Water System Design

Prepared for: SLO Botanical Garden

Site: SLO Botanical Garden

3450 Dairy Creek Road

San Luis Obispo, CA 93405

Site Visit Date(s): 9/26/22

Prepared by:

7th Generation Design

Casey Pfeifer | 805-680-2976
Wes Cooke | 805-234-6124

www.7thgenerationdesign.com

Table of Contents

Executive Summary

7th Generation Design was invited by the San Luis Obispo Botanical Garden (SLOBG) to design a water system for the 150 acre property they are leasing at 3450 Dairy Creek Road in San Luis Obispo, CA. The SLOBG team of directors have communicated their desire for this water system to rehydrate the soils of the property's broader landscapes in order to provide passive hydration to current and future plantings for longer into the dry season, be able to actively irrigate new plantings with collected rainwater, and reduce erosion.

The existing site features that are relevant to the design of the water system include:

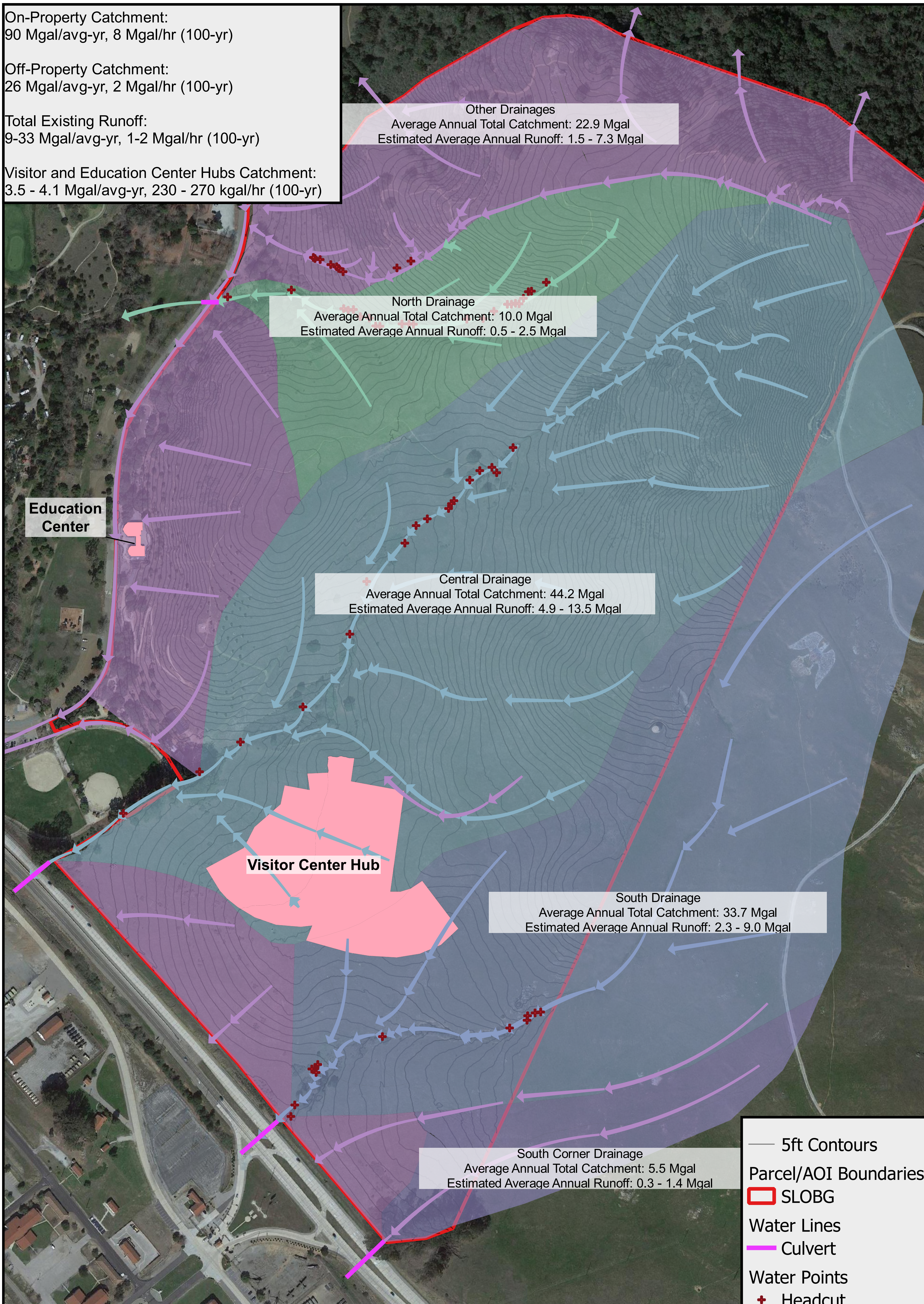
- Average rainfall of 22 inches per year, with approximately 90 million gallons (272 acre-feet) of precipitation falling within property bounds per average rain year and another 26 million gallons (80.4 acre-feet) falling on approximately 44 acres of adjacent property to the east that ultimately drains into the SLO Botanical Garden property.
- Three distinct ridges descending to the southwest, with hillsides containing predominantly sandy-clay loam soils with high susceptibility to erosion, moderate to high permeability, high run-off potential, and low water storage profile (20-40" to paralithic bedrock). These hillsides are largely dominated by annual grasses and forbs and upland vegetation encroaching right to the edge of the riparian corridors. Due in part to past clear-cutting and grazing practices and long periods of over-rest, a large amount of dead and oxidizing plant material is left standing each year, which ultimately inhibits the growth of young plants (especially desirable perennial native grasses) and decreases the soil's water infiltration and holding capacity.
- Three distinct drainages descending to the southwest that have limited riparian vegetation and are deeply incised and actively eroding, with 64 headcuts counted at the time of the site visit. This erosion is creating an increasingly dehydrated landscape year over year.
- An estimated 8 - 27 million gallons (25 - 83 acre-feet) of the average annual precipitation that falls within property bounds is lost to runoff, and an additional 1 - 6 million gallons (4 -20 acre-feet) of the average annual precipitation that lands on the adjacent contributing watershed to the east runs onto and ultimately exits the SLOBG property. The average runoff levels are likely increasing year-after-year, which is exacerbating dehydration of the hillsides and erosion in the drainages.
    - The roofs and hardscapes of the Visitor Center and Education Center Hubs as illustrated in the SLO Botanical Garden's 2022 Master Plan make up approximately 4 million gallons (12 acre-feet) of the total estimated runoff.

The water system recommended in this report is designed to halt the progression of further erosion on the property and begin rehydrating the landscape. Key features include:

- **A passive water harvesting system designed to slow surface runoff that develops during rain events, spread it out towards the ridges, and ultimately infiltrate it into**

the soil in order to provide hydration to downslope vegetation and minimize the amount of runoff entering the eroding drainages. The proposed network of linked passive water harvesting elements including infiltration basins, swales, and boomerangs located at strategic points throughout the landscape will infiltrate an estimated 7 - 21 million gallons (21-64 acre feet) of surface runoff that is currently being lost from the property.

- **Water-harvesting micro-earthworks in the broad acre planting protocols to increase infiltration and maintain dispersed sheet-flow during precipitation events.** Small earthworks installed by hand at the time of planting around each specimen tree or plant will serve to increase moisture availability and retain topsoil and mulch to help plants establish well and maintain themselves for a long, healthy life. Applied across the broadacre, these earthworks will increase soil moisture and organic matter and ultimately create a landscape that "pops" in a big way when bloom season arrives.
- **Aggradation structures in the drainages to accumulate sediment and enhance moisture retention.** These will 1) halt existing headcut progression in its tracks and save any additional soil from being lost, and 2) provide an opportunity to revegetate drainage bottoms with desirable species by accumulating sediment, banking moisture and intentionally re-introducing California native riparian species that have been lost. See Section 2 - Moving Things - Stabilize Headcuts Within Incised Drainages
- **An active water harvesting system designed to maximize collection, storage and infiltration of the run-off that develops on the roofs and hardscapes of the Visitor Center and Education Center Hubs.** This proposed network of cisterns and tanks with overflow basins and swales will allow for the storage of up to 4 million gallons (12 acre-feet) per average rain year in tanks and in the soil located high in the landscape, which can be used to irrigate downslope plantings via gravity.



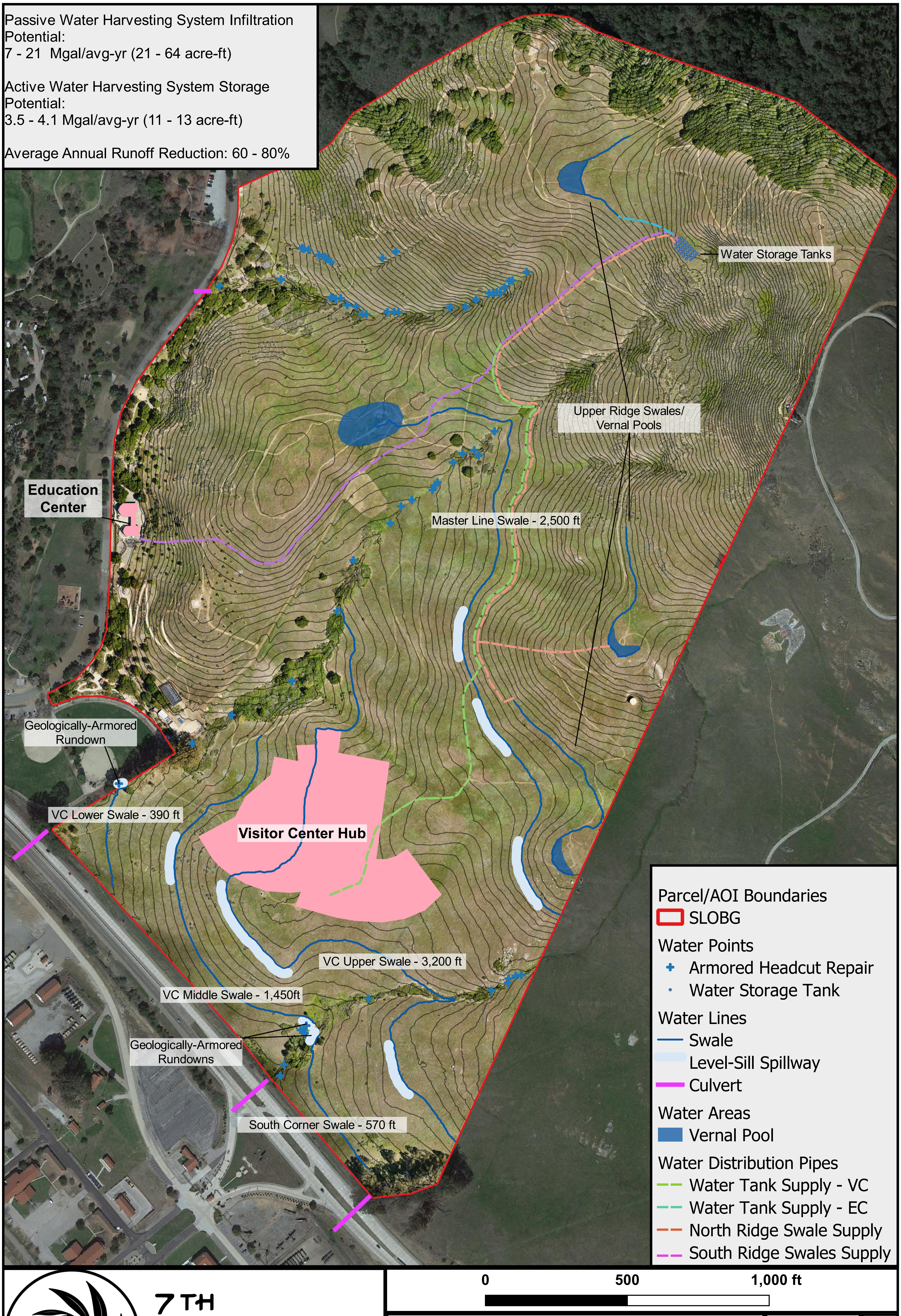
7TH GENERATION DESIGN

0 500 1,000 ft

San Luis Obispo Botanical Garden

Existing Water Features with Catchment Areas and Totals, Water Flows and Estimated Runoff

11/17/2022

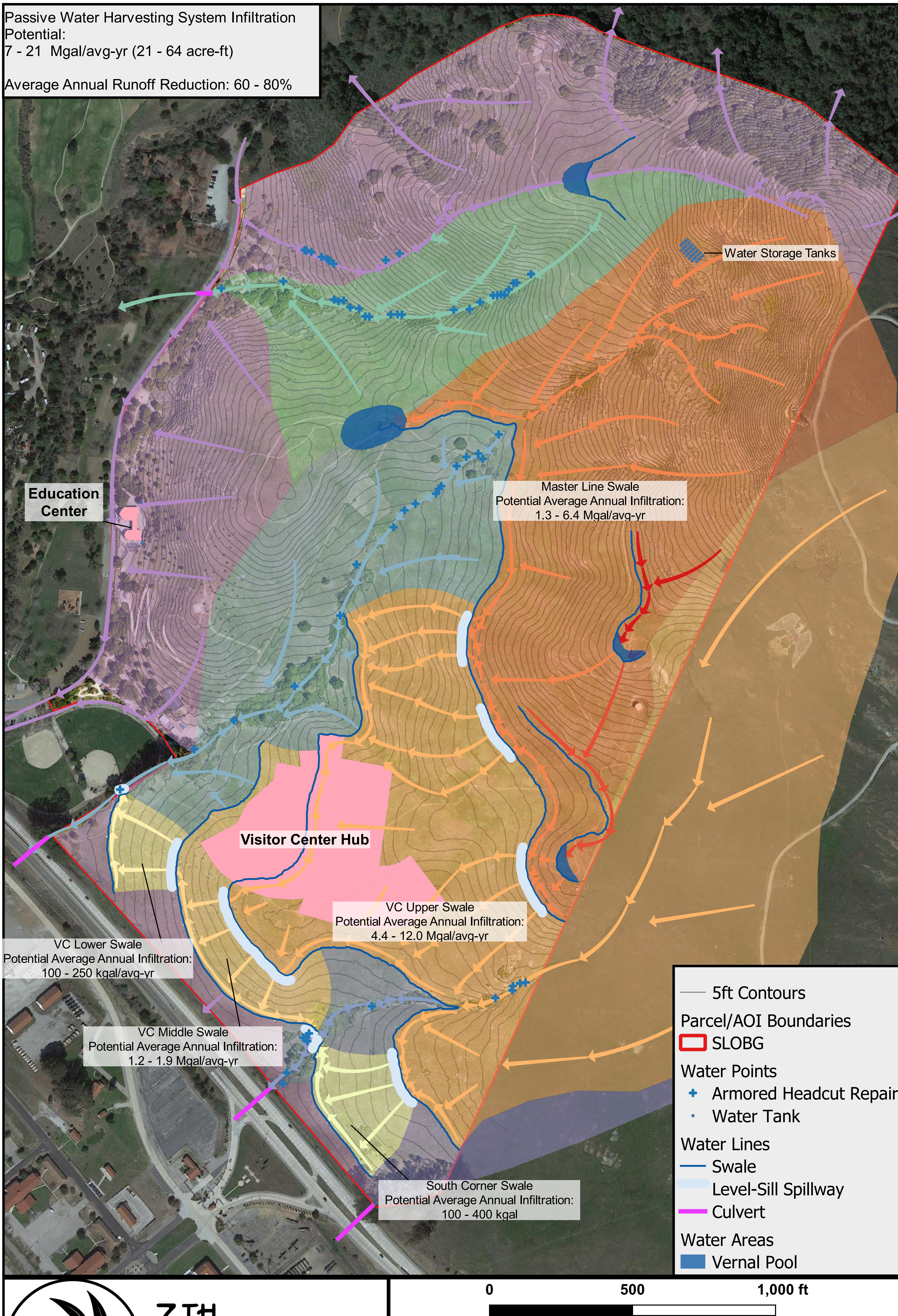


7TH GENERATION DESIGN

San Luis Obispo Botanical Garden

Proposed Water System Features

11/18/2022



7TH GENERATION DESIGN

San Luis Obispo Botanical Garden

Proposed Water Features with Catchment Areas, Water Flows and Infiltration Capacities

11/18/2022

Proposed Water System Features

The proposed water system for the SLOBG has the following features:

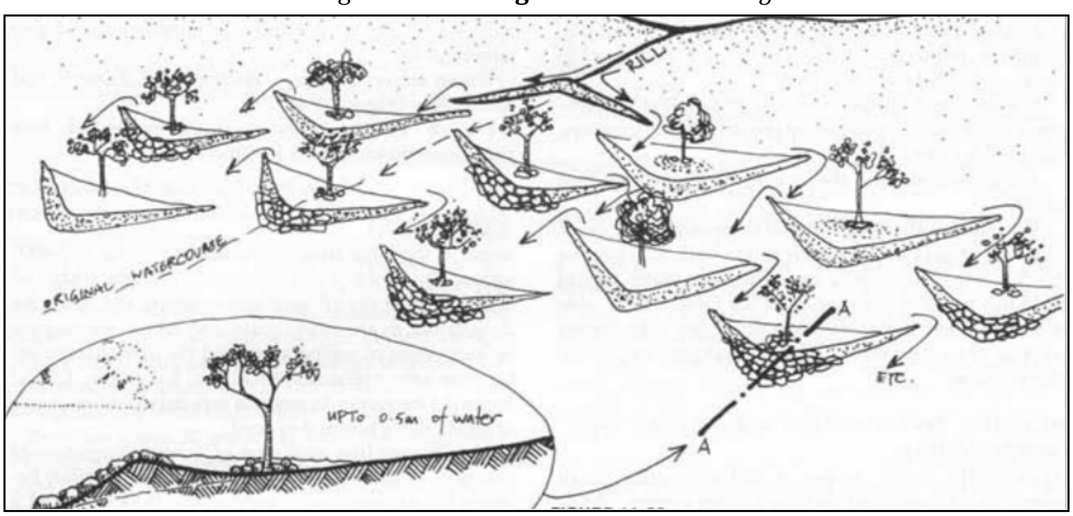
- "Boomerang" berm micro-earthworks on a per-planting basis across the broad acre to increase soil hydration at individual plant and tree root zones and reduce erosive runoff.
- Passive water-harvesting and drainage system of swales, infiltration basins, spillways, and armored rundowns to improve soil hydration across the broader landscape and reduce erosive storm run-off.
- Armored headcut repair structures in the drainages to halt further progression of erosion.
- Water storage tanks at the hidden pad at the top of the property to provide gravity-pressurized water to the entire property.
- Infiltration basins adjacent to the kiosks for roof catchment.
- Water batteries for irrigation-free establishment of perennial plants and trees across the broad-acre landscape where running irrigation lines or hauling water manually is not feasible or cost-effective.

"Boomerang Berms" for Broadacre Planting

"Boomerang berms", placed on the downslope side of trees as illustrated in Figure 1, are recommended for aiding tree establishment throughout the SLO Botanical Garden property. These earthen structures can be created using hand tools at the time of planting. Boomerangs will aid new trees by collecting sheetflow from a relatively broad area and concentrating that water in the root zone of the young tree, while also serving as a basin to retain topsoil and mulch. All of this will create a more humid feeder root zone for the developing tree, which will also help to establish and maintain any nurse plantings accompanying the keystone tree or plant.

Figure 1

Boomerang berms, placed on the downslope side of trees, are designed to capture nearby sheet flow and direct it into basins surrounding the trees. **Image:** *Permaculture Designer's Manual* - Bill Mollison.



The adoption of boomerang berms across the broader landscape in itself has the potential to eventually capture and infiltrate into the soil a significant amount of the runoff that is currently developing, which will also result in less water entering and eroding the drainages. However, as the planting of the broader landscape at SLOBG is slated to occur over several years, a site-wide passive water harvesting and drainage system described below not only immediately begin capturing surface runoff and mitigating erosion issues but also supplement the water infiltration providing by future boomerang plantings in the long run.

Site-Wide Passive Water Harvesting and Drainage System

A system of linked swales, infiltration basins, level-sill spillways, and armored rundowns will help to infiltrate run-off water higher in the landscape, before it enters the drainages and can cause further erosion, and improve growing conditions on the down-slope hillsides. The swales will also provide a place in which to direct run-off water away from areas that should remain dry (access roads and paths, structure and hardscape areas, etc). The entire system as illustrated in the design map is capable of infiltrating 7 - 21 million gallons (21 - 64 acre-feet) of water that would otherwise be lost to run-off during an average rain year of 22 inches. This is a reduction of 60-80% in the amount of runoff that is currently entering and eroding the drainages.

Table 1

Site-Wide Passive Water Harvesting and Drainage System Swale Information

Swale Name	Length (ft)	Estimated Average Annual Infiltration Potential
Master Line Swale	2,500	1.3 - 6.4 Mgal
VC Upper Swale	3,200	4.4 - 12.0 Mgal
VC Middle Swale	1,450	1.2 - 1.9 Mgal
South Corner Swale	570	100 - 400 kgal
VC Lower Swale	390	100 - 250 kgal

1 Mgal = 1,000,000 gallons; 1 kgal = 1,000 gallons

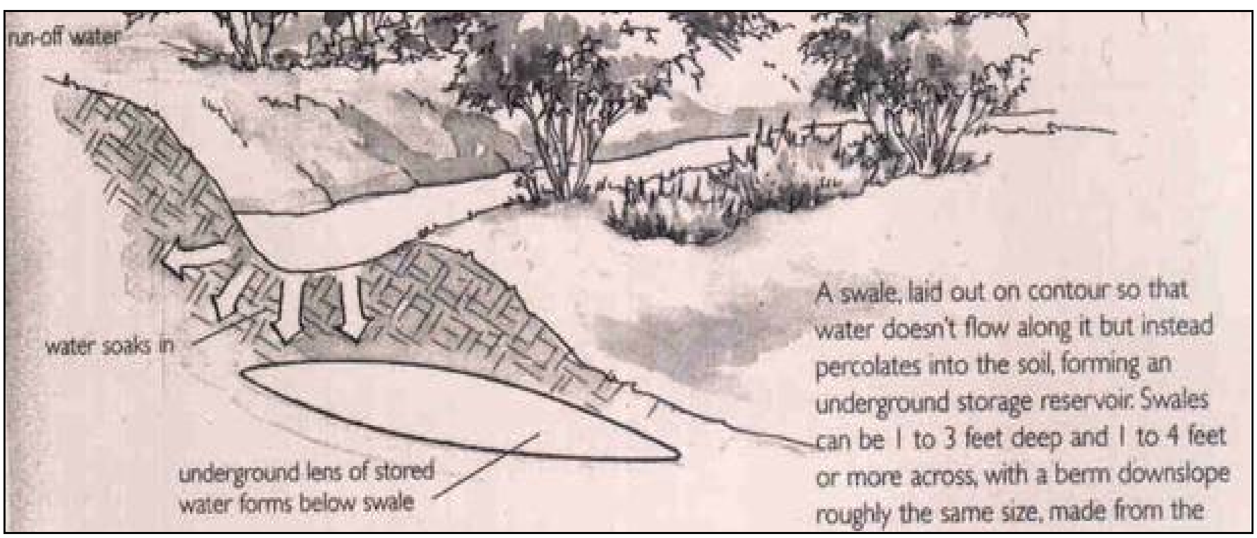
With an average swale width of 30” and depth of 12” and an observed average unsaturated soil infiltration rate of 0.82 gal/sq-ft/min, the proposed swale system can infiltrate an estimated 2.5 million gallons per hour, which can accommodate all of the runoff that develops upslope of the system during a 100-yr precipitation rate of 1.43 inches per hour. Once the soil becomes so saturated that its infiltration rate drops below the inbound flow rate, any excess runoff caught by the system will non-erosively drain over level-sill spillways located on the ridges to the swale below, until ultimately draining from the lowest swale (VC Lower Swale and South Corner Swale) into geologically-armored energy dissipating pools in the Central and South Drainages at the bottom of the property via armored spillways and rundowns.

Master Line "Equator" Swale

Swales are shallow ditches dug following a contour line (a level line that is always perpendicular to the slope it is crossing), with the soil excavated from the ditch mounded into a berm on the downhill side of the ditch. The bottom of the ditch and top of the berm are both level all the way across the landscape - which will create a long, thin, temporary "lake" when filled with water. The berm and the bottom of the ditch are left uncompacted to maximize the swale's infiltration capacity. Swales are typically 1-3 feet deep and 1-12 feet or more across, though can be much broader and shallower in deserts and areas with fragile soils prone to wind erosion.

Figure 2

Think of a swale as a long, narrow, winding lake with a porous bottom that is perfectly level end-to-end. Swales slow the flow of water, spread it out, and allow it to infiltrate into the soil. Image Credits; Top: Jesse Smith, Bottom: *Gaia's Garden* - by Toby Hemenway.



Swales capture sheet-flow and point-source run-off water in a level-bottom ditch, slowing it down and spreading it out across the landscape on contour. This allows water that may have otherwise run off the landscape a chance to infiltrate into the soil, creating a saturated "lens" of subsoil downslope, where it can be put to beneficial use growing trees and other perennial vegetation, recharging aquifers, charging downhill springlines and increasing soil moisture levels. Swales are ultimately tree establishment elements, with trees either being planted on or just below the berm along its entire length. Over a long enough time, swales will silt in or fill with fallen organic matter, their infiltration function replaced by the established tree roots and other vegetation.

A swale will have a measurable holding capacity as well as a generally known infiltration rate. There may be rain events during a swale's functional lifespan that exceed its capacity to infiltrate standing water as fast as new water is entering. When these events occur the swale will overflow, and thus planned overflow points called level-sill spillways - which allow for water to move safely without eroding the berm downslope soils, as described below - are critical in the design of swale systems.

The Master Line Swale represents the most advantageous line running across the SLOBG landscape to begin capturing, spreading and infiltrating sheetflow and channelized run-off.

There are two scenarios under consideration regarding the Master Line Swale:

1. The swale line could run continuously from where it intersects with the southeast property line to where the grade becomes prohibitively steep (~25%) south of the North Drainage, which is approximately 2,500 feet long as illustrated on the design map. This would offer the greatest hydration benefit to the landscape, and would enable the swale to feed into the proposed Vernal Pool located in the saddle of the Central Ridge (described below). This scenario requires that crossing the "blue line" Central Drainage with a swale at that location be legally allowable, which is unknown at this time and would require inviting CDFW representatives in to determine in fact.
2. The swale line could run continuously from where it intersects with the southeast property line to a point as close to the Central Drainage as any "blue line" regulations may allow. In this scenario it would not pick up any water already in the drainage as it moves down-watershed or any runoff between the saddle and the Central Drainage, decreasing the overall water harvesting capacity of the line and limiting the catchment available to serve the proposed Vernal Pool in the saddle of the Central Ridge (described below). This is the presumed scenario at the moment given the opaque legality of "blue line" drainages and the substantial administrative overhead required to perform work in them.

The Master Line Swale as described in the first scenario has the potential of infiltrating into the soil an estimated 1.3 - 6.4 million gallons per average rain year.

Small footbridges or culverts should be used at any locations where footpaths cross the Master Line Swale.

Since the Master Line Swale is a level line bisecting the SLOBG landscape, it is optimally suited to patterned around as a primary access route - for example, the proposed Maintenance Road leading from the existing vehicle access ramp that leads up the Central Ridge/proposed amphitheater location to the southeastern portion of the property could be constructed just uphill of the swale.

Any rainwater collected on the Maintenance Road could then be very easily drained into the Master Lines Swale. The road surface should utilize slight but frequent grade reversals or be installed with water bars or rolling dips to maintain road integrity and enhance water drainage. At any points where the Maintenance Road may cross the Master Line Swale, properly sized culverts should be installed over a well-compacted base to maintain swale functionality and provide 4-season vehicle access.

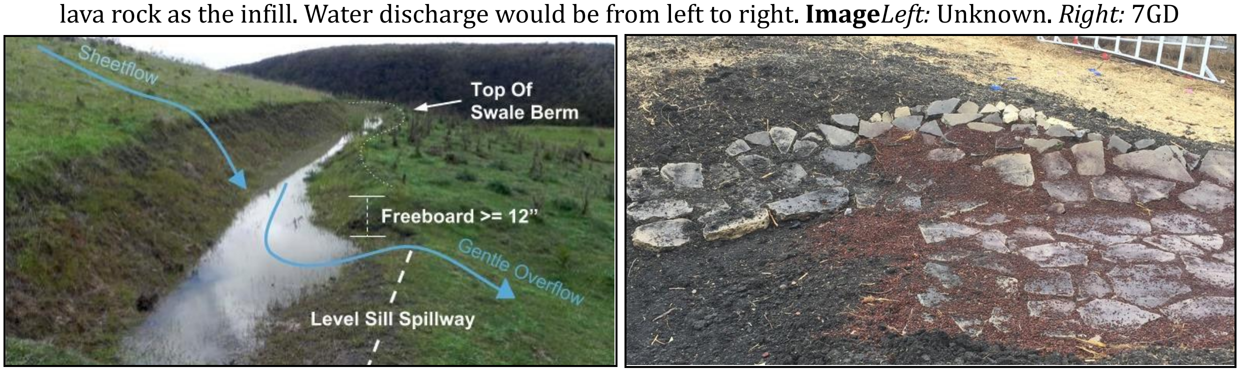
The Master Line Swale may nicely double as the "Equator" in the eastern half of the property. In this case, doubling the use of the Maintenance Road as a footpath in this configuration will allow patrons to experience multiple climate zones from an easily-traveled route while also getting a first hand look at some of the passive water harvesting systems employed by SLOBG to maximize the benefit of every raindrop received.

Master Line Swale Spillways

Critical in the design of swale systems are planned overflow points called level-sill spillways. A level-sill spillway is a broad, perfectly level area that serves as a predetermined discharge location for water flows greater than what the associated impoundment (swale, pond, lake, infiltration basin etc.) is capable of infiltrating or holding. The height of the level-sill spillway relative to the bottom of the impounding body determines the maximum water-holding capacity of that structure. The height difference between the spillway and the top of the impounding structure (dam wall, swale berm etc.) is known as the "freeboard", and should generally be a minimum of 36" for constructed ponds and 12" for swales. Depending on the climate, soil type and anticipated demands upon the structure, they should either be vegetated with perennial grasses or mat-forming vegetation with hairnet roots capable of binding soil that will "lay down" when heavy flows arrive, or geologically armored with knitted stone infilled with small gravel, or both. Level-sill spillways are sized to have the water discharge as slowly as possible, ideally flowing gently downhill until it is picked up by yet another linked swale.

Figure 3

Left: Level-sill spillways provide for the planned overflow of water without eroding the impounding structure (swale berm, dam wall etc). *Right:* Level-sill spillway constructed from knitted urbanite using fine-grained lava rock as the infill. Water discharge would be from left to right. **Image***Left:* Unknown. *Right:* 7GD



Any overflow that develops from the Master Line Swale will be discharged via three level-sill spillways located on the ridges, as illustrated on the design map, with any water that doesn't infiltrate into the soil downhill of the spillway being eventually captured by the Visitor Center (VC) Upper Swale.

Vernal Pool in Saddle of Central Ridge

Vernal pools are a unique and increasingly rare ecotope in California. There is an opportunity to create a vernal pool in the saddle of the Central Ridge due north of the proposed amphitheater location. This pool could be fed by the entire Master Line "Equator" Swale or smaller swales encircling the knoll of the Central Ridge and proceeding from the pool almost to the Central Drainage and from the pool to the West Drainage. A vernal pool would provide a unique and dynamic edge habitat for hosting additional species of plants, trees, animals, amphibians, insects and more, and will serve to educate people as to what these habitats can look like and why they are worth protecting and preserving (or even constructing). It will also serve as an infiltration basin perched above future showcase plantings zones.

Visitor Center (VC) Upper Swale

The Visitor Center (VC) Upper Swale, which is 3,200 feet long as illustrated on the design map, runs continuously from where it intersects with the southeast property line to wherever the grade becomes prohibitively steep (~20-25%) next to the Central Drainage or a point as close to the Central Drainage as any "blue line" regulations may allow. In addition to capturing any runoff that develops on the SLOBG property uphill of it (including approximately ⅔ of the Visitor Center Hub footprint as illustrated in the 2022 Master Plan) and below the Master Line Swale, it will also capture any overflow from the Master Line Swale via the Master Line Swale spillways (three as shown on the design map) and, if crossing the South Drainage as illustrated, runoff that develops on the portion of the neighboring property to the east that is in the South Drainage watershed. The VC Upper Swale has the potential of capturing and infiltrating into the soil an estimated 4.4 - 12.0 million gallons per average rain year.

VC Upper Swale North and South Spillways

Any overflow from the VC Upper Swale will be discharged via two spillways as illustrated on the design map: the VC Upper Swale North Spillway located on the ridge just southwest of the Visitor Center Hub and the VC Upper Swale South Spillway located on the ridge in the south corner of the property. Any water that doesn't infiltrate into the soil downhill of the VC Upper Swale North and South Spillways will be eventually captured by the Visitor Center (VC) Middle Swale and the South Corner Swale, respectively.

Visitor Center (VC) Middle Swale

The Visitor Center (VC) Middle Swale, which is 1,450 feet long as illustrated on the design map, runs continuously from a point just north of the South Drainage to wherever the grade becomes prohibitively steep (~20-25%) next to the Central Drainage or a point as close to the Central Drainage as any "blue line" regulations may allow. In addition to capturing any runoff that develops on the SLOBG property uphill of it (including approximately ⅓ of the Visitor Center Hub footprint as illustrated in the 2022 Master Plan) and below the VC Upper Swale, it will also capture any overflow from the VC Upper Swale via the VC Upper Swale North Spillway. The VC Middle Swale has the potential of capturing and infiltrating into the soil an estimated 1.2 - 1.9 million gallons per average rain year.

VC Middle Swale Spillways

Any overflow from the VC Middle Swale will be discharged via two spillways as illustrated on the design map: the VC Middle Swale North Spillway located on the ridge just west of the Visitor Center Hub, and a geologically-armored VC Middle Swale South Spillway located just north of and adjacent to the South Drainage.

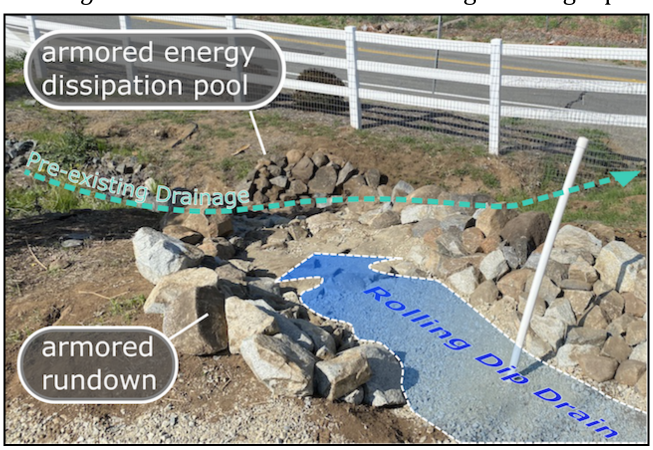
Any water that doesn't infiltrate into the soil downhill of the VC Middle Swale North Spillway will be eventually captured by the Visitor Center (VC) Lower Swale, and any overflow from the VC Lower Swale be discharged into a geologically-armored armored energy dissipation pool in the South Drainage via a geologically-armored rundown.

VC Middle Swale Geologically-Armored Rundown

An armored rundown is a "ramp" constructed of hand-knitted stone used to transition water across a sudden drop in grade. Rundowns are built from the bottom up, with a buried splash apron on top of which the armoring layers are keyed-in and knitted together. The middle of the rundown should be slightly dished (lower than the sides), and the shoulders should be anchored with larger stones where drive-through access is not required. The work area should be underseeded prior to beginning stonework with general erosion control seed mix to provide vegetative stabilization in addition to the geological armoring.

Figure 4

Left: Armored rundown constructed serving to drain a rolling dip down a slope into an existing drainage path. *Right:* Armored rundown connecting a rolling dip drain to a seasonal drainage bottom. **Image:** 7GD.



A geologically-armored rundown should be installed at the outlet of the VC Middle Swale Spillway in order to non-erosively direct overflow water down to the VC Middle Swale South Spillway Armored Energy-Dissipation Pool below.

VC Middle Swale Geologically-Armored Energy-Dissipation Pool

An energy dissipation pool is a structure, usually composed of geological materials such as rocks, that allows for the energy of water moving downhill to dissipate in a non-erosive manner. The rocks are stacked, starting from the bottom and working upwards, in such a way as to create a small pool of standing water to de-energize incoming fast-moving water (standing water is the most effective way de-energize moving water). The exit sill of the energy dissipation pool is set lower than the input to ensure the structure is self-cleaning and will not clog. Energy dissipation pools are often integrated with an uphill feature for moving water non-erosively, such as an armored rundown or culvert.

Figure 5

Armored energy dissipation pools, like this one located at a culvert outlet, allow for the energy in moving water to dissipate in a non-erosive manner..

A geologically-armored energy-dissipation pool should be installed at the bottom of the VC Middle Swale Geologically-Armored Rundown in order to dissipate the energy of any overflow water that develops from the VC Middle Swale before it enters the drainage and ultimately exits the property via the South Drainage Culvert. This energy-dissipation pool should ideally be integrated with one of the headcut repair structures described below.

South Corner Swale

The South Corner Swale, which is 570 feet long as illustrated on the design map, runs continuously where it intersects with the southeast property line to wherever the grade becomes prohibitively steep (~25%) next to the South Drainage. In addition to capturing any runoff that develops on the SLOBG property uphill of it and below the VC Upper Swale, it will also capture any overflow from the VC Upper Swale via the VC Upper Swale South Spillway. The South Corner Swale has the potential of capturing and infiltrating into the soil an estimated 100 - 400 thousand gallons per average rain year.

South Corner Swale Spillway

Any overflow from the VC Middle Swale will be discharged into a geologically-armored rundown to the South Drainage bottom via a geologically-armored spillway located just south of and adjacent to the South Drainage.

South Corner Swale Geologically-Armored Rundown

A geologically-armored rundown should be installed at the outlet of the South Corner Swale Spillway in order to non-erosively direct overflow water down to the South Corner Swale Armored Energy-Dissipation Pool below.

South Corner Swale Geologically-Armored Energy-Dissipation Pool

A geologically-armored energy-dissipation pool should be installed at the bottom of the South Corner Swale Geologically-Armored Rundown in order to dissipate the energy of any overflow water that develops from the South Corner Swale before it enters the drainage and ultimately exits the property via the South Drainage Culvert. This energy-dissipation pool should ideally be integrated with one of the headcut repair structures described below.

Visitor Center (VC) Lower Swale

The Visitor Center (VC) Lower Swale, which is 390 feet long as illustrated on the design map, runs continuously from wherever the grade becomes prohibitively steep (~25%) next to the South Drainage to wherever the grade becomes prohibitively steep (~25%) next to the Central Drainage. In addition to capturing any runoff that develops on the SLOBG property uphill of it and below the VC Middle Swale, it will also capture any overflow from the VC Middle Swale via the VC Middle Swale Spillway. The VC Lower Swale has the potential of capturing and infiltrating into the soil an estimated 100 - 250 thousand gallons per average rain year.

VC Lower Swale Spillway

Any overflow from the VC Lower Swale will be discharged into a geologically-armored rundown to the Central Drainage bottom via a geologically-armored spillway located just south of and adjacent to the Central Drainage.

VC Lower Swale Geologically-Armored Rundown

A geologically-armored rundown should be installed at the outlet of the VC Lower Swale Spillway in order to non-erosively direct overflow water down to the VC Lower Swale Armored Energy-Dissipation Pool below.

VC Lower Swale Geologically-Armored Energy-Dissipation Pool

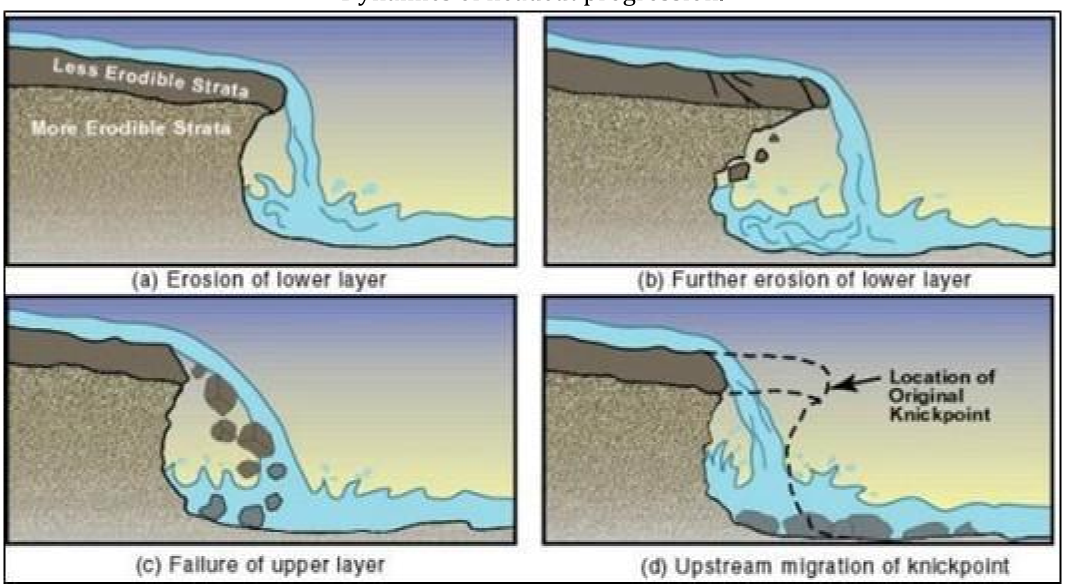
A geologically-armored energy-dissipation pool should be installed at the bottom of the VC Lower Swale Geologically-Armored Rundown in order to dissipate the energy of any overflow water that develops from the South Corner Swale before it enters the drainage and ultimately exits the property via the South Drainage Culvert. This energy-dissipation pool should ideally be integrated with one of the Zuni Bowls (headcut repair structures) described below.

Stabilize Headcuts within Incised Drainages

A headcut is a quick drop in elevation, typically vertical, within a streamflow that has a plunge pool at the bottom created by the turbulence of high energy water. When dry, headcuts can look like a small cliff (a foot or two deep) or sometimes can be the size of an actual cliff (20+' deep). The scouring action at the base of the drop caused by the high energy water continues to eat away at the uphill cliff face, until yet another overhanging segment collapses into the plunge pool. In this manner, headcuts move upstream (opposite the direction of streamflow), much like a zipper moving up through a landscape, and become larger and more destructive as they go.

Figure 6

Dynamics of headcut progression.



Headcuts are very destructive erosion patterns, and will continue to deepen the stream bed, further incising the channel and thus concentrating water flows, increasing their velocity, and creating conditions for an additional, larger, and more destructive headcut to form downstream and begin moving upwards. Headcuts work to dehydrate landscapes, as the ever more incised channels they create progressively reduces a stream's ability to connect with its floodplain and increase its ability to drain water reserves held in soils uphill, dropping ground water levels and leading to rapid shifts from riparian edge vegetation to upland vegetation. Headcuts often form where water flows have been concentrated and sped up by roadways or grading.

Between the three drainages and the one old farm road scar line on the west side of the property there are a total of 64 active headcuts: Old Farm Road Scar (9), North Drainage (23), Central Drainage (20), South Drainage (12). They range in size from no larger than a human footprint to over 8’ deep and 15+’ wide. The largest observed headcut can be seen in this video[1], part of a stair-step trio of headcuts located at the bottom of the West Drainage. Figure 6 contains photographs of a few of the headcuts observed while performing the site survey.

Figure 6

Top Left: A 6’ deep headcut in the Central Drainage. **Top Right:** A long 30” deep headcut. **Lower Left:** A 3’ deep incision observed in the West Drainage. **Lower Right:** The eroding face of an East Drainage headcut.

These headcuts are actively eroding, leading to further gully incision in all of the drainages, which is increasing the rate of dehydration of the adjacent landscape. As part of a whole site water harvesting plan, it is imperative that these headcuts be halted and that aggradation efforts begin within the incised drainages to ultimately reconnect them with their ancestral flood plains. If allowed to persist untreated, these headcuts will continue moving many tons of soil down the watershed, into the creek and ultimately out to sea as they move up the drainages.

Much work and expense is being considered to improve soil hydration throughout the property to sustain future plantings well beyond our current lifetimes. Any measures taken without also addressing the “holes in the bucket” will be much less effective and ultimately meaningless if the soil is gone.

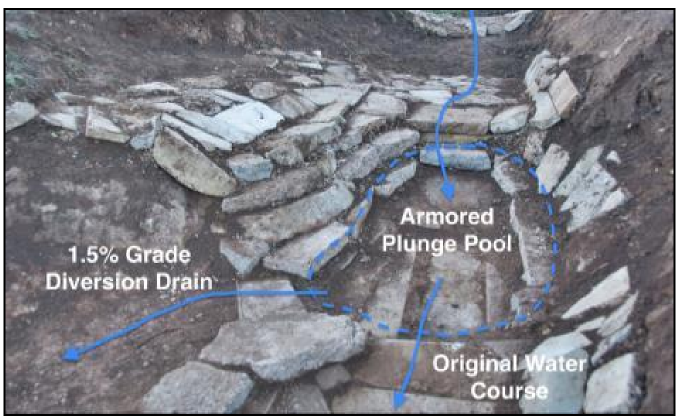
[1] https://youtu.be/uoXCnZ5boo0

The existing headcuts should be stabilized with zuni bowls installed in concert with one rock dams to bank moisture and sediment in the gully bottoms and promote healthy revegetation and ultimately reconnection with the ancestral floodplain.

Zuni bowls are geologically armored plunge pools effective at halting headcut erosion. Zuni bowls are utilized to 1) halt up-valley progression of headcuts by armoring the spill-over point with knitted rock and 2) to pacify high-energy inbound water flows by creating a small plunge pool filled with standing water into which the moving water falls (still water being the most effective way to calm turbulent water). Zuni bowls check the uphill movement of an existing headcut, help pacify seasonally heavy flows, eliminate the opportunity for further erosion, and ultimately assist in revegetation and moisture persistence in the gullies. Increased moisture persistence helps begin the vegetative restoration process in incised water channels with the ultimate goal of reconnecting them with their floodplain (in instances where this is possible and desirable) and rehydrating the landscape or simply halting the erosive processes and further damage. Zuni bowls are always installed with a one rock dam set a short distance down the drainage to further spread and pacify flows discharged from the zuni bowl and to assist with revegetation.

Figure 7

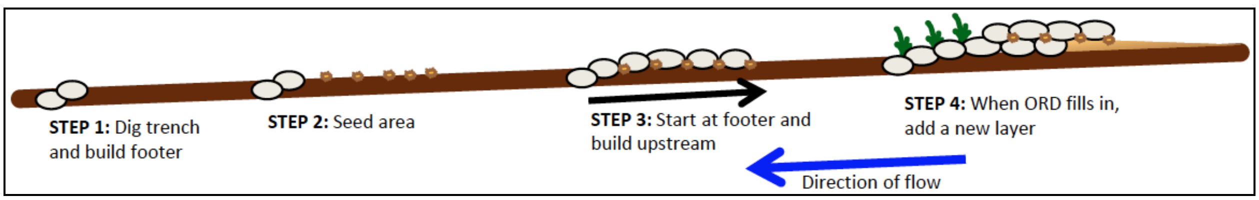
Left: Zuni bowl with 1.5% diversion drain installed into a headcutting gulley in Carpinteria, CA (Image: 7GD).
Right: Zuni bowl installed in an incised drainage to stabilize a headcut (Image: Craig Sponholtz).



A one rock dam is a band of rocks one rock high set across the width of an incised drainage. The rocks are knitted together, and generally stick up no higher than 3-4” above the drainage bottom. The band is generally 6-8 rocks deep for the entire width of the drainage. The edges are keyed into the channel edges (and go up the wall slightly).

Figure 8

Top: A small zuni bowl structure (upper) used to stabilize a young headcut, followed by a one rock dam (lower structure) to help aggrade and revegetate this small incision (Image: 7GD). *Bottom:* One Rock Dam in profile(Image: Bill Zeedyk and BorderLandRestoration.org).



One rock dams are used to slow and disperse channelized flows in shallow-grade scenarios and build up silt deposits on the upstream side, which improves moisture retention, flow pacification and vegetation recruitment. Good for gradually raising the height of incised streambeds or waterways over time.

There are two parts to a one rock dam - the sill and the dam. The sill is a single line of rocks, knitted together with a relatively broad, flat surface facing up, dug down until their tops are at the existing grade of the drainage and arranged perpendicular to the direction of flow. The dam consists of four to five rows of rocks knitted together tightly spanning the width of the drainage. The lowest row sits atop the keyed-in sill rocks. The sill acts as a non-erosive splash guard during high-flow events to prevent undercutting when water is moving over and through the dam rocks.

ORDs can be employed to raise the thalweg (deepest part of a drainageway) over time by creating sediment depositions upstream of the dam, which increases water and nutrient holding capacity, and thus becomes a more amenable site for vegetation to establish, which further slows down water, provides habitat, and reduces evaporative losses. ORDs utilize the already occurring natural process of erosion to aggrade (raise) incised drainages and ultimately reconnect them with their floodplains and restore or improve hydrological function. ORDs can be installed sequentially, year by year as conditions warrant, to continue gulley healing and improve overall landscape hydration. ORDs are recommended anywhere a drainage has become incised and disconnected from its floodplain, or where more dispersed overland water flows are desired.

Install Water Storage Tanks at Top of Property

Water storage tanks should be installed near the top of the property, on the close-to-level pad left over from prior agricultural land use as illustrated on the design map. This location is large enough to accommodate all 28 of the 5,000 gallon tanks currently proposed, and total storage could be increased further if larger, taller tanks were to be used. This area is high enough to gravity feed irrigation water to 90% of the property, and the 10% of the property that is higher in elevation is largely too steep for planting or safe access anyways. The total storage capacity of this network of tanks as currently specified would be 140,000 gallons.

The tanks could be supplied by the municipal connection or, more ideally, would be supplied water collected from the roofs and hardscapes of the Visitor Center and Education Center Hubs below. Water collected from roofs should be directed straight into either smaller "surge" tanks or cisterns (potentially located under the parking lots) fitted with a first-flush diverter. These cisterns should be outfitted with appropriate pumping infrastructure to immediately begin pumping this surge flow up to the tanks located at the top of the property. Water collected from less clean surfaces such as walkways and parking lot hardscape should be directed through some type of minimal filtration in order to remove any larger debris or refuse before being transferred to a protected sump where it too is pumped up into the water tanks.

The amount of run-off generated by the Education Center roof and Visitor Center Hub footprint during an average annual rain year is 3.5 - 4.1 million gallons (11 - 13 acre-feet), which is approximately half of the estimated annual irrigation needs of the garden. A 1 inch rain event will generate approximately 200,000 gallons of run-off. All of this water has the potential to be collected and pumped to the top of the property - the trouble is storing that water for use when it is most needed. Most of the precipitation at the SLOBG property falls within a window of a few months, during which the plants will need the least amount of supplemental irrigation, it is likely that the water storage tank system proposed will rarely be empty during most rain events, and in fact often may be full.

Assuming the tanks are filled twice and emptied once during each rainy season from run-off generated by the Visitor Center hardscape areas (a total of 300,000 gallons pumped), this would result in an excess of ~3 million gallons that will not be able to be stored in the tanks atop the property. The addition of large cisterns under the Visitor Center Hub parking lot may reduce this number by several hundred thousand additional gallons - however there will still be millions of gallons of water of overflow that cannot feasibly be stored. This overflow can be discharged into the Upper or Middle VC Swales (whichever is located downhill of the eventual tank overflow location), or, most ideally, pumped to the features of the recommended Upper Ridge Swale System described below.

Upper Ridge Swale/Vernal Pool System

To maximize the benefit that the Visitor Center run-off water can provide, and increase the ROI on all of the infrastructure dedicated to its collection, pumping and storage, an intermediate "earth storage" option is recommended. This would entail having one or several additional infiltration sites, composed of swales with integrated vernal pools up high in the landscape throughout the property. This will allow for additional water above and beyond the 150,000 gallon storage capacity of the ridge-top tanks (assuming thirty 5,000 gallon tanks) to be stored in the cheapest tank there is - the soil. The three upper ridge swales/ponds would allow for the million gallons of water that cannot be feasibly stored in tanks to be infiltrated *high in the landscape*, thereby increasing the hydration of the Northern Hemisphere zones that are otherwise not benefited by the Master Line Swale and everything below it.

The systems would work by overflowing from a "master tank" located slightly higher than all other tanks on the water storage tank pad that would have linked overflow lines running to the various infiltration basins / vernal pools with linked swale lines. Each overflow line would have an outlet control box with a manual float valve that sets the maximum water height for that individual earthen infiltration structure. The maximum water height would be set below the height of the level-sill spillway so as not to cause spillway discharge when not necessary - the focus would be entirely on filling the structure and allowing it time to infiltrate. This would also ensure that, during a heavy precipitation event when the infiltration structure may already be at capacity, the pump will not continue pumping to fill this structure.

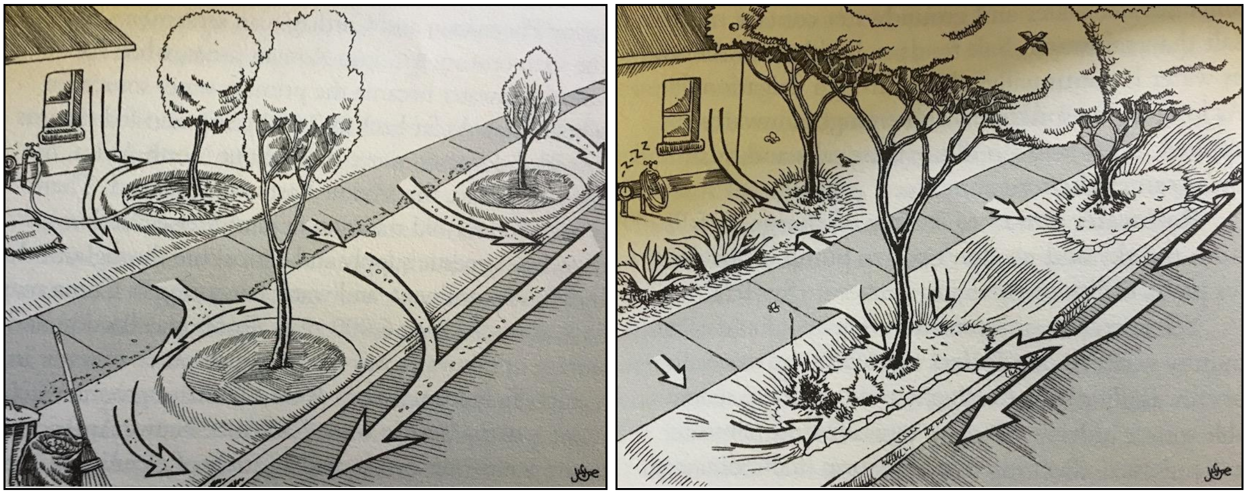
In summary, the water collected from Education and Visitor Center roofs and hardscapes would be prioritized as follows; 1) fill all storage tanks on the water tank storage pad, 2) continue pumping up to the storage tanks and then overflow into the infiltration structures located throughout the Northern Hemisphere zone until such time as they reach maximum capacity, and 3) discharge from the Visitor Center "surge" tank or collection cisterns directly into the Visitor Center Upper or Middle Swale (whichever is nearest downhill). This system will leverage the already planned collection and pumping infrastructure to pump and store 10-15x more water (mostly in-soil storage) than if it pumped to the storage tanks alone.

Direct Kiosk Roof Run-off into Adjacent Infiltration Basins

Roof run-off from the proposed kiosks should be directed into small swales dug on contour (with integrated spillways for overflow) or broad, shallow "infiltration basins" adjacent to and downhill of the kiosks, like those illustrated in Figure 9. These will provide a strong visual example to patrons of the garden about the importance of rainwater harvesting and its positive impacts in growing healthy, beautiful guilds of trees and plants. Each kiosk roof is proposed to be 200 square feet, which will yield approximately 2,750 gallons of roof run-off during a typical rain year of 22 inches and approximately 125 gallons per 1" rain event.

Figure 9

Left: Typically "high and dry" planting pattern found in most residential and urban landscapes**. Right:** Sunken infiltration basins that act as natural sink points for run-off water**. Image:** *Rainwater Harvesting for Drylands and Beyond - Volume 1* **-** by Brad Lancaster.



Utilize Water Batteries for Irrigation-Free Tree Establishment

Setting up piped irrigation for dense agroforestry or broadacre plantings gets expensive quickly. Polyethylene irrigation lines laid at the soil surface are also particularly susceptible to being chewed on by wildlife searching for water.

One solution to this is a water battery like the Groasis Waterboxx[2]. The Waterboxx is positioned around each seed or seedling and is pre-charged with several gallons of water. The water is contained inside a covered container that sits around the tree seedling or tree seed. A wick from the internal reservoir leaches out some 50mL per day of water - not enough to make the tree lazy, just enough to create a water column of moisture directly beneath the soil upon which the Waterboxx sits. There is not enough water in this column for the tree to thrive, but there is enough to continually stimulate the taproot to continue growing deeper into the soil (a very desirable trait in drought-prone climates). The water reservoir also serves as a thermal mass that condenses warmer, moisture laden air on the Waterboxx's surface, which refills the reservoir. These devices are meant to be filled once and left for a year or longer, and they will continue to self-fill by condensing moisture from the air during diurnal temperature fluctuations and funneling that condensate into the reservoir.

[2] https://www.groasis.com/en

Figure 10

Groasis Waterboxx

An animated walkthrough of how the Groasis Waterboxx works is available here[3].

Though the members of the 7GD team have not yet had the opportunity to personally test the Groasis Waterboxxes, after research and conversations with distributors, there are several benefits of utilizing them in an agroforestry system over conventional irrigation:

- If one fails or gets punctured by a wayward grazing animal, it affects only one tree, whereas if an irrigation supply line gets chewed by rodents, stepped on by a cow, or an emitter pops out at a single tree, the entire system's performance is degraded if not completely shut down. Integrating animals into pasture with irrigation tubing is guaranteed to be a costly and time-intensive endeavor.
- Capitalizing on the far lower cost of seeds vs seedlings, the ability to plant two seeds in each Waterboxx increases the establishment success rate of each planting to 99%, versus 85% for planting just a single tree. This equates to more trees established in a shorter amount of time when looking at a 3+ year time horizon.
- They allow time for observation and adjustment. As an example, 200 Waterboxxes in rotation every year would allow for an annual review of how things went the year prior - and allow time and space for the incorporation of new knowledge and understanding of the landscape, new species that have popped up on the radar, and changes in future land use ideas and desires etc.

Though the Waterboxxes are pricey, a quantity can be purchased that fits the landowner's budget, used to start a block of trees, and then reused the following year for an entirely new block. This can continue year after year until the property is populated with the desired number of trees. As an example, if 2,000 trees are planned for establishment over a 10 year period, only 200 boxes are required. In this example, based on current Waterboxx pricing, the per tree establishment cost (irrigation, protection) at the end of that 10 year period comes to approximately $3.10 -

[3] https://www.youtube.com/watch?v=HRF2bUBPA90&t=1s

approximately 75% less than the estimated per tree establishment cost if using conventional poly irrigation line and drip emitters.

Increase Frequency of Footpath Cross Drains

Footpaths should be drained frequently in order to prevent water from accumulating on the trail surface and increasing its energy and erosive potential. Where footpaths do not have built in grade changes (briefly shifting between positive and negative grades being the simplest, cheapest way to drain pathways), surface cross drain structures such as channel drains, rolling dips, stone diversions and water bars should be utilized to move water off of the footpaths early and often. Discharge locations should be selected carefully to avoid creating "double fetch" scenarios that frequently occur with switchback trails - where the water discharged from one trail section is picked up by the switchback below it, further compounding the erosion hazard. To help combat this, cross drains should be patterned into appropriately sized media luna flow spreaders (described below) to return concentrated water to dispersed flow immediately upon discharge from the path surface. This will slow the water down, spread it out, and provide a greater opportunity for infiltration and reduce the potential for erosion.

Figure 11

Left: Stone cross drain. *Right:* Manufactured channel drain - helpful for ADA pathways.

Media lunas are crescent shaped structures composed of several courses of hand-knitted rock laid close to contour depending on desired function. The crescent tips can be oriented either uphill or downhill. Media lunas are used to either concentrate or spread sheet flow to prevent erosion. There are two types of media luna structures.

- **"Tips Down"** - used to concentrate dispersed sheet flow as it enters a steeper section of the landscape that is prone to rill formation (rills are precursors to runnels and ultimately gulleys) into a properly armored or stabilized drainage channel. Tips down media lunas get their name because the tips of the rock crescent are pointing downslope.
- **"Tips Up"** - used to disperse erosive channelized flow and reestablish sheet flow after transitioning from steep, high energy sections of the landscape to flatter, lower energy

sections of the landscape. Tips up media lunas spread out concentrated water flow and reduce its energy, allowing the water to drop any bed load it may be carrying.

Figure 12

Media lunas act as either flow-spreaders or flow-concentrators depending on their orientation; "tips up" or "tips down" respectively. Image: *Erosion Control & Restoration Treatments In Drylands* - Ecology Artisans.