CROSSINGS

LANDOWNERS HANDBOOK 2017

1 Understand your river reach

Understand the big picture of Front Range watershed and river processes and how they impact your river reach and crossing.

2 Assess your site

Learn how to assess the resilience of your current crossing, identify crossing issues, and understand terminology for discussing crossing design.

3 The Crossing Toolbox

Which crossing is right for me? Learn about the crossing design options, important considerations, where to locate your crossing, alternative solutions and ways to protect your crossing.

4 Working with an Engineer

Learn what services and value water resource engineers provide, and be prepared with a conversation checklist.

5 Navigating Permitting

What type of permits do I need? Who do I contact? And where can I find support for my project?

6 Constructing your Crossing

Know the steps from design to permitting to construction, what to expect during the construction process, and what to do to maintain and inspect your crossing.

Handbook Overview

The **Resilient Crossings Landowner Handbook** is designed to inform private landowners about resilient crossing considerations and construction techniques in the context of living along a Front Range river. The concepts presented here can be broadly applied to sites in the canyons, foothills and plains and beyond. It provides information to begin the design process, material to facilitate your conversation with supporting engineers and permitting agencies, and resources to help you move more confidently towards making informed decisions for your crossing project.

Note: This handbook should be only used to inform landowners about design and construction techniques, and is not a substitute for design consultation with a Professionally Licensed Engineer.

Handbook Background

In September 2013, portions of the Colorado Front Range foothills experienced unusually intense rainfall. The area received the equivalent of a year's worth of rainfall in 36 hours. Flooding was widespread along the Front Range, and in many locations rivers exceeded historical flood magnitudes.

The 2013 storm event was transformative to river valley communities of affected Front Range watersheds. Many private residential properties became inaccessible during and post-flood, as private roads and bridges were destroyed. Record stream flows in upland drainages caused heavy erosion and transported large debris (rocks, trees, and trash) downstream, fundamentally altering the physical character of rivers in this region.

After the flood, many emergency crossings were installed for property access, and other crossings were reinstalled identical to pre-flood conditions. In these instances, crossings remained as vulnerable, if not more vulnerable to future flood damage. Landowners lacked a comprehensive resource that illustrated the crossing design process, permitting, and construction considerations. This handbook is intended to fill that void by providing a resource for landowners that illustrates the crossing design and installation process, to be used now or in the future.

The purpose of the **Resilient Crossings Landowner Handbook** is to provide an educational resource that empowers private landowners to understand their properties within the context of the larger watershed and river reach scale. It informs the design of resilient crossing structures that meet landowner needs while accommodating flood flows, in-channel debris transport, and supporting natural aquatic and riparian biological communities. This manual is intended as an overview guide for landowners; however, it is not meant to substitute working with a professional engineer who understands geomorphology and stream hydraulics for survey, design, and construction oversight.

*A **resilient crossing** allows for the stream to function in a near-natural condition as it passes through the crossing, and is therefore less susceptible to structural failure and repair, and more beneficial to fish and wildlife living along the riverine corridor.*

Photo by: AP Photo/Colorado Heli-Ops, Dennis Pierce

Watershed Processes

What are they and why do they matter?

Watersheds are comprised of streams and the surrounding landscape that contributes surface water to them. Within a watershed, natural and human processes are strongly interconnected, requiring that human-made elements be capable of accommodating natural processes and hazards (wildfires, floods, debris flows, etc.). The health of the riverine system is a function of watershed connectivity, from upstream to downstream and into the adjacent floodplain.

Watershed processes include: sediment erosion, transport and deposition; riparian vegetation establishment and maturity; natural disturbances occurrence and propagation (such as floods, fires, and debris flows); and the natural dispersal and interaction of fish and wildlife. A healthy, functional watershed contains and allows these processes to occur to the maximum extent allowable, in conjunction with meeting the needs of local human residents.

The Role of Floods

Productive and destructive processes.

Floods are naturally occurring events and are vital for transporting the energy and materials (water, soil, nutrients) that maintain riparian ecosystems and downstream floodplains. Floods are created by precipitation and snowmelt, and their intensity depends upon land-use, geology, and stream conditions. Living along rivers requires an understanding and appreciation for flood cycles to make informed management decisions for your riverside property, and to be prepared for fire and flood events. Buildings, roadway crossings, and other infrastructure should be properly located, designed to consider the river's patterns and processes, and built to withstand floods of a known magnitude. Working with the river and allowing it room to adjust within its floodplain is a strategic consideration when designing crossing infrastructure.

Downstream Risks

Of fire and floods.

Many factors impact the level of risk to a crossing. Often the most significant

Photo by: Milehightraveler

Photo by: Milehightraveler

risk factor is the interaction between fire, climate, and slope. Over a century of suppressing and preventing fires has left greater amounts of downed trees, branches, and other 'fuel' available for fires to spread across the forest floor. This has increased the likelihood of more intense, frequent, and larger forest fires across the Front Range. In the steep, confined canyons and foothills, an upslope fire reduces a watershed's ability to store and slow rainwater as a result of exposed soils and destabilized slopes. Then, when a high intensity rainstorm occurs—which is expected to increase in frequency in the coming years—it creates flood events that carry large debris loads. Debris loads mainly occur in the form of sediment, logs, and boulders, and create an increased risk to infrastructure—such as crossings—for those living in the canyons or downstream.

Disaster Preparedness

What's your risk comfort level?

The risk and inconvenience of losing access or egress from private property varies by person and family. Frequency of access, physical ability, and preparedness to shelter-in-place for an unspecified time period may determine the amount of risk a landowner is comfortable with. For year-round home dwellers, those in poor health, or those with elderly or

Photo by: defense.gov

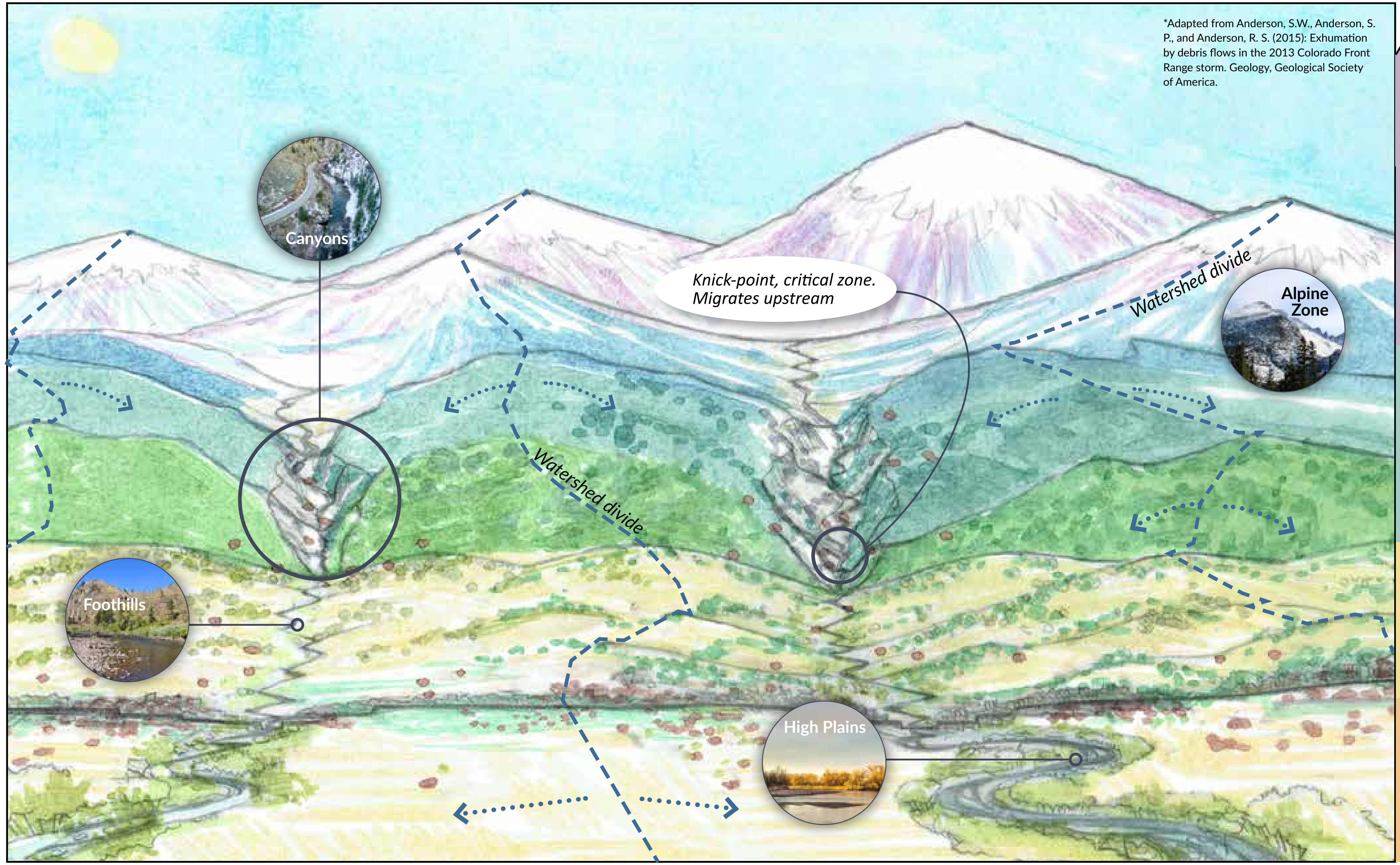
infant family members, the need to be able to reach supplies or care may be more urgent. These circumstances may determine how much increased cost that a landowner is willing to spend. Higher costs are typically correlated with a crossing's increased ability to withstand a larger flood event.

Being a Good Neighbor

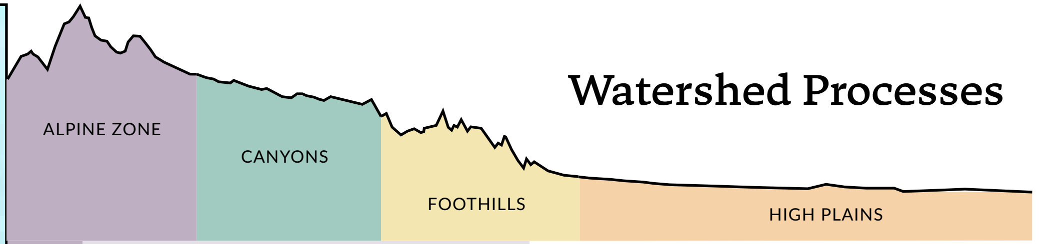
Upstream and Downstream

Road crossings are introduced impediments in the river landscape and can create unnatural changes in the river and prevent flood flows from spreading out onto their floodplains. Multiple crossings in succession can create insurmountable obstacles for fish and wildlife who rely on the river corridor. The ideal crossing is built for performance and cost-effectiveness while providing minimal interruption to the river that passes through or underneath it. In an ideal setting, a migrating fish could move along the river corridor without realizing it's traversed a crossing. Designing for stream corridor continuity through multiple crossings maintains a viable river system for fish and wildlife, while improving the likelihood that infrastructure can withstand flood events.

Photo by: ML Haring



*Adapted from Anderson, S.W., Anderson, S. P., and Anderson, R. S. (2015): Exhumation by debris flows in the 2013 Colorado Front Range storm. Geology, Geological Society of America.



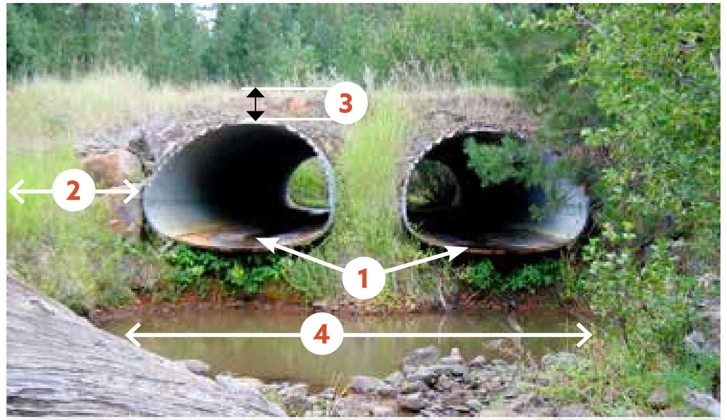
Watershed Processes

ALPINE ZONE	The headwater, or Alpine zone, often has the steepest gradient. Streams here are relatively narrow and flow swiftly from glacier melt or groundwater. Considered a 'source' zone, sediment erodes from adjacent slopes and streambanks and moves downstream.
CANYONS	Steep channel slopes continue through the narrow V-shaped canyons where floodplain space is very limited. Sediment and other material is both sourced from streambanks and hillslopes and transferred through this zone. Rapids and step-pool sequences are common here.
FOOTHILLS	Valleys widen and stream slope becomes more gradual through the Foothills. Step-pools continue and but riffles and pools are more prevalent. Debris, such as logs and sediments, are generally transferred through this reach.
HIGH PLAINS	Channel slope flattens and valley width expands dramatically. Upslope sediments are deposited and stream energy slows. Stream channels move laterally and gentle riffle-pool sequences, runs, and glides are prevalent.

The rugged appearance of the Front Range landscape we see today was formed by complex interactions between the uplift of mountains and water-driven erosion. Between 65 million and 10 million years ago, the hard, crystalline rocks of the Front Range peaks were thrust upward, leaving behind the relatively flat and smooth sedimentary rocks of the High Plains. As rivers flowed down the Front Range's steep, narrow canyons onto the open, flat High Plains, they crossed the sharp contrast between harder to softer rock. Over time, at this transition point, the force of the water created steps or 'knickpoints' along the streambed. As water continued to flow over these knickpoints, the streams continued to chip away at them, slowly moving these knickpoints further and further upstream. This process, repeated over millions of years, lowered the streambeds of the Front Range in relation to the landscape around them, and created the steep, confined canyons we see today.*

Millions of years later, these interactions between rivers, geology, and climate have split the Front Range into four unique zones - the Alpine Zone, the Canyons, the Foothills, and the High Plains. Today, each zone shares similar river patterns, processes, plants, fish and wildlife.

Identify Crossing Issues



Crossing 'issues' inhibit stream processes and can increase the risk of failure during flood events or under heavy vehicular loads.

1 Two openings rather than one large opening, limits debris, flow, and sediment passage.

2 Fill material in floodprone width limits debris and flood passage.

3 Limited cover compromises the ability of culverts to support vehicles.

4 Upstream pooling of water increases the risk of the stream overtopping your crossing.

5 Incision and head-cutting (temporarily stabilized by boulder step) poses risk of undermining structure and obstructing fish/ aquatic organism passage.

6 Flat top of boulder step increases the risk of failure and stream incision.

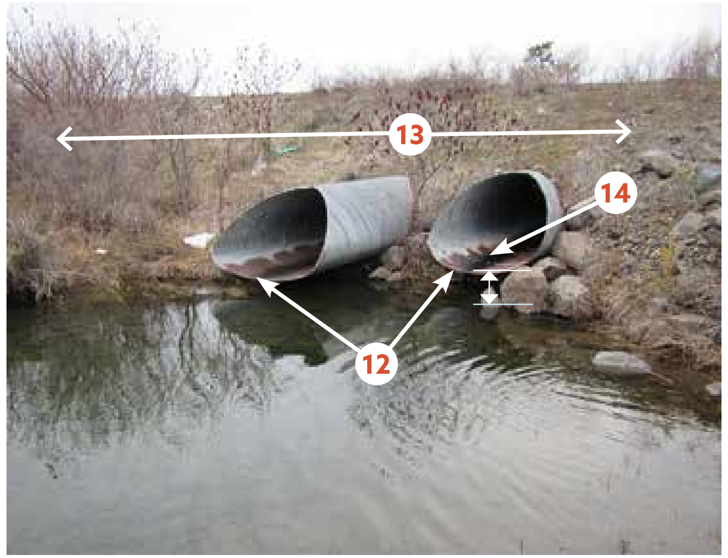
7 Absence of low-flow path creates a fish passage barrier.

8 Limited depth of cover between roadway and top of culvert compromises the culvert's ability to support vehicles.

9 Lack of 'bedding' (supporting backfill) to stabilize hydraulics and vehicle traffic.

10 Crossing misaligned with channel flow path which limits stream continuity and may cause erosion.

11 Deposition created from the culvert's impoundment.



12 Perched culverts create a barrier to fish and other aquatic organisms and suggests that the channel is incising.

13 Fill material in the floodplain blocks the passage of flood water, debris, and sediment.

14 Exposed metal increases flow velocity & scour potential.

Terms & Definitions

impoundment: typically an area where slowed, widened and deepened water and/or sediment deposition is caused by a downstream barrier in the stream (e.g. dam, culvert)

sediment deposition **-** when materials, such as sand and gravel, have fallen out of the water column, and collected in an area. Usually this is observed on the inside of river bends and in impounded areas.

incision: the process of channel lowering (a.k.a. head-cutting, knickpoint migration). This can be localized (e.g. headcuts) or more regional (e.g. through a 'reach' of stream).

fish / aquatic organism barrier: an obstruction preventing the movement of fish or other aquatic organisms upstream or downstream.

debris jams: a buildup of materials (such as wood, stones, or sediment) transported by the stream.

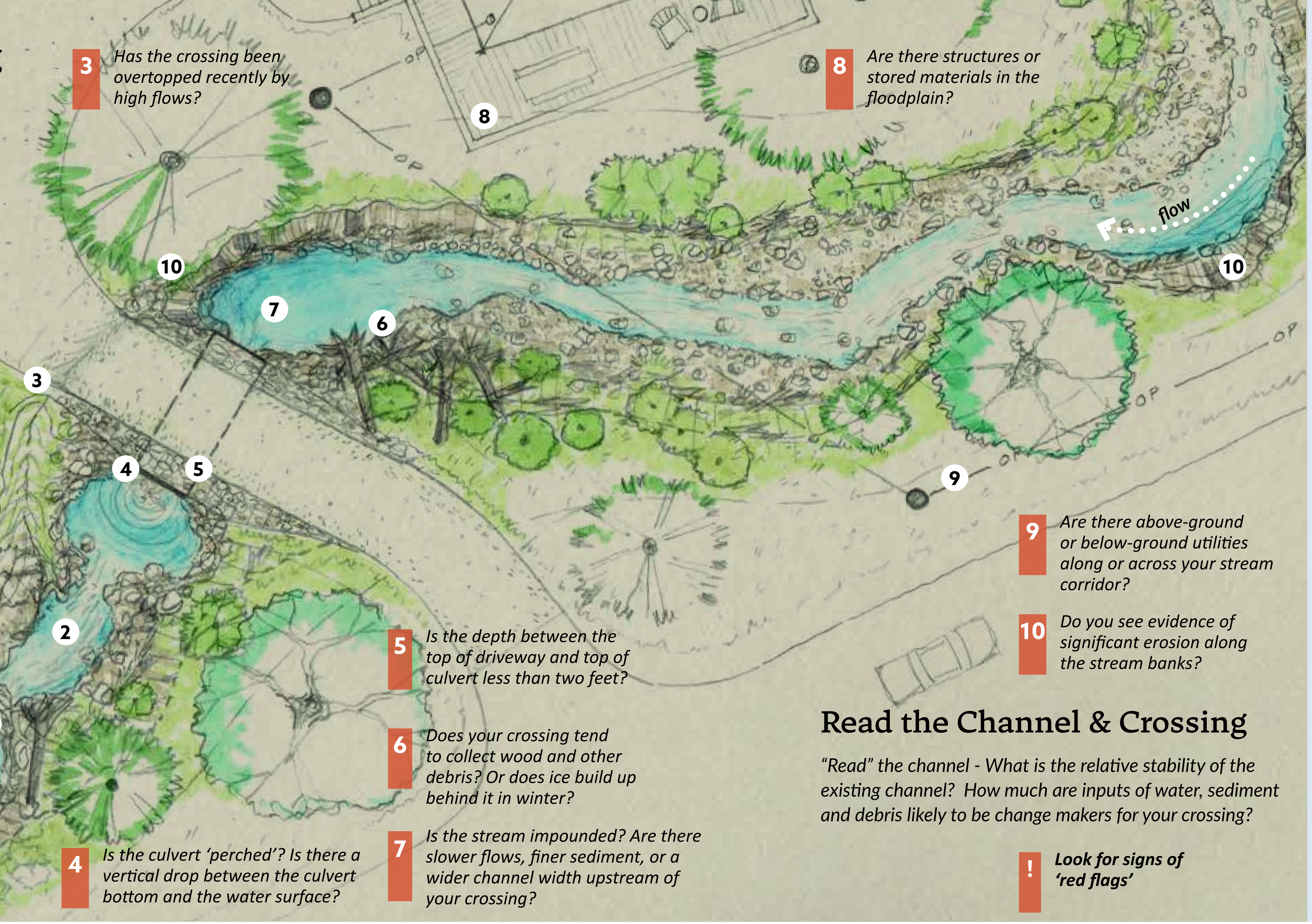
reach: a similar length of channel or river that shares common characteristics such as geology, slope, access to floodplain, similarity in channel patterns, and/or landuse.

perched culvert: a term used to describe when a culvert bottom is vertically higher than the streambed.

scour / scour hole: the result of erosive hydraulic forces acting around or below structures, such as crossings, in the flow path. This typically creates a "hole" around structures in the channel.

Assessing Your Crossing

Now that you have a better understanding of the big-picture watershed processes, it's time to study your specific crossing area with a site investigation. Take a look at both the crossing location as well as the crossing's "geomorphic reach" (the area of the channel that has similar appearance and patterns upstream and downstream from the crossing.) These reaches are likely shorter in the canyons and foothill where the channel is less likely to migrate, versus longer in the plains where the streambed and banks are more likely to move side-to-side.



1 *Are there signs of active headcutting or significant drops in the channel bed?*

2 *Does the channel steepen or flatten significantly upstream or downstream of your crossing?*

3 *Has the crossing been overtopped recently by high flows?*

4 *Is the culvert 'perched'? Is there a vertical drop between the culvert bottom and the water surface?*

5 *Is the depth between the top of driveway and top of culvert less than two feet?*

6 *Does your crossing tend to collect wood and other debris? Or does ice build up behind it in winter?*

7 *Is the stream impounded? Are there slower flows, finer sediment, or a wider channel width upstream of your crossing?*

8 *Are there structures or stored materials in the floodplain?*

9 *Are there above-ground or below-ground utilities along or across your stream corridor?*

10 *Do you see evidence of significant erosion along the stream banks?*

Read the Channel & Crossing

"Read" the channel - What is the relative stability of the existing channel? How much are inputs of water, sediment and debris likely to be change makers for your crossing?

! ***Look for signs of 'red flags'***

Does Your Crossing...

✓ **Readily pass floodwaters?**

Does your crossing pass floodwaters or cause water to backup? Do flood flows overtop the crossing? Look for: flood debris (logs, sticks) around crossing; sands/silts on the roadway; holes or paths created by floodwaters going over or around the crossing.

✓ **Pass sediments and debris through the structure?**

Is sediment size significantly different upstream to downstream of the crossing? For example, are there large cobbles upstream and only sands downstream? Are there 'jams' of logs or leaf litter that appear stuck upstream of the crossing?

✓ **Maintain a smooth channel slope transition through the crossing?**

Is there a significant change in steepness from upstream to downstream of the crossing? Is water moving more swiftly upstream or downstream? Are there noticeable 'steps' (headcuts) in the channel? Where?

✓ **Maintain water velocity through the crossing?**

Does your crossing smoothly pass stream flows? Does water noticeably speed up or slow down as it enters or exits the crossing? Does the upstream side of the crossing appear to block streamflow and create a 'pool?'

✓ **Allow the channel to laterally migrate (move side-to-side)?**

Is your crossing on the outside of a river bend, or on a relatively straight reach? Is there evidence of erosion on the streambank, such as undercutting or bank slumping?

✓ **Have vegetation along the stream banks?**

Is vegetation present upstream & downstream of your crossing? What is the dominant plant form: trees, shrubs, grasses? Is the vegetation dense or sparse; young or mature?

Anatomy of a Resilient Crossing

Resilient crossings are those that can literally weather the storm. Primarily, they provide a large enough opening to allow the free movement of water and debris transported by the river channel during storm events. They do not disrupt the natural flow of water, sediment (from sand to boulders) and organisms (from fish to mammals) along the stream corridor. In general, the less a crossing structure disrupts river processes, the less likely the river will cause the crossing to fail.

Resilient Crossings Can:

- ✓ Readily pass floodwaters (to a specified design flow.)
- ✓ Pass sediments and debris through the structure.
- ✓ Maintain a smooth channel slope transition through the crossing.
- ✓ Maintain water velocity through the crossing.
- ✓ Maintain a bankfull channel plus space for overbank flows (recommended 2' on either side)
- ✓ Maintain a consistent substrate through the bottom of the crossing.
- ✓ Avoid areas where the channel may laterally migrate (move side-to-side)
- ✓ Allow for development of vegetation along the stream channel banks.

Useful Terminology

bankfull: the width or depth associated with the elevation where channel flow begins to spill onto the floodplain.

ordinary high water (OHW): an elevation along the stream channel where water is typically at or below. While this term has a number of different definitions, here it is defined as the line defining persistent woody vegetation.

floodprone width: the flat-lying area, or valley bottom, adjacent to the stream channel that conveys water at relatively regular (e.g. 10-year) flood events.

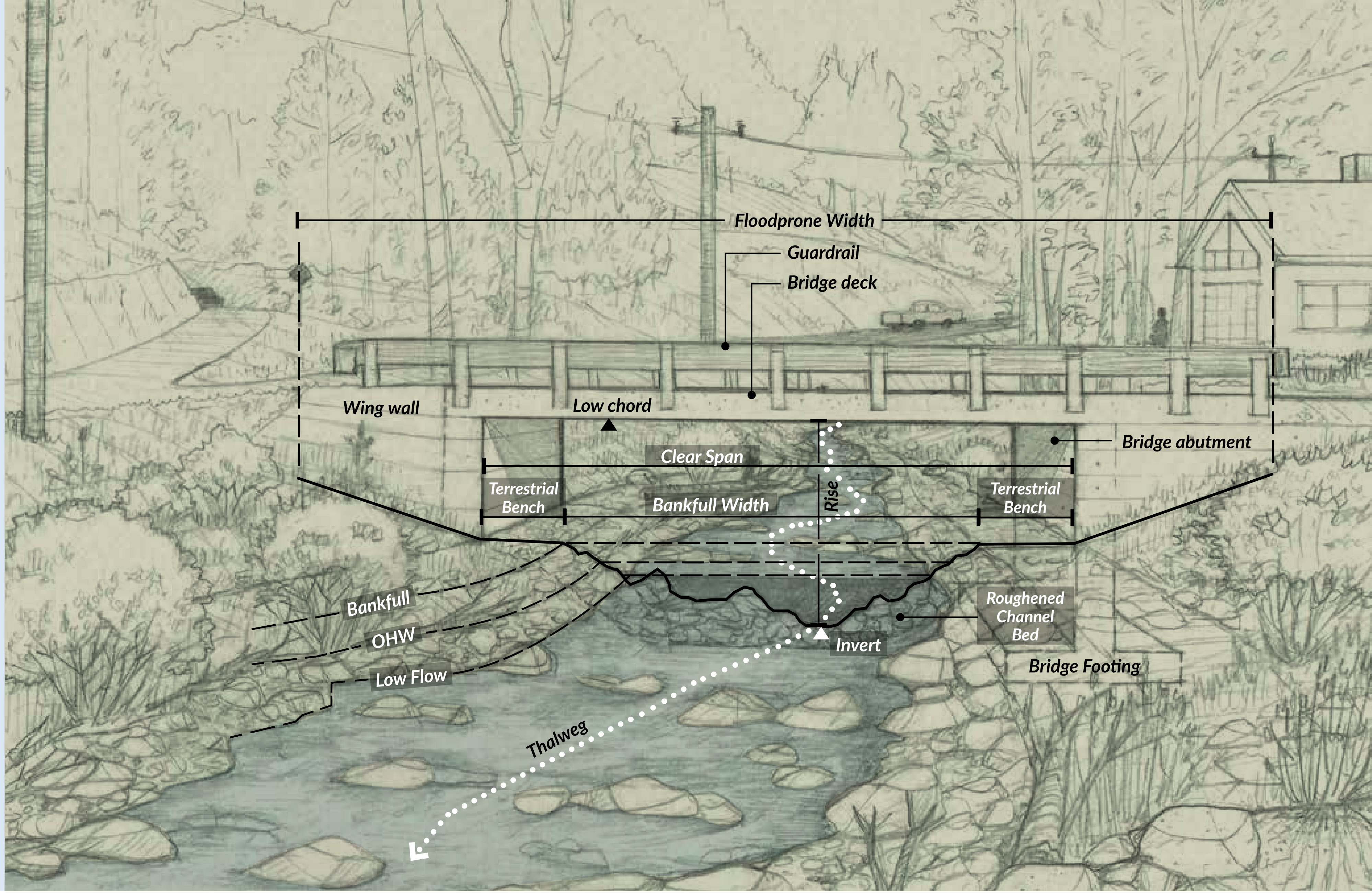
thalweg: a line that connects the deepest, or lowest points, along the streambed.

channel: the portion of water movement most often below the elevation of "ordinary high water".

clear span: the widest point between the inside surfaces of the sidewalls/abutments (bridge, box culvert) or maximum width (above ground) of a pipe arch culvert.

low chord: the lowest point or elevation of the bottom of a bridge structure.

abutment: the end 'walls' of a bridge structure that supports the bridge deck.



Crossings Toolbox

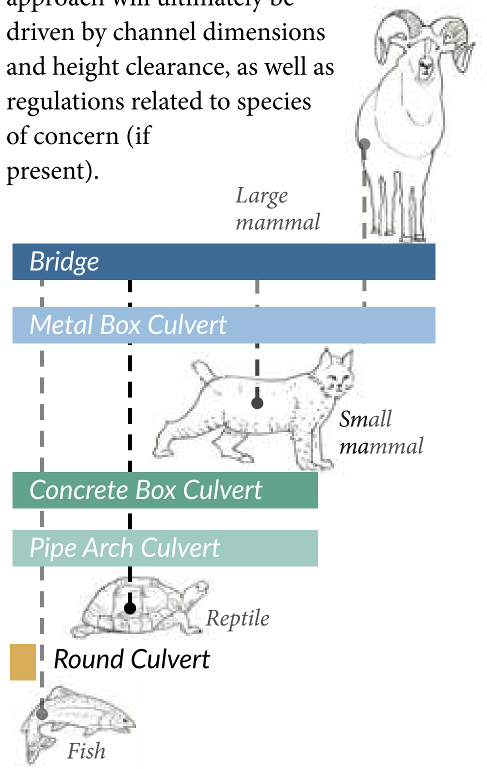
The Crossings Toolbox is intended to familiarize you with the 'anatomy' of a resilient crossing, its components and terminology, and provide a framework for comparing crossing options and considerations for your property and personal needs. The handbook presents four types of crossing solutions, as well as considerations for crossing placement, and a resilient approach to crossing protection known as Roughened Channel Design.

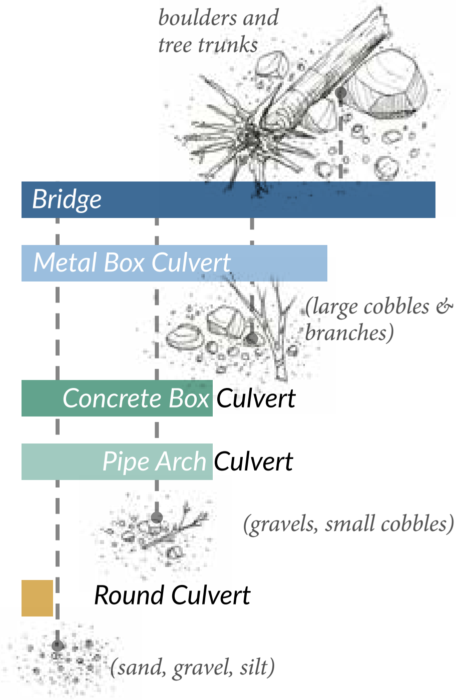
Depending upon your property's site conditions, there can be multiple appropriate crossing options or just one. This depends on a range of factors including, but not limited to: channel slope, channel width, local stream energy, local topography, access needs, county permit requirements, and your ability to shelter in place should your crossing become unsafe during/following high water.

It is important to work with an engineer to understand which potential crossing options may work for you and your property. Once you choose a preferred option, you can decide which flood event level you want your crossing to withstand. These options range from the minimum required by your local County to much larger (> the 100-year flood event). In general, increasing the size of your crossing increases it's ability to pass debris, fish and wildlife, and to withstand a flood event. Short-term higher design and construction costs can be weighed against the long term benefits of maintenance and repair or replacement.

Ecological Passage

Resilient crossings provide better connectivity of critical habitat for a variety of animals along stream corridors. These corridors act like highways for mammals, reptiles and fish. Designing a continuous streambed under the crossings allows passage of fish and aquatic organisms. Terrestrial benches are relatively flat shelves at the edges of the stream under a crossing that allows the passage of reptiles, small and large mammals. The design approach will ultimately be driven by channel dimensions and height clearance, as well as regulations related to species of concern (if present).



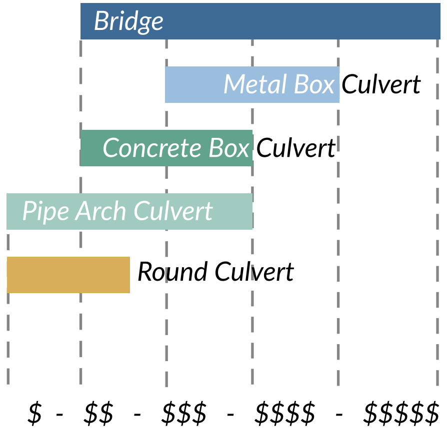


Debris Passage

A crossing's ability to pass debris (silt, sand, cobble, boulders, logs) ranges widely. It is important for the landowner and engineer to discuss the likely risks of debris flows relative to watershed position and recent landuse history (i.e. is the channel steep and downslope of a recent forest fire, or in a relatively flat and straight section of channel where debris flows are less likely?) It is essential to understand a crossing's relative risk to debris blockage, and evaluate the potential consequences of these risks - including crossing failure.

Cost vs. Risk

There are trade-offs specific to each location and landowner when weighing a crossing's cost to risk. Wider and typically more costly crossings allow increased passage of water, sediment and debris flow, and are generally more resilient to infrastructure failure. However, at some point the benefits have diminishing returns when compared to the likelihood of a storm or flood event occurring within the watershed. Evaluation of these costs vs. benefits and risks will be specific to each location and to each landowner's circumstances.

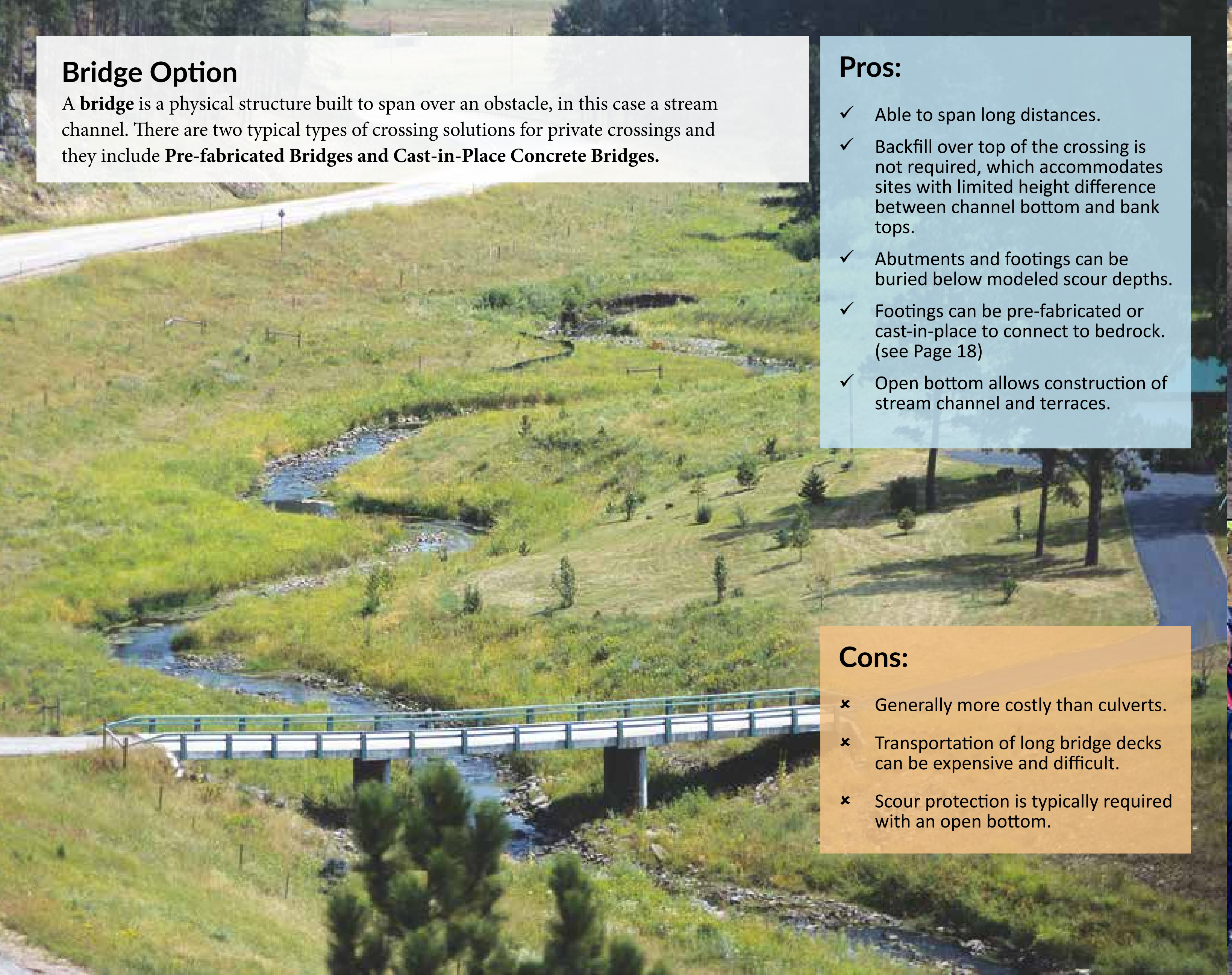


Crossing Placement

When locating your crossing, it's important to put your investment in an area that's less susceptible to dynamic changes in the river's shape and course. Understanding how rivers are likely to change over time will not only help you better protect your investment, but help promote the health of the river you live along and the fish and wildlife who depend upon it.

The following pages outline a crossing 'toolbox' and four crossing structure solutions:

- **Bridge (Pre-fab or Cast-in-Place)**
- **Metal Box Culvert**
- **Pipe Arch Culvert**
- **Concrete Box Culvert**



Bridge Option

A **bridge** is a physical structure built to span over an obstacle, in this case a stream channel. There are two typical types of crossing solutions for private crossings and they include **Pre-fabricated Bridges and Cast-in-Place Concrete Bridges.**

Pros:

- ✓ Able to span long distances.
- ✓ Backfill over top of the crossing is not required, which accommodates sites with limited height difference between channel bottom and bank tops.
- ✓ Abutments and footings can be buried below modeled scour depths.
- ✓ Footings can be pre-fabricated or cast-in-place to connect to bedrock. (see Page 18)
- ✓ Open bottom allows construction of stream channel and terraces.

Cons:

- × Generally more costly than culverts.
- × Transportation of long bridge decks can be expensive and difficult.
- × Scour protection is typically required with an open bottom.

Pre-fabricated Bridge

"Pre-fab" bridges are made of standard components fabricated at a manufacturer's facility in controlled conditions. Typically, these bridges have concrete footings that are stacked together on-site to the specified height with a metal or concrete bridge deck.

Pros:

- ✓ Typically rapidly available.
- ✓ Easier transportation of individual bridge modules.
- ✓ Shorter construction time than cast-in-place if lead times are sufficient.
- ✓ No on-site welding required.
- ✓ Standardized/inter-changeable components, replaceable parts, are often more cost-effective for smaller crossings.
- ✓ Can be customized for site-specific conditions.

Cons:

- × Lead times on prefabricated materials may cause delays.

Cast-in-Place Bridge

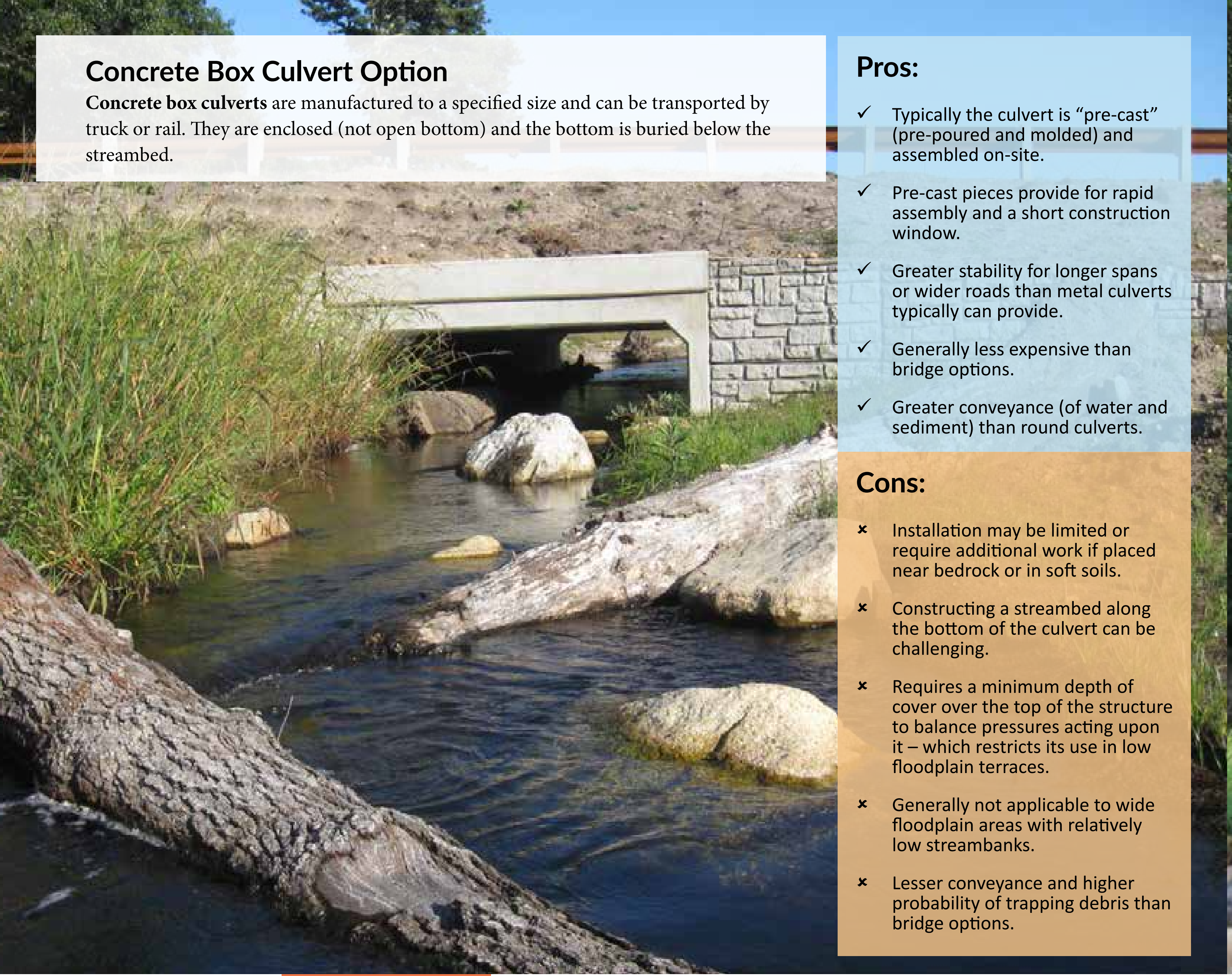
Cast-in-place bridges often include a pre-fabricated metal or concrete deck with custom designed, site-specific footings and abutments formed and the concrete poured on site. Concrete construction testing standards typically require a 28-day cure time and lab testing of poured samples to ensure the concrete meets the required strengths specified.

Pros:

- ✓ Provides custom fit for unique geometries.
- ✓ Ability to pour on-site if pre-fab pieces are on back-order or extended lead time.

Cons:

- × Cast-in-place concrete requires time and logistics including: concrete forms; field quality check, and a 28-day concrete cure time before crossing can be put into service.
- × Can be more expensive.



Concrete Box Culvert Option

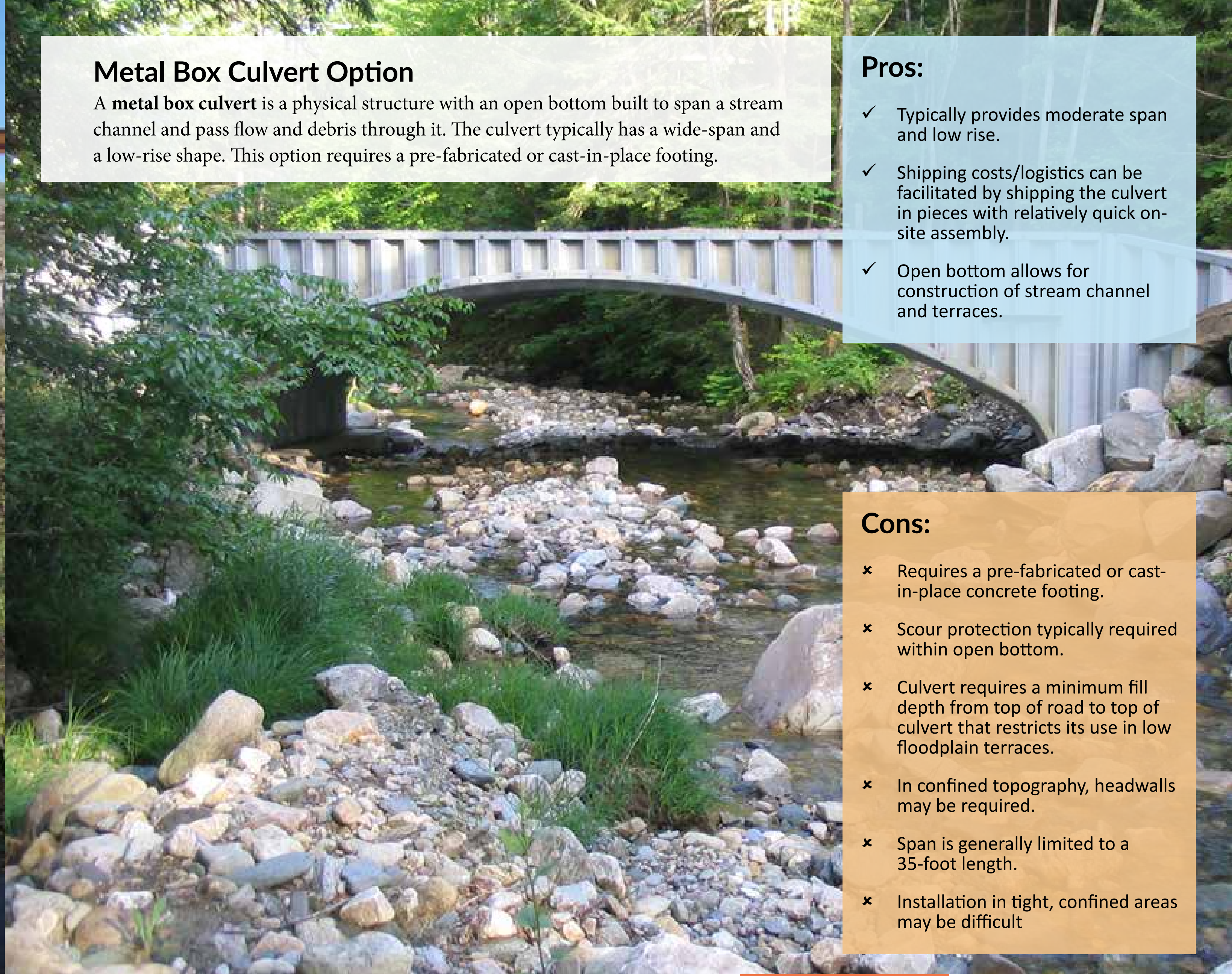
Concrete box culverts are manufactured to a specified size and can be transported by truck or rail. They are enclosed (not open bottom) and the bottom is buried below the streambed.

Pros:

- ✓ Typically the culvert is "pre-cast" (pre-poured and molded) and assembled on-site.
- ✓ Pre-cast pieces provide for rapid assembly and a short construction window.
- ✓ Greater stability for longer spans or wider roads than metal culverts typically can provide.
- ✓ Generally less expensive than bridge options.
- ✓ Greater conveyance (of water and sediment) than round culverts.

Cons:

- × Installation may be limited or require additional work if placed near bedrock or in soft soils.
- × Constructing a streambed along the bottom of the culvert can be challenging.
- × Requires a minimum depth of cover over the top of the structure to balance pressures acting upon it – which restricts its use in low floodplain terraces.
- × Generally not applicable to wide floodplain areas with relatively low streambanks.
- × Lesser conveyance and higher probability of trapping debris than bridge options.



Metal Box Culvert Option

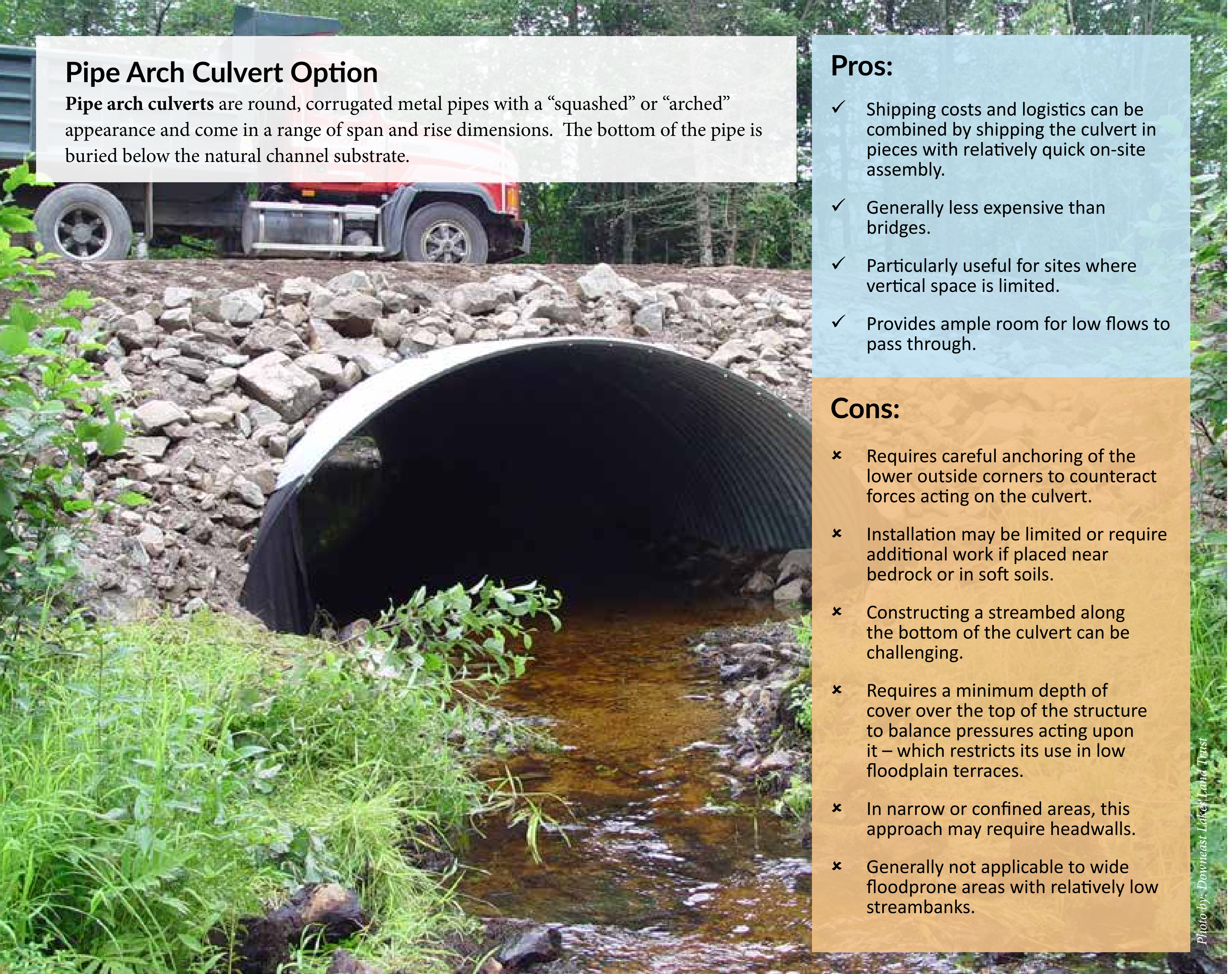
A **metal box culvert** is a physical structure with an open bottom built to span a stream channel and pass flow and debris through it. The culvert typically has a wide-span and a low-rise shape. This option requires a pre-fabricated or cast-in-place footing.

Pros:

- ✓ Typically provides moderate span and low rise.
- ✓ Shipping costs/logistics can be facilitated by shipping the culvert in pieces with relatively quick on-site assembly.
- ✓ Open bottom allows for construction of stream channel and terraces.

Cons:

- × Requires a pre-fabricated or cast-in-place concrete footing.
- × Scour protection typically required within open bottom.
- × Culvert requires a minimum fill depth from top of road to top of culvert that restricts its use in low floodplain terraces.
- × In confined topography, headwalls may be required.
- × Span is generally limited to a 35-foot length.
- × Installation in tight, confined areas may be difficult



Pipe Arch Culvert Option

Pipe arch culverts are round, corrugated metal pipes with a "squashed" or "arched" appearance and come in a range of span and rise dimensions. The bottom of the pipe is buried below the natural channel substrate.

Pros:

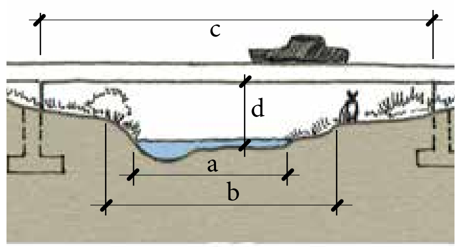
- ✓ Shipping costs and logistics can be combined by shipping the culvert in pieces with relatively quick on-site assembly.
- ✓ Generally less expensive than bridges.
- ✓ Particularly useful for sites where vertical space is limited.
- ✓ Provides ample room for low flows to pass through.

Cons:

- × Requires careful anchoring of the lower outside corners to counteract forces acting on the culvert.
- × Installation may be limited or require additional work if placed near bedrock or in soft soils.
- × Constructing a streambed along the bottom of the culvert can be challenging.
- × Requires a minimum depth of cover over the top of the structure to balance pressures acting upon it – which restricts its use in low floodplain terraces.
- × In narrow or confined areas, this approach may require headwalls.
- × Generally not applicable to wide floodprone areas with relatively low streambanks.

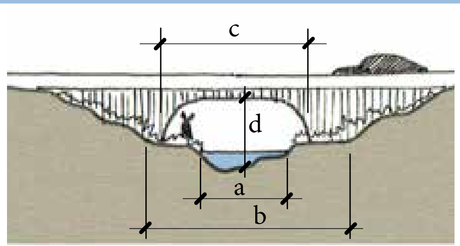
Photo by: Downeast Lakes Land Trust

Bridge



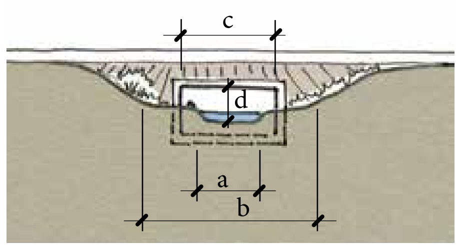
Approximate dimensions*	(feet)
OHW width (a)	1 - 46
Floodprone width (b)	2 - 100+
Clear span (c)	3 - 50+
Rise (d)	5 - >15

Metal Box Culvert



Approximate dimensions*	(feet)
OHW width (a)	4 -21
Floodprone width (b)	4 - 50
Clear span (c)	8 - 25
Rise (d)	8 - 10

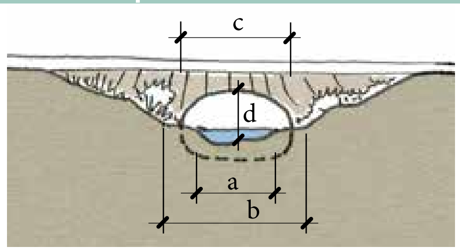
Concrete Box Culvert



Approximate dimensions*	(feet)
OHW width (a)	1 - 11
Floodprone width (b)	10 - 40
Clear span (c)	<15
Rise (d)	4 - 8

Pipe Arch Culvert

Photo by: Downeast Lakes Land Trust



OHW = Ordinary High Water

Approximate dimensions*	(feet)
OHW width (a)	2 - 16
Floodprone width (b)	4 - 30
Clear span (c)	6 - 20
Rise (d)	4 - 13

**Range of dimensions are approximate. Hired engineer will select the optimum size for your site.*

Locating your Crossing

Avoid placing your crossing at a river bend. Avoiding bends in the river allows the river to move side-to-side and places your crossing foundations away from potential erosion and scour by these natural lateral river forces.

Select the most naturally narrow area of your property. Rivers want to spread out on their floodplains. Limiting the river's connection to the floodplain can cause the river to locally speed up, eventually adding more erosive forces around the crossing.

Align your crossing perpendicular to the river's flow. Aligning the crossing perpendicular to the bankfull flow of the stream flow provides less interruption to water movement, helping minimize increased water velocities that over time can erode the crossing.

Select the most stable section of your river reach. Is there an area where the banks are closer together, where the channel bottom has large rocks, or exposed bedrock, or where the streambanks are lined with large trees? These may indicate stable banks.

Avoid areas of significant change in the river or valley. Transition areas, such as marked changes in the stream's gradient and planform (such as a single channel to braided) affect the river's velocity and channel elevation stability over time, possibly shortening the lifespan of your crossing.

Crossing Alternatives

Although your property may have had a traditional vehicular crossing in the past (bridge or culvert crossing), alternative solutions are available depending on your specific site conditions and your family's circumstances.

Pedestrian Bridge Option
If there is suitable parking on the road-side of your property, a pedestrian bridge crossing may be an appropriate crossing solution.

Shared Crossings
If your driveway is in close proximity to your upstream or downstream neighbor, it may be possible to design a shared crossing. This can help share significant costs associated with the design and construction of crossings and reduce impediments to the river.

Low-Flow Ford
If you live along an ephemeral stream—one that does not flow all year round—and the grade change between the roadway and stream channel is gradual, then a constructed low-flow ford may be a solution. This solution needs to be vetted with local county officials. Determine the frequency of flood risk with your engineer and floodplain manager, and evaluate your level of comfort in regards to limited access to and from your property in the event of a flood.

Roughened Channel

If the streambed through your crossing reach is vertically unstable, then your structure may need something to hold the streambed elevation steady. This will help minimize risk of scour and maximize your new crossing infrastructure investment. For a resilient solution to vertical streambed stability, the Roughened Channel approach can be utilized.

Roughened channels are continuous engineered ‘stone blankets’ along the streambed. They are designed to protect your structure from scour and provide a nearly natural streambed through your crossing reach.

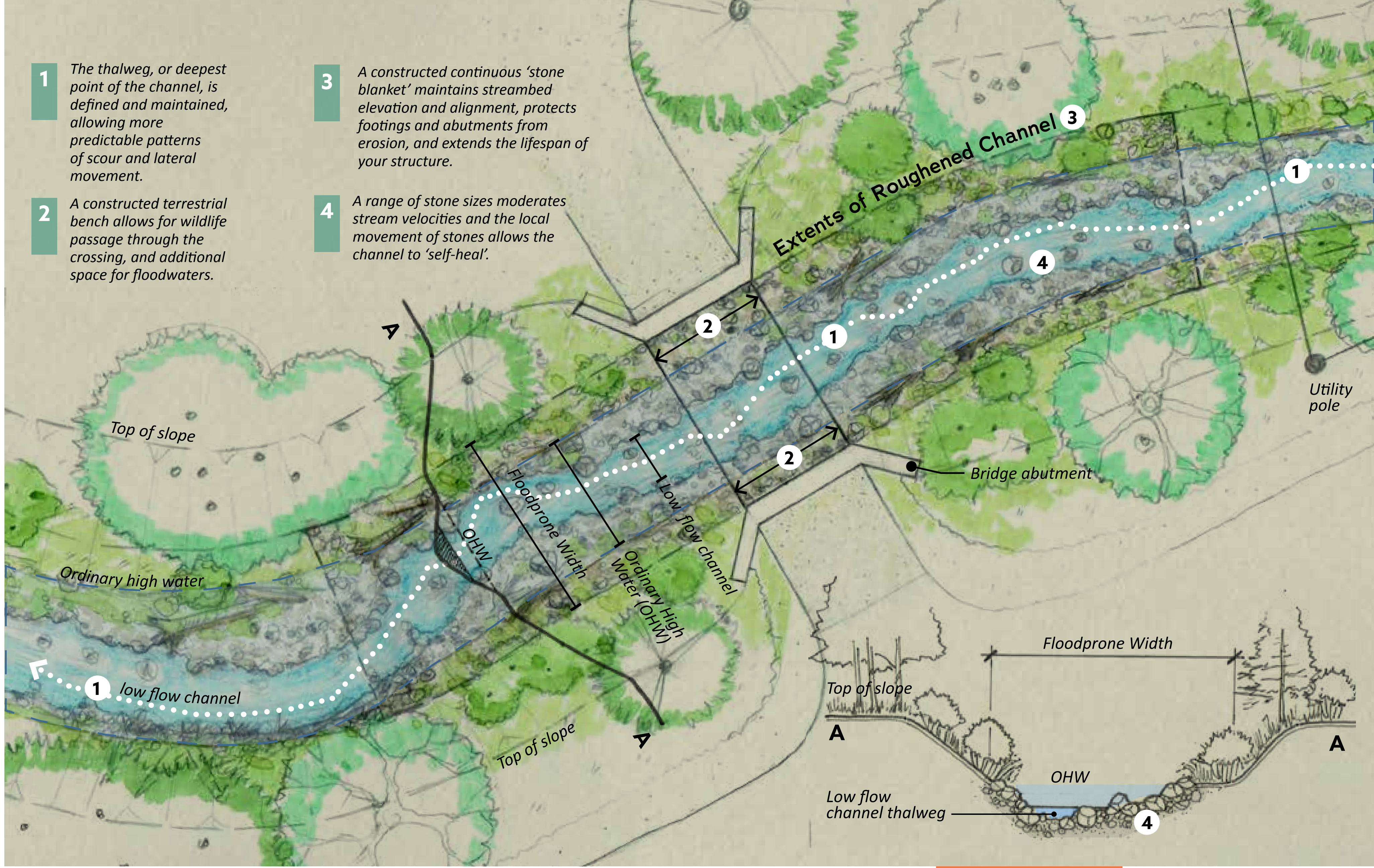
Engineered by careful analysis of streambed rock size and the hydraulics around your crossing, the foundation of a roughened channel is traditional riprap. This riprap is placed along the length of streambed your engineer determines to be unstable. From here, a gradation of river rock sizes (from gravels to boulders) is placed between these larger riprap stones. For a finishing touch, fine material is washed in to fill any remaining voids. This provides a natural aesthetic and improves channel function.

As a solution that is applied continuously along the streambed, the roughened channel is able to ‘self-heal’ by the natural movement of individual gravels and rocks filling in any localized ‘holes’ created by scour.


Before: culvert and channel


After: crossing and roughened channel installation


Placing roughened channel stone



Working with an Engineer

Once you've contacted your county and conducted your own onsite investigation of your crossing and reach, the next step is to hire a professional water resources engineer. The only way to effectively and safely determine which crossing is right for you, and get your crossing permitted, is to work with a professionally licensed engineer who understands stream geomorphology and hydraulics and can answer questions like:

"Is my channel vertically stable?"
"Is it laterally stable?"
"What are the likely sediment/debris inputs?"

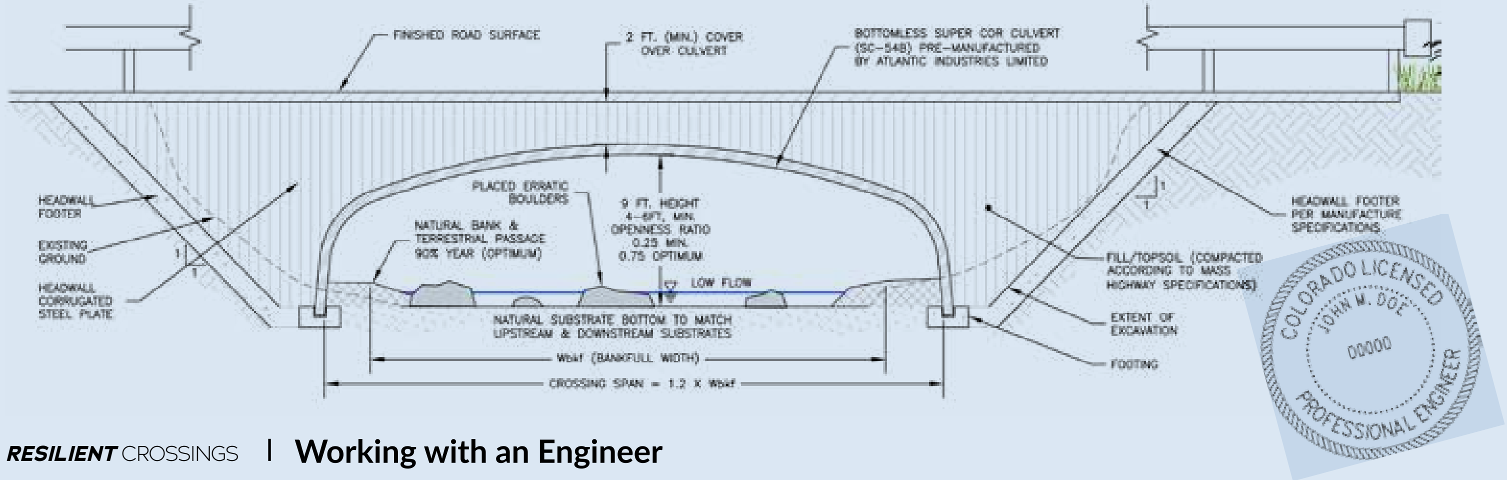
(Your County can help you find a list of qualified engineers.)

Your engineer will perform a more detailed site analysis, professional surveying, hydraulic modeling, and prepare feasible alternatives for crossing options, including cost estimates. Your crossing location may also require a geotechnical engineer to analyze soils and design the crossing foundations for stability, and a civil engineer if larger roads or utilities are nearby. Once you select a crossing solution, your engineer can aid in the permitting process, assist in hiring a contractor, and provide construction observation.

To build a crossing, an engineer will develop a set of construction documents that include drawings (scaled visual display of the crossing construction) and technical or performance specifications (written description of acceptable materials, and construction standards). These will be used to bid the project, hire a construction contractor, and provide the blueprint for the final constructed project.

Drawings will need to be stamped by a professional engineer, which indicates the designs have been prepared with due diligence (reasonable engineering analysis) to meet acceptable standards, and allow for safe use of your crossing up to a specified flood event.

Review the following checklists to inform your conversations with the engineer and construction contractor.



Design Conversation Checklist:

- ✓ What's included in the design package? An alternatives analysis that provides a range of solutions from minimum county requirements to a more resilient crossing? Is it a bid-ready set of drawings?
- ✓ Is construction oversight provided by the engineer? Is the engineer acting as a general contractor and will hire your construction contractor?
- ✓ Walk the site with your engineer and examine your crossing. Discuss your expectations for your crossing, such as: *"What kind of flood can I expect it to withstand?" What are my access and egress needs?"*
- ✓ Talk to your county's permitting representative ahead of time so you can come prepared with information on your local county requirements.
- ✓ Talk with your engineer about the expected lifetime and anticipated maintenance of your structure.
- ✓ Coordinate with local Fire Protection District for their needs.

Hiring a Contractor Checklist:

- ✓ Will your project be a design/build project where you pay a lump sum for engineered designs and construction? Or did your engineer prepare stamped drawings for bidding with contractors?
- ✓ Work with your County point of contact and engineer to prepare a list of qualified contractors with experience working in and around rivers and installing crossings. Once you have a list, contact the contractors to get at least 3 bids, or estimates on how much construction will cost.
- ✓ Carefully examine your bids – did they estimate a total project cost by completion? Did they estimate it based on time and materials? Look for an all-inclusive cost (materials, labor).

Preconstruction Meeting Checklist:

- ✓ Discuss your expectations for construction: how long will it take?
- ✓ Are there trees you want to be careful to save?
- ✓ Where is it okay for the contractor to 'stage construction" i.e. drive and park vehicles, and store equipment and materials? How much space do they need for staging?
- ✓ What work hours and days are acceptable?
- ✓ How will they handle stream diversion?
- ✓ What is the plan for controlling traffic into and around the site?
- ✓ Has the contractor located all utilities (above ground and below ground) in the work area?
- ✓ Who is responsible (liable) if something goes wrong?
- ✓ Who is documenting the construction?
- ✓ Who obtains all the permits and what is needed to close out a building permit?

Post Flood Inspection Checklist:

- ✓ Have new scour holes in the channel appeared around your crossing? Check around the foundations and footings.
- ✓ Is there a new significant slope change in the channel upstream or downstream of the crossing?
- ✓ Has a 'plug' of debris or sediment collected upstream of the crossing? Is there any damage to the footings or deck structure from debris impact?
- ✓ Has the channel moved from side-to-side (laterally) upstream or downstream of the crossing?
- ✓ Are there places in the road / driveway that appear soft or are remaining wet? Does it appear the channel has eroded the road or driveway surface?
- ✓ Are there new bare spots where vegetation has been washed away? Do the streambanks appear to be 'eroding'?

The Permitting Process

The permitting process has been developed to promote safe access and egress to private property, as well as support the safety of your downstream neighbors and safeguard shared natural resources. The design criteria regulated by the county are the minimum standards required to install a private crossing.

The permitting process varies by which county you live in. There is likely some information available on your county's website, but regulations and permit requirements often change, and certain requirements can be subject to interpretation by local staff.

This chart provides a general overview of the process, but it's important to note many of these steps occur concurrently, and due to changing requirements and personnel turnover, it is critically important to call your county representative and the US Army Corps of Engineers (USACE) early in the process to establish a point of contact to help guide you through the entire permitting, design, and construction process.

Also continue to check in with your design engineer that he/she is complying with county and USACE design requirements and collecting and generating the documentation (such as stamped design drawings, as-built documentation) that you will need to obtain your permits.

County Permitting

Roadway Access

- Does my drive connect to a STATE road? → *yes* → *CDOT Access Permit required*
- Does my drive connect to a COUNTY road? → *yes* → *County Access Permit required*
- Does my drive connect to a PRIVATE road? → *yes* → *Access Permit not required. Contact entity responsible for maintenance of road for permission and additional requirements*

Land Disturbance

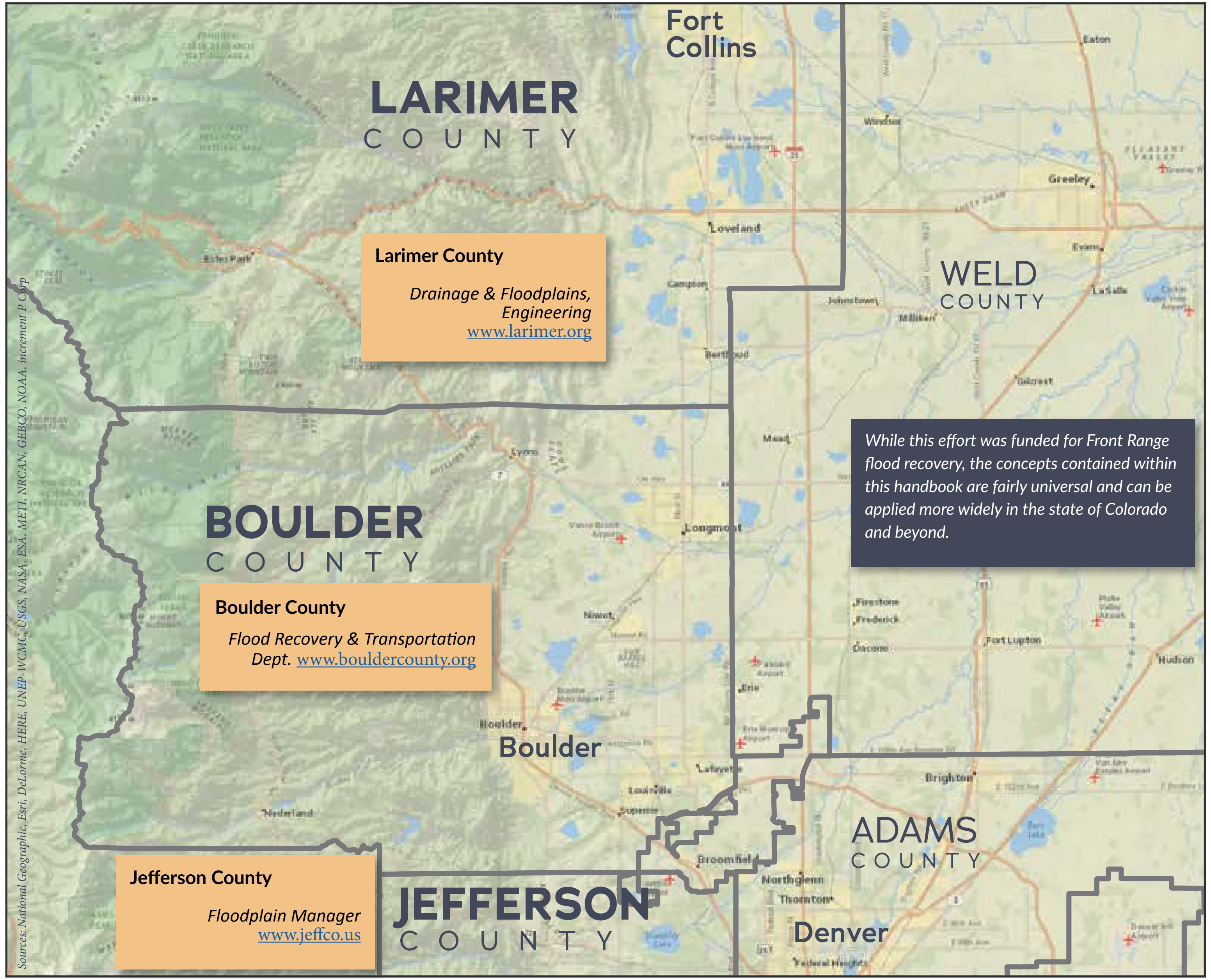
- Will construction require grading, clearing, or excavation? → *yes* → *Permit land disturbance through your County*

Floodplain Overlay District

- Is my crossing within a Floodplain Overlay District?
  - *yes* → *County-specific floodplain regulations apply*
  - **no** → *Floodplain development permit not required. Structure design criteria & stormwater drainage requirements still apply*

National USACE Permitting

- Replacing/installing any type of crossing while work in the waterway → *yes* → *Apply for US Army Corps of Engineers Nationwide Permit (NWP) (Typ. NWP 14)*



Begin Design

Here's an overview of the steps involved in taking your crossing project from idea to reality. On average, you can expect one year from your first call to the County through final construction inspection. Being well informed and staying in close contact with your County Point of Contact and Engineer will help keep your project on track and ensure it meets your expectations.

Contact your County

Check in first with your county to establish a Point of Contact. They can help you effectively navigate the process from asessment to design to permitting and construction and provide useful tips and guidance.

Assess Your Crossing

Identify your location in the watershed and local reach and site specific crossing issues. How is your current crossing functioning? Is it in a good location?

Hire an Engineer & Explore design options

Hire an Engineer to perform hydraulic analysis and understand potential crossing solutions. Look at all the potential solutions that meet permit requirements and decide what's the best solution for you. Your Engineer will prepare construction documents to conform with permit requirements.

Obtain Permits!

It's critical to obtain ALL necessary county, state, and federal approval and permits before initiating crossing construction. Contact your county permitting representatives with questions.

Super!
You are now ready to retain a contractor & construct your crossing.

Begin Construction

Following permitting and design, you're ready to hire a contractor and begin construction. Work with your design engineer to understand the project bidding and contract process. The construction process may include:

Fish Rescue

If you're in a fish-bearing stream, you may need to rescue & relocate fish from your work area to downstream.

Diversion & Dewatering

Contractor isolates a dry work area by pumping or directing the stream's water around your future crossing.

Construction Mobilization

Contractor begins to 'stage' for construction, begins traffic control measures, and moving in heavy equipment and construction materials.

Pre-construction meeting

Landowner, County, Engineer, and Contractor meet to discuss logistics, timelines, construction considerations, and inspection requirements.

Demolition

Out with the old! Your contractor will remove and dispose of your old crossing/culvert materials off-site in a legal disposal area.

Excavation

Contractor will dig out the new foundation footprint for your crossing. These depths are determined by the engineer's analysis and crossing design – and thus can vary widely!

Foundation Installation

Pre-fab bridge modules are stacked and assembled. Cast-in-place foundations are poured from concrete trucks, and given time to cure before proceeding.

Structure 'Bedding'

An 'envelope' of backfill material determined by geotechnical engineer is placed. This is critical to provide adequate vehicular support and varies per crossing option.

Roughened Channel (Optional)

Includes excavation to a specified subgrade, and placement of streambed 'stone blanket' and fine sediments across the channel width and along the length of specified project reach.

Crossing Structure Install Placement

Bridge footing installation (poured if cast-in-place, or assembled together if pre-fab) and installation of bridge deck OR culvert placement and backfill over and around your new structure.

Site Reclamation & Demobilization

Once the structure is complete, it's clean up time! This includes repairing surfaces, installing erosion control, and re-seeding the impacted grading zone. Contractor removes any remaining materials & equipment.

Road / Driveway Grading

Once the structure is in place, the Contractor will reshape and resurface the adjacent road and driveway surface to create a smooth transition.

Final Inspection

Project Engineer and County point of contact does a final walk through to ensure project is per contract documents, and creates a final punch list for the Contractor.

Congrats! Your Crossing is Complete!

Maintenance & Inspection

Performing routine maintenance by clearing debris from under and immediately upstream of your crossing will help prevent debris jams and overtopping. Keep an eye on your crossing's roadway surface, and note any signs of erosion or washout.

After a big flood event, it's a good idea to examine your crossing for damage. Refer back to the "Assessing Your Crossing" page for signs of 'red flags'. If you identify any of these, it's a good idea to call your engineer for an inspection. Refer to page 28 for the Post-Flood inspection checklist.

Resources & References

In addition to requirements specified in the Colorado DOT Hydraulics Manual, below is a collection of references that the information in this handbook draws upon.

Culvert & Bridge Analysis and Design

- *See a variety of manuals from the Federal Highways Administration including:* Design for Fish Passage at Roadway-Stream Crossings: Synthesis Report, Evaluating Scour at Bridges, 5th Ed, Stream Stability at Highway Structures, 4th, and Culvert Design for Aquatic Organism Passage.

Long Profile & Reach Assessment

- Harrelson, Rawlins et al. 1994. Stream Channel Reference Sites
- Lagasse, Spitz et al. 2004. Handbook for Predicting Stream Meander Migration.
- Rapp and Abbe 2003. A Framework for Delineating Channel Migration Zones.

Channel Assessment and the Stream Simulation Approach

- USFS. May, 2008. Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings
- WDFW Aquatic Habitat Guidelines
- WDFW Integrated Streambank Protection Guidelines
- WDFW, 2013. Water Crossing Design Guidelines, available online at: http://wdfw.wa.gov/publications/01501/wdfw01501.pdf

Substrate Analysis

- Bunte, Kristin, S.R. Abt. 2001. Sampling Surface and Subsurface Particle-Size Distributions in Wadable Gravel- And Cobble-Bed Streams for Analysis In Sediment Transport, Hydraulics And Streambed Monitoring. USFS General Technical Report RMRS-GTR-74.

Ecological Function & Debris Passage

- USBR. 2016. National Large Wood Manual (Section 5.7.3).
- AFS. February 2014. The Economic Case for Bigger Culverts.

Other Watershed Resources

- Regional Stream Stewardship and Recovery Handbook: A Landowners Guide to Living Along Colorado's Waterways.

We hope this handbook sheds light on the crossing design and construction process, and provides an appreciation of the watershed processes in the Front Range and beyond. We recognize that a resilient crossing may not be financially obtainable for all landowners, but hope that the information contained herein enables landowners to make more informed choices about the risks, costs, and advantages of different crossing solutions.

The partnership of Watershed Coalitions and handbook contributors would like to thank the landowners who offered access to their properties for assessment and attended outreach workshops. Their input and support to this effort, as well as throughout the broader flood recovery effort, is invaluable to the development of more resilient communities and rivers along the Front Range. Special thanks to the Colorado Department of Local Affairs for their funding of this effort, and the technical reviewers and County representatives who provided insightful feedback throughout the process.

Photo by: marekuliasz

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