Chapter 2: The stream and its surroundings.

Objective and Purpose

This chapter discusses the physical characteristics of streams that affect the selection and design of fish passage structures. Stream systems are very dynamic. The ground water/surface -water interactions that create a stream differ regionally. It is beyond the scope of this chapter to discuss stream classifications. Some common definitions are provide below for reference.

Hyporheic Zone: Surface water and groundwater are considered by hydro geologists a single system. The hypoheic zone is the mixing zone of stream water and groundwater.

Stream Reaches Categories for exchange of groundwater and surface water: Unconstrained, Constrained, aggrading or degrading.

Aggrading Reaches: A reach of stream that is depositing sediment.

Degrading Reaches: A reach of stream where active down cutting and erosion is occurring.

Constrained stream reaches can be defined as fluvial plains less than four times the active channel width.

Unconstrained stream reaches have fluvial planes greater than four times the active channel width.

Stream Groundwater flow scenarios : Gaining, losing, flow though and parallel.

Gaining flow: Stream condition when the hydraulic head in the sediments underlying and adjacent to the stream is greater than the stream stage.

Losing flow: Stream Condition when the hydraulic head described above is less than the stream gage and the stream is losing water.

Flow through scenario: The head on one side of the stream bank is higher than the head on the other and water moves through the stream perpendicular to its flow.

Parallel Flow: Stream condition when the stream stage and hydraulic head in the adjacent sediments are equal than parallel flow or “ zero exchange” occurs.

Hydrograph: A plot of streamflow against time.

Quantitative Hydrology: The study of stream flow records to determine a given flow for a particular site and time.

Stream Dynamics

For design of in stream structures we model the stream as having a given amount of energy and discharge. The discharge is a function of three parameters: channel width, channel depth and channel velocity. Since the discharge is constant at any given point, a change in any given parameter must be balanced by a change in the remaining parameters. The width, depth, and velocity of the channel must be maintained through the crossing structure to keep the system balanced such that it will have the same physical features above and below the crossing structure. Changing any of these parameters will affect the others. Velocity and depth are affected by the streams roughness, stream slope and it's cross sectional area. The table below will help illustrate this concept.

Table 2.1

FACTOR	VELOCITY	DEPTH
Increasing Channel roughness	**decrease**	**Increase**
Increasing Cross Sectional Area	**decrease**	**decrease**
Increasing channel slope	**increase**	**decrease**

Physical Characteristics of the Stream

The physical characteristics of a stream affect the selection of alternatives and designs. These characteristics are discussed in more detail in this chapter.

1. Stream Bed Materials: type, depth, durability.
2. Channel type: Confined, incised, broad wide, etc.
3. Relationship to other streams: Watershed size and streams location within the watershed.
4. Gradient of Stream: Profile of Existing Streambed
5. Incision History of channel and the value of culvert as nick point
6. Width of Stream bed in area: Active Stream width, bank full width
7. Geology of area ,potential for debris flow
8. Diversion Potential of Road Crossing

Site Survey and Initial Monitoring

1. Conduct site survey of project site. (Typically a two person crew).
   - A Extend survey up stream and downstream several hundred feet as needed to show the stream profile how the reach the present stream is aggrading or regrading
   - B Set local bench marks using rebar or permanent nails. These points later become the controls for construction. Locate controls in areas that will not be disturbed..
   - C Locate all man made features, bench marks, property lines, facilities, and items of interest.
   - D Locate trees for saving.
   - E Locate any natural and man made nick points such as rock outcrops, Boulder clusters, gabions,etc.
   - F Note best locations of proposed grade control weirs.
   - G Minimize brushing. Obtain permission for brushing site on and off right of way. Discuss with owners or agency in advance acceptable brushing limits.
   - H Take cross sections of channel upstream and downstream. Note station of cross sections
     - i. Bank Full Width
     - ii. Ordinary High Water
     - iii. Active Channel
   - I Notify all private land owners at time of survey. Get permission in advance for entry onto their lands.
2. Classify bedding materials in channel.
   - A Use table 2.1 for surface rocks in stream. .
   - B Field classify foundation materials in accordance with unified soil classification. Take samples of soil in plastic bags. Typically soils samples can be taken from exposed cuts or with the use a hand auger. For complex sites follow up with backhoe pits or drilling. .
   - C Locate Depth to bedrock. A simple method is to drive a rebar with a hammer to resistance.
3. Photos and Photo points
   - A Photo points are often used to show before and after affects of projects. Set stakes at these locations.
   - B Take photos of inlet, outlet, upstream conditions, downstream conditions, inside of culvert and features recorded in survey.
   - C Take photos of cross section sites where measurements were taken of channel widths.
   - D Photo document private and public property features adjacent to stream and adjacent to construction such as signs, utilities, building, etc.
4. Local History of site
   - A Record in work books interviews with local residences.
     - i. Presence or absence of fish in stream
     - ii. Flood records
     - iii. Land owner preferences for repairs or replacement
     - iv. Contact person for visiting sites. Obtain permission to cross fences.
     - v. Items of importance to land owners within site such as plants or features

Evaluation of the stream reach information

1. **F**rom Ordinary High Water, Active Channel and Bank Full Widths :
   A Select minimum width of replacement structure
   B Consider bridges for active channel widths greater then 20 feet.
   C When widths are less then 6 feet embedment is difficult and will require conveyors or chutes.

2. From Stream gradient profile
   A Establish optimum grade for each alternative
   B Install structures on steeper gradient than stream when necessary to to avoid down cutting of channel at inlet.
   C Install rock control structure to prevent future degrading below new structure from high flow hydraulic jumps.
   D Back watering of culvert is always the most economical and reliable of stream simulation methods.

3. From observed channel degrading or regrading
   A Design for potential regrading affects by increasing footing heights or enlarging structure.
   B Add in-stream structures such a boulder clusters to capture and hold sediments in previously degraded rock sections.

4. From Stream bedding materials
   A The objective is to retain bedding materials in the new culvert similar to the existing materials in the stream. If stream has smaller bedding materials adding extra width to the structure may be an appropriate method to resist shear forces and loss of bedding fines.

5. From observed wetlands and pools
   A Determine extend of down cutting that is appropriate at inlet and outlet. Streams have normally regraded from fills and cuts resulting from previous structures. As an interdisciplinary team establish minimum and maximum limits of disturbance that are now acceptable.

6. From Soils Data
   A Design foundation for new structure.

Stream Bed Materials

The stream bed is defined as the lands below the high water marks of a stream. Within the stream we have the exposed hardened substrate. Substrate materials actively move with deposition and aggradation occuring continually within the channel. Under the substate is the foundation material which may be soil or rock.

Substrate in Channel

The table is provided as a guide for classification of materials found in stream beds. This table is a reprint of one developed by Oregon Dept of Fish and Wildlife and several other state agencies in Oregon and Washington. .

Table 2.2

Type of Substrate	size	relative size
Bedrock	13 ft diameter	Bigger than a car, continuous Underlayment.
Boulders	10" to Bedrock	Basketball to Car Size
Large Cobbles	6" to 10"	Cantaloupe to Basketball
Small Cobbles	2.5" to 6"	tennis ball to cantaloupe
Coarse Gravel	0.6" to 2.5"	Marble to tennis ball
Fine Gravel	0.1" to 0.6"	Ladybug to marble
Sand	0.1"	Smaller than ladybug but visible as particle
Fines	Not visible as particles	Silt clay muck not gritty

The stream bed materials affect the selection and design of structures. We typically field classify the reaches of the stream while surveying sites for design. This information is used later:

1. The size of substrate will indicate if a culvert will self embed or will require embedment
2. Streams moving larger rocks will typically have higher velocities and narrower channels then a stream with similar flows having smaller bedding materials.
3. The hydraulic roughness of the existing channel is used in the Mannings formula for calculation of the approach velocity and depth of flow.
4. The sizing of material to embed the culvert with should be similar to the size of material in the adjacent natural stream channel. If existing materials is small , the culvert may need to be embedded in layers with larger scour resistant materials on bottom.

Foundation Materials :

Foundation materials are the materials below the stream bed that the culvert or footings will set upon. On sites with soft soils the foundation will almost always require reconstruction . If bedrock is near the surface the structure will use the bedrock for its foundation. The selection of possible crossing alternatives will always depend on the foundation and the depth to bedrock. Some authors have referred to the depth to bedrock as the depth of the valley fill material.

Valley fill refers to layers of gravel, sand cobble and other sediments that lie over the top of the bedrock. The depth to bedrock is a construction issue. If bedrock is not ripable, placing a culvert can be very expensive and require blasting. In those cases an open bottom structure is usually preferred. However if bedrock is ripable then an embedded culvert is a reasonable option. Placing an open bottom arch on an erodible foundation will require care in design of a riprap foundation to prevent undercutting of the foundation or down cutting of the upstream substrate should the foundation be eroded.

The selection of a footing type will depend on the bearing capacity of the soil or rock, the potential for settlement and the potential of the foundation to erode.

1. Foundation Requirements

A good foundation for an underground conduit will maintain the elevation of the conduit in it' desired location and shape, without concentration of foundation pressures that produce excessive stresses in the conduit.

2. Initial Foundation Investigation

Evaluation of the foundation may require subsurface exploration to detect undesirable foundation materials such as rock ledges or muck or soft materials. The extent of this investigation will vary depending on the proposed structure, the cost of delays and the potential remedies if unacceptable materials are found in the excavation. For smaller projects plans will include details for remedies to soft soils in lieu of an extensive soils' exploration at the site. A minimum site investigation should include

A. Determining depth to bedrock by visual or drive probes
B. Hand Auger sampling of stream in soft soils for depth of soft materials
C. Field classification of materials in channel and exposed side slopes

A detailed investigation is appropriate for larger structures and those with complex designs such as bridges with pile foundations and open bottom structures. A typical investigation will include drilling and mapping of the subsoil strata. The drill logs or test pits will provide information about soil types, bearing capacity of the layers and the presence or absence of ground water.

3. Foundation Improvements

The following are recommendation by the American Iron and Steel institute.

"When foundations must be replaced, excavation should extend along the entire length of the conduit to a width at least one diameter on both sides of the conduit greatest width. Soft materials must be removed and replaced across the entire foundation width, but ledge rock or rocks beyond the bedding may be left. Foundation preparation in a trench bottom while based on these principals, should be confined to practical widths."[1]

The AASHTO Standard Specifications for Highway Bridges notes

" Special design considerations may be applicable; a buried flexible structure may raise two important considerations. The first is that it is undesirable to make the metal arch relatively unyielding or fixed compared with the adjacent side fill. The use of massive footings or piles to prevent any settlement of the arch is generally not recommended.

When poor materials are encountered, consideration should be given to removing some or all of this poor material and replacing it with acceptable material. The footing should be designed to provide uniform longitudinal settlement of acceptable magnitude from a functional aspect. Providing for the arch to settle will protect it from possible drag down forces caused by the consolidation of the adjacent side fill.

The second consideration is bearing pressure of soils under footings. Recognition must be given to the effect of depth of the base of footing and the direction of the footing reaction from the arch"[2]

When should an arch structure be installed on rock. Installing an arch on rock is desirable if the rock under the structure extends to the side slopes creating a uniform zone under the entire structural envelope to include the footings, side slopes, and fill . A situation to be avoided is if the rock is located under the footings only fixing the foundation separate from the side slopes.   This condition will create drag down forces on the structures.

4. Designing foundations for Soft Soils

In very soft soils the use of geogrids and soil mattresses are recommended The soil mattresses must support the pipe, the adjacent fills and side slope.   Consolidation or settlement is expected. If the settlement occurs uniformly under the culvert and embankment the affects can be mitigated by resurfacing of the roadway at a latter date. If the consolidation is confined only under the conduit drag down forces could cause the conduit to fail and become distorted.

5. **Unified soil Classification**

Engineers typically classify soil according to the Unified Soil Classification System. The following table describes the symbols used. For classification procedures see any foundation engineering reference manual.

Table2.3

Group Symbol	Typical Descriptive Names	Friction angle Density= 0%	Friction Angle Density = 100%	Friction Angle Density =100% NFEC 7.02
GW	Well graded Gravel and Sand mixtures, little or no fines	35	45	.>38
GP	Poorly Graded gravels, gravel-sand mixtures little or no fines	33	43	>.37
GM	Silty gravels, poorly graded gravel sand-clay mixtures	33	43	>34
GC	Clayey gravels, poorly graded gravel sand -clay mixtures			>31
SW	Well Graded sands, gravelly sands , little or no fines	Coarse = 33 Medium= 31 Fine = 29	Coarse =43 Medium= 41 Fine = 39	>34
SP	Poorly graded sands , gravelly sands ,little or no fines	Coarse = 31 medium = 29 fine = 27	Coarse = 41 Medium= 39 fine= 37	37
SM	Silty sands, poorly graded sand-silt mixtures	31 fine SM= 27	41 fine = 37	34
SC	Clayey sands, poorly graded sand-clay mixtures			31
ML	Inorganic silts, rock flour , sandy silts, and clayey silts with slight plasticity	26	36	32
CL	Inorganic Clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays			28
OL	Organic silts and silty clays of low plasticity			
MH	Inorganic silts, minacious or diatomaceous , elastic silts			25
CH	Inorganic clays of high plasticity, fat clays			19
OH	Organic clays of medium to high plasticity, organic silts of medium plasticity			
Pt	Peat and other highly organic soils			

6. Bearing Capacity of Foundation Materials

The bearing capacity of the soil is a typically estimated by the engineer. On complex structures tests are performed to quantify strength. Strengths are often interpolated from standard penetration tests performed during drilling operations. The following table is provided as a guide to demonstrate the variations in bearing capacities of soils by types.

Table 2.4

Type of Materia1	Consistency in place	Bearing pressure tons/sq foot[1]	Use and Recommendations
	Heavy Sound Rock not ripable	15 to 20	Open bottom structures . Excavation would not be cost effective for pipes, arches .etc
	Soft rock ,weathered, or broken, except for shales argillaceous rock	8 to 12	Same as hard rock above consult local contractors about ability to rip. If ripable can use pipes, arches, etc.
	Compaction shale or other highly argillaceous rock in sound condition	8 to 12	Material is normally ripable and erodible. May need to blanket with riprap for scour protection if open bottom structures are used
GW-GC, GC,SC	Well graded mixture of fine and coarse-grained silt: glacial till, hardpan, boulder clay compact	10	Material is normally ripable and erodible. May need to blanket with riprap for scour protection if open bottom structures are used
Gravel, gravel-sand mixtures , boulder gravel mixtures (SW,SP, SW,SP	Very Compact Medium to compact Loose	7 5 3	Normally excellent material for pipes. Avoid placing open bottom structures in less then compact materials because of concern with piping, and fill erosion.
Coarse to Medium sand, sand with little gravel, SW,SP,	very compact medium to compact Loose	4 3 1	Normally excellent material for pipes. Not recommended for open bottom structures without special analysis and protective footings. High groundwater may destabilize foundation..
Fine to medium sand, silty or clayey medium to coarse sand. (SW, SM, SC)	very compact medium to compact Loose	3 2.5 1.5	Normally excellent material for pipes. Not recommended for open bottom structures without special analysis and protective footings. High groundwater may destabilize foundation
Homogeneous inorganic clay, sandy or silty clay, CL, CH	Very stiff to hard medium to stiff Soft	4 2.0 0.5	In soft soils will need to add foundation improvements such as a soil mattress or removing and replacement with rock. Settlement is expected.
Inorganic silt, sandy or clayey silt, varied silt-clay-fine sand	very stiff to hard medium to stiff Soft	3 1.5 0.5	In soft soils will need to add foundation improvements such as a soil mattress or removing and replacement with rock. Settlement is expected

[1] Bearing Capacity is shown in tons per sq foot for footings with least dimensions of 3 foot. If dimensions are less then 3 feet. The allowable bearing pressure shall be 1/3 the nominal bearing pressure multiplied by the least later dimension in feet.

Theory and Formulas

The accepted reference for foundations of Bridges and Culverts in the United States is the Standard Specifications for Highway Bridges published by the American Association of State Highway and Transportation Officials, Inc. The Bearing Capacity equations they recommend were developed by Terzaghi and are well documented in all foundation engineering textbooks. The design method proposed is the service load Design Method, allowable Stress Design.

Qult= cNc + 0.5YBNy +Qnq (4.4.7.1-1)

The allowable bearing capacity shall be determined as

Q all= Qult/ FS (4.4.7.1-2)

The Factor of Safety for spread footings is typically in the range of 2 or 3. A safety factor of 3 is commonly used when c>0. Per AASHTO 4.4.7.1.2 use a Factor of Safety of 3.0. ,

When a footing is setting at or below the ground water height as would be the case of a foundation in a stream use Y'= buoyant weight of the soil.

Punching Shear Failure

In loose or relatively compressible soils, punching or local shear failures may occur at lower bearing pressures. Punching or local shear failures are characterized by a poorly defined failure surface, significant vertical compression below the footing and very little disturbance around the footing perimeter.[2]

If local or punching shear failure is possible, the value of Qult may be estimated using reduced shear strength parameters "c" and "phi" in 4.4.7-1 as follows

c = 0.67C

"phi" = tan(-1)(0.67 * (tan"phi")

Bearing Capacity Factors

Effective stress methods of analysis and drained shear strength parameters shall be used to determine bearing capacity factors for drained loading conditions in all soil. Additionally the bearing capacity of cohesive soils shall be checked for undrained loading conditions using bearing capacity factors based on undrained shear strength parameters.

The AASHTO reference also provides guidelines for modifying the formulas noted above for

- Footing shape
- ground surface slope

[2] NFAC DM7.02, 7.2-130

base inclination

- inclined loading
- Eccentric loading
- Embedment depth
- Ground water
- Layered Soils
- Settlement with criteria for tolerable Movement

Representative Values for angle of internal friction[3] , Also see section on soil classification for other values

Table 2.5

Soil	Unconsolidated, undrained UU	
Gravel medium size	40- 50	
Gravel sandy	35-50	
Sand loose cry	28.5- 34	
sand loose saturated	28.5-34	
sand, dense dry	35-46	
sand ,dense, saturated	33-44	
Silt loose	20-22	
silt dense	25-30	
Clay	0 if saturated	

[3] Foundation and Design, Joseph E. Bowles, second edition, page 30, table 2-2

Bearing Capacity Sample Calculation

Find: Bearing Capacity of soils beneath a culvert with a concrete footing.

Given:

Soil Classification : GP, Poorly graded gravel, medium compaction, dry unit weight= 115
Depth of footing below ground= 1 foot
Culvert foundation is at level of stream or ground water
Estimated width of foundation=2.5 feet
Height of surcharge over footing = 5.5 feet
Punching Failure is not a concern

Preliminary Design

From tables: use an angle of internal friction of 33 degrees

	BEARING CAPACITY OF FOUNDATION		
	Factor of Safety	3.00	
	Estimated width of Foundation B	2.50	feet
	Given phi of soil	33.00	degrees
	Nc	38.64	
	Nq	26.09	
	Ny	35.19	
Df	Depth of overburden to base of footing	5.50	feet
Y2	Density of overburden over base of footing	115.00	lbs/cubic foot
Zw	Depth of Groundwater below base of footing	0.00	feet
Y2	Y2- total unit weight of soil or rock	115.00	lbs/cubic foot
	y2 adjusted for groundwater	52.60	lbs/ cubic foot
	B	2.50	Least lateral dimension of footing
	c	0.00	cohesion of soil
	q1	632.50	Effective overburden pressure at base of footing
	cNc	0.00	lbs
	q1Nq	16501.93	lbs/sq foot
	0.5*Y1*B*NY	2313.74	lbs/sq foot
	Ultimate bearing Capacity of foundation=	18815.67	lbs/sq foot
	Qult Adjusted for Factor of Safety	**6271.89**	**lbs/sq foot**

Sizing rock for protection of foundations and Slopes

Rock used for foundation protection, slope protection and embedment must be adequately sized to prevent scour during peak flow events Q100 or Q50. Use calculated sizes in conjunction with stream indicators of material that have moved during those events. Two of the most commonly used formulas are presented below as a reference . When performing designs refer to reference documents developed for each of these methods for an explanation of their use and limitations. Stream gradients in nature have binding forces greater than those we calculate as the channels harden from flows. Constructed channels require additional protection.

I. Corp of Engineers method for Steep slope riprap design (em1110-2-1601) Design criterions include":

- A. Unit discharge is low
- B. The guidance for steep slope riprap generally results in large riprap sizes. Grouted riprap is often used instead of loose riprap in steep slope applications
- C. Slopes can range between 2 to 20 percent
- D. General formula

$$D_{30} = \frac{1.95\ S^{0.55}\ q^{2/3}}{g^{1/3}}$$

S= slope of bed

q= unit discharge

g= gravitational constant

- E. Use filter fabric beneath Rock
- F. Multiply q by flow concentration factor of 1.25 . Increase factor if approach flow is skewed.

II. HEC 11 in the March 1989 version provides a velocity based riprap design relationship based on shear stress theory.

- A. General Formula

$$D_{50} = 0.001\ V^3/(d_{ave}^{\ 0.5}(k^{1.5})$$

- B. D_{50}= 50% size of riprap
- C. k = The bank slope correction factor
- D. V= Average section velocity in the main flow
- E. Developed for use in rivers or streams with typical non uniform flow conditions and discharges normally greater then 50 cfs. The

Riprap for channel protection is normally placed with a filter. A good commentary on selection of filters is included in HEC 11 a portion of which is quoted below .

"4.4 Filter Design:

A filter is a transitional layer of gravel, small stone or fabric placed between the underlying soil and the structure. The filter prevents the migration of the fine soil particles through voids in the structure, distributes the weight of the armor units to provide more uniform settlements and permits relief of hydrostatic pressures within the soils For areas above the water line, filters also prevent surface water from causing erosion (gullies) beneath the riprap. A filter should be used whenever the riprap is placed on non cohesive material subject to significant subsurface drainage (such as in areas where water surface levels fluctuate frequently and in areas of high groundwater levels).

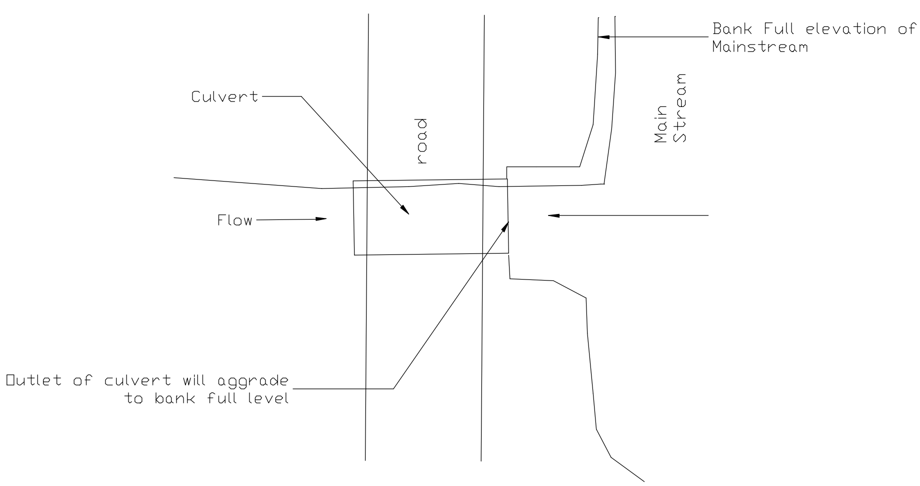
The proper design of granular and fabric filters is critical to the stability of riprap installations on banks. If openings in the filter are too large, excessive flow piping through the filter can cause erosion and failure of the bank material below the filter. On the other hand , if the openings in the filter are too small, the build up of hydrostatic pressures behind the filter can cause a slip plane to form along the filter resulting in a massive[3] tranlational slide failure.

Flows at the Confluence of two Streams

Channel aggrading and regrading will occurs at the confluence of two streams where a smaller streams enters into a larger stream. The larger stream may backwater the culvert such that deposition occurs to the point of plugging the smaller culvert. During alternate storms the channel may degrade

This movement or rising and falling of bedload material though dynamic is predictable. . The following observations have been made at these sites.

1. The depth of deposition is to the bankfull depth of the larger stream
2. The affect of the backwater on the flow capacity of the smaller pipe will normally be negligible but can be easily calculated with Culvert Master or other programs.
3. The deposition may plug or partially plug the pipe if the culvert does not have flows large enough to flush the gravels out at a latter date.
4. Knowing this will happen, design the culvert anticipating deposition at certain times and a flushed condition at others. The culvert footings or size may need to be enlarged to accommodate those concerns.
5. A culvert constructed for stream simulation will self embed to the depth and extent of the backwater from the larger stream which will vary by storm event..



Bank Full Width = Ordinary High Water = Active Channel Width

In stream simulation designs, new culverts are sized as wide or wider than the bank full width of the stream. The bank full width is the stream width that occurs when larger streamflow events occur. The recurrence interval for these events is about once every year or two. My reviews have shown that state agencies have described this same width as "bank full width", "Active stream width", "Stream channel width" , "active channel width", "normal high water" and "ordinary high water" width. For this handbook, I refer to this width as the "**Bank full width** Common indicators of width include the following:

A. Vegetation changes
B. Changes in bank channel substrate
C. In alluvial streams when bank changes from steep to flat or steep to gentle
D. In incised streams where the active channel marks on bank occurs
E. Other indicators are changes in rock coloration, changes in intensity of moss, highest level of flow debris in vegetation, and changes in bank shape.

Definitions Bank full width : note similiarities

Bank Full Width: Refers to the stream width that occurs when a fairly large storm comes. The recurrence interval is once every one or two years.

Ordinary High Water Width: The legal definition of OHW as defined in the WAC (220-110-020(31)) is: Ordinary high water line means the mark on the shores of all waters that will be found by examining the bed and banks and ascertaining where the presence and action of waters are so common and usual and so long continued in ordinary years, as to mark upon the soil or vegetation a character distinct from that of the abutting upland Provided, That in any area where the ordinary high water line cannot be fund the ordinary high water line adjoining saltwater shall be the line of mean higher high water and the ordinary high water line adjoining freshwater shall be the elevation of the mean annual flood"..

Stream Channel Width: Is the horizontal distance between the streambanks on opposite sides of the stream measured at right angles to the general orientation of the banks. The point on each bank from which width is measured is usually indicated by a definite change in vegetation and sediment texture.

Measuring Stream Widths

1. Take a minimum of three section measurements in the reach or a similar reach that fish passage restoration work is being done. Ten sections are desired.
2. Do not take readings near crossings or abnormally wide or narrow sections.
3. Do not include islands in width of stream.

"Considerable judgment is required to identify representative OHW marks. It may be difficult to identify the mark on cut banks. In warm months grasses or hanging vegetation may obscure the OHW mark. Artificial structures (culverts, bridges, or other constrictions) can affect the OHW mark in their vicinity by creating marks on the shore which are consistent to OHW marks, but above the elevation that is usually found in undisturbed river reaches."[4]

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[4] State of Washinton Web site

Low Water Surface

A second measurement I take when doing field work is the low water surface. This width is less than the bank full width. It is the non vegetated portion of the stream. This is the minimum width for any replacement structure and normally will be less than that required for traditional culvert designs at a headwater to depth ratio of 1 or less.

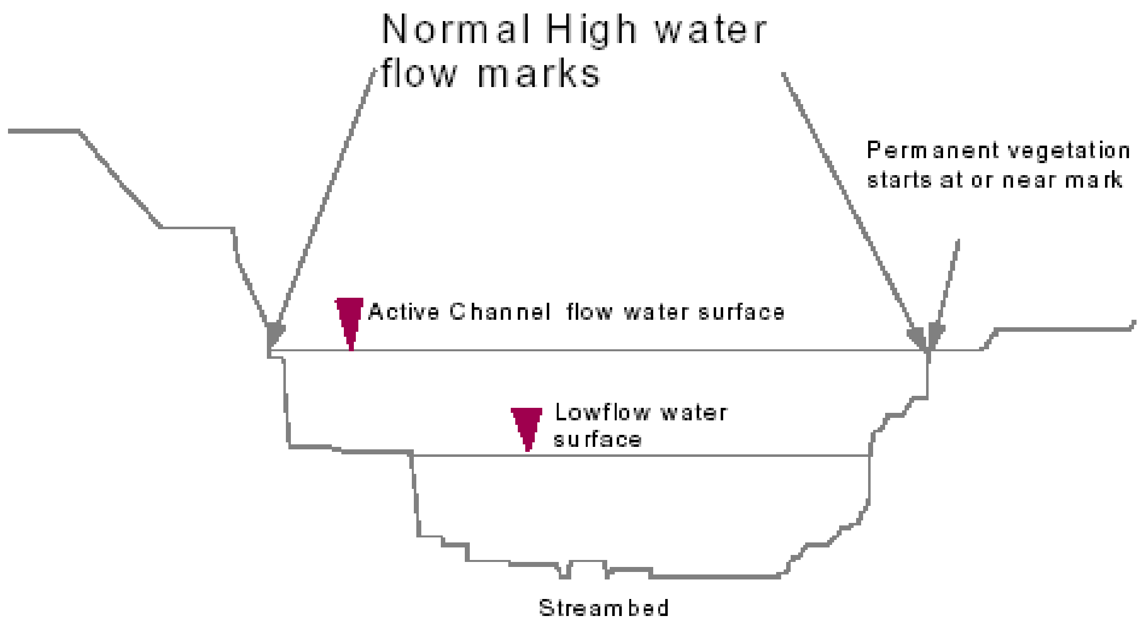

Figure 10. Highwater flow marks and active channel width schematic.

Minimum Span or Bed Width of Culverts

The desired minimum width of the bed for the new structure is always selected wider then the low water surface. The desired width is bank full width or wider.

This requirement for a minimum width developed from the existing stream widths is defensible.

1. The extra width prevents inlet drop and flow constriction of the pipe at the inlet.
2. The culvert width must be larger to retain embedded material and unfavorable hydraulics for fish passage. .

Culvert designed with fishways will not technically require as wide a span as embedded culverts designed stream simulation designs. In practice, we seldom make that adjustment because of concerns over entrance velocity, debris passage and the higher velocities associated with a constricted entrance.

State Recommendations

Washington and Oregon have both establish criterion for the minimum widths of culvert beds. The table below compares their recommended widths .

STATE RECOMMENDATIONS FOR SELECTION OF MINIMUM CULVERT WIDTHS

Wch= Width of the channel Bed- active channel

W= Width of bed inside of new culvert

Table 2.6

Formula	**Design Methods or conditions**
W= 1.2 Wch +2	WDFW for full stream simulation design method
W= Wch	WDFW for Roughed Channels and no slope method ODFW for Stream Simulation Channels
W= Width of channel + 2'	WDFW for Stream simulation design method in confined valley channel where the stream width does not change substantially with stage.
W= undefined, interactive process. Begin process with width equal to streambed width then adjust	Hydraulic Method: Width is a function of fish passage as calculated.. Avoid a constriction at inlet by maintaining a width of at least the channel width.

Hydrology

Hydrology refers to the study of water and for culverts the estimation of design flows. .

As a minimum , a culvert is sized large enought to carry a design storm and its assocated debris . Bridges are designed for a Q100 flow with 4 to 5 feet of freeboard. With culverts the Q 100 flow is used and the sites are often hardened to resolve debris flow. Culverts designed by the hydraulic method have a headwater to depth ratio greater than one, they will be significantly smaller than a culvert designed for stream simulation where the headwater to depth ratio is less than 1 and normally in the range of 0.75.

Design Flood Q 100 or Q50

Q100 is the 100 year design flow or a storm that has a 1% chance of occuring in any year. The minimum flow required for State projects is a Q50 whereas for federal projects the minimum design flow must past a Q100 storm event.

3. In 0regon we predict this flow using a the following methods

   USGS method
   WRRI method
   Comparison to at least three gaging stations.
   Oregon Dept of Forestry Peak Flow Map for Forest streams

These methods are well documented with manuals prepared on each of the methods. In general a designer should use two or three methods for each site. Predicting flow is not an accurate science and should yield a range of values not a specific value for each flow. Programs that makes these calculations are available upon request.

2. In Washington State the following methods are recommended .

   USGS Method
   Powers- Saunder Method
   Comparison to gaging Stations

Estimating flow when fish are moving   Qhfj, Qlff-Dons Method

This is the estimated highest flows when juvenile fish (Qhfj) and the lowest flows (Qlff) flows when juvenile fish are expected to be moving through the culvert.   The objective is to design culverts or structures such that fish movement is never delayed.   In particular such that juvenile fish movement is never delayed. The following is this author's method of selecting those values when required. .

For culverts designed for **stream simulation** such as open bottom structures and pipes that trap gravels, high and low fish pass flows are **not** used in the design process. Juvenile movement is expected to occur between the roughness elements in the substrate.   There does not seem to be any question of adult passage if juvenile passage can be obtained even though the adults may not find the resting areas that the smaller fish can. Randy Reese with the Oregon Highway Dept has suggested that we add shadow rocks in the substrate for the larger fish as well. On our more recent designs we have added this feature .

Culverts which are designed using the fishway procedure or hydraulic method require an estimate of high and low fish passage flow values. This author uses the high mean monthly flow value as a good estimate for Qhfj and the low mean monthly flow for Qlff flows . State gaging station records have summaries of the the monthly flows for each station by month and % exceedance. A procedure for comparing gaged and ungaged site is documented in the State Hydraulic Manuals used by the Oregon Highway Department and the USGS.   By using the comparisons as recommended in this USGS method, we can proportion the desired monthly flow values from the gaged to the ungaged sites.

WDFW Procedure for defining fish passage flows :

" WAC 220-110-070 (Water Crossing Structures) requires that the high flow design discharge be the flow that is not exceeded more than 10 percent of the time during the months of migration. This report provides regional regression equations for ungaged catchments to estimate this flow.

For gaged catchments the 10 percent exceedance flow for any month is determined by developing a flow duration curve. For ungaged catchments, the two-year peak flood is used to estimate this flow (Cummans, 1975). The two-year peak flow is often much higher (300 to 400 percent) than the 10 percent Exceedance flow. Bates (1988), reviewed current agency criteria and developed two regression equations relating basin parameters to the 10 percent exceedance flow.

The U.S. Geological Survey (USGS) are in the process of updating regional regression equations for flood frequencies in Washington. This report utilizes the same regions and basin parameters to develop regression equations for the 10 percent exceedance flow for the months of January and May. These months were selected to represent the high fish passage design flow (Q) for two periods when upstream passage has been observed (Peterson, 1982) and (Cederholm, 1982). January represents the month of highest flow when adult salmonids are passing upstream, and May represents the most critical month for upstream passage of juvenile salmonids. Other months are also important, but January and May represent the two extreme combinations for design considerations. Equations were developed for three regions of Western Washington (Figure 1). Data was also analyzed for Eastern Washington, but no correlation between design flows and basin parameters could be found.

ODFW Procedure for defining fish passage flows

The Oregon ODFW guidelines (Appendix A) stipulate that culvert should be designed to pass fish for at least 90% of the stream flows for a given season when fish are likely to pass. In other words the culvert should pose a fish passage problem only 10% of the time. In the guidelines, the following equation is given to relate this 90% flow to a two year peak flow:

$$Q10 = 0.18 * Q2 + 36$$ (For two year peak streamflows greater than 44 cfs)

Where: Q10 - The 90% exceedance flow where fish passage is a problem only 10% of the time

Q2 - The two year peak flow

In general, the two year peak flow is approximately 40-50% of the 50 year peak flow.

Channel Headcut and Regrade affects - Commentary from WDFW website

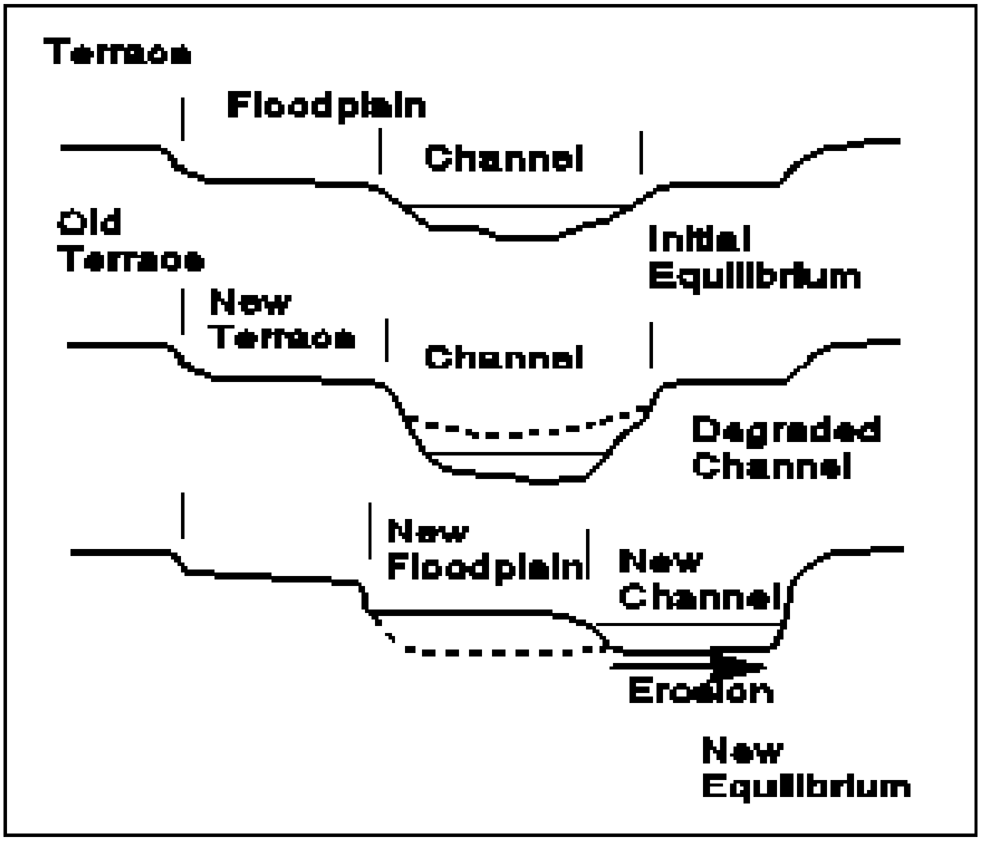

Figure 7. Evolution of Degrading Channel

Channel headcut and regrade factors

A channel degrades when its bed scours and lowers over time either by natural process, exacerbated by watershed changes and/or lowering or removal of a control point in the channel. Channel headcut is the process of the upstream channel being lowered locally by scour in response to a replacement culvert being larger and/or set at a lower elevation. The headcut itself is a steep section of channel the erodes and, in that process, migrates upstream eventually lowering the entire channel for some distance. The same situation occurs if an undersized culvert is replaced with a larger one since the flood hydraulic profile is lowered by the reduction of the culvert constriction. Habitat impacts of channel degradation can be extensive and prolonged. They can be managed by reconstruction of the upstream channel either into a natural grade or steepened with hydraulic controls.

A reach degrades when there is a net lowering of the bed elevation. During the initial stages of degradation, a channel will becomes deeper and narrower, the relative height of the banks increases and the banks steepened. Loss of floodplain connection and concentration of flows within the channel exacerbate the degrading process. Reinforcement of root structure is decreased. Banks fail and the channel then widens over a period of time erosion until the channel reestablishes its natural slope, floodplain, and bankfull width and depth at the lower elevation. This process is shown graphically in Figure 7.

A variety of habitat impacts may occur during the degrading process. The most obvious is the erosion of the bed and habitat associated with it. The remaining bed is narrow, confined, and usually consists of a steep run with little diversity because the channel has no floodplain for relief from high flows. Bed and bank erosion introduce additional sediment. A degrading channel may lower the ground water table to below the root zone dewatering the bank and adjacent wetlands or side channels and affecting the survival of vegetation. This in turn may trigger secondary causes of erosion such as reduced vegetative structure.

Channels that are most vulnerable to habitat impacts of a degrading channel are those that have functional flood plains, habitat diversity, and/or adjacent side channels or wetlands and channels with banks that are already over steepened and on the verge of failure.

The following aspects should be part of the consideration of a channel regrade. Detail information on some of these issues may be required if the expected degrade is greater than about a foot.

1. Extent of regrade
2. Condition of upstream channel and banks
3. Habitat impacts to upstream channel from incision
4. Habitat impacts to downstream channel from sediment release
5. Incision history of downstream channel and the value of culvert as nick point
6. Decrease in culvert and channel capacity due to initial slug of bed material
7. Risk to upstream utilities and structures
8. Potential for fish passage barriers created within the degraded channel
9. Access.

Extent of regrade

The extent of regrade depends on the upstream bed slope and composition, sediment supply to and through the reach and the presence of debris in the channel. The length of regrade in may be less in cobble bedded streams than in shallow gradient sand bedded streams. Sandy beds often regrade uniformly without increasing slope until they hit the next nick point of debris or larger bed material.

A channel rich in bed material transport will be affected less and heal more rapidly than channels with limited bed material transport. Structures and utilities must be identified in the upstream bed that might be exposed or affected by the degrade. Culverts should be designed to transport sediment at the same rate as the adjacent channel.

The upstream channel slope and bed composition influence sediment supply to maintain the bed inside a culvert and is especially important in culverts that are dependent on the recruitment of that material.

Condition of upstream channel and banks

Two extremes of upstream bed condition are an incised channel and an aggraded channel created by the backwater of an undersized culvert. The incised channel and banks will be further affected by a channel degrade as described above. Any floodplain function will be further reduced and in stream habitat will be subjected to increased velocities and less diversity. Banks will become less stable by the degrading channel undermining them. An aggraded channel on the other hand can be stabilized and returned to its natural condition by allowing some degrade through it

Habitat impacts to upstream channel from incision

The channel of a degrading stream is narrow, confined, and usually consists of a steep run with little diversity or stability because the channel has no floodplain for relief from high flows. Eventually the channel may evolve back into its initial configuration but there may be substantial bank erosion and habitat instability in the meantime.

Habitat impacts to downstream channel from sediment release

Habitat impacts to downstream channel and habitats from sediment release.

Aquatic habitats downstream will also be at risk from the increased sediment released. In addition to the volume of material, it will be released at moderate flows until the upstream channel and banks have stabilized.

Incision history of downstream channel and the value of culvert as nick point

Channel degrading can be a natural process or it can be caused or accelerated by watershed land use practices. A culvert can provide a valuable function as a nick point that prevents a downstream degrade from progressing further upstream; lowering the culvert will likely allow the degrading process to continue upstream. Compare channel conditions upstream and downstream. If the downstream channel is degraded (narrow, incised, over steepened bank, without floodplain function) and the upstream channel is the opposite, consider maintaining the culvert elevation as a nick point while designing it for fish passage.

Decrease in culvert and channel capacity due to initial slug of bed material

Allowing an uncontrolled headcut upstream of a culvert may result in a slug of material mobilized during a single flow event. As this material moves through the culvert and the downstream channel it can reduce the flood capacity of both. Less degrade should be allowed where the culvert has significant but even a short term risk of plugging by a mixture of a slug of bed material and debris. Similar limitations should be considered where structures downstream are at risk from a loss of channel capacity or where banks are at risk of erosion. Without further technical analysis of degrade implications and culvert flood capacity, a culvert inlet should be depressed no more than 40% of its rise or diameter. Relevant factors to consider include design flow probabilities, bank height, culvert dimensions, substrate material, and allowable headwater depth.

Proximity of upstream utilities and structures

If a regrade is allowed to continue upstream it can jeopardize structures in the channel or on the banks. Be aware of buried utilities under the channel and the risk of increased bank erosion on structures on or near the channel banks.

Potential for fish passage barriers created within the degraded channel

The last headcut consideration is the potential for fish passage barriers to be created within the degraded channel. Buried logs and compacted till or clay sills are commonly exposed by channel headcuts. As the channel headcuts to these features, they become the new nick point and fish passage barrier. Adding to the difficulty, these problems may occur where they are not visible from the project

1.ASCI Handbook of Steel Drainage and Highway Construction Products, 1994 edition, page 281.

2.AASHTO Standard Specifications for Highway Bridges, the 16th edition, 1997, Section 12.1.6.3, Arch Design.

3.Design of Riprap Revetment, Report no FHWA -IP-89-016, HEC 11, March l989,page 38.