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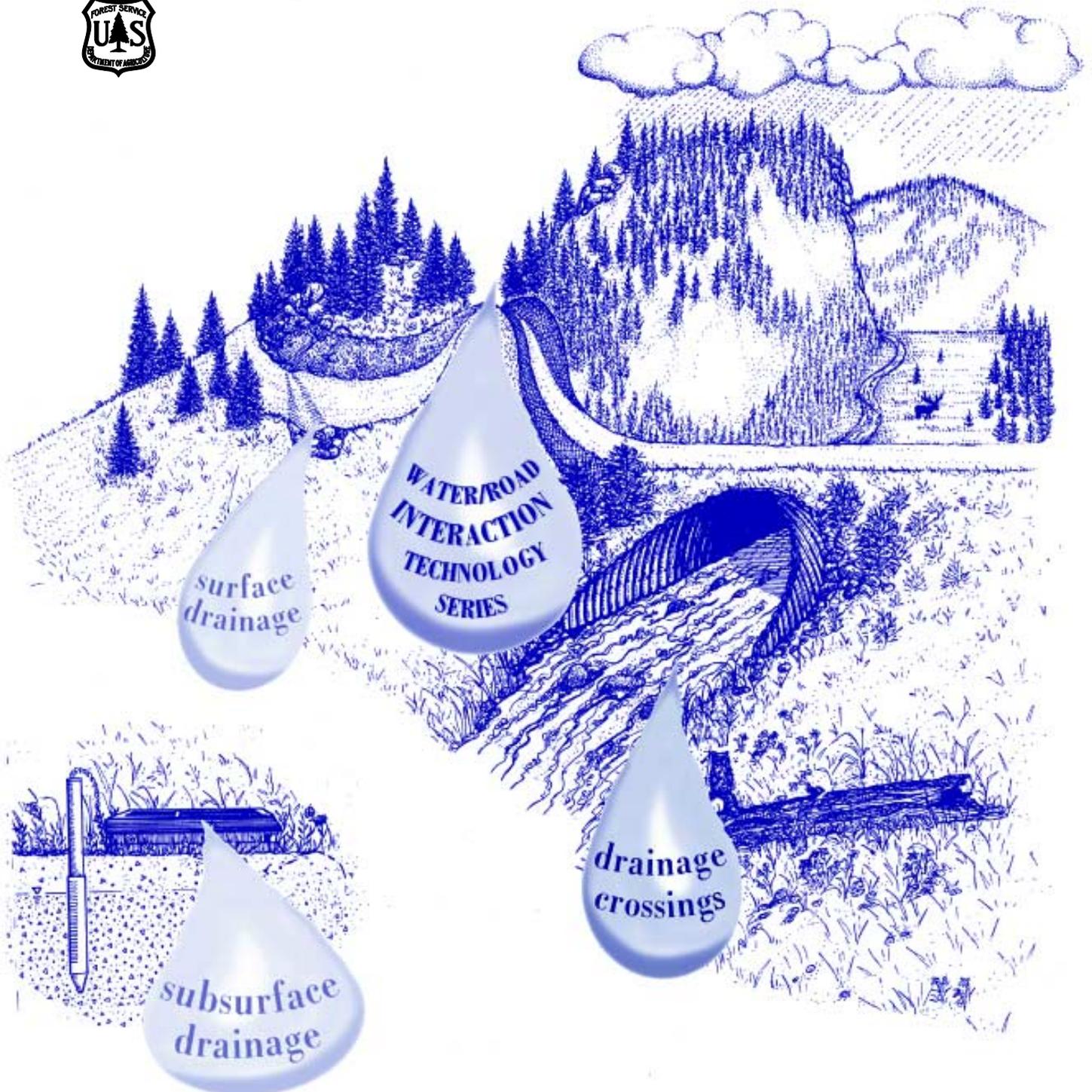
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A Guide to Computer Software Tools for Culvert Design and Analysis



A GUIDE TO COMPUTER SOFTWARE TOOLS FOR CULVERT DESIGN AND ANALYSIS

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INTRODUCTION

Forest engineers and hydrologists regularly calculate design culvert dimensions for use in wildland road-stream crossings. This project investigates existing software tools to aid resource managers in culvert design and analysis requirements for low volume forest roads.

Computer models can make culvert design and analysis less cumbersome, but not all software products will meet the designer's needs.

How to Use This Guide

This guide is a snapshot of information on software tools for culvert design and analysis gathered as of June 1998. To select a cost-effective software product that meets design needs, the reader can:

1. Look sequentially at all the tables, particularly the product review summary, which compares all the products. The tables, in order, are

Table 1. Stream Crossing Culvert Design Considerations

Table 2. Factors for Inlet and Outlet Control

Table 3. Product Reviews

Table 4. Culvert Product by Focus

Table 5. Input Data

Table 6. Output Data

Table 7. Criteria Weighting Factors

Table 8. Selection Matrix Example

2. Read the paper.
3. Follow the decision matrix methodology suggestions located in appendix A.

A glossary of terms and notations is presented in appendix B, and a decision matrix with selected criteria is presented in appendix A.

OBJECTIVES

The objectives of this study were to provide background information on culvert design and analysis and to locate and inventory existing

computer software for use in culvert design and analysis. Products were evaluated with two questions in mind: what does the product do, and how does it do it?

SCOPE

This paper

- Compares commercial software applications used to size culverts
- Considers products for use on DOS, Windows, Macintosh, and UNIX operating systems
- Evaluates programs designed for use as stand-alone products
- Includes larger programs designed for river or watershed system analysis containing strong culvert modeling components
- Contains a glossary of culvert design and analysis terms
- Includes a system for making a software choice based on user needs

but does not

- Consider watershed modeling tools without culvert components, geographic information systems, engineering computer-aided design packages without a culvert component, storm and sanitary pipe modeling, or
- Make recommendations or ratings of products.

Because no central organized database for locating software exists, it was necessary to develop sources of software information. These sources included interviews with U.S. Department of Agriculture (USDA) Forest Service personnel; private and transportation agency hydraulic and hydrologic engineers; on-line Internet searches of World Wide Web sites; software catalogs; literature and book reviews; trade journals; professional magazines and product literature. This guide is not a comprehensive list of products, but does give a good overview of features found on current market

products. The guide is not complete; new software is constantly being developed and current products are being upgraded, making a definitive comparison of culvert design software impractical.

CULVERT DESIGN AND ANALYSIS

Goals

The principal goal of culvert design is to determine the size, alignment, and functionality of the culvert with respect to passage requirements. In addition to the flow of water, a culvert must pass woody debris and sediment and allow passage of aquatic species. The term “size” refers to the dimensions of the barrel, including the culvert diameter and length. Alignment considers the culvert placement, usually horizontal, respective to stream flow direction and road centerline. Functionality refers to the culvert operations under given conditions and includes culvert hydraulic capacity. Additional goals of design include structural stability, durability, cost, ease of maintenance and safety (Gribben 1997).

According to Donahue and Howard (1987), the greatest source of error in culvert design is in design flow analysis. The complex array of variables that influence runoff, statistical uncertainties associated with hydrologic analysis, and a lack of comprehensive assessment methodology contribute to this error. Given this initial source of variability, a design goal is to minimize additional error wherever possible, particularly in the selection of culvert size and the determination of outlet velocity.

Design Criteria

The selection of design criteria for a particular culvert is a function of many interacting factors including culvert hydraulics, watershed hydrology, and land management activities, according to Pyles (1989). Design criteria for a culvert installation are unique to a given installation; however, the list of items in table 1 should be considered for any culvert installation (Pyles 1989). Not all the items will pertain to every installation.

Design Phases

Three phases are considered in culvert design. Phase one evaluates the hydrologic demands

placed on the culvert. Phase two looks at culvert specifications and site considerations. And phase three evaluates culvert hydraulics. In addition to the American Iron and Steel Institute (1994 and 1995) handbooks on drainage design, Gribben (1997) and Ramsbottom et al. (1997) are comprehensive sources of complete culvert design theory with applications. The following schematic (figure 1) combined with terms in the glossary (appendix B) illustrate concepts and definitions used in culvert design and by the software products.

Phase 1-Hydrology

Design begins with the choice of a design storm, a parameter usually determined by policy or rules (for example, the 100-year design storm). After the design storm is determined, the discharge through the culvert can be computed. In some instances, this discharge may be chosen by the designer or varied to determine culvert performance. Design storm estimators include the Rational Method, regional regression equations, and the SCS (National Resource Conservation Service) curve method. American Iron and Steel Institute (1994 and 1995) summarizes the many methods. Peak volumetric flow rate, which is conveyed through the culvert, is ultimately a result of rainfall intensity and duration. This information can be in the form of actual rainfall events, representative design storms, intensity duration frequency curves, or a statistical analysis of rainfall records.

For culverts on steep forested wildlands, debris and sediment plugging cause culvert failure more frequently than peak flow capacity exceedence. (Furniss et al. 1998). Because the software reviewed in this paper incorporates flow rate as the initial design criteria, careful and judicious use of software for culverts on steep slopes is encouraged.

Phase 2-Culvert Specifications and Site Considerations

An existing drainage or the need for ditch relief on a road segment usually dictates culvert location.

The allowable headwater depth (AWD) is the maximum depth of ponded water upstream of the culvert inlet measured vertically from the invert and

Table 1—Stream crossing culvert design considerations (adapted from Pyles 1989).

Category	Item
Peak Flow Events	Pipe size Slope Entrance type Freeboard Ponding Inlet/outlet control Rainfall Watershed modeling
Fish Passage	Migration period Water velocity Pipe inlet/outlet geometry Water depth Stability of outlet pool
Maintenance	Woody debris Bedload Maintenance funding Current maintenance cycle Scour effects
Economics	Life span Costs of environmental and structural damage from failure Installation costs Maintenance costs Replacement costs
Legal Requirements	Forest practice regulations Construction timing

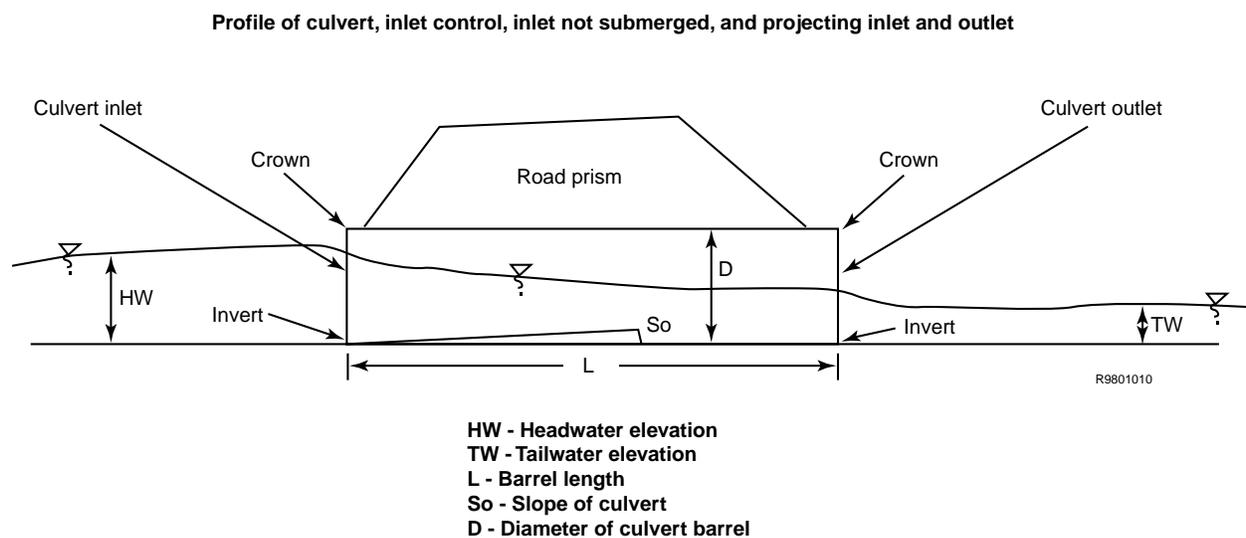


Figure 1—Schematic design of culvert in longitudinal cross section.

controls hydraulic design. AWD may be determined by the depth of fill over the culvert, which is dictated by local topography and roadway geometry and standards. Frequently, a headwater (HW) to culvert diameter (D) ratio is specified, such as $HW/D = 1$, which places the allowable headwater elevation at the inlet crown of the culvert.

The choice of pipe material, shape, and size may be fixed by economics, availability, site conditions (fill, bedrock, bedload), and fish passage concerns (Gribben 1997).

Site parameters important in the design of culverts include the length and slope of the culvert alignment, allowable headwater, fill depth, and effects on inlet geometry. Fill depth is determined by design loads, local topography, roadway geometry, and standards.

Phase 3-Culvert Hydraulics

Culvert hydraulic modeling conventions assume that the flow through a culvert is steady and incompressible with constant density (Donahue and Howard 1987). The cross sectional area of the culvert is assumed not to change. One of the software products evaluated will allow changes in slope within a culvert, otherwise, the slope is assumed constant.

The capacity of a culvert can be affected by upstream and downstream conditions and by the hydraulic characteristics of the culvert. Combinations of these factors can be grouped into two types of flow conditions in culverts, inlet control and outlet control (table 2). These types of flow control can also be defined by the location of the control section at the culvert inlet or outlet.

Inlet control occurs when the culvert barrel is capable of conveying more flow than the culvert inlet will accept. Water can flow out of the culvert faster than it can enter the inlet. Critical depth occurs at or near the entrance to the culvert, and the flow downstream from the inlet is supercritical. Hydraulic characteristics of the downstream channel do not affect culvert capacity. Most culverts, except those in flat terrain (less than 3 percent), are designed to operate under inlet controlled conditions (Ballinger and Drake 1995).

Because the capacity is controlled by entrance geometry, minor modifications to the culvert entrance can affect hydraulic capacity with both inlet or outlet control.

Outlet control is physically more complex than inlet control (table 2). Outlet control occurs when the culvert barrel is not capable of conveying as much flow as the inlet opening will accept. Water can enter the culvert faster than it can flow through the culvert. Culvert discharge, influenced by the same factors as inlet control, is also modified by tailwater elevation and barrel characteristics. Barrel characteristics include culvert roughness, cross sectional area, length, shape, and slope. When culverts are operating in outlet control, changes in barrel characteristics or tailwater elevation will affect capacity. Hence, friction must be considered in calculating discharge and velocity (American Iron and Steel Institute 1994).

Culvert design is an iterative process. Results from hydraulic analysis might indicate that pipe size, shape, number, and materials produce conditions unacceptable to the designer. If this is the case, the designer starts over basing the next design on results obtained from the previous analysis. The approach used by Normann (1985), which is incorporated into many of the software products (see table 3), is to analyze a culvert for both types of flow control. Adequate performance under the least favorable conditions is ensured by designing for the control that is least efficient at moving water as indicated by the higher of the two (inlet or outlet control) inlet headwater elevations. The higher elevation requires more energy to pass a given flow and is, therefore, the design elevation.

ACQUIRING INFORMATION

The above criteria serve as comparisons for each software product. Information on each product was gathered from software use, interviews, product literature, and training.

Although every effort was made for product review consistency, information may differ because not all products experienced the same level of review. The potential exists for uneven analysis as not all software products were reviewed from the full

Table 2—Factors for inlet and outlet control.

Factor	Inlet control	Outlet control
Headwater elevation	X	X
Inlet area	X	X
Inlet edge configuration	X	X
Inlet shape	X	X
Culvert roughness		X
Culvert shape		X
Culvert area		X
Culvert length		X
Culvert slope	*	X
Tailwater elevation	X	

*Culvert slope affects inlet control performance to a small degree, but may be neglected (Normann et al. 1985).

commercial product. See Review Level in table 3, Product Reviews, for comparison of review levels. To ensure accuracy, the product developer and distributor checked all reviews.

Each software product was evaluated using a Dell 486DE with 24 MB of RAM, 1 GB hard drive, CD-ROM or Macintosh 8100 with 36 MB of RAM, 1 GB hard drive, running System 8.0.

INFORMATION ORGANIZATION

Information on each reviewed product is coded into a two-page summary report. These reports will be available by the summer of 1999 on the USDA Forest Service Intranet at <http://fswb.sdtc.wo.fs.fed.us/programs/eng/w-r/eccs>. Detailed information on price, platforms, names, addresses (web sites, e-mail), algorithms, source code availability, modeling techniques, and remarks are noted. Input data requirements, application results, and output formats are compiled. All products reviewed are summarized below in tables 3 and 4 for a quick comparison of costs, operating systems, application focus, and solution methodology. Product sources, vendor, and developer information for each product is found in appendix A.

FINDINGS

Thirty-three products were considered for inclusion. Thirteen of these are not currently available or appropriate. This resulted in a review of twenty products, which are summarized in table 3. Culvert hydraulic design products, complex CAD software, and watershed modeling software with

a culvert design component make up the majority of products located to date.

Most culvert design and analysis software programs are based on Federal Highway Administration (FHWA) research, primarily Normann (1985) (table 3). The cost of these products ranges widely from free to \$795.00.

Software products perform a variety of functions and give the culvert modeler a wide choice of features. Not every product accomplishes all goals, so it is best to determine the culvert design needs first, compare product features, and then weight costs. Most products provide a choice of units of measure and options for defining hydrology. A few software products will model roads along with culverts to provide the opportunity for determining capacity exceedance. Tables 5 and 6 summarize all input and output features for each product.

DISCUSSION

Software is capable of returning extremely precise results that can be misleading. Culvert software for design and analysis requires informed, experienced use, incorporating awareness to assumptions and “bugs” embedded in products. For example, pipe arch definitions differ among software products. A pipe arch described by a software product may be a structural plate pipe arch, ellipse set below grade, open bottomed culvert, or a prefabricated ‘squashed pipe.’ This information may show in cross-sectional area computational differences, variations in Manning’s n through a closed or open bottom arch, visual sketches, or results. The software product’s

Table 3—Product reviews.

Application	Review level*	Focus	Cost	Operating system	Algorithm sources
CAP-Culvert Analysis Program	2 3	Culvert design and analysis	Free from ftp site, \$145.00 as part of HydroCD	DOS, UNIX	Bodhaine (1969)
CHAN v.2	1 2 3	Watershed modeling with culvert component	\$259.00	Windows 9X	Normann (1985)
Culvert Master	1 2 3	Culvert design and analysis	\$495.00	WIN 3.X, Windows 9X, NT	Normann (1985)
Xing-Risk	1 2 3 4	Hazard analysis for culvert failure	Free	WINDOWS 9X, NT	Piehl et al. (1988)
Drainage Calculator	1 2 3	Culvert design (slide rule format)	\$8.00	Hand held paper slide rule	Normann (1985)
DrainCalc	1 2 3	Drainage system design and analysis with culvert component	\$295.00	DOS, DOS Emulator in Windows	California Highway or Manning's equations
Eagle Point Watershed Modeling v 7.0S	2 3	River modeling with culvert component	\$800.00	Windows 9X	Normann (1985)
Eagle Point Water Surface Profiling	2 3	Water surface profiles with culvert component	\$800.00	Windows 9X	HEC-2
FishPass	2 3	Fish passage design for culverts	Free	DOS, DOS Emulator in Windows	General hydraulic theory, Powers and Orsborn
FishXing	1 2 3 4	Fish passage design for culverts	Free	WINDOWS 9X, NT	Normann (1985) Behlke et al. (1991), Behlke (1993)
HEC-RAS v 2.2	1 2 3	River modeling with culvert component	Varies, from free download, \$145.00 as part of HydroCD, \$150.00 from catalogs	WINDOWS 9X, NT	Normann (1985)
HY-8 (Culvert Analysis)	2 3	Culvert design and analysis	\$120.00 to \$145.00 from HydroCD, possible shareware	DOS, DOS Emulator in Windows 9X	Normann (1985)
HYDrain	2 3	Culvert design and analysis, shell contains HY-8 and WSPRO (water surface profile)	\$145.00 as part of HydroCD, to \$350.00 from catalogs	DOS, DOS Emulator in Windows 9X	Normann (1985)
HydroCAD	2 3	Stormwater modeling with culvert component	\$195.00-1195.00	Windows 9X	unknown

Table 3—Continued.

Cost	Review Level*	Focus	Cost	Operating system	Algorithm sources
HydroCalc Hydraulics, v 1.2a	2 3	Culvert design and analysis	\$145.00 as part of HydroCD, \$29.00 for separate Windows version	Windows 3.1/9X/NT	Normann (1985)
HydroCulv v.1.02	2 3	Culvert design and analysis	Shareware, \$50.00 for manual & support	Windows 9X	General hydraulic theory
MacCulvert	1 2 3	Culvert design and analysis	Shareware	Macintosh systems	Normann (1985)
Quick Pipe Pro	1 2 3	Culvert design and analysis	\$375.00	DOS, OS/2, Win 3.1/9X/NT	Normann (1985)
RIVERCAD	1 2 3 4	River modeling with culvert component	\$2690.00	Windows 9X, NT	Normann (1985), HEC-2
THYSYS	1 2 3	Culvert design and analysis	\$5.00 from Texas DOT or \$795.00 from Haestad	Windows 9X, DOS for earlier Haestad version	HEC-12 and HEC-22

Review Level*

Review code	Information source	Details
1	Interviews	Product developer, marketing, users, specialists
2	Literature	Publications, product literature, WWWWeb pages
3	Testing	Demo copy, evaluation copy, full commercial copy
4	Training	From developer, company engineer, classroom

Table 4—Culvert product by focus.

Culvert design and analysis	Watershed/river modeling with culvert component	Specialty culvert design and analysis
CAP-Culvert Analysis	CHAN v.2*	Xing-Risk
CulvertMaster*	Eagle Point Watershed*	FishPass
DrainCalc	Eagle Point Water Surface Profiling	FishXing
Drainage Calculator	HEC-RAS v 2.2*	
HydroCalc for Windows 95 v. 1.2a*	HydroCAD	
HY-8, Culvert Analysis*	RiverCAD*	
HYDrain*		
HydroCulv v.1		
MacCulvert*		
Quick PipePro*		
THYSYS		

*Incorporates Normann (1985) as algorithm source.

definition of a pipe arch must be in agreement with the culvert designer's concept of a pipe arch.

System compatibility is critical to successful use of a software product, so it is very important to match software product to available computer equipment. There is a difference between a product that runs in DOS and one that runs in the DOS emulator mode of Windows 95. True DOS software is batch input and will not run in Windows.

Cost of the software product is a factor in any acquisition decision. In addition to the initial software purchase, the culvert designer should consider any hidden costs that may be associated with the initial purchase. If new system requirements or hardware such as a CD-ROM drive is necessary, these costs should be taken into account. Additional expenses may be associated with product support, or user manuals. Finally, costs associated with learning to use the product also need to be considered.

Be careful of "feature bloat," which is defined as unnecessary and expensive additions to products.

A user-friendly product running faster and requiring less disk space is more desirable than one with many unnecessary features. The additions make the product more difficult to use. Product support and a clear and concise users' manual are vital to the successful and continued usage of a software product. They are also more important than expensive features. Some of the products reviewed are complex and include several design features. If, after careful evaluation, a total river modeling system with culvert design capabilities and CAD features are needed in a software product, the cost may be justified.

A DECISION METHODOLOGY

One approach to this guide is to combine product information with specific needs as determined by the reader. A decision matrix with suggested criteria can be found in appendix A. The following procedure guides the user through this decision process.

Software selection begins with the resource manager, who defines a list of needs and

Table 6—Output data.

Software product returns the following data:

Software Name:	Size	Slope	Inlet controlled tailwater depth	Inlet controlled headwater depth	Inlet controlled discharge	Outlet controlled tailwater depth	Outlet controlled headwater depth	Outlet controlled discharge	Slope type	Flow regime	Energy grade line	Water depth	Flow area	Wetted perimeter	Hydraulic radius	Water surface topwidth	Froude number	Velocity at inlet	Velocity at outlet	Total discharge	Discharge over road	Discharge/barrel	Normal depth	Critical depth	Critical slope	Outlet scour	Tactive force	Rating curves	Generates report	Copy/paste to other applications	Water surface profile	Print screen	Flow duration curve	Internal note pad	Fish passage capabilities	Environmental risk assessment		
CAP - Culvert Analysis Program			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
CHAN v.2		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
Culvert Master	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
Xing-Risk																																			X			
Drainage Calculator	X																																					
DrainCalc	X	X		X																																		
Eagle Point Watershed Modeling v7.0s				X																																		
Eagle Point Water Surface Profiling	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
FishPass																																						
FishXing		X																																				
HEC RAS v 2.2		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
HY-8 (Culvert Analysis)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
HYDrain	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
HydroCAD																																						
HydroCalc Hydraulics Win95 v1.2a		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
HydroCulv v1.02		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
MacCulvert		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Quick Pipe Pro		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
RIVERCAD		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
THYSYS	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	

requirements. Each product is examined or evaluated in terms of the users' desired application. A list of criteria emerges from this step. A weight is assigned to each of these, with the more important criteria having a higher value. This approach requires careful evaluation of weights, but the

users can tailor the selection process to their specific needs. If the product has that feature, the chosen weight is assigned. If the product does not have the desired feature, a score of zero is assigned. A suggested weighing factor (WF) for each criterion is shown in table 7:

Table 7—Criteria weighing factors.

WF	Descriptive statement
2	= very desirable feature, must have
1	= necessary for operation of software
0	= not necessary or program does not contain this feature

Example: A simplified selection matrix might look like table 8. In this instance, the hydrologist researching culvert software determines the following criteria are important and assigns relative weights to each criterion. If a product meets a selection criterion, the associated weighting factor

Table 8—Selection matrix example.

Requirements based on list of criteria	Weighting factor	Product A		Product B		Product C	
Rainfall modeling incorporating user defined parameters	1	yes	1	no	0	yes	1
Inlet/ outlet control modeling	1	no	0	yes	1	yes	1
Model multiple culverts in parallel or in series	0	yes	0	yes	0	no	0
Fish swimming abilities incorporated into design capabilities	2	no	0	no	0	yes	2
Total points			1		1		4

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**APPENDIX A
Decision Matrix**

SUGGESTED DECISION CRITERIA	WEIGHTING FACTOR	CAP CULVERT ANALYSIS PROGRAM	CHAN v.2	CULVERT MASTER	XING-RISK	DRAINAGE CALCULATOR
UNIX Compatible		X				
DOS Compatible		X				
Windows Compatible			X	X	X	
Macintosh Compatible						
Product support		X	X	X	X	
Unit Choice		X		X	X	
Watershed Modeling			X			
Rainfall Modeling			X	X	X	X
Peak Flow			X	X	X	
Flow Rate / Discharge		X	X	X		
Roadway Modeling			X	X	X	
Normann (1985) basis for Culvert Modeling			X	X		
Maximum Allowable Headwater		X		X	X	
Inlet /Outlet Configurations		X	X	X		
Break in Slope						
Alignment		X		X		
Fall		X		X		
Negative Elevation			X	X		
Multiple Barrels		X	X	X		
Shape Choices		X	X	X		X
Corrugation Choices			X			
Channel Definition		X	X	X	X	
Hydraulic Parameters		X				
Size Calculation				X		X
Slope Calculation				X		
Slope Type				X		
Inlet and Outlet Control		X	X	X		
Scour Prediction / Tractive Forces						
Fish Passage						
Culvert Exit Velocity		X	X	X		
Erosion Hazard / Risk Assessment					X	
Water Surface Profile Data/Graphics			X	X		
Rating Curve Output				X		
Generates Report		X	X	X	X	
Cost of Product as of June 1998		Free	\$459.00	\$495.00	Free	\$8.00
Total						

APPENDIX A — Continued.

SUGGESTED DECISION CRITERIA	WEIGHTING FACTOR	DRAINCALC	EAGLE POINT WATER SURFACE PROFILING	EAGLE POINT WATERSHED MODELING v7.0S	FISHPASS	FISHXING
UNIX Compatible						
DOS Compatible		X	X	X	X	
Windows Compatible		X	X	X	X	X
Macintosh Compatible						
Product support		X	X	X	X	
Unit Choice			X		X	X
Watershed Modeling			X	X		
Rainfall Modeling		X		X		
Peak Flow			X			
Flow Rate / Discharge		X	X		X	X
Roadway Modeling			X			
Normann (1985) basis for Culvert Modeling				X		
Maximum Allowable Headwater		X	X	X		
Inlet and Outlet Configurations			X	X		
Break in Slope						
Alignment						
Fall						
Negative Elevation						
Multiple Barrels		X	X	X		
Shape Choices		X	X	X		X
Corrugation Choices			X	X	X	X
Channel Definition		X	X	X	X	X
Hydraulic Parameters			X			X
Size Calculation		X				
Slope Calculation		X	X			
Slope Type			X			X
Inlet and Outlet Control			X	X		
Scour Prediction / Tractive Forces		X				
Fish Passage					X	X
Culvert Exit Velocity		X	X		X	X
Erosion Hazard / Risk Assessment						
Water Surface Profile Data/Graphics			X		X	X
Rating Curve Output				X		X
Generates Report		X	X	X	X	X
Cost of Product as of June 1998		\$295.00	\$800.00	\$800.00	Free	Free
Total						

APPENDIX A — Continued.

SUGGESTED DECISION CRITERIA	WEIGHTING FACTOR	HEC RAS v2.2	HY8	HYDRAIN	HYDROCAD v5.0	HYDROCALC v1.2a
UNIX Compatible						
DOS Compatible			X	X	X	
Windows Compatible		X	X	X	X	X
Macintosh Compatible						
Product support		X	X	X	X	X
Unit Choice		X	X	X	X	X
Watershed Modeling		X			X	
Rainfall Modeling			X	X	X	
Peak Flow		X	X	X	X	
Flow Rate / Discharge		X	X	X	X	X
Roadway Modeling		X	X	X		
Normann (1985) basis for Culvert Modeling		X	X	X		X
Maximum Allowable Headwater		X	X	X		
Inlet and Outlet Configurations		X	X	X	X	
Break in Slope Alignment						
Fall		X	X	X		
Negative Elevation		X				X
Multiple Barrels		X	X	X	X	
Shape Choices		X	X	X	X	X
Corrugation Choices		X				X
Channel Definition		X	X	X	X	X
Size Calculation			X	X		
Slope Calculation		X	X	X		X
Slope Type		X				
Hydraulic Parameters		X	X	X	X	X
Inlet and Outlet Control		X	X	X		X
Scour Prediction / Tractive Forces		X	X	X		
Fish Passage						
Culvert Exit Velocity		X	X	X	X	X
Erosion Hazard / Risk Assessment						
Water Surface Profile Data/Graphics		X	X	X		X
Rating Curve Output		X	X	X	X	X
Generates Report		X	X	X	X	X
Cost of Product as of June 1998		Free to \$150.00	\$120 to \$145	\$145.00 to \$350.00	\$195.00 to \$1595.00	\$29.00
Total						

APPENDIX A — Continued.

SUGGESTED DECISION CRITERIA	WEIGHTING FACTOR	HYDROCVLV v1.02	MacCULVERT	QUICK PIPE PRO	RIVERCAD	THYSYS CULVERT v1.1
UNIX Compatible				X		
DOS Compatible				X		
Windows Compatible		X		X	X	X
Macintosh Compatible			X			
Product support			X	X	X	X
Unit Choice			X	X	X	X
Watershed Modeling					X	
Rainfall Modeling					X	
Peak Flow					X	
Flow Rate / Discharge		X	X	X	X	X
Roadway Modeling				X	X	X
Normann (1985) basis for Culvert Modeling			X	X	X	
Maximum Allowable Headwater		X	X	X	X	X
Inlet and Outlet Configurations		X			X	
Break in Slope						X
Alignment						
Fall						
Negative Elevation						
Multiple Barrels				X	X	X
Shape Choices		X	X	X	X	X
Corrugation Choices				X	X	
Channel Definition		X	X		X	X
Size Calculation						X
Slope Calculation		X	X	X		X
Slope Type		X		X		
Hydraulic Parameters		X		X	X	X
Inlet and Outlet Control		X	X	X	X	X
Scour Prediction / Tractive Forces				X	X	
Fish Passage						
Culvert Exit Velocity		X	X	X	X	X
Erosion Hazard / Risk Assessment						
Water Surface Profile Data/Graphics		X			X	
Rating Curve Output		X		X	X	X
Generates Report		X	X	X	X	X
Cost of Product as of June 1998		Free	Free to \$100.00	\$375.00	\$2690.00	\$5.00
Total						

APPENDIX B
GLOSSARY OF TERMS AND NOTATIONS

Note: These definitions are specific to the subject of this report.

alignment	Placement of the culvert with respect to the streamflow and road crossing.
allowable headwater depth (AHD)	Allowable depth of water immediately upstream of a culvert, measured from the invert at the first full cross section of the culvert. A design criteria.
allowable headwater elevation (AHE)	The maximum permissible depth of water surface immediately upstream of culvert at the design discharge, measured from a datum. Note: datum may differ between software applications; measured from culvert invert, or another datum.
arch	Structural plate corrugated steel pipe formed to an arch shape. The invert may be the natural stream bed or any other suitable material, but is not integral with the steel arch. See pipe arch for comparison.
backwater	The rise of water level upstream due to a downstream obstruction or channel confluence or constriction.
backwater curve	Water surface elevation for gradually varied flow, where changes in velocity occur very slowly, with negligible acceleration. Units are in length.
backwater effect	The effect that changes in flow rate or water depth have on upstream hydraulic conditions. Backwater effects can only occur in subcritical flow.
baffle	Obstruction, usually wood, concrete, or metal, placed inside a culvert to deflect and check the flow of water for fish passage.
bedload	Sediments, rocks, and boulders not in suspension, but rolled or drawn along a stream bottom by force of water movement.
beveled inlet	A flare on the inlet edge of a culvert to improve efficiency or capacity of inlet controlled culverts, reduces the inlet coefficient K_e .
box culvert	Short segment of closed conduit, rectangular in cross-section.
capacity (hydraulic)	The effective carrying ability of a drainage structure. Measured in volume per time.
coefficient of runoff	Percentage of gross rainfall that appears as runoff. Also ratio of runoff to depth of rainfall. Used in the Rational method for computing design discharge.

competent velocity	The velocity of water that can just move a specified type or size of streambed material.
corrugated metal pipe (CMP)	Galvanized steel or aluminum sheet metal formed to finished shape by the fabricator.
cost effective	Providing the optimum effect at the most reasonable cost.
critical depth	Depth of flow at which specific energy is minimum for a given flow. Not affected by downstream phenomenon.
critical flow	Flow at critical depth, where the sum of the velocity head and the static head is at a minimum. Flow with Froude number of 1.
critical slope	Slope of channel or culvert when normal depth equals critical depth. The slope at which a maximum flow will occur at minimum energy.
critical velocity	Mean water velocity at critical depth.
culvert	A hydraulically short conduit that conveys stream flow, sediment, debris, and aquatic species through a roadway embankment or past some other type of flow obstruction.
debris	Floating, suspended, or waterlogged woody materials moved by a stream flow.
design discharge	The discharge that a structure is designed to accommodate without exceeding the chosen design constraints. A quantity of flow that is expected at a certain point as a result of a design storm or flood frequency.
design flood	The peak discharge (when appropriate, the volume, stage, or wave crest elevation) of the flood associated with the probability of exceedence selected for the design of a highway encroachment.
design frequency	The recurrence interval for hydrologic events used for design purposes. As an example, a design frequency of 50 years means a storm of a given magnitude has a 2 percent (1/50) chance of being equaled or exceeded in one year.
design life	The length of time a structure is designed to function without major repairs or replacement.
design storm	A precipitation event, with a specified probability of occurring in any given year expressed in years or percentage, used as a design parameter. May also be a particular storm that contributes a design runoff, depth, duration, or frequency.

diameter (D)	Inside diameter, measured between inside crests of corrugations.
discharge	The volumetric rate of movement or flux of a quantity of water flowing from a drainage structure or past a given point per unit of time. Also, flow rate.
endpoints	Resources or facilities of value or importance that could be potentially affected by crossing failure.
energy grade line (EGL)	The line that represents the total amount of energy available at any point along a culvert. Where water is motionless, the water surface would correspond to the energy grade line. It is established by adding together the potential energy expressed as the water surface elevation referenced to a datum and the kinetic energy, usually expressed as velocity head, at points along the stream bed or culvert profile.
energy head	The sum of the hydraulic grade line at any section plus the velocity head of the mean velocity of the water in that section.
entrance loss	The head lost in eddies and friction at the inlet to a culvert. Also, contraction loss.
environmental risk assessment	Methodology for determining the likelihood of modification by to one or more values.
fall	A steeply inclined channel length in or immediately upstream from a culvert inlet; designed to improve culvert capacity.
fish passage	Movement of fish through a fishway or culvert.
flood frequency	Exceedence interval, recurrence interval or return period. The average time interval between occurrences of a hydrological event of a given or greater magnitude. The percent chance of occurrence is the reciprocal of flood frequency, e.g., a 2 percent chance of occurrence is the reciprocal statement of a 50-year flood event.
flow rate	The volume of water flowing from a drainage structure per unit of time.
flow area	Cross-sectional area of flow calculated on the basis of inside culvert diameter.
flow duration curve	Graph showing the percentage of time mean daily discharges have been equaled or exceeded.
flow line elevation	Elevation at the lowest point in a channel or culvert cross section.
flow regime	Flow classification based on Froude number, i.e., supercritical or subcritical.

freeboard	The height from a design water level to the top of a roadway or embankment.
Froude number	For a rectangular or very wide channels, $F = V/(gy_h)^{0.5}$ where F is the Froude number; a dimensions number used to determine flow regime. V is the average velocity of flow, g is gravitational acceleration, and y_h is the hydraulic depth. If $F > 1.0$, the flow is supercritical and is characterized as swift, if $F < 1.0$, the flow is subcritical and is characterized as smooth and tranquil, and if $F = 1.0$, the flow is said to be critical.
gradient	The rate of rise or fall of a length of a line or culvert as determined by the ratio of the change in elevation to the length. Expressed as a percentage or a decimal
gradually varied flow	Nonuniform flow where the depth of flow changes slowly with distance. Resistance to flow dominates and acceleration forces are negligible.
head (static)	The height of water above any datum.
headwall	The retaining wall at an inlet or outlet (usually aligned at right angles to the culvert but can be skewed).
headwater	The height of water at the inlet of a culvert. Usually expressed as the water height relative to the diameter of the culvert, HW/D. For example, if water at the inlet is twice the height of the culvert diameter, the headwater to culvert diameter ratio is 2.
headwater elevation	The water surface elevation upstream from a culvert entrance invert, measured from a datum. Note: datum may differ between software applications; measured from culvert invert or another datum.
height of cover	Distance from crown of culvert to road surface.
helical CMP	Corrugated metal pipe with a continuous helical seam, either lock or welded. Has decreased roughness within the barrel compared to annular rib corrugations (lower Manning's n value).
hydraulic capacity	The maximum flow of water that a culvert can continuously pass.
hydraulic depth	The ratio of the flow area to the top width.
hydraulic design	The hydraulic capacity that a culvert is designed to accomodate.
hydraulic grade line (HGL)	A line representing the total potential energy; a combination of energy from the height of the water and internal pressure. In an open channel, this corresponds to the water surface.
hydraulic jump	A sudden transition from supercritical flow to subcritical flow, which is caused by a higher downstream depth, producing a rise in water surface elevation.

hydraulic radius	The ratio of flow area to wetted perimeter.
hydrograph	A graph of stage, discharge, velocity, runoff, or inflow over time.
inlet	The upstream entrance of a culvert.
inlet control	Culvert flow capacity determined by inlet shape characteristics and headwater depth.
inlet/outlet crown	The uppermost outside point on a cross section of a culvert.
invert	The flowline at the inside lowest point of a culvert cross section.
long span culverts	Culverts that are designed on structural aspects rather than hydraulic considerations. Usually constructed of structural plate.
maintenance cycle	Frequency of inspection, routine cleaning, and repair.
Manning equation	An empirical equation used to estimate friction loss and discharge in culvert design. Incorporates channel roughness, hydraulic radius, and cross-sectional area of flow. Assumes uniform flow or gradually varied flow.
Manning's n	An empirical coefficient relating the effect of channel boundary or culvert roughness to energy losses in flowing water.
normal depth	Depth of water at normal flow, where discharge, velocity, and depth do not change with length.
outlet	The downstream end of a culvert; the outfall.
outlet control	Culvert flow capacity determined by the barrel roughness, length, slope, and tailwater elevation.
performance curve	A plot of culvert discharge versus inlet headwater elevation or depth.
pipe arch	A corrugated metal pipe shaped to a span (width) greater than rise (height), structurally continuous, usually prefabricated.
projecting end	A culvert inlet or outlet that projects from the face of the fill or embankment. Also called a perched or shotgun culvert.
rapidly varied flow	Nonuniform flow where depth of flow changes rapidly over a relatively short distance, such as a hydraulic jump.
rating curve	A curve that correlates flow rates to flow depths in a channel or culvert.
rational method	An approach to estimate the rate of storm runoff based on an intensity-runoff relationship; $Q=CIA$. C is the coefficient describing runoff potential of an area, I is the rainfall intensity during the core time of concentration, and A is the drainage or watershed area.

return period (T_r)	The average period of time expected to elapse between successive storm event occurrences of a given size or larger. It is not a statistical guarantee that a damaging storm will appear on schedule, rather, it is the reciprocal statement of probability (p): $T_r = 1/p$.
rise	The maximum vertical height inside a culvert, usually measured at the center line.
risk analysis	Assessing the probability of failure and values at stake for alternate culvert designs.
runoff	The part of precipitation and snowmelt that reaches streams and eventually the sea by overland and subsurface flow. This is the stream flow before it is affected by artificial diversion, impoundments, or other manmade changes in or on stream channels.
scour	Degradation of the channel at the culvert outlet as a result of erosive velocities.
skew	The acute angle formed by the intersection of the line normal to the centerline of the road with the centerline of a culvert. Also, the angle formed between the centerline of the culvert and the channel thalweg.
slope	(1) The gradient of a stream; (2) Inclination of the face of an embankment, expressed as the ratio of the horizontal to vertical projection; (3) the face of an inclined embankment or cut slope. Expressed as a percent or decimal.
slope type	Water surface profiles classified according to channel slope type (mild, steep, critical, horizontal, or adverse).
steady flow	Discharge, velocity and depth of flow constant through time.
subcritical flow	Flow at velocities less than critical, with a Froude number less than 1. Gravity forces are more pronounced than inertial forces. Flow has a lower velocity and is often described as steady, tranquil, or streaming.
supercritical flow	Flow at velocities greater than critical, with a Froude number greater than 1. Inertial forces are dominant, so the flow has a higher velocity and is usually described as rapid or shooting.

surface profile type	First letter of the type of slope (M, S, C, H, or A) combined with the actual depth of flow in relation to the critical and normal depths (Zone 1: actual flow depth is greater than both normal and critical depths; Zone 2: flow depth is between the normal and critical depths; or, Zone 3: flow depth is less than both normal and critical depths). An example is S2.
tailwater depth	Depth of water immediately downstream from a culvert, measured from the culvert outlet invert.
tailwater elevation	Depth of water immediately downstream from a culvert, measured from a datum.
time of concentration	The time required for storm runoff to flow from the most remote point of a drainage area to the point of consideration. It is usually associated with a design storm.
topwidth	Chord describing free surface extent of water in a culvert.
tractive force	Drag or shear that is developed on the wetted area of a channel by erode material. Acts in the direction of flow, related to scour.
uniform flow	Depth of flow not varying with distance, implied that flow is also steady.
unsteady flow	Discharge, velocity and depth of flow changing with time.
water depth	Measurement from culvert invert, pool or channel bottom to water surface.
water surface profile	A profile plot of water surface elevation through a culvert or open channel.
wetted perimeter	The cross-sectional length of wetted contact between the water prism and the culvert, measured at right angles to the culvert.
wingwalls	The retaining walls that provide a transition from the culvert headwall to the channel.

