Watershed Management with Respect to Low-Volume Road Drainage Detention Structures

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The availability of state and federal monies to replace local bridges has allowed engineers to evaluate watershed management in conjunction with the bridges' physical replacement. By using computer-driven watershed models, engineers can incorporate flood reduction measures into bridge replacements. Bridge and culvert openings have been restricted and modified to temporarily store flood runoff on low-volume county and township roads. The result can be an economical bridge replacement with a significant reduction in peak runoff. Properly designed and constructed, road detention structures can modernize the rural transportation network of farm-to-market roads. The background and procedure for designing detention structures are outlined.

Over the past several years, Lyon County, Minnesota, has begun using a series of creative flood control practices on local roads to reduce damage to roads and bridges. In various situations and in different combinations, Lyon County has restricted culverts and bridge waterway openings and created temporary flood storage to meet the overall goal of regional watershed management. To date, nearly 40 projects have been constructed in Lyon County, saving project construction costs and significantly reducing peak runoff discharge.

Background

Flood damage reduction is a high priority for Lyon County, which averages about $26,000 in damage to roads and bridges each year. Damages to local roads and bridges occurred frequently in 1957, 1969, 1983, and 1993. Damage for a single event has been as high as $830,000 for county and township structures. Soil loss, streambank, and crop loss estimates by the Soil Conservation Service are as high as $500,000 per year. In 1989 the county received support from the Department of Natural Resources (DNR) to incorporate flood storage into county and township bridge replacement projects. A two-staged outlet structure sized to the reservoir has reduced the peak runoff by as much as 80 percent with less cost than a conventional design.

Typically, bridges and culvert structures are designed to pass the 100-year or 50-year runoff events with little stage increase. The resulting hydrographs therefore show very little difference between inflow and outflow and little runoff storage. The state and federal bridge replacement programs have provided the impetus for this type of design by minimizing the financial commitment from the local unit of government.

Since the program's initiation, Lyon County has evaluated 80 potential road and bridge projects based on terrain, land use, hydraulic, and economic considerations. For each project, the drainage area, the flood pool size, volume of flood storage available, the percent reduction in peak discharge for the 10-year and 100-year floods, and projects costs were identified. From this information, several ratios to help prioritize potential storage sites were developed. These ratios included volume of flood storage to area, cost per acre-foot storage, and cost relative to reduction in peak runoff. Typical projects have an average cost per structure of less than $100,000, which is economical for a multipurpose project compared to costs for bridge replacement, flood damage, and crop loss (typically 25 to 35 percent higher).

Example Projects

The first project completed was on Three Mile Creek, a tributary to the Redwood River. This project involved replacing an existing small bridge on a county road that has routinely washed out. The land upstream of the crossing is pastured and therefore not damaged by short-term flooding. For this project, Lyon County put in a 12-ft-wide by 7-ft-high box culvert with a V-notch weir constructed into the upstream apron (Figure 1). The road was raised a maximum of 6 ft for a distance of 1,000 ft.

Because of the large watershed (14.0 mi^2), the county needed additional storage areas. The DNR agreed to the temporary flooding of the property to the northeast of this crossing, part of the Furgamme Wildlife Management Area (WMA). In conjunction with the V-notch weir, a 48-in.-diameter culvert was installed into the Furgamme WMA so that, during flooding, water could back up into Furgamme WMA and flow back out as water recedes on Three Mile Creek.

Another complication was that the old crossing had a 6-ft overfall that the DNR wanted maintained because it served as a fish barrier for rough fish migrating to Goose Lake, a walleye-stocked and aerated lake, located 2 mi upstream. A cutoff wall was constructed to support the end of the apron along with rock gabions on the outlet of the box culvert. The gabions were necessary because of the steepness of the road ditch following the raising of the road and high outlet velocities expected through the culvert.

The total project cost was $75,230, of which approximately $30,000 was associated with the raised road, the diversion culvert, and the specially constructed V-notch weir apron. The project reduced the 100-year peak discharge by 40 percent. The upstream landowner in this case was given a one-time easement payment of $200 per acre for the 85 acres inundated by the 100-year flood.

The second road project completed was on the Cottonwood River, a major tributary to the Minnesota River. The drainage area on this project was 26.0 mi^2 of agricultural land. In this case, Lyon County decided to replace the existing bridge that had 196 ft^2 of waterway area with a 12-ft-wide by 10-ft-high box culvert. The inlet of the box culvert was modified with a 36-in.-diameter, low-flow culvert designed to allow the normal flow of water through the structure (Figure 2). When the capacity of the 36-in. culvert was exceeded, the structure would impound approximately 8.5 ft of water over an 80-acre pool. As runoff increased, the flow then started over the drop box inlet and through the 12-ft by 10-ft box culvert; in this case the road was raised a maximum of 6.2 ft for a distance of 550 ft.

The upstream property was again pastured seasonally. Because the county could not acquire enough upstream land rights for an extremely effective flood control project, they decided to try to develop this area for other uses. Since the county owned the land immediately upstream of the structure and topsoil was needed

FIGURE 1 V-notch weir.

FIGURE 2 Cottonwood River box inlet structure.

FIGURE 3 Cottonwood River wetlands.

for road projects and the county landfill cover, it was decided to go into the area above the structure and excavate topsoil. Lyon County excavated about 3 ft of material and left five nesting islands for waterfowl within a shallow permanent pool wetland area (Figure 3). This multipurpose project has become a model for the county DNR. The cost was $45,000 for the structure and excavation of the roadway, and the peak flow as reduced by 20 percent.

Recommendations

The other 38 projects are of similar design. Most have fairly small watersheds and involve installing a low-flow pipe with a concrete riser of different heights and sizes depending on the storage available and watershed size. On most projects, the road is raised substantially; for example, one road was raised 25 ft. In addition to decreasing the time that some roads are inundated by floodwaters, the road fill serves several other substantial purposes, including the improvement of sight distance, wetland criteria, wider structure for farm equipment, and less winter maintenance.

Inlet types have generally been drop inlet spillways using precast concrete elements. Flow characteristics of the drop inlet will vary according to the proportional sizes of the different elements. Typically, the free-falling overflow drops vertically into the base of the structure; a plunge pool can be induced by placing impact blocks at the base of the structure to help dissipate energy. The purpose is to dissipate energy within the drop structure and not subject the outlet to excessive stream velocities.

Consideration must be given to the high heads and resulting increased outlet velocities and the dissipation of energy and erosion control downstream. Energy dissipating rings, drop inlets, and hydraulic jump stilling basins have been used with consistent success.

Commercially available software similar to that of the Soil Conservation Service (SCS) TR-20 and TR-55 programs has been used. The process of analyzing runoff, routing, ponds, and hydraulics is extremely quick and readily allows investigation of alternative designs.

Design Procedure

The following is an example of the reports and graphics for a small project involving a single watershed and structure.

This project has a watershed area of 1,772 acres with a weighted curve number of 78, which is applied to a SCS Type II, 24 hr rainfall of 5.7 in. The structure in this case is on a county highway and replaces a 25-ft span bridge. The selected structure is a low-flow 36-in.-diameter culvert inlet at the natural flow line. This inlet connects to a 60-in.-diameter outflow pipe with a 60-in.-diameter vertical orifice at a point 29 ft above the flow line (Figure 4).

The runoff hydrograph calculations are made based on the watershed characteristics (Figure 5). The resulting stage versus discharge curve is shown in Figure 6.

The stage-storage data are calculated from the pond surface area by the prismatic method. The result is the inflow/outflow hydrograph indicating the peak elevation, peak storage, and drawdown time (Figure 7).

FIGURE 4 Typical structure cross section.

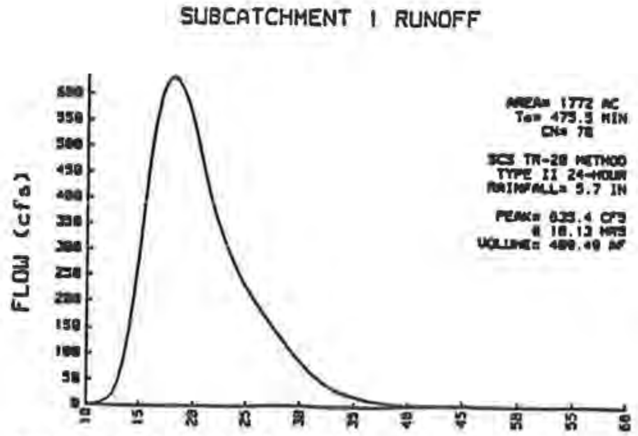

FIGURE 5 Runoff hydrograph.

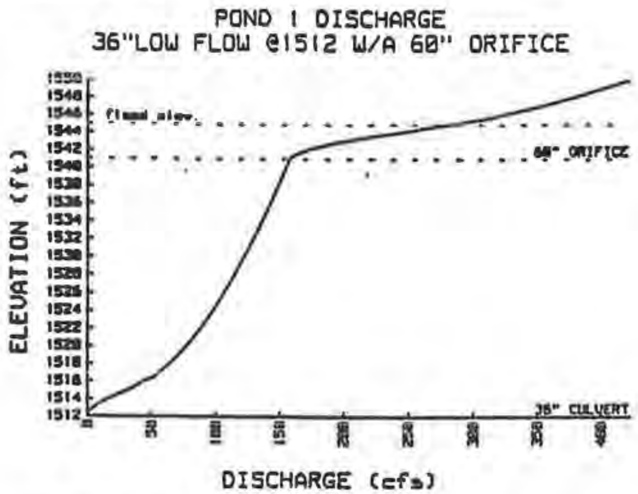

FIGURE 6 Stage versus flow graph.

In the case of this 100-year rainfall event, the peak discharge was reduced by 55 percent with a cost savings in the bridge versus retention structure of $60,000. Most projects constructed provide similar cost savings and flood protection.

CONCLUSION

The incorporation of flood storage into road and bridge projects is well accepted by the public and local officials. The road structure dam is designed with its top wide enough to accommodate a road and has an outlet that slowly drains away stormwater impounded above

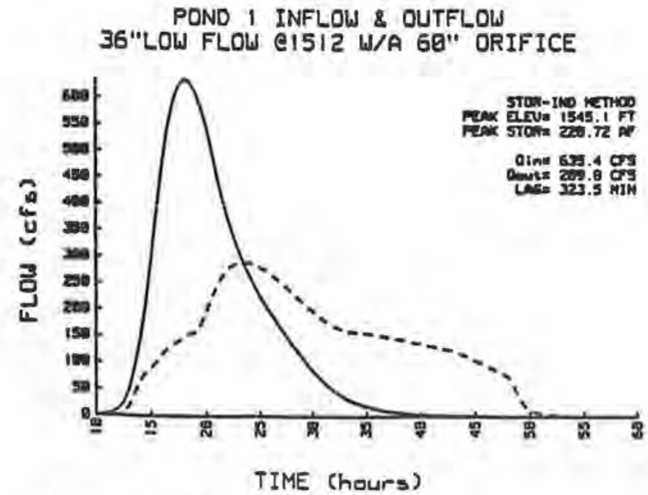

FIGURE 7 Inflow-outflow hydrograph.

the permanent pool. These projects are subject to the Minnesota Department of Transportation's requirements for standards and funding and DNR environmental concerns.

Lyon County has an annual budget of $300,000 per year for these types of projects and a goal of 80 projects by the year 2000. In numerous cases, the dam on the road can have more beneficial results than a replacement bridge or even a large pipe. The road structure will cost one-fourth to one-third that of a new bridge and will reduce the peak runoff to one-fourth to one-third of the peak discharge.

A road detention structure is usually a multipurpose project, because it can provide

1. A roadway across the top of the dam;
2. Flood control by slowly releasing runoff from intense storms;
3. Erosion control by stabilizing the stream grade;
4. Improved downstream water quality by trapping sediment;
5. A potential site for recreation;
6. Wildlife habitat areas, including the reservoir itself and planting sites upstream, downstream, and adjacent to the reservoir;
7. A possible source of water for irrigation or other farm needs, and
8. An economical bridge replacement.

Long-range plans call for developing similar projects in adjacent counties that affect Lyon County's tributaries.