

Trail Notes

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1 The Trails of the South Mountain Reservation (SMR)

The [South Mountain Reservation](#) is a 2112 acre park of Essex County New Jersey.

South Mountain Reservation covers 2,112 acres in the central section of Essex County, extending through the municipalities of West Orange, Maplewood, and Millburn, bordering South Orange, between the first and second ridges of the Watchung Mountain Range. The presence of the early Lenape Indians lingers in the name given to the Watchung—the “high hills.”

The reservation has changed only slightly through the years. It’s been preserved primarily in its wild state. Woodlands abound in a variety of hardwood trees, and tall hemlocks tower above streams, creeks and ponds. The west branch of the Rahway River flows through the valley. A reservoir and watershed owned by the City of Orange lies in the northern tract

Largest of the Park System’s reservations, it was built from land purchases begun in 1895—the first year of the Park Commission’s life. It took a decade to untangle the deeds and assemble all the lands at South Mountain.

Before he delegated design of the Essex Parks to his stepson’s firm, Frederick Law Olmsted visited the newly acquired reservation. He regarded it as some of the most beautiful and promising terrain he had ever seen. The design of South Mountain was finalized by the Olmsted Brothers in stages over the years. A good deal of construction work—trails, foot bridges, shelters, etc.—was carried out by the Civilian Conservation Corps in the 1930’s.

The [South Mountain Conservancy](#) is a volunteer-driven, non profit:

The South Mountain Conservancy serves as steward and advocate for the South Mountain Reservation. We work to preserve, protect and restore its ecology, natural beauty, and infrastructure through our volunteer programs, promoting sustainable use, informing public policy and community engagement.

1.1 Maps

A few maps of SMR are publicly available:

- 1902 Guide map of the South Mountain Reservation in Long Hill Township, Essex County, N.J. sponsored by the Essex County Park Commission. Surveyed under the direction of Howard J. Cole, Engineer in Chief and Gordon H. Taylor, Topographer. [Olmstead Brothers design](#)
- 1980s(?) (author and date unknown) [Essex County Map](#)
- 2000s The SMC has released at least three version of its [trail map](#), the last two produced by Susan Brand. These have been available for purchase and remain a source of revenue for the SMC. In addition, the map is available on both Androd and Apple through Avenza.

2 History of the trails

It is believed¹ that the 1902 design served as an inspiration for the trail system, but the original trails were laid out by the CCC in the 1930s.

Likely there were adjustments when Cherry Lane and Brookside Drive were made to be continuous and the deer paddock was removed.

However, it is also likely that the [county map](#) from the 1980s(?) reflects the state of the trail system until 2007 or so when the **SMC Trail Work Crew** was formed by Don Schatz and Michael Feldman July 7th and 8th 2007 with the energy of the Mountain Bike Community.

This is from a followup email to the initial event:

Both personally and on behalf of the South Mountain Conservancy, I want to thank you for supporting the recent IMBA/Subaru Trail Care Crew visit at South Mountain. I do not believe the Reservation has ever seen such a positive outpouring of support from the mountain biking and hiking communities. Clearly, the considerable potential of these groups working together was demonstrated over the weekend of July 7th and July 8th. The fact that important decision makers and County officials were on hand Sunday to see the result of our efforts and participate in the trail building was really great.

If you are interested in the numbers, we had 20 participants at the Friday VIP reception, 60 students at the TCC Saturday classroom session, 45 trail workers on Saturday afternoon and over 40 trail workers on Sunday morning. The new trail is almost 7/10 of a mile long and took approximately 260 man hours to construct.

Sometime over the next several years, the leadership of the Trail Work Crew fell to Dennis Percher and John Verzani, who have carried the effort forward into 2024.

2.1 Primary hiking trails of the SMR

The [SMR Trail Guide](#) is a 60-page guide, describing the 50-plus miles of trails in the South Mountain Reservation with details of recommended hikes. What follows is a very brief description.

¹This needs to be confirmed

The [Lenape Trail](#) was established in 1982 and connects many parks and reservations through Essex County. Its longest section runs through the SMR from Locust Grove to Route 10 (south to north).

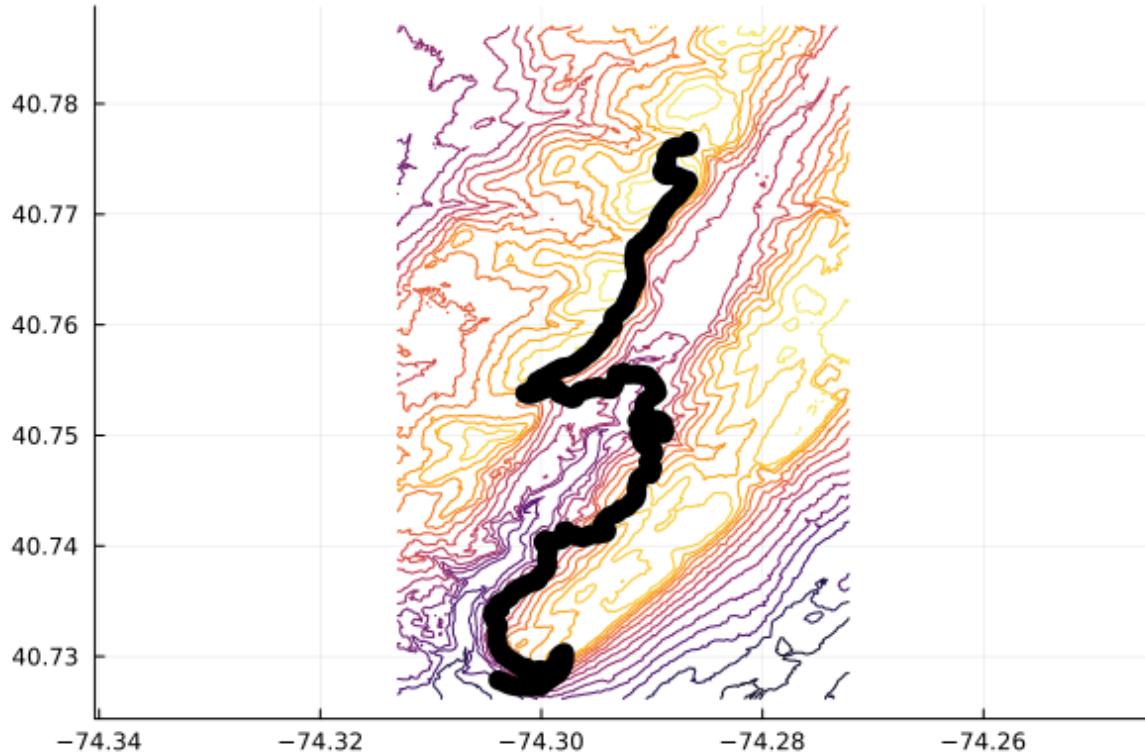


Figure 2.1: Lenape Trail

In addition to the Lenape trail, the following main trails are blazed

- the white-blazed Rahway Trail (with part of it known as the Fairy Trail)
- the red-blazed Swampy Trail
- The blue-blazed Elmdale Trail
- The red-blazed Oakdale Trail
- The green- and white-blazed Mayapple loop
- The orange-blazed Turtle Back Trail

The Mayapple and Turtle Back trails form loops; the Oakdale and Lenape trail; the Elmdale and Dogwood trail form a loop; and the Swampy, Summit, Openwood, Rahway form a loop within the five main areas, partitioned by South Orange Avenue, Northfield Avenue and Brookside Drive and Cherry Lane

There are other connector trails carrying the colors of both trails that combine these loops, among some other trails.

2.2 The carriage roads of the SMR

The reservation also has many *carriage roads* with the name of “trail.” The River Trail combined with the Reservoir Trail extends from Millburn to West Orange in the heart of the reservation; the West Ridge Trail runs along the western boundary; Crest Drive (paved) and the Longwood Trail extend along the Eastern boundary. In addition there are several carriage roads running east to west (Sunset Trail, Pingry Trail, Grassy Trail, Bear Lane, Balls Bluff Trail, Openwood Trail, Scout Trail, Hillspur Trail, Ravine Trail, CCC Trail, and North Trail).

Carriage roads have not been a priority for the Trail Work Crew, though some efforts at water management have been undertaken.

2.3 The main projects of the Trail Work Crew, 2007-2023

The Trail Work Crew has constructed or supervised the construction of numerous enhancements to the trail system of the SMR since 2007. The following chronicles the efforts by region and then chronologically. Any omissions are unintended and corrections are welcome. As possible, before and after images are provided from the county map and the SMC map or openstreetmap.org.

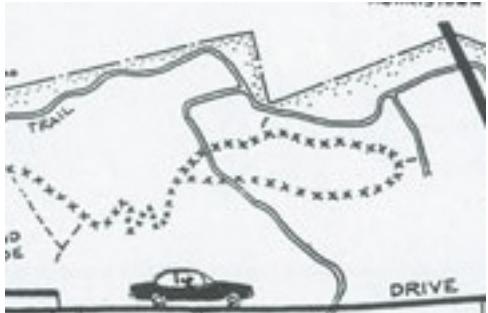
2.3.1 Elmdale region

The Elmdale lollipop reroute was the second project undertaken by the Trail Work Crew and aimed to close down a portion of the Elmdale trail that was severely eroded. In the process it created a trail past pyramid rock.

The Painter’s point picnic area had no natural entry to the trails west of Brookside Drive. A connector was an early project allowing trail access all the way to Old Short Hills Park.

A re-route of the high-low trail was done for safety reasons, as the old trail was dangerously close to a drop off.

Dogwood hill has ample parking, but only had connections to the trail system to the west. The Dogwood hill connector headed north towards the sledding hill. It also provided access to two small parking areas on Brookside drive.



(a) Elmdale lollipop original

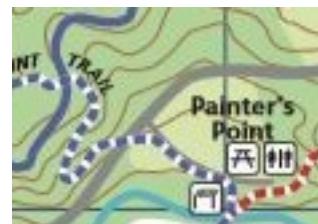


(a) Elmdale lollipop reroute

Figure 2.3: Reroute of Elmdale “lollipop” avoiding washed out region and giving access to pyramid-shaped rock.



(a) Painter's point before



(a) Painter's point connector

Figure 2.5: Create Painter's point connection to elmdale trail creating painter's point trail



(a) Elmdale high-low before



(a) Elmdale high-low after

Figure 2.7: Small reroute of high-low trail for safety reasons.



(a) North of dogwood hill



(a) North of dogwood hill

Figure 2.9: Addition of trail from dogwood hill north. Not seen, are spur trails to two small parking lots giving immediate access to the trail system.

South of the Dogwood Hill parking area a trail was added to connect with the Painter's Point trail. This gave two layers of trails on that hill side in addition to the West Ridge Trail carriage road.

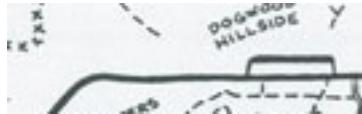


Figure 2.10: Trail connecting dogwood hill to the Painter's Point trail.

2.3.2 Oakdale region

There is a planned re-route of a wet area of the Oakdale trail, but otherwise no substantial changes to the trail system have been undertaken by the Trail Work Crew.

2.3.3 Mayapple region

The Lenape trail runs through the Mayapple section and continues northward towards Route 10. An early project was to reroute the trail north of the picnic area. A more recent project was to add an alternate route for the Lenape connecting the Mayapple loop to the carriage road that encircle the fields.



(a) Lenape near Mayapple fields, before

(a) Lenape near Mayapple fields, after

Figure 2.12: Reroutes for the Lenape trail through the Mayapple region

A large grant allowed the professional construction of several long trail segments. Included in that was the Mayapple Loop trail which added to the east side of the hill a stretch of trail affording a pleasant 2.5 mile loop. (The biking side trail further east was not designed or encouraged by the SMC.)

An 11-acre section of land north of the [Mayapple](#) was purchased in 2009. This is now accessible through the professionally built Mayapple extension trail which stretched the portion of the Lenape trail in the SMR further north. Further work, not shown on the map, was done to extend the Lenape to Route 10 in coordination with West Orange.

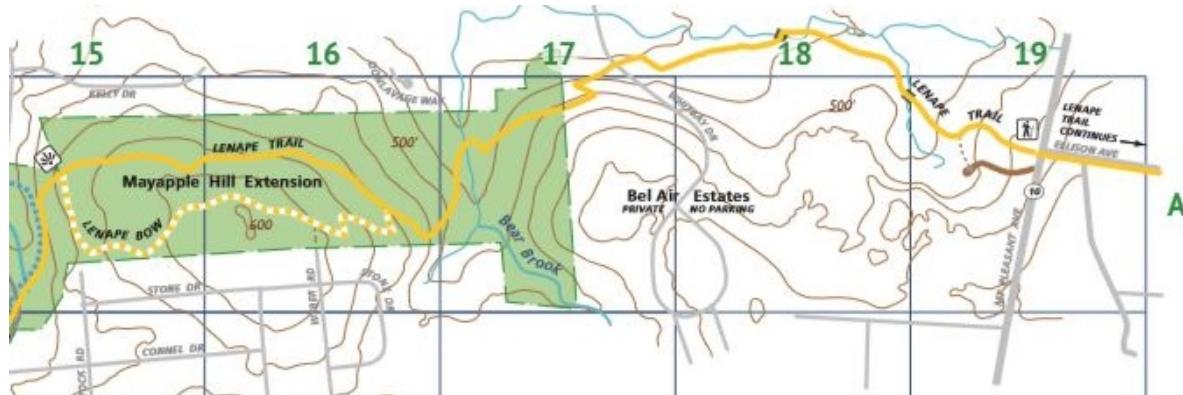
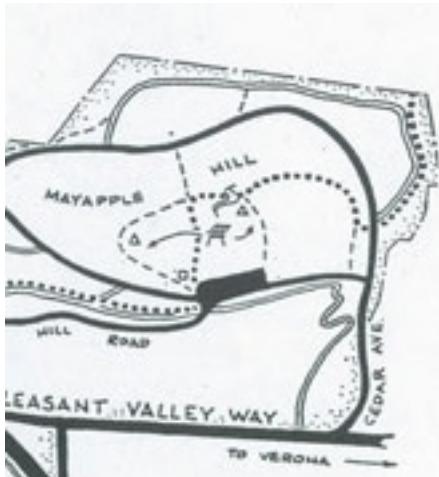
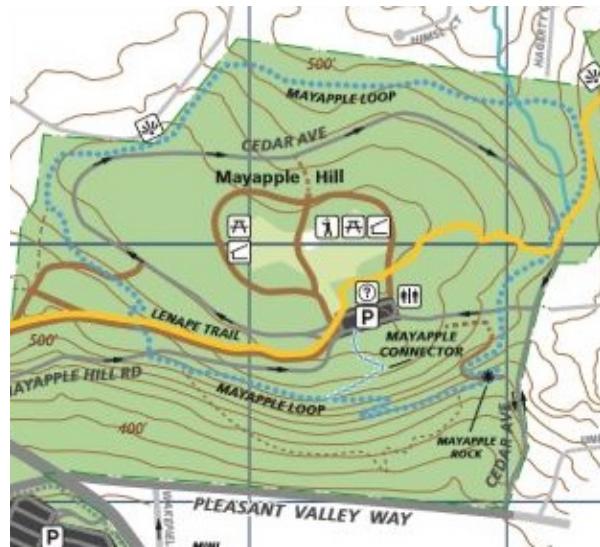


Figure 2.15: Mayapple extension



(a) Mayapple loop before



(a) Mayapple loop after

Figure 2.14: The Mayapple loop added a professionally built eastern portion.

2.3.4 Turtle Back region

The first project of the Trail Work Crew was a reroute of the Upper Turtle Back trail. The old trail was a fall-line trail and suffered from erosion issues. This project was led by IMBA volunteers. Subsequent work was done to create “five-corners,” an intersection of the Turtle Back Bypass, the Turtle Back connector, and the upper Turtle Back trail.

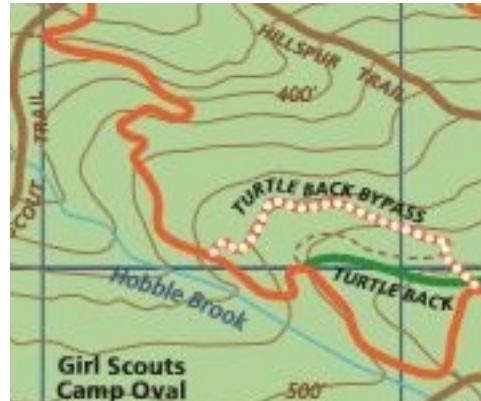


Figure 2.16: Reroute of upper Turtle Back trail avoiding fall line trail

The Zoo loop started as an effort to connect the Reservoir trail to the Orange Reservoir, at the time encircled by a fisherman's trail. In discussion with the County to make a loop trail

back towards the zoo, the paved Orange Reservoir trail was spawned. This has proven hugely popular. The zoo loop takes advantage of this paved trail, the reservoir trail, and a portion of trail constructed professionally that connected the CCC trail with Northfield Avenue. (The trail along the Turtle Back Zoo was planned to be shut down with a zoo expansion, though the trail is still walkable.) The portion of the zoo loop along Northfield Avenue goes by the original 0.11 acre purchase across St Cloud Avenue that began the SMR.



Figure 2.18: Creation of zoo loop, leveraging several new and old pieces.

The Reservoir connector trail linked the popular loop around Orange Reservoir with parking near the Boy Scout Area.

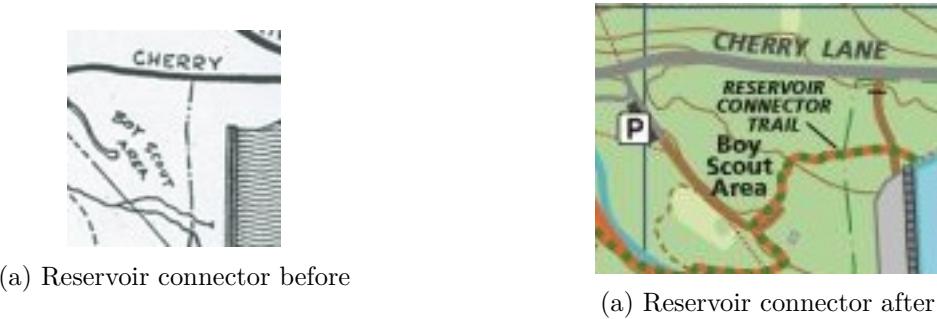


Figure 2.20: New trail connecting the Orange reservoir trail with parking near the Boy Scout Area in Tulip Springs.

2.3.5 Main area of the reservation

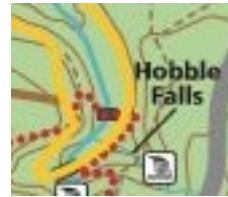
The south-east quadrant of the reservation is easily the most used with its main access points being the Summit field/Crest Drive area, the Locust Grove parking area and the parking for the waterfall, in addition to a few others. We discuss efforts in different regions.

2.3.5.1 Hemlock falls region

Hemlock falls remains a popular attraction. The rerouting of the Lenape Trail approach to Hemlock Falls from the south was an early project and the trail now gracefully enters following the contour of a natural amphitheater.



(a) Hemlock Falls reroute before



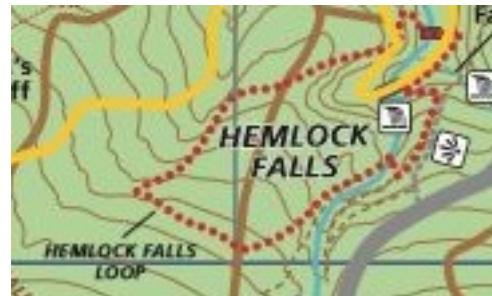
(a) Hemlock Falls reroute before

Figure 2.22: Reroute of Lenape Trail as it approaches Hemlock Falls from the south

The Hemlock falls loop was added following a suggestion by Dave Hogenauer. It provides a short loop incorporating the water fall.



(a) Hemlock falls loop before



(a) Hemlock falls loop after

Figure 2.24: Addition of Hemlock Falls loop

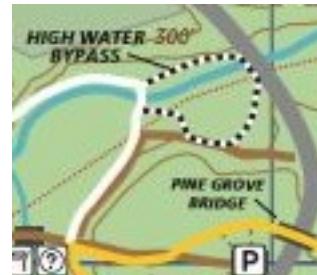
The Rahway trail west of the River trail near the Hemlock Falls parking area involved a stream crossing. This proved challenging when the water was high and a reroute was done. In addition a high-water bypass was created utilizing the bridge over the Rahway on South Orange Avenue.

The Rahway to West Connector trail gave access to the Elmdale area from the Rahway trail by trail and not carriage road. It crosses over the intermittent Will O' the Wisp brook

The popularity of Hemlock Falls on a nice weekend day leads to parking demand far in excess of the small parking area off South Orange Avenue. As suggested by Dave Berry, an overflow parking area was created by the County in its Maintenance area and a connecting trail was constructed by the Trail Work Crew.



(a) Rahway bypass before

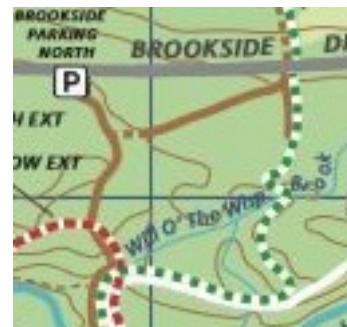


(a) Rahway bypass after

Figure 2.26: Reroute of Rahway trail as it crosses Rahway river branch



(a) Rahway to West Connector before



(a) Rahway to West Connector after

Figure 2.28: Addition of trail connecting the Rahway Trail to the West Connector



(a) Parking lot connector before



(a) Parking lot connector after

Figure 2.30: Connector trail from overflow parking area for Hemlock Fall's access

2.3.5.2 Summit field region

An extension of the Swampy trail to Summit trail was made. This allows a more natural south-to-north alternative to the Lenape trail.



(a) Swampy trail to summit, before



(a) Swampy trail to summit, after

Figure 2.32: Extension of Swampy Trail to Summit Trail

2.3.5.3 Washington Rock region

An old parking area dating to when Crest Drive allowed vehicular traffic was removed and in its stead a pavilion was put in. This was the impetus for moving the Lenape trail from along Crest Drive to the inside of the loop.



(a) Lenape trail reroute, before

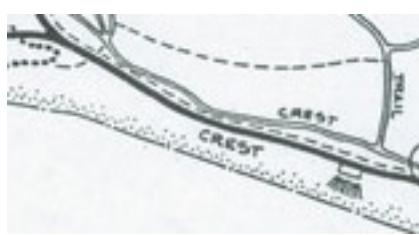


(a) Lenape trail reroute, after

Figure 2.34: Reroute of Lenape trail near Washington Rock

The Hogenauer trail was reclaimed and blazed

The small Swampy extension near Washington Rock allowed a red trail to connect the Locust Grove picnic area to the Turtle Back Rock picnic area.



(a) Hogenauer trail, before

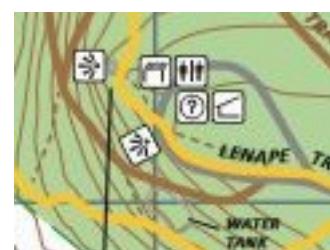


(a) Hogenauer trail, after

Figure 2.36: Reclamation of Hogenaeur trail.



(a) Swampy extension near Washington Rock, before



(a) Swampy extension near Washington Rock, after

Figure 2.38: Extension of swampy trail towards Locust Grove.

2.3.6 2023 onward

As of 2023, the trail system in the South Mountain Reservation is quite mature. Major new trails are unlikely. However, the current trail system – with over 50 miles of trails – needs maintenance.

The Trail Work Crew has organized several work days to improve trail sections, primarily along the Lenape trail near the Pingry Trail intersection and between Balls Bluff Trail and the Openwood Trail.

Beginning in 2023, Dave Berry has organized a SWAT team to fix trail issues. This group has spent productive time in the Turtle back area, on the Swampy trail, and on the Lenape trail.

3 Trail construction

```
#| echo: false
#| output: false
using PolygonOps
using Roots
using Plots
nothing
```

3.1 Sustainable trails

Since 2007 the South Mountain Conservancy, primarily through the work of its Trail Work Crew, has incorporated several new miles of trails within the 50+ miles of trails. These new trails have been built with sustainability in mind. What makes sustainability an issue is *water erosion*. A failure to account for water flow can quickly turn a trail in good shape into a disaster.

In the following, we mention a few terms related to trails:

- hill slope – the slope of the “fall line” at a given point on the hill
- trail grade – the slope of the trail in the direction of the trail
- outslope – slope of the trail in the direction *perpendicular* to the trail

Water, when unconstrained, should flow in a sheet manner down a hill following the hill slope. When this water hits the trail, it may run along the trail, not down the hill. This can cause erosion of the trail. Accounting for the various slopes is an important part of trail layout.

Water is the enemy of a trail system

Water is the primary enemy of a trail system. Even in its most benign presence, when a trail is muddy, hikers tend to avoid the mud and widen the trail in the process. Even more damaging is when water is concentrated enough and flowing fast enough to cause erosion.

Water can carry sediment. Faster water can carry more sediment. During heavy rain, much of the trail surface can be picked up and moved by fast-flowing water. When water

slows, it can not carry the same amount of sediment, and deposition occurs. A single storm can erode a trail section and also quickly fill in areas.

Doing everything possible to ensure flowing water does not run down the length of the trail is the key to having sustainable trails.

The five essential elements of *sustainable* trails¹:

3.1.1 1. The half rule

The half rule says the trail grade should not exceed half the hill slope.

For an example, a fall line trail would have slope equal to the hill slope and would exceed the half rule. A contour trail would have zero slope and would satisfy the half rule. Of course, trails must gain and lose elevation, this rule limits how much elevation can be changed given the hill side.

The guidelines note that this is *still* important when the slopes are gentle.

For very steep hill sides, the slope should still not exceed more than 10-12 degrees, though there are instances where for very short lengths this rule may be ignored.

A simple rule of thumb is if it takes x steps to walk directly up a hill, and it takes $2x$ steps to walk on a zig zag, the angle of the zig-zag route is less than half that of the direct one. This figure illustrates a possible switch back design with twice the length to walk and an angle less than half the original:

```
#| echo: false
raw"""
Why half?
Let ``\sin(\theta)=1/x`` , ``\sin(\gamma) =1/(2x)`` then
``\sin(2\gamma) = 2\sin(\gamma)*\cos(\gamma) = 2/(2x) * \cos(\gamma) = \sin(\theta)*\cos(\gamma)``
So ``\sin(2\gamma) < \sin(\theta)``; as ``\sin(x)`` is increasing over ``(0, \pi/2)`` we have
"""
= pi/6
y = 1
x = 1/sin()

plot(Shape([0,x,0,0],[0,0,y,0]);
      legend=false, aspect_ratio=:equal,
      axis=([], false),
      fill=(:gray, 0.05))
```

¹*Trail Solutions* IMBA's Guide to Building Sweet Singletrack

```

S1 = Plots.scale(Shape([0,x/3, x/3, 2x/3, x/3, x/2, 0, 0],
                      [0, 0,-1/6,-1/6, 1/4, 1/2, 1, 0]), 2, 1)
S2 = Shape(S1.x[2:3], S1.y[[2,5]])
S3 = Shape([S1.x[6], S1.x[6]], [S1.y[6], 1/16])
plot!(Plots.translate(S1, 3x/2, 0),
      fill=:gray, 0.05)
)
plot!(Plots.translate(S2, 3x/2, 0))
plot!(Plots.translate(S3, 3x/2, 0))

```

3.1.2 2. The ten percent average guideline

The half rule applies for a small section of trail; the ten percent average says the end to end grade should be no more than 10 percent. (1000 feet over 2 miles is an example.)

We have generally been conservative here.

3.1.3 3. Maximum sustainable grade

The maximum grade is the maximum slope of a section of a length more than 10 feet. It is said 15-20 degrees is the maximum. For hiking trails, we've aimed for 10 degrees. Factors which can change the maximum slope are: soil type, rock, rainfall, grade reversals, number of users (more users, less slope)

3.1.4 4. Grade reversals

A grade reversal means varying the slope of the tread from downhill to uphill. Any water flowing along the trail will fall to the changeover where it can be removed off the trail with a knick (semi-circular shaved down section of trail). Grade reversals are laid out when the new trail is built.

3.1.5 5. Outslope

Outslope is recommended to be 5 degrees. This encourages water to flow off the trail.

Of course, one can't outslope the trail tread 5 degrees if the hill slope is less than 5 degrees. It isn't advised to put trails on flat ground, as it is difficult to manage water flow.

Road construction offers an analogy: a road is crowned online its middle and slopes outward to both edges. This encourages water flow to the edges. At the edges curbing (often Belgian

block) is used to constrain the water flow parallel to the road way. If this is not present, erosion at the road edge is common.

The outslope is similar to the crown. Also important is the **avoidance** of mounds on the trail edge that act like curbing. Unlike a road, water flow should flow off the trail and *not* parallel to the trail. Berms naturally build and may be knocked down by foot.

```
#| echo: false
#| fig-caption: Cross section showing outslope of 5 degrees, benchcut of 45 degrees, dirt to
hill_slope = 30*pi/180
outslope = 5 * pi/180
width = 24
x = -width * cos(outslope)
y = width * sin(outslope)
p = (x=x,y=y)
q = (x=0,y=0)
# solve((x - sqrt(2)/2 * t ~ -sqrt(3)/2*s, y + sqrt(2)/2 * t ~ 1/2*s), (t,s))
r = (x=-51.62, y=29.8)

plot(Plots.Shape([r.x, r.x, q.x], [r.y, q.y, q.y]));
  legend=false, aspect_ratio=:equal,
  axis=([], false),
  fill=(:gray, 0.1), line=(2,))
plot!(Plots.Shape([r.x,p.x, q.x, r.x], [r.y, p.y, q.y, r.y]);
  fill = (:gray, 0.3))
plot!([p.x,q.x],[p.y,q.y], line=(5,), color=:red)
plot!([p.x, p.x, q.x], [r.y, p.y, p.y], line=(1, :gray, :dash))
annotate!([-15, 1.5*sin(outslope), "5 "],
          (-5, 2*5*sin(outslope), "30 "),
          (-30, 15, "Benchcut"))]
```

The figure shows a cross section of the trail. The tread is in red. The 5 degree outslope is about 5 inches over 5 feet, which coincides with the width of the head of the **McLeod** and its handle length. This allows eyeballing the correct slope by placing the head on the tread and ensuring the end of the handle is just about over the edge of the head. Even more informally, 5 degrees is just about the angle where one feels pressure on the downhill side of ones shoe when pointing in the direction of the trail.

3.1.5.1 Benchcut

The figure shows the benchcut needed to make an outslope of 5 degrees when the hill slope exceeds 5 degrees. The dirt should be removed and broadcast widely to hide the activity.

Benchcuts should not be too steep (the one in the figure is 45 degrees).

The interface between the benchcut and the tread should not encourage water flow down the trail – it should be smooth

Take care when roughing out the trail so that the top edge of the benchcut is a smooth line in the direction of the tread. The benchcut will guide walkers to stay on the trail tread during the months when leaves have fallen on the trails.

3.1.6 Trail layout

A new trail is first sited roughly using ribbon to mark out the passage. New trails should consider not just water flow, but also purpose. The trail systems is quite mature and new trails are likely not needed anymore. In the event a trail is to be designed, try to incorporate natural features (large rocks, streams, viewpoints, ...) in the design. New trails should avoid excessive growth, like grass or ferns which indicate an abundance of water.

When designing the trail path, think about reverse grades.

After roughing out the trail, a clinometer is brought in to assess the angles to ensure the trail does not exceed the slope requirements suggested.

A trail is then flagged with pin flags. We flag the *uphill* part of the trail, where a bench cut would be set. (The bench cut would connect the flags in a straight segments).

When there is a switch back, two pin flags are used to indicate a switch of uphill side.

The tread width is 18-24", about shoulder width or a bit wider for single track. Making the trail wider is counterproductive. We want footsteps to compact the trail inhibiting vegetation.

The creation of a trail tread involves several steps:

- move any leaves *uphill* of the intended trail. (These will be used at the end to cover off-trail dirt.)
- use an adze hoe or McCleod to make the bench cut
- remove the wedge of dirt needed. Dirt should be broadcast down hill; not lumped into an unnatural pile
- We aim to remove the *organic* dirt from the tread. Organic dirt holds moisture and leads to mud, not water flow.
- Some rocks may stay – if large and anchored; others are dug out. It is not recommended to try and fill holes that are made – it is better to leave large rocks, not large holes.
- Small roots should be cut; larger ones left. (Though roots which may encourage water flow along the trail should be removed.)
- Once roughed out, use the McCleod to smooth the trail in the direction of the tread.

- Ensure the trail has proper outslope and no berm on the downhill side. Do not put rocks or limbs on the downhill side (a path to Grandma's house), as this inhibits water flow off the trail.
- Use the head of the McCleod to tamp down the loose dirt
- Use the reserved leaves to cover up any dirt and form the downhill edge of the trail

i Not what is in the IMBA guide

The IMBA guide suggests this order:

- dig the tread
- cut the backslope (bench cut)
- outslope the tread
- compact the tread.

The order above prioritizes the initial bench cut to give a cleaner edge to the finished trail.

i Trail building is slow

Trail building proceeds at a slow and steady pace. Trying to do too much results in poor, unsustainable trails.

i Organic soil removal

Trail building for the uninitiated might seem easy, just scrape the grass or leaves away and you have a new trail. However, it is much more involved. Beyond managing the layout and the slopes, another key is the removal of the organic top level of soil. This layer is formed by the decomposition of leaves and in general is a good thing, as vegetation is likely to grow faster and bigger in organic soil.

However for a trail, we want soil that does not retain water, rather sheds it. We want soil that can compact, and inhibit vegetation. The soil under the organic layer in the SMC is usually clay-ey and is desirable. Organic soil is darker and fecund looking; clay is less dark and compact. When removing the organic, we look for a color change. Depending on location, organic soil can be 1/2 inch to several inches deep.

3.2 Existing trail

Water management for *existing* trails is different. In the South Mountain Reservation, much water flow is engineered by the use of swales and culverts to **not** flow as sheets along the surface. For such concentrated flows, simple trail design as above is not enough.

We mention here a few techniques to manage water flow once it has aggregated.

3.2.1 Fords

Fords are designed to allow water to flow *across* the trail. This water is already channeled, as can happen through uphill engineering (drainage of culverts for example) or natural water flow.

The design for fords takes *two* basic shapes: a trench or a smoothed out crossing.

3.2.1.1 Trenches

Trenches are commonly reinforced on the edges with rocks, a common design on the trails dating to the CCC days. Most of these are *also* accompanied by uphill drainage collectors, often in the shape of a “Y” – with two collecting arms and the bottom of the “Y” forming the ford. The collecting arms may also be called drainage swales.

The width of a trench has a few constraints:

- If a trench is too narrow, leaves will get caught on sides and block water flow
- The trench can't be wider than a single step across for a hiker. This means *maybe 18"* maximum.
- If they are wider than a bicycle wheel can comfortably cross, the bicylists will *often* put in a rock to cross the ford **thereby defeating the purpose** which is for water to flow through the ford.

The depth of the trench and the width determine the cross sectional area which must be large enough to accommodate peak water flow.

The following illustration shows how a wheel of a given radius flows over a ford. In this illustration the ford is kept fixed and the radius varies, unlike in real life where the radius of a wheel may be $29/2$ inches.

```
#| echo: false
#| eval: false
function f(R=29/100)
  ts = range(-2, 2, 251)
  f(x) = 1 + sum(sinpi(k*x)/k for k in 1:2:17)
#  R = 29/100 # inches
function wheel(c, x)
  s = range(0, 2pi, 100)

  (x .+ R .* cos.(s), c .+ R .* sin.(s))
```

```

end

y = -2R
xs = vcat(ts, reverse(ts), first(ts))
ys = vcat(y .+ zero.(ts), f.(reverse(ts)), y)
poly = tuple.(xs, ys)

ips(c,x) = sum(inpolygon(pt, poly) for pt in zip(wheel(c,x)...)) - 1/2
g(x) = find_zero(c -> ips(c,x), (0,2 +3R))

as = range(-1.75, 1.25, 251)
bs = f.(as)
cs = g.(as)
plot(as, bs, legend=false, aspect_ratio=:equal)
for (i, (a,c)) in enumerate(zip(as, cs))
    iszero((i-1) % 3) || continue
    us, vs = wheel(c, a)
    plot!(Plots.Shape(us, vs), fillcolor=:gray, fillalpha=0.001, linewidth=0)
end
plot!(as, cs; linecolor=:red)
current()

anim = @animate for r in 0.2:0.1:1.5
    f(r)
end

imgfile = "construction_graphics/trench_size.gif"
gif(anim, imgfile, fps = 5)
nothing

```

The red line shows the axle of the wheel.

While not the strongest illustration, the point to take away is:

- the animation shows what would happen were the trench twice the width of the wheel (bumpy) to half the radius of the wheel (smooth).
- if the trench is too wide for wheel – when the trench is wider in the animations – the wheel will not roll smoothly (leading mountain bikers to act). The wheel is typically

around 15 inches in radius, and anything bigger than 12" would be problematic.

Most of the current fords are much narrower, maybe 6-8 inches across. It is believed 8-12 inches is a better balance between allowing sufficient water flow while providing a good experience for both hiker and biker.

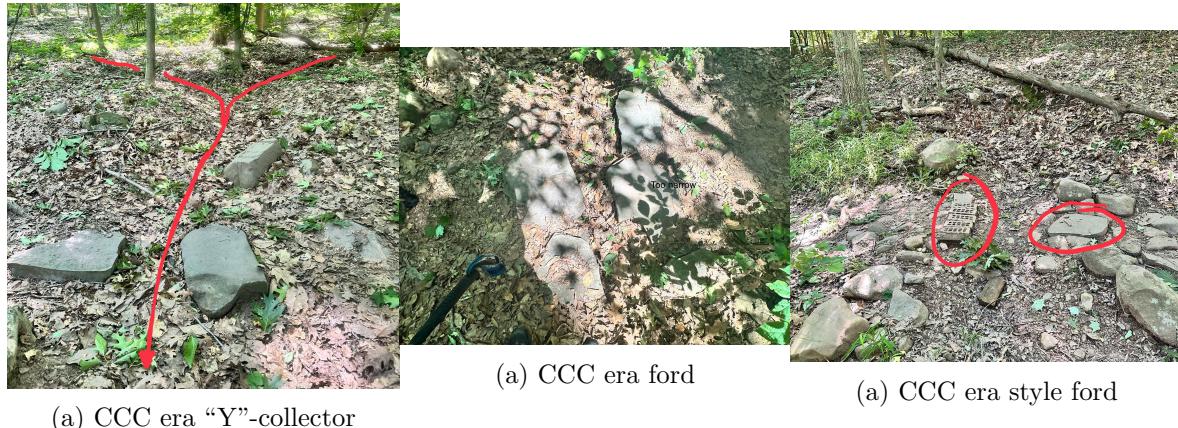


Figure 3.3: Two CCC fords and a new one in the style. On the left is hint of the "Y"-collector design. The stones for the ford could be re-positioned. The middle figure shows a too-narrow part. Though hard to see in the photo, there is much leaf accumulation in the narrow part which inhibits effectiveness of the ford. The right figure illustrates two issues: use of non-natural materials, insufficient size for stepping rock.

3.2.1.2 Fords

A better design is to use a smooth entry and exit for the bicycle rider. The figure below illustrates three possible cross sections. This design allows the same *cross sectional area* as a trench (important so water can flow during peak times) by varying the width and depth, but is smoother for the user.

```
#| echo: false
f(x) = cospi(2x - 1)
g(x) = 1/2 + f(x/2)/2
x = [-1/2, -1/4, -1/4, 1/4, 1/4, 1/2]
y = [1, 1, -1, -1, 1, 1]
plot(f, -1/2, 1/2; legend=false, axis=([], false))
plot!(x,y)
plot!(g, -1, 1)
```

The suggested design would be about 2 feet across and 4-5 inches deep.



Figure 3.4: A smooth ford that is both effective and unobtrusive on Turtleback Connector

i Takeaway

For existing trenches, make sure they are clear and sufficiently wide to not catch leaves.
For new fords, use a smoother design for better trail experience.

Do **not** design new fords so deep that you want to put a rock in the ford to facilitate the step over – this defeats the purpose of the ford. Wider is better than deeper for the user.



Figure 3.5: Example ford dug so deep a rock is placed to step/ride across

For heavily traversed areas, Belgian block reinforced fords have been used.

In addition, fords may gather *sediment* over time, reducing the amount of water that can flow across in a given period of time. This is due to water slowing down at the ford. Slower water can carry less sediment, so when the flow slows, sediment will be dropped.

Water slowing down can happen for several reasons:

- the downhill angle of the ford is less than the downhill angle of the uphill waterflow
- the width of the ford is narrower than the width of the water flowing into the ford.
- The ford narrows at a point
- the ford has a bend
- there is inadequate downhill drainage for the ford

All of these should be considered when creating a new ford and minimized as best as possible

to reduce the need for future maintenance.

New ford construction

The suggested new ford construction then would be:

- Site fords where water is crossing or entering the trail. Often such water is channeled above the trail.
- Use “Y” collector design to capture as much surface flow as possible
- Ensure sufficient water run off so that water won’t back up into ford or flow back onto trail downhill from the ford

“Y” collectors may do *two* things:

- collect water running along surface during heavy rains *and*
- capture groundwater as it moves downhill after a rain.

The former leads to a necessary design of a 4-6 inches of depth, more on steeper sections. The latter is different. Groundwater mostly runs between layers of soil: the organic and the more compacted inorganic. When there is groundwater seepage, The depth of the “Y” collector arms should be at least a few inches deeper than this soil boundary.

The arms of the “Y” collector (drainage swales) should be sufficiently off the trail to not be a tripping hazard for walkers. They should run downhill – not on a contour. They should be a straight as possible. They will likely have vegetation over time or be filled with leaves. When constructing – like all *off-trail* features – they are ideally covered with leaves to mask their presence.

3.2.2 Water bars

Fords allow channeled water to cross over a trail in a perpendicular manner. A *water bar* is used to move water that is flowing *down* the trail off the trail.

Water bars may be constructed of rock or wood, but we use rock harvested on the site to create water bars. This ensure the longest lasting, most natural looking waterbar.

The placement of a waterbar considers

- a waterbar should capture the waterflow as early as possible
- if designed well, they should capture all the water coming down the trail. They need not be spaced close together

The design of a waterbar²

²The AMC’s *Complete Guide to Trail Building and Maintenance* is consulted here. Waterbars are not favored in the IMBA book, as knicks and other on-trail drainage provides a better biker experience.

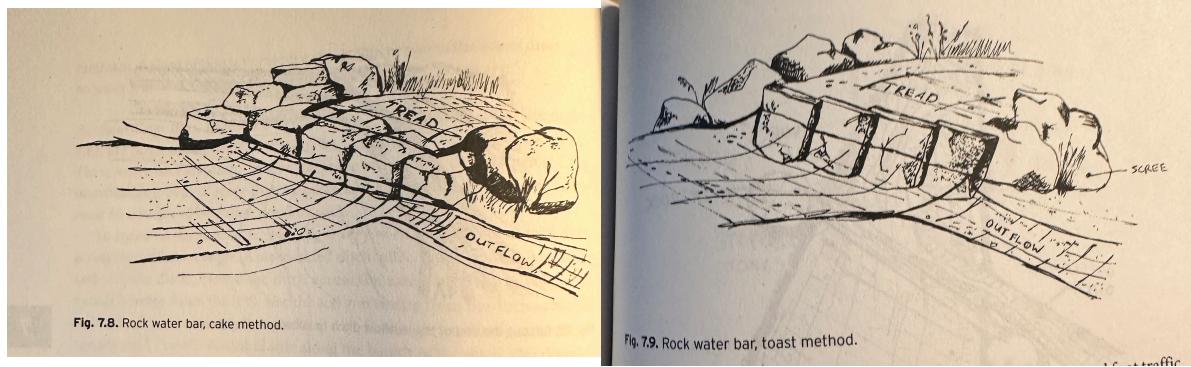
- the should be at a 45-60 degree angle to the trail. As the water slows down on hitting a waterbar, there will be more sediment buildup were the water bar at less of an angle

```
#| echo: false
theta = 60
x=[0,1]
y = [sind(0), sind(60)]
plot(x, y; legend=false, aspect_ratio=:equal)
vline!([0,1], line=(:gray, 0.5))
annotate!([(0.1,.05, " ~ 45-60 degree", :left)])
quiver!([0.5], [0.2], quiver=[[0.0],[0.5]])
```

- the waterbar is a vertical feature, like the curbing on the road. It does not include a swale in front of it. Swales will only fill in with sediment over time. (This is not necessarily suggested by the AMC, but experience shows otherwise.)

Waterbars are made of rocks. The face of the waterbar should extend up 4 inches. (Like the curbing on a road.) Ideally rocks can be found to allow for shingling so water does not seep through the interface between two rocks.

The AMC describes two styles: the *cake* style where large flat rocks abut each other giving a place to step on the top of the water bar and a flat face for the water to flow across; the *toast* style uses shingle like rocks (overlapped) and are generally narrower and not meant for stepping on.



(a) Cake

(b) Toast

Figure 3.6: Two waterbar construction styles. (AMC)

Waterbars should have rocks *solidly* anchored in place. Anchoring a rock requires a few things: first the rock should be sufficiently large so 6-10 inches of rock can be buried below the surface. Next, dig a “grave” for the rock as tight as possible. Then hammer (with a pick or large rock) pointed rocks on the side of the rock to firm up the placement. Back fill with gravel or smaller rock, then use dirt to cover.

Anchored

Any rock on the trail should not rock when stepped on and should definitely not be loose. This requires the use of large rocks. Do not expect rocks to “settle.” They should be solid when the waterbar is constructed.

Rocks placed on the side of a water bar force the users to stay on the trail. If not anchored, these should be piled large enough to discourage being stepped on.

For hikers and bikers adding packed dirt to the height of the *downhill* portion of the waterbar allows both to smoothly move uphill. The height of the waterbar is not so high to make it difficult to cross going downhill (yet still tall enough to capture and divert strong waterflow).

In the middle of the trail, it is helpful to have a rock placed that has a top face encouraging stepping on. (The cake method has all its rocks so.)

3.2.3 Swales

The engineered design of the woods roads was done by the CCC and involves swales and culverts. In addition, on the trails the CCC used drainage swales as part of the “Y” drainage features. The design of these drainage swales is less critical. We discuss the design and maintenance of the carriage road swales here.

The basic design employed by the CCC when putting in a carriage road had downhill waterflow channeled into an uphill swale running parallel to the road. Periodically the water is routed under the road using a culvert. After nearly 100 years, this design has mostly held up, but there are areas where maintenance is needed.



Figure 3.7: Working swale and culvert on Hillspur carriage road

The peak amount of water a swale sees is related to the surface area of the region draining into the swale and the amount of rain falling. The swale must be large enough in cross-sectional area to accommodate peak water flow, otherwise it will be breached.

The swales are often filled with rock called riprap.

3.2.3.1 Technical design of swales

The following primarily comes from consulting a [State of Mississippi](#) document.

Swales are broad shallow ditches used to capture rainwater.

Swales may be filled with grass or riprap, erosion resistant rock used to slow water flow and inhibit soil erosion.



Figure 3.9: Breach on Hillspur trail leading towards massive downhill erosion. The breach is due to: side flow entering trail; a tree that has grown to block swale flow since the 1930s; deposition of leaves due to water slowing

Drainage swales, as described, are used to divert stormwater into designated fords.

The swales along the historic carriage roads are used to manage larger volumes of stormwater uphill of the road until a culvert is used to discharge the water, crossing under the road to the downhill side.

The design of a swale cross section and lining is based primarily upon the volume and velocity of flow expected in the swale. Riprap-lined swales should be used where velocities are in the range of 5 to 10 ft/sec.

In road construction, Riprap-lined swales are trapezoidal in shape. (The steepest permissible side slope of the swale should be 2:1; Horizontal: Vertical.) In South Mountain Reservation, the swales are “U”-shaped.

We read “outlet conditions for all swales should be considered. This is particularly important for the transition from the riprap lining to a vegetative lining. Appropriate measures must be taken to dissipate the energy of the flow to prevent scour of the receiving swale.” This may not be applicable in the SMR, though there is engineering in the swale as they approach a culvert.

“Lined swales shall be designed to convey the peak rate of runoff from a 10-year 24-hour rainfall event.” We can only assume this calculation was done correctly in the 1930s during the construction.

Design flow depth should accommodate peak water velocity which by the [Manning formula](#) is

$$V = \frac{k}{n} R_h^{2/3} S^{1/2}$$

where:

- S is the bed slope in (feet/feet). Steeper slopes lead to increased velocities in a square root manner
- R_h is the hydraulic radius of the swale. It is basically the cross-sectional area divided by the perimeter. (Water flows slower along the boundary, so perimeter length inhibits velocity.)
- n is Manning's coefficient of roughness (which is modified by the rip-rap; bigger n means slower velocities.)
- k a conversion factor.

The parameters that can be engineered are n (by adding riprap) and R_h .

The latter is manageable. The cross sectional areas of the swale can be impacted by several manageable things:

- often cut logs are placed in swales
- since the 1930s trees may have grown on the edge of swale
- pinch points where leaves collect can cause a reduction in cross-sectional area
- some rip-rap is too large for the use and reduces the area

For the latter, Mississippi gives guidance from the *Design of Rock Chutes* by Robinson, Rice, and Kadavy:

For slopes between 2 and 10 percent the median diameter is given by $(q \cdot \sqrt{S}/4.75 \cdot 10^{-3})^{1.89}$.

In short:

- Bigger swales have bigger qs , so bigger rocks are permissible.
- Bigger slopes allow bigger rocks.

Empirically, softball sized stones seem to be appropriate for larger stones

Mississippi says:

- The layering should be a dense, uniform, and wellgraded mass with few voids. Riprap should consist of a well-graded mixture of stone (size and gradation as shown in design specifications) that is hard, angular, and highly chemical, and weather resistant.
- Larger stone should predominate, with sufficient smaller sizes to fill the voids between the stones.
- The diameter of the largest stone size should be not greater than 1.5 times the d50 size.

- Minimum thickness of riprap liner should be 1.5 times the maximum stone diameter.

Mississippi says for maintenance:

- Inspect channels at regular intervals and after storm events. Check for rock stability, sediment accumulation, piping, and scour holes throughout the length of the channel.
- When stones have been displaced, remove any debris and replace the stones in such a way as to not restrict the flow of water.
- Look for erosion at inlets and outlets.
- Give special attention to outlets and points where concentrated flow enters the channel and repair eroded areas promptly by extending the riprap as needed.

The design of swales in the SMR, and elsewhere, at an outlet (a culvert) is to give a slight uphill wiggle in the otherwise parallel-to-the-road route. This encourages water flow into the culvert by bouncing it on the opposite wall or inducing an eddy.

However, this design also slows water, which causes sediment – and noticeably leaves – to accumulate some 5-10' uphill of the culvert. Clearing this should also be added to maintenance.

3.2.4 Principles

Rocks

Tread

Aesthetic

4 Maintenance