Utah Department of Natural Resources
Division of Water Rights
Dam Safety Section

Dam Safety Guidelines for Small, Low Hazard Dams

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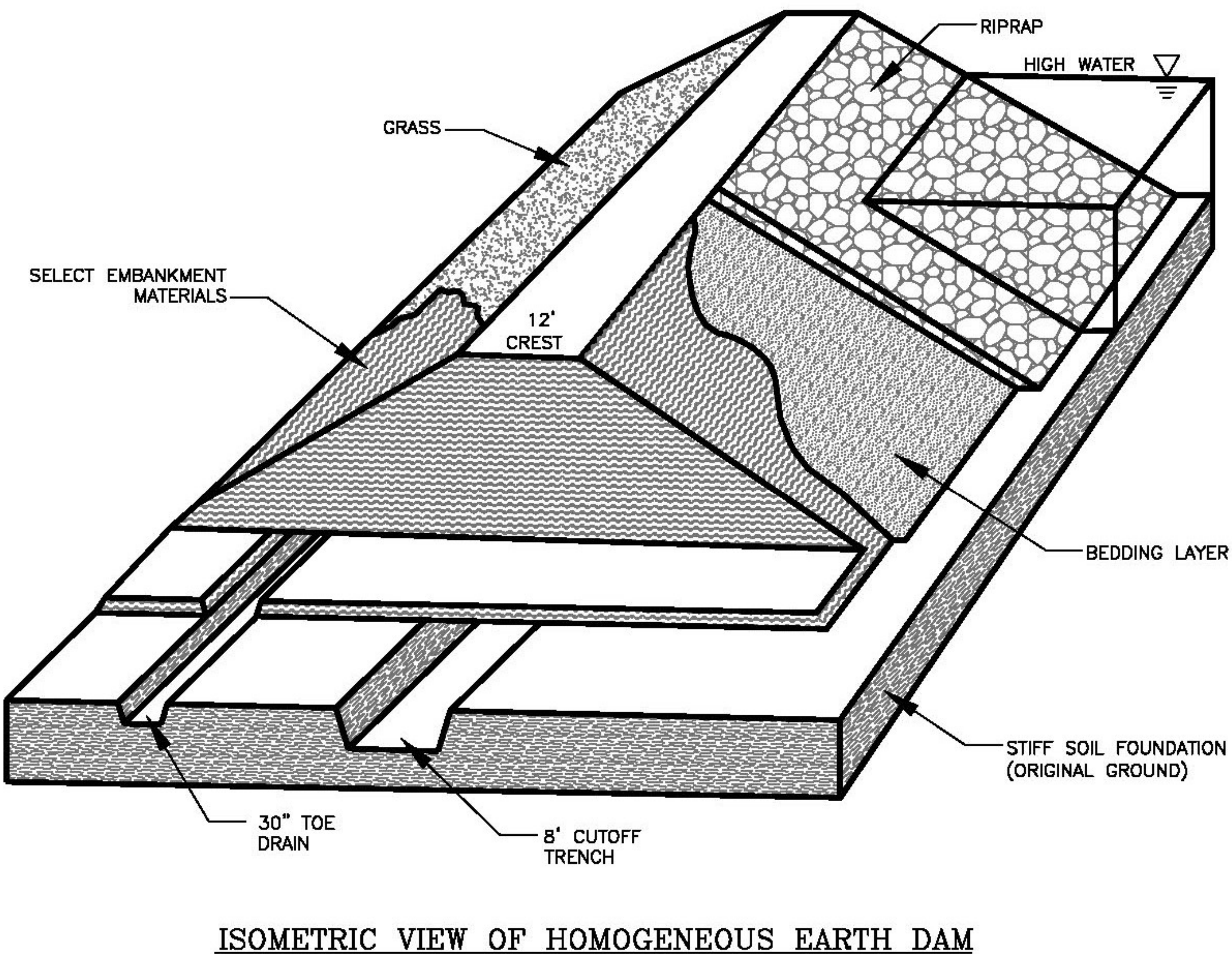

ISOMETRIC VIEW OF HOMOGENEOUS EARTH DAM
NOT TO SCALE

Dam Safety Guidelines for Small, Low Hazard Dams

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Utah Department of Natural Resources Division of Water Rights, Dam Safety Guidelines for Small, Low Hazard Dams

PURPOSE AND SCOPE

The purpose of these Guidelines is to provide those potential owners of small dams with a general description of the legal and engineering requirements that they must meet to construct and operate a small dam in Utah. The requirements illustrated apply specifically to small dams with heights ranging up to 10 feet, with capacities less than 20 acre feet, and in areas where downstream hazards are minimal. The engineering requirements illustrated apply to a hypothetical dam at a specific site. Since conditions and materials vary widely from site-to-site, it should be recognized that the Guidelines may not directly apply.

APPLICABILITY

Only dams approved pursuant to Section 73-5a-202 (1) and Section 73-5a-202 (3) should use these guidelines. All other dams requiring formal plans pursuant to Section 73-5a-202 (2) must be designed by a Professional Engineer. The referenced section of the Utah Code is as follows.

73-5a-202. Submission of plans

(1) Before a dam is constructed, enlarged, repaired, altered, removed, or abandoned, plans for the work shall be submitted to the state engineer for his approval, unless the dam:
- (a) impounds less than 20 acre-feet of water; and
- (b) is not classified as a high hazard structure under Section 73-5a-106.

(2)
- (a) The plans shall be submitted 90 days before:
  - (i) awarding the construction contract; or
  - (ii) the commencement of construction, if the owner constructs the dam.
- (b) The state engineer may shorten the 90-day review period if the owner and the design engineer submit satisfactory preliminary plans and design reports for review.

(3) The state engineer may waive the requirement of plans if it can be demonstrated that failure of the proposed dam:
- (a) does not constitute a threat to human life; and
- (b) may result in only minor property damage that would be limited to property held by the owner of the structure.

INTRODUCTION

These guidelines are intended to illustrate the general requirements for the design and construction of a small earthfill dam on a stiff soil foundation. These guidelines are not intended to constitute a text for the design and construction of small embankment dams. A set of reference **Plan Sheets** is included at the back of this guide, and are referenced within the text.

The approval of an application to construct a small dam does not grant the right to appropriate water, the applicant must have a water right approved by the State Engineer prior to filing an application to construct a dam.

SMALL DAM SITING

In order to assure safe and satisfactory performance of a small dam, certain topographic and geologic features should be avoided in the process of site selection.

1) Overly steep valley walls adjacent to a site may indicate a potential for site impacts by landslides, debris flows, etc. Such impacts could damage a dam, bury the outlet, or reduce reservoir storage.

2) Past evidence of landslides, slumping and seep sources on slopes tributary to the dam site would require thorough assessment.

3) Evidence of past debris flows may indicate flash flood potential in tributary drainages. This could result in dam erosion and sediment filling the reservoir basin.

4) Shape, slope and vegetation conditions downstream of a potential dam site should be taken into consideration. The existence of healthy, soil retaining vegetation in the downstream drainage indicates adequate water supplies. The disruption of surface and ground water conditions posed by a new dam site may result in reduction of downstream vegetation. This could cause development of steep gullies and increase erosion susceptibility. Any head cutting resulting could undermine the dam.

5) Fractures, faults and joints in bedrock within the reservoir basin, at the dam abutments and even buried beneath the cutoff trench can cause unwanted seepage losses to underlying or adjacent rock formations. The concealment of such features by overlying alluvium can make their identification difficult. For this reason attention should be paid to any rock outcrops exposed in an area. Attempts should be made at visualizing any subsurface traces that may pose future seepage concerns, especially in areas where free standing reservoir water or saturated soil materials may have a hydraulic connection to buried bedrock.

6) The use of natural topographic features for dam and reservoir development should be approached cautiously. A natural depression may look inviting as a ready-made reservoir basin but the dam builder must question the depression's origins. Several "high and dry" dams can be visited today whose storage function was completely lost to sinkhole development within the reservoir basin. Careful review of topographic maps for indications of sinks or caves can be a "first cut" at avoiding such problems. Because sinkholes are universally associated with limestone and/or high gypsum content rocks, the dam builders review of nearby rock outcrops should bear this in mind.

7) Attempts to reduce embankment volumes by "tying in" to existing "natural embankments" should also be approached with caution. Such features may be deposition areas of past landslides which may pose future ground water and stability problems. Such features could also be glacial moraines which may have porous materials (especially at their base), or coarse open graded pockets (rock nests) within their mass. Utilizing such features as a portion of an embankment without sufficient exploration and testing, could lead to long term seepage or instability and potential failure.

To conclude, the dam builder's review of the foregoing topographic and geologic setting may effectively avoid failure of a needed water storage facility and loss of time and money. The review may also lead to questions that are best investigated by a professional with the tools and experience to adequately answer them.

SUBSURFACE INVESTIGATION

1) While a dam site may be topographically suitable for the proposed purpose, it is also essential that a subsurface investigation be conducted to determine that the foundation as well as the materials intended for use in constructing the dam are suitable. For the types of structures under consideration in this document, this investigation can normally be accomplished through a series of test pits excavated with a backhoe. Test pits should be excavated to a depth of 10 feet along the length of the proposed embankment, the outlet conduit, spillway alignment, as well as in potential borrow areas (see Reservoir Plan View). The locations and types of soils encountered in the test pits should be noted for future reference.

2) The foundation soils should be sufficiently firm to provide adequate support for the embankment and should have low permeability to allow for water retention. The foundation area covers the dam's "footprint" from abutment to abutment. The depth to this firm material at various locations along the dam center line should be noted for possible future use. The presence of bedrock, coarse and porous sands and gravels, or soft soils require design and construction considerations which are beyond the scope of this document. Where such conditions are unavoidably encountered, an engineer experienced in the design and construction of earthfill dams should be hired to investigate, design, and oversee construction. The subsurface investigation should also identify the presence of ground water conditions. The depth to the water table should be noted. Any construction requiring de-watering of any project excavation is beyond the scope of this document.

3) Borrow soils that will be used to construct the embankment should likewise have sufficient strength for embankment construction and low permeability to retain the reservoir water in a safe manner. Typically, soils with greater than 15% fines (i.e., silts and clays smaller than a standard #200 mesh screen opening) will be sufficiently impermeable for foundation and embankment soils.

EMBANKMENT DESIGN

1) The upstream slope of an embankment founded on firm materials should be no steeper than 3:1 (horizontal to vertical) and the downstream slope no steeper than 2:1 (See Cross - Section of Dam). The dam should have a minimum of 3 feet of freeboard (the vertical distance between the spillway flowline elevation and the crest of the dam). The dam crest should have a minimum width of 12 feet and the surface of the crest should be graded to provide positive drainage toward the reservoir basin. Roadbase should be placed as the top wearing surface on the dam crest to prevent rutting and other erosion.

2) A 2 foot deep (or to a depth indicated by test pit data) cutoff trench should be excavated beneath the centerline of the crest. The side walls of the cutoff trench should be no steeper than 1:1 and the bottom of the trench should be sufficiently wide to allow equipment access, with a minimum width of 8 feet.

3) Toe drains and other seepage collection features are often not included in the design of small dams. If there is any concern at all about foundation or embankment materials, a toe drain needs to be installed. The inclusion of a toe drain is a sound defensive design provision that should be given consideration. The design of a toe drain or other drainage control features may need to be reviewed by an engineering consultant. Typically, toe drains are placed near, but beneath the downstream toe of the embankment (See Toe Drain Cross - Section and Reservoir Plan View). The drain can be excavated in a trench parallel to the toe and at least 6 feet inside the toe, beneath the embankment. This trench should be excavated after one foot of fill material has been placed and compacted, and should be 3 feet in depth. In this way, the drain will penetrate 2 feet into the foundation through the embankment/foundation interface and one foot into the embankment itself. All drain pipes should be a minimum of 4 inch diameter (preferably 6 inch diameter to allow for internal pipe inspection). An appropriate drain material that is often used is ASTM C-33 fine aggregate concrete sand. For drain pipe encapsulated in C-33 concrete sand, pipe perforations should be no bigger than 0.02 inches. The perforated pipe must be surrounded on all sides with a minimum of 12 inches of the sandy drain material. A non-perforated drainage outfall also needs to be provided that extends to a visible location where seepage flows can be monitored. Drain material should be placed and compacted in 6 inch lifts.

4) Rock riprap is typically placed on the upstream slope of the embankment to protect it from wave action. Small dams made of cohesive embankment soils have often performed well without such protection. Riprap should be provided in areas where strong winds that could generate waves in the reservoir are possible. A granular (a sand and gravel mixture) bedding layer between the embankment soil and the riprap should be provided. Exposed portions of the embankment (i.e. the downstream slope of the dam, and upstream slope if not rock protected) should be seeded with grasses.

5) The embankment should include provisions to restrict livestock from grazing on the dam since they damage protective vegetation, increase erosion by establishing trails, and they can obscure signs of impending failure.

CONSTRUCTION SPECIFICATIONS/TECHNIQUES

1) The first stage of construction consists of stripping the ground surface, underneath the entire proposed dam, of all topsoil and organic material. All vegetation and brush/trees should be removed from the site and wasted. All roots greater than 1 inch in diameter should be grubbed out of the ground and wasted. Organic soil can be stockpiled and saved for later placement on exposed portions of the embankment prior to seeding.

2) Following stripping and grubbing, the cutoff trench should be excavated to the design depth. Excavated soil that is suitable for embankment material should be stockpiled for later use. Prior to fill placement, the bottom of the cutoff trench and the other foundation soils beneath the embankment need to be scarified (roughened by plowing, etc.) to a minimum depth of 6 inches and any over-sized rock or other unsuitable material removed. The surface should then be moisture treated and compacted.

3) The embankment will likely be constructed out of suitable soils encountered during the subsurface investigation. Typically, these soils will be borrowed (taken) from inside the reservoir basin, but could alternatively be imported from another site. Construction of the embankment should begin at the lowest ground surface elevation, beginning in the cutoff trench. The embankment should be constructed in nearly horizontal lifts that extend from abutment to abutment, as far as is practical. Borrow should be hauled onto the lift placement areas by trucks or other hauling equipment and should not be pushed into place. Once dumped into piles and windrows, dozing equipment should spread the soils so the thickness is no greater than 6 inches before compaction. Where some coarse material (rock greater than 2 inches) is present, these fractions should be raked to the outer thirds of the embankment, both upstream and downstream. Materials in the fill should not in any case be greater than 4 inches in size. Rock in the fill should not be allowed to form coarse open graded pockets (rock nesting), but should instead be spread out and evenly distributed.

4) In order to achieve optimal compaction, the soil needs to have the proper moisture content. Many soils are near their optimal compaction moisture content when a "bead" of soil rolled in your hand or on a clipboard just begins to crumble at a diameter of 1/8 inch. The moisture needs to be uniformly distributed throughout the lift. If the soil is too dry, moisture should be added to the soil, preferably in the borrow area. In this way, the moisture is evenly distributed throughout the borrow during the hauling and placing process. Alternatively, a disc could be used to "turn" the soil over on the fill to distribute moisture. If a soil is to wet, then drying of the borrow will be required. This is typically done by deep scarifying, discing, etc. to turn the soil over and allow excess water to evaporate.

5) Once the fill has been placed, spread, and the moisture content properly adjusted, the soil should be compacted by either rubber tired equipment (front end loader with bucket filled) or with equipment specifically meant for soil compaction. Compaction should consist of a minimum of 8 "passes." Meaning that each square foot of the lift should be passed over by the compaction equipment 8 times. Prior to placing the next lift, the prior lift should be lightly scarified or harrowed (maximum of 2 inches deep) to allow for bonding between lifts. A typical bonding problem occurs when the surface of the fill becomes dry between lifts. Sometimes scarifying will correct the problem. If not, moisture treating of the soil is needed. Following storms or improper use of watering equipment, the surface of the soil may also become too wet, again requiring proper moisture conditioning prior to placement of the next lift.

6) Fill placed within 2 feet of any concrete structures should be a select material with maximum particle size of 2 inches, placed in lifts not exceeding 4 inches. Compaction of these soils should be accomplished by hand operated equipment designed for this purpose. Such methods also apply to any restricted areas or areas where large mechanically operated equipment cannot adequately cover and compact a lift.

OUTLET FOUNDATION DESIGN

Construction of the outlet conduit is a critical aspect of the construction that must be done in the right way. The foundation for the outlet conduit should be investigated by at least two trenches to determine location and character of adequate base materials. Erosion failures caused by seepage along embankment/structure contacts are one of the most common failure modes for embankment dams, including small dams.

1) The embankment cutoff trench should first be constructed beneath the outlet conduit prior to its placement. An outlet conduit trench should be excavated from its intake location in the reservoir basin to the downstream toe, or beyond, of the embankment. All loose material must be removed so that the bottom and sides of the trench are in firm soil. The outlet conduit should be placed in the trench and soil disturbed during placement removed from the trench. The trench should be backfilled with concrete to form an encasement around the pipe (See Outlet Concrete Encasement). The bottom of the trench should be at least 6 inches below the bottom of the pipe and there should be a minimum of six inches of space between the pipe and the sides of the trench. Prior to placing concrete around the outlet pipe, the pipe must be restrained to prevent it from floating buoyantly before the concrete has set. It is preferable to encase the outlet pipe to six inches above the top of the pipe so that the conduit is totally enclosed in concrete. If this is not practical, then the conduit must be cradled in concrete beneath the pipe up to at least its mid height. In any case the concrete should not be placed above the top of the trench.

2) A sand collar filter/drain needs to be incorporated into the outlet design. The sand collar should be placed around the outlet conduit at a location beneath the downstream slope of the dam that is approximately midway between the dam crest and downstream toe. The sand collar should extend at least 3 feet beyond the outlet conduit in all directions and be at least 5 feet in length along the outlet pipe (see Sand Collar/Stilling Basin profile). At an elevation equal to or lower than the bottom of the outlet pipe a perforated pipe should be placed within the sand collar material, penetrating approximately 2/3rds of the sand collar's length. The pipe should be connected to a solid pipe outside the sand collar that

extends to a visible location below the downstream toe of the dam. This sand collar material and perforated pipe should be consistent with the descriptions given above for toe drain materials.

3) The bottom portion of the sand collar will need to be placed prior to placing the outlet pipe in the trench. In the location of the sand collar, the trench will need to be deepened and widened to the dimensions of the collar. The bottom of the sand collar up to the concrete encasement elevation should be placed and compacted prior to placing the pipe and concrete in the trench. Because the trench will be wider in this area, forms will need to be placed in this area during placement of encasement concrete. Once the concrete has been placed and properly cured, the forms should be removed and the sand collar material placed and compacted along the sides of the conduit to the top elevation of the trench. Portions of the sand collar that extend above the top of the trench will need to be constructed simultaneously with the surrounding embankment. For each lift, the sand collar material should be placed first and compacted so that it maintains a minimum elevation of 6 inches above the surrounding fill at all times. It is critical that any contamination (mixing) of the sand collar material with other soils be prevented.

HYDRAULIC DESIGN FOR OUTLETS

A low level outlet is used for lowering the reservoir in case of emergency; or for inspection of the dam, reservoir, and appurtenances; as well as for releasing water.

1) The final alignment of the outlet conduit should be determined in the field after site stripping operations, and after the embankment cutoff trench is excavated. Curved alignments and changes in grade may be desirable or necessary to locate the conduit on the most competent materials.

2) The outlet conduit should be positioned so that it can drain at least 90% of the reservoir's capacity.

3) Outlet conduits should be sized to meet downstream requirements. In addition, they should be large enough to discharge 90% of the reservoir capacity in a period of 30 days. The outlet diameter should be a minimum of 8 inches to allow for possible future camera inspections of the interior.

4) It is preferred that outlet conduits have an upstream control device. A trash rack should be provided upstream of the control with a bar spacing of 2 inches unless a finer screen is required. An air vent pipe is required just downstream of the control valve. An outlet conduit which is connected directly to a distribution system should have an emergency bypass valve at or near the downstream toe of the dam.

5) All outlet conduits should be designed for internal pressure equal to at least 1½ times the full reservoir head and for the external embankment loads.

6) Consideration should be given to dissipating the energy of outlet discharges (see Sand Collar/Stilling Basin profile) and providing access to the outlet when it is connected directly to a piping system.

SPILLWAY

1) The spillway should be located in natural ground, sufficiently apart from the dam to prevent erosion of the dam embankment (see Reservoir Plan View). The best location is in a saddle or cut completely isolated from the dam. An unprotected spillway over the dam embankment is not acceptable.

2) Usually, a trench at the spillway crest and one or two along the channel would be sufficient to determine if erodible material is present, if so provisions to control erosion must be included. Methods to prevent erosion may include lining the spillway channel, piping the spillway flows, extending the spillway length to have a very flat grade, or installation of riprap, concrete or other protective materials.

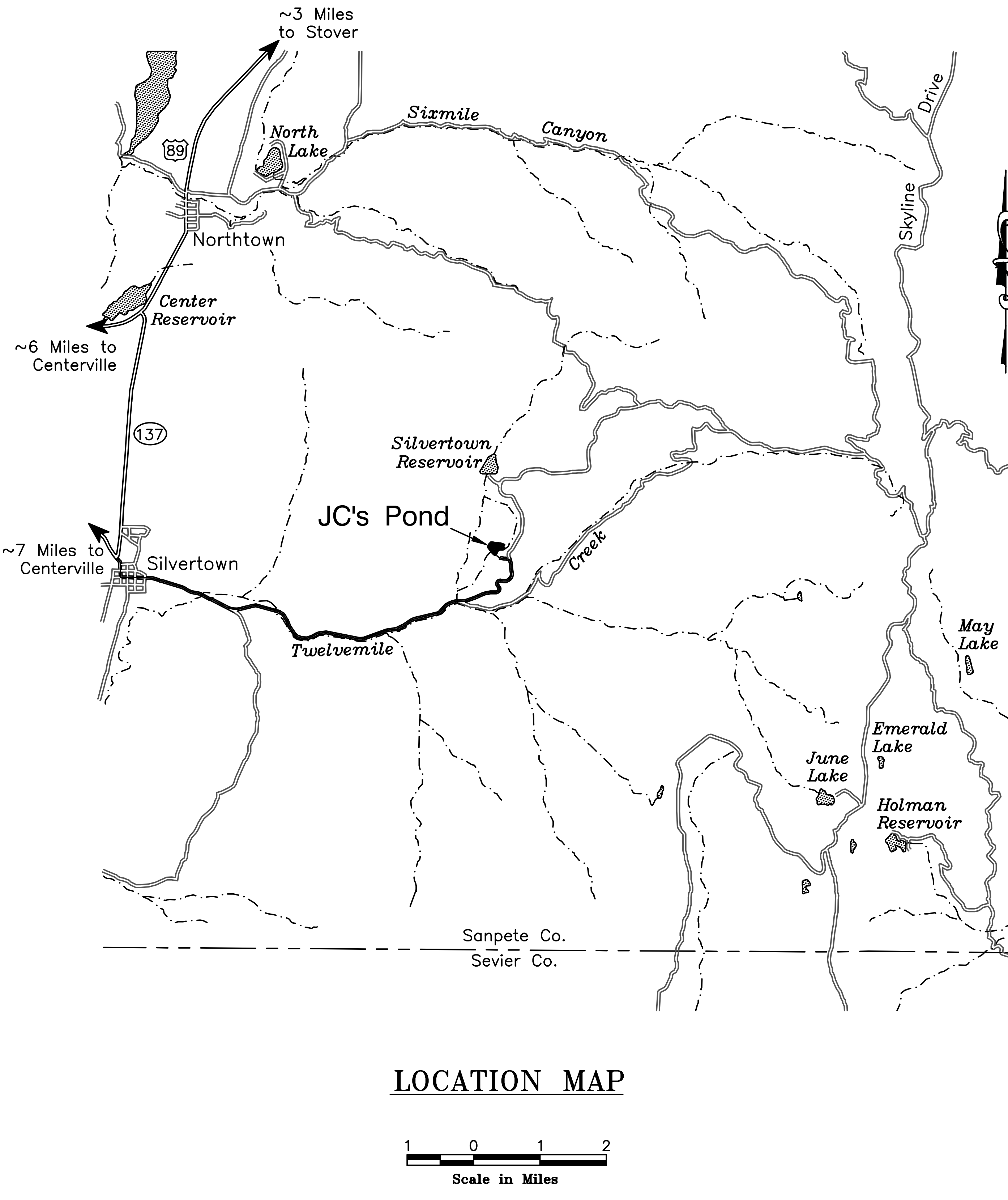
3) The spillway should be designed to route as a minimum the anticipated 100 year flood event.

4) For an off-channel reservoir the minimum spillway capacity should be equal to the capacity of the ditch or canal supplying the reservoir.

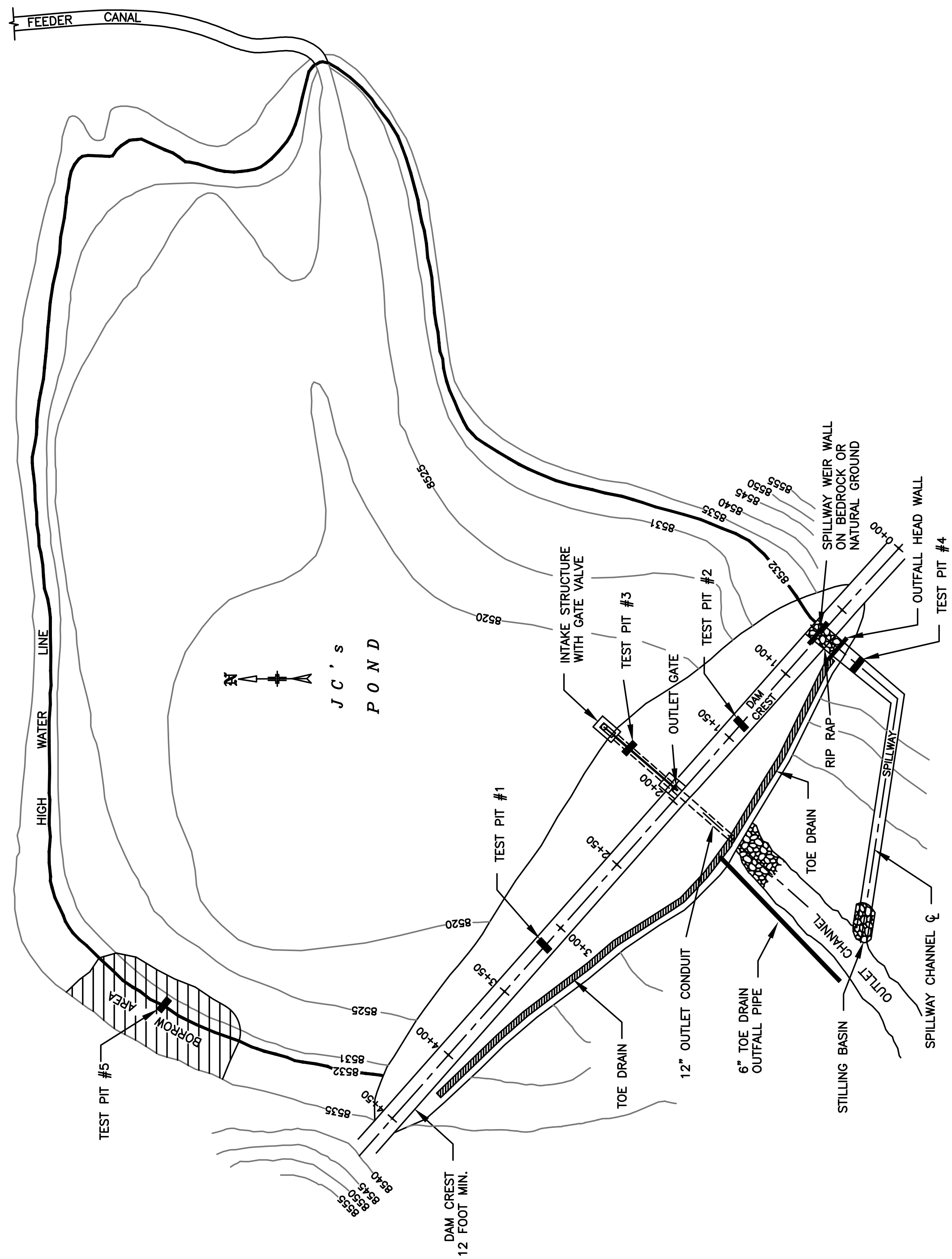
5) The minimum freeboard (vertical distance from the bottom of the spillway to the top of the dam) required is 3 feet.

6) Any spillway walls in the vicinity of the dam must contain the maximum spillway capacity with at least 6 inches of freeboard..

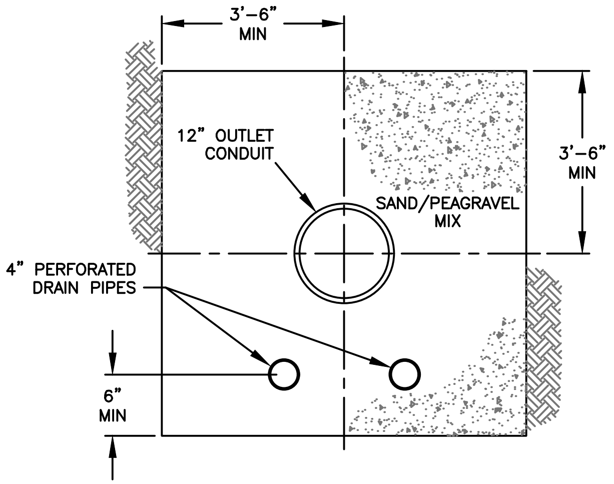
7) Consideration for the dissipation of energy to prevent erosion at the end of the spillway should be given.



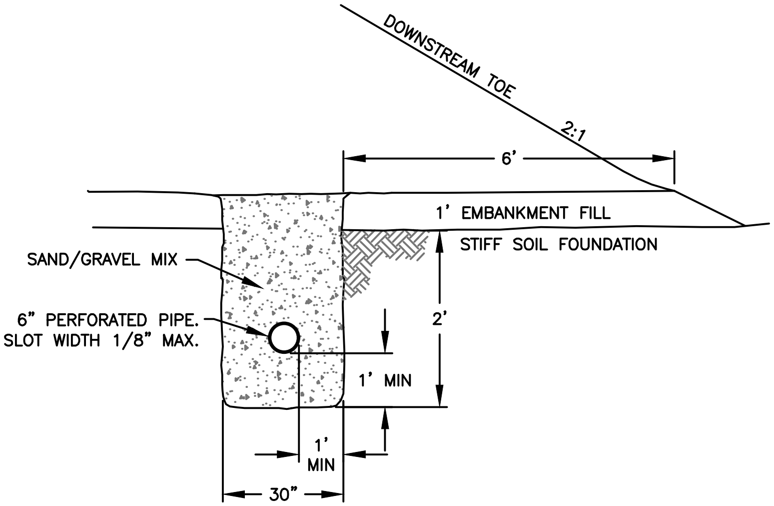
LOCATION MAP



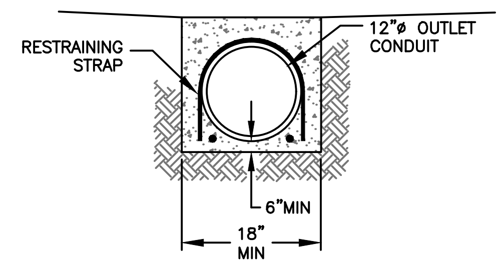
RESERVOIR PLAN VIEW
NOT TO SCALE



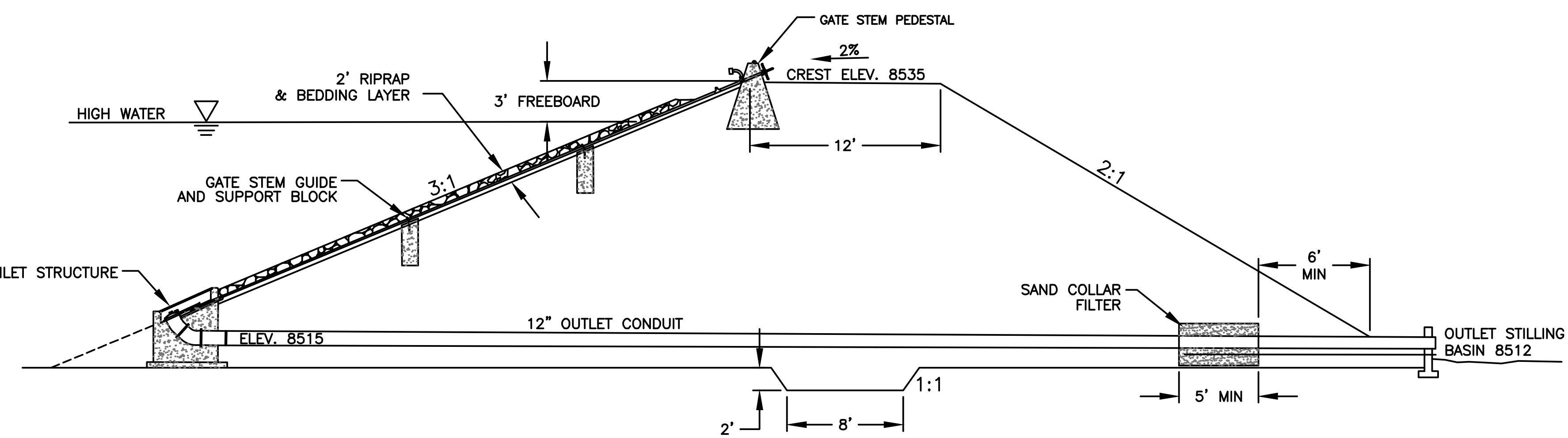
SAND FILTER CROSS-SECTION
NOT TO SCALE



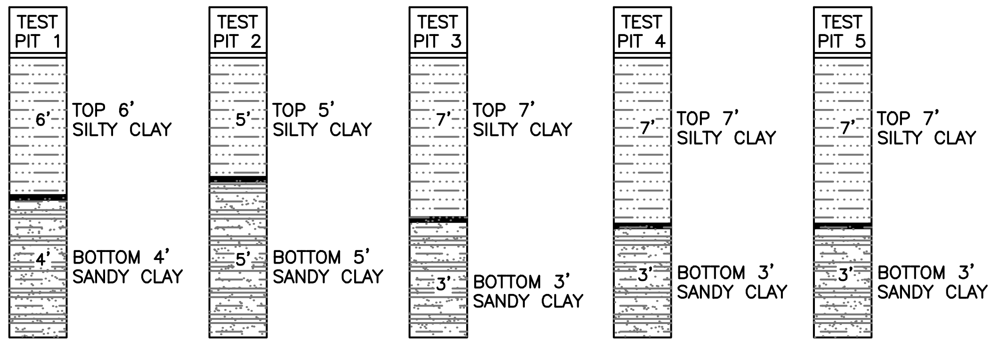
TOE DRAIN CROSS-SECTION
NOT TO SCALE

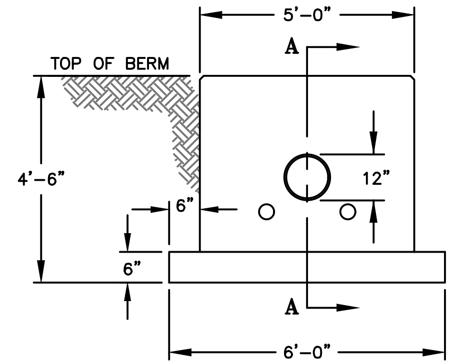


OUTLET CONCRETE ENCASEMENT
NOT TO SCALE

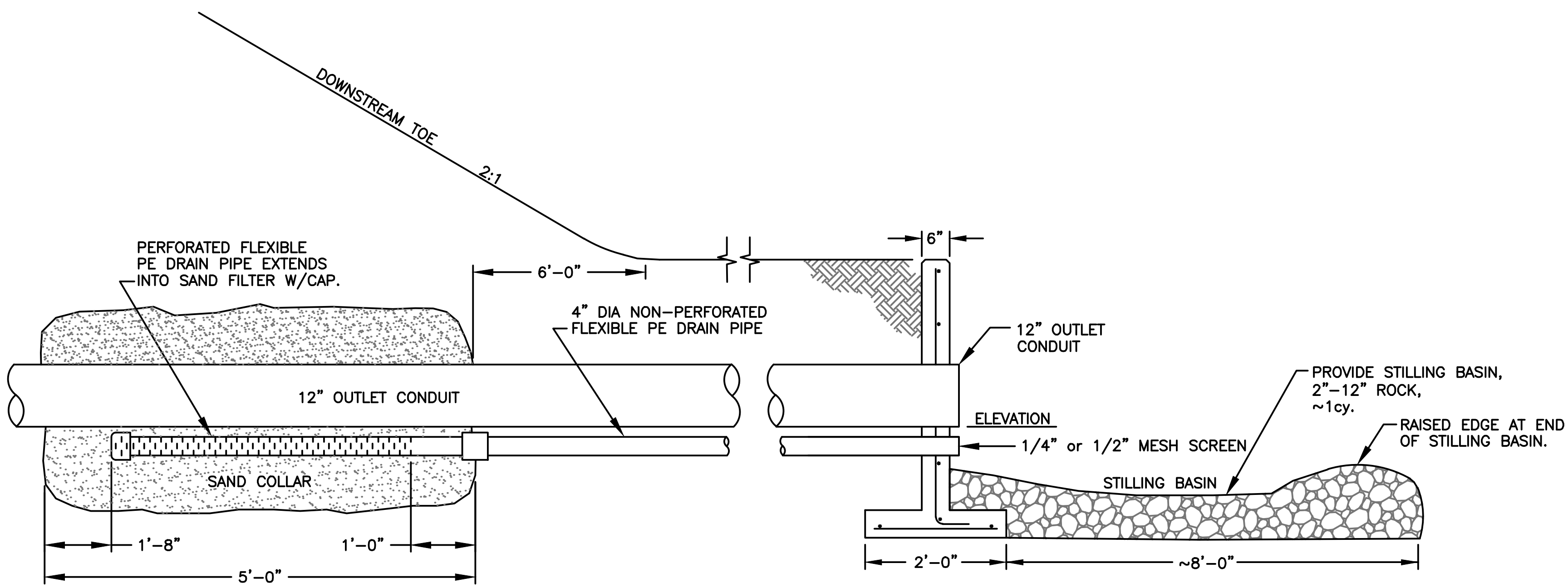


CROSS-SECTION OF DAM
THROUGH OUTLET CONDUIT
NOT TO SCALE





OUTLET HEADWALL
SCALE: 1/4" = 1'



SECTION A-A

SAND COLLAR FILTER/STILLING BASIN
NOT TO SCALE