Wetland Restoration 101

U.S. Fish and Wildlife Service

Partners for Fish and Wildlife

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Introduction

This tutorial was written by USFWS Private Lands Wildlife Biologist, Scott Ralston. It is put together from his experience with wetland restorations in the Devils Lake Wetland Management District (WMD) in ND and the Windom WMD in MN. Devils Lake has some of the most intense surface drainage issues in ND. Windom is the most intensely subsurface drained and modified portion of MN and has provide ample opportunities to learn about tile drainage and complex restorations. This tutorial is based on job experience but is not a substitute for true engineering. Some techniques here are derived from working with and copying engineers plans but much of it has been simplified and generalized for our purpose. Always error on the side of safety and overbuild or consult others if you are unsure of a project.

What are the landowners goals?

- If their goal does not fit with yours then it ends here. i.e they want a 15ft deep fish pond with steep side walls and you want shallow waterfowl pair ponds.
- Educate. Explain what types of wetlands benefit wildlife the most, limitations of the landscape and native conditions of the wetland in question.
- If needed compromise if the end result can provide adequate benefits to wildlife and still give the landowners what they want to see. Example a wetland with a deeper pocket for open water the landowner wants to see with shallow water surrounding for more waterfowl benefit.
- If their goals can match yours then move on to do a site evaluation
- Both in on and off site evaluations keep an eye open for possibilities that the landowner has not inquired about. They may envision only one opportunity and you many identify an alternative that they had not seen but is acceptable or at least negotiable. Almost all restorations are a give and take. It was drained for a reason which likely had a positive economic benefit at the time so the restoration is gaining its own wildlife, sporting and conservation values but the landowner is giving something else up so this is a negotiation process and your job is to get the best deal for wildlife. Never assume the landowners proposal is the only option. If you do your biology right, in the end the results will show themselves and the landowner will appreciate the work. If you make a big deep farm pond that the landowner had thought was the ideal thing for wildlife but it never holds a duck then they will be disappointed.

Site evaluation.

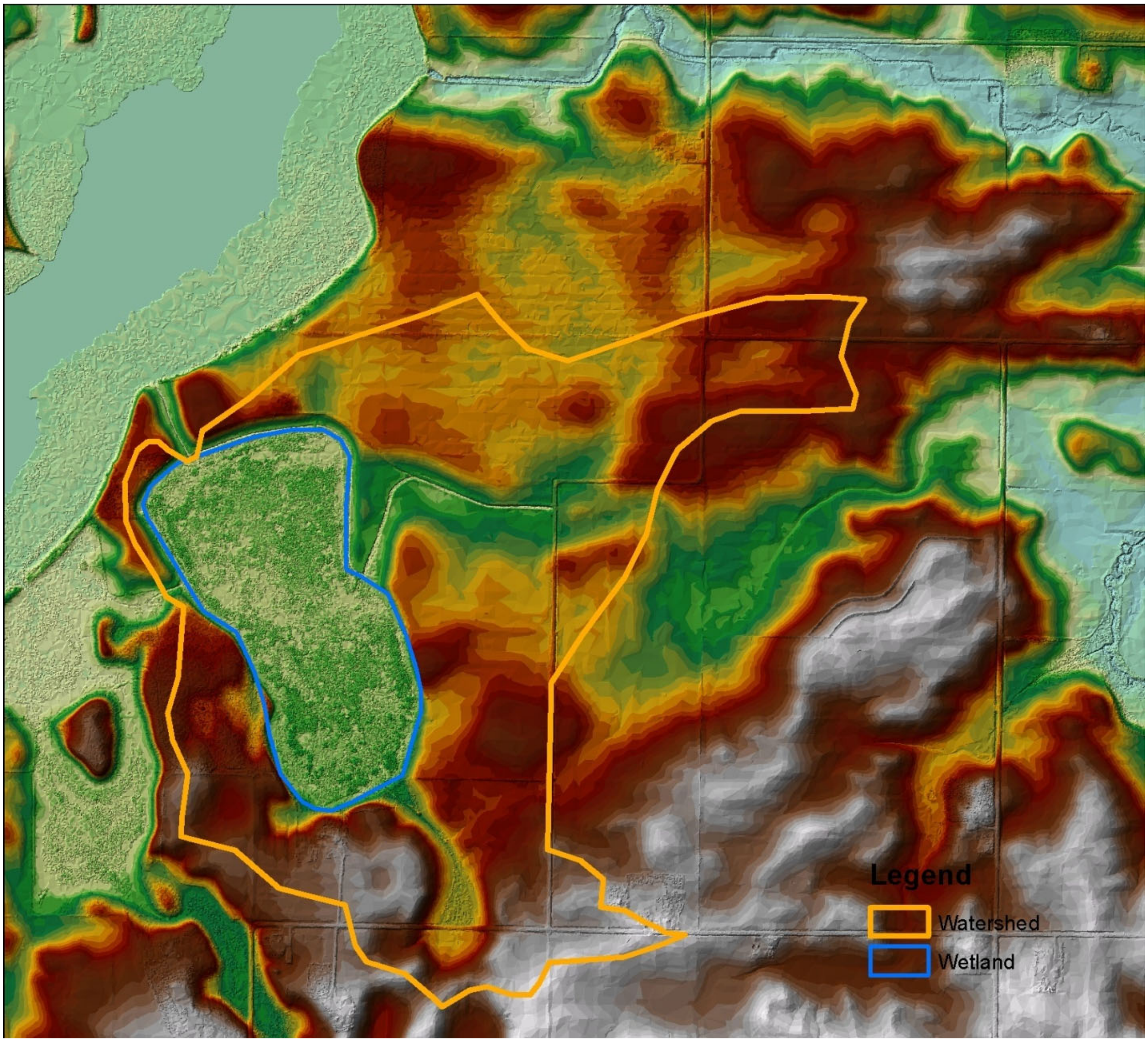
Is it a wetland? Hydrology, Soils & Vegetation

- If Yes it is a wetland then is it the regime that it is supposed to be or has it been degraded or modified? If it is appropriate then leave it alone. If it is degraded or non-functioning then restore. We do not do type conversions for the sake of more water unless biologically justified
- If No, not a wetland then the option is do you have the need and ability for a creation? Creations are not a bad option if there is the lack of achievable native restorable wetlands and the landscape supports conversion. Creations are often more costly however.

Check your soils. Even wetlands that have been drained for many years will have hydric soil indicators to tell the history of the site as well as can identify limitations such as sand or gravel below.

Remote Tools: Evaluation off site first. Save time & money

- There are many things you can see with off site tools and sometimes rule out things based on remote evidence such as LIDAR showing there is no way to restore a basin without flooding the neighbor. You may eliminate the need for extra time and travel for a field visit. Never do all your planning remotely but you can identify many possibilities and then confirm with an onsite visit. If you use GPS, map out areas or points of interest such as tile lines etc to get you close to the right area to search on the ground.
- Aerial Photography: Use as many years as possible to see diversity through time. Spring photography if available. http://datagateway.nrcs.usda.gov/ or http://www.mngeo.state.mn.us/chouse/airphoto/
- Lidar: Great tool for topography. See depressions, extent of possible water, area of impact, micro watershed. http://www.mngeo.state.mn.us/chouse/elevation/lidar.html or https://www.dnr.state.mn.us/maps/mntopo/index.html
- Previously mapped wetland layers: NWI (National Wetlands Inventory), RWI (Restorable Wetlands Inventory), State protected lakes, rivers, streams layers, County drainage layers if available. https://gisdata.mn.gov/
- Soil Surveys for Hydric Soils. http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx



LIDAR data as seen above is a VERY valuable tool in wetland restoration planning. If it is available in your area learn to use it! Topography is show in very high detail with MSL elevations. Even in areas that don't have LIDAR there is commonly USGS DEM data that is often 10 meter resolution that is fairly good for watershed level work. See LIDAR attachment in supplemental materials.

On Site Evaluation

Drainage: Tile or Surface? Ditches, intakes, outlets, blowouts etc. Elevations of flow lines? Ability to block? Ability to outlet in wetland without impacting non-target areas? Ability to reroute under or around if needed?

Look for signs of drainage such as this tile blowout. If the site is being restored then there must be a reason such as drainage couldn't keep up so blowouts like this are common on restoration sites. Use this as a point to identify tile direction and elevation.

Water Budget? Diversion?: Is there enough incoming water through runoff or stream, channel or tile flow to fill the wetland within its regime? Too much water so change regime?

Examples: if you want a temporary wetland but outlet a tile into it which flows constant it may change into a semi-permanent? Or if you are looking for brood/semipermanent water but drainage has diverted most of the watershed around or under your wetland you many not get more than a temporary in average years.

Water budget Example: Very rough figure of half of rain will soak in and half runoff (variable with slope, landuse & soil types) so if watershed that is inputting to a wetland is 100 acres and you estimate 12 inches of rain in a given time period (a month in spring) then 6 inches runoff over 100 acres = 50acre ft of water will end up in the basin. If the wetland is 25 acres then it would be 2ft deep which would be a reasonable watershed for a seasonal or small semi-perm wetland. If the watershed is 20 acres, the wetland is 10 acres and the landowner wants you to build a big dam 10ft deep to make semi-permanent *water you can see it would not be worth the cost because there isn't a water budget enough to fill it more than 1ft deep in average rainfall for an entire month thus you would only have a temporary wetland no matter how high you build a dam.*

Personal Knowledge: Ask landowner about history of the site or contact those that know it (neighbors) and tour the site with you if possible. Tile or drainage maps available? Does the wetland ever overflow on its own?

Vegetation: Appropriate or not? If appropriate for the regime then it is not worth disturbing or identify areas to avoid disturbance. Hydric vegetation in areas of drained wetlands that have become upland can indicate subsurface water such as linear lines of reed canary, thistle, doc or just more vigorous growth can locate tile below.

The photo above is a vegetation indicator over a tile line. It is a drained wetland where it was difficult to find the tile. However notice the line of redish brown curly dock running through the middle of the wetland down the center of the photo. Doc is a water loving plant and is growing over the tile line running with water. Also the patch of thistle (white area already went to seed) with the tile probe sticking out of the middle of it in the foreground on this same line is also an indicator since thistle likes water also. Look for these linear patterns as possible tile locations.

Survey

Before starting a survey identify goals and needs so you know if you need to survey and if so what information is pertinent. Surveying is time consuming so be efficient.

Equipment needed: Laser level (preferably self leveling), Tripod (preferably telescoping head), staff/rod (25ft), laser receiver & mount for survey rod, extra batteries, GPS (preferably with ArcPad and any GIS layers available for site plan), GPS bracket to mount to rod, pencil, paper, aerial photo/map, calculator, extra batteries for equipment, survey flags or stakes, 100ft tape measure, tile probe if needed, hammer & large nails or rebar if TMB is needed or pounding in stakes, tiling spade/shovel, ATV

In the absence of a survey grade GPS, tie a standard GPS to your laser level staff. If available use a GPS with ArcPad or smartphone or tablet with ArcCollector and record all elevations with your GPS points directly on screen and later import into GIS for post processing.

Make a Plan: If a survey is needed, identify areas you need elevations for and make a plan. General points for surveying are: basin bottom/pool depth, find native or proposed pool level (hydric indicator lines, trash lines, overflow point etc), drainage infrastructure, tile intakes & outlets & flowlines, culvert top and invert, natural low points/overflow or outlets, ditch bottom and tops, impact areas or maximum extents such as low points on property boundaries or any point that can not be flooded. Elevation profile of ground over installation routes such as dike footprint or tile install route.

Generally I do an initial site review first such as marking tile routes etc so I don't have to drag the laser equipment all over the site and have the battery running on the laser while I am just searching for general infrastructure.

Set up Laser: Identify good location to set the laser and if turning points will be needed. Laser placement needs line of sight to all areas to be surveyed. It must be higher than any point to be surveyed. Stand at the proposed station location and see if you can see all points you need shots of. Must be within distance/capabilities of the laser (~500 yards depending on your equipment). Must be within the vertical height range of the staff (20ft). and when possible be at the lowest end of that vertical range (less staff height is more stable). When possible one laser location should cover the entire area. If needed multiple station locations can be used for complete coverage as long as they are tied together with a common point called a turning point so elevations can be compared.

Benchmarks: Identify a Benchmark (BM) or Temporary bench mark (TBM). BM is a permanent established monument such as a USGS or DOT geodetic monument with known location usually tied to MSL (http://www.dot.state.mn.us/surveying/Geodetics/geodetics.html)

TBM is a point you establish as a point to relate to all other points. It may or may not be tied to MSL. It should be a hard point unlikely to move in the near future or within the time frame of the project and not be where it would be impacted by construction. This could be a large boulder, a road culvert or point on a bridge, corner of a foundation, head of a large nail pounded into a solid fence post or utility pole or a long rebar driven into the ground and marked/labeled. I generally have multiple TBM's on site in case one is moved or destroyed. The permanent road culvert that you used may be changed by an unforeseen road construction.

Once you have all equipment and have a plan, set up the laser. Make sure the tripod cleats are pushed in and it is as stable as possible with all screws tight. If it is self leveling, get it generally level and turn it on. If it is not self leveling use the mirror and level bubble at the bottom to level it and tighten the locking screw. If it is windy, keep your range pole heights to a minimum as the range pole extended will bend in the wind making it hard to control as well as make it difficult to get an accurate elevation shot. Wind can also cause vibration in the laser or rock the tripod which is amplified with further distance so the laser beam may bounce up and down a few tenths or more. In windy conditions you may need to restrict your survey area with 100 yards or less from the station and 10ft or less in vertical height. Laser's need line of sight so rain fog or snow can decrease the range as well.

GPS your laser location so you have a record for future site visits.

Always have at least one benchmark on your survey. Temporary benchmarks can be fixed objects on site such as a large rock or place your own such as a rebar driven into the ground and staked and labeled. If available you can use a Geodetic Survey Benchmark such as the bottom photo and record the number off the plate to look up the msl of that point online.

Collecting elevation Points

Shooting Elevations: The term "shoot" is used for an elevation reading of a particular location. There are multiple methods for how people use range poles/staffs/rods. The standard method is mount the laser receiver at the top of the range pole, thus the lowest reading you can take is about 5.6 ft. which is the height of the staff fully collapsed. The laser level then must be positioned 5.6ft higher than the highest elevation you need to survey. If you find the need for a position lower on the rod than 5.6ft during your survey you can take the receiver off and hand hold it down the fixed portion of the staff to take a reading.

Reading the Rod: Go to a point you want to survey. Keep the bottom of the rod firmly on the ground or object you want to measure and keep the staff as vertically level as possible. When the receiver is mounted at the top of the staff you should read the height where the last extended segment inserts into the sleeve of the collapsed segment. On most survey rods there are two sets of numbers. The first outer rod section counts up from the ground. From there the two sides of the rod differ. One side continues sequential measurements from the largest segment to the smallest segment so the top of the smallest segment is 25ft or full rod length. The other side of the rod measures distance from ground to top of the rod as you pull out each segment starting with the smallest section going to largest. The numbers are usually red. Use this red numbering side for your survey shots. Numbers are in tenths and hundredths of a foot. Record that number which is the height between the ground and the laser beam. Further explanation of the survey number reading will be expanded below. Pull each segment out in consecutive order from the smallest to the largest. As each segment comes out make sure it locks into position. *Note there are spacers nested down in the bottom of each rod segment so each segment sticks out an inch or two above the next. Leave these spacers in or the scale on the rod will be wrong.* The most important thing to remember is the numbers are all relative so just do your readings the same every time.

Receiver: Depending on your receiver it may have an eye that can see the laser beam only on one side (about 160 degree view) or some may cover a larger area such as 280 degree. Make sure the eye can see the laser

Generally there is a range of about 2 tenths of a ft vertical that the receiver can see the laser. As you raise the staff in the air the laser will hit the top part of the receiver first and it will beep slow and lower pitch. Continue to slowly raise the rod and when it hits the center of the receiver it will be a solid midtone beep. This center point is where you want to make your reading off the rod. If you continue to raise the rod past center it will have a faster and higher pitched beep which means you are too high. Unless you are in very calm stable conditions close to the receiver it is often hard to get and keep the solid center beep. Just slowly raise or lower the rod until you get the tone switch and use that point. You can waist a lot of time trying to get an exact steady tone and in most cases at the point you are hearing a tone change you are within a few 100^{th} ’s of a foot so determine how accurate to you really need for your application. For real quick work where accuracy is less important, remember the size of the eye is only 0.2ft so if you get any beep at all, you are within 2 tenths of a foot so record and move on. Except for benchmarks or solid objects, general ground shots can be within a few tenths and not make a big difference in your planning.

Shooting Order: The order of shooting locations doesn’t really matter, however I generally start at a benchmark or TBM so I have a fixed location to relate everything else to just in case the equipment would fail or for some other reason you can’t finish the entire survey in one session. I then like to survey my proposed pool elevation if that is known or if unknown or yet to be determined, survey the limiting factors such as low point on property boundary or natural overflow point. Once water levels are determined you can find and survey elevations for anything else that may be impacted such as tile lines, ditch elevations, spillway areas, dike areas etc that are relevant in the engineering. Some random ground shots are nice or do a grid pattern if you want to know general landscape dimensions. If you find a specific location that is important to return to, mark it with a flag or stake such as marking a tile line. You should also have a GPS point.

Shoot elevations for anything relevant to the restoration such as ditch bottom, ditch top, drainage features and limiting factors.

Impact avoidance: anything you need to avoid flooding such as you don't want to back water against a road, submerge a tile outlet, back into a culvert or a non-target property line or cropland; make sure to survey those locations in detail. Also then estimate maximum bounce of the wetland (default design is often 2ft but can vary greatly based on watershed input rate, outlet size and wetland size) and survey elevation and location where maximum pool can be with allowable bounce/head room.

Fishing for an elevation: Rather than finding the elevation of a desired location, the survey rod can also be used to find the location of a desired elevation. If you have a known elevation such as a desired pool elevation and you want to know where on a hillside slope that waterline will be, rather than shooting many shots on the way up or down the hill until you find the right spot, do the calculation to determine what the rod would read at the desired elevation. Then starting at the bottom of the hill, keep the receiver pointed toward the laser and carry the rod as close to the ground as you can and walk uphill slowly until it beeps which you then know you are within a couple inches vertically of the desired spot. Move the rod up or down on the ground until you get to the constant tone or tone change and you found your location for that elevation.

Visualizing depth: The survey rod can also be used to visualize an elevation such as water depth or dike top height. Similar to the fishing method described above, set your rod height to the appropriate reading corresponding to the elevation you want such as the proposed water pool level. Walk down to the bottom of the wetland and raise the rod off the ground until it beeps. You can then have a visual of water depth will be even with the bottom of the survey rod. This is also a good method to use when working with contractors on building a dike or berm. As they build it up you will need to check their height. Set the rod to the desired dike top reading. Standing on the dike hold it off the ground at the elevation where it beeps and signal to the contractor on their next pass with the scraper they have that far to go to fill dirt to the bottom of the rod. Alternatively in the same dike scenario if the bottom of the rod is on the ground and you need to tilt the rod to the side in order to get it to beep then the dirt is too high.

Note on tile lines: Survey ground level over the tile. Push tile probe down to the top of the tile and measure the length of probe from tile to ground for tile depth. If possible push/punch probe through tile to measure length again to get the size of the tile and depth to flowline. If an open intake is available survey top and you can get depth down the bottom of the intake. Run tile probe down to top of tile just outside the intake and subtract from flow line shot inside the intake to get tile size. Don’t forget about backing water underground. Wetland restoration impacts in tile areas must factor in the restoration water level in relation to the tile flowline elevation not just the ground elevation. You can back water inside the tile onto a neighbors property and cause problems and be liable for damages even if the surface water is nowhere near the property line. Tile lines filled with water also are more prone to malfunction and don’t flow at the same rate as an empty tile so if you flood a tile you may reduce it’s function. You may need to consider outleting it if you have the elevation drop needed to shallow the grade and pop it out of the ground above pool level, reroute around the wetland, run non-perforated tile under the wetland or modify your restoration design to avoid.

To shoot the elevation of a tile, get the elevation at ground level, then push your tile probe to the top of the tile and measure the length of the rod in the ground.

Culverts: survey the top or invert (bottom of curve) and measure diameter to get the other value or just survey both and subtract to get diameter. Sizing is often important in notes for general hydrology information.

Survey in water: If there is water on the site and you need to survey the wetland bottom, shoot the top of the water, then go out with waders and a survey rod without receiver to get water depths and add that to the elevation of the surface. Less equipment hauling into the water is safer and less cumbersome.

Trees: Shooting through trees the signal may be intermittent so wait as the wind blows and moves leaves or branches to get a signal or move the rod back and forth.

ATV Transport: If using an ATV, take the receiver off when you get on the ATV unless the receiver mount is very strong. Bouncing at the end of the survey rod you can loose and run over the receiver if the clamps aren't tight or the brackets can break.

Measuring with Staff: If you are surveying the site on foot reduce the number of tools to take with you. Remember the survey rod can serve as a tape measure up to 25ft or the length of your staff. This can be helpful when staking out a dike where you walk down the centerline, shoot the ground elevation and subtract from the planned dike top to get the height of the dike in that location the multiply dike height by the slope rate (such as 3 for 3:1 slope) and add half the dike top width and that is the distance out from centerline to mark the toe of the dike. Just start the survey rod at centerline and lay it down extended to the desired length and place the stake at the end. The survey rod will also fit down most tile intakes to measure depth to flowline or lay across the intake to measure diameter. If depth below ground is determined with a tile probe you can lay the probe next to the rod to see the length.

Calculations

The numbers on the survey rod are relevant only in relation to each other. It is a measurement of the height from the ground to the laser beam. The laser beam elevation is a fixed constant value during the survey. So by comparing two different points we can look at the height of the survey rod at each point and if the height of one reading is bigger than the height of the other then the bigger reading is a lower elevation than the smaller reading. It is a little inverse of initial reasoning because a bigger number on the rod equals lower elevation but remember that rod reading is being subtracted from a constant laser beam plane. It may be easier to think of a lake and a depth finder where the laser beam is the water surface and the rod reading is the depth of the water so larger depth number equates to a lower point in the lake bed.

Conversion to Relative or MSL Scale: As mentioned the scale of elevations coming off of rod readings are inversed so it is standard practice to convert to a relative elevation scale or MSL (mean sea level) scale. If you have a benchmark with known MSL elevation then use that as your reference point for conversion calculations. If you have lidar data with a location with wide flat hard surface that is easy to identify on screen then in the field you can get approximate MSL (within 6 inches). To do this use lidar to identify the MSL elevation of the center of a road intersection or other hard surface where lidar would be most accurate then shoot that spot during your survey so you utilize the rod reading from that point with the lidar MSL elevation. If no MSL elevation is known or needed just assign and arbitrary value to one of your points in the survey such as if you use the top of a large rock as a TBM then assign the point as elevation 100ft. Either using MSL or a relative scale you calculate all other points in relation to that known elevation point.

<u>Elevation Formula:</u>

(Elevation of known point – (Rod reading of shot to be determined- Rod reading of known point) = Elevation of shot)

Example: If my Rock used as a TBM I call elevation 100ft and during the survey I got a rod reading of 10.0ft on that rock. I also shot a culvert invert during the survey and got a rod reading of 15ft. What is the elevation of the culvert invert? (100-(15-10)=95ft.

What if then I decided I needed a MSL elevation for the culvert so I can compare it to contour lines from lidar in GIS?

I shot the center of a road intersection and got a rod reading of 8.0ft. Using GIS and lidar layers I identified the center of that road intersection is 1400ft MSL. What is the MSL elevation of the Culvert Invert? You can calculate it in two ways.

First if both the road intersection and the culvert rod reading shots were done using the same survey with the same laser level location you can calculate directly using the same methods as before but use the road intersection as your known point of reference. (1,400ft MSL – (15-8) = 1,393ft MSL on Culvert Invert).

The second method can be used regardless of if the shots of the road and of the culvert were done at the same time. Maybe the need for the MSL was and afterthought and you returned to the location and shot the TBM rock and the road intersection at a later date. We already know from the first survey that the rock we called elevation 100ft and the Culvert was therefore determined to be 95ft. On the return trip I set the laser at a different spot and the rod reading for the TBM Rock was 7.0ft and the Road intersection was 5.0ft. I can now convert the Rock TBM to MSL using the rock as the unknown elevation and the road as the known (1,400ft MSL – (7-5) = 1398ft MSL) now to get the culvert elevation we go back to using the Rock TBM as the reference point and the culvert as the unknown the same as we did in the relative scale calculation (1,398-(15-10)=1,393ft MSL on the culvert).

Of course there are a lot of ways you can run the numbers. The road intersection could also have been converted to the relative 100ft scale of the Rock TBM (100-(5-7)=102ft). Then compare the culvert (95ft) to the road (102ft) which there is a 7ft difference so subtract the road msl from the difference of the culvert (1,400ft MSl-7ft = 1,393ft MSL on the culvert invert). All these calculations can be done in a batch process if collected in an attribute table in GIS or a spreadsheet.

Official Survey Method: If you look at official surveying books or other survey field notes you may notice slightly different notations and calculation methods. The official method differs slightly from what I described above but is essentially using a few different steps to arrive at the same goal. Since I do all my calculations in a batch during post processing I rarely calculate relative or MSL elevations of my survey points in the field thus lump everything into one formula. If you prefer to write it all down in a log and calculate as you go the official method may be a little easier. In the official method, the first shot you take is of your benchmark which is called a BS or Backsight. From your backsight shot and the known elevation of the benchmark you calculate the elevation of the laser beam call HI or Height of Instrument (Known elevation of BM+BS = HI). Once you know HI in terms of relative elevation or MSL then you can shoot any of your survey points which are called FS or Foresight and subtract HI-FS = elevation of that point.

Returning to a site: As mentioned in the example above, if you return to a site to do additional survey work always shoot a BM or TBM used in the previous survey in order to reference the two surveys together using that common point. Your rod reading will change every time your laser level is moved or re-setup due to a change in exact HI. The relative elevation scale or the MSL elevations will remain constant through all surveys on all points.

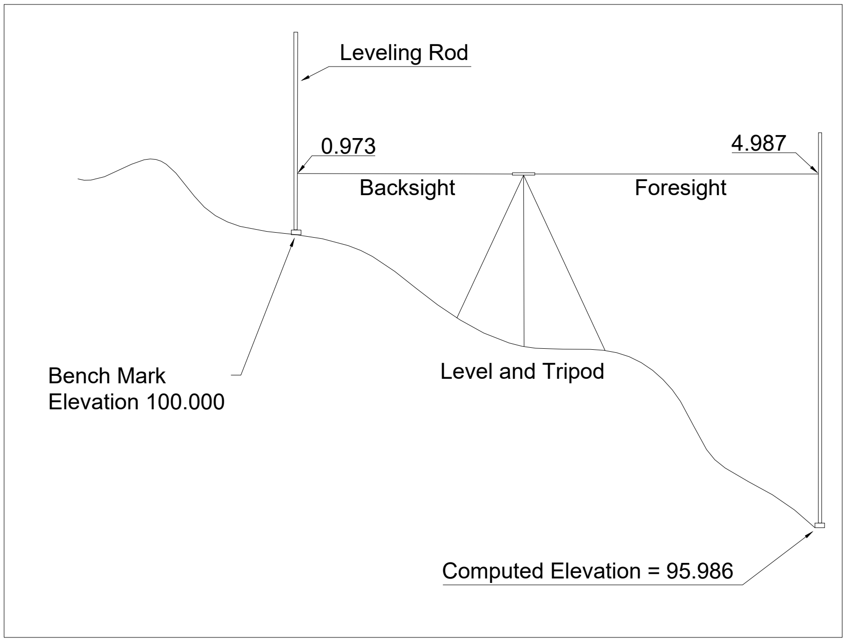


Diagram above shows a general depiction of a standard laser level survey with benchmark and survey point.

Turning Points: If you ever have to move your laser level, you must have a TP or Turning Point before you move it. This is a reference point that you shoot before you move the laser, then shoot the same point after you move the laser thus you can compare the two sets of surveys. Once you move the laser the relative scale will change because your laser height will almost certainly be different in the new location. The turning point can be a random temporary spot or you can use one of your BM's or TBM's you established on site. Make a note after you have moved the laser level because all subsequent shot readings will not relate to the number scale in your previous laser location except via doing the math relating to the before and after turning point shot.

Example: In the first station location I had a benchmark that was 1400ft MSL and the survey rod reading for that shot was 10.0ft. Before moving the laser I shot a turning point location (random rock I marked in the field) that read 5ft on my rod so the elevation of that turning point was 1405ft MSL. (Rod reading of BM-Rod Reading of New Shot + MSL of BM = MSL of New shot point; 10-5+1400 = 1405ft MSL for the marked rock). I then move my laser location because a hill was in the way of where I needed to survey next. I shoot my same turning point again (marked rock) and get a rod reading of 6.0ft. I also shoot the elevation of a tile intake and get a rod reading of 12.0ft. What is the MSL elevation of the tile intake? Same math as the first calculation but use the turning point MSL and rod reading in place of the BM location. (Rod reading of TP-Rod Reading of New Shot + MSL of TP = MSL of New shot point) (6-12 = -6; -6+1405ft MSL = 1399ft MSL tile Intake).

Any other shots taken in this laser location would be calculated the same using the know turning point as the reference elevation. Any shots taken in the first laser location use the benchmark as the reference elevation in calculations.

Use a GPS: Old survey methods mostly used the laser rod readings to collect elevation data and location data was crude and often a mark on a hand sketch or just a description in field notes. With the availability of GPS and ability to integrate into GIS now there is no reason you should not use a GPS with your survey. A basic GPS will take a waypoint which you can record the waypoint number with the elevation shot on your log sheet and tie the two together later. ArcPad was the next step bringing mobile GIS in the field. Newer methods now also use ArcCollector with AGOL on a smartphone or tablet to integrate GIS maps in the field. You can load predetermined features such as lidar contours, wetland outline polygons drawn from aerial photos, tile lines seen on aerial photos, etc which will help you capture the most relevant data while in the field. Survey points can be captured on screen so at any point you want to shoot, capture the waypoint for XY location, fill in the attribute table with a description of what you were surveying or other notes and enter the survey rod reading right on screen so all data can be pulled directly into GIS and displayed on screen without messing with extra equipment like a clipboard, and paper in the field. Post processing elevation shot numbers is also much quicker with batch calculations in a table rather than one at a time from field notes.

Engineering

Never modify drainage to a wetland without having a plan for where the water will go and how it will get there. Even if it is likely to be a temporary wetland that doesn't seem like it will ever overflow, plan for climate change and intense storm events.

"I'm not an engineer but I play one on TV": Most people in the USFWS wetland restoration profession are classically trained in a biological science field not as engineers. However much of our job is engineering to safely control the input and output of water in our wetlands. Uncontrolled water can do damage or cause undesired flooding. The main thing to remember is let the biology guide the engineering, not the other way around. Keep the goal in mind and shape the design around it. Also true engineering takes into account many more variables than we will likely do and get more exact specifications. We will make a lot assumptions and if in doubt over build! Even the best engineering with the fanciest equations are still based on a real world scenario that is unpredictable and far from average in every storm. Hydrology calculations for water flow are based on soil type, land cover type, slope, rainfall rates & duration all of which change a lot in the real world. Most of our project should be designed to last but if they fail it will only result in the loss of the restoration and possibly some temporary flooding. If the project would involve possible damage to life, property or infrastructure don't be afraid to admit it is above your expertise level and seek a partnership to do the engineering review on it. It may cost more at that point but will be worth the liability to have it done right.

Clues to visual engineering evidence: There is a lot of design that can be based on visual cues instead of numerical equations. Look at existing water control structures upstream and downstream of your project. If there is a road culvert just downstream of the outlet to your wetland restoration you know that structure had to handle all the water in the past as it will again in the future or possibly less because the wetland will have some storage & some buffer. Look at the size of the culvert. There are tables that can show flow rates for various sizes and types of culverts. Inquire with locals if the culvert ever runs full or if water overtops the road because it is undersized? If the culvert has historically kept up then design your wetland output to match the culvert capacity. If it didn't keep up then overdesign and possibly include more storage in the basin if possible to alleviate some downstream problems. Same thing for tile lines; If the tile lines have historically kept up with draining then use the same size or larger as the outlet.

Visual clues like culverts or drainage downstream or upstream of the wetland restoration as well as local history can tell you a lot about the amount of waterflow through the area. Culverts like the ones seen above would indicate a lot of potential flow through this area and local history would tell you how often and how full these run. Does it ever over top the road so these culverts are even undersized and you should plan bigger?

Hydraulic Modeling

Other important aspects to consider before picking a design is how much water is coming and how often. Water input from rainfall events can get complicated to try to get accurate estimates. We will simplify things here and make some assumptions. This is only to get a rough estimate of water flow needs, but as mentioned earlier, over estimate & over build! It is almost impossible to set real general rules that fit all watersheds since there are so many variables so we can't come up with just a simple general formula for run off.

Streamstats: Further methods will be outlined below but A recent method developed for estimating peak flows has been developed by FWS Hydrologist using the online resource streamstats. See the guidance here (https://ecos.fws.gov/ServCat/Reference/Profile/101741) and website here (https://streamstats.usgs.gov/ss/)

Modeling Programs: We must use a statistical model to do the complicated math for us. There are many programs available and get varying degrees of complexity. In this case we will use the simplest program and make some further assumptions within that program. You will need to download the free program called EFH-2.
(http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/?&cid=stelprdb1042480)

Other programs are also available. Another good free tool is HydroCad. (http://www.hydrocad.net/) It has a free version for simple watersheds and there is a fee to utilize functions for more complex systems but most of that would be beyond our engineering anyway. Hydrocad gets more complicated so you have to get a bit more detailed on your input data but if you have larger and more complex projects it may help to learn how that program works. HydroCad is nice if you get through the process and terminology because it can also graph input vs output for your wetland structures and see graphic & tabular outputs of your water flow. There are training videos on Hydrocad on Youtube.

Input data: EFH-2 requires a few basic inputs about your watershed. You can answer most of these questions using GIS maps or online soil maps.

Map Watershed: First map your watershed. Look at a topo map or Lidar and go from hilltop to hilltop and visualize a drop of water falling on the land and if it will eventually flow downhill into your wetland then that is part of your watershed. Calculate acres for the watershed. Enter that number in EFH-2 on the Basic Data Tab under Drainage Area.

Runoff Curve Number (RNC): This is a number based off of soil hydro group type, land use and condition class. It basically helps determine how quickly water will flow across different surface types and how much water will soak in. As a default for most general agricultural areas in south or central MN we can use 75 as an approximate number. Enter that number into the Runoff Curve Number blank on the Basic data tab of the EFH-2 program

If you want to do the work to get a more detailed number you need to look up the hydro group soil classification for your watershed (http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx) as well as what land use type those soil units are in and their condition (in most cases just use good condition). Look under the RNC tab in EFH-2 and break out your acres by each of your classifications and when done it will give you your RNC value.

Watershed Length: Using GIS look at your watershed for the wetland in question. Use the measuring tool and measure the longest route a drop of water would have to take in the watershed. Not a direct line but measure the path the water would have to travel from the farthest point in the watershed to the outlet of the wetland. That distance is what you enter in the blank in the Basic data tab of the EFH-2 program.

Watershed Slope: Use the start and end points of the watershed length you just calculated above. Generally the farthest away point is the highest point of the watershed. If the farthest point is not the same as the highest point you could average your numbers a little to get more of an average slope. Use a topomap, lidar or your survey to get an elevation of that highest point in the watershed/farthest away point. Also get the approximate elevation of the outlet to your wetland. Subtract the two numbers and that is the average rise or fall you have in the watershed. Divide that number by your watershed length. Slope in terms of Percent grade is Rise/Run X 100. Enter your slope in the Basic data tab of EFH-2.

Time of Concentration: The easiest way to think of this is when a storm starts, this is the amount of time it takes for the first drop of water that lands on the farthest point of a watershed takes to reach the outlet of the wetland. At that time the entire watershed is contributing to the output flow. This is calculated automatically in the program if you enter the other data first.

Rainfall Type: There are many different storm types ranging from long steady storms to quick bursts. You can do an internet search for maps of rainfall types for various parts of the country or world but most of the Midwest usually use a Type II rainfall event. This is found in the dropdown box in the Rainfall/Discharge data tab in EFH-2.

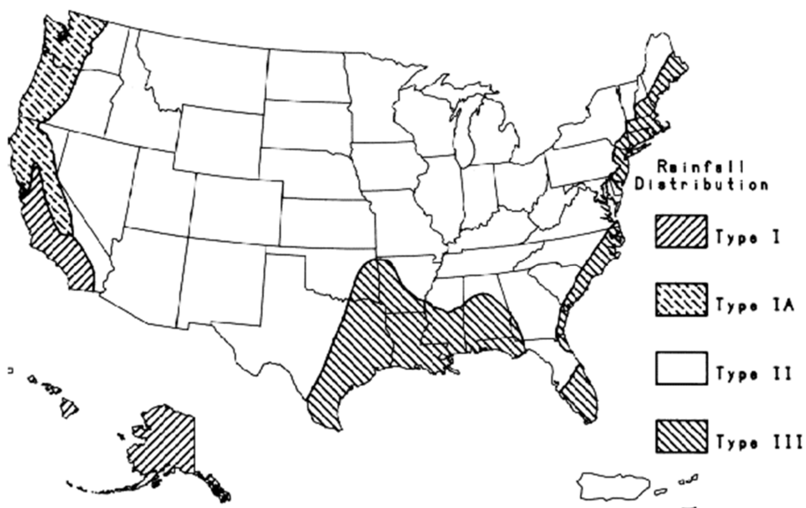
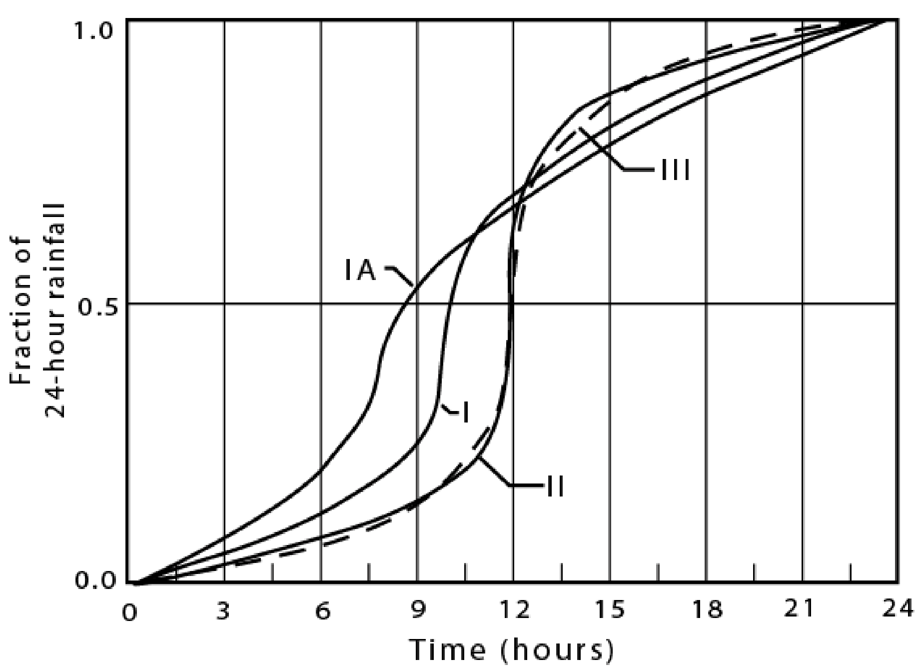
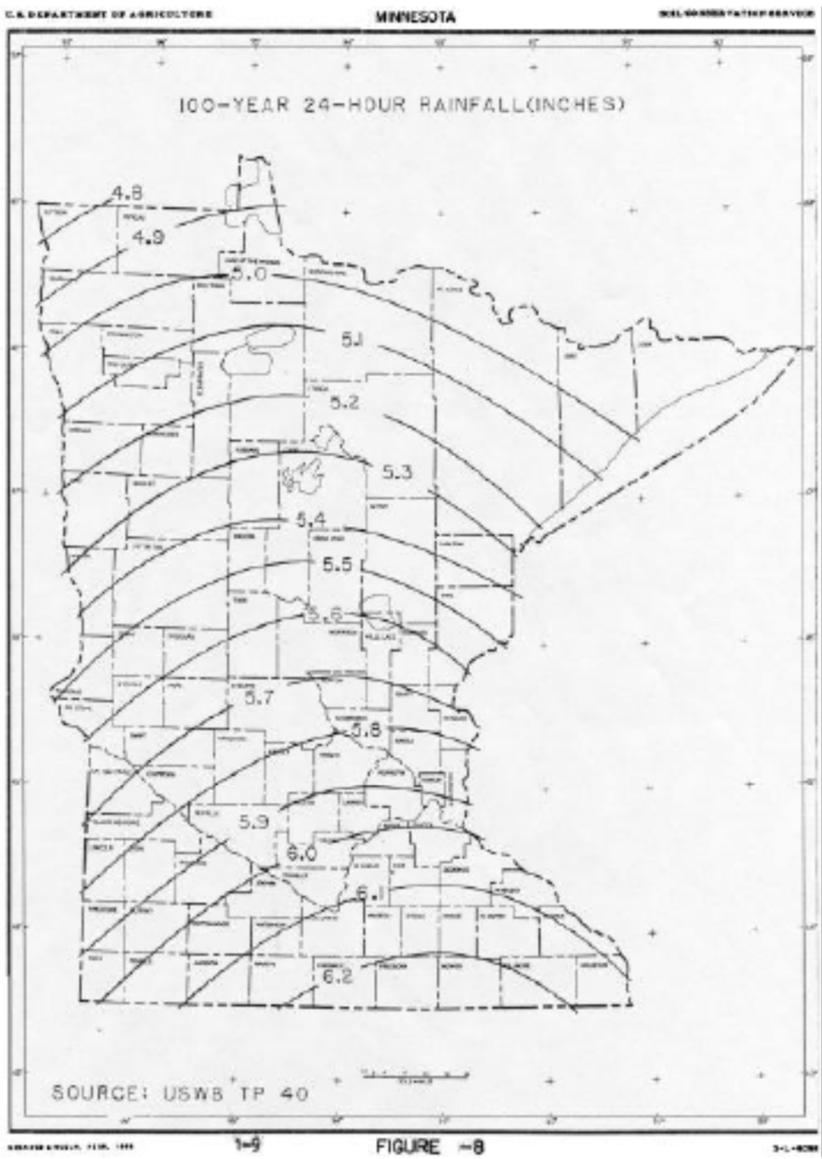


Figure B-2.—Approximate geographic boundaries for SCS rainfall distributions.



Map of Rainfall event types and graph of rainfall rates/duration. In the Midwest we are generally Type II.

Storm Events: You can model many different storm in the EFH-2 program. You can also download data files that have look up tables to populate frequency events and rainfall totals for various areas depending on the state and county you entered on the Basic data tab. However in the absence of the data file you can hand enter the storm event you want to model. Look up rainfall event maps on the internet for your area. In general we are looking for average 24 hour rain events in 1, 2, 5, 10, 25, 50 or 100 year averages. I prefer to use the biggest event to see what is likely the worst storm I would encounter. In Southern MN a 24hr 100year storm is about 6 inches of rain. Enter 100 in Frequency and 6 inches in the 24-HR Rain columns for a storm event in the Rainfall/Discharge data tab in EFH-2.



This is a map of 100 Year 24 hour rainfall events for MN. Use these types of maps to plan your rain events.

Peak Flow: After entering all of your data in EFH-2, it will output Peak Flow in the Rainfall/Discharge data tab. This in in Cubic Feet Per Second (CFS). This is the maximum expected flow coming to the wetland outlet in the storm event your modeled. Assuming your wetland is in worst case scenario, and there is no storage in the basin, this is the amount of water you need to pass through your spillway at one time. Again remember this is peak flow for short duration and you will more than likely have some storage in the wetland to buffer the incoming water. Water will come into the basin and depending on the surface area will spread out. Larger surface area means slower rise. Less rise means less head pressure and less flow needed at the outlet. Also remember a wetland is concave so the higher the water gets the more acres it spreads out thus more storage so again it is a complex, non-linear calculation.

Example: Flow rates are on continuous curves of input vs. output rates so hard numbers are not a true representation but can be used for general illustrations. If your peak runoff is 300cfs and we assume that rate is constant for 1 hour (overestimate). That is about 25 acre feet of water in 1 hour. If your wetland is 10 acres then in that hour time it would raise the wetland 2.5 ft. If our outlet is only designed for 150cfs when running 2.5ft deep then it will take off half of the water coming in. Then the net gain to the wetland during that hour is only 1.25ft at the peak of the storm. If your wetland has enough vertical storage space and can absorb the temporary rise in water then as you can see the outlet rate doesn't necessarily have to match the peak flow rates. However to cover worst case scenarios it is good to engineer at least an emergency spillway that can handle the worse peak flows. If you want to visualize your input vs output use HydroCad or you can set up excel tables to run incremental calculations like was done here to get an approximate curve if you are good at table formulas.

Input Vs Output: In your design you need to balance input vs output. Again models can get very complex. Using advanced programs like Hydrocad, AutoCad, HEC or others you could do hydrographs which model rainfall event inputs vs hydraulic flow rates of outputs, basin storage etc. Again that may be above capabilities of average users. In short we can make an assumption that if you use one of the methods above to estimate peak flow such as from the streamstats process then we match an outlet capacity to meet peak flow for a given event. Generally full capacity should have at least a 100 year 24hr rain event capability through all combined structures. To be safe a 500yr even would be better. Doing this assumes no wetland storage so the system could be completely full and any incoming water at that point can be outleted.

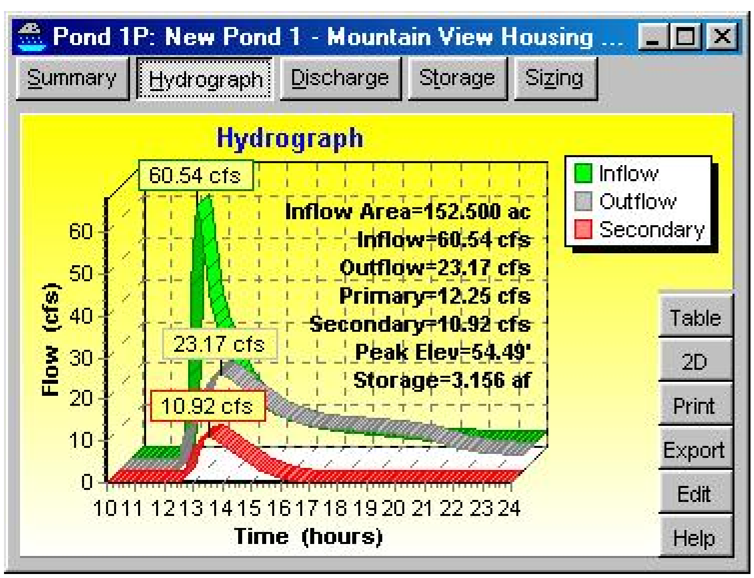
EFH-2 ESTIMATING RUNOFF AND PEAK DISCHARGE Version 1.1.0

Client: Jim Grants
County: Jackson State: MN
Practice: Wetland Restoration
Calculated By: USFWS Date: 9/30/2010
Checked By: __________ Date: ____________

Drainage Area:	815	Acres	(user entered value)
Curve Number:	73		(provided from RCN Calculator)
Watershed Length:	12800	Feet	
Watershed Slope:	.5	Percent	
Time of Concentration:	7.08	Hours	(calculated value)
Rainfall Type:	II		

Storm Number	1	2	3	4	5	6	7
Frequency (yrs)	1	2	5	10	25	50	100
24-Hr rainfall (in)	2.4	2.85	3.65	4.3	4.9	5.53	6.10
Ia/P Ratio	0.31	0.26	0.20	0.17	0.15	0.13	0.12
Used	0.31	0.26	0.20	0.17	0.15	0.13	0.12
Runoff (in)	0.51	0.77	1.28	1.75	2.20	2.70	3.17
(ac-ft)	34.64	52.30	86.93	118.85	149.42	183.38	215.30
Unit Peak Discharge (cfs/acre/in)	0.110	0.114	0.119	0.122	0.123	0.125	0.126
Peak Discharge (cfs)	46	72	124	173	222	275	325

Example of EFH-2 output for a watershed

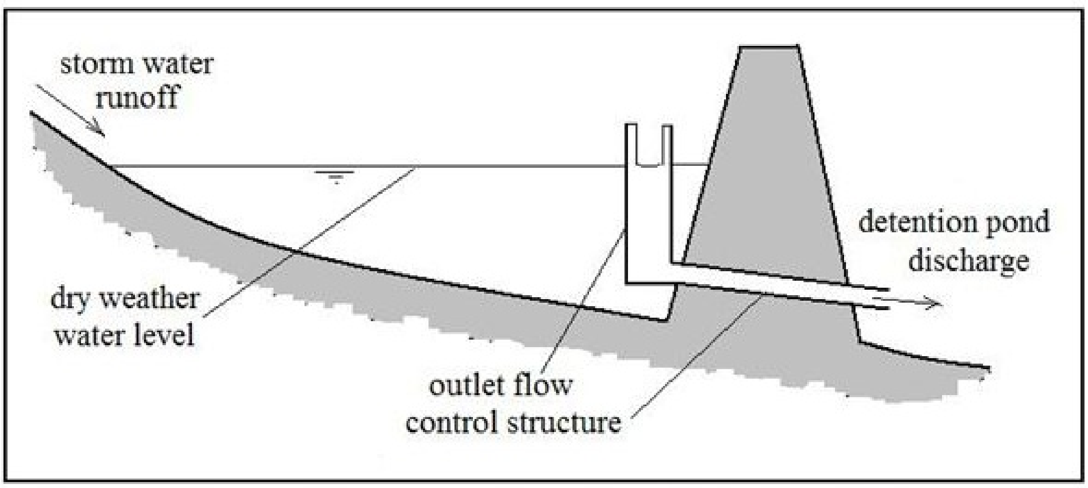


Example of Hydrocad output which includes graphical plot of input vs output of water.

Runoff: Runoff is the proportion of rain that fell that will end up in your wetland. The Runoff output number in EFH-2 isn't as important in engineering as the peak flow but it does give you a general estimate of the total water volume in the wetland for that storm. If you want to look at pure storage basins where possibly the basin would be empty at the start of the storm and you want to see if it would fill enough to even reach an outlet you can look at Runoff.

If in a 6 inch rainfall event the model says your will have 3 inches (0.25ft) of Runoff and your watershed was 100 acres then you have 25 acre feet of water coming to the basin. If the basin is 10 acres then in the entire storm you would raise the basin water level by 2.5ft assuming no outlet.

Multiple Spillways: Putting water through a pipe or enclosed structure is often ideal because it is neat, clean and controlled. However that greatly limits the amount of water going through it by funneling it through a small space. In most cases if you are using a pipe (tile culvert, water control structure, etc) that will be the primary water flow for small rain events but your will always have to plan for an emergency overflow which will be an large open spillway at a slightly higher elevation than the pipe or structure. The difference between the smaller primary and the larger emergency spillway will be the storage space for the wetland. You should maximize this storage when possible.

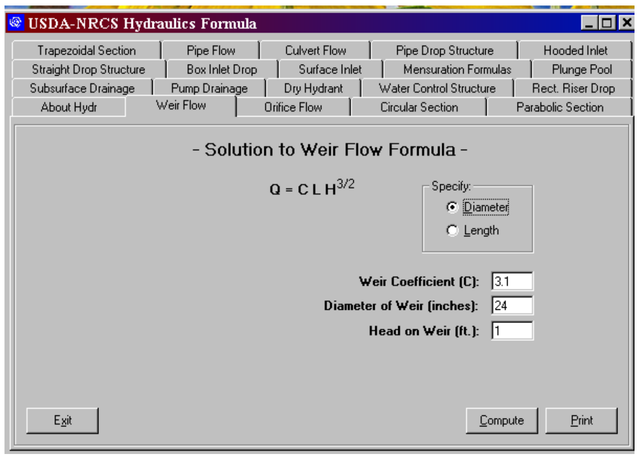


Storm Water Retention Pond and Control Structure

To have floodwater storage space you need a primary outlet with lower capacity set at a lower level and a emergency overflow spillway. Water will fill up during a storm and slowly drain back down. The bounce volume is your storage capacity.

Structure Flow Rates: Flow rates for various types of structures can be found online such as (http://www.sd-w.com/civil/channel_flow.html) or use the USDA-NRCS Hydraulics Formula calculator built into the Engineering Field Tools (EFT) which can be downloaded for free from the internet (http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/?cid=stelprdb1042198) . Flow calculations are generally based on 3 factors which are head or height of water flowing through the outlet, weir length which is the cross sectional surface that water is flowing over and a frictional coefficient which is the amount of drag on the water against the type of surface of the structure. Head of water will depend on your landscape but as a standard rule of thumb for many of our small wetlands I try to plan for about 2ft of flow over each structure so if I have a tile intake I will plan 2ft above that to be the emergency spillway elevation and have 2ft above the emergency spillway for flow room. Thus the whole system running full will have the tile running full at 4ft of head and the emergency spillway would have 2ft for head.

Example: If I have an 18 inch tile riser intake it will run about 20csf at full capacity. If I have an emergency grass spillway about 20ft wide and 30ft long running 2 feet deep it will flow about 160cfs. Total that is 180cfs through both the primary and secondary spillways.



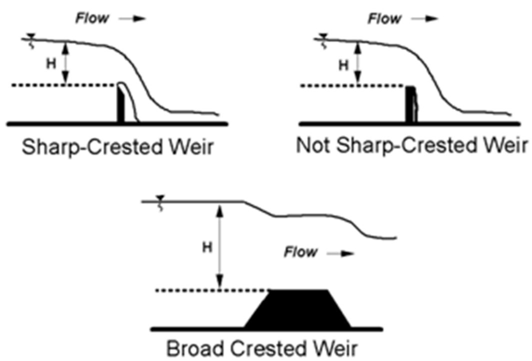
Hydraulics Formula Calculators can be used to show flow rates of various structures.

Weir Formula: Again you can find specific formulas for different type of structures. A very basic Weir Flow formula is Q = CLH^(3/2). C is the Weir Coefficient for friction so a higher number such as 3 is very little friction like a sharp crested sheetpile weir. Lower numbers like 1 might be a more of a grass spillway. L is the length of the weir so on a sheetpile it is the length across the bottom of the sheetpile. On a riser pipe or vertical tile intake weir length is the circumference of the pipe however also look up the capacity of the pipe which may be less that the capabilities of pure weir length. H is the head or height of water above the weir prior to the sagging effect of water dropping as it goes over the weir.

Types of structures/formulas: Very important to think about and use the right formula for flow for the right structure. Subtle differences can have dramatic results on flow.

- Weir – A weir by definition is a spill over point. Water movement is driven just by the head pressure of water higher in a pool than on the outlet. No velocity of slope of incoming water. This is generally most of our wetland restoration spillways. Then break into many types of weirs from hard structures to sharp or broad crested spillways.
- Hard structures: There are many specific formulas for hard structures like pipes, boxes, culverts etc and these are probably the most accurate to calculate as there are easier to model with fewer variables than complex natural channels etc.
- Channel Flow: Some formulas are for channel flow this is for flow through a ditch or stream where there is a slope and velocity to the channel that influence flow as well as friction along the bed of the channel that may slow it.

- Chute flow: this is an engineered channel down a slope. Again has an incoming velocity and slope that influence the flow. This may be the slope coming off a spillway or weir running down to an outlet but the weir or spill point of a basin at the top would be more of the limiting factor generally than the chute so calculate the weir to match the outlet need of the wetland then the chute most likely could be sized smaller than the weir because you have velocity down a slope to increase flow per unit area.



There are many types of weirs and flow calculations. Above are a few examples of weirs. The sharper the weir the less friction and the greater the flow but may also have more energy and need more reinforcement.

Adjust Flow Rate: In your design you can adjust several factors of your wetland. If you want very little bounce the factors that are important are large surface area of the wetland and long weir length/high capacity outlet at low head. This is good if you have property or infrastructure nearby that should not be flooded. If you want a lot of storage capacity, again you need large surface area but have a moderate to small primary outlet and as much head room as possible between your primary and emergency overflow. This design will absorb a lot of flood water and let it out slow. This is good if you want to alleviate pressure on an overloaded downstream tile line or drainage ditch. If the landscape doesn't allow space for a primary and secondary outlet just design one very large outlet that can handle all the flow.

Extreme example of intake structure. Notice the shape of the intake is much more than decorative. The baffles in the intake maximize the weir length (flow perimeter) for the intake so they get much more flow at low head levels than a simple circular pipe of the same diameter.

Durability: Another factor to consider in the type of outlet other than size is durability. If your wetland is a temporary wetland that is very unlikely to ever overflow then almost no engineering is required and just plan an appropriate grass area where it can overflow if needed but likely a formal spillway cut is not needed. If you have a primary and secondary spillway and the primary is a tile riser that will take any flow 90% of the time and will not erode since it is hard surface like a pipe and the emergency spillway will likely only run once a year or less in big rain events, a grass spillway is fine. Any grass spillway, design as wide as possible so when it flows it will be a slower sheet flow with less pressure on a small area and less likely to cut down. You can never over size an emergency spillway. If your outlet will have a constant base flow such as spring or stream fed or other frequent or high velocity flow then you want it to go through a pipe or some other armor such as a sheetpile, cement or rock spillway.

Restoration Designs

There are only a few ways a wetland is drained including surface ditch, tile drainage or filled in. Beyond that you have creation or enhancements including dike/berm building or excavation

Soil: For all design elements make sure to check your soil! The best designed restoration is no good if water can seep through or wash it out. Check web soil surveys. They have a classification for dike/dam building which will show limitations in the definition descriptions. Also on site use a soil probe to check the soil down as deep as your probe goes. Do a texture and ribbon test pushing the moist soil through your thumb and finger to form a flat ribbon. It should extend at least an inch or more before breaking off to build with. Taking borrow from the bottom of a wetland is preferred since the area will be hidden under water when finished, however even the best clay is hard to build with if it is too wet and mushy. If needed move up the slope and make your wetland wider instead of deeper with your borrow site. Too dry can also be hard to pack and shape. If you need clay but can't find it on site consider trucking it in if needed and if affordable. Be on site when the contractor starts digging to inspect the soil as they dig and uncover possible sand or gravel veins that may be an issue in your restoration.

This soil probe shows a sand layer about 12 inches below the clay layer in the wetland. Puncturing through this clay lens would effectively drain my wetland as well as the sand is a limiting factor for on-site borrow material.

Compaction: Compaction of the soil is also one of the most important elements to consider. Even marginal soil can withstand a lot more water and resist seepage if it is highly compacted. Don't let a contractor convince you driving over it with any tracked equipment will provide good compaction. Even heavy tracked equipment is likely only putting down a little more pressure than your foot. If you walk or stomp the ground over where they drove with their equipment and you see your shoe print then you are putting down more weight than the machine did. Use at minimum heavy wheeled equipment to drive over it or preferably a vibratory sheep's foot or a loaded scraper. A good test is if you can push a tile probe into it then it is not compacted enough. Place soil in lifts of 6-10 inches and compact between the next lift. Tracked equipment about 10-20 psi, Loaded wheeled scraper about 100psi, Sheepsfoot about 200psi.

A vibratory sheepsfoot will provide the best compaction. The second best option is a loaded scraper. Compaction is critical in durability of earth structures.

Types of Restorations

Surface drainage: Strip off all vegetation and sod in the area you want to block off/overflow point of the wetland. If it is a big ditch or will have a lot of head pressure (+2ft) dig a core trench down the center of your plug area. This is generally an excavator bucket width (3-5 ft) and a couple feet deep or until you make sure you are down to a solid base preferably in a good clay layer. Then find a good borrow area with as good of clay material as you can find (also preferably below the proposed water line) and build a ditch plug raising and compacting between lifts every 6-10 inches. Plug should be minimum 10ft wide flat top and 3:1 slopes and should be mounded slightly higher than the ground on each side of the ditch. You will likely have some other water output design elements here also but you do not want water to overflow your ditch plug. Water should go around it or through a structure.

If possible fill the remainder of the ditch in past the plug as well for a full landscape restoration. If a solid plug is in place the rest of the ditch fill can be lower design standards such as no sod stripping or core trench. Just fill in as much as possible and mound some to compensate for settling. If you are doing sediment removal in a wetland, the ditch fill is a good spot to place the spoil. Usually there is a berm on each side of the ditch from when the ditch was dug and that can be leveled and pushed in to the ditch to use as fill. If there is not enough fill be careful not to just push in the sides resulting in a wider shallower ditch that water can still drain down. If needed use shallow borrow areas on alternating sides of the ditch filling the ditch but leaving behind scattered shallow bowls that can act like temporary wetlands but not in a straight line that water will channel through.

Bull dozer filling in a long ditch after placing a solid ditch plug at the wetland edge.

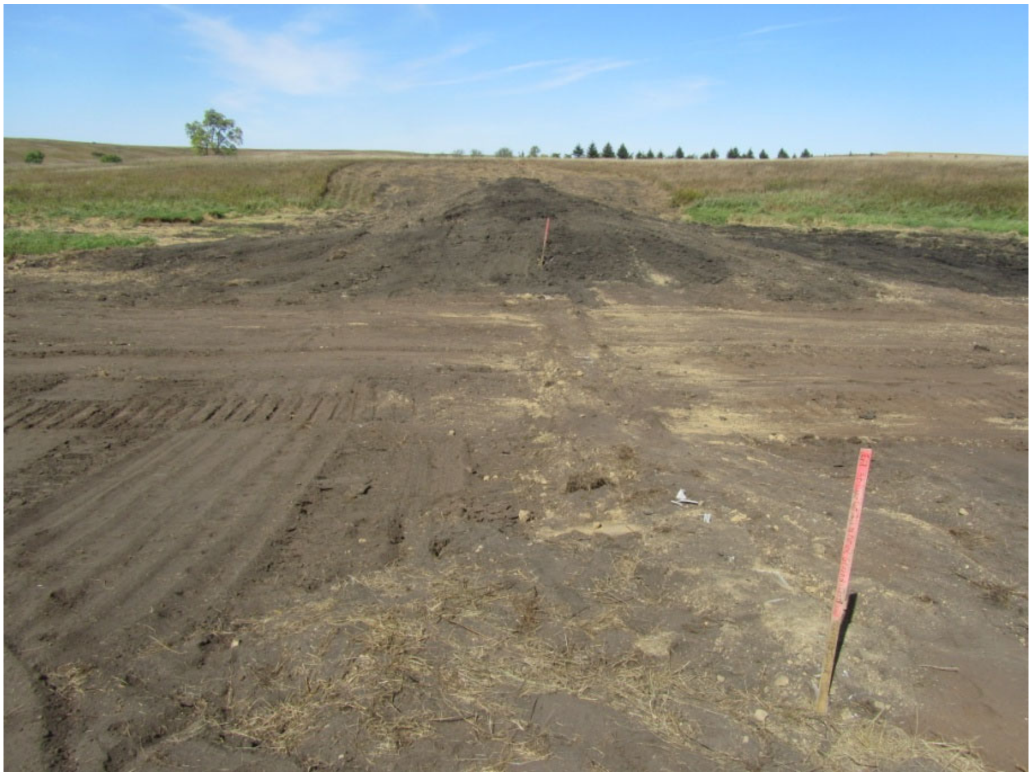
Tile Drainage: Determine if the tile needs to remain functional or not. If not, find the maximum limit of the wetland edge which is likely the natural spillover point along the path of the tile. From that point, excavate and remove the tile a minimum of 100ft downstream. If the tile is clay or cement it can be thoroughly crushed and mixed with the spoil and compacted back in the trench as long as a crushed line is not left that can act as a gravel seam. If it is plastic, this does not crush so it must be removed and disposed of off site or buried in a hole on site if the landowner allows. If the Tile only has to function for the benefit of an outlet for your restoration, break/remove the tile as described above and hook on to the tile at the end of the break with non-perforated tile and run that non-perf back into the wetland to create your structure with a riser set at your pool level. If the tile has to maintain drainage from upstream and the tile could not be outleted above the wetland then do the tile break as described above. Also locate the tile 100ft upstream of the incoming edge of the wetland. Hook with a non-perforated tile at that point above the wetland and reroute around if possible or through the wetland bottom if needed to hook back to the downstream tile. Install a midline intake riser if needed for your water control structure but make sure all seams are water tight. Gasketed bell and spigot fittings can be ordered for water tight tile as well as putting a bag or two of dry quickcrete or bentonite around the seams can also help. Routing around the basin is much better in case future maintenance is needed after the wetland is full of water.

Tile reroute replacing with non-perforated tile around a wetland.

Tile break of plastic tile centered on the wetland edge and broken 50ft each direction. All plastic tile must be removed from the trench and backfilled with compaction.

Dike building: As described above in the ditch plug, a dike is constructed much the same but larger. Strip the sod off to footprint. If it is over 2ft of water behind it or prone to seep, dig a core trench down to solid clay or dig through any sand or gravel seams (generally 3ft is a good target depth). If diking off an old waterway, dig a very good deep trench through the old channel areas and any soft sediments. Build dike up in lifts with minimum 10ft wide top, 3:1 slopes. Wider if they need the dike for vehicle/tractor crossing. Also shallower slopes especially on the wet side if it is prone to muskrat damage. Greater than 5:1 is recommended for reduced burrowing or burry coated chain link fence in the slope centered on the water line to reduce burrowing. Compaction should be enforced with greater than 50psi equipment (i.e. tracked equipment does not provide adequate compaction). Use a vibratory sheepsfoot if possible. Allow a minimum of 1ft of height from dike top to the maximum water height you expect to run through your emergency spillway. If the dike is large (~10ft tall) and prone to wave action (long fetch) you may need to design a berm/terrace on the front side. Build spillway away from the dike if possible. If it must run right next to the dike, build a wing dike to channel water out past the toe of the dike so water doesn't run around the side and erode down the toe slope of the dike. Dikes must use as good of clay as possible. If clay is limited, use the best material for the core/center of the dike and truck it in if you have to, then build the slopes with more marginal material. Built the dike to specs then cover with an additional couple inches of black dirt for vegetation to grow on and establish. Over build your dike by about 10% height as it will settle over time.

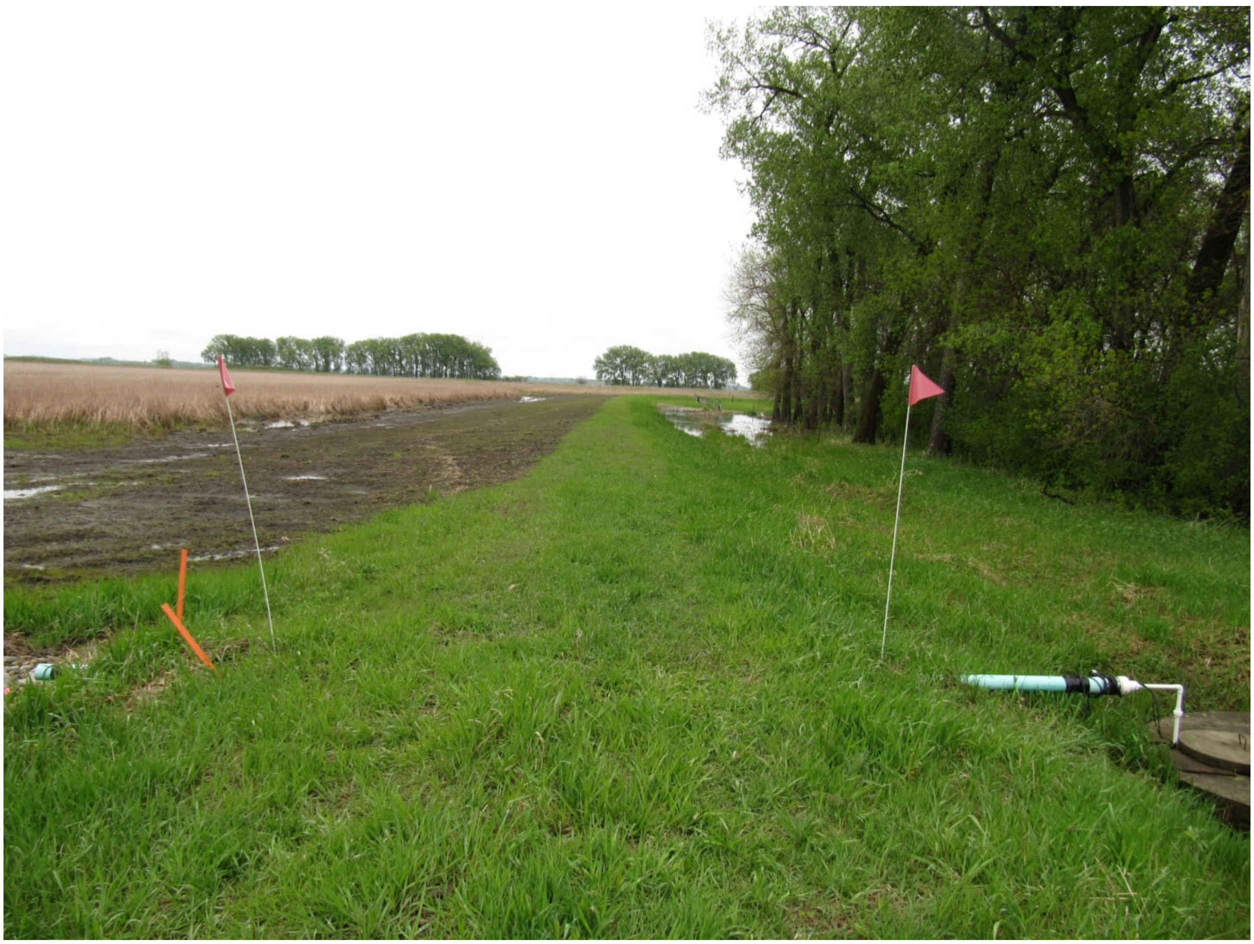
Core trench down the center of a dike footprint. Excavate down to a solid layer to build up from and cut through and sand or gravel seams.



Finished dike with emergency spillway in the foreground around the side of the dike (between the 2 stakes)

Chain link fence buried at waterline on this dike to prevent muskrat damage as well as greater than 5:1 slope.

Separation Berm: This will follow the same guidelines as a dike but instead of holding water back in order to raise an outlet it's purpose will hold water back from spilling over on to a neighbors property. It can be used if you only own part of a wetland and the neighbor is not willing to restore their share, then you can restore the basin but leave their side dry. Don't build right on the property line since seepage or hydraulic pressure can keep the ground moist on the dry side of the dike. I recommend at least a tractors width on your side so you have access if you need to work on or around the dike berm. The main thing to remember for separation berms is dikes hold water in either direction. If the water that is on the dry side of the dike was meant to flow into the restored basin then you will pool water on the back side of the dike. If this is the case then plan for drainage of their side. If it is already tile drained then you can just break and reroute any tile needed that goes under the separation berm but keep their side functional and possibly put in additional intakes. If there is no good gravity drainage or tile to support their side you can install an entirely new tile line or feed a short tile system into a cistern and install a pump lift station to get the water over the dike. Remember pumps take maintenance and have firm understandings and written agreements of who is responsible for the electric bill before it is placed.



Separation berm from wetland on the left to farmstead tree grove on the right. Electric pump in cistern fed by tile line along back side of dike.

Excavation/Sediment: If the wetland is filled in you may do an excavation. Also keep in mind that depending on the landscape if the goal is just to excavate for more water holding capacity and not native restoration it may be cheaper to build up the wetland outlet with a berm rather than dig down the whole basin. Digging 2ft of dirt out of a 2 acre basin is about 6,500 cubic yards and in many areas it may cost you at least $3/cy so that is nearly $20,000. A 4 ft dike (2ft of water and 2ft of spillway head room), 200ft long, 10ft top & 3:1 slopes is about 650 cubic yards and likely around $2,500. Advantages of sediment removal over building up an outlet is the removal of excess nutrients in the wetland, possible exposure of native seed banks and native substrate type which may be different from the sediment. If the goal is just to hold more water but the wetland isn't ditch or tile drained then determine if excavation will gain anything or if the water budget is the limiting factor. If the wetland never naturally overflows so infiltration and evaporation exceed precipitation then it doesn't matter how much you dig down or build up because it will not gain any more or less water. The exception to this is if you are near a high water table and digging down will access that water table revealing the recharge capabilities of the wetland.

In general determination of sediment amount is a matter of digging down and taking a soil sample and looking for a change that does not belong. The most obvious sediment is if there is a lighter color soil over a dark soil. In nature it is almost always dark over light. Also look for texture difference such as if the hillside around have a sandy soil and you find a layer of sandy material over a layer of black clay then you know the sandy stuff is sediment.

Assuming you have determined the need to excavate and how much to remove , excavation is fairly straight forward. Be sure you check your soils that it is not a clay lens over a sand or gravel layer or you will drain the wetland like pulling a drain on a bathtub. Find a place to put you spoil. It is most efficient closer to the wetland however by most standards, any soil moved must be placed outside the wetland boundary but you also don't want it on a slope to erode back into the basin or a lump that will impede incoming water runoff into the basin. Often spreading on the downslope side of the wetland can work well. Sediment removals work well on sites that will have upland grass planting following the restoration so the spoil can be disked over and planted.

Excavator digging sediment out from a small basin

Water control Structures

Culverts: Culverts are the most common water control structures in the private sector but probably the worst to use from a design perspective. A culvert does not flow much water until the head is well over the culvert top. Think in terms of weir length for flow calculations. A culvert being round is very narrow at the bottom and widest in the middle before narrowing down again. For a 12" culvert the weir length with a few inches deep of water is only a few inches long. You don't utilize the full capacity of the pipe until it is running 1 foot deep and only then will hydraulic head pressure start really building to increase velocity through the pipe. Alternatively if we have the same 12" pipe but lower it and put a 90 degree elbow on the end so the intake is vertical instead of horizontal the water will flow into the pipe around the entire circumference right away so even at only an inch of water depth were are utilizing the full capabilities of head pressure. Because culverts need a lot more head of water to fully function they have to be covered by a lot more dirt. A 12 inch culvert needs not only the 12 inches of dirt to cover the pipe but if you want to allow 2 feet of head pressure for maximum flow and then another foot of dry safety room above that we are talking about a berm at minimum 4 feet higher than the pool level/bottom invert of the culvert which is a lot more dirt and more expense. If you do need to use a culvert, use it as an equalization tube for leveling water on two sides of a crossing or for a simple low flow crossing. Use good compaction during the install. Use an anti-seep collar if possible. Extend the pipe out past the dike or berm surface and armor around it with rock on the intake side. When possible dig a pit in front of the culvert outlet to keep large open water in front and room for sedimentation before dirt would fill the pipe.

Culvert being installed in a new dike. Dike used for crossing and low flow expected on culvert.

Horizontal tile intake: It functions much like a culvert and has the same issues of flow rates but instead of just being a pipe through a berm it is a horizontal intake into a tile line. Use only if there isn't enough depth available to have the tile deep enough to put in a vertical tile riser or if head/bounce of the wetland is not a concern. Install is simple, just put intake at desired elevation and trench at proper grade to connect to existing tile line. Depending on the slope you are installing into you may need to anchor the intake with cement, rock or dirt. If the tile is shallow, mound dirt so you have at least 18 inches or more of dirt over it.

Horizontal tile intake being installed with rock around it.

Tile risers: These are fairly easy, common and inexpensive for a fixed elevation. It can either be used to tie into an existing tile line or just run the tile through a dike or ditch plug and outlet the pipe on the other side. Place it near the wetland edge in a location it will be easy to access and inspect. All you need is a vertical section of non-perforated tile with a 90 degree elbow at the bottom connecting to the horizontal line or a T if it is a through line. Size should match the underlying tile and the tile line should be non-perforated for any extent close or within the wetland edge. It is easier to install a longer piece for the riser and then cut to height at the end. The horizontal line should be at least 3 feet down so the flowline is below the frost line. Install an antiseep collar on the horizontal line under the dike if seepage may be a concern. To make it more stable you can place a larger sleeve over the tile, cut a U shape in the bottom to fit over the outgoing tile line and fill the space in between the sleeve and the vertical tile with cement/quickcrete. *Example would be a 12" tile with and 18" sleeve.* This will help secure the pipe so it doesn't move with ice movement or frost heave, provide some protection against fire, help stabilize and water seal the elbow joint and make it more tamper resistant so a landowner can't just cut the plastic pipe off to drain the wetland. Always put a trash rack/bar guard on top. If you are unsure of exactly how high you want the water you can leave 4-6 inches of the inner tile sticking out of the cement over the proposed elevation and monitor it over the first year or two. If there are no problems you can keep the higher elevation or even use a coupler to attach an additional piece on the exposed tile. If the higher water is causing problems you can cut it off down to the cement. Flag it so it is easy to find. It is often helpful to put erosion cloth down around the base and put rock over it to prevent vegetation form growing several feet around the structure and keeping the intake more clear. If a lot of vegetation trash is expected you can build a trash rack fence around it (5ft square) with wire mesh.

Installation of a Tile riser Intake: Left Photo shows non-perf tile run under dike into wetland edge with antiseep diaphragm in the middle, elbow joint with riser. Right photo is a U shape cut out of a larger collar to fit over the tile riser.

Left Photo, Collar fit over riser pipe and filled in between pipe space with cement. Right Photo is finished riser intake with little extra stub left above the cement collar.

Left Photo, inline tile intake within a tile reroute with larger sleeve and using cement truck to seal base and collar. Right Photo is trash fence built around intake riser to keep vegetation and animals from clogging it.

Inspection ports: The same process for a tile riser can be put in for non-intake needs as well such as it may be good practice to put one in downstream of a dike that has a tile line running under it as an inspection or clean out port or so if water runs through the emergency spillway it can dump into that intake instead of going over land. Locations not directly in long term water should not need the cement sleeve. If you are installing a long tile reroute you may also want an inspection port on the upstream side of the wetland. These ports also serve as an air pressure relief for the tile which sometimes they can get an air bubble trapped in them and not run as efficient so an intake provides a release point. If a tile is plugged a jetter truck can use these ports to run a high pressure hose down to clear the obstruction.

Barrel Risers: The same riser design can be used on a larger scale with barrel risers which are generally like a metal culvert stood on end with a stub sticking out of the side near the bottom to hook the outlet pipe or tile to. Barrel risers are generally custom ordered from a metal culvert company. If you get into a large size (24”+) then in addition to a trash rack on top you may want an anti-vortex shield which is a fin that sits vertically on the top center of the structure. It will prevent the whirlpool effect as water flows in which reduces the flow rate. Large barrel Risers would generally be installed on a terrace/bench built off of a dike. Use some of the tips outlined in the inline and intake type water control structures for securing the pipe such as sealing the base in cement or some barrel risers come with a turnbuckle assembly to secure the pipe to the stub.

Barrel risers like this one are generally custom ordered. Circumference of the top is your weir length and order appropriate stub for the size and flow rate of outlet pipe you need on the bottom. This would generally be installed within a bench or terrace off a dike.

Inline water control structure/Whistle Tube: This is used if you want to manage water levels. It can be used within a dike with the intake and outlet pipes exposed on each side of the dike or this can be used within a buried tile line downstream of the wetland to raise and lower water levels within the tile in a wetland. Whenever possible use exposed intakes and outlets. Anything in buried tile is much harder if fix or unplug if needed. The advantage of this over an exposed stoplog bay is the water intake is near the bottom of the wetland and the water is overflowing inside the stoplog box buried in the ground so it is less prone to beaver damage trying to plug running water. Also the box is generally placed on higher dry ground so it is easy to manage/access without getting wet. Prefab structures can be ordered through

Agridrain. If installing to an existing tile you order a size to fit the tile. If in a dike order as big as you can afford. These flow much less water than you would think with the larger structures maxing out at 25-30cfs. Larger structures are easier to maintain and possible to climb down into if needed. You can custom order and choose a larger structure and a smaller pipe if you need specific options. My preferred combination is the 24” structure box with the 18 inch pipe and generally 8ft tall or height of dike. Custom larger sized structures can be ordered from agridrain or many other metal culvert companies and made out of metal. However metal is prone to rust and may only last 10 years. If you use metal, inquire about coatings or alloys to make it last.

To install, build your dike first (if putting in a dike). Excavate a trench through it or expose the tile you are installing it on. Make sure it is plum and level and follow manufacture directions. I usually pour a couple bags of dry quickcreate down and use a hand level to level it then place the structure. The quickcrete will harden on its own with soil moisture and give a firm base after install. I coat the pipe couplers (first 2 ribs) with thick trowel grade roofing tar as a sealant and attach the pipes and tighten the clamps (tip – tar is messy, use gloves and WD40 works well to remove from skin and clothes). Put pipes at a slight downhill grade especially the outlet pipe so water doesn’t pool in the pipe when not running. Install an antiseep collar on the upstream side pipe about half way between the end and the structure. Solid collars are better than the rubber ones and can be special requested from agridrain.

The next step is not required but I have found it saves a lot of trouble. Form a frame around the structure and pipe fittings. This can mostly be done with dirt to make a form about 12 inches around all sides of the structure and pipe fittings. Pour cement to cover and seal the base of the structure around all sides and pipe fitting up to about 6 inches over the pipe. This will prevent separation and seal the pipe to the structure. Most failures of these structures are at the joint of the pipe to the structure. If damage is ever bad enough that you have to excavate it you will likely need to replace the structure anyway. If it is the dike that fails you can rebuild/repair around the structure without having to reset it. I use 4,000lb grade cement with air entrainment and fiber reinforcement (cement contractors will know what this means). Generally 1-2 yards of cement should be enough (often there is a penalty fee for less than 3 yards so you might as well order the minimum and pay for cement instead of paying for not ordering enough cement). Cost is close to $100/yard. If you have a cement truck on site anyway and if the application is in a dike I would also put some cement on the top of the pipe at the input end to use as ballast to make sure the pipe doesn’t raise up or float over time (dual wall pipe is hollow in the ribs, thus floats) and if any cement is left over, pour a little over any other pipe joints or seep collar joints. Once cement is set, pack dirt back over the pipe with a jumping jack/whacker in small lifts to rebuild to the dike or ground profile. Be careful to only hand or foot tamp next to the structure to avoid damaging or warping the structure. Leave all stop logs in the structure during install for more reinforcement. Some suggest putting a large culvert/collar around the structure and fill the interior space with pea rock so then you can compact next to the collar without compressing the structure. The base of the collar and structure would still be sealed in cement as before. This is more difficult to get a large enough collar pipe on a large structure but works good for smaller ones.

After install I would suggest leaving it empty or very low head pressure while dirt settles and grass grows on disturbed dirt. General elevations for these structures used in a dike would be intake pipe &

structure base at the lowest level you want to drain to with the outlet pipe about another 6 inch drop. *Common Example in a dike: Assuming you want a maximum of 4 feet of water we leave room for up to 4ft of stoplogs in the bay. You then have 2ft of head room at which you install your emergency spillway at that elevation and have 2 additional feet of head room in that spillway to the top max water flow level so the top of the structure is 8ft tall from the base to top and at normal full pool of 4ft deep there is 4ft of free space inside the structure from water surface to structure top. The dike top may be another 6 inches or 1ft above the top of the structure if you want that space as freeboard above the maximum emergency spillway level.* Placement of the structure in a dike will generally be centered on the deepest part of the dike. The structure can be in the middle of the flat top or off-set if you plan to drive over the dike and do not want it in the way. If the dike top will be higher than the structure top, adjust the structure position down the slope of the dike. I prefer to position on the back slope just off of the flat dike top. It is then out of the way for driving but if you need to do any maintenance it is easier to work on the dry side of the dike. Place a rat guard on the outlet pipe and a use heavy zip straps to fasten a bar cone bar guard on the intake side.

One option for these type of structures whether in a dike or in a tile line is to design it so the top of the structure is set at an emergency overflow elevation (must be placed on the wet side of the dike or along the wetland edge in a tile line) and put a trash rack on top instead of a solid cover. This will allow the top of the structure to act as an emergency intake if water levels get too high and the water running through the intake pipe can't keep up or if the intake is clogged.

Installing an inline water control structure. Left Photo, trench cut through dike, pipe installed with antiseep collar, structure set just off centerline of dike. Right Photo, tar used to seal first couple ribs of pipe before inserting into structure flange and tightening clamps.

Left Photo, Base of structure sealed in cement about 12 inches around all sides and pipe joints. Right Photo, cement also placed on end of pipe as ballast to prevent floating and trash cone zip-strapped to intake.

Inline Water Level Control Structure™

- Rugged 1/2" PVC structure.
- Heavy Steel lockable top.
- Stainless steel screws and custom anodized aluminum corner extrusions are used for strength and durability.
- 5" & 7" stoplogs for adjustability.
- Flexible couplers allow PVC, plastic pipe, or other materials to be easily attached. (Please specify type of pipe when ordering)
- 5-Year Warranty on all parts
- Please allow up to 2 weeks for shipment.

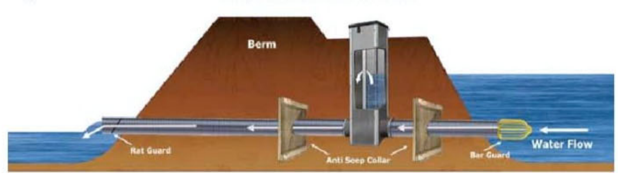
Inline Water Level Control Structure			
Pipe Size	Available Heights	Width	Depth
4"	2' - 12'	8"	10"
6"	2' - 12'	8"	10"
8"	2' - 12'	12"	12"
10"	2' - 12'	14"	16"
12"	2' - 12'	16"	20"
15"	2' - 12'	20"	24"
18"	2' - 12'	24"	28"
24"	3' - 10'	31"	39"

Durable stainless steel lifting hooks.

Comes with a handle to install and remove stoplogs.

TYPICAL INSTALLATION

Inline Water Level Control Structure



Manufacture outline of Agridrain inline water control structures

Intake Water Control Structure: This style is very similar to the Inline WCS mentioned above and can be used in the same situations. However instead of an intake pipe leading to the stoplog box, in this case the box is exposed out in front of the dike with the stoplog boards directly exposed to the water surface. The outlet pipe is still sent through a dike or into a tile line. The disadvantage of these types of structures are they have to be right at the water's edge and it is hard to design and keep good access to the structure to add or remove boards when water is present. Since the box must be exposed it is also harder to anchor and stabilize the base as well as leaving it exposed to the elements and animals such as beaver who will try to plug the running water. Since the stop log bay is wide open this type is easier to clean out than a submerged pipe if it does plug. Follow the same basic guidelines as the inline WCS installation. Sizes and flow rates are basically the same as the inline WCS as the limiting factor is the weir length/sloplog size more than the pipe flow in most cases. Again anchoring this type of structure is more difficult so I would suggest setting the structure slightly lower (2ft) than the wetland bottom so you may have about the bottom 2ft of boards in to reach up to the bottom of the wetland level. Seal those bottom two feet including all around the pipe connection in cement. Be careful during the process not to get cement inside the structure. Put an anti seep collar about 10ft downstream on the outlet pipe. Prefab structures are available through agridrain or custom ordered metal structures (AKA half round risers or flash board risers) can be ordered from metal culver companies.

Inlet Water Level Control Structure™

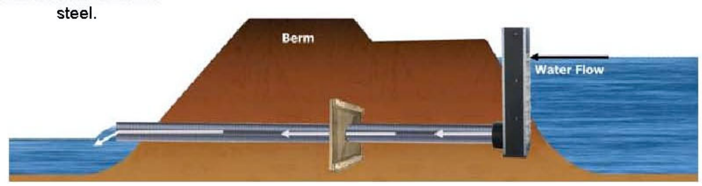
- Rugged 1/2" PVC structure.
- Stainless steel screws and custom anodized aluminum corner extrusions are used for strength and durability.
- 5" & 7" stoplogs for adjustability.
- Flexible couplers allow PVC, plastic pipe, or other materials to be easily attached. (Please specify type of pipe when ordering)
- 5-Year Warranty on all parts
- Please allow up to 2 weeks for shipment.

Inlet Water Level Control Structure			
Pipe Size	Available Heights	Width	Depth
4"	2' - 6'	8"	5"
6"	2' - 6'	8"	5"
8"	2' - 6'	12"	6"
10"	2' - 6'	14"	8"
12"	2' - 6'	16"	10"
15"	2' - 6'	20"	12"
18"	2' - 6'	24"	14"
24"	2' - 6'	31"	18"

Aluminum extruded corners with stainless steel.

TYPICAL INSTALLATION

Inlet Water Level Control Structure



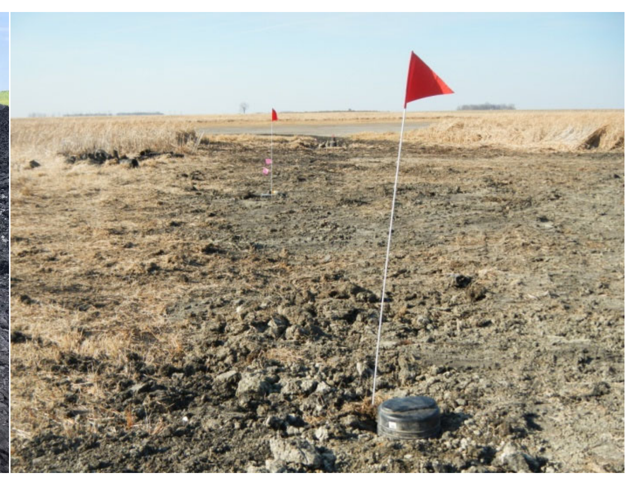
Manufacture outline of Agridrain inlet water control structures

Example of installed inlet structure with intake style top for overflow

Drain Field: A drain field can be installed in a tile line as an outlet to a wetland. This is a good option for large basins that do not have flashy watersheds since it usually does not take real high flows. The advantage is they are much less prone to getting plugged by sediment or by animals. The general idea is dig a trench out into a wetland 2-3 feet lower than the wetland bottom and about 6ft wide. The size of the drain field depends on the amount of water intake needed and the capacity for the size of pipe you are using but a 100ft section should be adequate for most average drain tile. You can also drill additional ¼ inch holes in the pipe for increased capacity. Continue a channel out into the wetland from the drain field to the lowest part of the basin to feed the drain field. Lay erosion control cloth down in the bottom of the drain trench. Fill in about 6 inches of the bottom with rock. Lay the perforated pipe down on the bed rock. Either cap the end or put on an elbow and a riser pipe in a cement collar if you want an inspection and overflow port at the end of the drain field. If you install this riser, put the intake at the maximum water level desired. Place large rock (6”-12”)at the end of the trench drain field. At the downstream end of the drain section, hook on to your perforated tile with non-perforated tile and run out of the wetland and repack your tile trench. Refill the drain field rock. It should be 2-3 feet deep over the pipe and be mounded slightly higher than the surrounding soil grade. For the outlet, if you want a fixed crest, angle the non-perforated pipe up and level off at the desired outlet elevation which will be the control area of the outlet pipe before angling back down to hook into and existing or new tile line or this type of structure can be used to outlet to a back side of a dike. Size of rock seems to be best with general cobble about 4-6 inches. Too small and it can get plugged with fine material. Too large and it could crush the pipe. Washed and graded to avoid fines that could plug perforations.

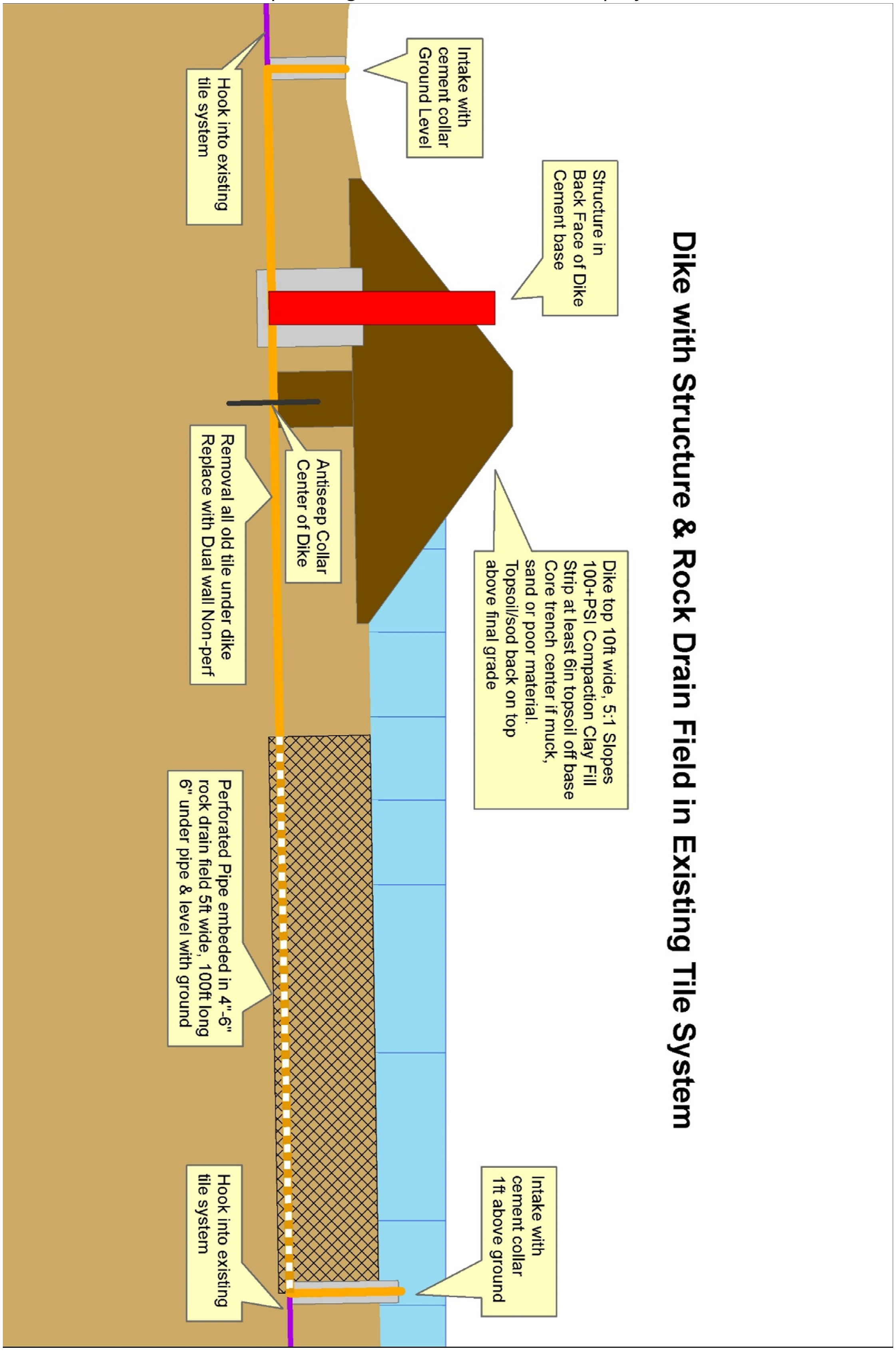
If you want a variable crest you can install an inline water control structure in your outlet pipe outside of the wetland boundary where it is easily accessible. Follow the guidelines above for installation directions of an inline structure. You can also install an inspection and cleanout tile riser port just downstream of the inline structure for access if the system is ever plugged past the structure. Cutting this riser off at ground level after the structure or putting a trash rack on top of the structure itself will function as an emergency intake in case the drain field is ever plugged and the water gets up high enough to overland flow into the top of the structure or tile riser intake instead of coming through the drain field line.


Left Photo Drain field trench with filter fabric down and perforated tile ready to be filled with rock. Right Photo is installation of tile riser at the end of the field to act as extra emergency overflow intake as well as inspection/cleanout port.

Left Photo is filling the trench with rock over drain tile, Intake port at end, Right photo is farther back upland with intake/inspection port in main tile line in foreground, then flag mid picture is inline water control structure, then drain field beyond.

Example Design sheet from a drain field project:



Open Spillways: Open spillways will pass the most amount of water through and the least likely to plug due to large area & volumes. The type of spillway depends on the potential for erosions and can range from grass to rock or sheetpile. In all cases the general concept is the same. They will be trapezoidal shape. Side slopes are variable but a good rule of thumb is 3:1 or flatter. If you get too steep they tend to slump. The bottom should be flat across unless you plan a multiple stage spillway which is rare for our applications. Width depends on amount of flow needed. I recommend wider/shallow is better. A bulldozer blade width is usually 10-15ft so regardless of your hydraulic calculations you might as well never design less than 15ft flat bottom. The more narrow the concentrated flow the deeper it will be and more energy the water will have and chance for erosion. If dealing with a dike or berm make sure when the maximum planned water flow is going through your spillway you still have at least 6 inches to 1 foot of freeboard on the dike to avoid saturation or in general 3 feet of freeboard between normal pool elevation and the dike top (2ft of max flow + 1ft freeboard). Check soil types when considering erodability and the need for reinforcement such as rock, concrete or sheetpile.

The length of the spillway (in the direction of water flow) is important as well. The longer the length the more friction encountered thus slower the water flow. For example if running a spillway around a dike it may be 100ft from the waters edge to the opposite side of the dike. However the spillway does not have to be flat the entire length. An entrance ramp can be made that goes up to a flat spillway top that may be 25ft long then slopes down with an exit ramp, therefore the narrow limiting area of the spillway is only the 25ft flat “control area”. Don’t get the spillway top too narrow or you risk erosion cutting through it. Minimum recommendation is 25ft. Slope of exit ramp should be between 2%-12% slope. Entrance ramp should be greater than 2%. Make sure the entrance and exit ramps as well as the flat top are level in the width direction through the whole length. On a tilted spillway water will not flow evenly through the whole spillway and cut more on one side than the other. Also the length of the spillway should be the same on each side through the control area and exit ramp. If one side of the ramp is shorter thant he other water will flow faster on that side. To accomplish a straight equal sided ramp, make the control area and exit ramp run perpendicular to the topographic contour lines. The entrance ramp does not matter length so it can be curved to lead up to the control area.

Grass Spillway

The best design is to make sure that your spillway's exit slope and level section are at the same grade, distance and slope throughout.

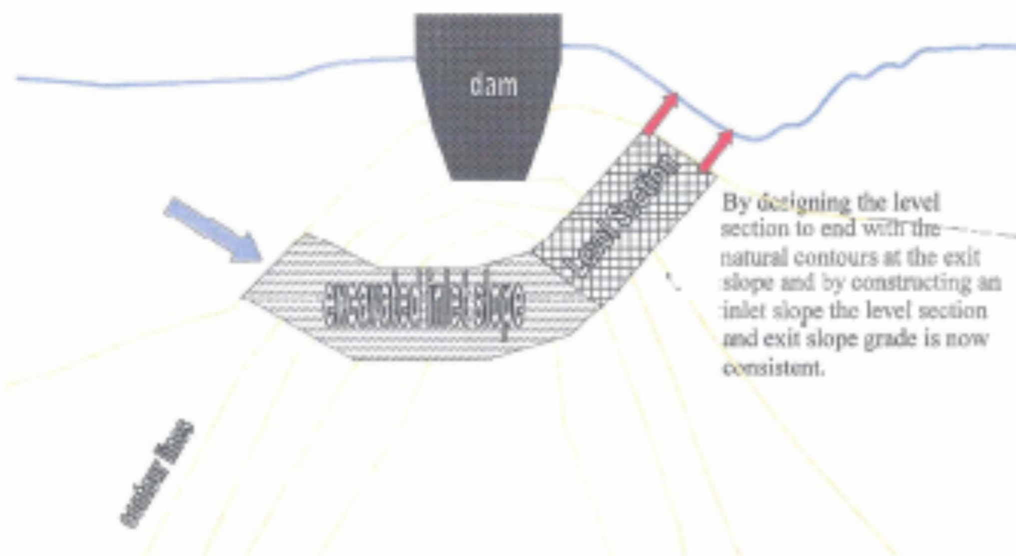
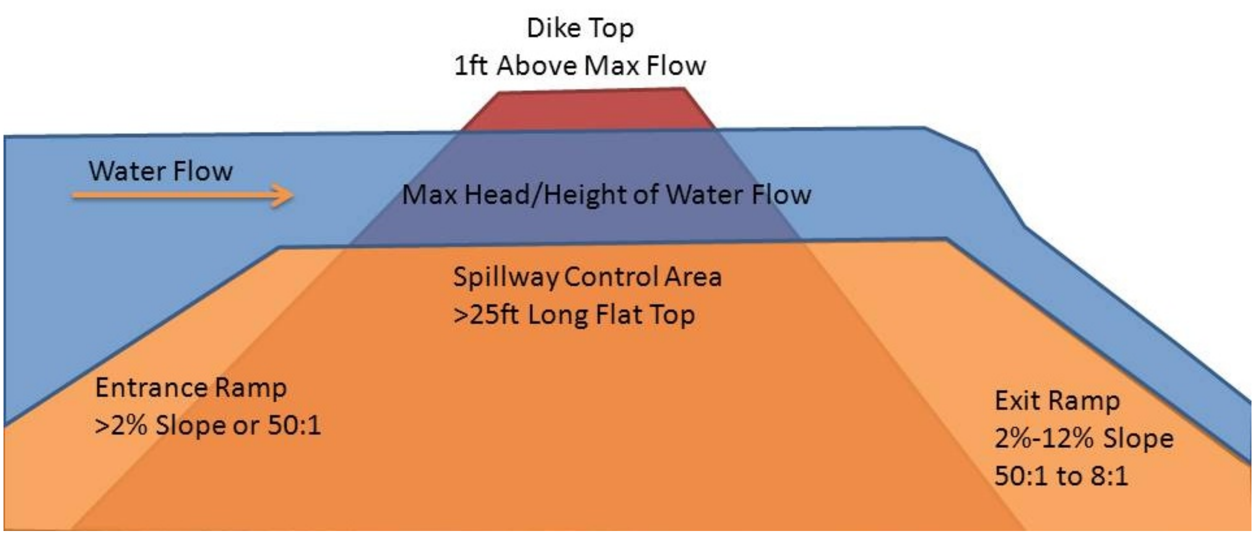
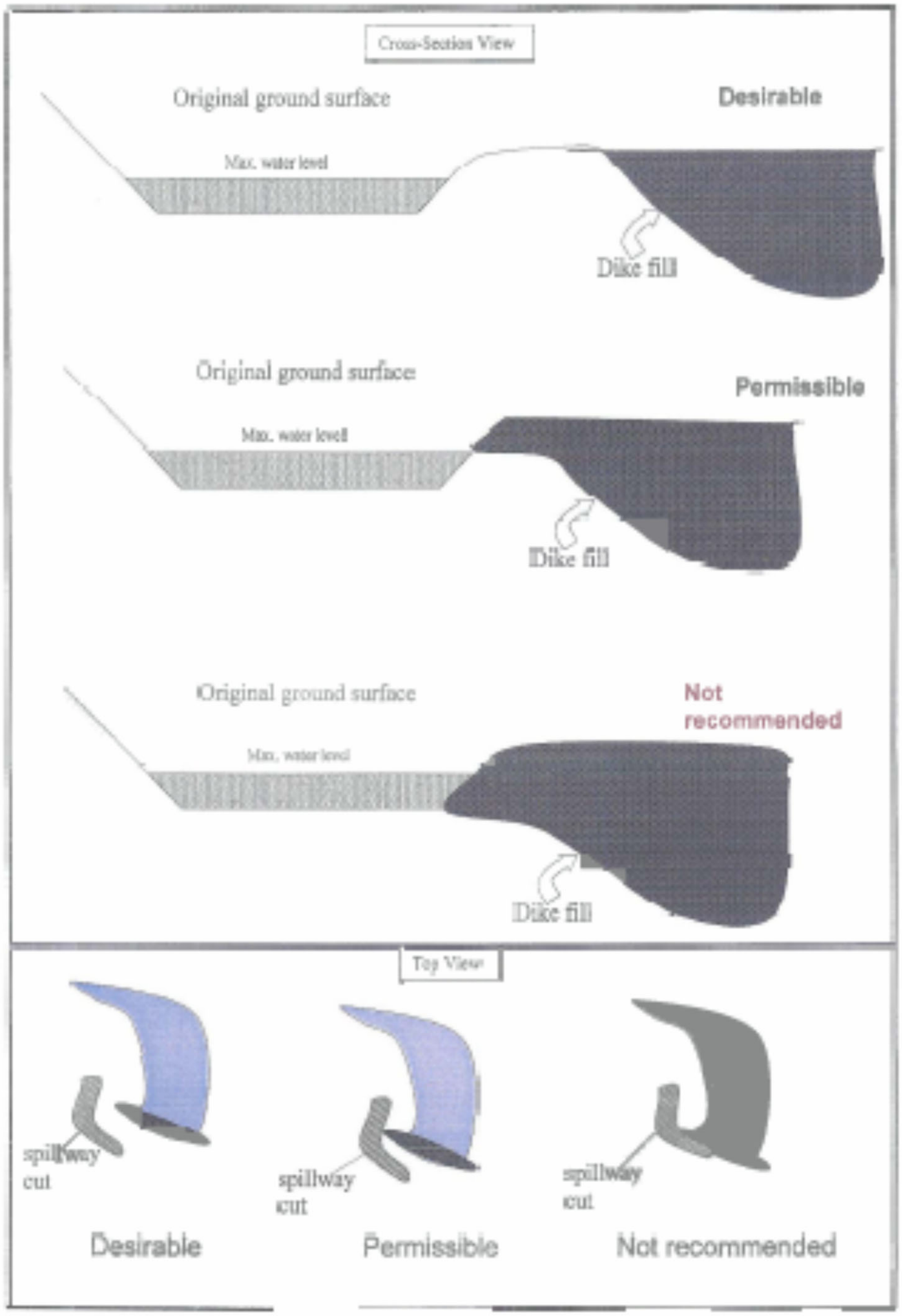


Diagram showing correct position of level control area and exit ramp position should be perpendicular to the topographic contour lines for even flow through the spillway. Entrance ramp does not have to be straight.



General depiction of relative elevations of spillway, water and dike.



Recommended positioning for spillways. Best is have spillway separate from dike, permissible is spillway next to dike but through natural ground, not recommended is water flow adjacent to fill material more prone to erosion.

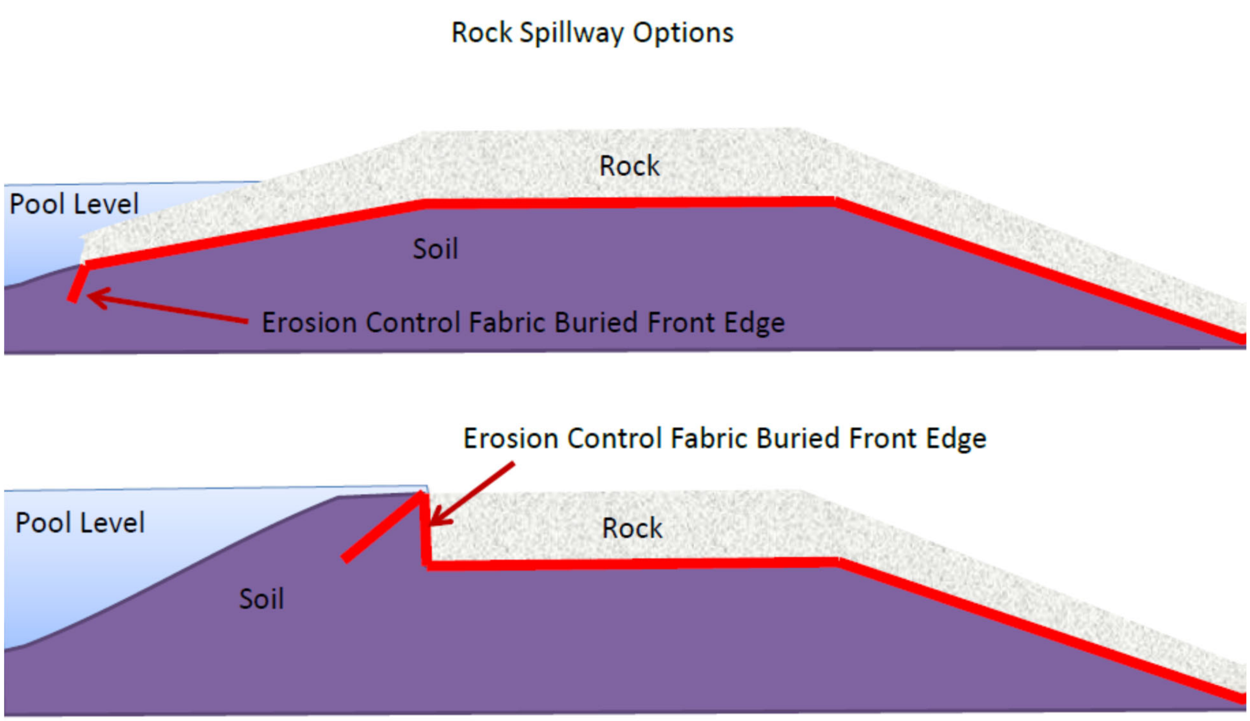
Grass Spillway: Only use a grass spillway if it is a secondary emergency overflow where most water will go through a pipe or structure first or if the wetland is unlikely to overflow often and when it does it is low velocity. Whenever possible the spillway should be placed over natural ground and not within a constructed berm. If natural landscape allows a spillway without cutting the sod then use that route as established sod will erode less than cut soil. If the spillway is disturbed but will remain grass only, plant some quick cover crop on it along with quick establishing grass in the mix. It is most vulnerable in the first year or two. Other erosion control can also be used for temporary reinforcement such as geojute mesh, spreading straw bales and run it over with tracked equipment or lay down straw mats or silt fencing or hydroseeding with mulch.

Example of dike with water control structure installed in the center as primary spillway. Emergency spillway around the side of the dike not in preferred position next to dike but limited due to landscape, thus wing dike can be seen extending from the center of the image extending to the right which directs water through the spillway and out past the toe of the dike. Hay mulch was used in addition to seeding as temporary erosion control.

Rock or Armored spillway: If there is potential for erosion of an open spillway you should armor it, such as if it will be the primary spillway, has loose soils or flashy high flow watersheds. The same basic rules as the grass spillway apply just cover it in rock. The armor should cover up the side slopes as high as the water could run. If it is short you can cover the whole length. From the midpoint/overflow of the spillway the upstream area isn't as important to cover all the way into the basin since water is just pooling there. Water will pick up speed and energy as it is funneled through the narrow point and starts flowing back down-hill. If affordable, armor the exit ram all the way down to the new flowline or bottom of the channel it will go into. Armoring only the top of the spillway may cause head cutting on the downstream end over just dirt and eventually erode back to the spillover point. If you can't armor all the way to the bottom, make sure the spillway fans out wide and as shallow of a grade as possible on the exit ramp.

Rock spillways should be underlain by some type of erosion control/geotextile fabric. There are smooth woven plastic types, however rocks tend to slide on it easier. I prefer the felt type material in a 6 or 8oz weight. Rolls are generally 12-15ft wide and you cut off what you need. If the spillway is wider than 1 role, overlap in a manner consistent with the direction of water flow. Edges should be buried so water does not flow under the fabric.

Elevations of rock spillways are a bit more tricky since during low flows, water will filter through the spaces between the rocks so pool level would be at the ground level/base of the rocks. At high flows the flow between rocks is essentially negligible and you would calculate based on the top surface of the rocks. Also over time the space between he rocks may fill in with dirt and debris. If this variability in crest elevation is an issue and you want to be more exact you can set your pool elevation using dirt at the entrance to the spillway. Make a dirt spillway at the desired height, then at the spillway point cut down a "box" for the rocks so the ground flowing into the rock area is the controlling height. If it is very high flow you can also use sheet piling for a solid crest height.

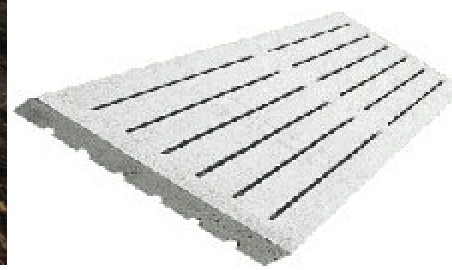


Examples of rock either whole spillway or use soil shelf in front as a more controlled set elevation

Depth of Rock should be 12-18 inches deep or more if you have a lot of flow. Size of rock is also important. Generally 6-12 inch rock should be good. Too small and it will wash away. Too large and it doesn't fit well to provide good coverage. If you have a lot of high velocity flow, order some larger rocks 18"-36" and put in a line or two in the crest and downstream portions of the spillway across the width of the spillway which will brace the smaller rocks against.

Type of rock also makes a difference. Field stone is more rounded and smooth with will role easier than quarry rock but cost and availability must also be factored. In some locations, crushed cement may also be available for cheap but consider if ascetics matter as well as smooth flat surfaces flow water faster so it may increase velocity as it flows downstream. Rock spillways are also good to use if you need a vehicle crossing known as a Texas crossing. Design your rock spillway as normal but top it off with ¾ inch rock to cover and fill in spaces between the larger rock and pack in place with heavy equipment. During low flow or dry periods ATV's, tractors or 4WD vehicles should be able to cross. Other prefab material options also include hog slats which are large flat sections of cement as well as cement mats which are blocks or lengths of cement tied together with cable similar to those you may see at boat ramps.

Example of Rock spillway in dike

Left example of rock spillway in dike with small rock over top so crossable by equipment. Left is a cement hogslat that can also be used in place of rock for spillway crossings.

Sheet pile: Sheet pile is used when there is a need for a lot of water flow and possibility of a lot of cutting action such as constant water flow. Without real engineering don't bother with metal sheet pile. However there is a new synthetic PVC/vinyl sheet pile on the market that is easy to install. There are many different specs and most are originally designed for use as sea wall reinforcement on the coasts but it works great for wetland sheetpile weirs. The type I use is by Crane Materials International and is called SG425. It is a 2ft wide sheet cut to desired length. Cost is about $5/square foot of wall so a 8ft long sheet is $80. Large cost is shipping so order as much as possible in one load to stockpile and use on multiple projects.

Proper engineering can get complicated but for our use plan on length enough to get down into the native soil so if installing in a dike go below the base of the dike by another foot or two. Other guidelines are if it will be sticking out of the ground have 2/3 or ¾ of it buried so if 2ft sticks out you need 6ft buried for a total of 8ft. For stability, never use less than 6ft sections or it may lean under pressure.

If you have a proper vibratory hammer for driving it, you can drive this the whole way but almost no one in this area has proper sheet piling equipment and it would be very expensive to locate and rent it. The easiest install is dig a trench along the sheet pile path down to a depth of 1-2ft from the bottom of where the sheet pile would be. You can generally push the sheet pile in 1-2ft with the weight of an excavator bucket. The sheets have a male and female groove that slide together start at one end of the weir and drive the first piece with the male edge pointing toward where the next piece will go. If you drive the female edge first, the slot will be filled with dirt and harder to push down and the male edge may slip out of the slot. The first couple sheets are the most important to get level and plum because since they are slotted together they will follow each other and a lean or tilt will be amplified all the way across. Develop a jig to fit the shape of the top for the excavator to push on without damaging the top. Make sure they push straight. Get the excavator bucket flat and have a good operator with a light touch.

If it starts to twist or tilt the bucket isn't on flat so release and reset. If you have trouble getting all sheets driven to the exact height or tops level with each other you can drive them close and leave it a little long and cut it off with a saw when finished. If you hit a rock you can try to pull the sheet and excavate it out or if the depth is sufficient just drive to that depth and cut excess of the top. Once all the sheets are driven the last 1-2ft in the trench you can backfill against both sides up to the desired ground level. Use a jumping jack/whacker to compact it.

The top design can vary. For the maximum flow rate you want a sharp crest weir, which means water will spill/fall over the edge of the sheet. For this leave about 3 feet sticking out of the ground and fill 2 feet with rock and leave about a foot of open space for the "waterfall". If you have the spillover effect, make sure erosion control cloth and rocks are pushed all the way up into the grooves of the sheet pile wall to reduce erosion down the face of the wall. If the flow rate isn't that important and you just want to use sheetpile because it is sandy soil that may seep or to reinforce the ground so it doesn't cut down over time you can have the top of the sheetpile even with or below the rocks or if it is just a grass spillway then leave it at ground level and you will not even know there is sheetpile there once vegetation grows. You can cut the side slopes down to fit the angle of the slope or just leave the stair step type look and the weir length/flow will increase in stages as the water level rises. There are caps available if you want it more astatically pleasing or you can create your own with treated lumber (2X6's bolted to each side with 2X12 on the top screwed to the 2X6's) but it doesn't change much of the functional purpose. Make sure your sheet pile goes all the way across the bottom as well as up the side slopes of the spillway and at least 2 sheets into the flat top of the dike top on each side to make sure water doesn't cut around the side of the sheet pile.

Left a metal jig designed to fit the top of the sheet piling to protect it while driving. Right, plastic sheet piling trenched in and then driven the last 1-2 feet and soil compacted back in the trench against the sheets.

Left, Sheet piling being drive/pushed in with a excavator bucket. Right rock being placed over the spillway around the sheet pile wall.

Left, Sheet pile being driven in a grass spillway with a vibratory packing head on a backhoe (only works on soft soils without trenching). Right the same finished sheet pile weir in a grass spillway, invisible when done since driven to ground level but prevents cutting a channel through the spillway (only low to moderate flow wetland).

Left example of wood cap on sheet pile. Right Example of aluminum cap on sheet pile.

Stop log bay: Open water level control structures can be used combining the ideas from the inline water control structure and open spillway. Some type of dike or wall will be used and design a stoplog bay in the middle. This may border on too much engineering and design for average FWS personnel. However if the project is low complexity you may be able to design a simple structure. For example use the sheetpile weir as described above. Then fabricate (local machine shop) an aluminum or stainless stoplog frame that would fit by cutting the center sheet down lower (3ft?) or driving that piece in deeper and bolt and calk the frame to this cutout on the upstream side. (Each sheetpile sheet is 2ft wide for the example style of SG425 so cutting out 3ft of the middle sheet would give you a drawdown channel of 3 vertical feet by 2ft wide weir length). Design the fabricated stoplog channel to fit a standard size stoplog such as those that can be ordered for the agridrain water control structures. An alternative would be again use the sheet piling or design a dirt dike and utilize cement to make the stoplog bay. However you need to have a contractor with experience forming cement. With any dirt dike, use good wing walls to channel the water in and out of the stoplog bay so it doesn't erode around your structure. You can also contact a cement fabrication company and have them prefab a stoplog bay that just has to be set in place and fill in around. However this may be costly and installation of a larger more expensive structure may require more technical expertise so you may need and engineer anyway. The most simple cement stoplog bay would be order a large square cement box culvert which you bolt on a fabricated aluminum or stoplog channel on the front of it. Bury the box culvert in the dike using good compaction with heavy clay soil and some type of wing walls to act as an antiseep collar.

Left, example of stoplog bay bolted on to a large cement culvert running under a dike with wing walls on each side. Right Aluminum fabricated stoplog bay using agridrain logs which can be mounted on a cement wall or bolted to a sheet pile cutout.

Staking

Visual cues are needed to lay out your restoration to contractors. For simple projects flagging can be used. Laths or stakes are often more visibly and used for bigger projects. Use highly visible flags or paint the lath. Florescent pink is the best color to use for paint. Color codes are used by utility companies which most sites have to have utilities marked so don't use confusing colors. White is also a safe color to use but slightly less visible. 3ft wood lath can be bought at any lumber yard. Prep paint them before field work if possible so they are dry and ready to write on when in the field, otherwise place and paint all of them, then come back to the start to mark them. If the ends of the lath are square, cut them with a saw before going to the field or bring a hatchet to angle the end to make them easier to pound in. Brace the base with your foot and the center with your knee while pounding in to avoid bending and breaking. When ordering flags get the longer ones (24”) that can be seen in tall grass. I tend to use lath to mark the start and end points of something or where directions are needed. I use flags to mark outlines such as tile routes.

Write clearly on the lath or flag with a big black marker what it stands for such as *(START DIKE HERE – TOP = 1402FT MSL, 3:1 SLOPE)*. Write on both sides so it is visible from both directions. If your stakes are out for more than a month before the work remember to recheck them before the contractor starts as they may fade in the sun and words will not be visible. I also tend to put wire flags in at the base of my wood lath. Lath can break off, wash away, burn up or get kicked over by animals or people so doubling up on the marking improves your chance of finding some type of marker. I also GPS the major points in case all stakes are removed then I don’t have to re-measure everything.

If marking a slope the general accepted staking is angle the stake if it shows a slope in the same direction as the slope, thus marking the slope toe of a dike the outer stakes will angle away from the center of the dike. For dike work, those toe slope stakes will be the most important since the contractor is likely to run down the centerline stakes on his first pass stripping sod and use the outer stakes as the outline for his work area. Place the toe stakes a foot or two past where you want the actual toe to be since again the contractor tends to try not to hit them with his equipment so will drive the dozer or scraper a foot or two inside the stake. Toe stakes can be marked using basic survey calculations. Mark your centerline then take a survey shot at the center to find the height from the ground to the planned dike top. Assuming you are on relatively flat ground the toe will be the height of the dike multiplied by your slope ratio plus half of the top width. (6ft tall with 3:1 slopes and 10ft flat top = 6*3+5 = 23ft out from center). If you are building on a slope add more distance to the toe on the downhill side and less on the uphill side and if you need ot be exact shoot the elevation at the estimated toe and recalculate distance from centerline based on that elevation to double check if you need to be closer or farther.

If marking a length using plain English is fine, however you may also see official survey/engineering notations will use 1+number to indicate 100ft + the remainder so 1+65 means 165ft. 3+100 means 300ft. You can use this if you want or again most contractors are fine with plain English. Just explain staking and any notations in a preconstruction meeting.

Also near the work area it is helpful to establish a temporary benchmark so a contactor can easily check his elevations or you can inspect the work when finished without having to go far or carry a turning point from a far away benchmark. I like to use a 2ft rebar driven in the ground at the exact same elevation as what I want the dike top or spillway to be. Using a common elevation like dike top you can quickly set up the laser and shoot the dike without having to worry about calculations. Just zero the survey rod on the Rebar TBM and you are set to check if the dike was built up properly. Mark the TBM with an inverted tripod of highly marked lath with flagging or ribbons to make sure they don't run it over. Also place it out of the equipment driving path likely on the downstream side of the work area.

After a work area is staked is a good time to take before pictures. You can then visualize what will be done and frame the photo to include the project layout before work is done. Don't forget to take during and after shots from the same perspective.

Example of staking a dike before construction. In this case we have centerline stakes, toe stakes and a spillway wing dike in the left foreground.