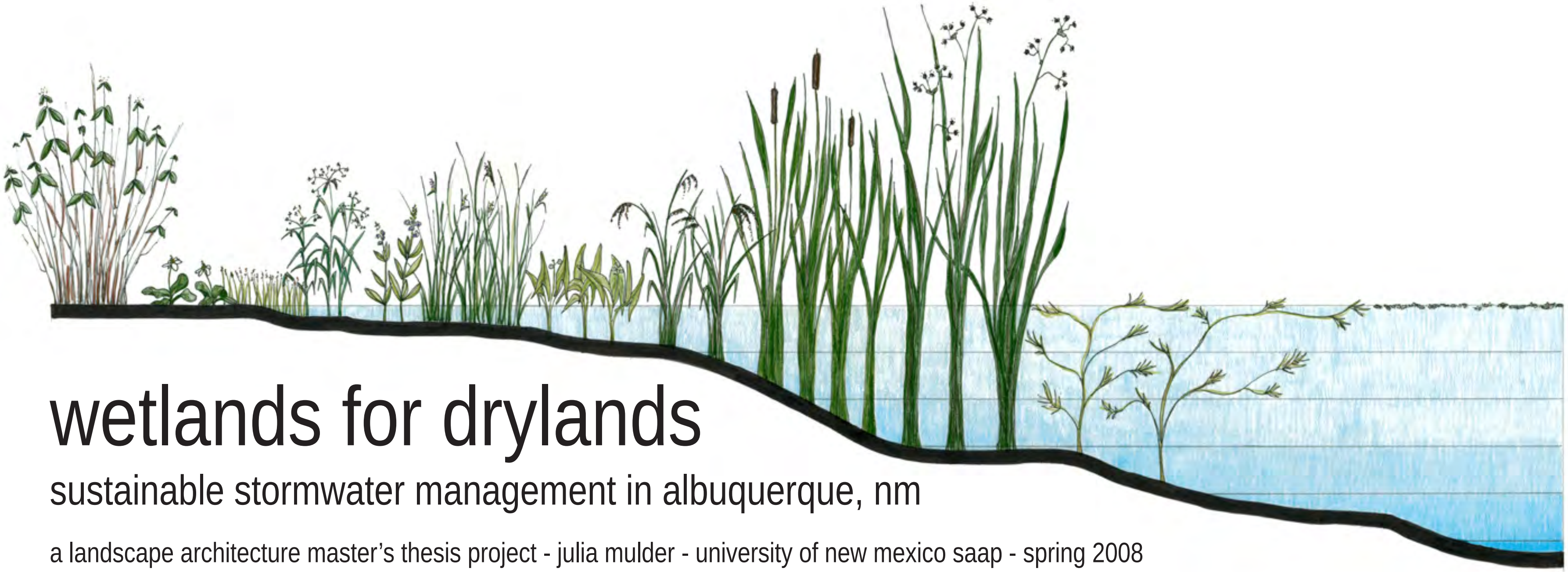

wetlands for drylands

sustainable stormwater management in albuquerque, nm

a landscape architecture master’s thesis project - julia mulder - university of new mexico saap - spring 2008

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thank you to:

my committee for their guidance and support

and to the following people who generously shared their knowledge, expertise, and resources:

Allison Abraham
Amos Arber
Phillip Bowman
Jeff Burnham
Christy Burton
Craig Campbell
James Cleverly
Ross Coleman
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Missed Opportunities

Current stormwater management practices in Albuquerque, New Mexico do not utilize the valuable resources of land and 'waste' water to their full potential. Specifically, commonly used single-purpose stormwater detention areas do not take advantage of the multiple opportunities that stormwater management presents, including water quality improvement, reconnection with infrastructure services, habitat creation, collaboration between professionals and the community, artistic interpretation of natural processes, and increased stewardship for the urban landscape. This project proposes a strategy for graywater management and on-site stormwater detention facilities in Albuquerque in response to the missed opportunities inherent in current practices. This investigation addresses the potential for, and logic behind, creating multifunctional combined stormwater/graywater wetlands in place of single-function dry detention areas on new academic, medical, corporate, and industrial campuses in the Albuquerque area. The exploration concludes with an application of these findings through the preliminary design of a wetland system for a new high school campus site on Albuquerque's West Mesa.

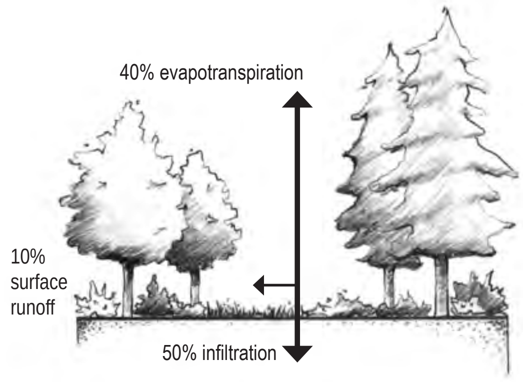
Current Practice and Concerns for Albuquerque

STORMWATER MANAGEMENT

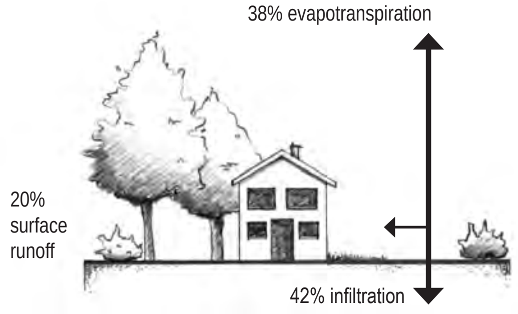
Figure 1
Concrete lined arroyos in Albuquerque, New Mexico

Urban stormwater drainage is a topic that most people would say is best left to engineers. Campbell and Ogden (1999) identify a general public indifference over what happens to urban stormwater as long as it is kept out of sight. Current stormwater management practices reinforce this trend, whisking stormwater away as quickly as possible and limiting human understanding of, and interaction with, storm cycles. Conventional practice tends toward massive stormwater collection and treatment systems rather than multiple small ones, primarily due to the belief that larger structures provide an economy of scale (Figure 1). However, this line of thinking takes into consideration only capital costs and does not reflect performance and maintenance (Thompson and Sorvig 2000). Dunnett and Clayden (2007) warn that these large, concrete-based approaches often serve to merely postpone problems or, worse, push them off to those downstream. Additionally, systems in which stormwater comes in contact with only engineered surfaces result in higher speeds and volumes of runoff, no opportunity for groundwater recharge, and limited or no benefits to plants and animals (Thayer 1994). Construction and development interrupt natural drainage patterns; limit infiltration through vegetation removal, soil compaction, and paving; and concentrate and speed up stormwater flows (Thompson and Sorvig 2000).

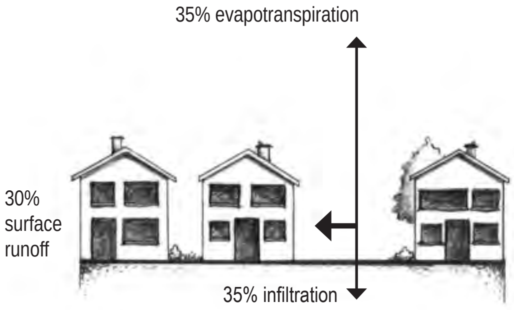
Urban stormwater runoff is a large source of water pollution worldwide. On undisturbed forested land stormwater is held by the soil or infiltrates into the ground at a rate that results in virtually no runoff, while in urban areas runoff estimates are as high as 85% (Figure 2). This means that only 15% of



0 - 10% impervious surface



10 - 20% impervious surface



35 - 50% impervious surface

stormwater that falls on urban areas is being absorbed on site, while the majority of the water has to be directed elsewhere (Hough 2004). As it flows through the urban environment, stormwater picks up and carries along a host of pollutants, including pesticides, herbicides, sediments, oils, gasoline, heavy metals, animal waste, bacteria, and excess nutrients (Dunnett and Clayden 2007, Muthukrishnan, Madge, and Selvakumar 2006, USEPA “Phase II” 2005). These pollutants are eventually deposited into streams and rivers along with the stormwater, causing a wide range of problems, which can include:

- algal blooms
- fish kills
- degraded drinking water
- degraded wildlife habitat
- health risks for humans and wildlife
- diminished tourism and recreational qualities (Dunnett and Clayden 2007, Muthukrishnan, Madge, and Selvakumar 2006, USEPA “Phase II” 2005).

These problems are intensified in areas that experience sudden storms (Hough 2004). In Albuquerque, infrequent rainfall throughout the year allows for the accumulation of pollutants on impermeable surfaces, causing the first flush of stormwater to become highly contaminated (Campbell and Ogden 1999).

Official attempts to address these problems in the United States began with the implementation of the Clean Water Act in 1972 (USEPA “Clean Water Act” 2008). Initially, however, state and federal regulations resulting from the Act focused on flood control, or stormwater quantity, and did little to improve stormwater quality. It was not until 1987 that an amendment to the Clean Water Act addressed the problem of stormwater pollution directly and led to the widespread development of stormwater best management practices (BMPs). BMPs include structural, operational, and educational practices aimed at limiting the transport and discharge of pollutants through stormwater. Examples of commonly used BMPs include dry detention ponds, wet ponds, stormwater wetlands, vegetated swales, infiltration trenches, and porous pavements (Muthukrishnan, Madge, and Selvakumar 2006). The use of multiple BMPs or a ‘treatment train’ to manage stormwater on a single site is often recommended (Campbell and Ogden 1999, Dunnett and Clayden 2007, Lyle 1994).

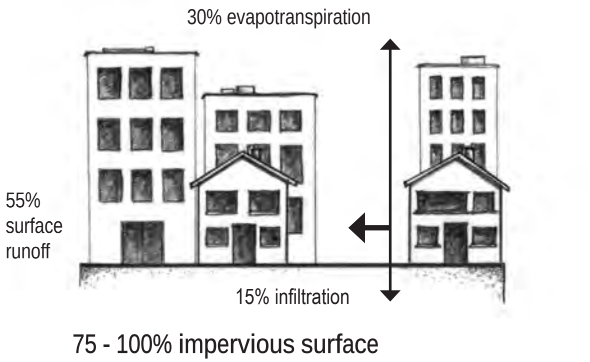


Figure 2
Stormwater runoff increases with urban development.

ALBUQUERQUE AND STORMWATER DETENTION

Albuquerque’s most frequently used on-site stormwater management system is the dry detention pond. Detention ponds, designed to temporarily hold and slow stormwater runoff in response to increased impervious surfacing and lack of vegetation in the urban landscape, do a good job of detaining runoff at the site. However, these water collection areas are sized to accommodate maximum storm flows, leaving them barren and dry for much of the year in the southwest climate. Albuquerque receives less than 9 inches of precipitation per year, the bulk of which comes in the form of late summer monsoonal rains (USACE 2004). These seasonal rains can result in large quantities of runoff over very short time periods, necessitating large detention areas, despite the overall aridity of the climate. Albuquerque's detention areas are generally unplanted and covered in gravel to limit wind erosion. Surrounded by chain link fence, they are off-limits spaces that collect wind-blown trash and harbor weeds. Detention ponds are pushed out of sight and out of mind and represent large areas of dead space on a site. They are generally unattractive, industrial structures that detract from a site's appearance (Campbell and Ogden 1999).

While detention areas serve the purpose of detaining storm flows well, they do little to encourage infiltration or improve water quality (Campbell and Ogden 1999). Essentially, detention ponds do not purify or reduce runoff; they only delay its release. Bruce Ferguson (1991), a pioneer in the field of stormwater infiltration, argues in his award-winning article "The Failure of Detention and the Future of Stormwater Design" that detention areas can actually increase the flooding problems that they are intended to mitigate when the outputs of many individual detention areas join forces downstream. He identifies a need to "reinitiate the self-sustaining kinds of long-term environmental processes that occurred before impervious surfaces were installed," namely the infiltration of stormwater near where it falls (Ferguson 1991, 78). This process eliminates run-off flows and improves water quality through soil filtering before it reaches groundwater or streams.

In Albuquerque's current system, excess nutrients, heavy metals, and petroleum hydrocarbons remain suspended in stormwater flows and are carried on to enter receiving waters upon leaving the detention pond (Campbell and Ogden 1999). This results in natural wetlands and other natural water bodies receiving concentrated pollutant loads that could have been contained and treated by constructed wetlands at inland sites (Hammer 1997). In Albuquerque, detention ponds are often the only BMP used

Figure 3
Stormwater detention basin on the Intel campus in Rio Rancho, NM

on site, rather than serving as a link in a 'treatment train' of multiple BMPs. The lack of vegetation in Albuquerque's detention ponds greatly limits their filtration and cleansing capabilities. Plants and their associated microbes are essential elements for stormwater purification in structural BMPs (Campbell and Ogden 1999, Hammer 1997).

While in many areas of the country, most notably the Pacific Northwest, stormwater BMPs have led to active and attractive stormwater detention and retention areas, the limited rainfall and high evaporation rates of the desert Southwest have made the implementation of certain BMPs here difficult, if not unfeasible. Due to an extended hot and dry period that coincides with the growing season, availability of water to maintain aquatic plant life in a constructed wetland system is our limiting factor in Albuquerque. This project proposes the augmentation of stormwater runoff with graywater from surrounding buildings in order to meet water supply needs and give site managers a measure of control over water levels throughout the year.

As Albuquerque continues to grow and build on previously undeveloped land, stormwater flows are disrupted and sped up by increased impervious surfacing. These concentrated and accelerated flows increase erosion, carve out gullies in the landscape, and contribute increased sediment, nutrient, and toxin flows directly into the Rio Grande. In response, a frequently employed solution is to collect and hold stormwater flows on site before releasing them at a slowed rate. Thus, the dry detention area has become a ubiquitous sight throughout the city. Because substantial areas of land are already being designated for these systems, they represent an opportunity to utilize and maximize the resources of land and 'waste' water to add value to the overall site. In the place of a fenced-off eyesore, we have the opportunity and resources to create a site of activity and beauty. As we continue to grow and expand, cutting off natural processes and increasing our demands on natural resources, we must consider new strategies that maximize our use of natural resources.

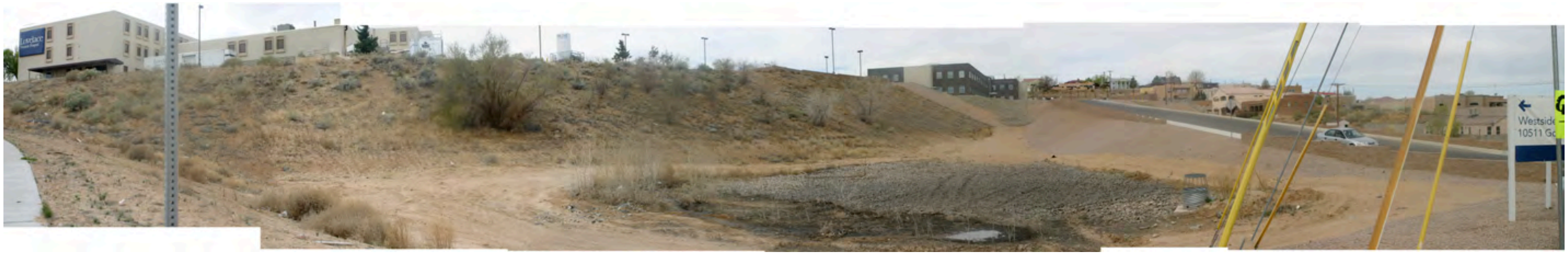


Figure 4

Stormwater detention basin on the Lovelace Hospital West Side campus in Albuquerque, NM

WATER HARVESTING AND INFILTRATION

The term ‘water harvesting’ refers to the processes of collecting, storing, and redirecting rainwater to landscape plantings. As Hough observes, “the basic lesson that nature provides in the water cycle is one of storage” (Hough 2007, 71). By trapping and infiltrating water on site, it is possible to minimize runoff and maximize groundwater recharge. Water harvesting calculations treat runoff as a resource rather than a nuisance. As Thompson and Sorvig (2000) have noted, the results of water harvesting in arid lands, such as Albuquerque, can be particularly significant: greening landscapes, limiting erosion, and raising the water table. Similarly, Dunnett and Clayden (2007) argue that even individual site-level changes in rainwater collection and re-use habits can have large impacts. Water harvesting enables us to use a free resource to reduce our demand on treated municipal water and enrich the aesthetic appeal of our landscapes.

Water harvesting promotes on-site infiltration of stormwater. Infiltration, as discussed above, is widely considered to be the best option for stormwater management and to have many benefits, including groundwater recharge, which is “especially important in the arid West” (Campbell and Ogden 1999, 135, Ferguson 1991, Thompson and Sorvig 1997). In New Mexico, however, due to surface water

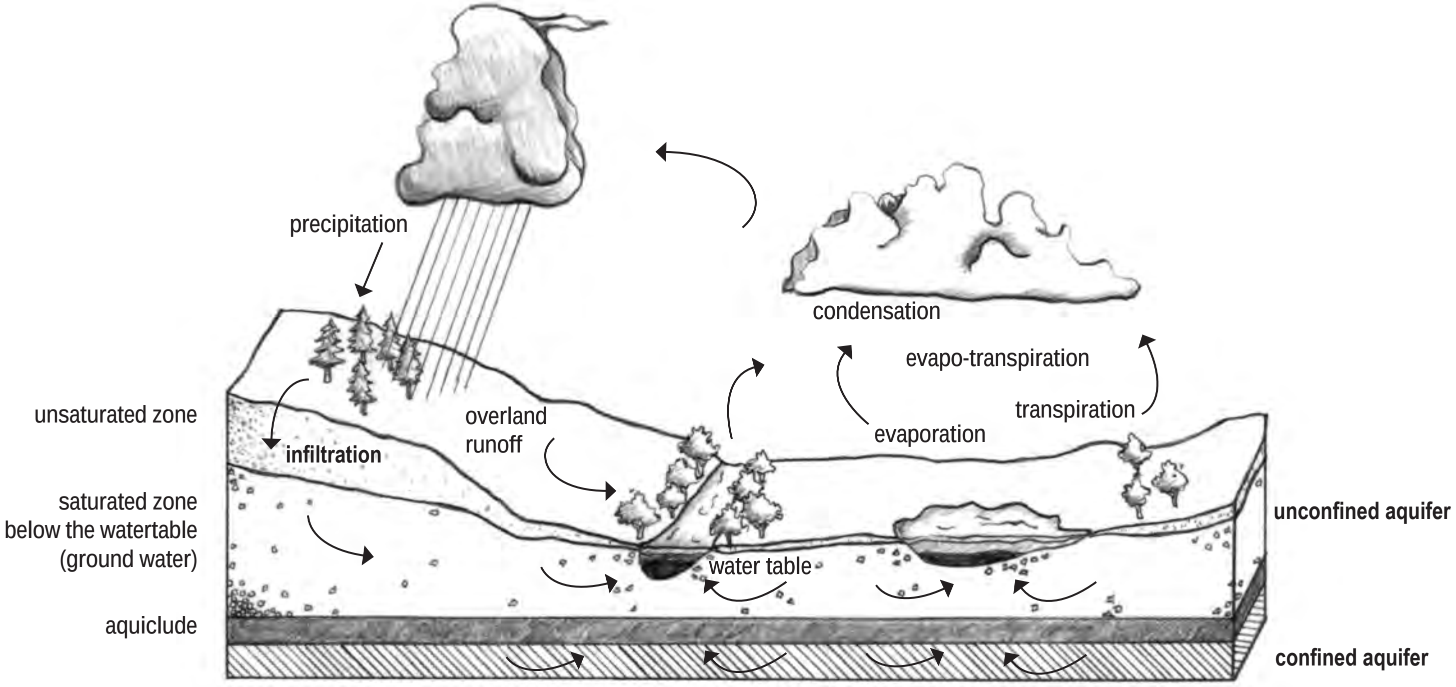


Figure 5
The Hydrologic Cycle

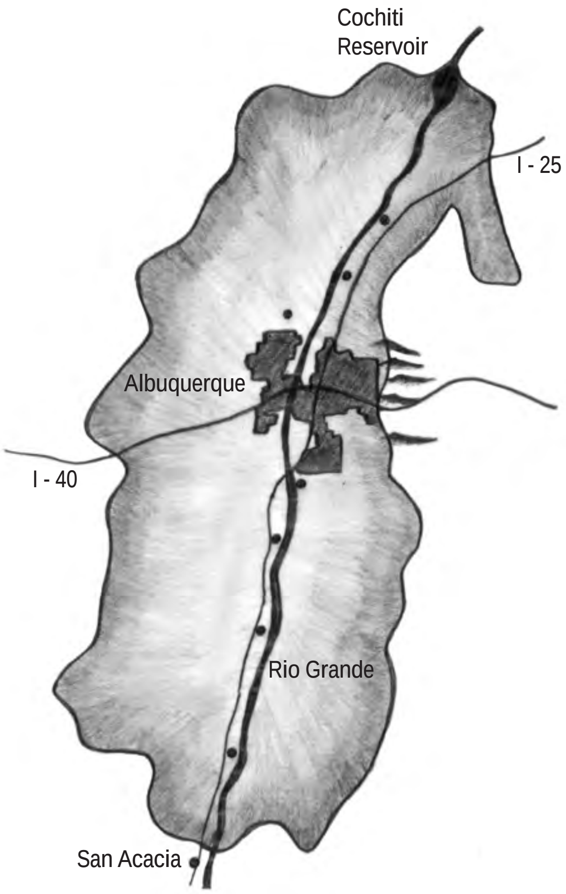


Figure 6
The Santa Fe Group Aquifer

rights and downstream delivery obligations, infiltrated water has often been considered 'lost' water and legal issues complicate site owners' ability to implement infiltration techniques. The very notion that groundwater infiltration is possible or beneficial in New Mexico has been questioned. The depth of our water table ranges from 1 – 1,200 feet throughout the city, causing some to argue that groundwater recharge can only occur in certain areas (Campbell 2008, USGS 2008). City of Albuquerque education guides report that only eight to ten percent of precipitation penetrates the soil surface moving downward to the aquifer under current conditions (Earp, Postlethwait, and Witherspoon 2006).

Despite these challenges, the potential benefits of infiltration for Albuquerque are too great to go ignored or untested. As Thompson and Sorvig argue, "loss of infiltration capacity due to development is one of the single most serious barriers to sustainability" (2000, 136). They also note that wetlands, "whether natural, restored, or constructed" can serve as "major sites of infiltration" (2000, 157). The loss of infiltration capacity in the urban landscape, and the resultant loss of groundwater recharge, can reduce groundwater supplies and beneficial groundwater flow to wetlands, streams, and lakes (Brander, Owen, and Potter 2004). Brander, Owen, and Potter find that on-site infiltration has several advantages, including the relative ease of siting a smaller on-site system in comparison with a large, regional system (2004).

POTABLE WATER USE

Projections for population growth and available fresh water supply in the American West are troubling at best, while global warming trends only stand to increase problems through higher temperatures, decreased winter snow pack, and drought (Gertner 2007). In fact, climatologists are predicting a Southwest mega-drought (Gutzler 2008). The Santa Fe Group Aquifer (Figure 6), Albuquerque's main water source, is being reduced at a rate of 71,000 acre-feet per year (Gaines 2008). Additionally, as water supplies are diminished, we are utilizing lower quality water sources that require more expensive treatment (Howe 2008). At the same time, the U.S. Census Bureau has projected a 54% average population increase for Arizona, New Mexico, Colorado, and Utah between 2000 and 2030, which will only increase our demand on limited water resources (Thomson and Thomas 2006).

Urban water supplies are generally taken from surface or ground sources, treated to potable quality, used once, and then returned through sanitary sewers to be treated again for re-use or release into streams. This practice is energy-consumptive and wasteful (Thayer 1994). Increasingly, we are coming to recognize that fresh water is a limited resource and that it can and should be used multiple times before requiring re-treatment. Potable water is also used in many cases where the use of water of lesser quality would be appropriate. In New Mexico potable water is widely used for landscape irrigation, greatly increasing demands on municipal water sources. The State of California considers the use of potable water for this purpose ‘unreasonable’ and encourages water harvesting, the use of graywater, and water conservation (CWSGR 1993). Utilizing ‘waste’ water for landscape irrigation also benefits the goal of on-site infiltration without drawing on limited potable water resources.

GRAYWATER RE-USE

The environmental benefits of using graywater for landscape irrigation and other purposes are receiving increased recognition. Not only does graywater reuse limit our demand on treated municipal water sources, but it also reduces the overall wastewater load entering the municipal sewer system for re-treatment. The New Mexico Office of the State Engineer has defined graywater as untreated wastewater from washing machines, bathtubs, showers, and bath sinks, which excludes water from kitchen sinks, dishwashers, diaper-washing and toilets (NMOSE 2001). The New Mexico Environment Department has recently issued guidelines to “promote the safe use of reclaimed wastewater to offset the use of limited potable water sources in the State” (NMED 2007, 1). These guidelines encourage the development and use of new processes and equipment in regard to wastewater reuse.

Depending on its intended use, graywater can generally be used directly from the source without any cleansing or treatment efforts. In some cases, simple pre-treatments such as sand filters or settling tanks for water cooling, settling of large particles, and separation of grease and oils are used to improve graywater quality prior to use. Occasionally, where human contact with graywater is likely, greater cleansing measures, such as chlorine, iodine, or UV disinfection or treatment in reed beds are required (Dunnett and Clayden 2007, Duttle 2005). While graywater does have greater potential implications for human health than stormwater, it can be managed safely and incorporated as a supplement to stormwater wetlands in dry times (Dunnett and Clayden 2007). As Lyle (1994) points out, reusing water in constructed wetlands can be particularly beneficial for wildlife in arid areas where water is a limiting factor and supplies have been diminished by human practices.

WETLANDS MISPERCEPTION AND LOSS

The previous sections have addressed storm and wastewater management practices and their implications as background and support for the proposed use of combined stormwater/graywater wetlands in Albuquerque. Also of value to this discussion are the issues of wetland loss, wetland functions, and wetland creation.

Wetlands have been historically misunderstood and, subsequently, mishandled. Not only have wetlands been viewed as wastelands unfit for cultivation, but also as reservoirs of disease and even “haunts of unimaginable monsters” (Hammer 1997, 1). As a result, there has been a net loss of half of the original 197 million acres of wetlands in the United States (France 2003). This loss constitutes the destruction of 50 to 90% of wetlands in all states (Thompson and Sorvig 2000). Agricultural practices involving the draining of wetlands have historically caused the majority of wetlands losses, while 80% of current wetlands losses are due to development and construction (Hammer 1997, Thompson and Sorvig 2000). France (2003) argues that although the value of wetlands has become widely recognized in recent years and conservation efforts have been enacted, the response has not been commensurate with the scale of the impact of wetland losses.

Figure 7
The San Antonio Oxbow is one of the few remaining natural wetland areas along the Middle Rio Grande Valley.

The National Wildlife Federation reports that one-third of New Mexico's wetlands have been lost since European settlement, a quantity that amounts to "approximately 3.25 acres per day over the past 200 years" (2001, 3). However, other reports suggest that the State's actual wetlands losses are even greater if the massive destruction of wetlands associated with New Mexico's major rivers is taken into consideration (Figure 7). The U.S. Army Corps of Engineers (2004) reports that wetland-associated habitats along the Middle Rio Grande Valley underwent a 93% reduction between 1918 and 2004, while a City of Albuquerque and Bernalillo County-sponsored study reports that between 1935 and 1989, 83% of wetlands were lost along the Albuquerque reach of the Middle Rio Grande Basin (CWSGR 1993). These losses are particularly damaging in the arid southwest where water is in limited supply and existing aquatic habitat is highly degraded. Fifty-five percent of New Mexico's wildlife species, including 25% of the state's threatened and endangered species, are dependant on aquatic, riparian or wetland habitat for survival (NWF 2001). New Mexico's wetlands are critical breeding areas for fish, amphibians, and migrating birds. Recent decreases in wintering waterfowl populations in the state highlight the alarming trend of continued wetland loss and shrinking water supplies (NWF 2001).

NATURAL WETLAND FUNCTIONS

As Hammer (1997) points out, although concern over wetlands has reached the general public, there is still misunderstanding and ambiguity concerning what constitutes a wetland and its processes, even within the community of wetlands scientists. A generally accepted definition describes wetlands as places that are wet long enough each year to produce oxygen-poor soils favoring vegetation with specialized adaptations (Hammer 1997, EPA "Definitions"). Thompson and Sorvig (2000) add that wetlands are a critical link in the water and food webs, fostering great diversity and productivity and providing habitat for many endangered species. Hammer also states that wetlands consist of a combination of wet and dry areas and often contain areas that are "essentially terrestrial habitats" (1997, 5). Specifically, wetland habitats are not generally stable and are, in fact, dependent on periodic inundation and drying. Wetlands are dynamic, transitional systems that vary from deep water to complete drying and, as a result, are host to specially adapted plants and animals (Hammer 1997). This cycle of inundation and drying is particularly important in arid environments, such as Albuquerque, where the availability of water is a limiting factor.

Wetlands perform multiple functions that are only recently becoming fully recognized for the services and benefits that they provide in human terms (Campbell and Ogden 1999, Thompson and Sorvig 2000). These functions include:

- Water cleansing through physical, chemical, and biological processes
- Groundwater recharge
- Flood and erosion attenuation
- Biological productivity and diversity
- Recreational and aesthetic value (Campbell and Ogden 1999, Hammer 1997, Thompson and Sorvig 2000).

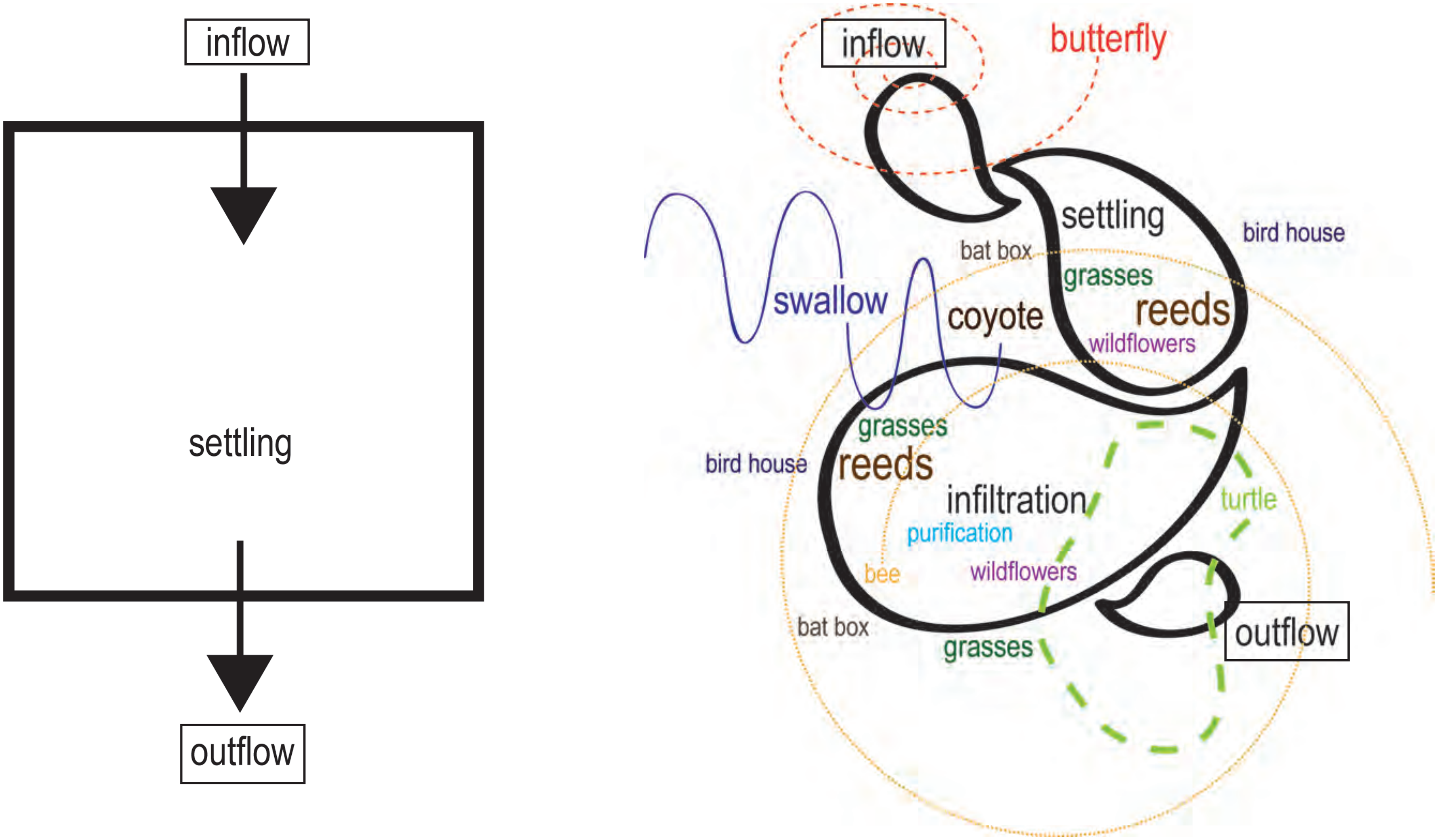
As France (2003) points out, many of these functions have site-specific benefits, as well as benefits to the region-wide landscape. Acknowledgement of these values has led not only to increased preservation efforts, but also to the development and rapid growth of the field of constructed wetlands for the purposes of mitigation, wastewater and stormwater treatment, and habitat creation (Hammer 1997, Thompson and Sorvig 2000).

CONSTRUCTED WETLAND FUNCTIONS

Wetlands are constructed for a wide variety of reasons and, in turn, have a wide variety of potential forms and functions. Thompson and Sorvig (2000) caution that while constructed wetlands can perform many important functions, they are unlikely to perform all of the functions of a natural wetland. Similarly, Hammer (1997) states that constructed wetland systems can serve many functions, but that the specific desired functions of a system will determine the type of wetland that is constructed. He emphasizes the importance of formulating clear, measurable goals for constructed wetland projects, reflecting specific site conditions and functional objectives. Despite this, desired constructed wetland functions should not be viewed as mutually exclusive, as multiple secondary goals will be met in the process of meeting primary requirements (Dunnett and Clayden 2007). For example, stormwater collection is the primary functional goal of the system proposed here. However, in creating a system that accomplishes the goal of stormwater collection, the goals of habitat creation, water purification, infiltration, aesthetic enhancement, and education are also met. Hammer (1997) points out that while the conservation and restoration of natural wetlands are extremely important, wetlands construction should also be encouraged in order to increase overall wetlands resources, especially in areas where wetland habitat is rare, such as in Albuquerque, where wetland habitat has been decimated by levee construction and channelization along the Rio Grande Valley (USACE 2004).

Figure 8
The Candelaria Wetland at Albuquerque's Rio Grande Nature Center was constructed to offset habitat loss.

Dry detention ponds are designed according to formulas for expected water flow and anticipated detention needs. They are single-use structures designed solely for the one purpose of holding and slowing stormwater before releasing it off site. While occasionally serving as home to weedy plant growth or a watering hole for sparrows, they are cut off from their surrounding sites by fencing and are placed onto a site, rather than being developed from or responding to it. By creating constructed wetland systems in their place, we can replace these holes in the urban landscape with areas of growth, life, and activity.



typical detention areas

combined graywater & stormwater wetlands

Figure 9
Constructed stormwater/graywater wetlands foster activity and life in contrast with the dead space created by typical dry detention areas.

Sustainable Practice & Stormwater Management

Whether it is termed “ecological democracy” (Hester 2006), “deep form” (Lyle 1991), or sustainability, a new mode of thinking concerning the built environment is becoming increasingly prevalent in the design and planning community. Along with the rest of the world, landscape architects and allied professionals are realizing that we cannot continue with business-as-usual in the face of global climate change, increasing populations, and limited natural resources. Some theorists have also identified a spiritual crisis in our society, triggered by our remoteness from nature and the processes and systems that make our daily lives possible (Hester 2006, Strang 1996). While individual approaches may differ somewhat, the following sections highlight some of the vital common threads within current thinking on sustainability and meaning in the landscape and their implications for water management practices.

MULTI-FUNCTIONALISM

A widely held tenet of the growing sustainability movement is that multi-functionalism is key to the development of sustainable practices. We are beginning to question single-use spaces and constructions, such as stormwater detention basins. Lyle (1985) has termed these “single-purpose, unintentional ecosystems” (184). He illustrates their wastefulness by comparing the human system of transporting Colorado River water over 200 miles to California, only to be used once for toilet flushing and then released into the ocean, with natural water systems in which inputs and outputs are minimal, flows slower, and nutrients cycled and recycled to the benefit of a diversity of organisms. Hester (2006) argues that multipurpose landscapes tend to be more resilient to disturbance than single-purpose ones and Hough (1984) suggests that single-purpose landscape solutions actually tend to create new problems.

Fisher (2008) feels that it is not only our ethical duty, but, increasingly, our only option, to ask how one space can do many things for us, how we can work with what we have on hand, and how we can maximize our use of natural resources. In contrast to the ‘more is better’ attitude so common in our society, he suggests that we must ask ourselves at the beginning of each project whether we really need to build anything new at all or if the project requirements can be met with existing facilities and resources. In the case of stormwater management, we have a need to prevent stormwater pollution and, in turn, we have a designated space for detention basins and ‘waste’ water. Rather than merely slowing and holding water, these resources of space and water give us the opportunity to reuse water, create habitat, purify water, create public open space, and educate.

EVERYDAY INTERACTION

Additionally, sustainability advocates and theorists agree on the notion that in order for sustainable practices to be understood and accepted, they must be visible and present on an everyday basis and in everyday situations. Hough (1990) suggests that while the global problems we face are overwhelming and can leave one feeling helpless, small successes rooted in familiar environments can help to connect us to the larger picture. Similarly, Thayer (1994) proposes that a critical purpose of the sustainable landscape is to expose people to sustainable principles in “discreet, manageable chunks” (309). Designers of the built environment may be in a unique position to reach mass audiences by shaping the places that people interact with everyday. While many people understand the value of the rare and fragile, they may overlook the processes that make their daily lives possible. Increasing people’s awareness of their environments and celebrating the beauty of the everyday are important tools in fostering pride and stewardship of local landscapes (Hester 2006).

Through everyday landscapes we have the opportunity to add meaning and richness to our lives. Nassauer (1995) suggests that revealing ecological complexity in everyday situations has much greater power to convince than confrontational or preachy approaches, and will lead to sustainability. Likewise, Hester (2006) highlights the importance of creating alluring everyday landscapes that model non-consumption in attractive ways. He argues for what he has termed “inhabiting science” or “the act of making urban ecological principles a part of daily experience” (333). For Thayer (1994) this notion is expressed through ‘transparency’ or revealing the inner workings of a landscape system and ‘congruency’ or the notion that the look of a landscape must honestly reflect its function. For Hough (1990) this also becomes a vehicle for expressing regional character.

Stormwater/graywater wetlands represent a powerful medium for everyday exposure to, and engagement with, sustainable practices. As addressed above, current wastewater systems limit our understanding of natural and infrastructural processes and stormwater treatment is generally kept out of sight. By contrast, creating attractive and engaging stormwater catchment and treatment areas that are visible and accessible on an everyday basis can encourage understanding and acceptance of new, more environmentally friendly stormwater management techniques. These systems can promote awareness in multiple ways; graywater collection provides a link between building users and the outside landscape; plant growth and development encourage observation of seasonal change and conditions; changing water levels reflect available water supply; and wildlife observation helps to reconnect us with our surroundings.

ECOSYSTEM PROCESS AS MODEL

As Lyle (1985) argues, human beings design ecosystems whether they do so knowingly and intentionally or not. From the dawn of human civilization we have altered our environments to suit our needs, with both intended and unintended circumstances. By carefully observing ecosystem process and re-envisioning ourselves as a part of that process and function, we can design intentional ecosystems that contribute to both human and non-human needs. Hough (1990) identifies “the essential bond of people to nature, and to the biological sustainability of life itself” and promotes a conception of sustainability in which human systems actually contribute to the health of the natural systems that they depend on (179). This will require a fundamental shift in our thinking about urban areas since, as Ruff (1982) points out, our current city forms obscure our “awareness of the composition and function of the natural ecosystem” (175). Ruff suggests that this shift in thinking can be brought about by following seven principles for ecologically inspired landscapes, including a deliberate attempt to understand and respect the physical and biological characteristics of the site.

Hester (2006) points out that we have designed cities that do not take advantage of ecological processes and advocates the use of terms and theories from the field of applied ecology in promoting “holistic, systemic thinking” (59). Lyle (1985) argues that ecosystems are connected by flows of energy and materials and that, when we ignore these connections, we work against ecological process and create problems for ourselves. Instead, he proposes that we must learn from the concepts of ecology and identifies specific ecological modes of order that apply to the practice of human ecosystem-building. McHarg (1969), a determined and vocal advocate for ecology as the basis for all landscape architecture, developed an innovative method for planning and design that interpreted natural processes as resources that would define compatible communities of land use. In the following figure McHarg (1967) simply and clearly illustrates an ecological model for health that helps us to examine our urban forms:

	retrogression		*evolution*
ill-health	simplicity	health	complexity
	uniformity		diversity
	independence		interdependence (symbiosis)
	instability		stability (steady state)
	low number of species		high number of species
	high entropy		low entropy

Figure 10
McHarg’s ecological model for health.

Considering the above figure, constructing multifunctional stormwater/graywater wetlands in place of single-function dry detention areas in Albuquerque clearly represents a move from a model of simplicity and homogeneity, or ill-health, to a model of complexity and diversity, or health. Constructed stormwater wetlands encourage consideration of an individual site's place within a larger ecosystem and the connection between site-specific drainage conditions and the larger watershed. Water filtering by plants and microbes and water infiltration into the soil foster vegetative growth, attract other life forms, and connect human activities and natural processes, thus contributing to the overall health of the urban landscape.

MAKING THE MOST OF OUR RESOURCES

Connected to the need to reconsider our relationship to ecological processes is the need to reconsider our views on and use of resources. Rather than seeing natural resources as commodities or in terms of rights, we might consider them as ecosystem services (Gaines 2008). Rather than seeing water as something that we pay for and expect to come out of the tap, we might understand it in terms of the multiple benefits that it can provide both to us and to other forms of life. For example, in a constructed stormwater/graywater wetland, reclaimed water helps to create wildlife habitat and humans, in turn, derive great pleasure from wildlife (Hester 2006).

Sustainability advocates also agree that we must use locally available building materials and recycle local waste materials to the greatest extent possible (Hester 2006, Ruff 1982). These steps help to cut down on energy use in transportation of materials and lessen the demand on virgin natural resources. Hester suggests that we can learn an important lesson from those living in poverty: take inspiration and pride from using every bit of the resources that we have on hand. He also proposes that the "discovery of resources previously considered trash is key" to the creation of sustainable urban environments (Hester 2006, 64). Considering stormwater runoff and graywater not as nuisances or waste that must be dealt with, but as resources for improving our urban landscapes, can be a simple, yet powerful, step towards maximizing our use of locally available materials to add value to our daily environments.

COLLABORATION

We have the collective creativity and skill to improve our urban environments, but we need to learn to work together and draw on the specialized knowledge of associated professionals, as well as on local knowledge, to form new solutions. Hester (2006) calls for an approach to sustainability as "experiments in which we are all active participants: we are all designers, citizen scientists, and ecologists" (273). This notion implies an approach through community process, but also highlights the importance of drawing from a range of skills and experiences to forge a new design vocabulary. As Thompson and Sorvig (2000) state in regard to collaboration, “Contrary to the kind of conventional wisdom that favors narrow specialization, these overlapping arrangements can have great value in creating healthy places” (21). They suggest that collaboration should go beyond the fairly standard interactions between architects, landscape architects, engineers, and planners, but should also include owners, site managers, contractors, and users in the design process in order to form goals that everyone involved in the life of a design can understand and support.

The field of constructed wetlands is multidisciplinary by nature, drawing on the specialized knowledge and skills of ecologists, wildlife biologists, soil scientists, botanists, civil engineers, hydrologists, chemists, landscape architects, artists, and others to create successful designs. As Campbell and Ogden (1999) point out, the practice of constructing wetlands encourages “meaningful integration of diverse disciplines and areas of knowledge” (vii). Hammer (1997) recommends a team approach to wetland design, involving a core planning group and as many specialized consulting experts as needed for each specific project. Additionally, constructed wetland planting, monitoring, and maintenance are generally hands-on, low technology practices that can actively involve the community and site users, encouraging collaboration and stewardship.

Fundamental Disconnects

ECOLOGICAL ILLITERACY AND OUR DISCONNECT FROM NATURE

Our current urban forms and lifestyles have removed us from contact with nature, obscuring our awareness of everyday natural processes. Hester (2006) identifies in this trend a loss of local knowledge grounded in a particular place. He argues that this loss negatively impacts our abilities to make prudent decisions about our urban landscapes and to see ourselves within the larger context of our surroundings. Hester calls for a re-cultivation of local knowledge or native wisdom and uses the example of urban stormwater as a vehicle for exploring and understanding the watershed.

Hester (2006) and others also identify active involvement and community ritual as methods for reconnecting people to their environment and to natural processes. As Ruff (1982) points out, our built environments are generally built by people we don't know and, consequently, we have little investment in them. Through active engagement we experience the "joy of working on the solution" and forge a link between ecological principles and our everyday lives (Thayer 1994, 327). The constructed wetland systems proposed here provide opportunities for work days, clean-up events, seasonal celebrations, and daily monitoring activities that not only promote stewardship, but can also become community rituals that help us to mark and observe natural processes and changes in the landscape over time.

INFRASTRUCTURE DISCONNECT

Intimately linked with our general disassociation from nature, we have also become profoundly disconnected from our infrastructure systems and services. Strang (1996) argues that we are not only removed from and understand little about our infrastructure, but that we have designed our cities to deny and disguise the very systems that make our lives possible. He states that while pre-industrial cities integrated and celebrated their infrastructure in beautiful and meaningful ways, we have put more effort into hiding ours. Lyle (1985) has also identified this problem, observing that of the elements of design, precedence is generally given to "the plan," resulting in the less visible aspects of structure and function being ignored.

Strang (1996) and others have argued that we must explore the opportunities for meaningful design that are represented in our infrastructure systems in order to strengthen local identity and reacquaint us with the importance that infrastructure has in our lives. Specifically, he suggests that the biggest gains can be made in addressing single-use infrastructures, creating, for example, urban stormwater drainage that serves also as open space and a working biological system or allowing buildings to occupy more than one niche as well, for example serving as stormwater collectors and sources of graywater for the landscape. Recognizing the fundamental changes that human systems have imposed on natural systems, Strang calls for uniting the two to perform multiple functions. Pragmatically, he also observes that more money is budgeted for the repair of failing infrastructure than for open space and that we can capitalize on this fact by including open space as an important function of our infrastructure systems.

Morrish and Brown (1995) have observed many of the same oversights and challenges in our current infrastructure systems and, like Strang, contend that infrastructure done well has the power to heighten our sense of place and add value to the surrounding landscape. They argue that the traditional engineering approach to infrastructure design denies the richness of natural systems and breaks existing connections between plant and animal communities. In response, Morrish and Brown propose more complex infrastructure systems, which, they contend, are not only more economical in the long run, but are also multi-use and specific to place. Replacing single-function detention areas with combined stormwater/graywater wetlands represents a move from a very simple system to a more complex one that acknowledges and reveals the relationships between natural and human systems.

Good Design

ECOLOGICAL PROCESS AND CREATIVITY

While ecological processes must serve as models for and inform the urban landscape, this should by no means preclude artistic interpretation and the principles of good design. Hester (2006) argues against mechanically following the rules of sustainability, cautioning that lifeless and spiritless urban forms may result. Lyle (1985), although often viewed as a purely ‘ecological designer,’ also recognizes the importance of human creativity and suggests that while ecology serves as a model for planning, the “creative leap” to design is essential in shaping a plan (“Human Ecosystems” 185). He views ecology not as a constraint on creativity, but as creative inspiration. Likewise, Thayer (1994) states that “sustainable landscapes need not be austere, solemn, dictatorial x-rays of ecological processes blaring across our consciousness” and that they should not be “devoid of fun, fantasy, and human imagination” (313). In the case of the constructed wetlands proposed here, the hand of the designer can facilitate the appreciation and enjoyment of a functional system for stormwater and graywater management.

ECOLOGICAL AESTHETICS

A perceived schism between ecological design and aesthetic design has resulted in the development of new theory and approach towards a culturally responsive ecological aesthetic. Mozingo (1997) calls for an ‘iconic’ approach to ecological design that draws from design tradition and craftsmanship to create memorable and appealing landscape experiences (46). She emphasizes the importance of design techniques such as metaphor, contrast, and reiterated forms in giving “perceivable order” to the complex and often invisible processes of nature (49). Mozingo points out that too often ecological design is meant to ‘look natural’ and so is treated as a preserve, fenced off from public access and with little or no attention given to the detailing of the points of human interface. She argues that the “expressive marking of art” is essential in both signaling the importance of the place and in inspiring wonder and enjoyment (55).

Nassauer (1995) recognizes the need to approach ecological design through an appeal to human nature rather than a confrontation or attack. Specifically, Nassauer observes that “ecological quality tends to look messy” and that this makes ecologically functional designs susceptible to misinterpretation as unintended or unkempt (161). She stresses the importance of the look of human intention or, as she has termed it, “cues to care” (167). Such cues, Nassauer states, are “cultural symbols that can be used to frame more novel ecosystems in inhabited landscapes” (167). These indicators of care and intent can be as simple as bird houses and feeders, mown frames or access strips, and well-maintained fences and structural details, but have great power in making ecological designs approachable and comprehensible.

SITE SPECIFICITY AND IDENTITY

One of the exciting and inspiring characteristics of ecological design is its inherent site specificity. If created in response to very specific site conditions, no two ecologically informed designs will look alike. As Relph (1993) states, we can reclaim place identity through a careful response to conditions, rather than copying previous approaches. Hester (2006) has termed this "particularness" and sees it as a method not only for creating distinctive and memorable places, but also for reducing pollution and limiting the destructiveness of natural and economic disasters (145). He argues that "cities that develop unique local adaptations to live within the limits of their bioregion are typically more resilient than those that do not" (147). Particularly, Hester highlights the importance of watersheds as givers of framework for urban form and as inspiration for design patterning.

Site identity is also strengthened, and can only take on true meaning through, people's interactions with it. Access and engagement are keys to the experience of ecological design sites. Locating complimentary facilities alongside natural treatment infrastructure will aid in their acceptance and understanding. For example, creating picnic shelters alongside constructed wetlands or interspersing parking with stormwater collection swales will place these technologies in sites of daily human activity. As Thayer (1994) writes, "observability speeds the adoption rate" of new technologies (192). Importantly, providing these sites for easy access to green areas has also been shown to help "lower stress, combat mental fatigue, and make us less fearful" (Hester 2006, 303), making them important features for school, medical, and corporate campuses.

Good ecological design incorporates and encourages an awareness of scale. Not only is this important in terms of promoting the recognition of an individual's place within the larger world or a subsystem's role as a part of a larger system (Lyle 1985), but also as a design tool that can be used to strengthen site identity. Designs that function on multiple scales appeal to us both as a whole and in their details. They draw us in to investigate a site more closely and reveal the care that has gone into that site's development. Attention to design at multiple scales can create a sense of pacing or orchestration that has the power to mark the entrance to a special space and to invite investigation (Hester 2006).

ADAPTIVE MANAGEMENT

An essential component of good ecological design is the awareness and acknowledgement of change (Mozingo 1997). Change need not be feared or guarded against, but can be incorporated into design as an opportunity for experimentation, happy surprises, and adaptation to new conditions. Lyle (1985) highlights the vital importance of creative management of ecological designs by comparing the role

Figure 11
Entry planting at Volcano Vista High School and red-winged blackbird perched on a snag.

of the manager to that of the self-regulating mechanisms found within natural systems. Likewise, Ruff (1982) argues that sustainable landscapes must be adaptable to changing social and ecological requirements, rather than designed to meet preconceived goals. Adaptive management allows for the correction of mistakes in response to observed site conditions and, as Hester (2006) points out, encourages sustainable design experiments in which the outcomes are uncertain, but potentially beneficial.

Thompson and Sorvig (2000) see change as an inherent part of any landscape and landscape maintenance not as a way to keep things the same, but as a response to change. They view maintenance as such an important component of sustainable design that they have devoted an entire chapter of their book “Sustainable Landscape Construction” to its promotion. Particularly, Thompson and Sorvig argue for considering maintenance from the start of a design project, rather than as an afterthought once a design has been completed. By designing stormwater/graywater wetlands with future maintenance needs in mind, we can design systems to be largely self-maintaining and keep costly, labor-intensive upkeep to a minimum.

As functioning biological systems, stormwater/graywater wetlands have a different landscape role than spaces such as entry plazas or vegetative borders. While the latter may call for an appearance of neatness and order, the former must be allowed to respond to external conditions in order to maintain functional performance. In other words, stormwater/graywater wetlands must be allowed to change and cannot be expected to fit into closely prescribed visions for how they should look. For example, a dead tree in a formal entry planting will need to be replaced, while a dead tree in a stormwater wetland serves as valuable habitat and will soon be replaced by vegetation better suited to the growing conditions (Figure 11). Constructed stormwater/graywater wetlands certainly require care and maintenance, but can be designed to maximize their self-maintaining capacity and, in turn, provide a dynamic illustration of ecological process within an urban setting.

Bringing it all Together

Up to this point the discussion has focused primarily on building a case for the implementation of combined stormwater/graywater wetlands in Albuquerque in place of standard detention areas. The following sections address how this can actually be achieved, given the particular conditions that we face in our arid climate. With the exception of the inclusion of graywater systems, each section speaks to general considerations that apply to any constructed stormwater wetland project and deals specifically with the best choices that can be made for creating stormwater wetlands in Albuquerque.

SPECIAL CONSIDERATIONS FOR ARID CLIMATES

The vast majority of constructed wetlands projects have occurred in climates with average to high annual precipitation rates. Notably, many successful projects and developments in constructed wetland technology have occurred in Maryland, Washington, Oregon, and Florida. We can learn from these sources, but it is important to remember that arid lands will have some of their own particular concerns and challenges. As Ogden and Campbell (1999) observe, most research in the field has “been localized and not generated by regional pilot facilities in various climatic zones” (36). They state that the combination of sudden high-volume storms and long, dry periods in the arid West is a problem that has not yet been properly addressed. Previous constructed wetland projects in the Albuquerque area have struggled with high evapotranspiration rates and ability to provide adequate water supply for plant survival (Lusk 2007).

However, contrast in arid regions between areas receiving water and their dry surroundings can be very dramatic. In many cases, a little water in the desert goes a long way in creating suitable habitat for native plants and animals (Campbell and Ogden 1999). An understanding that wetlands need not be consistently wet and may, in fact, be dry for certain years or seasons, is important to keep in mind for arid land constructions (Hammer 1997). Importantly, the number of ‘accidental’ stormwater wetlands that can be found along ephemeral drainages throughout Albuquerque (Figure 12) support the feasibility of their implementation on a larger scale in our climate (CWSGR 1993).

Figure 12
Cottonwoods, willows, and grasses grow in a low area receiving parking lot and roadway runoff along I-40.

NATURAL WETLANDS AS MODELS

Local natural wetlands are the best models for planning new constructed wetland projects. As France (2003) suggests, humans can learn a great deal from “the self-designing capacity of nature” (27). Careful study of natural wetlands adapted to the regional conditions will increase constructed wetland success rates and limit costly mistakes and excessive operating costs. Hammer (1997) states that “regardless of the functional benefit expected from the new wetland (the objectives), the new system

Figure 13
Cottonwood Springs wetland, a spring-fed wetland at Albuquerque's Elena Gallegos Open Space.

should mimic natural wetlands as closely as possible" (171). Likewise, Wetzel (1993), calls for the incorporation of "fundamental operational characteristics of natural systems" in constructed wetland design (3). Observation of local systems will also provide a measure for the comparative evaluation of the new system.

For the proposed combined stormwater/graywater wetland systems in Albuquerque, the most appropriate local and natural models are the spring-fed arid-land wetlands or cienegas found throughout the western United States. These systems maintain a permanently wet core due to water supplied by a spring, while the surrounding area experiences periodic inundation and drying in response to precipitation (DRI 2002 and Linderoth-Hummel 1999). Here, graywater collected from nearby buildings serves as the equivalent of the spring source for maintaining a wet core, while Albuquerque's volumes and seasonal patterns of rainfall determine the hydrology of the surrounding wetland area.

SPECIFIC GOALS

Formulating clear and specific goals will also help to determine the form and approach taken in wetland construction. As addressed above, constructed wetlands can serve many functions, but will be most successful if they are designed with specific functional objectives in mind. Potential goals range from water purification to habitat creation and will likely provide multiple secondary benefits. For example, Hammer (1997) suggests that the goals for a wastewater treatment wetland might include the primary goal of purifying water, as well as the secondary goals of low construction and operating costs, the ability to be largely self-maintaining, manageability by those with little training, and aesthetic and educational benefits. As replacements for stormwater detention areas, the primary functional goal for combined stormwater/graywater wetlands in Albuquerque is stormwater collection. Concurrent secondary goals include stormwater infiltration, water purification, habitat creation, education, human access, and aesthetic improvement.

CONSTRUCTED WETLAND TYPES

Among the wide variety of constructed wetland systems, two general types can be identified. These are classified as either sub-surface or surface flow or, as Hammer (1997) has suggested, by substrate material; gravel in most sub-surface flow systems and soil in most surface flow systems. Each type has specific advantages and disadvantages and well-defined project goals will help to determine which is most appropriate on a case-by-case basis. For the combined stormwater/graywater wetlands proposed here, stormwater collection is the primary functional goal. As a result, the larger holding capacity of a surface system makes this type the recommended option. Additionally, surface flow wetlands more closely mimic the structure of natural wetlands, which will also aid in the secondary goals of habitat creation, education, and aesthetic enhancement (Campbell and Ogden 1999).

REGULATIONS

Building combined stormwater/graywater wetlands in Albuquerque requires compliance with a number of different national, state, county, and city regulations. At this time, laws and permitting processes regarding water management in New Mexico are neither easily accessible nor presented in a format that makes them clear to the general public. As Hammer (1997) has noted in regard to constructed wetlands nation-wide, “fear of regulatory complications is likely to discourage landowners interested in building a wetland” (10). This condition needs to change and measures must be taken to make these processes accessible, as well as to bring the various regulating agencies into collaboration. Where planning authorities are behind new approaches, there is incentive for developers to incorporate new technologies (Dunnett and Clayden 95). Conversely, where regulations are intimidating and the status quo is not questioned, there is little incentive to try new approaches and, in fact, innovators may actually be actively discouraged.

The following sections identify the agencies and regulations that potentially affect constructed stormwater/graywater wetland construction in Albuquerque. They are broken into the general categories of *Water Quality*, *Water Quantity*, and *Graywater Use* in an effort to provide a manageable introduction to our local regulatory issues.

Water Quality:

> United States Environmental Protection Agency (EPA) – regulations under the Clean Water Act, the Endangered Species Act, and the Migratory Bird Treaty Act.
>
> New Mexico Environment Department (NMED)/New Mexico Water Quality Control Commission (WQCC) - established by the State Water Quality Act, the WQCC is responsible for local enforcement of the federal Clean Water Act.

Stormwater/graywater wetland plans must comply with applicable sections of the New Mexico Administrative Code Section 20: Environmental Protection promulgated by the NMED/WQCC. The NMED may also issue permits, on an individual basis, for a system employing new and innovative technology, if the permit applicant demonstrates that the proposed system will not cause a hazard to public health or degrade a body of water (NMCPR 2008).

Water Quantity:

> New Mexico Office of the State Engineer (NMOSE) – responsible for the annual delivery of Rio Grande water to Texas under the Rio Grande Compact.

Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA) – responsible for grading and drainage plan review for all new development in the City of Albuquerque, particularly as it affects drainage systems off-site.

Bernalillo County – has a similar role to AMAFCA in terms of oversight of grading and drainage plans for new development.

City of Albuquerque (COA) – receives return flow credits for water returned to the Rio Grande.

Under the Rio Grande Compact signed in 1938 by the States of Colorado, New Mexico, and Texas, the State of New Mexico is obligated to deliver a certain amount of water annually to the State of Texas. Delivery quantities are calculated at the Elephant Butte Reservoir and the New Mexico Office of the State Engineer (NMOSE) is responsible for ensuring this delivery (CWSGR 1993). In order to meet delivery needs and compensate for large quantities of water lost through evaporation off of the Elephant Butte reservoir, the NMOSE has claimed rights to intermittent flows off of the Rio Grande and instated a 96-hour rule for stormwater detention. The 96-hour rule states that stormwater can only be held on site for a maximum of 96 hours before release to a stormwater conveyance leading to the Rio Grande. However, discussions with AMAFCA's Executive Engineer John Kelly have indicated that this rule is in fact a guideline, rather than a regulation, and that recent decisions by the NMOSE indicate a willingness to overlook the rule in cases where benefits such as improved stormwater quality, education, habitat creation, and, importantly, positive public perception are seen to outweigh the cost of decreased return flows (Kelly 2008).

Graywater Systems:

New Mexico Environment Department (NMED) – regulates all uses of graywater to ensure protection of public health and water quality.

New Mexico Construction Industries Division (NMCID) – regulates dual-plumbing systems for graywater through the Uniform Plumbing Code.

Bernalillo County – building permit provisions on graywater systems.

The New Mexico Environment Department regulates all graywater use in the state of New Mexico and has issued guidelines for graywater systems and above-ground graywater use (NMED 2007). These regulations do not directly address the type of system proposed here, but also do not include any information that is explicitly counter-indicative to the proposal. Alternative systems, such as combined stormwater/graywater wetlands, must be approved on an individual project basis and, as addressed above in the section on Water Quality, project managers must demonstrate that the proposed system will not cause a hazard to public health or degrade a body of water (NMCPR 2008). New integrated dual-plumbing systems for graywater collection must conform to guidelines in the Uniform Plumbing Code promulgated by The New Mexico Construction Industries Division (NMOSE 2001).

GRAYWATER SYSTEMS

The incorporation of a graywater system that collects water from surrounding buildings allows for the augmentation of stormwater flows. This measure utilizes a wastewater source to ensure adequate water supply to maintain aquatic plant life and create functional wildlife habitat in an Albuquerque constructed stormwater wetland. Graywater systems can range from extremely simple practices, such as emptying laundry rinse water into a bucket and carrying it outside to water plants, to fully integrated dual-plumbing systems (Little 2005). Although graywater system retrofits are the only option in many cases and can be quite successful, graywater systems are most effective when considered as a part of the initial design process in new construction (Ludwig 2007). Dual plumbing systems installed in new buildings are the “simplest, most economical way to make use of your graywater” (Little 2005, 17). By considering graywater use from the beginning of the design process it is possible to incorporate easily accessible graywater sources, cleanouts, and inspection points and to maximize gravity-fed graywater conveyance (Little 2005, Ludwig 2007).

Dual-plumbing systems integrated into the construction of new academic, medical, corporate, and industrial campuses are the recommended graywater collection systems for Albuquerque combined stormwater/graywater wetlands. These systems should consist of the following basic components:

> Collection and Conveyance: Pipes and valves move graywater from the source. In New Mexico these pipes must be color-coded in purple or clearly labeled to indicate that they do not carry potable water.
>
> Settling and Filtering: Settling tanks allow solids and large particles to settle to the bottom of the tank and grease, oils, and small particles to float to the surface. They also provide an opportunity for graywater to cool prior to reuse. After settling, a multi-media filter is recommended to increase water quality before release into the wetland pond.
>
> Pumping: Depending on the site layout and topography, systems may be gravity fed or may require a pump. While gravity-flow systems are recommended whenever possible, sump pumps or submersible pumps designed to handle grit can be used to get graywater where it is needed.

Overflow: New Mexico law requires all graywater systems to have an overflow diversion to the sewer.

Receiving Landscape: Vegetation, microbes, and soils that use, contain, and purify the graywater. In this case the receiving landscape is the constructed wetland, planted with aquatic plant species that, along with associated microbes, serve as the treatment mechanism for bacteria, nitrate, phosphate, soaps, and sodium that may be contained in the graywater.

Site Managers and Users: People generate graywater in everyday activities, experience and enjoy the landscape benefits of its use, and maintain the system (Little 2005, Ludwig 2007).

WETLAND SITING

Detailed site analysis is key to determining the best location for a constructed stormwater/graywater wetland and to avoid overly costly or unsuitable sites. In some cases, these evaluations may rule out the option of a constructed wetland on a particular site. Hydrology, soil type, climate, topography, adjacent land uses, and political and legal issues will all affect a site's potential to successfully house a constructed wetland (Hammer 1997). Particular considerations for combined stormwater/graywater wetlands in Albuquerque are introduced below and are illustrated further in the following design exercise.

Land Use and Adjacent Conditions

Current and intended land uses are important factors in siting a successful and well-accepted constructed wetland system. If land dedicated to the wetland is likely to be developed for other purposes in the near future, wetland construction will be a waste of resources. However, if land is dedicated to the purposes of stormwater detention, as is the case in new developments in Albuquerque, its use is less likely to be challenged or changed. Adjacent land uses and conditions may also affect project success. Natural wetlands function in a network with surrounding water bodies and fragmentation affects their performance (France 2003). Hammer (1997) states that proximity to natural wetlands and water bodies is also important for constructed wetlands in sourcing plant material and attracting wildlife. Despite Albuquerque's generally arid conditions, our city has developed such that from any point within the city, one is not further than 15 miles from the Rio Grande, and generally is much closer than that.

Proximity to the water source for the system and to the site's intended users will also affect project costs, user accessibility, and public perception (Hammer 1997). Albuquerque constructed wetlands fed by stormwater runoff and graywater sources should be sited close to site parking areas and buildings in order to limit the need for expensive piping and conveyance devices. Gravity should be employed to direct water to the collection area to the greatest extent possible. Siting wetlands close to areas of human activity also increases their visibility. In contrast with the current ‘back lot’ approach to site drainage, positive everyday interaction with and exposure to water management will encourage public acceptance.

Climate and Hydrology

Understanding the hydrology, or inputs and outputs of water, is an essential factor in the success or failure of a constructed wetland system (Campbell and Ogden 1999, France 2003, Hammer 1997, Wetzel 1993). Hydrology includes water quantity and quality, flow patterns, and seasonal changes (Hammer 1997). Hydraulic capacity is “the ability of the wetland to process a given volume of water in a given time” (Campbell and Ogden 1999, 94). Water level and its manipulation affect the plant species that the system can support, the ability to create wildlife habitat, and the bioretention capacity in constructed wetlands (Campbell and Ogden 1999, Guntenspergen, Keough, and Allen 1993, Wetzel 1993). Calculating a water budget for anticipated inflows and outflows of a system is the first step in determining the type and scale of wetland that can be created. Inflows include direct precipitation, surface and subsurface flows, and in this case, graywater sources. Outflows include infiltration, released surface flows, and evapotranspiration, which will be high in Albuquerque’s hot, dry, and windy climate. Water budgets can be calculated over a year’s time or over shorter periods in response to specific seasonal conditions (Hammer 1997).

Climate and weather play a large role in determining constructed wetland forms and functions. Precipitation, wind, and temperature all affect evapotranspiration, freezing, and the length of growing season (Hammer 1997). Seasonal conditions will cause fluctuations in water levels, which can be detrimental in some wastewater treatment systems, but, within an acceptable range, are considered beneficial in stormwater wetlands for plant diversity and habitat functions (Campbell and Ogden 1999). As Hammer (1997) states, “Obviously, inputs must equal or exceed exports, at least on an annual basis and, importantly, during the growing season or the site will not support a wetland system” (51). In the system proposed here, water for the growing period from spring until the summer monsoonal rains will be provided by the graywater sources.

Topography, Geology, and Soils

Existing site topography plays a large role in constructed wetland siting and project costs. It can mean costly earthwork or savings in the form of gravity-fed water collection. Topography will influence placement of water control structures and access for construction and maintenance. Soil types are also important, particularly in regard to their permeability and specific project goals. Extremely pervious soils may require heavy compaction or lining to contain untreated wastewater, while impermeable soils will be unsuited to groundwater recharge. On-site soils will also be used for forming dikes and dams and as the growing substrate for plants. Sandy loam is considered most appropriate for wetland plant growth. If on-site soils are deemed unsuitable, nearby borrow areas with suitable soils should also be considered in site evaluation (Hammer 1997). Albuquerque soils vary across the city, ranging from decomposed granite soils in the Sandia Mountain foothills to deep sand on the West Mesa, with a wide variety of other types in between (AMG 2005).

MACROPHYTES AND MICROBES

Wetland plants are the feature that most commonly characterizes a wetland in people’s minds. They are also often the best indicator of the existence of a natural wetland, as they are specially adapted to survive in the anaerobic environment of wetland soils (Hammer 1997). Wetland plant types vary widely and are adapted to distinct micro-conditions found within the wetland environment. Six major planting zones exist in typical wetlands: open water, deep marsh, shallow marsh, wet meadow, shrub wetland, and forested wetland. These planting zones support five major growth forms of vegetation: free floating, floating anchored, submerged, emergent, and woody (France 2003).

Although many constructed wetlands are planted with only a few plant species or a monoculture, Wetzel (1993) points out that natural wetlands do not consist of monocultures and argues that wetland designers should follow natural models. Incorporating a variety of plant types has been shown to provide more effective wildlife habitat, absorb more water, and treat water contamination more effectively than planting a monoculture. Shading of the water surface by larger plant species will help to reduce evapotranspiration rates and reduce the likelihood of algal blooms (Dunnett and Clayden 2007). Importantly, a variety of vegetation types will also add to the aesthetic appeal of a constructed wetland. As Dunnett and Clayden (2007) point out, stormwater wetlands encourage “rich diverse, herbaceous-dominated plantings, often based on native plant communities” as an alternative to “the ubiquitous commercial landscaping style of the same few common landscape shrubs that are used everywhere” (46).

Macrophytes, or large aquatic plants, and microbes are “integrated and interdependent” in a wetland system (Wetzel 1993, 6). Macrophytes support microbes with organic matter, while microbes provide macrophytes with the nutrients necessary for survival. Wetzel (1993) proposes that the following conditions, inspired by those found in natural wetlands, will aid in the creation of integrated ecosystems: intentional disturbances, multiple species diversity, maximized detrital and sediment surface area for microbial growth, and anaerobic conditions. Anaerobic conditions result when wetland soils are saturated in the growing season. Wetland plants have special structures called aerenchyma, which allow them to survive in oxygen-depleted conditions that would kill other plants. Aerenchyma allow plants to transport oxygen through leaves and stems and down to the roots for respiration and, subsequently, transport respiration by-products back up the roots, stems, and leaves for release into the atmosphere. Anaerobic soils and adapted plants' roots create a reducing environment in which toxic ions can be reoxidized and precipitated into the soil, allowing wetlands to act as 'sinks' for a number of potentially harmful substances (Campbell and Ogden 1999, Hammer 1997).

Plants selected for Albuquerque stormwater/graywater wetlands should be based on those found in local natural wetlands. Consulting local examples will guide choices about plant species and densities that are adapted to our regional conditions. Selecting plants that are known to tolerate both inundation and drying will be important for the stormwater zone, while the graywater wet core will allow for the use of floating and submerged plant types. Ross Coleman (2008) of Hydra Aquatic Inc., an Albuquerque-based aquatic plant nursery, states that many aquatic plants can survive dry or limited-watering conditions if they occur during plant dormancy in the winter and do not coincide with the plants' growing season. His nursery provides a plant list based largely on native species adapted to both inundation and drying. Local constructed wetlands advocate Paul Lusk (2007) found that in his home system, native plants thrived, while exotics died off over time. Planting selections should be based on native species and should strictly avoid any species known to be invasive in the State of New Mexico.

Wetland plants can be sourced from aquatic plant nurseries or, when possible, from local natural systems. Plants taken from existing wetlands have the advantage of bringing with them associated microbes and other small life forms, giving the new system a jumpstart on productivity and biodiversity (Hammer 1997). Regulations and costs may prohibit his approach, however, and nursery-grown plants are most commonly used (Campbell and Ogden 1999). Spring, after the last hard frost, is generally the best time for wetland planting. The ability to control and vary water levels is very important during the early stages after planting to ensure plant survival (Hammer 1997). Plantings for stormwater/graywater wetlands in Albuquerque may be sourced in part from existing systems, but can also employ the locally grown species available from Hydra Aquatic Inc. Mid-April through mid-May is the best period for wetland planting in our climate. There is little risk of frost during this time, while precipitation rates are generally low to moderate, allowing for planting to occur prior to inundation and providing the ability to control water levels through graywater application.

EVALUATION AND MANAGEMENT

Evaluation of the success of constructed wetlands projects has historically been complicated by a lack of specified measurable goals. As a result, success has commonly been measured by the percentage of vegetative cover on a site persisting for a defined period of time (Kusler and Kentula 1990). However, more accurate measures of the success of a constructed wetlands project depend on the specific goals and functions required of the system. Clear, quantitative, measurable, function-based goals linked to a timeline are essential for meaningful evaluation of constructed wetland function. Additionally, careful documentation of original goals, amendments to plans or objectives, on-site modifications, and unusual events such as flooding or vandalism are important to the accuracy of performance evaluation and extremely helpful to future site managers (Hammer 1997). Evaluation should also take into consideration community feedback for measuring acceptance of the new system and its social benefits. Community involvement and volunteerism will also help to meet maintenance and management needs (Funkhauser 2007).

The wetland systems proposed here are intended to replace stormwater detention areas. Therefore, an essential measure of their success will be their ability to effectively collect and hold stormwater flows throughout the year. Additionally, in order to validate the additional funding and effort required in creating combined stormwater/graywater wetlands, a measure of their ecological, educational, and aesthetic value will be important.

HEALTH, SAFETY, AND LIABILITY

Figure 14
An open water irrigation drain in Albuquerque's North Valley.

Concerns about safety and liability warrant careful consideration, but should not be seen as deterrents to stormwater/graywater wetland construction. Two primary concerns are public access and insect breeding (WERF "GIDC" 2007). In some cases public access is best controlled with fencing and locked gates, while in others, public access is an important part of the project's goals. The stormwater/graywater wetlands proposed here are intended to educate, invite exploration, and add to a site's aesthetic appeal. For these reasons, public access is key to their success. While Albuquerque ordinances require a minimum of 4' tall fencing around any detention area designed to temporarily store water of over 18" deep, the City's arroyo and historic ditch and drain systems of open and rapidly moving water (Figure 14) clearly present a greater potential hazard and set a good precedent for questioning this regulation (Campbell and Ogden 1999).

Safety concerns regarding accessibility can be addressed through a few fairly simple measures. Gentle, sloping banks help to create safe pond edges that make falling into the pond unlikely and getting out of the pond easy (Dunnett and Clayden 2007). Railings should be included on any areas with vertical drops of 30 inches or more (WERF "GIDC" 2007). Visibility is improved by locating ponds in active areas, rather than in remote corners of a site, and by avoiding the use of opaque fencing and walls (WERF "GIDC" 2007). Signage should also be used to educate visitors about the system's functions and to encourage caution around areas of open water.

Several simple steps can also be taken to prevent the stormwater/graywater wetland from becoming a mosquito breeding ground. Mosquitoes are not only a nuisance that would detract from a visitor's experience at the site, but are also a health concern. Mosquitoes breed in shallow standing water and it is essential to manage a constructed wetland to avoid areas of shallow water allowed to stand for more than 48 hours. If water cannot be infiltrated into the soil in that time, water should be directed to deeper ponding areas or treated with biological larvicides (WERF "GIDC" 2007). The graywater core in the proposed wetland system can also be stocked with mosquito fish (*Gambusia affinis*), a small, rapidly reproducing fish that feeds on mosquito larvae. Mosquito fish are distributed free of charge by the Bernalillo County Health Department (Campbell and Ogden 1999). Additionally, dragonflies will help to control mosquito larvae and bats and swallows assist in mosquito control. The installation of bat boxes and swallow nesting boxes around constructed wetland sites has had good results in the past (Campbell and Ogden 1999).

COST

Exact costs for stormwater/graywater wetlands in Albuquerque will vary based on specific project goals and site conditions. Generally, the highest costs in wetland construction are associated with large areas of gravel, liner systems, and extensive earthwork (Campbell and Ogden 1999). Designing the project with the goal of minimizing these elements may help to keep total project costs down. Generally, stormwater wetlands and other stormwater BMPs are a very cost-effective means of providing stormwater management. Compared with traditional stormwater systems, sustainable stormwater BMPs can provide savings in the following ways: on-site infiltration reduces the number and size of drainage pipes needed for handling runoff; community participation in construction and planting reduces capital and maintenance costs; and overall infrastructure simplification reduces construction and maintenance costs (WERF "BGD" 2007).

In new construction, the cost of dual plumbing systems for graywater collection will not be significantly higher than traditional plumbing system costs (CSBE 2003). Additionally, stormwater harvesting and graywater reuse save money by decreasing the need for water conveyance and treatment. The State of California uses 19% of the state's electricity and 30% of its natural gas "conveying, treating, distributing, heating, and cooling water from source to end user" (Funkhauser 2007). Reducing demand on treated water sources and aging sewer systems in Albuquerque will have direct financial benefits in the long run. Additionally, Campbell and Ogden (1999) point out that any cost/benefit analysis of urban constructed wetlands should take into consideration the amenities of open space, wildlife habitat, and recreational use.

CHALLENGING THE STATUS QUO

Some of the details of this proposal challenge regulations and accepted practices for stormwater management in the Albuquerque area. While this poses challenges for the implementation of some of the ideas, it does not discredit their potential as positive contributions to our urban landscape. This exploration is intended to give voice to the often-overlooked constituents of ecological process and open space in the urban landscape. Lyle (1985) notes that landscape architects engage in the act of making physical changes in the landscape, but that these often require legal and policy changes as well. Thayer (1995) rightly argues that we must try new things in order to know how to do them and that this will require challenging "business-as-usual" (324). Likewise, Hester (2006) identifies the importance of questioning "out-of-date standards" and the rules that govern a site (63).

Specifically, this proposal directly challenges only two particular rules, the 96-hour rule for stormwater detention and the fencing rule for water storage areas. As addressed above, there are local precedents for challenging both of these rules and the potential benefits that can be gained by rethinking their blanket application should be considered on a case-by-case basis. More generally, this proposal challenges accepted practices for wastewater disposal and stormwater detention. Although graywater reuse is gaining in popularity, it is still a relatively unknown practice in Albuquerque where the conventional disposal of wastewater through the municipal sewer system is the norm. Likewise, stormwater management through single-purpose detention basins designed by engineers is the accepted practice in Albuquerque and the use of constructed stormwater/graywater wetlands will require some adjustment in thinking. Lastly, and perhaps most importantly, this proposal challenges our perceptions of stormwater management infrastructure by encouraging us to view it as an amenity rather than an intrusion. By tackling these challenges Albuquerque could become a leader in sustainable stormwater management in the Southwest and a model for the region.

SUMMARY OF FINDINGS

Combined stormwater/graywater wetlands for Albuquerque should be modeled on spring-fed wetlands, consisting of a permanently wet core fed by a dual-plumbing graywater system and a flexible surrounding area fed by stormwater runoff. The system should be surface-flow in order to meet stormwater retention needs and maximize the potential for habitat creation, aesthetic improvement, and education. Systems should be sited to maximize public exposure and access, while also designed with public safety in mind. Systems should be integrated into the initial design of new academic, medical, industrial, and corporate campuses and sited to minimize costs associated with earthwork, water conveyance, and pond lining. Plant selections should be based on native species available locally and should represent a wide variety of species in order to maximize biodiversity and habitat richness. Projects should be designed with specific goals in mind, but must also be allowed to adapt and change in response to external conditions. Lastly, project designers must be aware of regulatory issues, but should not be intimidated by them. They should approach regulators and permitting agencies armed with well thought-out plans that emphasize the multiple benefits that combined stormwater/graywater wetlands can provide to both humans and the environment.

Design Exploration

The following design proposal is intended to illustrate and test the findings and recommendations outlined above. The design site is the Volcano Vista High School (VVHS) campus, the Albuquerque Public School system's newest facility. VVHS is located on Albuquerque's West Mesa, approximately five miles west of the Rio Grande. The 100 million dollar facility is currently open to one freshman class, with plans to add sophomore, junior, and senior classes as construction of the full site is completed in the coming year (Gran 2007). Situated at the border between housing developments and undeveloped mesa top, the school is, for the time being, in a unique position straddling the built and un-built environments.

Figure 15
General location of Volcano Vista High School.

Although this proposal advocates the incorporation of combined stormwater/graywater wetlands from the very beginning of site planning and development, the conditions at the already designed and under-construction VVHS provide parameters for this design study and also help to illustrate the missed opportunities represented by the use of conventional stormwater drainage systems. VVHS's current detention basin is located on the southern edge of the campus and is typical of its kind, consisting of a rectangle of approximately 1.9 acres of land excavated to a depth of 13 feet at its deepest end. The basin is unplanted and enclosed by a 6' tall chain link fence. This design exercise looks closely at the site conditions at VVHS and presents an alternative solution to site drainage through the use of a combined stormwater/graywater wetland to meet the basic needs of stormwater collection and add value to the site through outdoor gathering and classroom space, habitat creation, and aesthetic enhancement.

The following site analysis worksheet for the VVHS design illustrates the information needed for the site evaluation and planning of a combined stormwater/graywater wetland. It is based on the literature review and the topics introduced above in the section "Bringing it all Together."

Figure 16
Current detention area and adjacent parking at Volcano Vista High School

Figure 17
Current detention area at Volcano Vista High School showing standing water despite no recent precipitation at the time of the photographs.

Site Analysis Worksheet for Constructed Stormwater/Graywater Wetlands at Volcano Vista High School, Albuquerque, New Mexico

LAND USE AND OWNERSHIP

Ownership: The Albuquerque Public School System
Potential Site Users/Stakeholders: Students and their families, teachers, and neighbors
Current Land Use: Public high school campus, area designated for stormwater detention
Adjacent Land Uses: (see also Site Map, page 43)

Figure 18
To the North: undeveloped open land, a new church under construction, and housing subdivisions.

Figure 19
To the East: undeveloped open land and Universe Road.

Figure 20
To the South: undeveloped open land and housing subdivision in the distance.

Figure 21
To the West: undeveloped open land and construction sites for new elementary school and new housing subdivision.

Property Lines: See Site Map, page 43

Rights-of-Way (Utility): See Site Map, page 43

Prior Level of Disturbance: Site fairly disturbed due to construction and development process, disturbance due to over-grazing, major soil erosion primarily due to wind combined with the construction process.

TOPOGRAPHY AND GEOLOGY

Obtain 1-foot contour map:
Contour maps for pre- and post-construction site conditions show a general sloping to the southeast, thus the placement of the current detention basin.

Obtain geologic data (Bedrock? Sinkholes? Mines? Oil drilling?):
Depth to Basalt ranging 8” to 14’ throughout the site (Vinyard 2006).

Proximity and elevation in relation to water source:
Distance from building for roof runoff and graywater = an average distance of 1,500 feet.
Distance for other site runoff (inlets and surface) = ranges from 1 - 2,500 feet.

Elevation change from building = 20 feet, average slope just under 2%.
Over site = 28 feet, average slope just over 1%.

Low points where drainage naturally occurs:
All site drainage heads to the current detention area, as there is a general sloping towards the southeast in both pre- and post-development conditions.

Figure 22
Erosion caused by overtopping of the current detention area.

SOILS

Soil class: Alameda Sandy Loam (AmB), Madurez-Wink Association (MWA)

Soil composition: AmB = sandy loam, MWA = fine sandy loam

Soil depth: AmB = 20-40 inches to bedrock, MWA = sandy loam to 60 inches

Potential nearby borrow areas: Excavations of basalt during the construction process have yielded surplus basalt that may be available for use in the constructed wetland design.

Permeability/Percolation rates: AmB = Well drained, MWA = Well drained

Figure 23
Basalt boulders and rubble on the site.

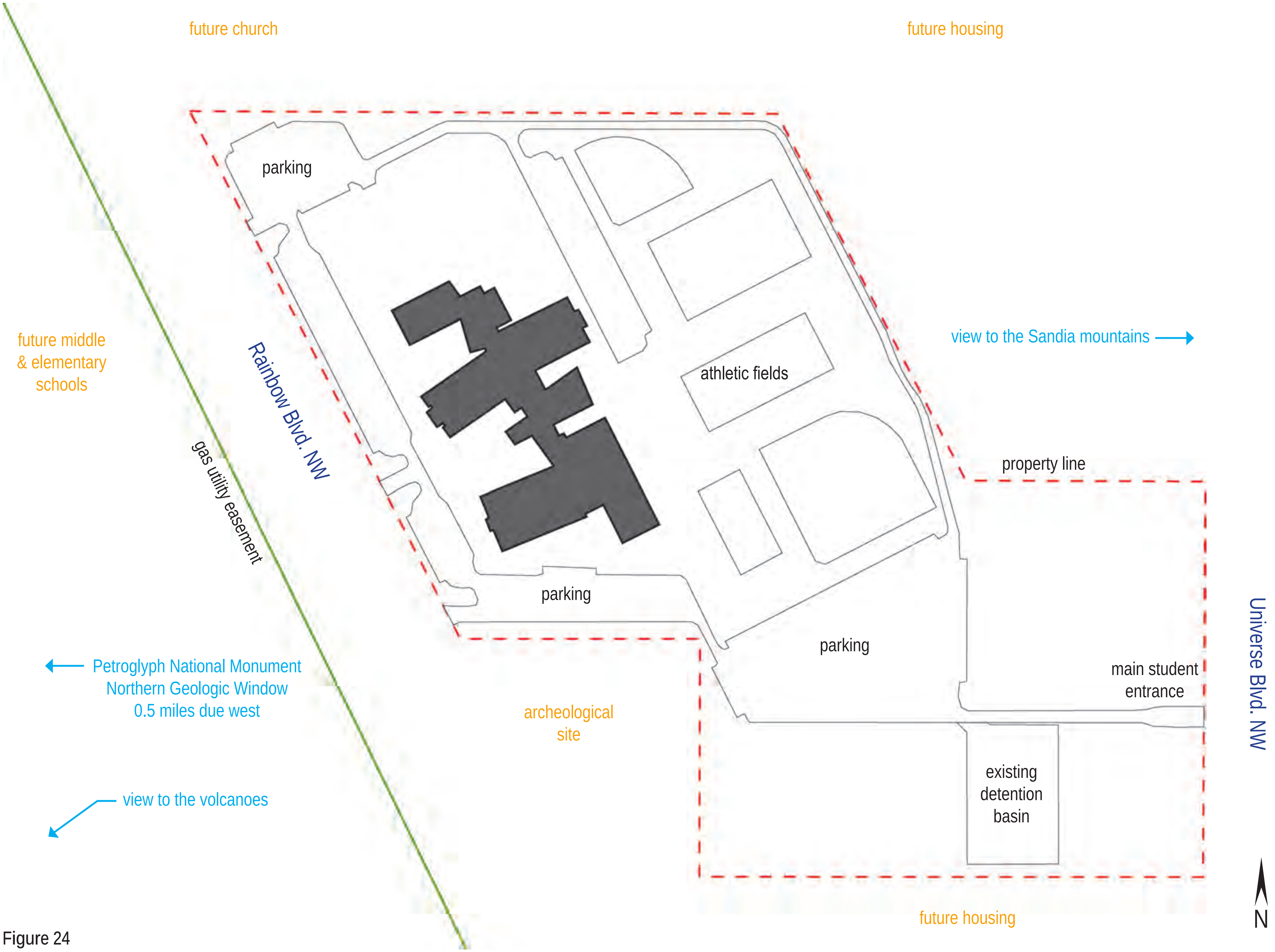


Figure 24
Volcano Vista High School Site Map.

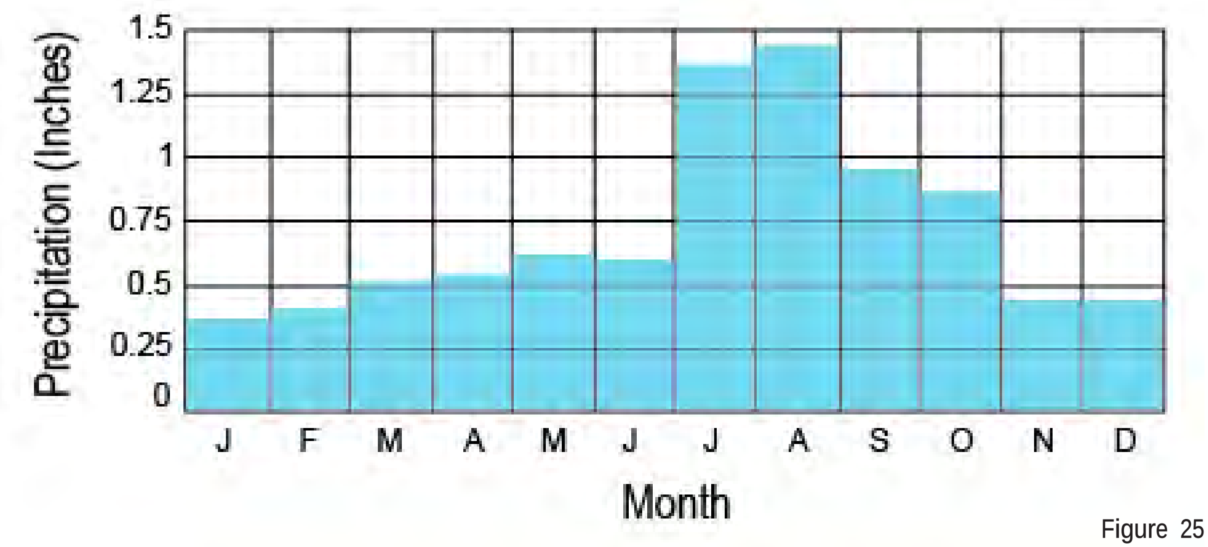


Figure 25
Albuquerque Monthly Precipitation.

Precipitation patterns: Low precipitation throughout the year with monsoonal rains in July and August, average annual precipitation of around 9 inches.

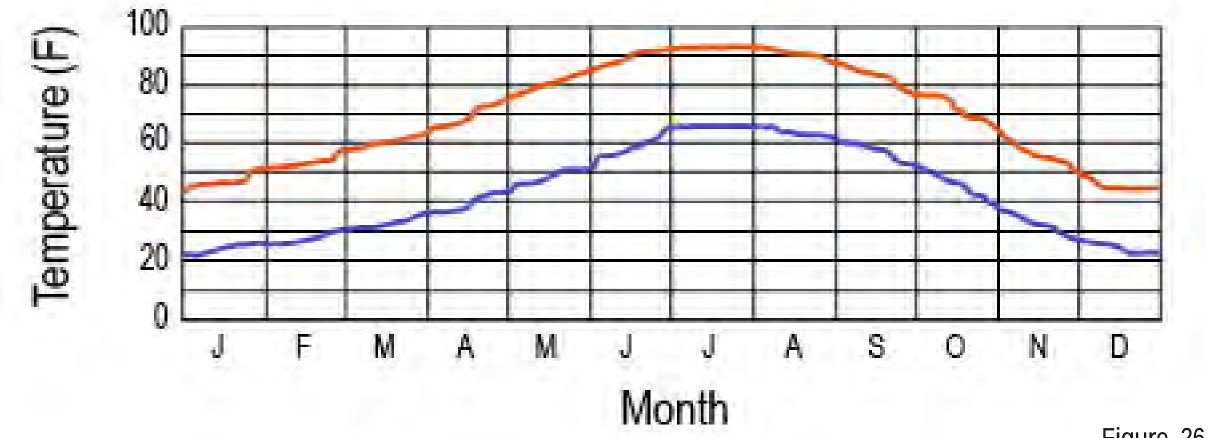


Figure 26
Albuquerque Monthly Temperatures.

Temperature patterns: Summer highs around 92 degrees F and winter lows around 23 degrees F.

Figure 27
Singleseed junipers dot the landscape surrounding the school.

Figure 28
Weedy species, such as Silverleaf Nightshade, are abundant on the site.

Figure 29
Low shrubs and grasses are the dominant vegetation on site.

Prevailing wind patterns: Spring – strong winds out of the SE, predominant easterly and northeasterly winds in region (Kurota 2006)

Relative humidity: 44%

Presence of vegetation: Vegetation fairly sparse and low-lying. Only trees are Singleseed junipers – mounded and shrubby.

Nearby landscape features (lakes, hills, etc.): Volcanoes, general sloping towards SE

Aspect: Sunny 76% of the year

Length of growing season: 170 to 195 days

BIOLOGY

Presence of Plants/Existing Vegetation Patterns:

Observed on site:

Artemisia filifolia Sand Sage
Gutierrezia sarothrae Broom Snakeweed
Juniperus monosperma Singleseed Juniper
Machaeranthera sp. Purple Aster
Opuntia sp. Prickly Pear
Psorothamnus scoparius Broom Dalea
Salsola kali Russian Thistle
Solanum elaeagnifolium Silverleaf nightshade
Grass spp.
Annual Forbes

Additional likely species particular to disturbed sites:

Achnatherum hymenoides Indian Ricegrass
Bouteloua eriopoda Black Grama
Bouteloua gracilis Blue Grama
Erioneuron pulchellum Fluffgrass
Kochia scoparia Kochia
Sporobolus cryptandrus Sand Dropseed
Tribulus terrestris Goathead or Puncturevine

Additional species likely to be found on site:

Atriplex canescens Fourwing Saltbush
Datura meteloides Jimsonweed
Dimorphocarpa wislizenii Spectacle Pod
Hilaria sp. Galleta grass
Phacelia integrifolia Scorpion Weed
Rumex hymenosepalus Curly Dock
Sphaeralcea angustifolia Globemallow

Presence of Animals:

Observed:

House Finch
Western Meadowlark
Scaled Quail
Ants
Burrows and Scat

Additional species likely to be found on site:

Western Diamondback Rattlesnake
Western Prairie Rattlesnake
Kangaroo Rats
Pocket Mice
White Footed Mice
Wood Rats
Lizards
Horned Lizards
Spadefoot Toad
Mourning Dove
Mule Deer
Antelope
Cottontail Rabbit
Black-tailed Jackrabbit

Figure 30
House finches perch on the fence surrounding the school's current detention area.

Animals or plants that would be negatively impacted by wetland construction:
No significant negative impact identified.

Presence of Exotic or invasive species:
Some weedy vegetation, but no significant presence identified.

Threatened or Endangered Species:
None identified or anticipated on site.

Figure 31
An unidentified animal burrow near the school's current detention area.

Presence of or proximity to existing wetlands and other bodies of water:

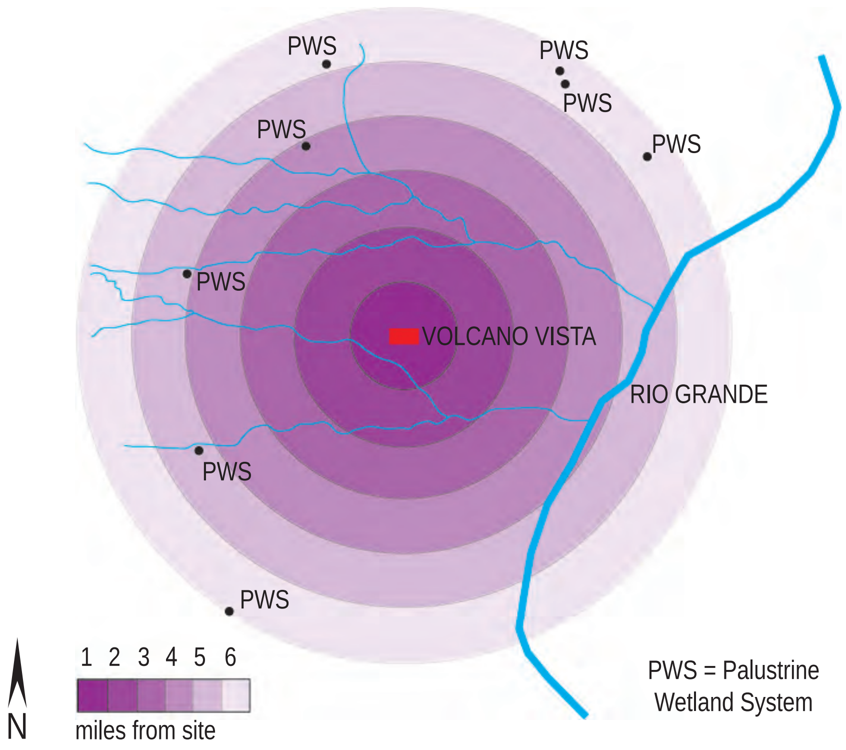


Figure 32
Nearby wetlands and waterbodies.

Eight wetland systems identified within 6 miles of the school site, as well as the Rio Grande and associated constructed and natural wetland habitats within 4 to 6 miles of the site.

Cultural and Historic Significance:
Archeological excavations performed on site revealed the remains of an Anasazi Pueblo IV (A.D. 1300 - 1600) fieldhouse that had consisted of a ramada structure, fire hearth, and probable dry-laid basalt windbreak wall, as well as traces of a late Archaic camp (1800 - 400 B.C.). The archeological team recommended that construction of the school be permitted on site, as long as an area in the southwest corner of the site remain undeveloped (see Site Map, page 45) (Kurota 2006).

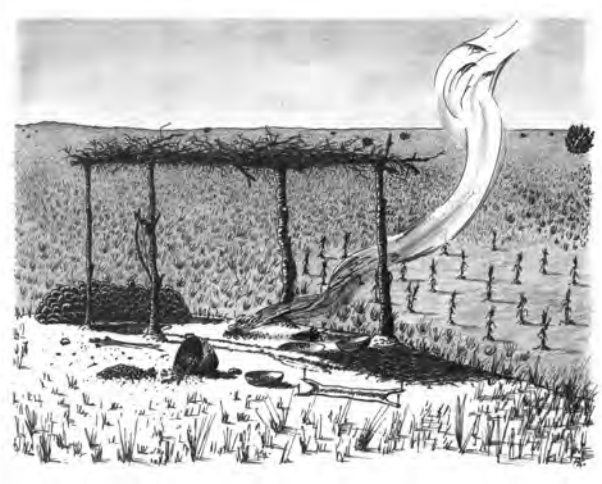


Figure 33
Artist's rendering of the Pueblo IV fieldhouse .

HYDROLOGY

Springs or sinkholes present: No
Groundwater depth: 105 – 130'
Groundwater quality: N/A

Inflows (see also Monthly Estimated Water Budget on page 51 and Appendix A: Calculations):
Direct Precipitation: 194,285 gallons annually
Surface/Piped runoff Inflows: 7,233,197 gallons annually
Subsurface inflows: N/A
Supplemental Graywater: 2,906,042 gallons annually

Outflows (see also Monthly Estimated Water Budget on page 51 and Appendix A: Calculations):
Surface Outflows: controlled by outlet structure – necessary only in overflow situation
Infiltration: slow and limited due to basalt bedrock
Evaporation: 1,400,525 gallons annually

Watershed, Subwatersheds: The Boca Negra and Mariposa arroyos make up a 21 square mile watershed. The watershed is generally bounded by the Calabacillas Arroyo basin to the north (roughly along Paseo del Norte corridor) and the San Antonio arroyo basin on the South (roughly along the Montano corridor). The watershed extends to a small area below the West Mesa escarpment and into the Mariposa Detention Basin (Shared Vision 2005).

Receiving Waters: The Mariposa Detention Basin and eventually the Rio Grande (Shared Vision 2005).

month	graywater	site runoff	direct precipitation	evaporation	available
January	274,312 gallons	311,646 gallons	8,348 gallons	-39,207 gallons	555,099 gallons
February	303,187 gallons	331,752 gallons	8,886 gallons	-51,836 gallons	591,989 gallons
March	259,857 gallons	432,283 gallons	11,579 gallons	-89,536 gallons	614,183 gallons
April	317,625 gallons	452,389 gallons	12,118 gallons	-136,660 gallons	645,472 gallons
May	216,562 gallons	527,786 gallons	14,137 gallons	-185,292 gallons	573,193 gallons
June	132,000 gallons	512,707 gallons	13,733 gallons	-212,058 gallons	446,382 gallons
July	132,000 gallons	1,156,106 gallons	30,967 gallons	-196,036 gallons	1,123,037 gallons
August	144,375 gallons	1,206,370 gallons	32,852 gallons	-169,646 gallons	1,213,951 gallons
September	317,625 gallons	804,247 gallons	21,542 gallons	-133,455 gallons	1,009,959 gallons
October	317,625 gallons	733,875 gallons	19,657 gallons	-95,756 gallons	975,401 gallons
November	274,312 gallons	382,018 gallons	10,233 gallons	-53,344 gallons	613,219 gallons
December	216,562 gallons	382,018 gallons	10,233 gallons	-37,699 gallons	571,114 gallons

Figure 34
Estimated water budget.

Design Development

In moving from the site analysis phase to the process of design development, two distinct, but complimentary, layers of design considerations emerged; functional considerations and cultural and experiential considerations. Figure 35 shows the overall site layout for the constructed wetland system with labels identifying some of the key design elements. The following sections describe the motivation and reasoning behind the design of these key elements and are broken down into the two categories of functional and cultural and experiential considerations.

FUNCTIONAL CONSIDERATIONS

Water Collection Systems: The proposed constructed wetland system relies on two distinct water collection systems.

The *graywater collection system* (Figure 36) takes water from the adjacent school building's drinking fountains, sinks, and locker room showers; through a preliminary cooling, settling, and filtration system; and into the constructed wetland's deepest central area. This system serves to maintain a wet core in the wetland and maintain aquatic plant life year round despite times of little to no precipitation. The graywater system allows the constructed wetland to function in a manner analogous to the spring-fed wetlands found in nature.

The second water collection system is the *stormwater collection system* (Figure 37). Stormwater is directed to the main pool stormwater zone through sub-surface piping carrying water from the building's downspouts and site drop inlets, as well as through surface grading directing surface runoff through the stormwater inlet and forebay.

Wetland Zones and Functions: Figure 38 diagrammatically illustrates the components of the wetland system and their roles. These components are described in more detail below.

The *forebay* receives the stormwater flows and is designed to serve two primary functions. First, the forebay slows the stormwater entering the wetland system by capturing it in a deep entry pool that must be overtopped in order to allow the water to flow over the vegetated berms and into the wetland main pool. This helps to limit scouring and vegetation damage in the wetland main pool during fast-moving, high flow storm events. Second, the forebay serves as a settling and collection point for sediment, trash, and toxins that are carried by the stormwater flows. Not only does sediment and some trash drop out of the stormwater as it slows, but the forebay is also planted with cattails and bulrushes that help to capture trash and take up and accumulate toxins. The forebay is one of two higher intensity maintenance zones within the wetland system. The other is the micropool and trash rack at the outlet of the system. The forebay may require periodic dredging and replanting as it accumulates sediment, trash, and toxins.

The *vegetated berms* are sited in two locations within the constructed wetland system; between the forebay and the main pool and between the main pool and the peak flow zone. The vegetated berms serve to define functional spaces and contain and direct water flow within the wetland system.

The *wetland main pool* is made up of two distinct zones; the *permanent graywater wet core* and the *stormwater zone*. The main pool is sized to contain the average seasonal high water level (see Figure 39). The permanent graywater wet core is fed directly by sub-surface piping from the school building. The wet core is planted with aquatic plant species that require a constant water level of at least three feet in depth. These plants serve to cleanse and filter the graywater. As mentioned above, the graywater piped into the system serves as the equivalent of the spring source in natural spring-fed arid-land wetlands or cienegas. The stormwater zone holds the majority of the stormwater flows into the system and maintains the vegetation adapted to shallower water levels and periodic flooding.

The *peak flow zone* will generally remain dry and will be inundated only when stormwater peak flows overtop the wetland main pool. Most flows that enter the peak flow zone will be taken up by plants and infiltrated. This area, along with the *maximum capacity zone* would need to become completely full before water is released through the system's emergency outlet.

The *micropool*, *trashrack*, and *outlet* serve as the last resort option for water flow when the system is receiving more water than it can contain, such as in a monsoon storm event. The micropool is a deep area that, like the forebay at the beginning of the system, serves to slow water flows and collect trash and debris. Water entering the micropool exits the wetland system through a trash collection rack and outlet pipe at the top of the micropool. The outlet connects to the municipal storm sewer for the emergency release of water. As mentioned above, the micropool and trashrack are the second higher intensity maintenance area of the system and will also require periodic dredging and clean-out. The perimeter walking path and maintenance bench road leading from the school parking lot driveway allows for easy maintenance access to the micropool and trash rack.

(continued on page 54)

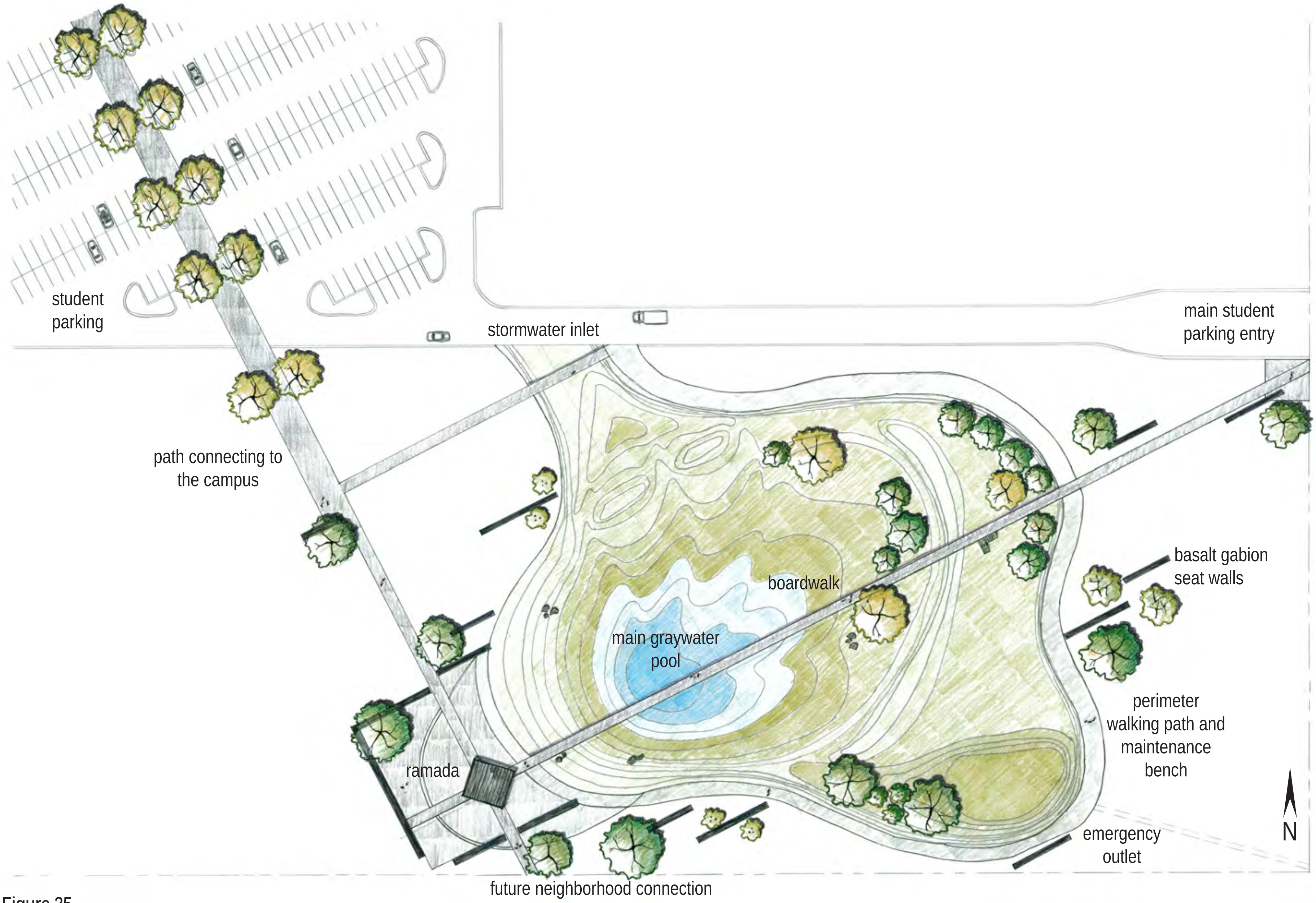


Figure 35
Volcano Vista High School Constructed Wetland Site Plan.

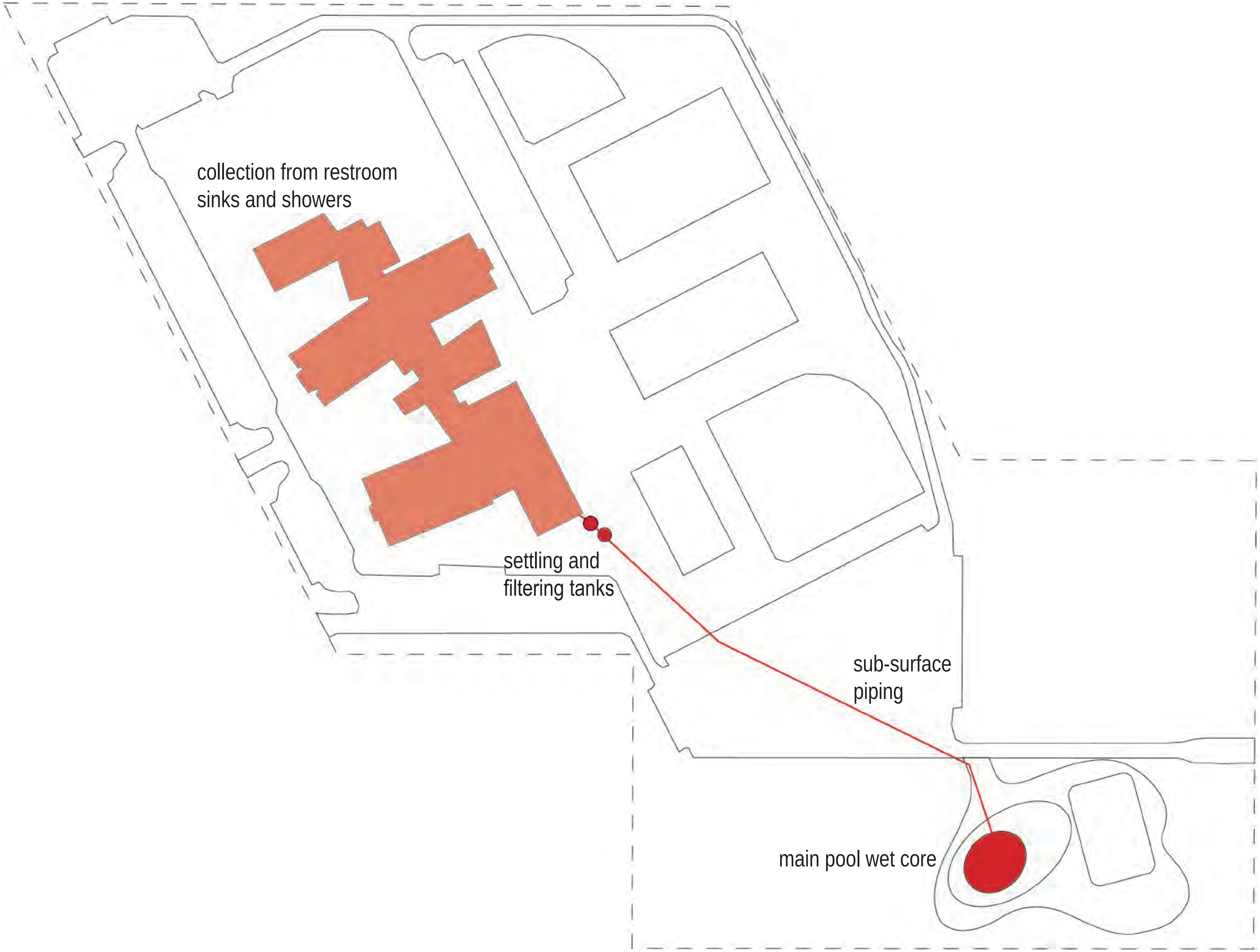


Figure 36
Graywater collection system.

Figure 37
Stormwater collection system.

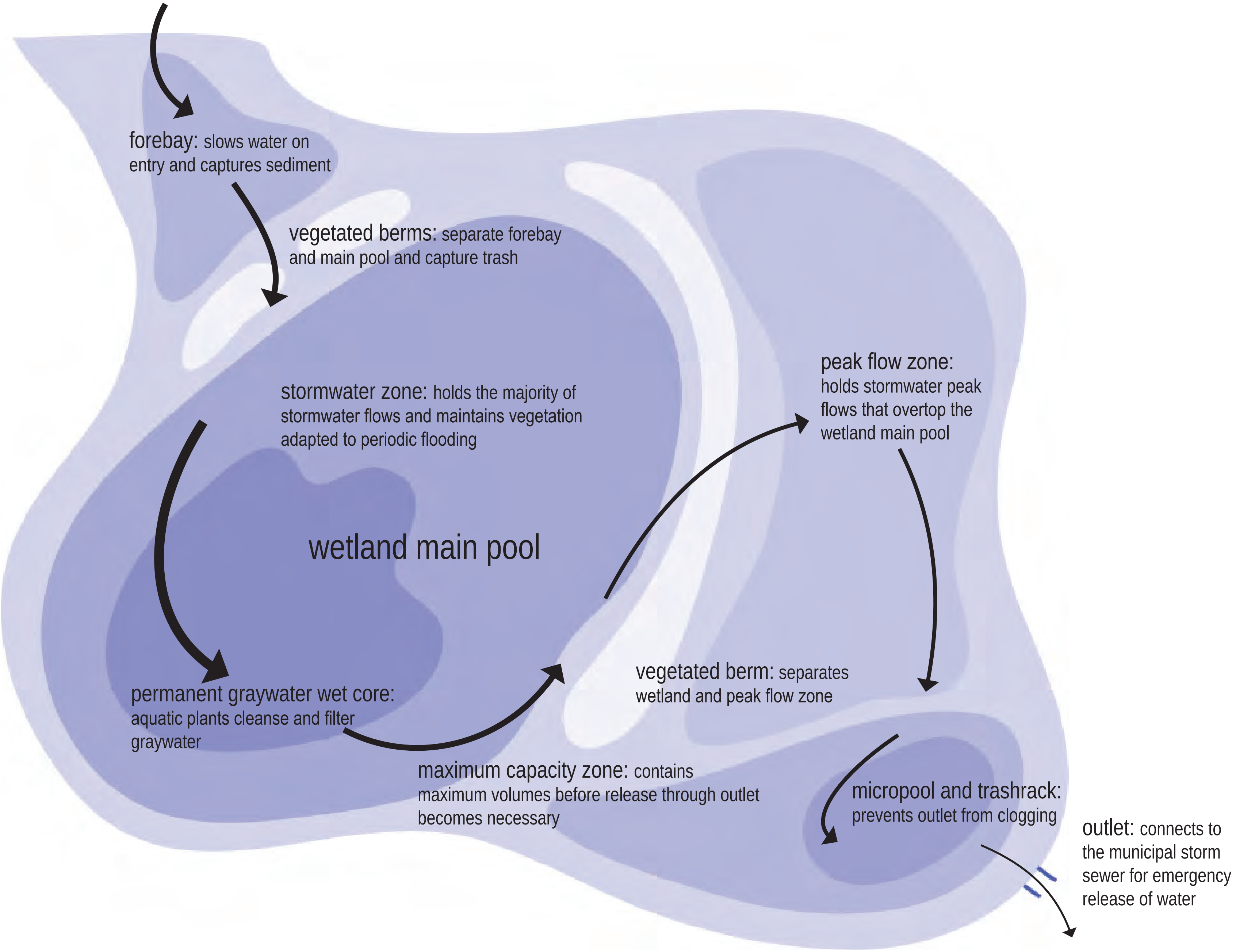
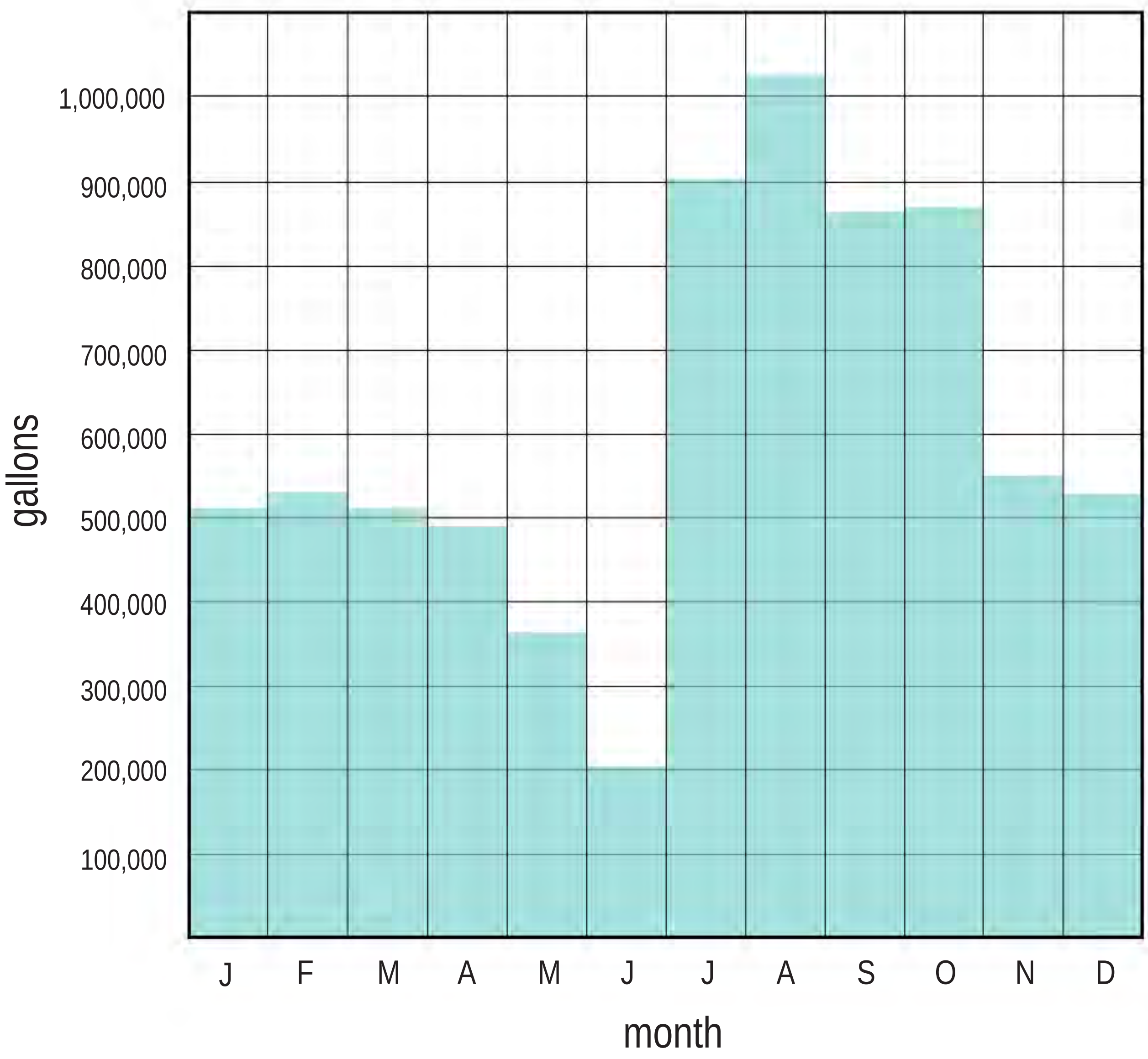
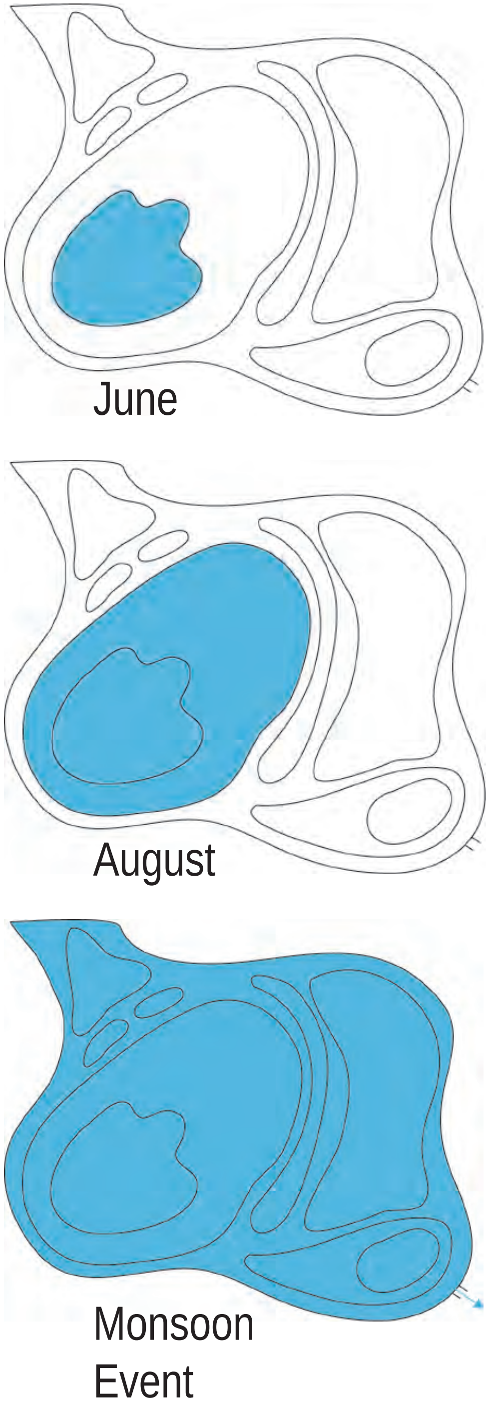


Figure 38
Wetland zones and functions.




June

August

Monsoon
Event

Figure 39
Monthly water budget and typical water level variations.

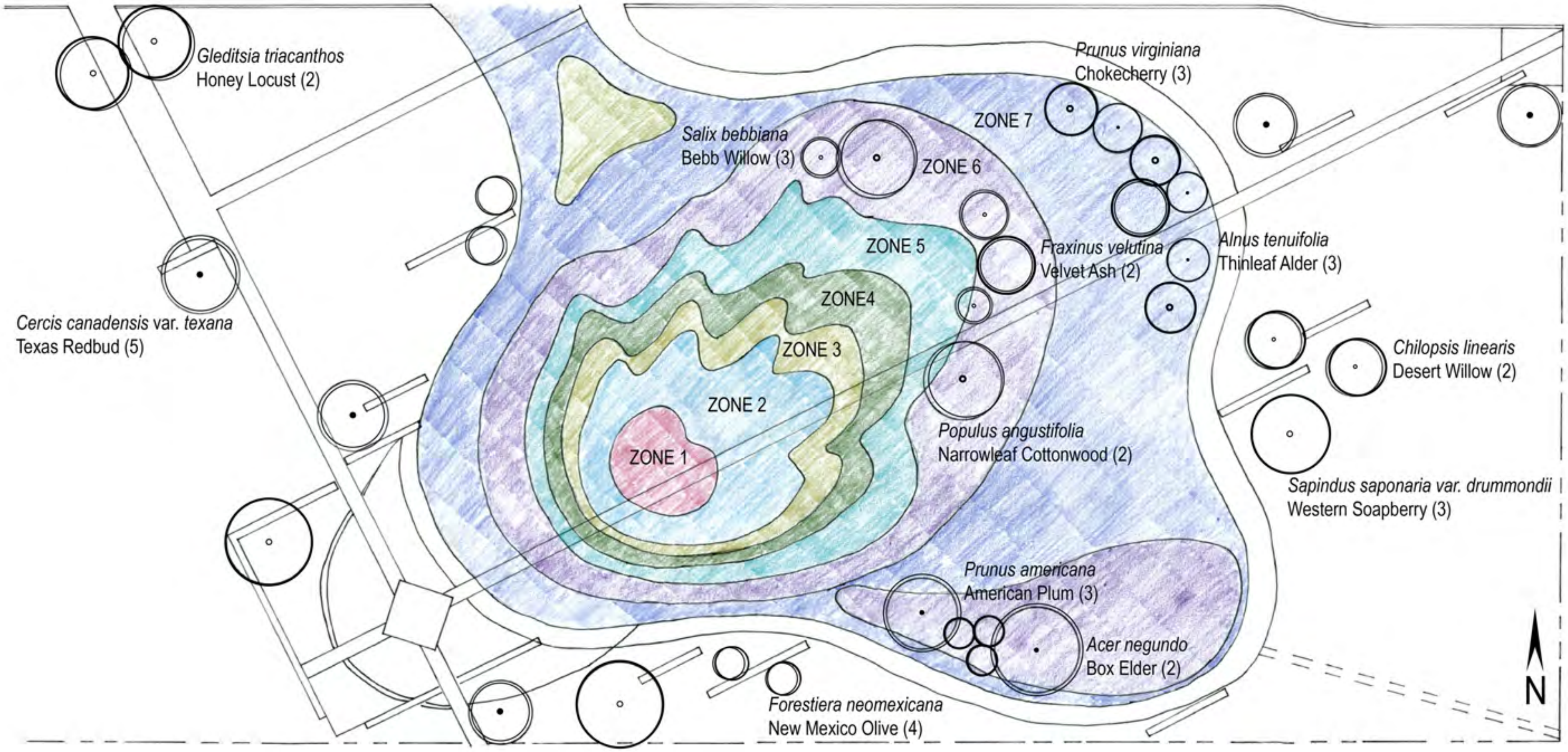


Figure 40
Planting plan.

Planting Plan:
The planting plan (Figure 40) is directly linked to the grading and water level variations within the constructed wetland system. Trees are individually sited and identified on the plan, while aquatic plants, grasses, forbes, and wildflowers are broken into seven zones based on their hydrologic adaptations. The plants identified for these seven zones can be found in Appendix B: Plant List. Topographical variations within the wetland basin are intended to foster the biological diversity of plant and animal species adapted to living within the system. The typical planting section on the following page illustrates species planted by zone according to topographical and corresponding water level variations.

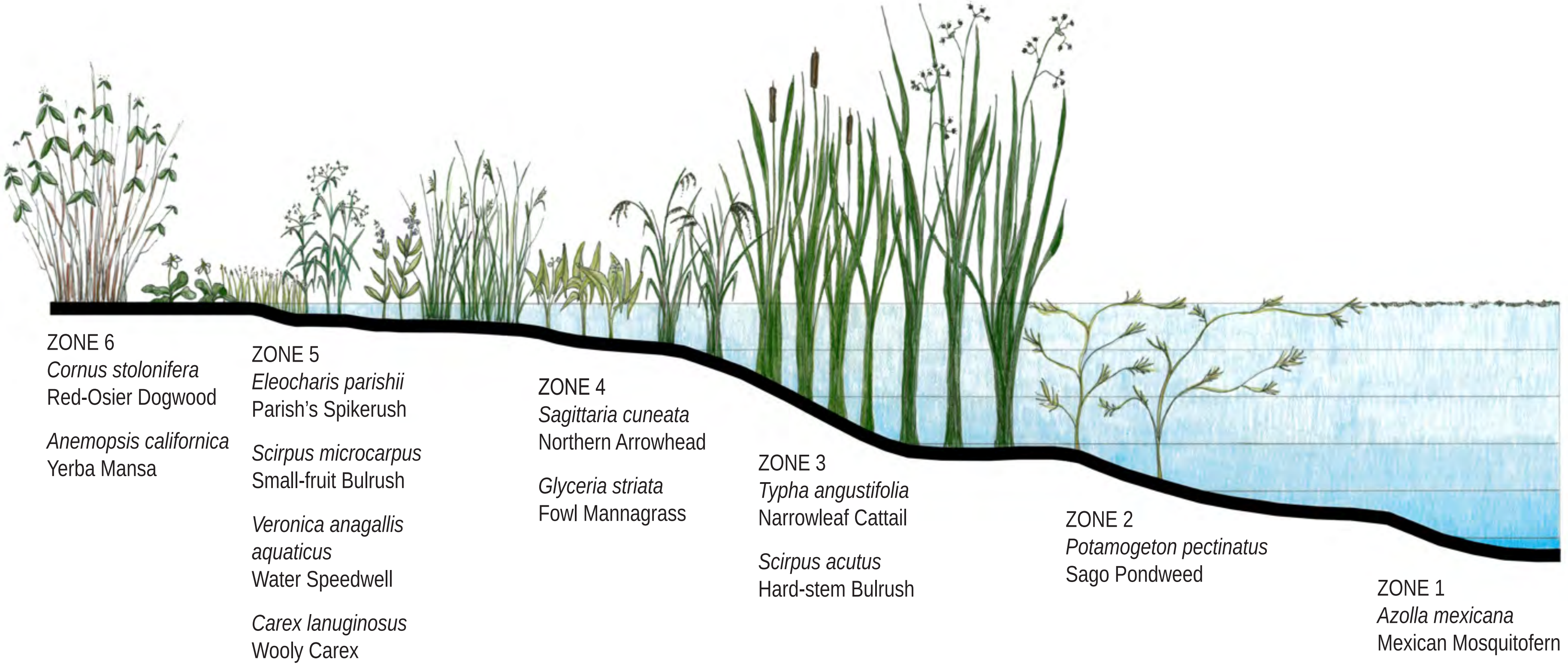


Figure 41
Typical planting section.

Plants play multiple roles in the system and are the key difference between the school's existing detention area and the proposed constructed wetland. As discussed in greater detail in the section "Macrophytes and Microbes" beginning on page 29, plants are essential to the wetland system's ability to cleanse and purify water. They also create wildlife habitat, reduce evaporation from the system by creating shady micro-climates, and, importantly, increase the stability of the system. Plants increase the system's stability in several ways; plant roots help to hold the soil structure together and plants uptake water, limiting the likelihood of system failure through overtopping as was seen in the current detention area (Figure 22).

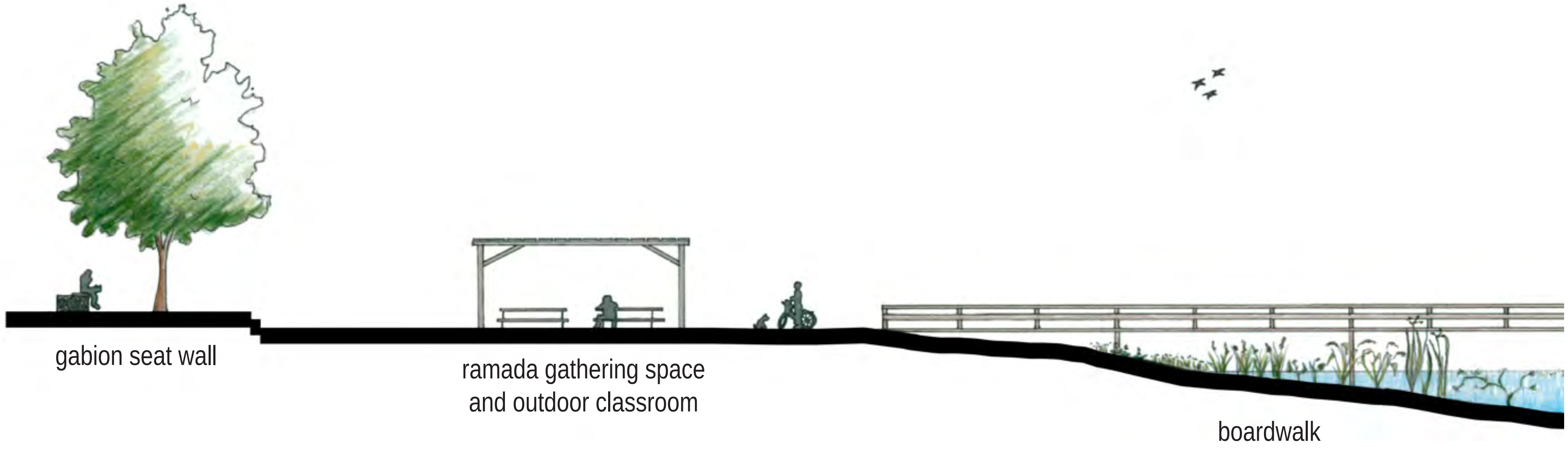


Figure 42
Section through the outdoor classroom and boardwalk.

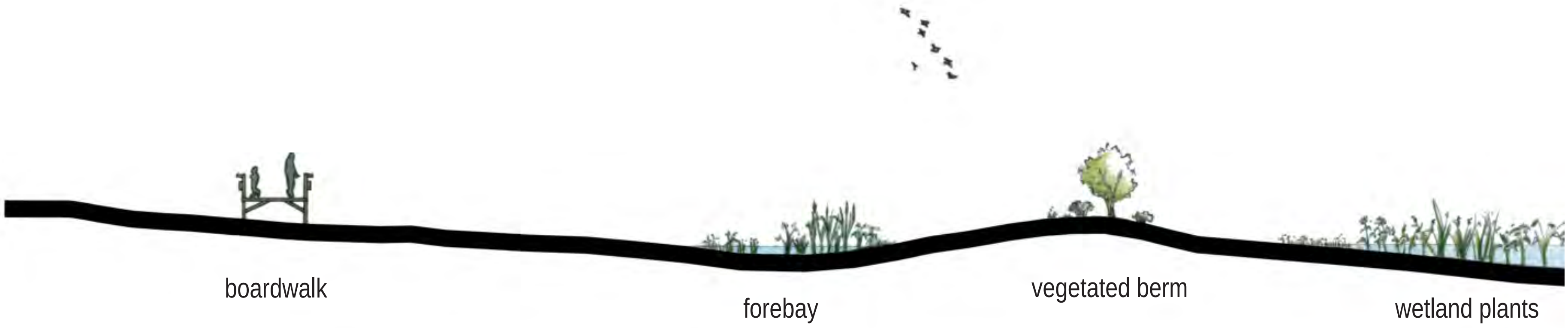
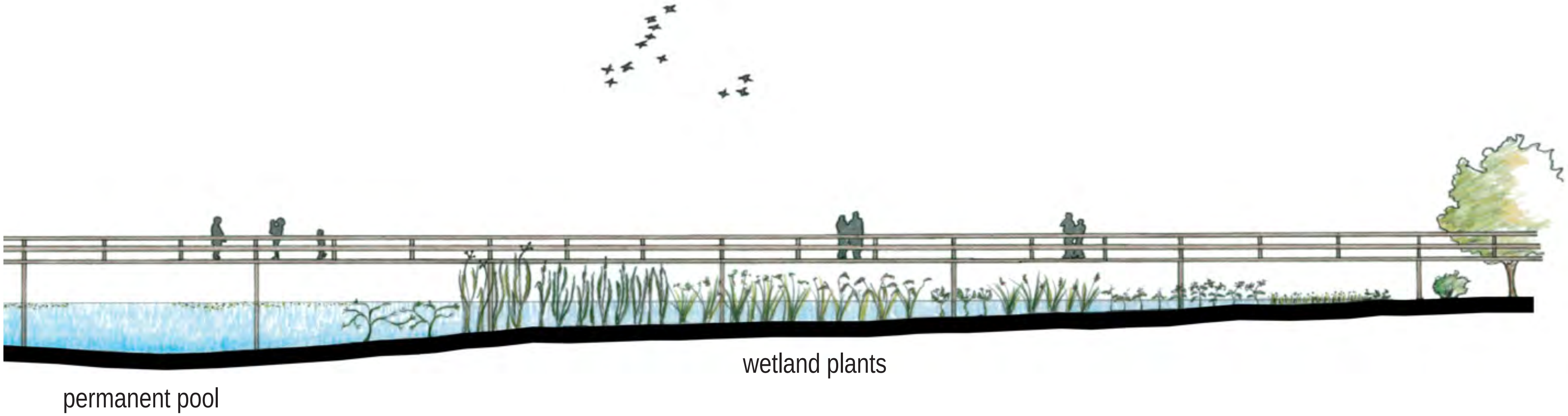
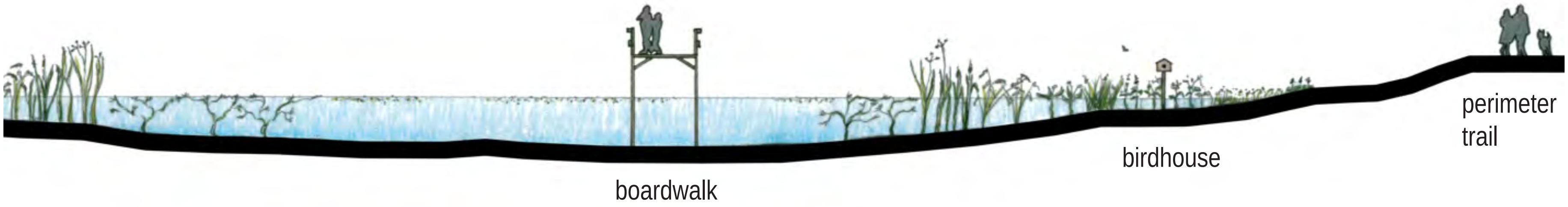


Figure 43
Section through the wetland features.


wetland plants
permanent pool


perimeter trail
birdhouse
boardwalk

CULTURAL AND EXPERIENTIAL CONSIDERATIONS

This second layer of considerations works with the functional considerations and adds an ordering to the site through design.

Connections to the School and Neighborhoods: The constructed wetland site is linked to the main school campus and to the future surrounding neighborhoods through two main diagonal axes which cross at the ramada and main gathering area. These axes consist of a walkway from the school campus through the student parking area and a boardwalk crossing the wetland system. These strong crossing pathways direct students and visitors into the constructed wetland site and encourage use of the site for daily activities. Additionally, the design includes small rainwater plantings at the school downspouts which are intended to serve as a visual link to the wetland system and a reminder of where stormwater is being directed (Figure 44).

Cultural History: Design components and layout were also inspired by the site's unique cultural history. As described above, the area was the site of an Anasazi Pueblo IV (A.D. 1300-1600) Fieldhouse. Archeological excavations revealed traces of a ramada structure and a dry-laid basalt wind break wall. The site design incorporates this history with low basalt gabion seat walls (Figure 45) and a ramada structure for gathering, instruction, and picnicking. The use of basalt cobble-filled gabions also takes advantage of the surplus basalt rubble material already found on site.

Facilitating Use and Understanding: The site design is intended to draw people in, provide places for gathering and instruction, and invite exploration (Figures 42 and 43). Specific points of interaction with the system include the mini-boardwalk over the stormwater inlet point, the main boardwalk across the entire wetland system, stairs leading down from the boardwalk into the overflow areas, the perimeter walking path (Figure 46), and the gradually-sloping shallow area of the main pool adjacent to the ramada gathering space and outdoor classroom. These design components allow visitors to experience the constructed wetland system from a variety of vantage points and scales; they can touch it, observe it from above, and enter into it when high levels of stormwater are not present.

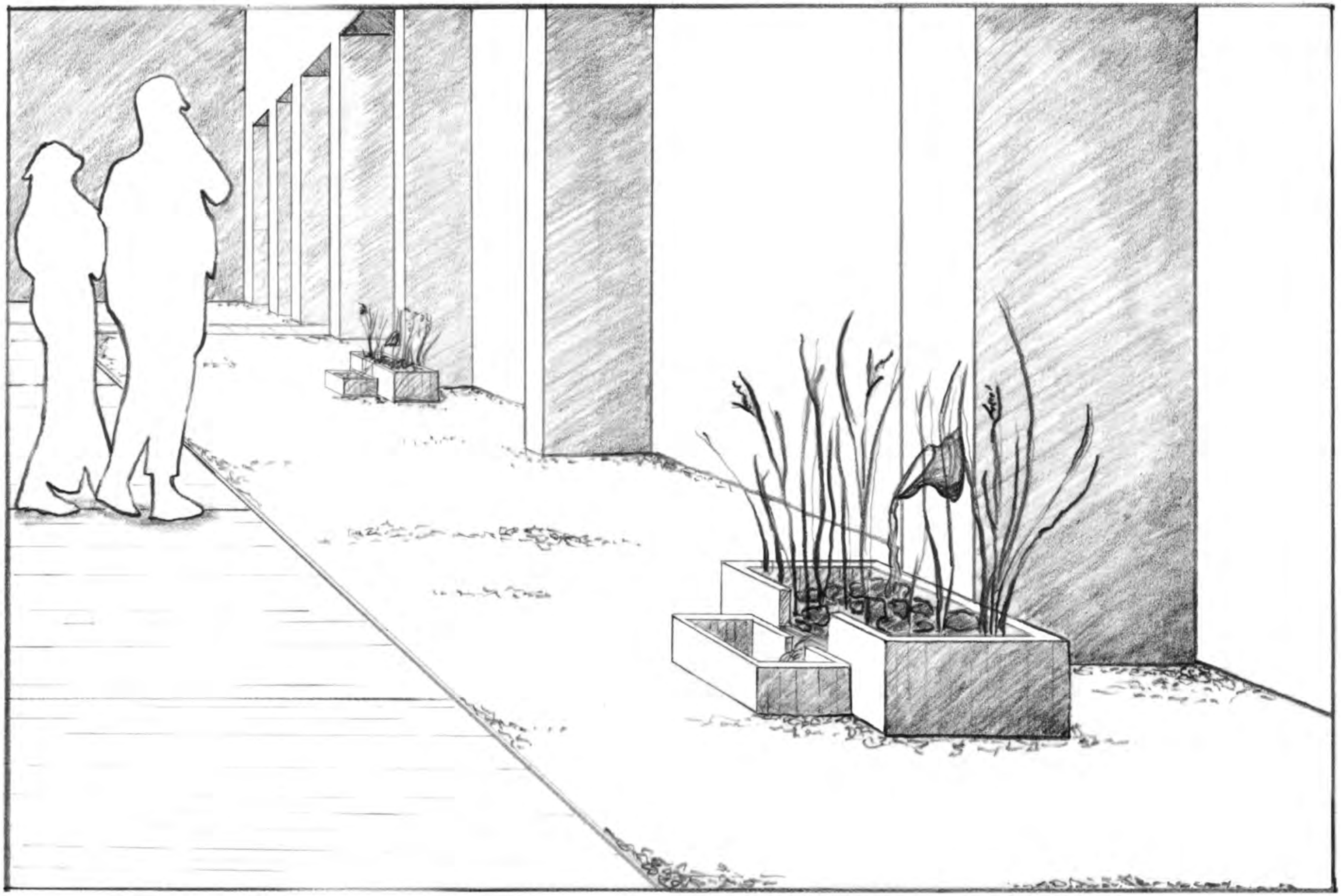


Figure 44
Rainwater downspouts at the high school building.

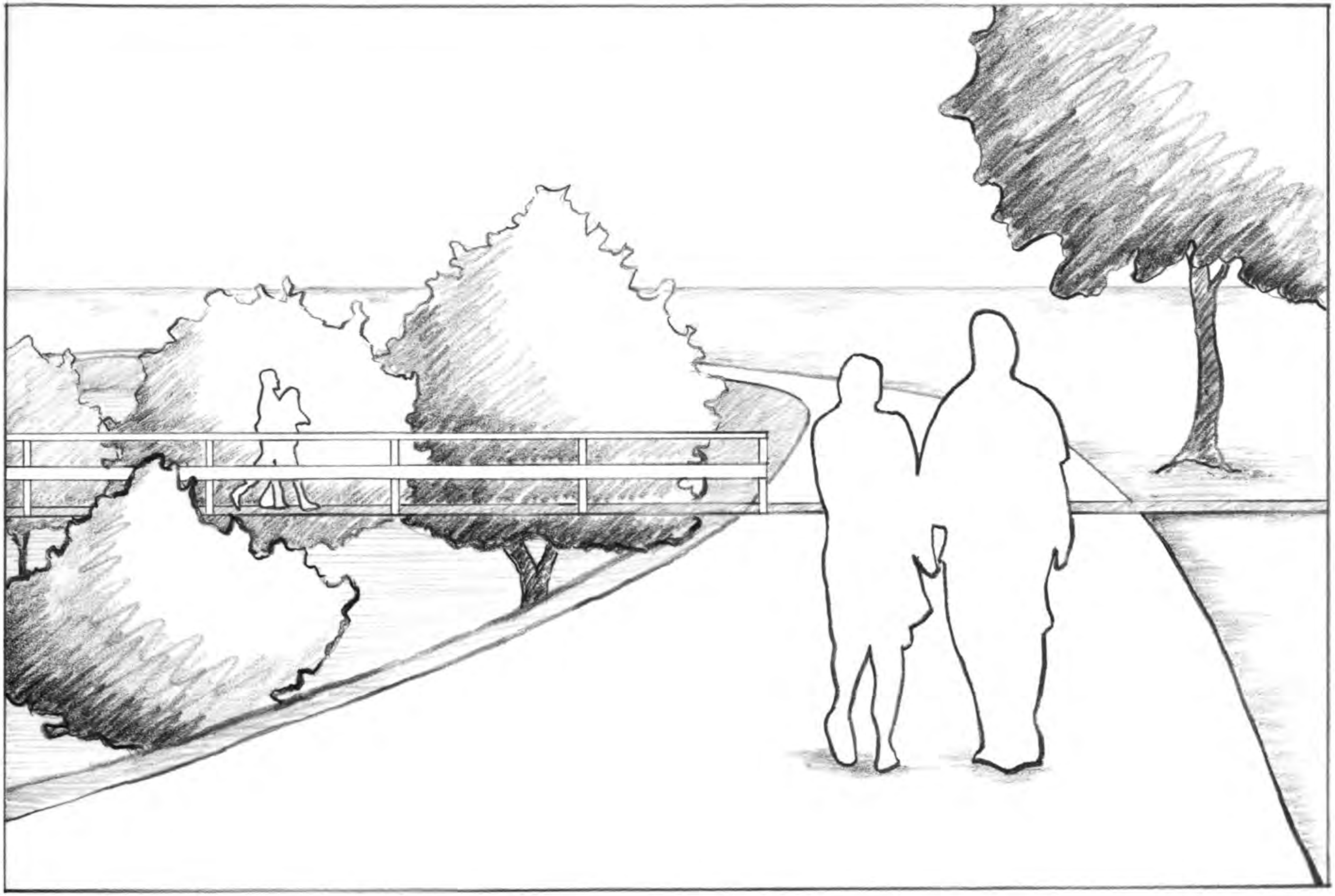


Figure 45
Perimeter walking path and boardwalk.

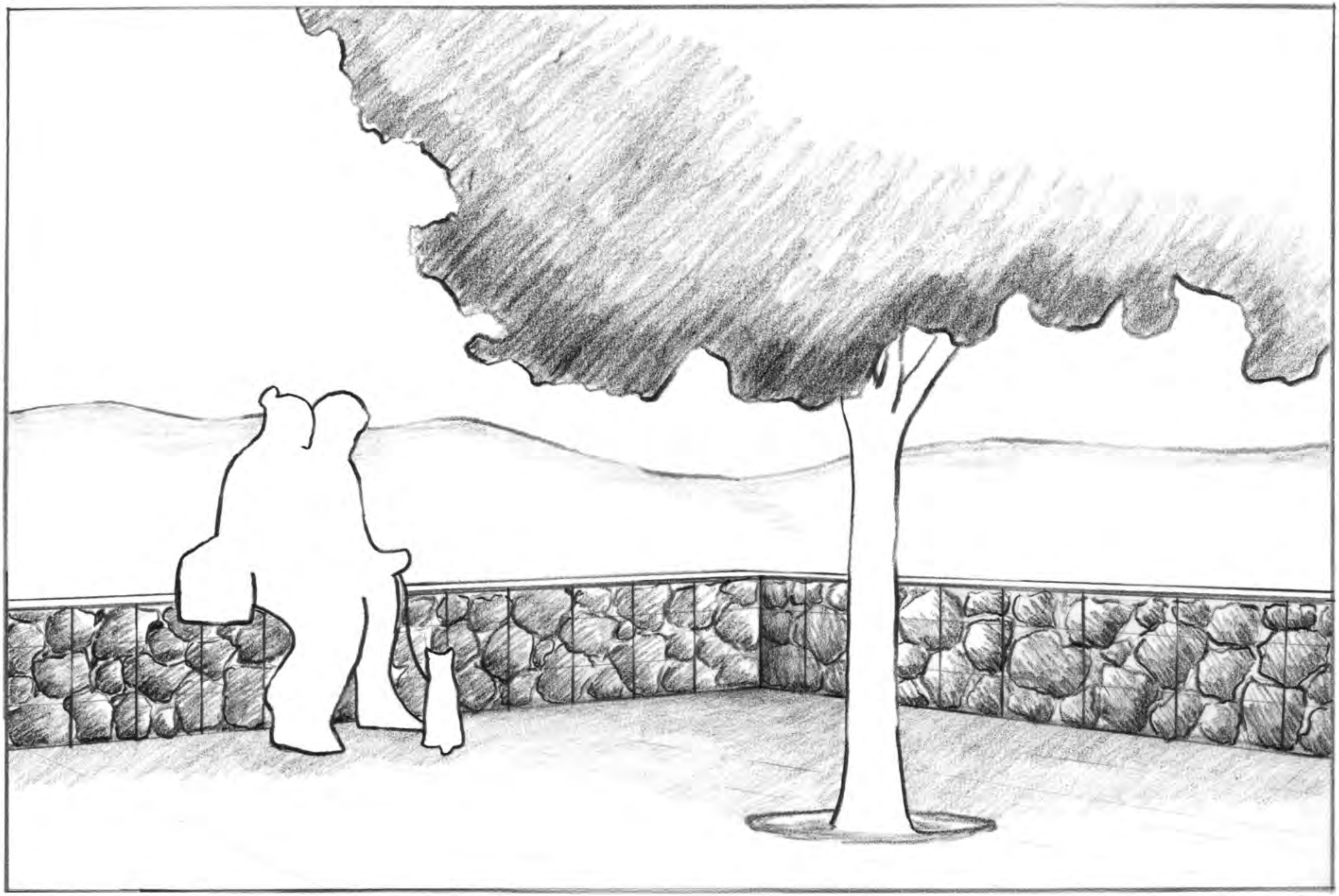


Figure 46
Gathering area with basalt gabion seatwall.

Reflections and Conclusions

This project developed out of an attempt to answer the question “How can Albuquerque’s stormwater detention areas be made more ecologically and aesthetically functional?” The creation of combined stormwater/graywater wetlands explored and presented here is one possible solution. In contrast with the lifeless, unattractive, single-function stormwater management solutions that we currently employ, these wetlands represent new opportunities for water quality improvement, education, reconnection with infrastructure services, habitat creation, collaboration between professionals and the community, artistic interpretation, and increased stewardship for our urban landscapes. Combined stormwater/graywater wetlands illustrate that by reusing ‘waste’ resources we have the opportunity to add value to our urban landscapes.

The process of developing this project also raised many questions. In particular, the design exploration brought to life the challenges involved in successfully implementing constructed stormwater/graywater wetlands. A successful built project will involve the extensive and committed participation of many parties, from site owners and designers to site managers and users. This prompts the question: Are there simpler ways to achieve some of the goals outlined in this exploration? For example, are there more efficient methods than constructed wetlands to encourage on-site infiltration of stormwater in the Albuquerque area? Would graywater be better used for irrigation of turf playing fields or other site landscaping? What are the trade-offs involved in selecting one approach over another? This exploration also brought up questions with applications that reach beyond stormwater management and are relevant to all landscape design projects. How can we best utilize existing resources with minimal inputs of new resources to add value to our urban landscapes? How can we impact people’s daily lives in meaningful ways through landscape design?

One conclusion seems clear: we need to develop the answers to these questions on a case by case basis and to question standardized approaches to landscape design projects. In order to determine sustainable and appropriate responses to such challenges as on-site stormwater management, experimentation and direct response to individual site conditions will be key. Landscape architects will have a unique role in this process in their ability to work with broad environmental circumstances and unique site conditions. If we hope to improve the sustainability of our urban landscapes, we must work with allied professionals and the community to integrate our infrastructure systems within the landscape in meaningful ways that facilitate public understanding and respect natural processes.

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Figure 2. Runoff increase diagram by author adapted from FISRWG 1998.

Figure 5. Hydrologic cycle diagram by author adapted from NMBGMR 2007.

Figure 6. Santa Fe Group aquifer diagram by author adapted from Kuss 2005.

Figure 7. San Antonio Oxbow Wetlands photograph from http://www.flickr.com/search/?q=san+antonio+oxbow+albuquerque.

Figure 10. Ecosystem process as model diagram by author adapted from McHarg 1967.

Figure 11. Red-winged blackbird photograph from http://www.flickr.com/photos/clovermountain/505249913/.

Figure 33. Archeological rendering from Kurota 2006.

Appendix B: Plant List

Acer negundo photo from The Brenton Arboretum at
http://www.thebrentonarboretum.org/Tree_Botanical_Names/images/Acer%20negundo_img_0.jpg.

Alnus tenuifoila photo from The University of Connecticut at
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Chilopsis linearis photo from Texas A&M AgriLife Extension at http://williamson-tx.tamu.edu/AG/HomeHort/FeaturedPlants/desertwillowtree.jpg.

Cornus stolonifera photo from Washington State University at http://www.wsu.edu:8080/~wsherb/images/Cornaceae/cornusstolonifera.jpg.

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Eleocharis rostellata photo from the Wisconsin Botanical Information System at http://www.botany.wisc.edu/wisflora/pictures/xl_photos/ELEROS_EJJ5_XL.jpg.

Forestiera neomexicana photo from Plants of the Southwest at http://www.plantsofthesouthwest.com/Plants/1265.ENLARGEMENT.jpg.

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Gleditsia triacanthos photo from the University of Arizona Pima County Cooperative Extension at http://ag.arizona.edu/pima/gardening/aridplants/images/Gleditsia_triacanthos.jpg.

Glyceria striata photo from the Ladybird Johnson Wildflower Center at http://www.wildflower.org/gallery/result.php?id_image=22641.

Helianthus nuttallii photo from Boulder County Nature Association at
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Liatris punctata photo from Missouri Plants at
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Mimulus guttatus photo from The University of British Columbia Botanical Garden at
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Muhlenbergia asperifolia photo from The University of Wisconsin Madison Department of Botany at
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Potamogeton pectinatus photo from Skye Flora at
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Prunus americana photo from The DeLange Homepage at
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Sapindus saponaria var. *drummondii* photo from Oklahoma Biological Survey at http://www.biosurvey.ou.edu/shrub/sasad.jpg.
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Scirpus acutus photo from The University of Wisconsin Madison Department of Botany at http://botit.botany.wisc.edu/images/veg/Wetlands_I_Plants/Bulrush_Scirpus_acutus_VK.low.jpg.

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Veronica anagallis aquaticus photo from Wildflowers of Tucson, Arizona at http://www.fireflyforest.com/flowers/violets/violet39.html.

Appendix A: Water Budget Calculations

Determining Monthly Direct Precipitation Estimates:

Average Albuquerque Monthly Precipitation Data:
January: 0.37 inches = 0.031 feet
February: 0.40 inches = 0.033 feet
March: 0.52 inches = 0.043 feet
April: 0.54 inches = 0.045 feet
May: 0.63 inches = 0.053 feet
June: 0.61 inches = 0.051 feet
July: 1.38 inches = 0.115 feet
August: 1.46 inches = 0.122 feet
September: 0.96 inches = 0.08 feet
October: 0.88 inches = 0.073 feet
November: 0.46 inches = 0.038 feet
December: 0.46 inches = 0.038 feet (WRCC 2008)

Area of Proposed Constructed Wetland System: 36,000 square feet

catchment area (sq. ft.) x monthly rainfall (ft.) x 7.48 gallons/cubic foot = direct precipitation (gallons)

Example:
August Direct Precipitation:
36,000 sq. ft. x 0.122 ft. x 7.48 gallons/cubic foot = 32,852 gallons

Determining Monthly Runoff Volume Estimates:

Site runoff estimates were calculated based on the following equation and runoff coefficients from Lancaster 2006. See also Average Monthly Precipitation Data above.

catchment area (sq. ft.) x monthly rainfall (ft.) x 7.48 gallons/cubic foot x runoff coefficient = runoff (gallons)

Volcano Vista High School Campus Catchment Areas:
Roof Area: 203,633 square feet
Paved Area: 802,078 square feet
Turf Area: 368,562 square feet
Soil with some vegetation or gravel area: 686,995 square feet

Runoff coefficients:
Roof = 0.90
Paving = 0.95
Turf = 0.15
Soil with some vegetation or gravel = 0.50

Example:
August Runoff Estimate:
Roof: 203,633 sq. ft. x 0.12 ft. x 7.48 gallons/cubic foot x 0.90 = 164,503 gallons
Paving: 802,078 sq. ft. x 0.12 ft. x 7.48 gallons/cubic foot x 0.95 = 683,948 gallons
Turf: 368,362 sq. ft. x 0.12 ft. x 7.48 gallons/cubic foot x 0.15 = 49,596 gallons
Soil with some vegetation or gravel: 686,995 sq. ft. x 0.12 ft. x 7.48 gallons/cubic foot x 0.50 = 308,323 gallons

Total August runoff = 1,206,370 gallons

Determining Monthly Graywater Volume Estimates:

Average Number of Site Users (Students and Teachers): 2,500 during the school year
1,500 during summer school

Average Lavatory (Restroom Sink) Uses per Day per Site User: 3 during the school year
2 during summer school

Average Showers Taken per Day: 75 during the school year and during summer school
(Site User, Lavatory Use, and Shower Use averages per VVHS Principal)

Baseline US EPAct Flush/Flow Rates

Fixture Type	Duration (seconds)	Flowrate (GPM)
Lavatory	45	2.5
Shower	300	2.5

(USGBC LEED-NC 2.2 Reference Guide)

Average School Days per Month
January: 17
February: 21
March: 18
April: 22
May: 15
June: 22
July: 22
August: 10
September: 22
October: 22
November: 19
December: 15

Example for September (School Year Weekday):
Sinks: Number of Site Users = 2,500
Average restroom sink uses per day = 3/person
Average of 45 seconds of water use at 2.5 gpm = 1.875 gallons per use

2,500 x 3 x 1.875 = 14,062.5 gallons/day

Showers: Average showers taken per day = 75
Average gallons per 5 minute shower = 5

75 x 5 = 375 gallons/day

Total: 14,0625.5 + 375 = 14,437.5 gallons per day

Multiply 14,437.5 by number of school days per month for average monthly volume.
14,437.5 x 22 = 317,625 gallons of graywater for September

Example for June (Summer School Weekdays):
Sinks: Number of Site Users = 1,500
Average restroom sink uses per day = 2/person
Average of 45 seconds of water use at 2.5 gpm = 1.875 gallons per use

1,500 x 2 x 1.875 = 5,625 gallons/day

Showers: Average showers taken per day = 75
Average gallons per 5 minute shower = 5

75 x 5 = 375 gallons/day

Total: 5,625 + 375 = 6,000 gallons per day

Multiply 6,000 by number of summer school days per month for average monthly volume.
6,000 x 22 = 132,000 gallons of graywater for June

Determining Monthly Evaporation Estimates:

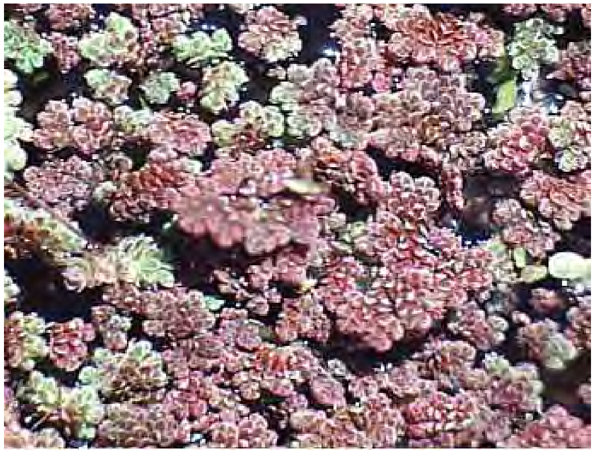
area of wetland (sq. ft.) x monthly pan evaporation (ft.) x 7.48 gallons/cubic foot x .7 (pan coefficient) = evaporation (gallons)

Example:
August evaporation:
36,000 sq. ft. x 0.9 feet x 7.48 gallons/cubic foot x .7 = 169,646 gallons

Average Albuquerque Monthly Pan Evaporation Data:
January: 2.5 inches = 0.208 feet
February: 3.3 inches = 0.275 feet
March: 5.7 inches = 0.475 feet
April: 8.7 inches = 0.725 feet
May: 11.8 inches = 0.983 feet
June: 13.5 inches = 1.125 feet
July: 12.5 inches = 1.042 feet
August: 10.8 inches = 0.9 feet
September: 8.5 inches = 0.708 feet
October: 6.1 inches = 0.508 feet
November: 3.4 inches = 0.283 feet
December: 2.4 inches = 0.2 feet
(OCS 2008)

Appendix B: Plant List

ZONE 1: OPEN WATER



Azolla mexicana Mexican Mosquitofern
Permanent flooding, free floating

Lemna minor Lesser Duckweed
Permanent flooding, free floating

ZONE 2: TO 5 FEET DEEP

Potamogeton pectinatus Sago Pondweed
Permanent flooding to 20 - 60”

ZONE 3: TO 3 FEET DEEP

Scirpus acutus Hard-stem Bulrush
Moist soil to 36” flooding, 5 - 9’ tall

Scirpus californicus California Bulrush
Moist soil to 36” flooding, 6- 12’ tall

Typha angustifolia Narrowleaf Cattail
Moist soil to 36” flooding, 6’ tall

ZONE 4A: TO 1 1/2 FEET DEEP

Glyceria striata Fowl Manna Grass
Seasonally flooded to 20" flooding, 24 - 36" tall

Eleocharis rostellata Beaked spikerush
Permanent flooding 6" - 20", 15 - 36" tall

ZONE 4B: TO 1 FOOT DEEP

Berula erecta Cutleaf Water Parsnip
Moist soil to 12" flooding, 12 - 24" tall

Sagittaria cuneata Northern Arrowhead
Saturated to 12" flooding, 6 - 18" tall

Scirpus americanus Olney's Bulrush
Moist soil to 12" flooding, 24 - 48" tall

ZONE 5A: TO 6 INCHES DEEP

Beckmannia syzigachne American Sloughgrass
Seasonally flooded to 6" flooding, 24 - 36" tall

Carex emoryi Emory’s Sedge
Seasonally flooded to 6” flooding, 15 - 40” tall

Carex lanuginosa Wooly Sedge
Seasonally flooded to 6” flooding, 11 - 40” tall

Carex praegracilis Clustered Field Sedge
Seasonally flooded to 6” flooding, 8 - 30” tall

Juncus torreyi Torrey’s Rush
Seasonally flooded to 6” flooding, 8 - 32” tall

ZONE 5B: TO 4 INCHES DEEP

Veronica anagallis aquaticus Water Speedwell
Moist soil to 4” flooding, 8 - 36” tall

ZONE 5C: TO 3 INCHES DEEP

Mimulus guttatus Common Monkey-flower
Moist soil to 3” flooding, 12 - 30” tall

ZONE 5D: TO 2 INCHES DEEP


Scirpus microcarpus Small-fruit Bulrush
Moist soil to 3” flooding, 2 - 5’ tall


Eleocharis parishii Parish’s Spikerush
Moist soil to 2” flooding, 8 - 12” tall


Ranunculus cymbalaria Marsh Buttercup
Moist soil to 2” flooding, 2 -12” tall


Veronica americana American Speedwell
Moist soil to 2” flooding, 12 - 36” tall


Phyla nodiflora Turkey Tangle Frogfruit
Moist soil to shallow water

ZONE 6: SEASONAL FLOODING


Amorpha fruticosa False Indigo Bush
Seasonal flooding, up to 12’ tall

Anemopsis californica Yerba Mansa
Seasonal flooding, 8 - 12” tall

Asclepias incarnata Swamp Milkweed
Seasonal flooding, 36 - 60” tall

Cornus stolonifera Red Osier Dogwood
Seasonal flooding, 6 - 8’ tall

Helianthus nuttallii Marsh Sunflower
Seasonal flooding, 60 - 70” tall

Muhlenbergia asperifolia Alkali Muhly
Seasonal flooding, 12 - 30” tall

Ribes aureum Golden Currant
Moist to occasionally moist soil, 4 -10’ tall

Sidalcea neomexicana New Mexico Checker-mallow
Moist to occasionally dry soil, 24 - 48” tall

Verbena hastata Riparian Vervain
Moist to occasionally moist soil, 12 - 30” tall

SEASONAL FLOODING - TREES

Acer negundo Box Elder

Alnus tenuifolia Thinleaf Alder

Populus angustifolia Narrow-leaf Cottonwood

ZONE 7: UPLAND

Bouteloua curtipendula Sideoats Grama


Desmanthus illinoensis Bundleflower


Liatris punctata Dotted Gayfeather


Monarda punctata Spotted Beebalm


Schizachyrium scoparium Little Bluestem


Sorghastrum nutans Indiangrass

UPLAND - TREES


Cercis canadensis var. texana Texas Redbud

Chilopsis linearis Desert Willow

Forestiera neomexicana New Mexico Olive

Fraxinus velutina Velvet Ash

Gleditsia triacanthos Honey Locust

Prunus americana American Plum

Prunus virginiana Choke Cherry

Salix bebbiana Bebb Willow

Sapindus saponaria var. drummondiii Western Soapberry