of 42,000, these two sports alone would account for over half a million visits annually to the eastern corridor, expanding the impact of the corridors beyond UA students and faculty.

Connection to Tucson: The City of Tucson has invested significantly in transit-oriented development beginning with the $2.1-billion-dollar investment in the Sun Link streetcar (Regional Transport Authority, 2019) that currently links the UA to downtown Tucson and the fast-growing neighborhoods just west of the Santa Cruz

River. *Against the Grain* proposes large-scale greenways that would significantly improve campus walkability and connect directly with the Sun Link street car stops. This encourages non-vehicular travel and boldly supports the City's investment in transit and downtown development.

Support and Partnerships from Local Organizations: A number of local non-profit organizations could be potential contributing partners to *Against the Grain* due to their focus on stormwater harvesting, functional pedestrian circulation, urban ecological interpretation, and/or community engagement. The existence and success of these local non-profits indicates that the goals of *Against the Grain* align with those in the broader Tucson community.

Stormwater Harvesting Project Manager Jon Choi at Trees for Tucson - a local nonprofit that provides low cost trees and passive stormwater harvesting basins throughout the city - voiced support for *Against the Grain* and provided guidance on basin sizing that was incorporated into the plan. Watershed Management Group is another local nonprofit that has partnered with UA to install passive stormwater harvesting basins on campus and provide education sessions to UA students. They install primarily passive rainwater harvesting systems throughout Tucson with the assistance of volunteers. They could potentially assist with the implementation of corridor basins, while providing education opportunities to volunteers.

Living Streets Alliance is a Tucson organization that provides funding and implementation assistance for complete streets. They focus on projects that enhance non-vehicular modes of transportation, promote human engagement and interaction along transportation routes, and provide native shade trees and plantings. Their goals, which stack pedestrian and ecological functions, align closely with those of *Against the Grain*, and they could be an important project partner to assist with implementation and community engagement through volunteer work days and plantings.

The Tucson Audubon Society has assisted with urban habitat creation and interpretation all around Tucson. They are identified as a potential partner that could provide assistance in developing and implementing interpretive signage discussing the native ecologies represented along the corridors. This would promote ecological literacy among corridor users and further enhance the connection between users and the Sonoran Desert through accessible educational opportunities.

Partnerships on Campus: Various classes at UA may also benefit from research and education opportunities provided by the corridors. Rainwater Harvesting (ENVS 454/554) is a course taught by campus planner Grant McCormick in the summer and fall semesters each year. This course teaches students about rainwater harvesting techniques in the desert, and culminates with the students constructing stormwater harvesting basins on campus. Some corridor basins could be constructed by this class, integrating student learning and work into the creation of the corridors.

The corridor basins also provide research opportunities for UA researchers such as Dr. Vanessa Buzzard who looks at soil function and biodiversity in urban systems, particularly in GI installations. The numerous connected basins in *Against the Grain* provide the opportunity to investigate the soil functions of different native ecologies planted in the basins, and to understand how soil function and water quality changes moving from street to basins further downstream.

IMPLEMENTATION & FINANCIAL VIABILITY

Historically, GI projects on the UA campus have been funded in two ways: (1) as tacked-on improvements during construction or renovation of buildings, and (2) as small grants projects from sources like the UA Green Fund and individual Colleges within the University. This has led to a piecemeal investment in GI on campus with limited integration and lack of watershed-scale stormwater management. One of the goals for *Against the Grain* is a solution that is holistic in scale yet feasible in design and construction – a buildable, financially-grounded, and phasing-minded strategy.

With this in mind, *Against the Grain* pairs watershed-scale phasing with two targeted approaches for implementation: (1) *passive* stormwater harvesting design, and

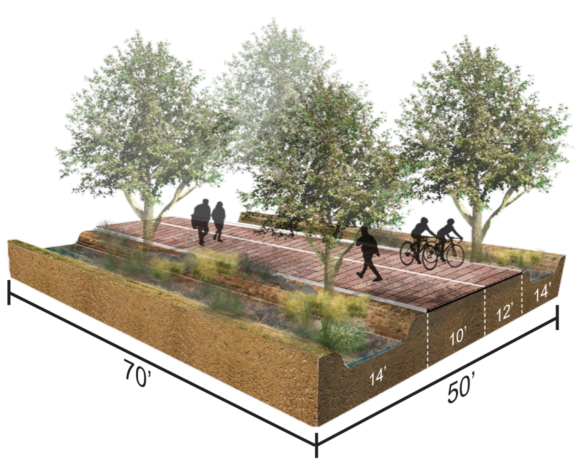

Fig. 10 - Typical 70' x 50' segment of corridor.

(2) diverse funding opportunities.

Passive Stormwater Harvesting: Based on field visits, discussions with maintenance staff, and data provided by UA Campus Planning, 4 out of 7 of the active rainwater harvesting systems on campus are not fully functional at this time (including cistern systems, underground stormwater tanks, and building condensate irrigation). This is due to construction near the system, mechanical failure, lack of maintenance, or improper installation of equipment during construction. At the same time, the complex components, engineering, and installation of active systems often make them significantly more expensive than passive systems for both initial construction and maintenance.

Considering the obstacles these issues present for implementation and feasibility, *Against the Grain* leans into the passive systems approach. It allows for major hydrologic, cross-campus impacts while keeping installation and maintenance costs reasonable and shareable.

The low-maintenance design of native vegetation basins coupled with the visibility of passive systems garnered the support of Woody Remencus, Landscape Manager for UA Facilities Management.

Costs: In order to calculate project construction and maintenance costs, a typical 70' x 50' section of the corridor was developed according to the average condition of Phase I proposed locations (Fig. 10). Costs were calculated for all materials, installation, and typical maintenance. These costs were first projected along the full length of Phase I, then along the total length of all corridors including Phases II and III. See

Calculations (p.16) for details.

Installation per typical 70’ x 50’ section:
$60,000
Installation of Phase I corridor
(1,300 linear feet): **$1.2 million**
Installation of full project, Phases I-III
(12,787 linear feet): **$13.8 million**

Maintenance: Using the same 70’ x 50’ typical segment, maintenance costs were developed based on actual annual costs of existing GI projects of a similar size and character on the UA campus. These costs were then projected for the complete Phase I corridor and for the entire project.

Annual maintenance costs per typical
70’ x 50’ segment: **$800**
Phase I annual maintenance: **$15,000**
Complete project (Phases I-III) annual
maintenance: **$183,000**

Diverse Funding and Partnership Opportunities

Specific Phase I Funding Strategies

$1.2 million over 2 years

UA Green Fund Annual Grant	$400,000
FEMA Flood Mitigation Assistance Grant	$640,000
EPA Urban Small Waters Grant	$60,000
Maintenance Strategic funding of .5% of the budget for each school on campus (modeled after existing maintenance funding regimes for campus landscape)	$100,000 annually
	$1,200,000

Full Project Implementation:
By layering GI with walkability and non-vehicular circulation improvements, *Against the Grain* strategically broadens the potential for public and private partnerships in a city that is doubling-down on transit-oriented development and complete streets. The following partnerships have been identified:

Walkability & Alternative Transportation

- City of Tucson Department of Transportation, Transportation Enhancement and Safe Route to School Grant
- Living Streets Alliance (Tucson) Complete Streets Partnership
- PeopleForBikes Community Grant Program
- US Department of Transportation Surface Transportation Block Grant

Urban Forestry

- AZ Department of Forestry Community Challenge Grant
- Tucson Audubon Habitat Restoration Program
- Trees for Tucson Stormwater Design and Tree Donations
- USDA Urban and Community Forestry Program

Green Infrastructure

- UA Green Fund Annual Grant for Sustainability Projects
- Environmental Protection Agency Clean Water Act Nonpoint Source Grant; Urban Waters Small Grants
- FEMA Flood Mitigation Assistance Grant

CONCLUSION

Against the Grain addresses stormwater management through a novel, holistic approach that sets an example for how stormwater can be integrated into cities in the arid southwest. It synergistically layers social and environmental functions by carving three corridors that mitigate flooding, take advantage of limited water resources, and facilitate pedestrian and bicycle movement. It addresses important goals and concerns voiced by UA and the Tucson community, incorporating existing information and original research to support a robust GI plan that is rooted in feasibility.

CALCULATIONS:

PC-Hydro Calculations:

Peak Discharge

$$Q_p = 1.008\, q\, A$$

Time of Concentration

$$T_c = \frac{n_b}{50}\frac{(L_c L_{ca})^{0.3}}{S_c^{\ 0.4}}q^{-0.4}$$

$$T_c = 0.02 n_b \frac{(L_c L_{ca})^{0.3}}{S_c^{\ 0.4}}\frac{1}{(C_w i)^{0.4}}$$

Q_p = peak discharge (cfs)
q = 2 (runoff supply rate at T_c, in/hr)
A = 81 (watershed area, acres)
T_c = time of concentration (hrs)
n_b = 0.2 (watercourse-length-weighted Basin Factor)
L_c=4033 (length of longest watercourse, ft)
L_{ca} = 2016 (incremental length of longest watercourse, ft)
S_c = 0.0092 (mean watershed slope of longest watercourse)

Basin Capacity:

Large basins:

Basin area at bottom (ft^2)	Basin depth (ft)	Basin Volume (ft^3)
6,747	4	26,988
2,145	4	8,578
2,826	4	11,304
4,171	4	16,682
12,973	4	51,890
1,269	4	5,076
2,145	4	8,578
1,540	4	6,160
1,086	4	4,346
1,108	4	4,432
1,879	4	7,518
1,269	4	5,076
2,826	4	11,306
		Total : 167,934

Linear basins:

Basin cross section = 20 ft^2
Basin length = 75 ft
Basin volume = 20*75 = 1,500 ft^3
Number of linear basins = 27
Volume for all linear basins = 27*1,500 = 40,500 ft^3

Total basin capacity:

167,934 + 40,500 = 208,434 ft^3
208,434/43560 = **4.78 acre feet**

11.79 acre feet = runoff generated in Phas 1 watershed during a 2-year 24-hour storm

4.78/11.79 = **40.57% runoff captured**

Financial Calculations:

	Quantity	Installation costs	Maintenance costs annually	Cost for 70' segment - Installation	Cost for 70' segment - Maintenance	Cost for Phase I - Installation	Cost for Phase I - Maintenance	Cost for full project - Installation	Cost for full project - Maintenance
detention basin	3360 ft3	$ 0.30	0.2	1008	336	18900	6300	230398.56	76799.52
permeable pavement	1540 ft2	$ 6.00	0.3	9240	462	171586.8	8662.5	2111986.8	105599.34
excavation for basins	1680 ft2	$ 3.83		6434.4		119486.808		1470710.808	
labor	3500 ft2	$ 12.00		42000					
24" box trees (specialty)	2	$ 187.00		374		7106		85485.18	
24" box tree (common)	2	$ 137.00		274				62628.18	
5 gallon shrubs	40	$ 25.00		1000		18750		228570	
			TOTAL COST	$60,330.40	$798.00	$1,131,195.00	$14,962.50	$13,789,719.53	$182,398.86

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