Think Like A Beaver!

A gross oversimplification of PBR for the soon-to-be talented

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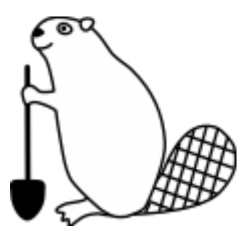


This is a living document, any and all feedback or questions are welcome.

If you have cool, surprising, amazing, tragic, or otherwise educational and noteworthy pages you'd like to contribute, please get in touch with the California PBR Network and we'll take a look.

Dear reader,

To the best of your ability, I recommend reading the below a little at a time, with a relaxed mind. The underlying philosophy is a basic acceptance of knowing only enough to get started right now, but being able to find out more over time. We can learn from beavers and the streams we work in only if we're willing to stay in conversation with them.

If we correct source problems and keep feeding structure to the river, offering it tools and toys, seeing what it likes and doesn't like, and committing to a relational framework, all will be revealed. That relaxed but curious mindset keeps us from trying to engineer the river, and ending up fighting the site. By carefully observing changes over time, and mindfully responding to indicators of success, we step out of the old diesel-based paradigms that seek to impose a form on the riverscape.

That's by design, because process-based restoration is too new, too powerful, complex and subtle to fit in the tired old boxes fossilized by a hundred years of civil engineering. Forget boxes—you can't fit nature in a box, you can't catch a river in a bucket, and there's no way to engineer a living system into submission without killing it first.

So, to properly employ process-based restoration, you've first got to restore *the process itself* to avoid perpetuating outdated design, permitting and implementation modalities. This document itself is an example of how we're doing that, and keep in mind that what's shown below is just my way of doing things—one of many. Also, for the lawyers, nothing in here necessarily reflects the beliefs or opinions of anybody else.

It will start with high-level concepts and then work down to the detail level to be sure we're thinking about the system as a whole before getting bogged down in minutiae. You'll also notice a refreshing lack of jargon, impenetrable charts, mathematical formulae, and the like. That approach has always struck me as an attempt to justify high design costs, and while this stuff is endlessly complex, there's no reason to make it complicated.

It's worth noting that this document is composed of two halves—this one is Think Like A Beaver because it's the first thing you've got to be able to do. Build Like A Beaver is the second half, and is available on request to anyone who has read this entire document first. It's set up this way to increase your chances of success and weed out impatient folks who just want to build something, anything, whether it makes sense or not.

And given the limitations of everything conceptual, it's best to see process in person, so find a project to volunteer on and don't be a stranger—we're all in this to make a better world. Thanks for reading.

Kevin Swift

Build Like A Beaver!

What Is Process-Based Restoration?

The art and science of restoring landscapes to optimal ecological function by addressing anthropogenic source problems, then manipulating on-site energy and materials with human-portable tools to initiate, hasten, and stabilize the ecosystem's recovery trajectory.

In this manual, we'll be specifically dealing with restoration of riverscapes, but the description above applies to any ecosystem.

Within the riverscape process space or erodible corridor, use of heavy equipment must be strictly limited to repair or removal of anthropogenic source problems as a purely *subtractive* measure, to ensure that interventions can be also be reversed by human-portable tools in case of undesired outcomes.

My deepest goal for process based restoration, one which extends 3 digits into the future, is to develop techniques, tools and design philosophies now, that ultimately will utilize exclusively on-site energy and materials, burn zero hydrocarbons, and offer full-time employment to a meaningful percentage of our nation's workforce, for a living wage.

Landscape Scale Guiding Principles

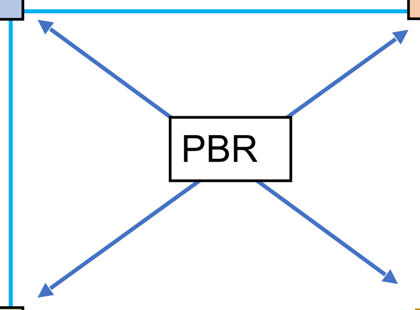
- Treat anthropogenic source problems first—address the root cause of disease, then the symptoms.
- Connect to floodplains as soon and often as possible. A disconnected river is like an amputated limb.
- Use sediment delivered by erosion to rebuild incised channels. It's only a pollutant if you're not using it.
- Increase complexity of habitat mosaics, both physically and temporally. Diversity of habitats IS ecosystem resilience.
- Add enough structure that the stream can self design, and let process make the final decisions regarding form.
- Ensure coming generations can still make their own decisions. We don't know everything, and bulldozer work gets harder to reverse as fossil fuels get scarcer.
- Do everything you can to recruit beavers.
- Set the stage for larger restoration actions up and downstream, and ensure that everything you do is coherent at reach, watershed and landscape scale. Water can't see fences or property lines.
- Use only local materials to reduce hydrocarbon burn and eliminate risk of non-native species introduction.

The 4 Corners of PBR

Process-based restoration depends on **Space**, **Time**, **Energy** and **Materials**. Just remember STEM. These foundational elements form a complex web of interactions that determines how successful a restoration project will be, and how fast it will recover. The 5th element here would be humans, but any attempt to predict their interactions with anything else is pointless, and so we'll continue in the grand tradition of vague hand-waving and ignore them for simplicity's sake.

Available process **Space** makes building the project worth the expenditure of irreplaceable fossil fuels, human lifespans and money.

Time is flowing and growing years—periods of geomorphic and biologic work being done by on-site energy, not just the passage of calendar time.



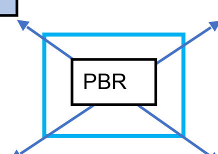
On-site **Energy** comes from stream power, vegetation and hopefully beavers. This **Energy** is applied over **Time** to the **Materials** we add and does the real work of the build.

Materials are wood, rocks, sediment, living vegetation, beaver dams and anything else the water interacts with. Adding material is our primary intervention

On any given project, you'll probably find that one corner is the limiting factor and causes most of the headaches. Do everything you can to identify it ahead of time and plan accordingly.

Lack of **Space** reduces potential benefits, increases risk, and may require lots of **Energy** and **Time** to show results.

Lack of patience in partners may mean a project isn't given enough **Time** to show results, or cause hurried implementation that requires lots of additional human **Energy**

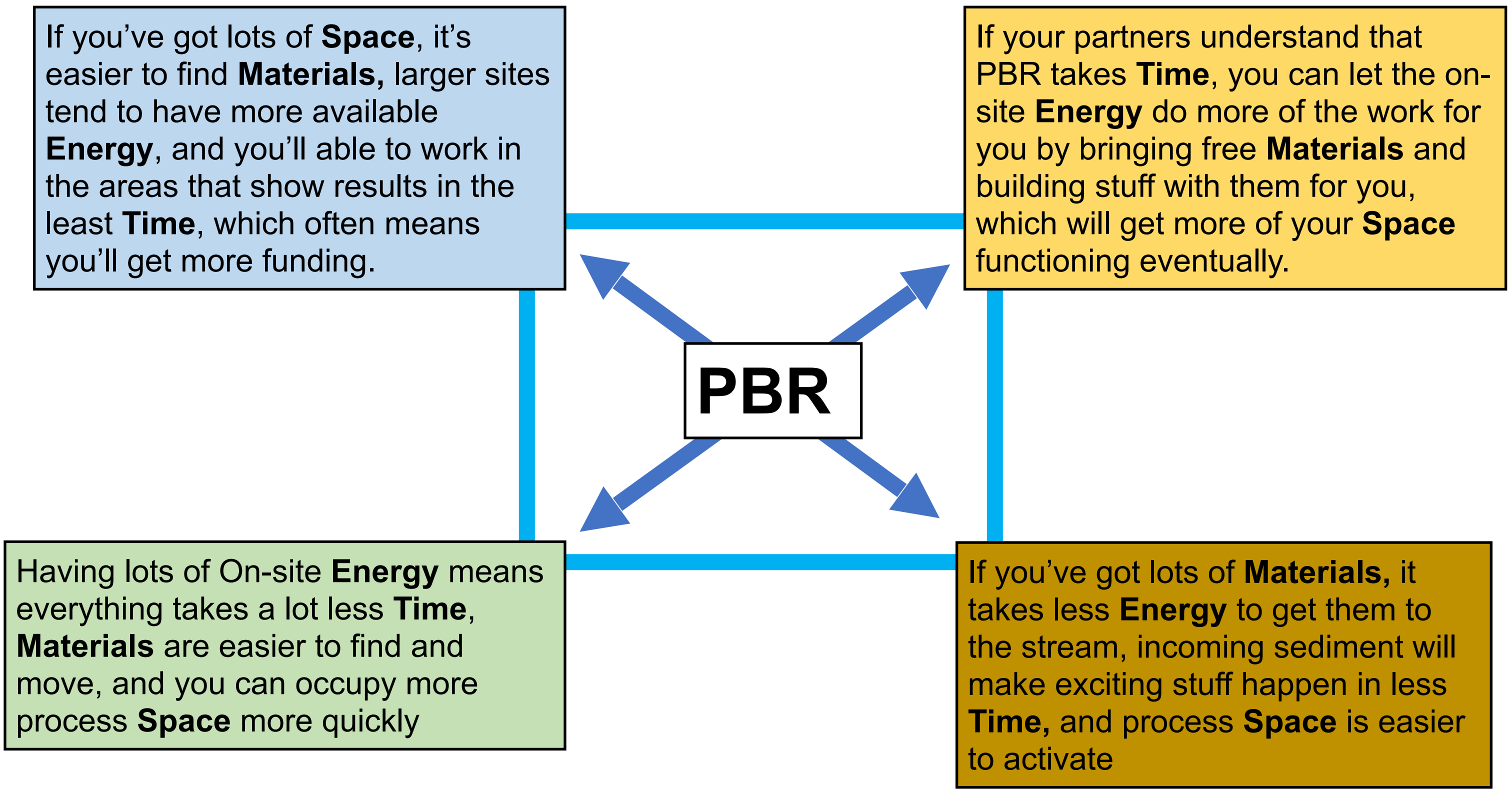


Lack of **Energy** on-site, in the form of weak or small streams, short growing seasons, lack of beavers, and few people working, may make a project take a long **Time**.

Lack of **Materials** can mean lots of **Energy** needed to import them, a project taking a long **Time** to grow enough vegetation for the build, or inability to occupy as much **Space** as you might like to.

The 4 Corners of PBR

Each element, to a degree, can take up slack for another (or several) that's lacking. The ideal project, of course, has all the below in abundance.

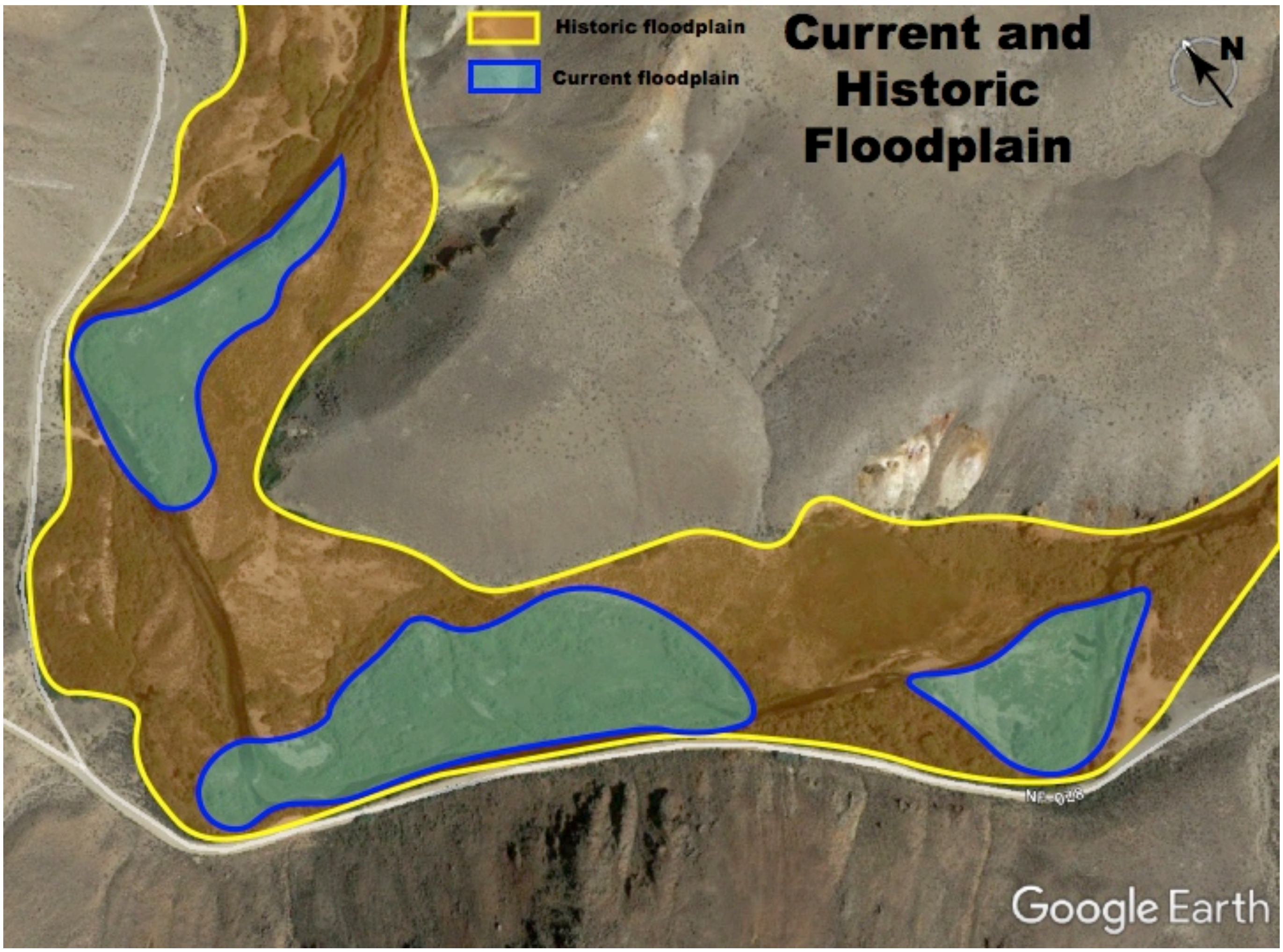


In the next few pages we'll look at all these elements using some examples, but keep this interaction rolling around in the back of your mind as you check it all out. If you've got a project of your own in mind, give some thought to what your likely limiting factor will be, the results that might have, and how/where you can make the above substitutions (and many, many other similar ones).

Space

Space for the river is space for everybody. Specifically, we're talking here about *process space*: the area that could conceivably become an active channel, floodplain or wetland. True hard limits are determined by geology, but human infrastructure usually constrains process space. In process-based restoration we always start by looking for ways to relax these constraints and give streams more freedom to migrate laterally, form and retire new channels, and safely flood.

Then we'll add structure to increase channel length, width of wetted and flooded area, variety of water depths and oxygenation zones, temperature differences and so on. Monitoring these measures of habitat diversity, and their improvement, shows whether we've gotten the kind of diverse, complex, time developmental mosaic of dynamic ecosystems we're looking for. Below is an example showing floodplain access over time.



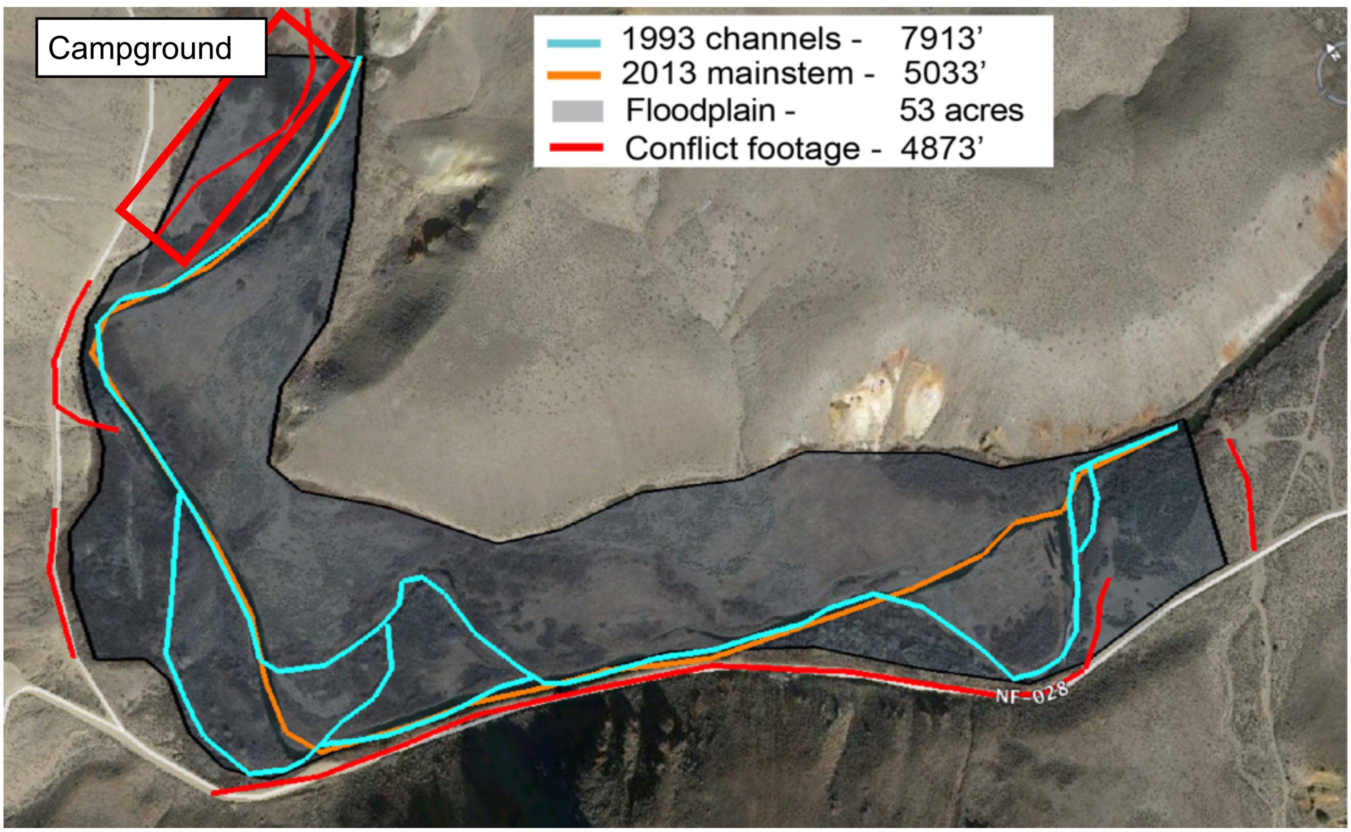
Our current process space in this example reach isn't great. There's a mile of stream with only 53 acres of floodplain, of which less than half is currently active. That's a little narrow, and having the road and campground squeezing the river isn't helping.

This is an important area for fishing and hunting, and does show good potential for increasing channel length and overall complexity. If there's no way to move the project and a minimal carbon footprint can be maintained, I'd say it's worth it, but there's much better potential a little downstream, which we'll get to shortly.

Channels and potential conflict

Most projects will have both source problems and infrastructure conflicts, since most land use in the U.S. developed well after indigenous genocide and near-extirpation of beavers initiated a process of incision and dehydration that continues today. This newly dry landscape made building in former floodplains and wetlands both possible and profitable, resulting in riverscapes littered with badly placed infrastructure.

This channel network, shown in blue and orange, has decent potential. A project reactivating the 1993 mainstem and 4 remnant channels would add 57% more channel length, new confluences, and some badly needed complexity. Additional channel length means more water for everybody, and more chances to slow this water down. Sounds good, right?



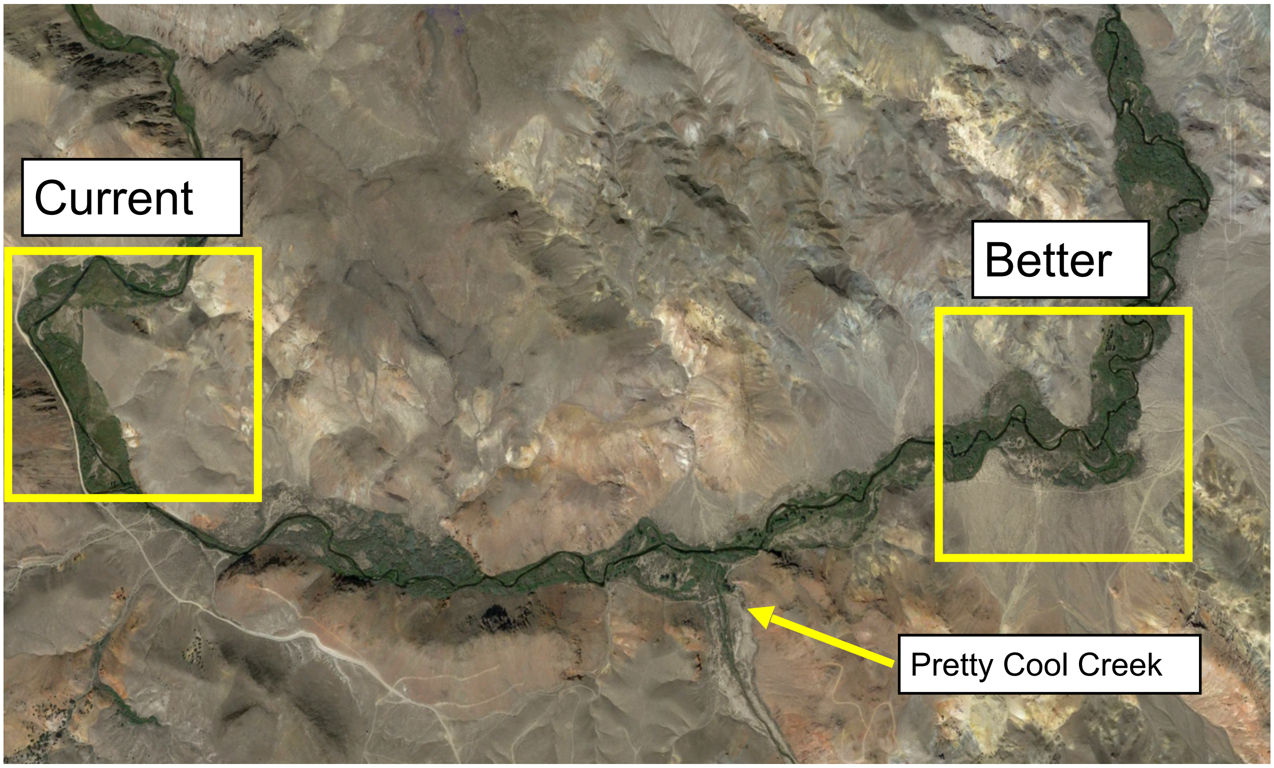
But there’s a catch: the red lines represent areas where human infrastructure is a source problem that conflicts with re-activating the historic floodplain. The campground is in the floodplain, and moving it is “a non-starter”. Everywhere the channel hits the edge of the road (NF-028), bank erosion and collapse of the road could occur.

While an unconstrained river would happily keep eating that sediment and eventually wander back across the floodplain, this river can’t, so the river is straightening out, speeding up, and cutting down as you’ll see in the energy section.

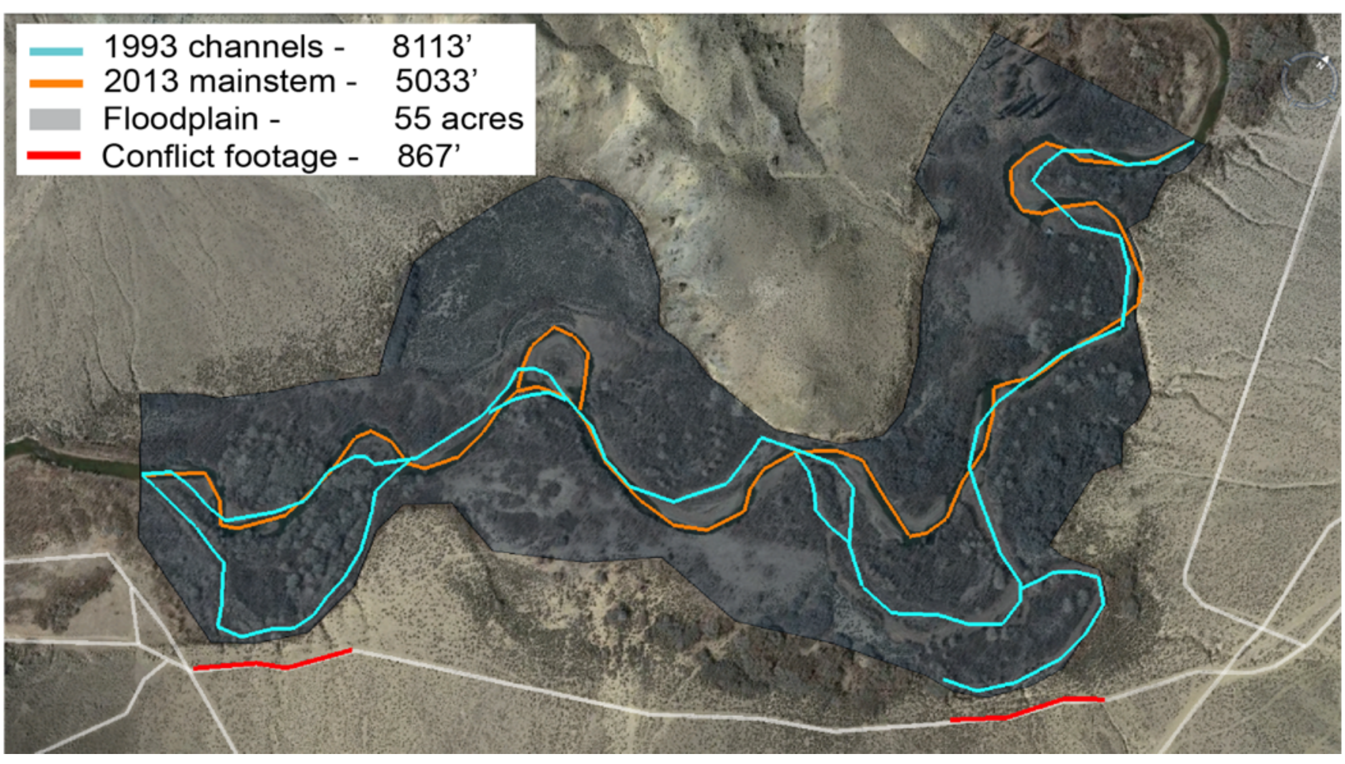
In this case the road and campground “can’t” (won’t) be moved or modified, which badly constrains our process space. Every time, every single time you propose modifying or moving human infrastructure, you’re going to get pushback, because folks think anything we’ve built is sacred. You’ll have to get used to it, and develop tools for effectively communicating how the cost/benefit ratio justifies your blasphemy.

Site Analysis

So let's find somewhere else to work, with fewer immovable source problems. Below is another reach of the Example River with the same landowner, .75 miles downstream of where Pretty Cool Creek comes in, with much better **Space** availability



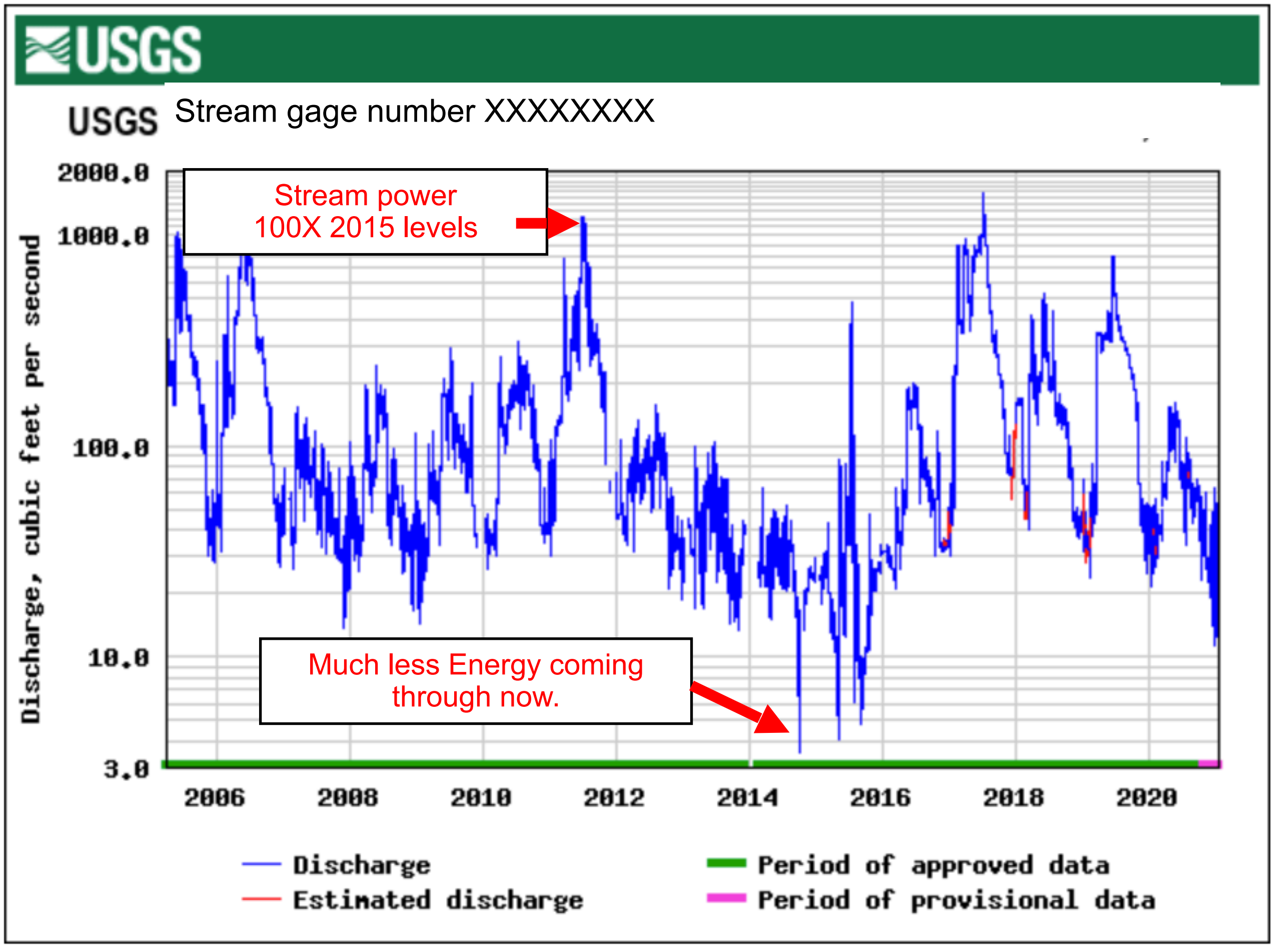
Below I've drawn in the same length of 2013 mainstem as at the current site—5033' feet including the current oxbow. Reactivating the 1993 channels here would yield 62% more channel length, but only require conflict consideration/mitigation on 18% as much road frontage, and possibly less depending on local topography. Thus if you can't remove a source problem, consider moving the project. Now let's talk about time.



Time: forget the calendar

To think properly about PBR, **Time** and **Energy** have to be considered together as a merged concept, similar to how Einstein thought about Space/Time. Mere calendar time is a useless metric that tells us nothing about whether onsite energy is available. **Energy over Time** is what matters: periods when stream power is available and geomorphic work is being done, or people and beavers are building, or plants are growing.

If you've ever seen a flood in action, it becomes immediately apparent that even a ten-year flood will do vastly more geomorphic work than ten one-year floods due to the sheer power available. You might see nasty incision in a matter of days, or great stuff happening just as fast—new channels forming, floodplain connection, fresh deposition and sorting, new scour pools showing up, and etc.



This USGS stream gage downstream of the project shows that flows on the Example River vary by as much as two orders of magnitude over a decade, so any materials in this system are acted on by wildly different levels of energy over time. Clearly, 2011 was doing more work than 2014, and properly directed by adding **Materials**, this free stream **Energy** can do incredible work **Over Time**.

To reduce the level of abstraction, as you're reading through all this, glance occasionally at the clock and consider what **Energy** has been working on the **Materials** that make up your physical self over the **Time** that's elapsed since you last looked.

Hunger is evidence of calories burned, getting warmer or cooler may be solar energy acting on you or your house, a nearby dog barking is incoming sonic energy, and so on. *The passage of time IS energy acting on materials in space*, and getting tired of pondering these weird dualistic concepts is evidence of your mental energy getting used up, so maybe take a quick walk here.

Energy Over Time

In process-based restoration, we prefer our energy sources to be free and already on-site. The stream power of water flowing downhill, solar and photosynthetic power expressed as vegetation, and the animal power of beavers and other keystone species are ideal.

Next in order of preference are muscle power, food and beer for the crew and the solar power that charges our electric chainsaws. Whenever possible, we avoid fossil fuels—they're largely imported from geopolitically unstable regions at great human and environmental cost, and their use contributes to the very problems we're attempting to solve. By obsessing over energy efficiency, we've arrived at a formula: no cut, no fill, no imported material, no heavy equipment, no road building.

A project that's properly designed and implemented should use intrinsic system power to do the vast majority of the work in restoring the riverscape. Our puny human nudging is only meant to begin correcting the trajectory of the energy that will be delivered over the next few centuries by the stream, the sun, the plants, and the animals that live on and move through the site.

This Google time series shows an oxbow cutting through in the middle of the project area, starting in 1996.

Scouring open this channel required a mobilization of roughly 2,000 cubic meters of material in 17 years, ignoring all the fresh incoming sediment that had to be flushed through, sorted and deposited.

If we put that energy to work intelligently, we can use the stream as our carbon-free materials delivery system and determine where the next 2,000 meters end up.

Riffing on the 4 corners of PBR: If your project area has little stream power to work with, like in 2014 on the stream gage above, you'll have to depend on human and solar (plant) power. These energy sources will take more calendar time to work. If you've got lots of energy, like in 2011, it might happen really fast.

Then again, if you're hamstrung by illogical work windows for the humans, or if it's cold, dry or frequently cloudy reducing solar gain, and you haven't got beavers, the project may take a *lot* more calendar time, and require more human input than one with more geomorphic power. If you have beavers though, expect immediate results—you won't believe how fast they work! And so on.

On-site Materials

Aside from posts, we don't import materials from outside the watershed we're working in—if there's nothing to work with on-site, we'll take a hard look at whether the project should be done at all, based on an intentionally pessimistic cost/benefit analysis.

While it can be tempting to mentally justify the negative impact of hydrocarbon use by offsetting it with our *potential* future positive impact, the hard reality is that there's no guarantee anyone's work will persist. Follow the "think globally, act locally" principle.

Whatever we're going to use will be hand-harvested as close to the site as possible. In the uplands this harvest will be fuel-load reduction and thinning toward healthy stand densities, mimicking a slow fire. Closer to the stream, we remove encroaching trees and shrubs, do invasive species removal, and cut for a release/regeneration event of riparian vegetation

Absolutely anything you find that's not toxic or dangerous is fair game. Conifers, willows, other shrubs, sod, gravel, rocks, dirt, branches, cow bones, sagebrush, juniper, live, dead, half-burned, rotten—this is no time to be choosy. If it'll hold water or drive process, use it.








Generic Source Problems

This is going to be depressing, so grab a second cup of coffee. No good doctor would ever treat symptoms and ignore causes of disease. Similarly, before we build a single structure, we've got to find out what caused the troubles you're having. This means looking upstream all the way to the ridgeline and finding all the hominid trickery that's been employed since about 1493. So let's look at the current entropic death spiral. How'd we get here?

Native American Genocide: we've nearly completely lost indigenous use of fire, and the tens of thousands of years of learning required to develop it. So all our forest are overstocked and thirsty, and less water is reaching our rivers. Not all rivers have a forest problem growing right in them, but the uplands probably do, and 50% of our water comes from forests.

Extirpation of beavers: once we killed most of the beavers and sent them across to get turned into hats, we were really in trouble. We lost base elevation control, and the now-thirsty streams started incising. Unfortunately for us, until you've got perennial flow and deep escape cover, there's no reintroducing beavers. Which means building habitat for them.

Cattle: kill off the indigenous folks and the beavers, ditch the meadows to drain them off, and let the cattle loaf in the creek all year eating all the vegetation, and pretty soon there's nothing to stop the water from down-cutting. It's a certainty that all available pasturelands were overgrazed in the past, and a vanishing rarity to find proper grazing management anywhere currently.

Roads: Once land is dry enough, folks build roads across it in all kinds of ridiculous spots and dehydrate large sections of downstream area while concentrating flow into undersized and/or perched culverts, which further drive incision.

Dams: upstream reservoirs derange hydrology with respect to timing and volume of flood pulses, and compounding the problem, only super-fine suspended sediments will pass a dam, which aren't much good for building a channel form since they're too mobile.

Logging, mining, agriculture, housing: again, predicaments. Nobody's going to quit eating, building houses or making stuff any time soon, so all you can do is figure out how to reduce the negative impacts of these industries, ideally by getting them entirely out of the process space.

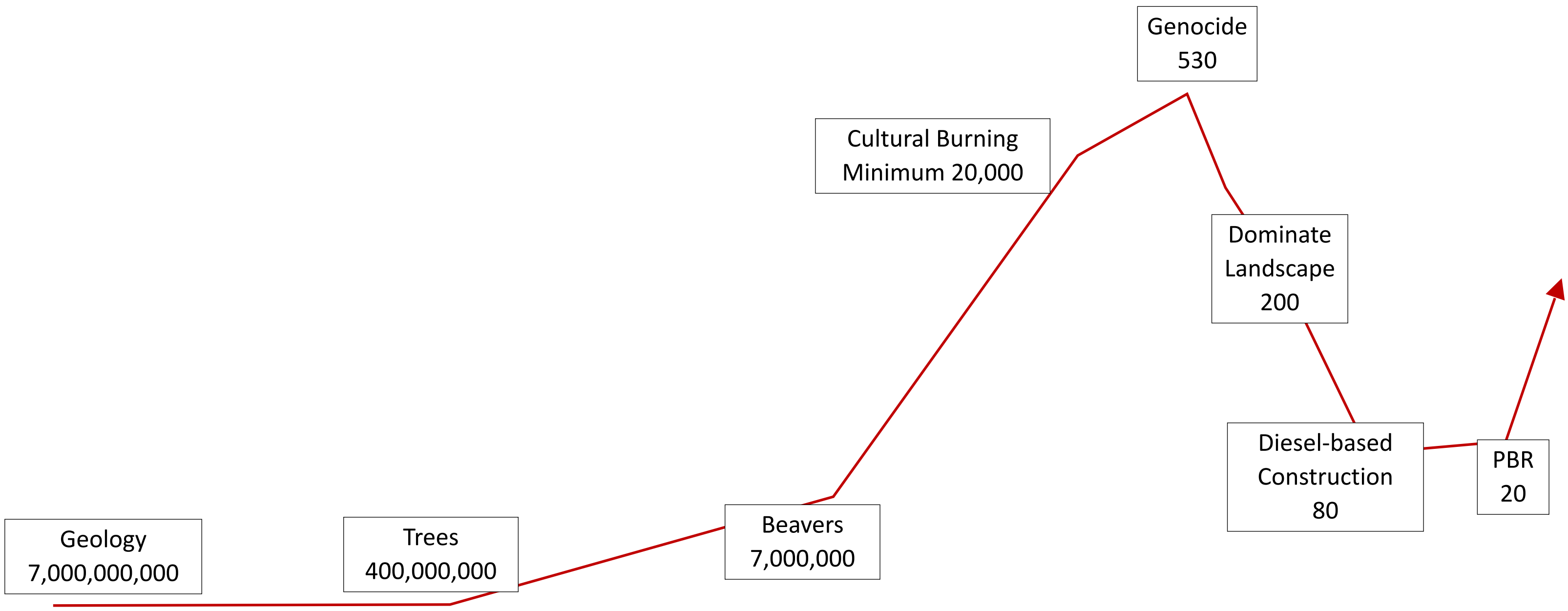
Invasives: there's no winning this fight, so I default to reconciliation ecology, and all I see is biomass and dam-building materials. Encroaching conifers are great building materials, and smell like Christmas when you stuff them in the dam. Ludwigia makes great packing material, Himalayan blackberry is awesome Velcro in structures, plenty of meadows have headcuts that are only supported by reed canary grass, and so on. A final question here, for the folks really worried about invasives "crowding out natives and taking over"—what do we know about monocrops?

Climate change: this is not a source problem, because problems can be solved. Properly stated, it's a source predicament, which has only outcomes to be mitigated and hopefully survived. Anticipate hotter and drier for longer and longer, with worsening flooding and ever-escalating water stress on every system. Every drop that flows through your property should stay around as long as possible—ideally years.

Source problems are always manmade, and most of the time somebody who should know better will fight against fixing them. How about a concrete (haha) example?

Channel form diversity over time

(Obviously not to scale)



Note: this is all about North America, but many of the same principles apply worldwide. The first forms were all geology—erosion and deposition of inorganic material, driven by gravity, water, wind, and time.

Then Gaia invented trees around 400M years ago, and things immediately got much more interesting. Ever-larger pieces of steadily more durable wood grew, fell in, and was washed from the uplands through the riverscapes. This wood drove complexity not just locally around itself as a static element, but over time as it moved through, functioning as mobile disturbance through the entire length of the stream until finally eaten by the sea.

7 million years back beavers showed up, and complexified things more than we can even imagine. Their disturbance was ongoing, orders of magnitude faster than wood moving through the system, and carried out at landscape scale.

Then people showed up, and began managing the forests with fire, selecting for lower stand densities and lower evapotranspiration load on the groundwater. Somewhere in there we could propose a point of maximum diversity.

Around 1492 (in America, anyway, it's an easy date to pinpoint), everything goes to hell—overstocked, thirsty forests, near-extirpation of beavers, the now-dry landscape is easily overgrazed, logged, mined, farmed, and paved under, and you get our current sad state of affairs.

Somewhere around the 30s and 40s, maybe with the Dust Bowl, people start wondering if this was all such a good idea, and begin trying to fix things using the same tools and thinking that caused all the disasters. Results are mixed at best, with very little complexity produced and much damage done.

Then Process-Based Restoration emerges, driven by the simple proposition that the same forces that originally complexified the landscape can do so again, and all they need is a little nudge from humans who have the humility to think like beavers and actually ask the river what it wants. Complexity emerges quickly, with little hydrocarbon input required.

Source Problem Analysis Example

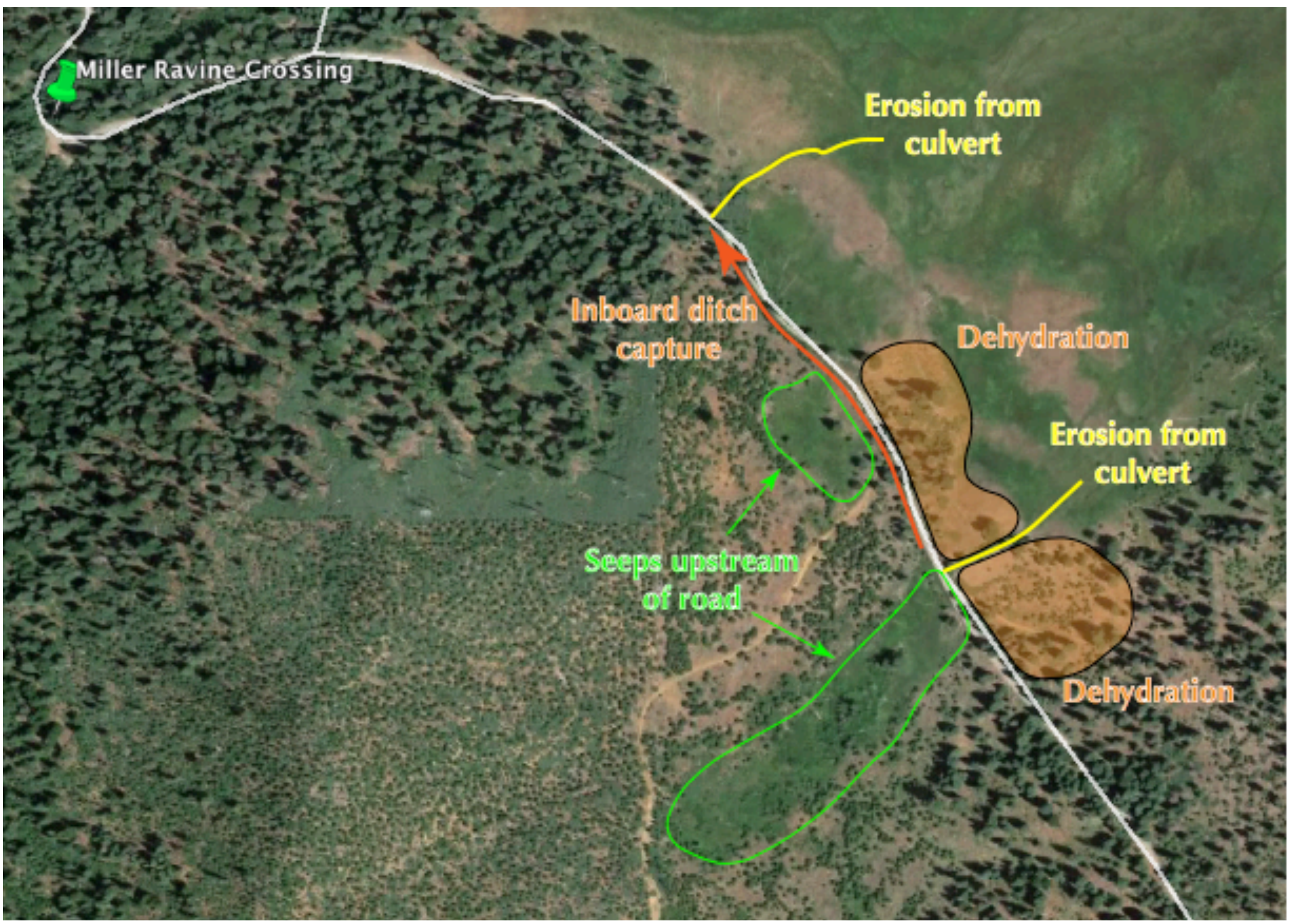
Here’s a fine example of how roads derange meadow hydrology. It’s worth noting that almost any other meadow or ranch could be substituted here—these problems are near-universal in the west.

In order to keep the road dry, seeps upstream of the road are concentrated by an inboard ditch, conveyed to arbitrary new locations while drying out historic meadow surfaces, and then dumped into culverts. Hilarity does not ensue.

Immediately downstream of the culverts, erosion cuts into the meadow surface due to the concentration of stream power and further dehydrates the meadow. Vegetation dried out by the inboard ditch capture becomes more vulnerable to erosion, and the cycle continues.

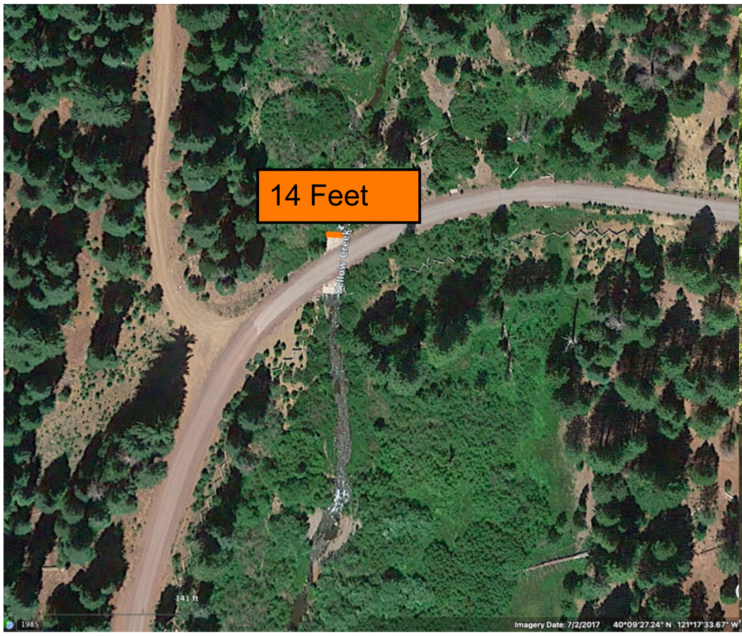
Without costly and eternal maintenance, eventually the perched culverts will fail due to either plugging or excess hydraulic head driven by the incision, or both, and the road will follow soon after.

The potential fixes are many: in order of preference we could decommission the road completely, outslope it and add rolling dips to open back up process space, or lastly add multiple culverts appropriately sized, sloped and sited at historic flow paths.

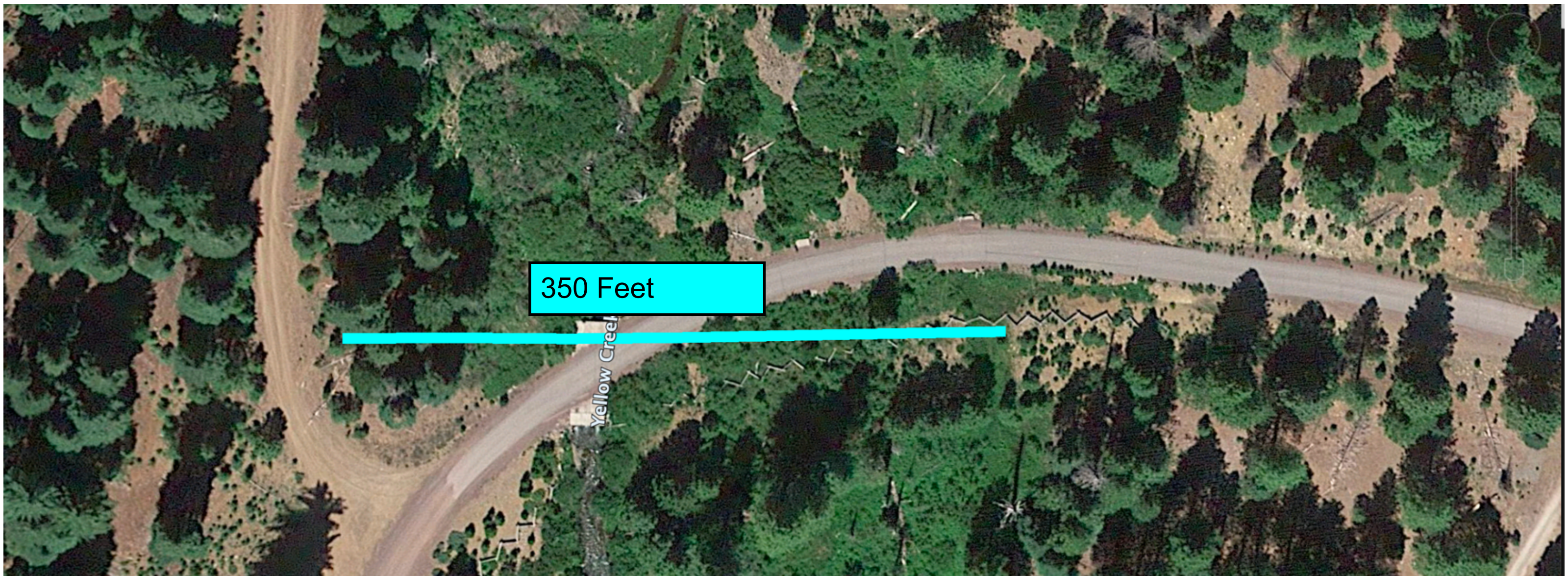


Source Problem Analysis Example 2

Upstream of the first example, here's the road crossing. The culvert is only 14' wide and also multiply divided—I defy you to stuff a tree through it that could make a difference for the kind of incision we've got out there. Worse, it's been in place so long that a conifer forest has grown on the new sediment upstream, stabilizing and further driving the depositional processes above the road. Normally we'd welcome this aggradation, except in this case all that wood and sediment can no longer reach the incised stream farther down.



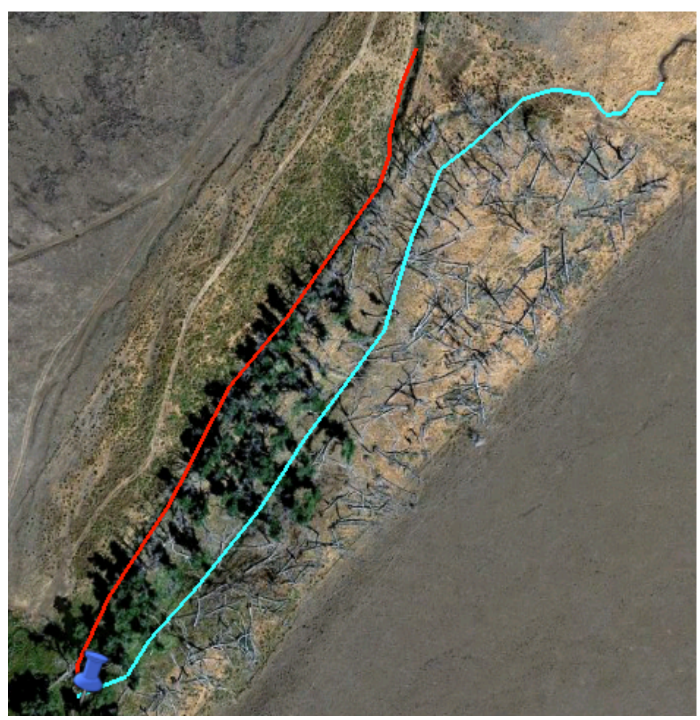
Cut off your sediment supply, and the stream incises. Simple. But full channel fill won't fix the source problem, and *will* cost huge amounts of money and carbon. Better to fix the crossing and regain sediment and wood supply



Where To Work?

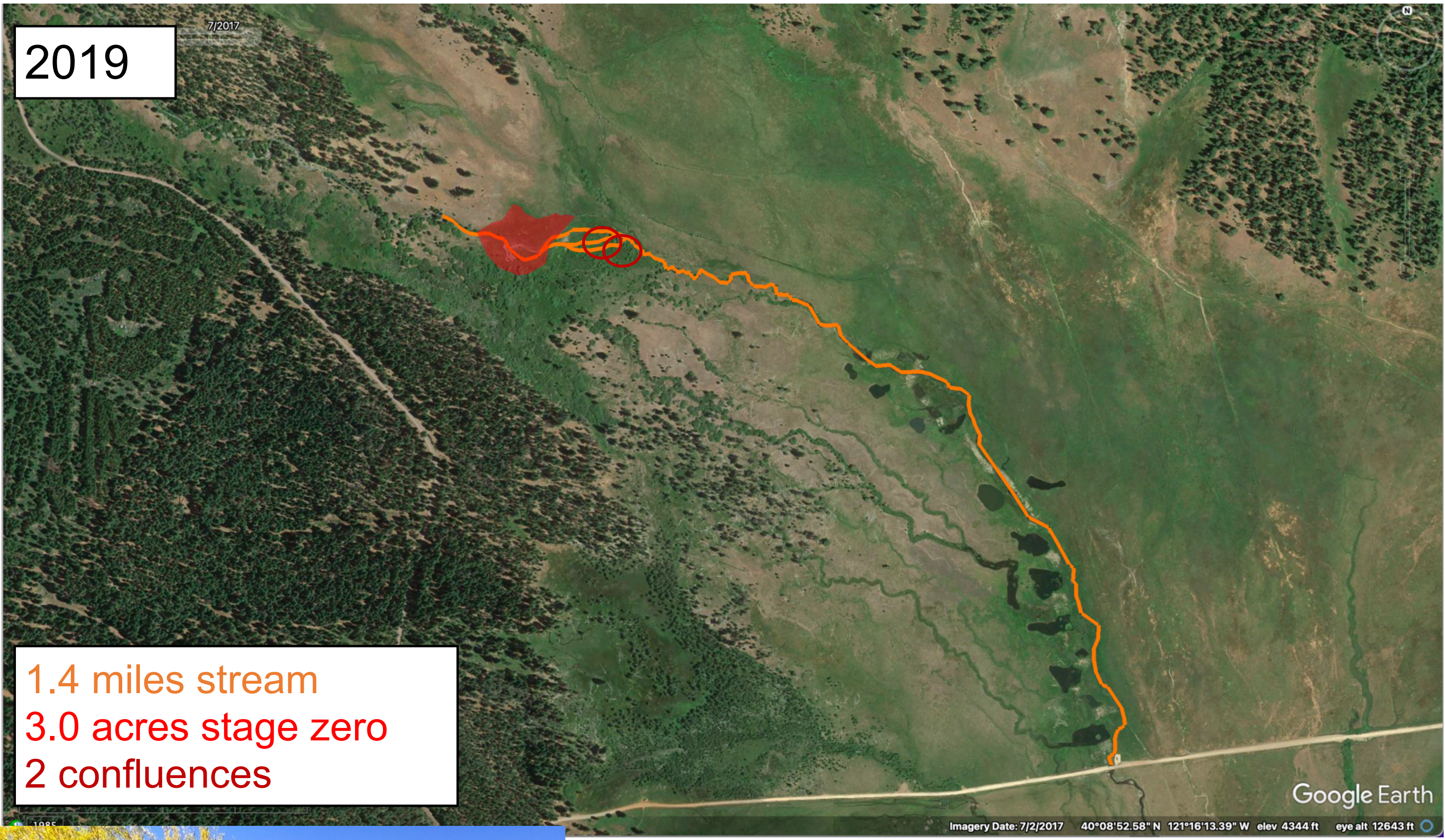
While it may seem counterintuitive, the area that looks the worst is almost never where you'll see big gains. The impulse to spend most of our time and money "fixing" it, while noble, leads to a lot of wasted time, energy and money that could be better spent on areas that provide more lift sooner. Here's an example from Shinn Ranch—this deep trench looked bad, and the client wanted it treated. So we threw in some trees as a gesture of goodwill:

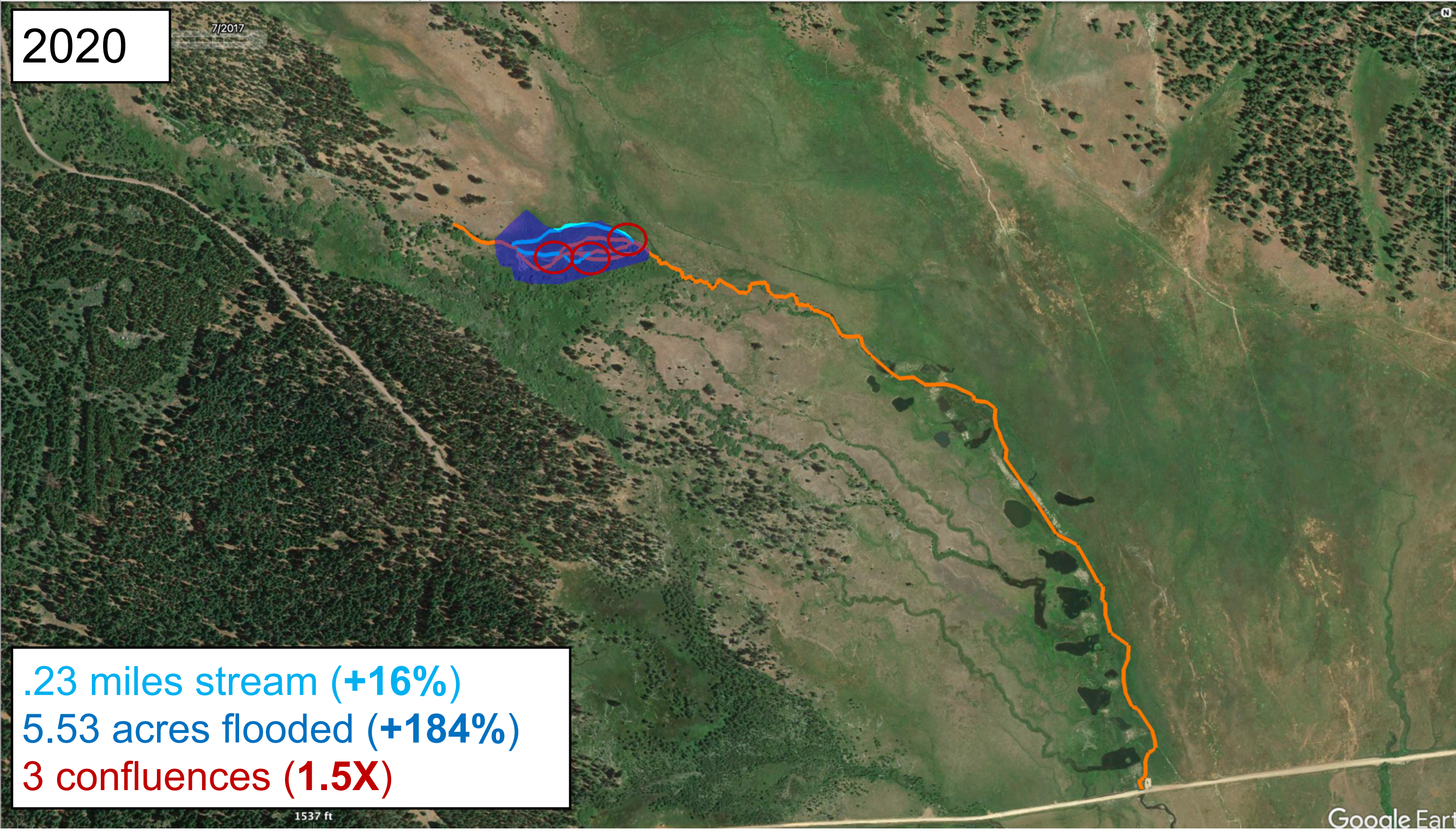
But that ditch is 9 feet deep, and that water's not getting back to the floodplain this decade—there just isn't the incoming sediment supply needed, the beaver's haven't come back, and 9' tall structures won't last. So we went 1/4 mile upstream, where a single 18" tall structure let us nudge the water out of the ditch before it got trapped. We gained 120% channel length from one structure that took less than half a day to build, and have done this same kind of thing enough that it's become standard procedure. The red line below is the incision, and blue shows new water in the formerly-dry floodplain channel.

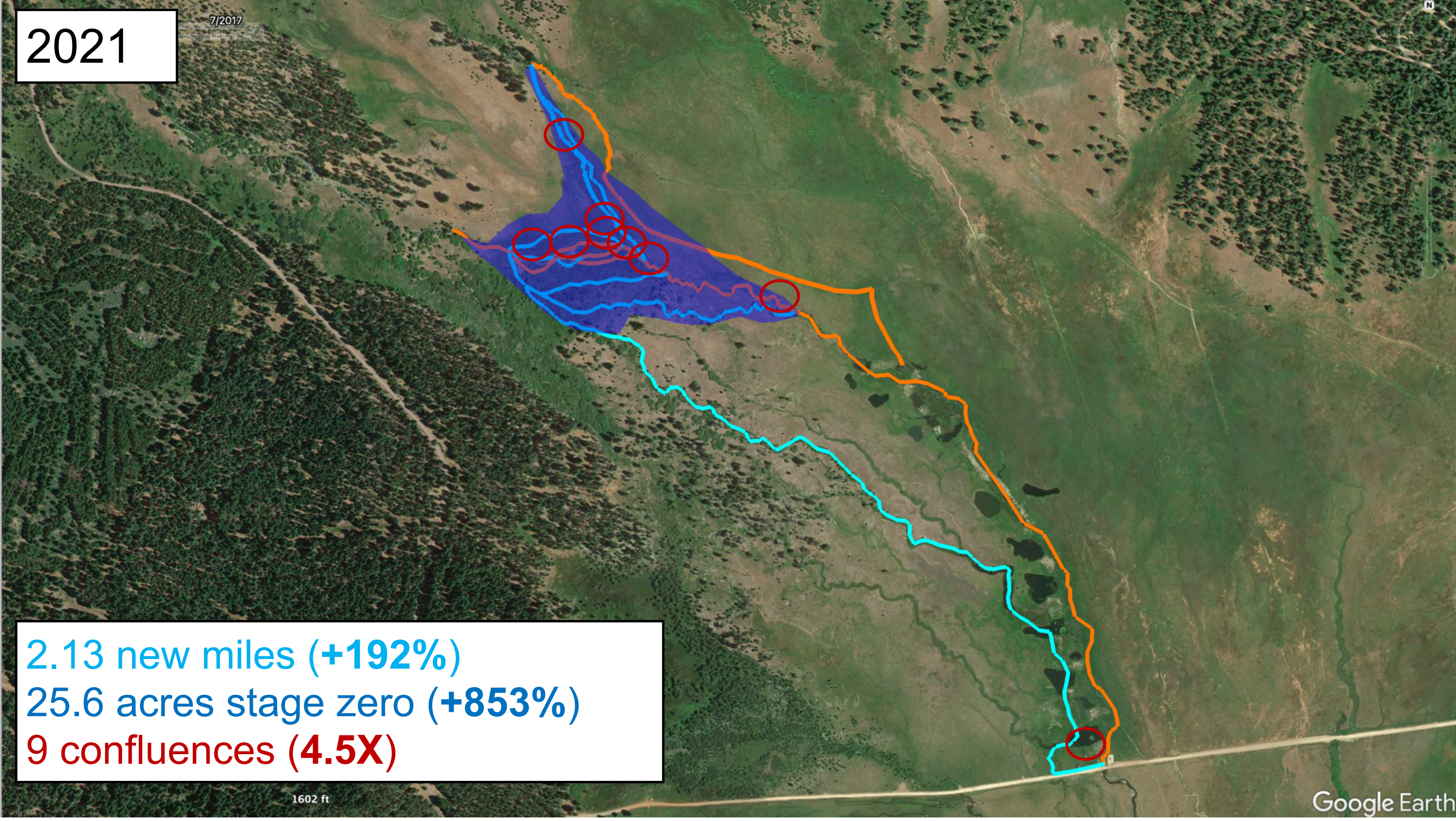


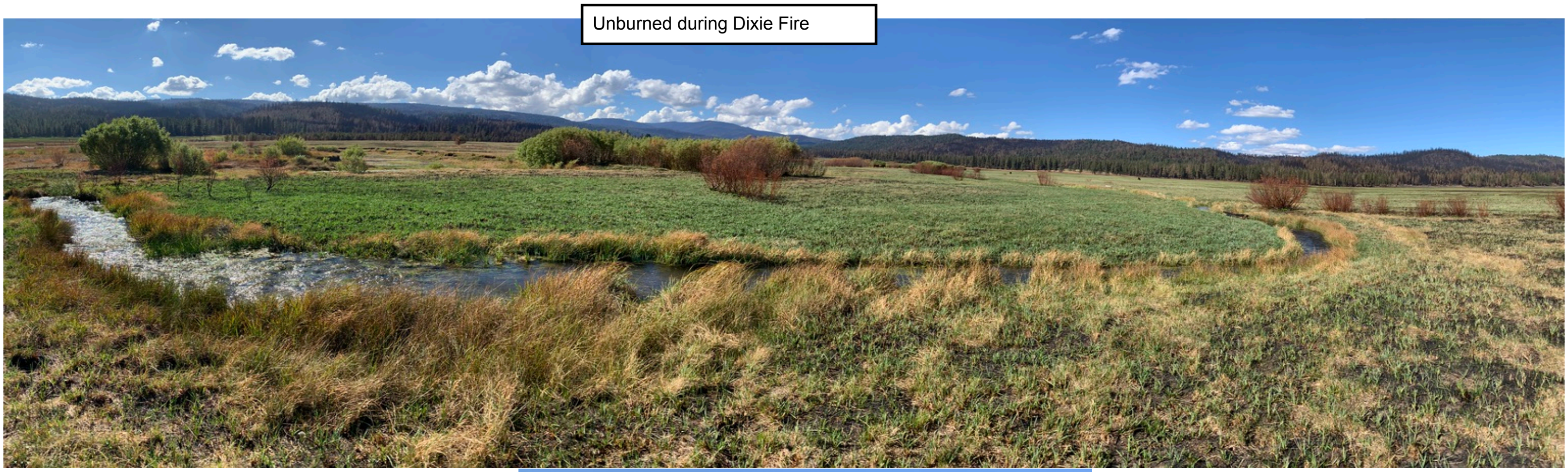
Watershed Scale Effects

The next pages shows 5 years work, and what you can get out of around 100 structures if you get the placement right. This project is **Materials** limited by the upstream road crossing from Source Problem 2 that concentrates stream power and impedes wood and sediment flow.



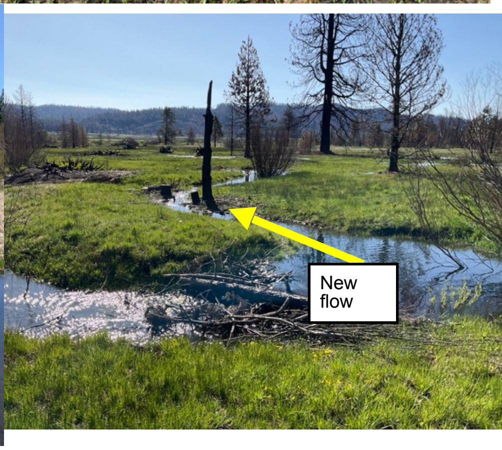

2020
.23 miles stream (+16%)
5.53 acres flooded (+184%)
3 confluences (1.5X)

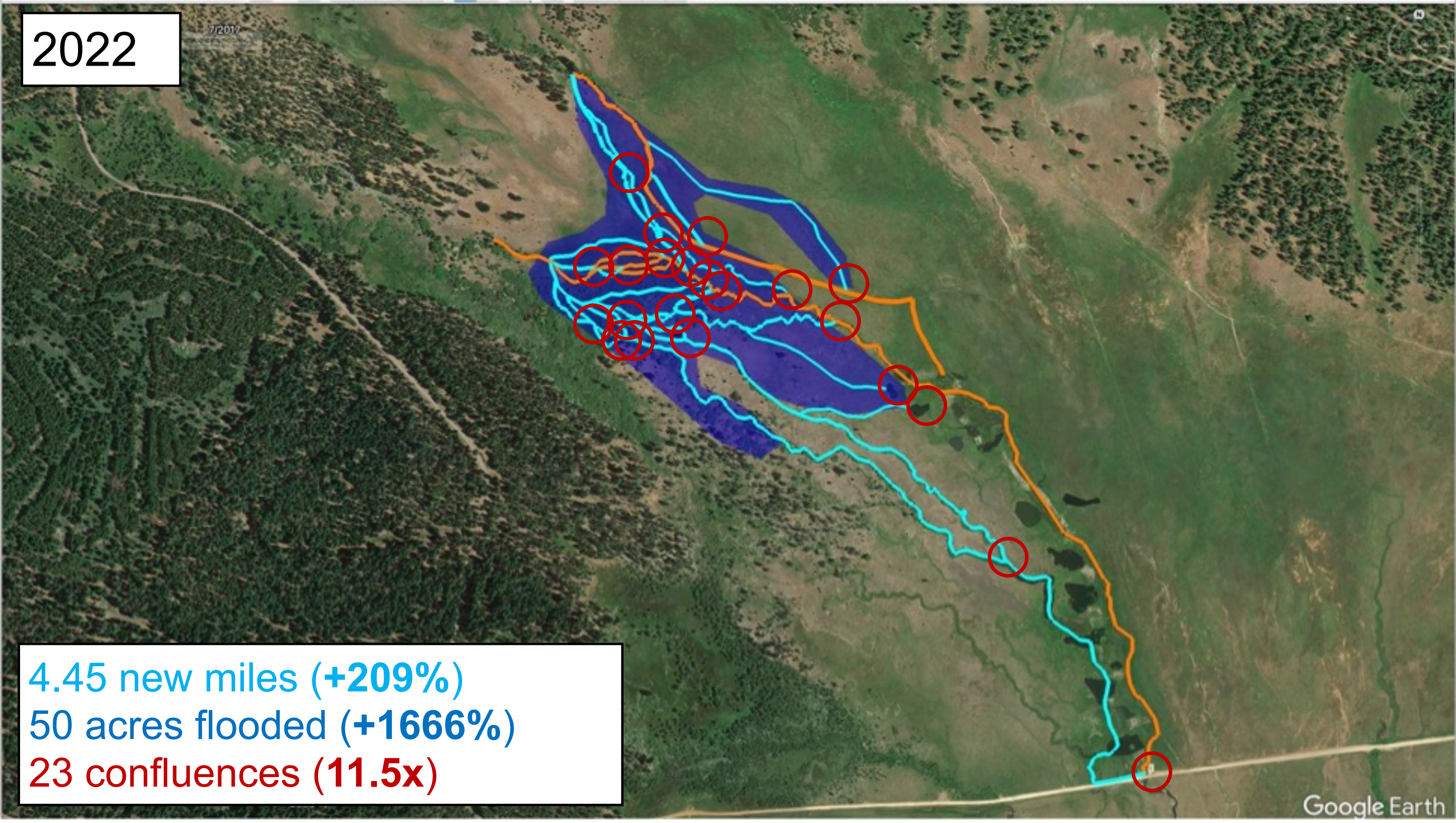

2021
7/2017
2.13 new miles (+192%)
25.6 acres stage zero (+853%)
9 confluences (4.5X)
1602 ft
Google Earth

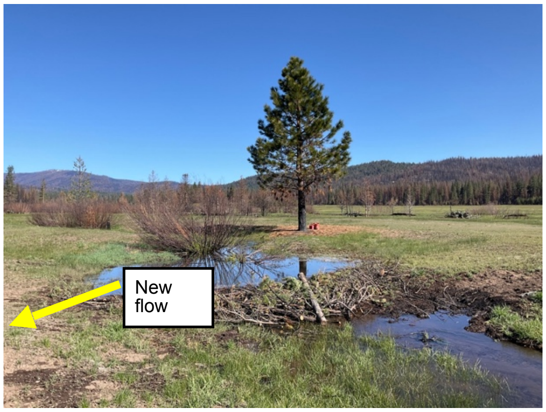

Unburned during Dixie Fire


New flow


New flow

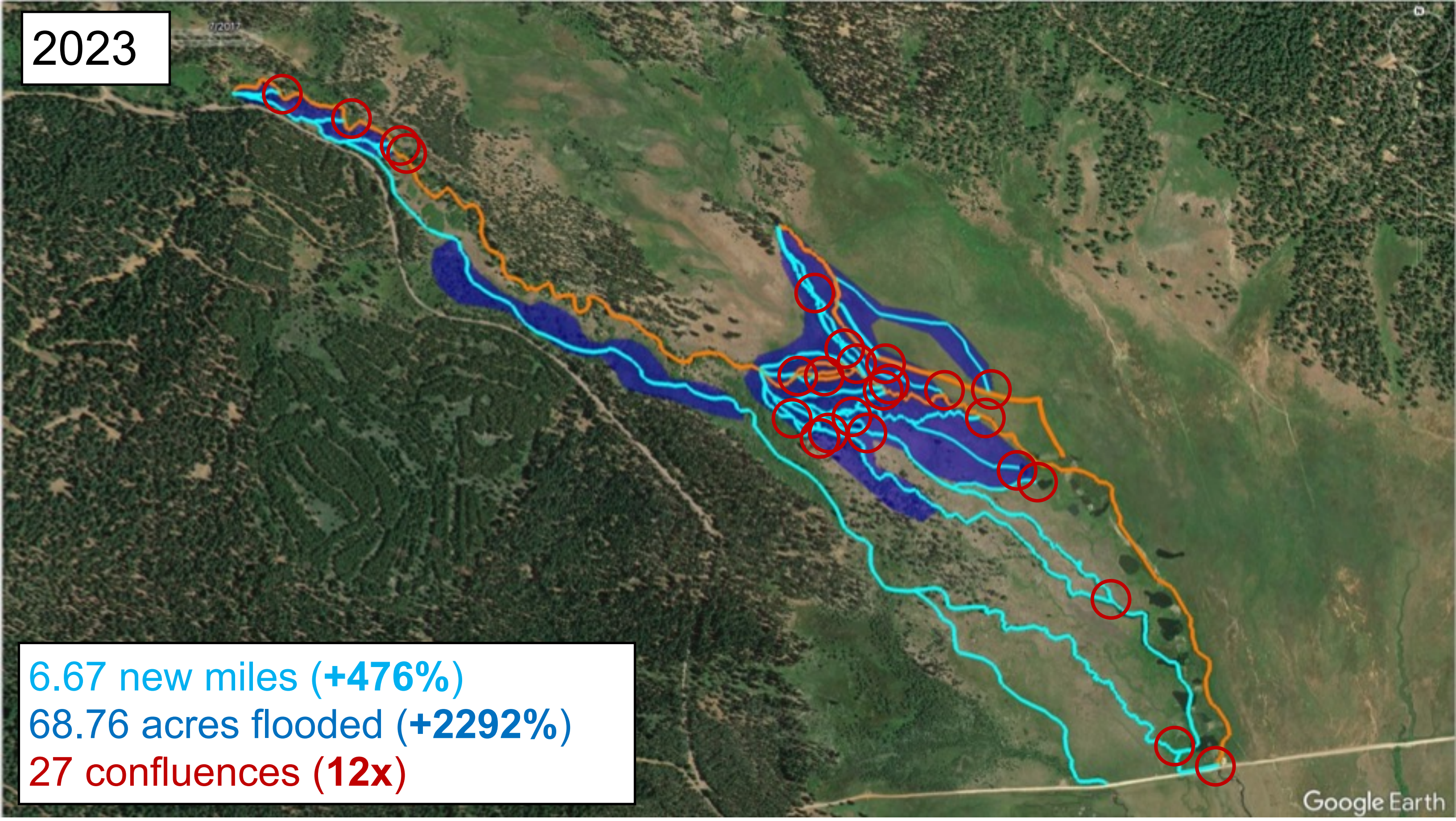

New flow


2022
4.45 new miles (+209%)
50 acres flooded (+1666%)
23 confluences (11.5x)
Google Earth


New flow


New flow


STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
259973
Filling groundwater wells from the top!



3-5’ of additional bank height from record snow pack adds a ton of stream power to rain on snow events, many structures get reworked. Pics from April 5, 2023

Even with all that power, any structure of decent size that had floodplain connectivity (like the one below) survived and caught what was moved from upstream. Highlights the importance of WIDTH in the stream power equation—it’s the only thing we can change.

Reach Scale Effects

PBR is both fractal and iterative, with watershed and reach-scale treatments, structural complexes, and individual structures all working with and similarly to each other.

Zooming in a little bit, here's a smaller build we did in the Bootleg fire footprint.

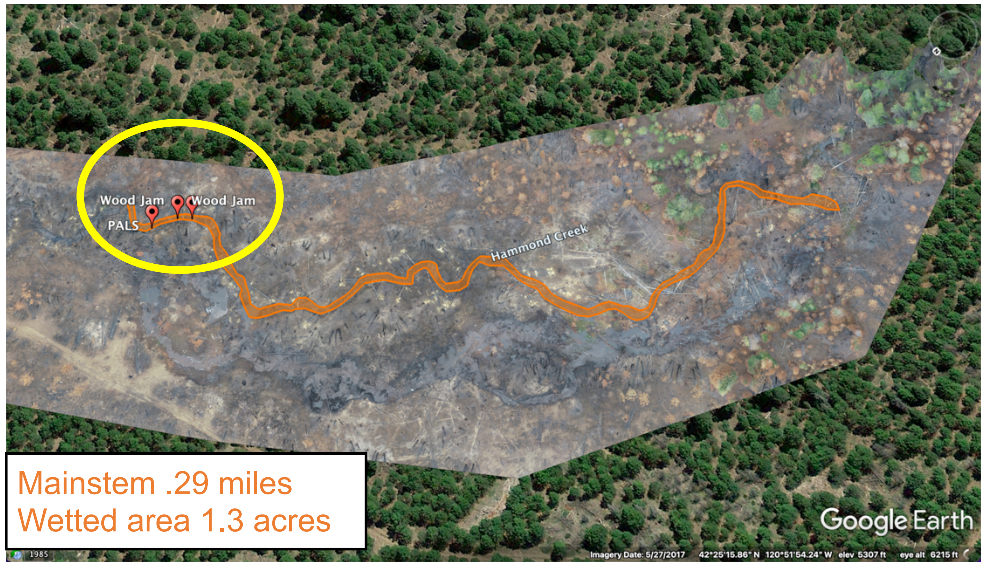
We built three packed logjams on the mainstem in a morning—a complex which connected to remnant channels on the floodplain and added 9 channels, 6 confluences and 162% more channel length.

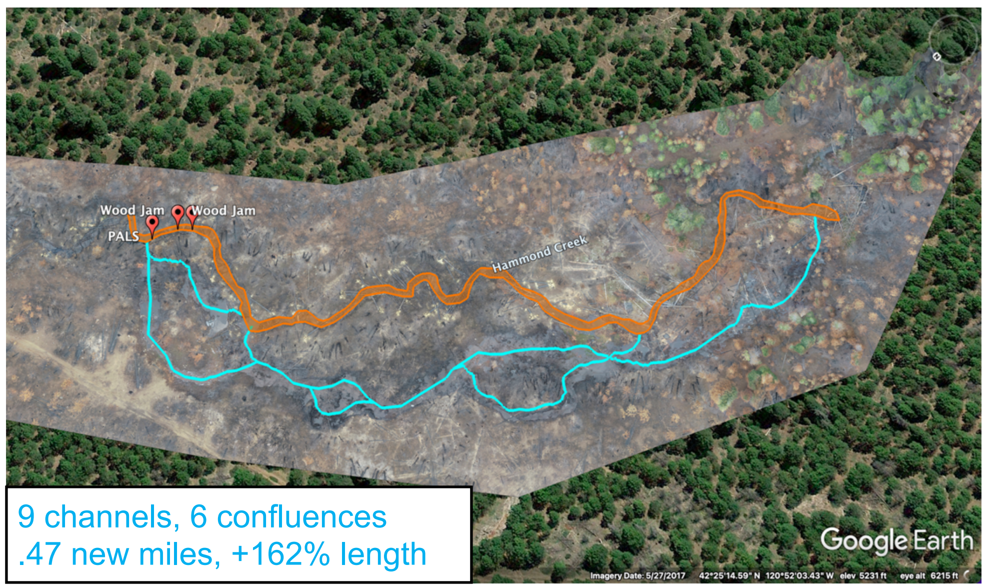
Once we'd built out the floodplain we had 448% more wetted area. And these results are by no means extraordinary.

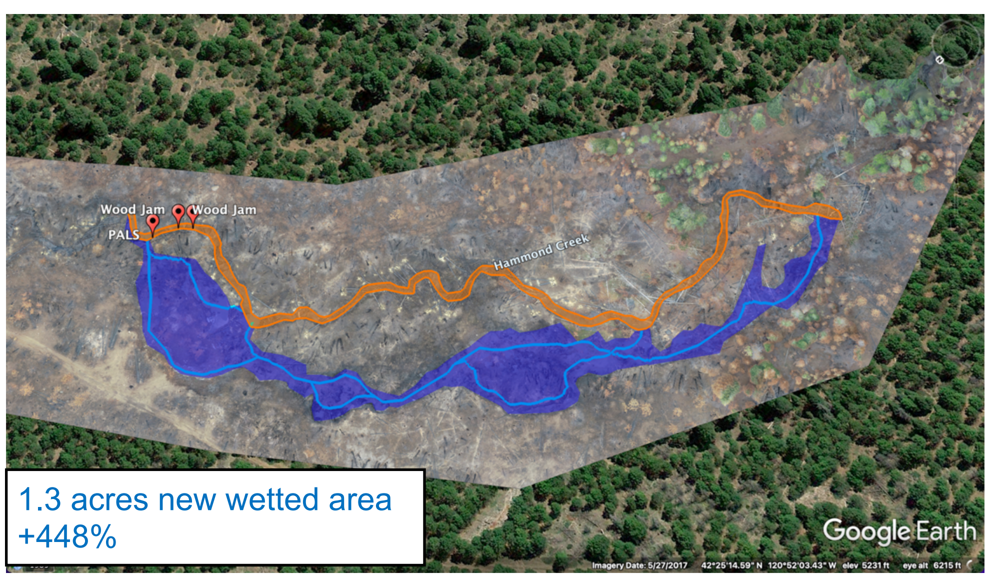
This build could be replicated by any competent practitioner with a decent team in a single working week.

Getting these kinds of results comes from building high-density complexes at strategic points, not obsessing over a single giant structure.

If you find yourself worrying about one structure, build 10.

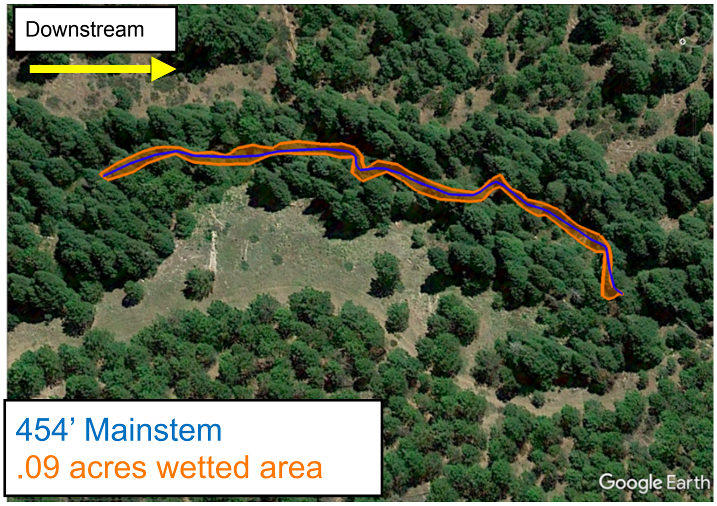






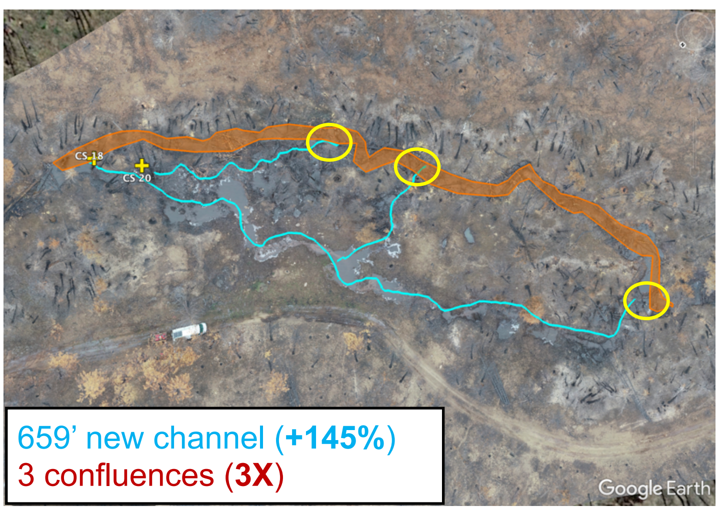
Reach Scale Effects

Here's another small example from the same watershed—the whole meadow is maybe 2 acres. But, since this work is a fractal, you're looking for complexity *at all scales.*

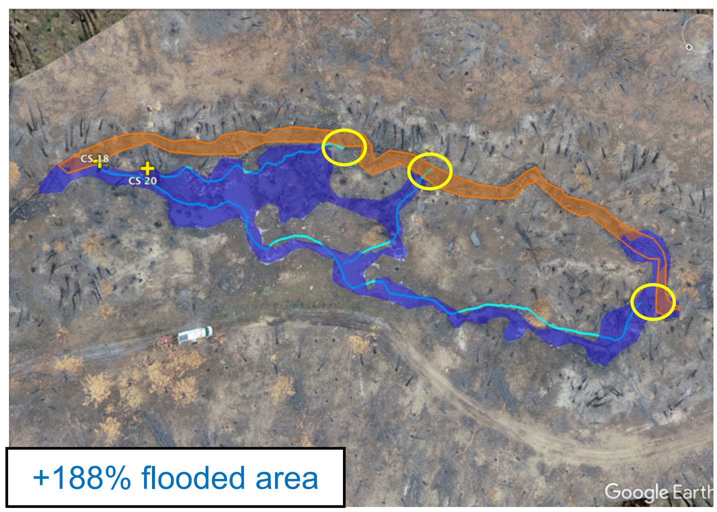


On July of 2021, the Bootleg Fire burned this area, and as you can see below there was hardly a single tree left in the area with any foliage on it. That wasn't just "a tragedy" either.

It was an opportunity. The stream suddenly had access to water, sediment and wood that had been trapped by the over-stocked forests for decades, liberated by the fire. We built 16 structures and the system did the rest.



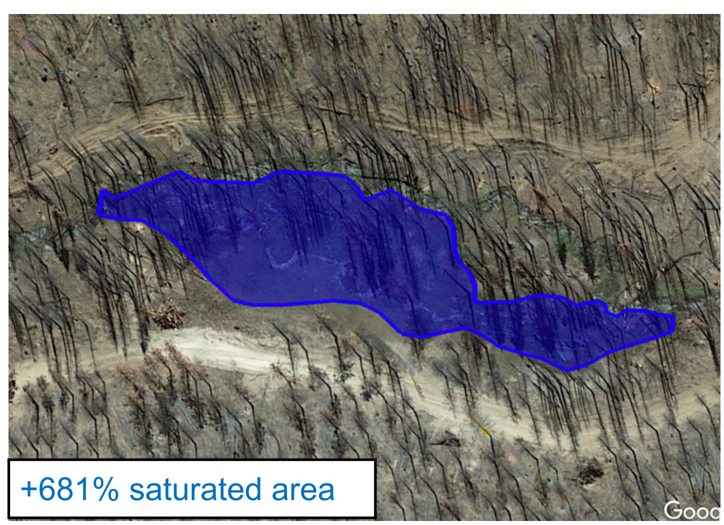
The results shown here are the least of it. When we came back 2 months later, after some serious rains, there were places where it was so complex we could barely find the formerly-incised mainstem.



Fire As Restoration Opportunity

We'll go into this more later, but I'd like you to mentally reframe fire as an opportunity for the rest of your life. It's a one-time chance to do a century's work in a few years, but that chance doesn't last. If you miss the sediment pulse, it's gone forever.

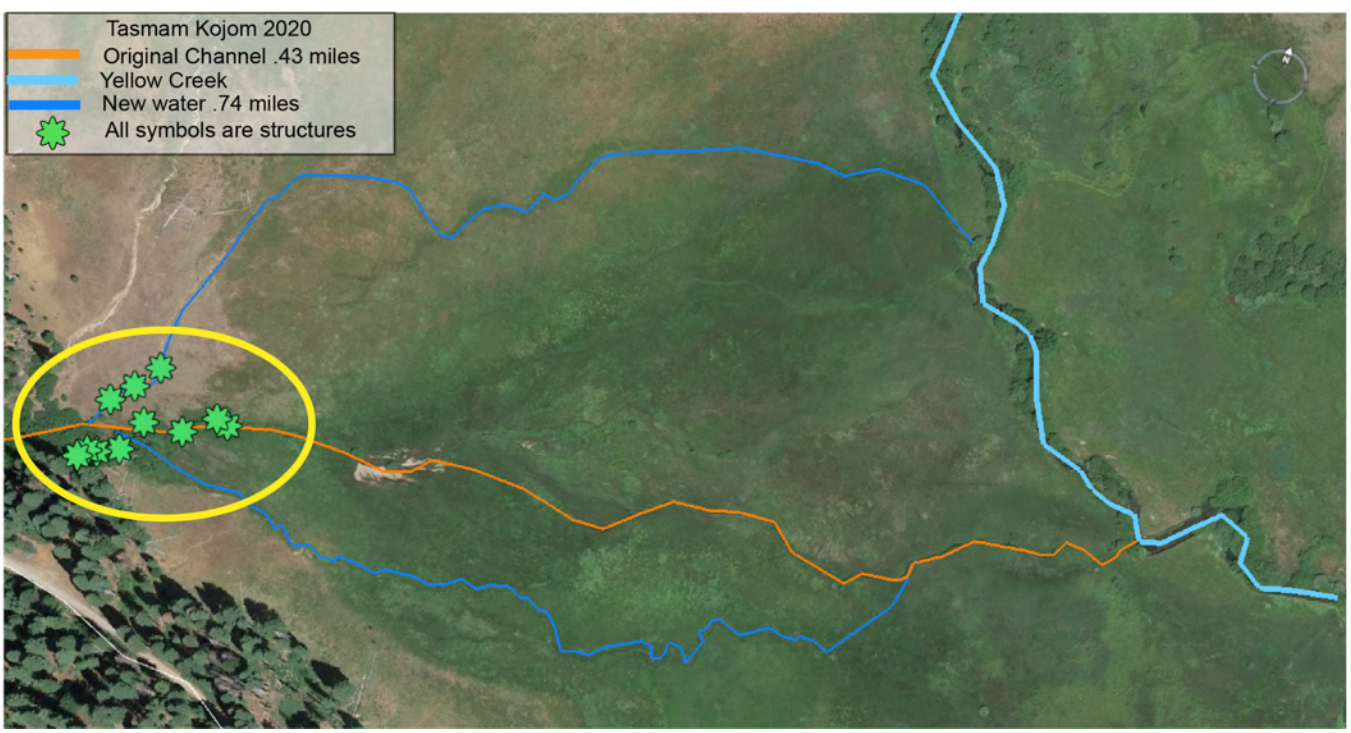
If you just had a fire in your watershed, you're holding a winning mega-lottery ticket that expires at midnight tonight, so act with appropriate urgency.



Structure Complexes

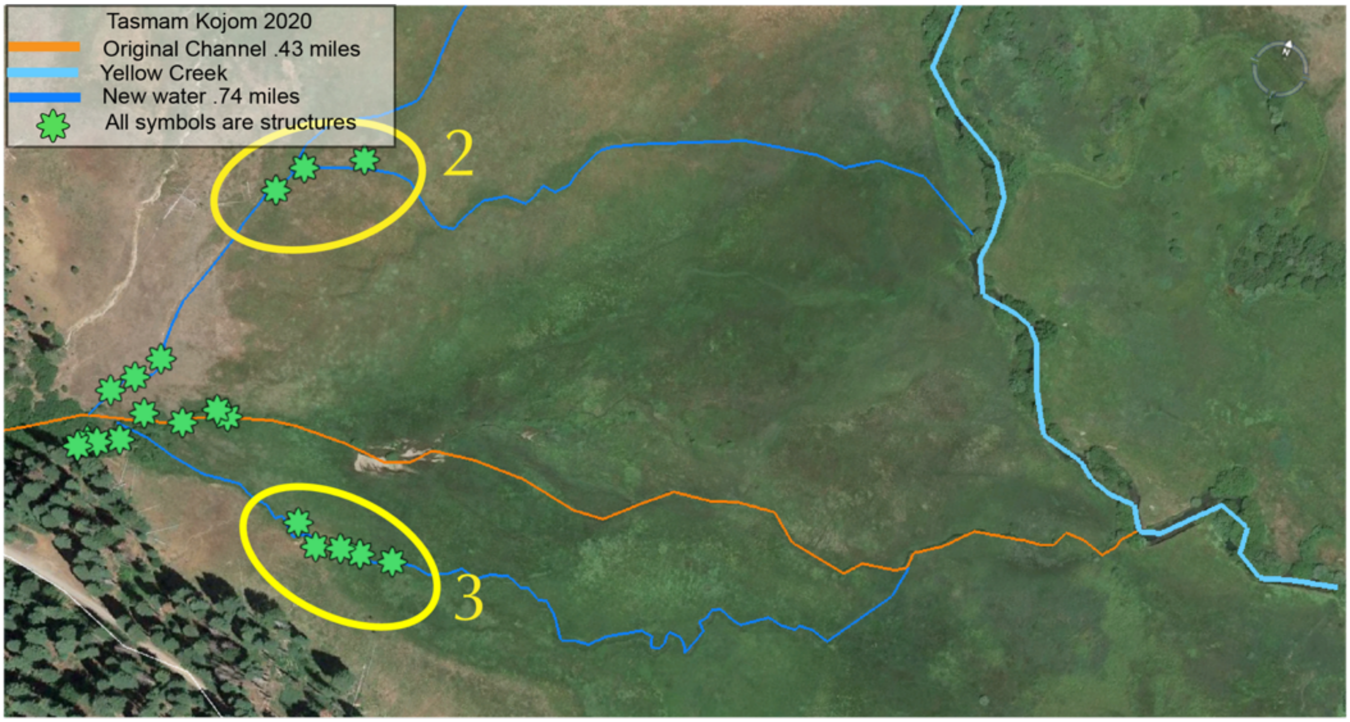
This example is also from Tasmam Kojom. The smaller, incised, single-thread side channel we worked in has a steep drop into Yellow Creek at the confluence. The surrounding wetlands is surviving, but has decreased in size, and doesn't stay as wet as long. Our restoration goals are reactivating the remnant channels and restoring this important wetland habitat.

Below we've added the first 11-structure complex to split the flow and create 2 new active channels, adding .74 miles of stream. The most active structures are the first (most upstream) three, as they actually do the heavy lifting where the flow diverges. The next 8 serve to hydraulically support them, by keeping the water deep and slow.

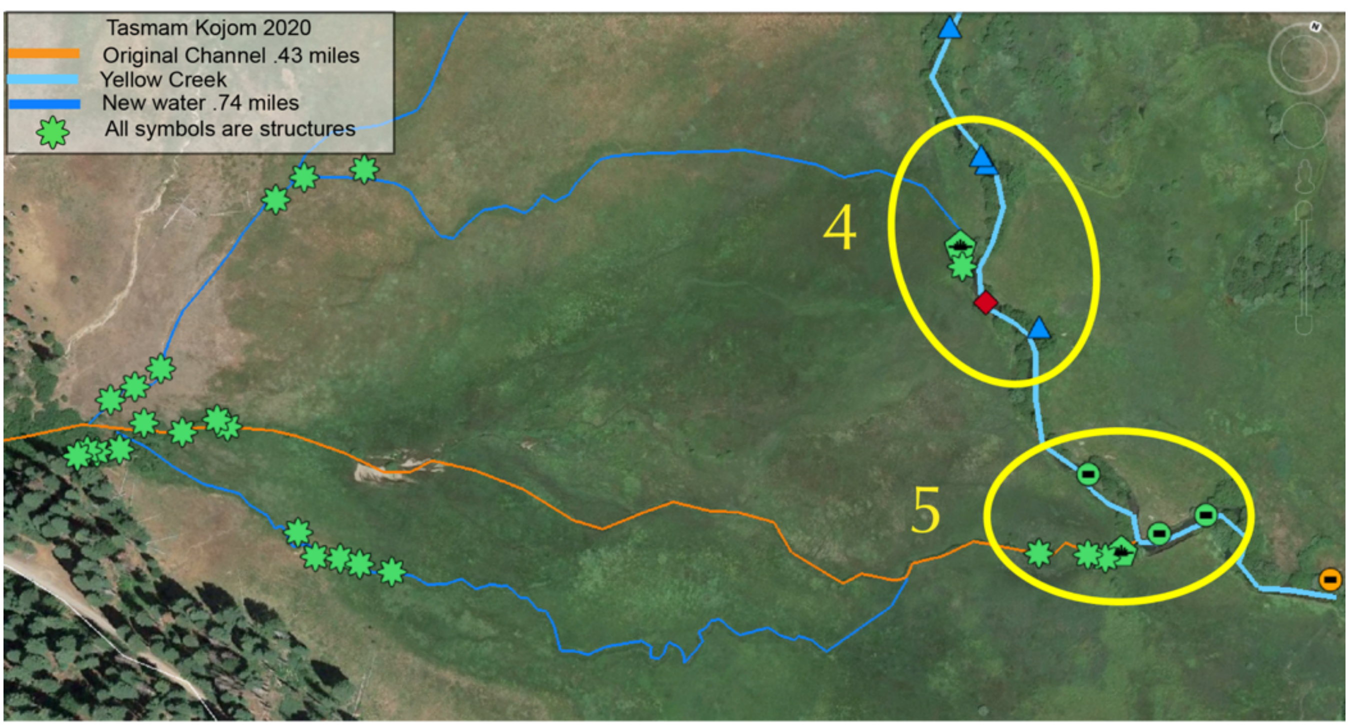


Structure Complexes

As the build continues, complex 2 splits the flow again, adding still more channel length (not shown in the totals) and complexity while storing water high in the landscape for late season flows. Complex 3 is a series of pools that will make great frog habitat and increase groundwater infiltration.



Here the build is complete for year one. Complexes 4 and 5 arrest head cuts that might otherwise migrate up into the meadow, and retain water on the floodplain longer. In turn, the Yellow Creek structures raise the water height at the confluence to support a higher water table, and reduce the drop from the floodplain into the mainstem to prevent erosion.



Evolution of a single structure

Now that it's clear how little importance a single structure holds, let's dive into the weeds for a bit and look at some of the ways they might evolve over time. The structure below is in Red Clover Valley, was built by another company, and we were asked to repair it. It's important to note that this is not a structural "failure", and my preference would have been to leave it as shown below. I'll tell you why in a moment. For now, note that it was built tight against a tall, unstable bank, and so evolved to an open-ended structure.

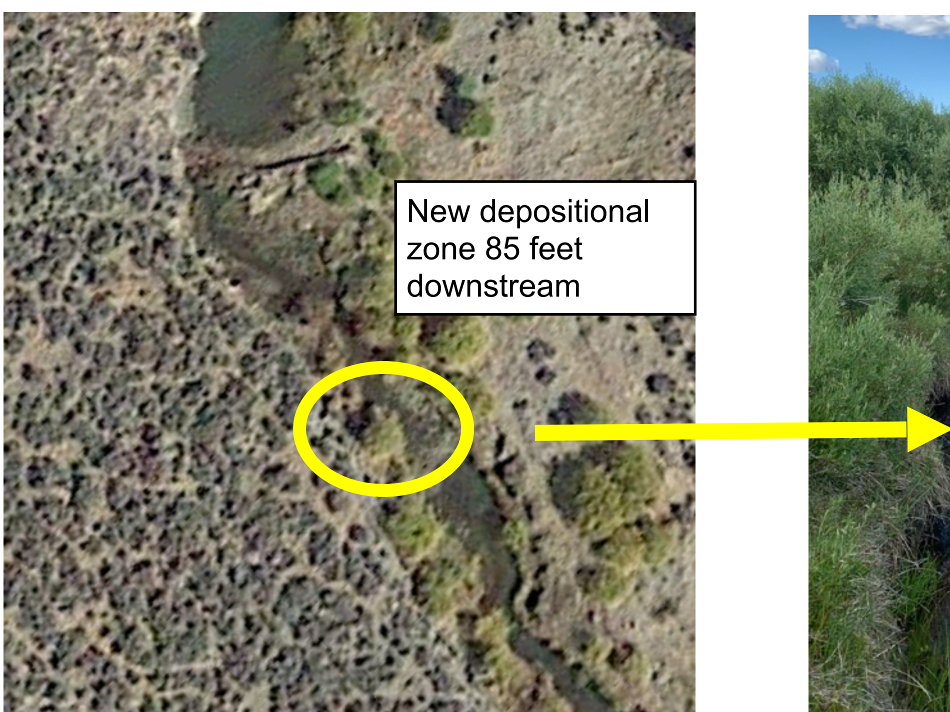
Here's the view from downstream, clearly showing how it has scoured under, piped, and is rapidly recruiting good amounts of highly mobile bank material.

We frequently design and build structures to do just this, which is much faster and easier than building a huge spanner like this one.

Evolution of a single structure 2

At the request of the funder, we re-packed this structure and shored up the corner. It looks good in the photos below, but did exactly what you'd expect—it routed around a second time in the same spot less than two weeks later.

In form-based construction, this would be a very expensive failure. But in process-based restoration, we're always looking a couple of moves ahead, and here's the next one. The river is now *showing us where to build*—just downstream where that sediment has settled out. This natural deposition reveals a low-energy site where a structure would be likely to persist and help aggrade toward floodplain connection. The move is to build here and take advantage of the evolution that's occurred, rather than repairing the structure again and fighting the site. In the example on the following sheet (from a different build) we did exactly that.



From structure to complex

The streambed here was pretty flat and relatively uniform, with minimal complexity and not much gravel sorting or oxygenation happening. Not terrible for fish, but not very dynamic either.

We built a decent-sized channel spanning PALS (Post Assisted Log Structure) right there, with several trailer loads of encroaching conifers. The right side is tied into a willow grove and was really hard to pack, so we moved on upstream instead of spending more time on it.

And this happened a couple of weeks later. That's about a thousand square feet of recently mobilized stream bed material, neatly sorted from largest to smallest into perfect spawning territory.

The PALS is becoming a bank attached meander maker, and sending flow river right. It's impossible to predict exactly what any given structure will do, except that it will be more complex and interesting than continued incision.

In the fall we took that new deposition as a cue to keep building, and so added a bank-attached structure right on top of it—this is the conversational element of the work.

We asked the river, "channel spanner?", and it replied, "Nah, I'd rather have a bank attached". So we left that one and built a second one too.

From structure to complex 2

These photos are taken a year later, after the Dixie Fire burned this site, and then a big atmospheric river swept through.

You can see the structures were lightly toasted but survived the fire, the upstream-most channel spanner has almost no hydraulic head, and the lower bank-attached is driving the meander farther downstream and producing more great sorting.

Taking these cues from the stream, what might you build in the below photo, where, and what do you think it might do over time?

The answer is always, "it depends", but here are some ideas:

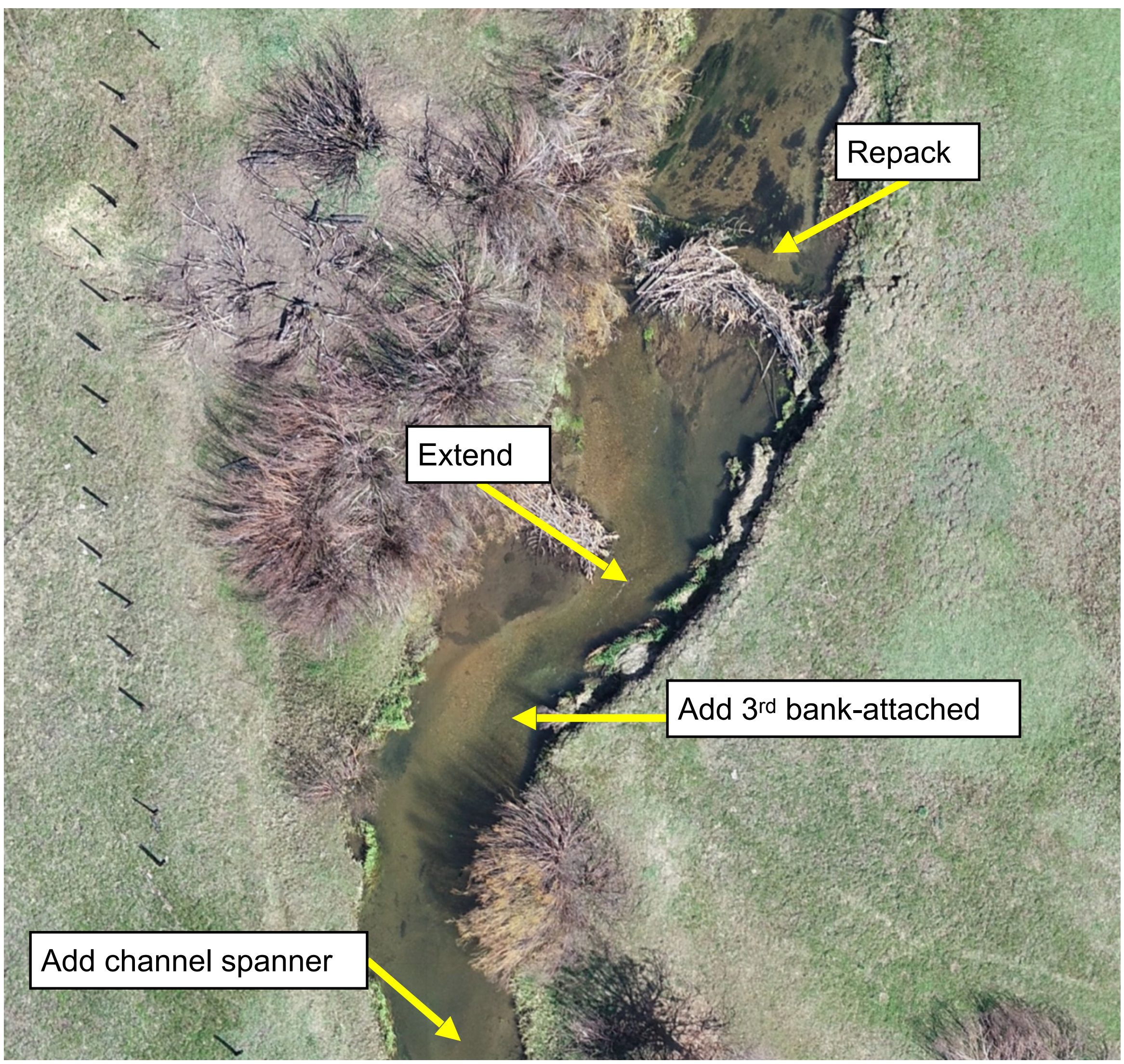
Repack the upper structure for deeper ponded water and more groundwater recharge.

Extend bank attached to recruit more bank material and support the upper channel spanner.

For more geomorphic dynamism, we might add a 3rd bank attached structure on river left.

We could add a channel spanner downstream to catch the sediment coming out of the upper structures.

My favorite answer is "yes, and."



Evolution of a single structure 3

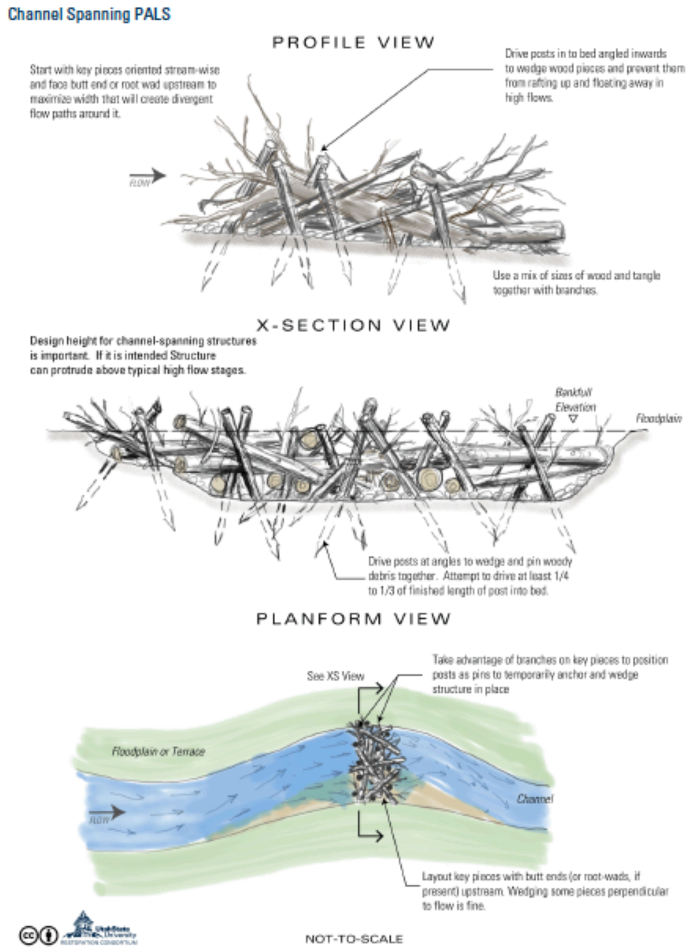
Another example is a small, early structure at Doty Ravine, built and then abandoned after year one as a test. Normally, we'd continue the conversation and add more structures, but what happened was really interesting.

It starts as a spanner in 2018, and observe the dramatic change by mid-2019. It aggrades a bunch of gravel and routes left, becoming bank-attached. Then it drives the meander another full channel width, stabilizes, and now there's a vegetated meander where before it was a straight, narrow channel.

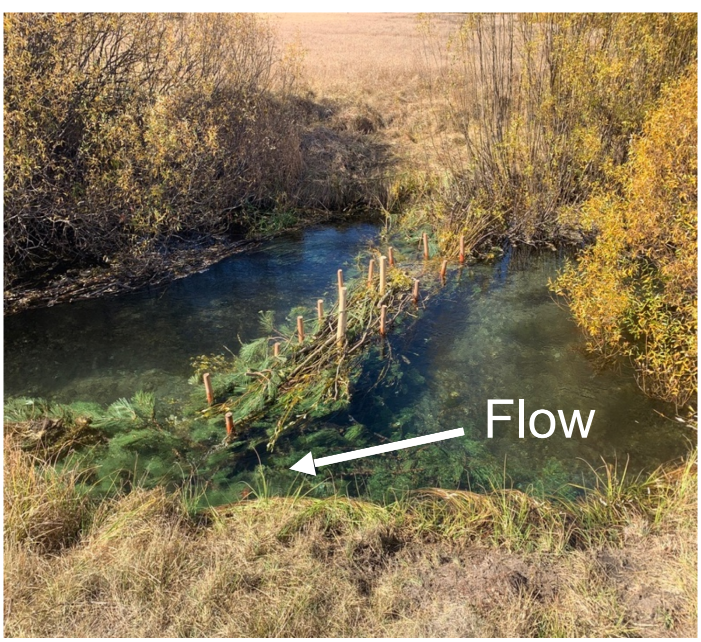
Remember—it's only about the structures until process takes over, and the beavers will have this drowned any day now.

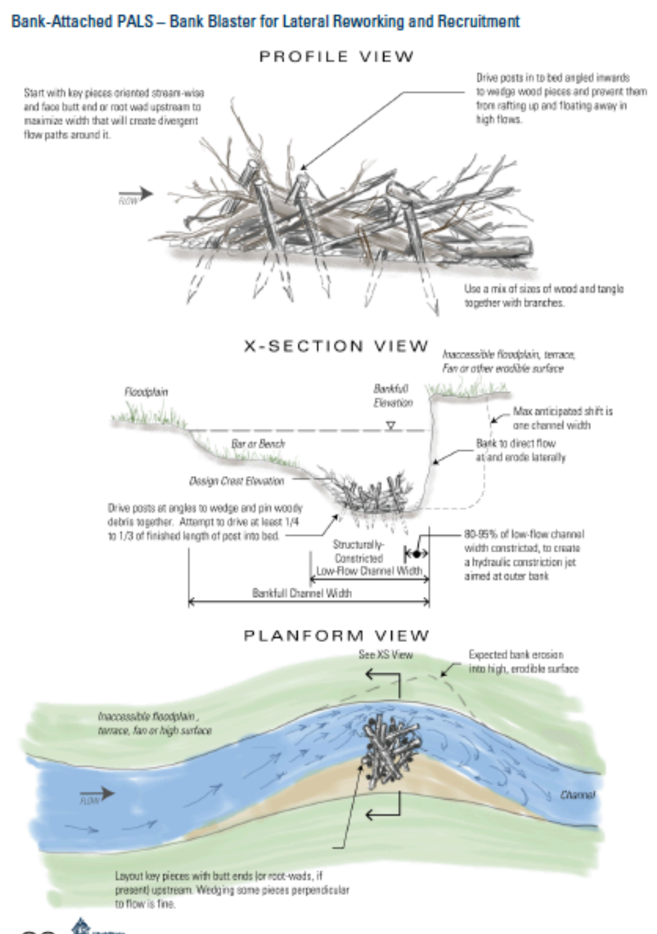
Post Assisted Log Structure (PALS)

Just what it sounds like—logs, brush and branches assembled to mimic a natural wood jam, then reinforced with posts. Can be packed with gravel and mud to add water height. Below is a channel spanner.



This PALS is intended to create a meander in an otherwise straight stretch of stream, reduce stream power and add sinuosity. Sediment recruited from the left bank will accumulate downstream, making the channel shallower so the floodplain is more likely to connect.

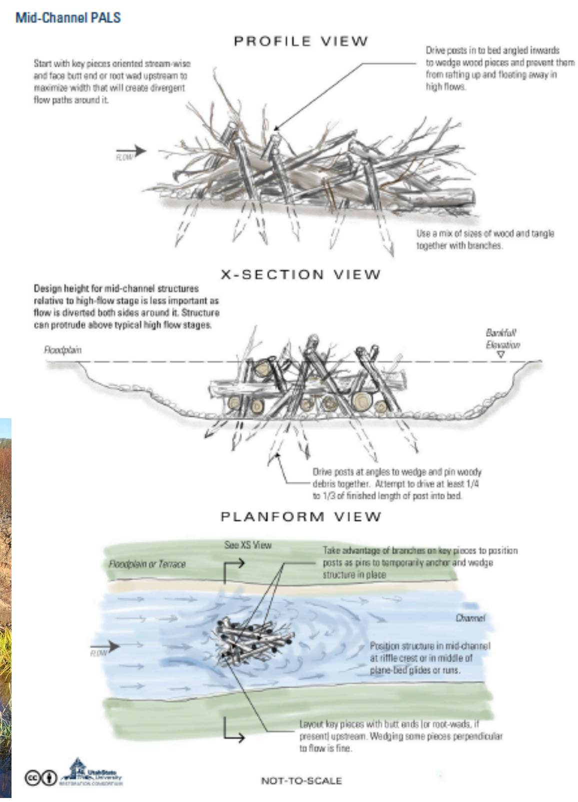




Mid-channel PALS

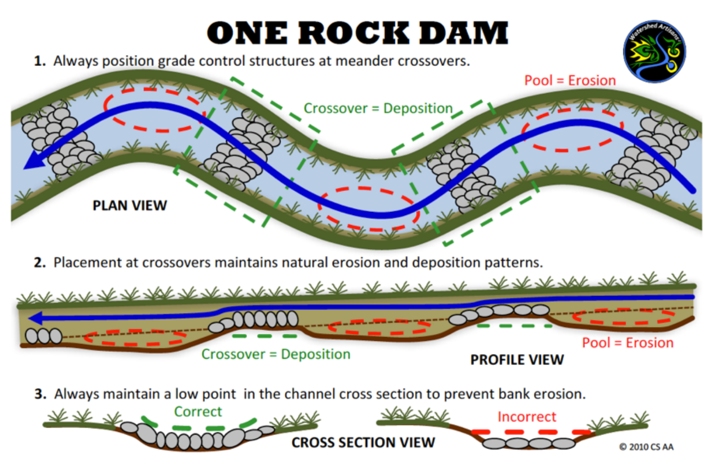
A mid-channel jam is an interesting critter. They work to split flow, which widens the channel, reduces stream power, and recruits fresh sediment from both banks.

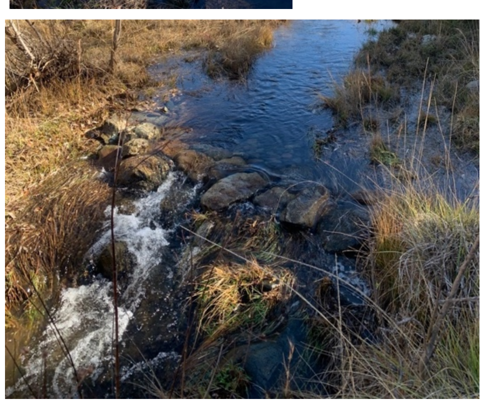
The cool feature of these is they can also readily evolve into a channel spanner or a bank blaster facing either direction, depending on what kind of debris comes downstream and whether beavers adopt them. The edges also produce great fish habitat, and promote sorting of spawning gravels.



One-rock dam

Obviously, ours are a good deal messier than this diagram—the real world always is. Pretty simple, it's like a dry-laid stone wall running across the stream. The real magic is in placement at key points in the riverscape that drive process and improve riverine and riparian function. They're also great fun to make.





Use whatever you have—rabbit brush, rocks, juniper, sagebrush, pine slash, cow bones, anything.

These two are nothing but conifer trunks, slash and gravel

Long-dead junipers and recent willow cuttings work fine


These are all hand-placed rock dams





Tiny—ankle deep water and an arm span wide.

Medium—waist deep water and 10'—20' wide.

Large—chest deep water and 30’ wide.

XXL—swimming depth, 40’ wide, and colonized by beavers year one.

Learn From Beavers

Unlike an excavator/dozer build that fossilizes the channel in a single season and calls it done, process-based restoration is a relationship.

Like all relationships, it takes work, evolves, and yields greater rewards over time.

While we don't have 5 million years of practice like beavers do, we can emulate them by letting the water do the work, and staying engaged with the landscape over time.

Each successive intervention should be easier, faster, less intensive and cheaper, building on the work already done.

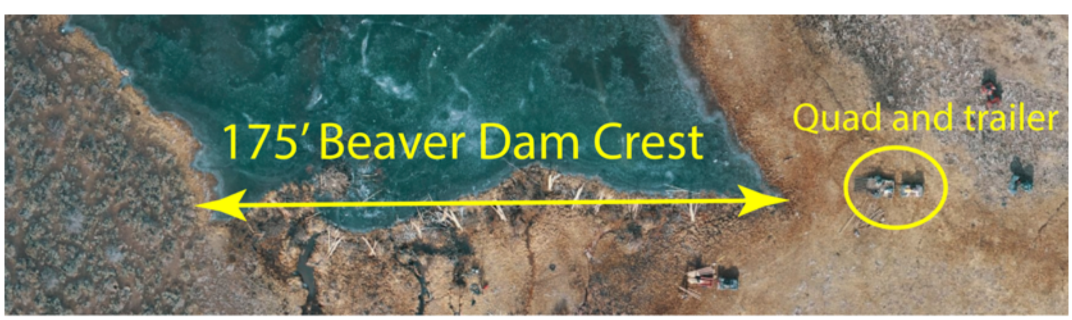
Support Beavers

Lack of beavers is a source problem in most Western streams, so it makes sense to help beaver dams persist by adding posts.

That way the beavers have more energy for expanding habitat and breeding, rather than making repairs.

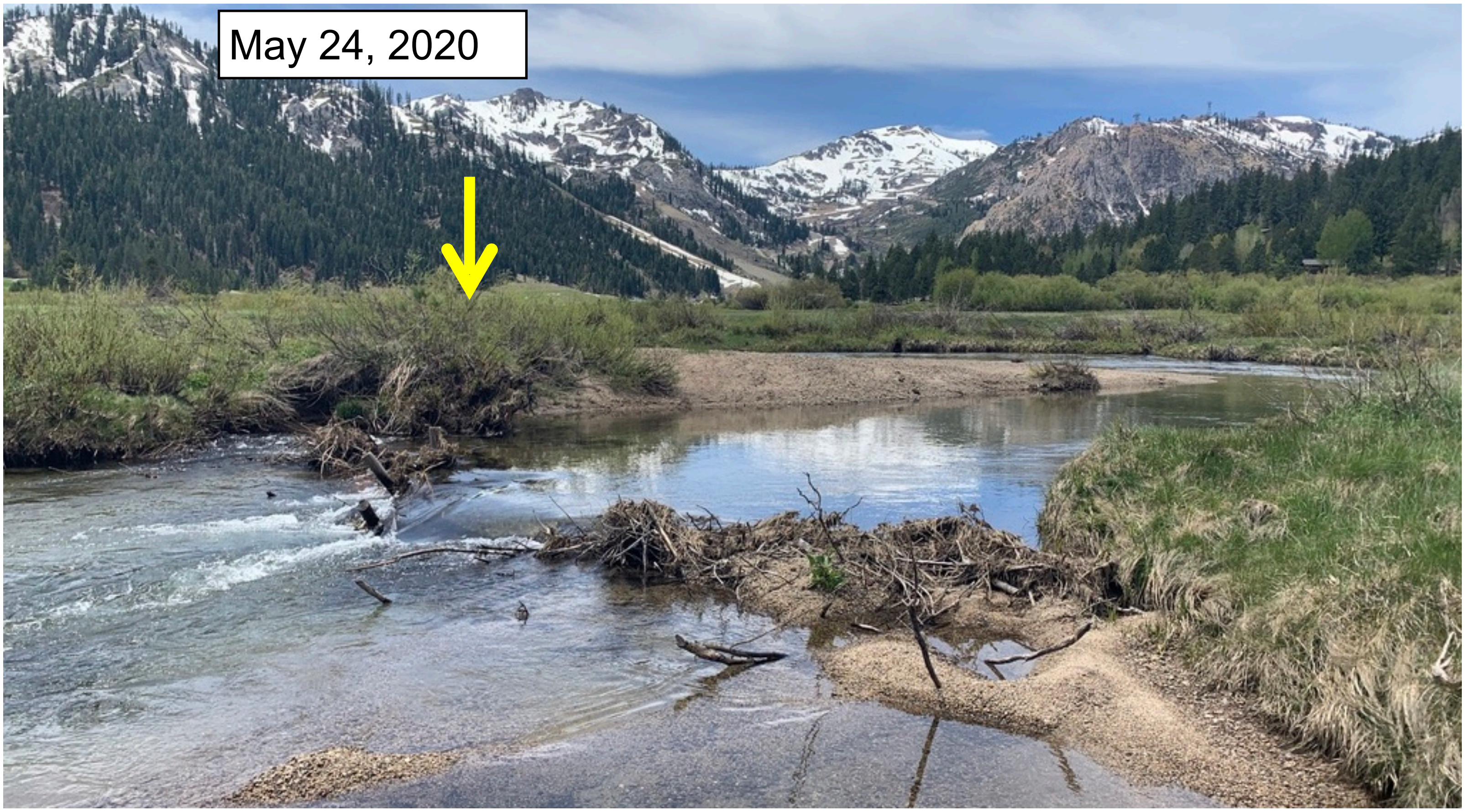
A very large dam like the bottom right can be reinforced in just a few hours, and small ones in a matter of minutes.

They'll still evolve over time like all beaver dams, thus ensuring dynamic equilibrium.



Enlist Beavers

Other folks built this structure which opened up, so we rebuilt it, and then the beavers took over and produced stunning results in under a year. For free. Without having to file for permits or wait for anyone.

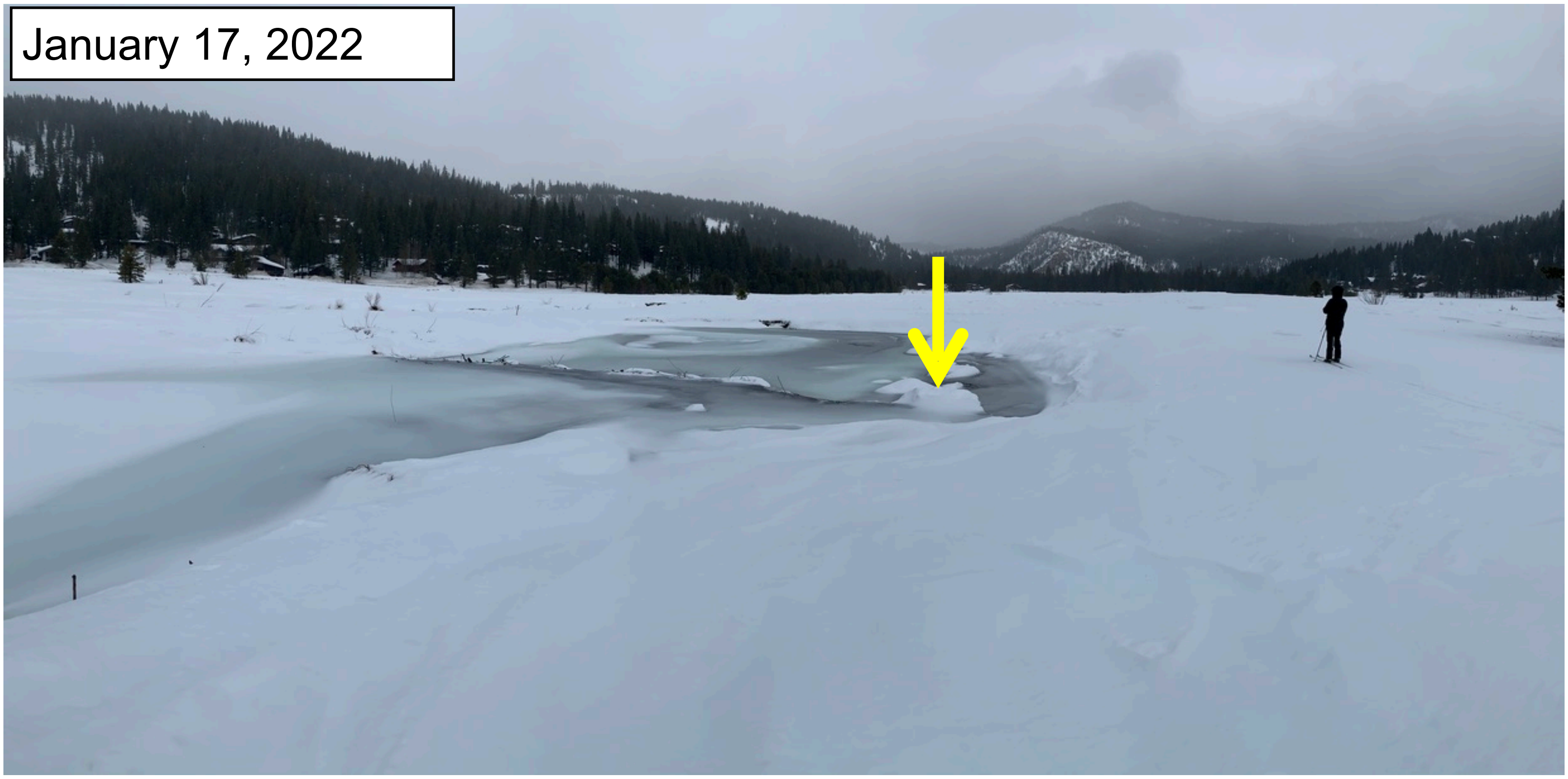


Enlist the Beavers

And not satisfied with merely stunning results, the beavers kept working until the dam was twice as large. And they're still going—the dam in the photo has since become a meander, and they've built two more structures upstream.

Enlist the Beavers

Now the river has a meander because the dam has evolved again. This evolution of a dam is part of the 5 million year co-evolution of beavers and salmonids, and illustrates ongoing passage around and through beaver dams over time, when there is enough water that passage is even possible.



Enlist the Beavers

The structures are also driving some pretty impressive deposition. Looking downstream from the beaver dam, here's a new bar from last winter's flow that's still developing. Looking upstream, we've got yards of sediment piling up as well, with this little 3-structure complex doing amazing work now that the beavers have taken over.

Enlist the Beavers 2

Here's another great example of how humans and beavers can work together and really make a difference for a system, in very short order. The below images are from Deming Creek, up in the Klamath Basin. This was the biggest lift we'd built to date—a stack of 4 structures that raised the surface water elevation a solid seven feet to gain a long-disconnected floodplain. If you read the LTPBR Manual, you'll find that this sort of ambition is more than double the maximum recommended lift height for a single build season, and thus something of a risk. But it ran from August late into November before the water dropped enough to shut off. There are beavers in the system, and they'd adopted another structure we built downstream (by the next morning, no less), but then abandoned it in the winter. So I wasn't sure if they'd use this one, but they took it over this Spring.

August 18, 2023

March 14, 2024

Fire As Restoration Opportunity

Fires provide rapid wood and sediment loading at landscape scales, offering an opportunity that cannot be matched by any human endeavor, no matter how much diesel we might throw at the problem.

This incredible, literally once-in-a-lifetime lottery winning of potential is almost always squandered by regulatory agencies that refuse to act in a timely fashion. The sediment pulse then washes away to choke spawning gravels on its way to clogging irrigation canals and ultimately wasting ever-scarcer reservoir storage that costs millions to reclaim.

If employed in a process-based restoration strategy implemented immediately after the burn, this material can rapidly aggrade incised streams to reconnect floodplains. And by ”rapidly”, I mean in weeks or months, rather than decades or centuries. It’s past time to begin taking advantage of fire as a restoration opportunity. The below is just one of many, many examples of the potent interaction of fire, water, PBR, and beavers—truly the next frontier in restoration.

Figure 6 – Example of structurally-forced resilience to fire where beaver dam activity kept parts of the riverscape from burning, providing critical wildlife and livestock refugia during the fire, and assisting in post-fire recovery. Example from Baugh Creek, Idaho.

While less well-documented, structurally-forced complexity may also yield greater resilience to wildfire. In one anecdote from central Idaho, beaver dam activity helped preserve riverscape structure and function in the heart of a 65,000-acre wildfire (Randall, 2018). The majority of riparian areas within the fire perimeter burned right up to the banks, leaving the floodplains black with ash. However, reaches that supported beaver dam complexes remained largely green and unburned. In larger valley bottoms, beaver dam complexes can act as actual fire breaks during the fire. In narrower valley bottoms like that shown in Figure 6, these complexes were not enough to stop to fire but still provided critical refugia during and after the fire for both wildlife and livestock. Moreover, in the post-fire recovery these are critically important habitats and seed banks for recovery as well as helping keep the riverscape resilient to elevated runoff and or debris-flows post-fire.

Fire As Restoration Opportunity

These photos are all from the Dixie Fire footprint, taken two weeks apart, from roughly the same points. In this steep creek we built over a hundred structures in 5 days, because we wanted to catch the fresh sediment the fire would bring us, and a week later got the same atmospheric river that did all the good work in the “structure to complex” example.

That burst of **Energy**, coupled with the sudden availability of **Materials** coming off the fire scar and our structures, resulted in aggradation we’d hoped for over years, happening in days. The light colored stuff in the photos is new sediment.

Fire As Restoration Opportunity

These structures went in really fast because we were just dropping trees and piling them up, and there's nothing complicated about that. This one took about 20 minutes. There was no available green material, so we depended on hydraulics to do all the deposition for us, and in the next stage we'll need plant **Energy** to stabilize the captured **Materials.**

Fire As Restoration Opportunity

Now imagine this kind of thing happening in all your incised creeks—obviously it won't happen overnight unless you have a fire, but you can see dramatic results quite quickly with PBR.

This structure is my favorite. You can see a crew member for scale, and the stump in the upper left, and below is all the fresh new sediment we caught, taken from slightly farther away..

Practice Mimicry

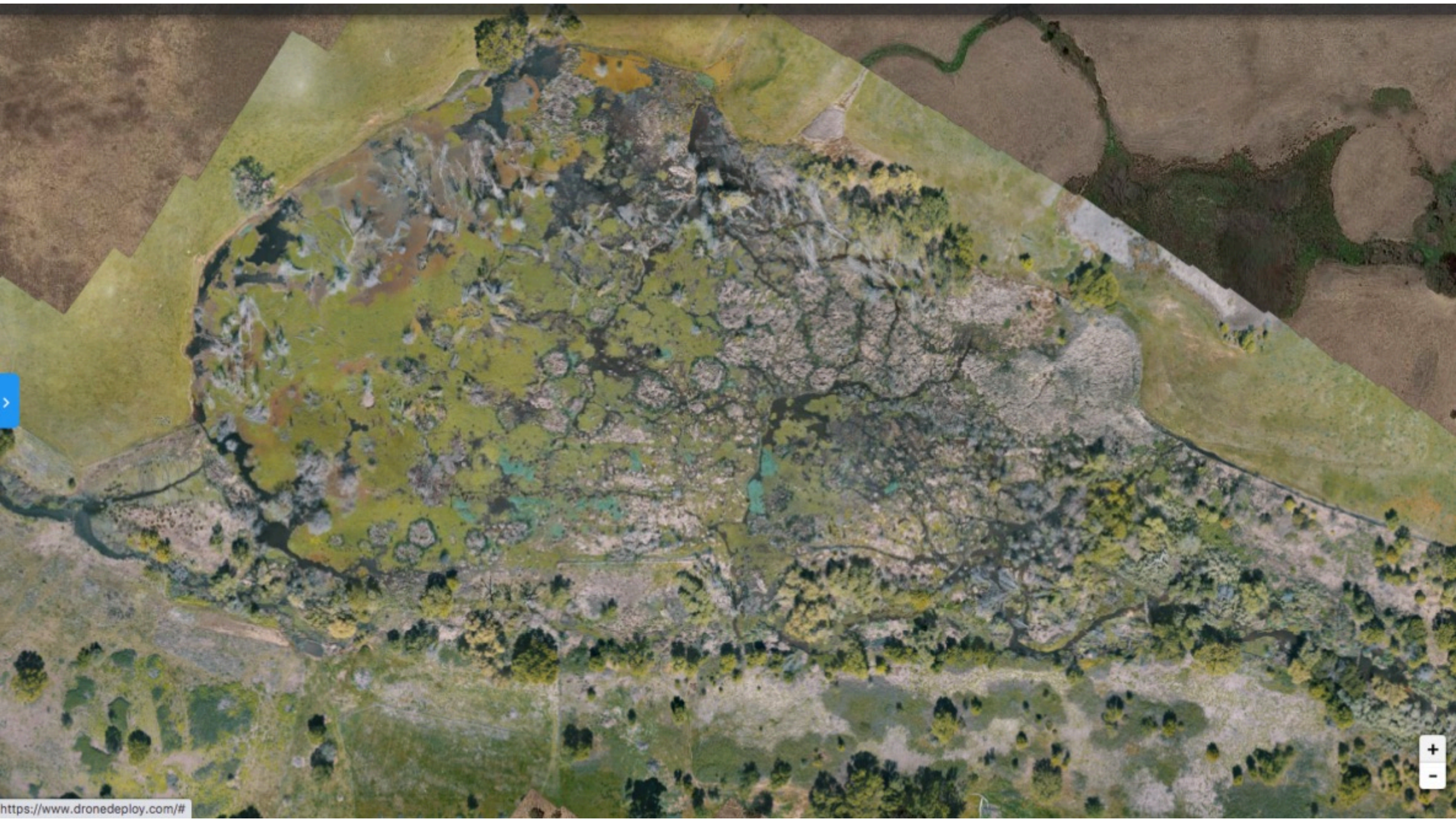
What this really means is that if you're building something that's immediately legible as human-built, something neat, tidy, linear, and evenly spaced, it's almost guaranteed that you're doing it wrong. Beavers don't build wicker, wood jams are always messy, and nature *hates* straight lines and square angles. A perfect example of a technique I no longer employ, this first example actually worked really well initially, and I can't help thinking that if we'd used the same amount of time and built 5 messy ones instead, we'd have gotten a lot more floodplain activation and complexity.

This is more of what we're building now. Since we don't care how they look they're much faster to build, and with 10x the material in each they have more interaction with the moving water and better survivability in higher flows. The lower left is 15 conifers reworked and washed into one of our BDAs, and it's doing great work

What success looks like in PBR: The End Point, at project scale

Success is simple to define: ecosystem function should improve over time, and interventions should become easier, faster, cheaper, lighter, less intensive and less frequent until the on-site energy has taken over the build entirely. This applies many different ways at many different scales, fractally:

- The highest-level restoration goal is to arrive a point when any human intervention would be either a waste of resources, or actively working against the recovery processes already underway. This end state is much, much easier to achieve when there are beavers in your work area, especially if they're protected from casual slaughter by "sportsmen" and not constrained by infrastructure. You did start by addressing infrastructure, right? Here's a drone deploy photomosaic from Doty Ravine that says it all—there's nowhere in this absurd mess that it makes any sense to work:



When you see a clear, obvious, stable recovery trajectory that is resilient in the face of most likely disturbances, this is a good time to take a pause and pivot to monitoring, until you get a reworking flow or a fire or something else that could set back the work. Then go in, take what the system has given you, and use the new opportunities now present.

What success looks like in PBR Reach Scale

Reach: If all the material you've added is still in the reach you're working on, that could be a success. If the complexes are driving recovery, and the fluvial effects are showing through the entire reach, you're getting somewhere. Shallower groundwater, increased channel and meander length, any of the complexity metrics should be improving, and one really good sign is seeing something surprising that you hadn't thought of that appears after a big flow event.

Perhaps the single best success metric for reach scale analysis is up-valley flow. This is surprisingly hard to achieve, and a very common effect of beaver complexes. There are only a couple spots in this massively complexified, highly successful build on Yellow Creek where that's happening. As good as this looks, it's just barely getting started.

What success looks like in PBR Complex Scale

Your structural complexes should still be interacting in some fashion after a good flow year, and driving recovery processes like aggradation, sorting, improved vegetative productivity, shallower groundwater and so on. It doesn't matter at all that they look the same as before. In fact, that itself might be considered a degree of failure, unless there's been too little flow to change things around.

Each complex should also have a clearly explicable restoration goal, and be fairly assessed as to how well it's doing. Below you can see photos from a stack of 8 or 10 structures that are all supporting each other, and drowning several headcuts including one that's 6+ feet tall. The restoration goal was simply to arrest the incision and headcutting, but a couple of the structures have connected to the floodplain at base flow, and are now adding significant sheet flow to the meadow on both sides.

What success looks like in PBR: Keeping the big picture in focus

Structure level analysis is mostly a waste of time, like a mental version of those glue traps for mice—get stuck on pointless minutiae, thrash around, make a bunch of noise and go nowhere. But, here goes: any given structure may evolve towards complete burial and stabilization by long-lived plant species, or complete mobilization, and as long as it contributes to *improved function of the build as a whole*, that's fine. Images from slide 26 "Evolution of a structure 3"—this is not a failure, but an evolution that resulted in improved sinuosity, new spawning gravels, increased complexity, and more vegetative productivity. But calling it a success is not to say you can simply move the goalposts and declare victory. Not at all. Like any real game of pool, you have to call your pocket—explain clearly and simply, up front, in 15 seconds, what you want the structure to do. Then you come back later and see if it did that. If not, what it did should be equally helpful, and equally useful to the riverscape as a whole, and you should know why it did that.

Maybe the channel spanner that opened up on one side has recruited sediment that's been caught by the next one in the stack. Maybe the mid-channel structure has caught a bunch of new wood and become a channel spanner. Maybe the bank-attached structure racked up a bunch of wood, scoured on both ends, and turned into a mid-channel.

Anything can evolve into anything else, if the system wants it to, and once the reworking is done, you'll know the system likes that exact configuration of materials, right there, for now. So look at each change as an opportunity to learn, iterate and adapt.

In this case, *I* failed to reach *my* short-term local restoration objective, which was persistent pool habitat right here, but the structurally-forced complexity did some good for the system anyway. Had pool habitat been a requirement, I would have taken the channel widening as an opportunity to rebuild this structure as a channel-spanner, and hoped that in the now lower energy environment it would stick. It's jazz, not baroque orchestra.

What success looks like in PBR: Human-placed, fluvially reworked

Structures moving around, changing shape, end-cutting, turning into mid-channels, and other instances of increasing water passage are one direction any given complex might go. Here's the other. In 2020, we built this little BDA at a nice riffle crest to see if we could pond up some water and drive some deposition. A year later it had tightened up nicely, but looked about the same.

Since it had held up, we wood-loaded the incised reach upstream with a bunch of trees, but weren't able to drive any posts due to a cobble-armored streambed, and most of the structures mobilized during the atmospheric river. Then the real magic happened: all those trees washed down to this little BDA and made a glorious mess.

This crazy pile of 20 or so conifers has aggraded several feet of fines in the structure, and caught nearly a foot of gravel at the head of the pool it created. It's also where the freshest beaver chews are, and this single structure activates literal miles of 3 other remnant channels annually.

Dream Bigger

"IN OUR EVERY DELIBERATION, WE MUST CONSIDER THE IMPACT OF OUR DECISIONS ON THE NEXT SEVEN GENERATIONS."

THE GREAT LAW OF THE IROQUOIS CONFEDERACY

Remember how time is more than just the calendar? Well, process-based restoration is about *much* more than just fixing a road crossing or building some structures. Part of what we're restoring is a sense of deep time, of the millions of years of geology that built your project site, the vanishingly tiny span of our work, and the immense potential effects of that work over centuries to come.

We're thinking about beaver dam complexes we'll never live to see that will flood thousands of acres, elk herds that will graze across state lines on meadows a hundred miles apart, and salmon that will spawn on the gravel our structures started to sort, long after our dams have silted in and been grown over by thousands of willows.

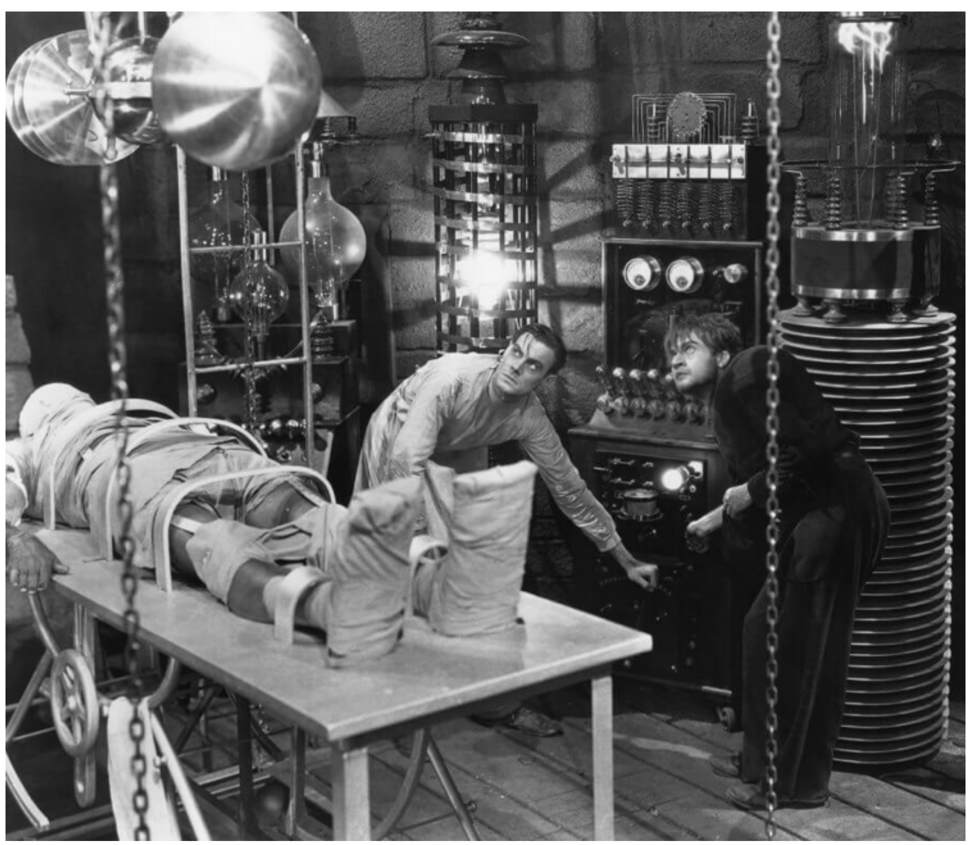
And we're thinking of the people who will drink that water, hunt those elk and fish those salmon—of a people whose future we can't imagine yet, sitting in the shade of trees our structures watered centuries ago.

Remember—it's all an experiment

A little humility never hurt anybody. After all, we are in the middle of accidentally running a planet-wide experiment in climate destabilization, and everyone is a mandatory participant.

That suggests we should be a little less sure of ourselves and our actions, and do nothing to limit the possibilities of generations to come.

It's why we build with hand work, using biodegradable materials, and never harden a channel or fight the site.



Join the many organizations practicing PBR

Here are some of the great folks we've worked with—many thanks to all of you, and apologies to anyone I've forgotten.

If you have any questions or would like to visit a build, please get in touch.

Swift Water Design

Process- and Beaver Based Restoration

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