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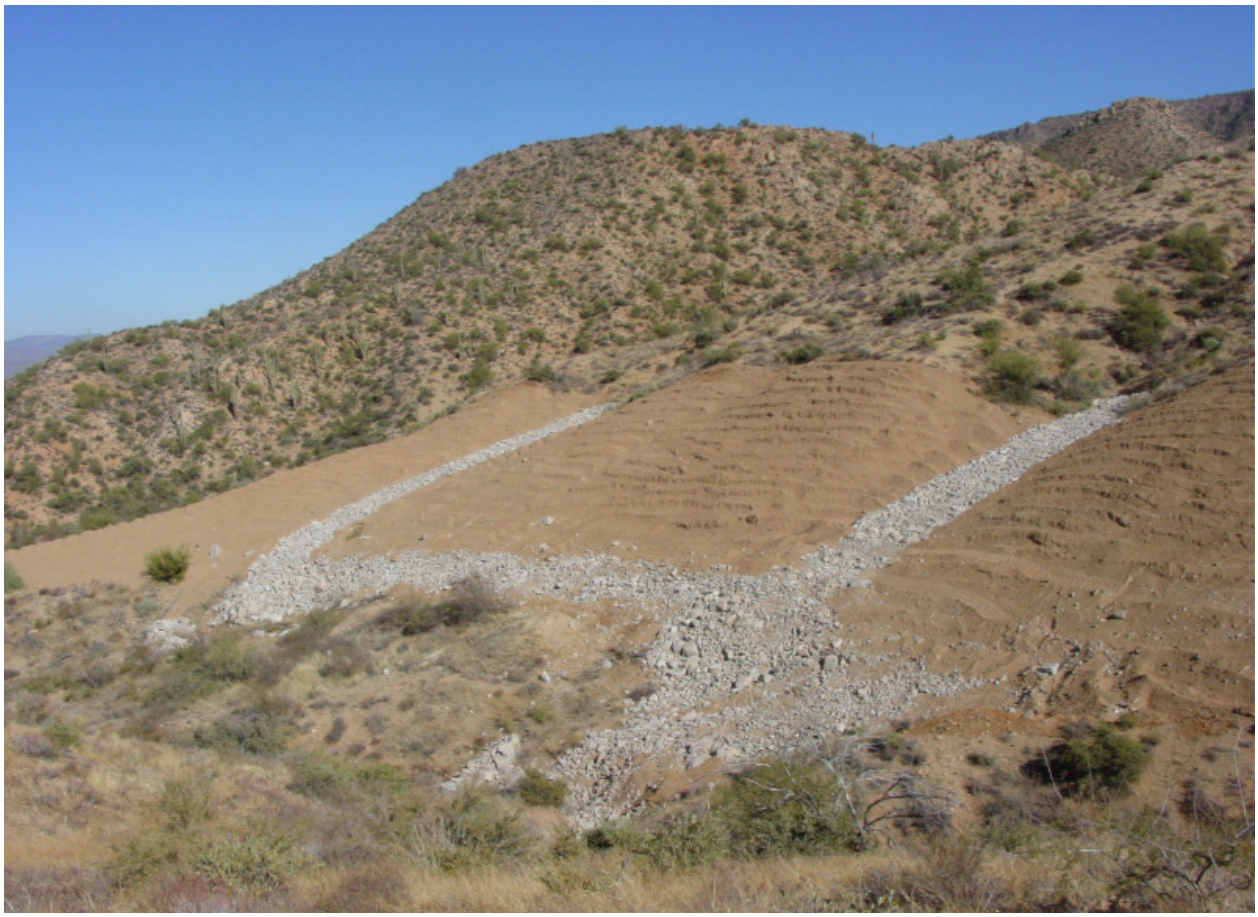
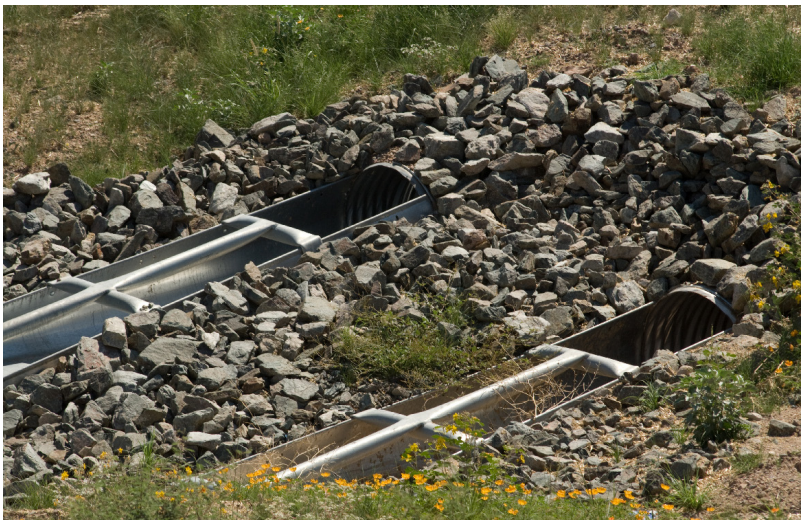
CHAPTER 6: DRAINAGE DESIGN AND CONSTRUCTION





CHAPTER 6: DRAINAGE DESIGN AND CONSTRUCTION

6.1 CHAPTER GOALS

The goals of this chapter are to describe opportunities and concerns for the design, construction and maintenance of new drainage facilities to best integrate them into the existing landscape.

Drainage structures discussed in this chapter are limited to pipe culverts, channels and ditches. Bridges and box culverts are addressed in Chapter 5 (Major Structures).

Riparian areas are extremely important resources. As defined in this manual and used in this chapter, riparian areas include natural perennial, intermittent and ephemeral streams and the habitats associated with them.

Arizona Pollution Discharge Elimination System

Erosion is not only an aesthetic liability, it also results in sediment loss and material transport contributing to increased maintenance costs and to the degradation of water quality. Transported material is considered a pollutant. To address this concern, all ADOT projects must comply with Arizona Department of Environmental Quality requirements for erosion control as described in both the National and Arizona Pollution Discharge Elimination Systems (NPDES and AZPDES) (refer to Chapter 8).

In order to meet the requirements of NPDES/ AZPDES, ADOT must employ permanent and temporary Best Management Practices (BMPs). The term BMP refers to operational or physical controls that reduce the discharge of pollutants and minimize potential impacts upon “receiving waters”. Receiving waters are standing bodies of water and natural drainages, and used in this context, include natural perennial, intermittent and ephemeral streams in Arizona.

Drainage structures are permanent BMPs. These structures will be discussed further in this chapter. Other permanent and temporary BMPs are described in greater detail in both the ADOT Erosion and Pollution Control Manual and the ADOT Post-Construction BMP Manual.

6.2 SCOPING AND NEPA PROCESSES

For projects on lands managed by BLM or USFS, the following concerns must be considered early in project development:

- The protection of riparian areas is of critical importance.
- Where damage to existing riparian areas is unavoidable, mitigation may be required such as restoration, or enhancement of other riparian areas.
- The proposed design should minimize impacts to riparian areas both within and outside of the right-of-way.
- Easement acquisition should not be a limiting factor in the design of drainage structures. Both BLM and USFS will consider greater than typical right-of-way acquisition where necessary in order to design and construct a low impact highway. Additional easement might be considered for crown ditch alignment or for reducing (making flatter) cut slope ratios in order to reduce erosion and promote revegetation (refer to Chapter 7).
- Access for future maintenance to drainage structures following the conclusion of construction.

6.3 DESIGN

NEPA Documents

As discussed in Chapter 2, the NEPA process may make recommendations regarding impacts to natural resources. During the design process, the project team should regularly review NEPA documents to ensure that these recommendations are reviewed and included in the construction documents.

ADOT Drainage Report

Submitted as a part of Stages II (30%) and III (60%) reviews, the Drainage Report should gather the following information:

- Floodplain jurisdictional delineation.
- Assess existing and future conditions affecting watersheds, flow patterns and flood areas.
- Prepare drainage map showing topographic features and drainage features.
- Calculate hydrology for project area including peak runoff rates from each drainage area.
- Describe stream channels, including high and

low water elevations, previous floods and other events, and the streambed material.
- Propose concepts for management of storm water during and after construction.
- Summarize design criteria, procedures, methodology and assumptions for analysis and design.
- Specify initial size and location of major drainage structures and channels that affect the roadway location.

Sections 404 and 401 of the Clean Water Act

Section 404 of the Clean Water Act regulates the discharge of fill or dredged materials into the waters of the United States and establishes a program to issue permits. In Arizona, the U.S. Army Corps of Engineers (Corps) administers this program. In addition, the U.S. Fish and Wildlife, the National Marine Fisheries Service and State resource agencies (Arizona Department of Environmental Quality, Arizona Game and Fish Department, Water Resources) have important advisory roles. The 404 program has considerable impact on the design, construction and maintenance of Arizona's highways in general and on highway drainage design in particular. Essentially, any proposed work in washes, rivers, streams, lakes and wetlands requires ADOT's Environmental Protection Group (EPG) to obtain a permit from the Corps.

Section 401 of the Clean Water Act enables the State to provide certification that the draft 404 permit is in compliance with State law regarding water quality standards. ADOT EPG obtains 401 certification during the design process.

Riparian Areas

The designer shall seek to protect riparian areas in all cases. As used in this manual, riparian areas include natural drainages and the habitat associated with them, *Figure 6.1*. Waterflow in these drainages may be perennial, ephemeral or intermittent. Impacts to riparian areas may be minimized by consideration of the following during the design process:

- Riparian areas should be inventoried during the design process.
- Changes to natural stream channel dynamics should be minimized. In general, the less the geometry of the natural drainage is altered, the smaller the impact to the dynamics of the natural flows.
- Riparian areas typically act as wildlife corridors. Seek input from wildlife experts to determine those species that may be negatively impacted, where those impacts are anticipated to occur and what preventive measures might be taken. Refer to Chapter 3 for more information concerning highway corridors and wildlife habitat.
- Avoid or minimize armored bank protection.
    - Installed primarily to control the erosion of drainage structures, bank protection can take several forms including rock riprap, gabion baskets, *Figure 6.2*, rail bank, revetment systems, concrete, shotcrete, soil cement and metal sheet piling.
    - Even when installed over relatively short stretches of streamside, bank protection can have far-reaching impacts to the dynamics of channel flows both up- and downstream.
    - Alternatives to bank protection include

Figure 6.1 Riparian areas.

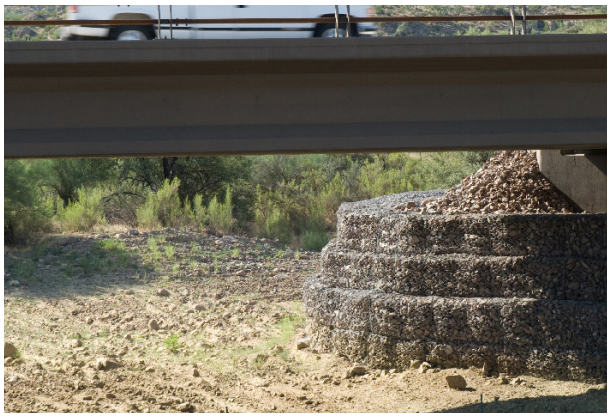


Figure 6.2 Gabion baskets used for bank protection.

dip sections, changes in alignment, and bridge structures that completely avoid the floodplain.
    - Consider construction requirements for bank protection. Shotcrete, for example, requires large staging and batch plant areas and haul roads, all requiring significant clearing.
    - Consider the aesthetics of proposed bank protection.
- For streams designated as important fisheries by Arizona Game and Fish, restrict construction activities that will affect streamflow to appropriate times of year as determined by Game and Fish.
- Anticipate requirements for access during construction:
    - Temporary roads should not degrade water quality, damage streams, disturb channels nor impede fish passage.
    - Ensure that equipment is not allowed to operate in actively flowing streams.
    - For perennial streams designated as important fisheries by Arizona Game and Fish, design temporary access that allows the passage of fish and other riparian wildlife.
    - Evaluate options regarding temporary road construction and temporary stream crossings. Potential crossing techniques include culverts, coarse rock fills, hardened fords, low water crossings and temporary bridges. The temporary crossings should not erode into the riparian area.
    - Minimize the number of temporary crossings.
    - Design temporary crossings to be as perpendicular to natural drainages as possible.
    - Minimize excavation at the stream banks.
    - Remove temporary crossings at the conclusion of construction and reclaim the affected areas.
- Minimize sediment transport into riparian areas from excavated areas within the natural drainage:
    - Provide temporary erosion control measures for containing sediment eroded during in-channel and in-stream excavation.
    - Identify staging areas for stored materials that are clear of the floodplain.
    - Divert water flows around construction sites.
- Minimize sediment transport into riparian areas caused by erosion of disturbed soils adjacent to riparian areas. Ensure proper design and installation of both temporary and permanent erosion control measures.
- Reclaim areas disturbed by construction. Successful reclamation incorporates permanent erosion control and establishment of perennial native vegetation, *Figure 6.3*, (refer to Chapter 7).

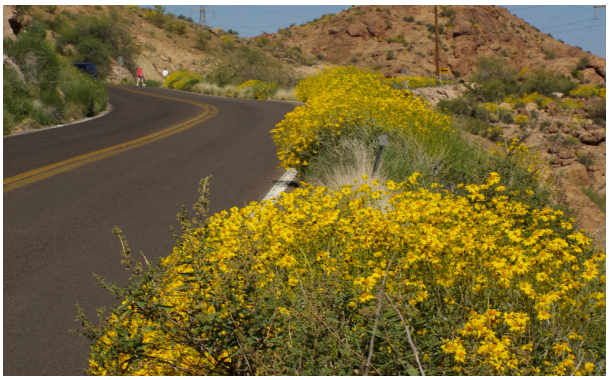


Figure 6.3 Successful reclamation incorporates perennial vegetation.

Drainage Structures

As part of drainage design, the project team shall review the need for and the design of drainage structures in order to minimize erosion to (a) the structures themselves, (b) to the new cut and fill slopes and (c) to the inlets and outfalls of the structures. These concerns are discussed as follows:

Ditches and Dikes

These are concentrated flow structures used to intercept and direct surface runoff into a drain or into an existing drainage.

Because they concentrate storm water runoff, ditches are highly susceptible to erosion. Therefore, the designer should consider the following:

- Calculations of peak runoff flows and velocities and appropriate erosion control measures.
- Installation of riprap for all ditches and dikes that exceed profile grades of four percent in order to prevent downcutting. Riprap should be embedded into both fore- and backslopes to prevent blowout.

Figure 6.4 Rock check dams reduce runoff velocity.

Figure 6.5 Crown ditch installed at the top of slopes to divert sheet flow.

Figure 6.6 Slope ditch installed to intercept sheet flow and convey concentrated flows.

- Installation of rock check dams, *Figure 6.4*, to reduce runoff velocity and capture eroded sediment.
- Aesthetics of erosion-control materials, especially where applied near rest areas, roadside viewpoints, trailheads, etc. Materials that appear more natural are preferred.

Ditches and dikes also act as devices to prevent erosion to new cut and fill slopes:

- **Crown ditches:** Installed at the tops of slopes to divert sheet flow from adjacent undisturbed slopes onto newly constructed cut slopes, *Figure 6.5*.
  - Construction should take place prior to excavation of the slope.
  - The designer should give careful consideration to ditch alignment and outlets. In order to avoid erosion and to minimize ditch maintenance, ditches should not be installed parallel to the roadway, which can lead to steep ditch profile grades and subsequent scouring by concentrated runoff flows during storm events. Instead, ditch profile grades should be designed in response to existing site topography and project soil types in order to minimize ditch scouring.
  - Ditches should be designed to daylight into existing drainages.
  - Both measures described above will possibly require additional easement.
  - Since crown ditches can be highly visible to motorists, consideration should be given to ditch layout and existing vegetation. Ditches should typically be staked in the field before construction and ditch alignment should avoid existing vegetation where possible.
  - Design team should keep in mind that all ditches require maintenance; therefore, crown ditch access should be a consideration.
- **Slope ditches:** Installed between the top and toe of a slope to intercept and carry sheet flow and convey concentrated flows, *Figure 6.6*.
  - **Embankment curbs:** Installed on fill slopes at the edge of the roadway to intercept sheet flow from paved surfaces. Embankment curbs are of special consideration where the roadway is super-elevated, thereby directing all sheet flow to one side of the pavement. The designer should pay particular attention to the locations and spacing of spillways or downdrain

pipes that drain concentrated runoff collected by these curbs. Spillways and associated outfalls should be armored against erosion. Downdrain pipes should be buried.

- **Cut-to-fill slope transition protection:** Installed at the intersection of cut and fill slopes. Cut ditches that discharge at cut-to-fill slope transitions, *Figure 6.7*, will normally require erosion protection until runoff flows reach an existing stable drainage.

Figure 6.7 Erosion protection at cut-to-fill transition.

Overside Drains

Overside drains are pipes, downdrains and spillways used to protect slopes against erosion by collecting surface runoff and conveying it down the slope to a stable drainage. The designer should consider their use as follows:

- **Cut slope spillway:** Installed where offsite runoff will intercept a cut slope, *Figure 6.8*. The designer should give careful consideration to the following:
  - The angle at which the existing drainage intersects the top of the cut slope. The constructed spillway should typically follow that same angle down the face of the slope.
  - Anticipated runoff volumes: the constructed spillway should be oversized to prevent blowout from storm events.
  - Spillways should be armored. Where rock riprap is used, note that slopes steeper than 10H: 1V will require some means of rock containment (typically wire mesh).
  - Because cut slopes typically are visible to motorists, consideration should be given to the aesthetic design of these structures. They are typically warped back into the cut slope.
- **Fill slopes:** Where embankment curbs are installed, openings in the curb are constructed that drain into a spillway, *Figure 6.9*, or downdrain pipe. Generally, downdrain pipes are used for aesthetic reasons where slopes will be visible from a main roadway.

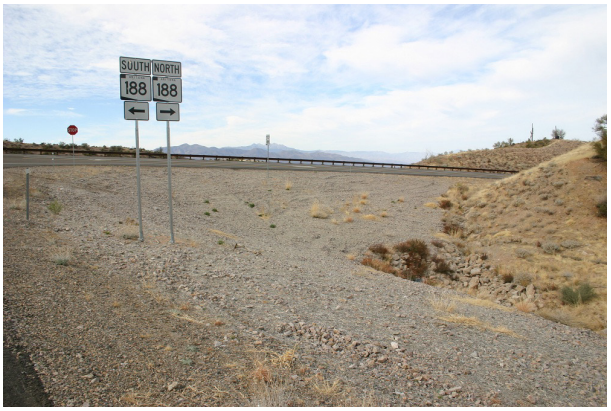


Figure 6.8 Area where runoff will intercept a cut slope.

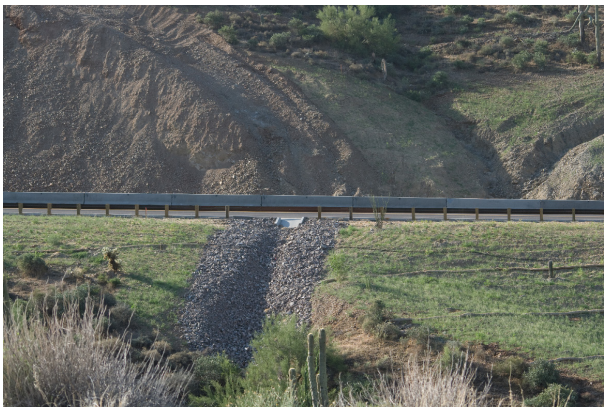


Figure 6.9 Embankment curb opening into a spillway.

Culvert and Channel Inlets and Outfalls

Culvert and structural channel inlets and outfalls are typically areas of high concern for erosion. The designer should consider the following:

- Careful review of inlet invert elevation: When lower than the existing natural channel, the channel backslope must be protected to avoid headcutting of that slope by runoff.

- Flared end section: These are typically installed at the inlets and outfalls of pipes and channels to improve the hydraulic operation, retain the embankment near pipe conveyances and help prevent scour, *Figure 6.10*.
- Outfall protection/ velocity dissipation devices: To prevent scour at the outfall and to reduce runoff flow velocity, rock riprap, *Figure 6.11*, or some other measure is typically installed. These devices should be constructed during or immediately after construction of the culvert. Refer to Chapter 3 for concerns regarding armoring and wildlife habitat.
- Protection at the soil/ drainage structure interface: The interface between fill slope soils and concrete or metal structures is typically prone to erosion. While this interface frequently occurs at drainage structure openings, it is also possible at the edges of spillways and bridge abutments, *Figure 6.12*. The designer should consider the use of rock or other protective measure to prevent erosion in this area.

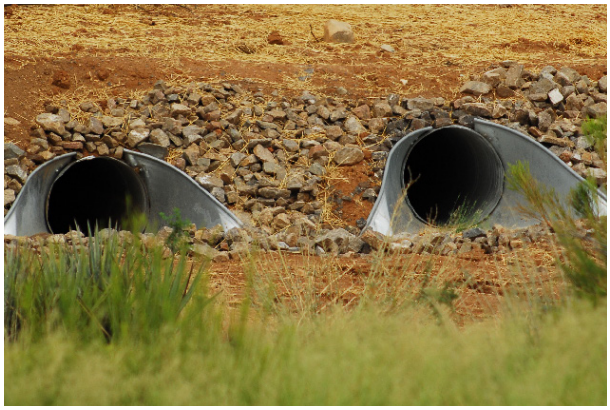


Figure 6.10 Flared end-section of a culvert.

Figure 6.11 Riprap helps to reduce erosion at outfalls.

Figure 6.12 Protection from erosion at edge of bridge abutments.

Aesthetics

As discussed for some drainage structures earlier in this chapter, the appearance of these structures should be considered during the design process.

- Highly visible concrete headwalls may be constructed utilizing formliners, concrete stain, exposed aggregate, paint or integral concrete.
- Riprap may be stained.
- Highly visible channels and ditches can be laid out in less rectilinear and more curvilinear alignments.
- Crown ditches should be staked in the field in order to minimize disturbance to existing vegetation.
- Culvert inlets and outfalls can be trimmed or formed to follow the finish grade.
- Cut slopes can be warped to better hide slope spillways.

6.4 CONSTRUCTION

- Prior to allowing earth-moving equipment to operate on BLM/USFS lands, the equipment will require washing as described in the ADOT Erosion and Pollution Control Manual.
- Prior to any earth-disturbing activities, the contractor shall prepare and deliver to ADOT his proposed erosion control plans for approval by ADOT in consultation with BLM or USFS. Drainage structures carry storm water runoff from the upstream side of the highway to the downstream side. Where that runoff enters areas disturbed by construction activities, it

will typically erode those areas and transport sediment eroded from those soils. Therefore, drainage structures should be installed as early in the construction sequence as possible. Before they are installed and during their construction, ensure that temporary erosion control measures are properly installed and maintained.

- As described above, invert elevations of culverts will strongly affect streambed geometries. Ensure that the elevations of the concrete forms are properly set before allowing installation of concrete.
- Review and adjust, if necessary, proposed alignments for crown ditches prior to excavation.
- Review project contract documents regarding contractor access into natural drainages.
- Review project contract documents regarding contractor staging areas adjacent to drainages: minimize potential for erosion of disturbed soils into natural drainages.
- Remove temporary access and restore disturbed areas as soon as possible.

6.5 ADDITIONAL RESOURCES

ADOT Roadway Engineering Group: Drainage Design Section:
http://www.azdot.gov/business/engineering-and-construction/roadway-engineering/drainage-design

ADOT Post-Construction BMP Manual:
http://www.azdot.gov/docs/planning/post-construction-best-management-practices-(bmp)-manual.pdf?sfvrsn=0

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