U.S. FOREST SERVICE
NATIONAL STREAM AND AQUATIC ECOLOGY CENTER

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MOGOLLON RIM STREAM INSTABILITY ASSESSMENTS

Client: Coconino National Forest
Location: Mogollon Rim Ranger District, Arizona
Date of Visit: 9/20/2016
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Four impaired stream reaches were visited on the Mogollon Rim ranger district, specifically Buck Springs, Houston Draw, Dick Hart Draw, and Willow Valley. All of the reaches but Willow Valley have not had livestock grazing for about 10 years but do experience large impacts from elk grazing and browsing. These channels have been disturbed with historic livestock grazing and current elk grazing and browsing, resulting in incision of varying depths and spatial extent.

The riparian vegetation disturbance has resulted in channel bank and valley bottom instability, from the lack of root density and depth providing mechanical resistance to erosive flow. Local incision leads to deepening and widening of channels and floodplain disconnections, with increased unit stream power and shear stress. Low amounts of flow resistance also increase the erosion and incision potential of the stream reaches. Generally, woody vegetation, large in-channel wood, bedforms, and sinuosity are the primary sources of flow resistance in these channel types.

Restoration and rehabilitation options and recommendations are provided for each of the four visited streams. Expansion of the use of existing methods for arresting headcuts is one option. However, these structures will need periodic inspection and potential maintenance in perpetuity, due to the rapid drop in longitudinal profile at the stabilized headcuts being likely locations of future incision, especially during large flood events. Additionally, they maintain the current lower grade and impaired conditions (compared to pre-disturbance conditions) with constrained riparian hydrologic and vegetative conditions.

An alternative approach is to perform full meadow restorations, which is preferred where possible given the availability of sufficient borrow material and funding. Restoration of channel and floodplain connectivity provides for long term stabilization and ecosystem recovery, and can best satisfy goals and objectives. This is done through earth movement, grade control, revegetation efforts, provision of bank structures or large wood, and channel bed armoring and floodplain vegetation. Such restoration provides for a gradually-varied longitudinal profile, as well as appropriate planform and sinuosity

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INTRODUCTION

Four impaired stream reaches were visited on the Mogollon Rim ranger district, specifically Buck Springs, Houston Draw, Dick Hart Draw, and Willow Valley. These channels are experiencing incision of varying depths and spatial extents. All of the reaches but Willow Valley have not had livestock grazing for about 10 years but do experience large impacts from elk grazing and browsing. The reintroduced Mexican gray wolf is not present in the area, prohibiting tropic cascade culling and behavior modification of these elk herds, lessening impacts to riparian zones (Beschta and Ripple 2012). While livestock grazing has not occurred for some time, the impacts of historic grazing practices during the late 19th and 20th centuries are likely influencing current impaired conditions.

The current conditions of the four streams are presented in the next section. Following this, a condition summary section is provided, followed by restoration options and recommendations for each visited reach.

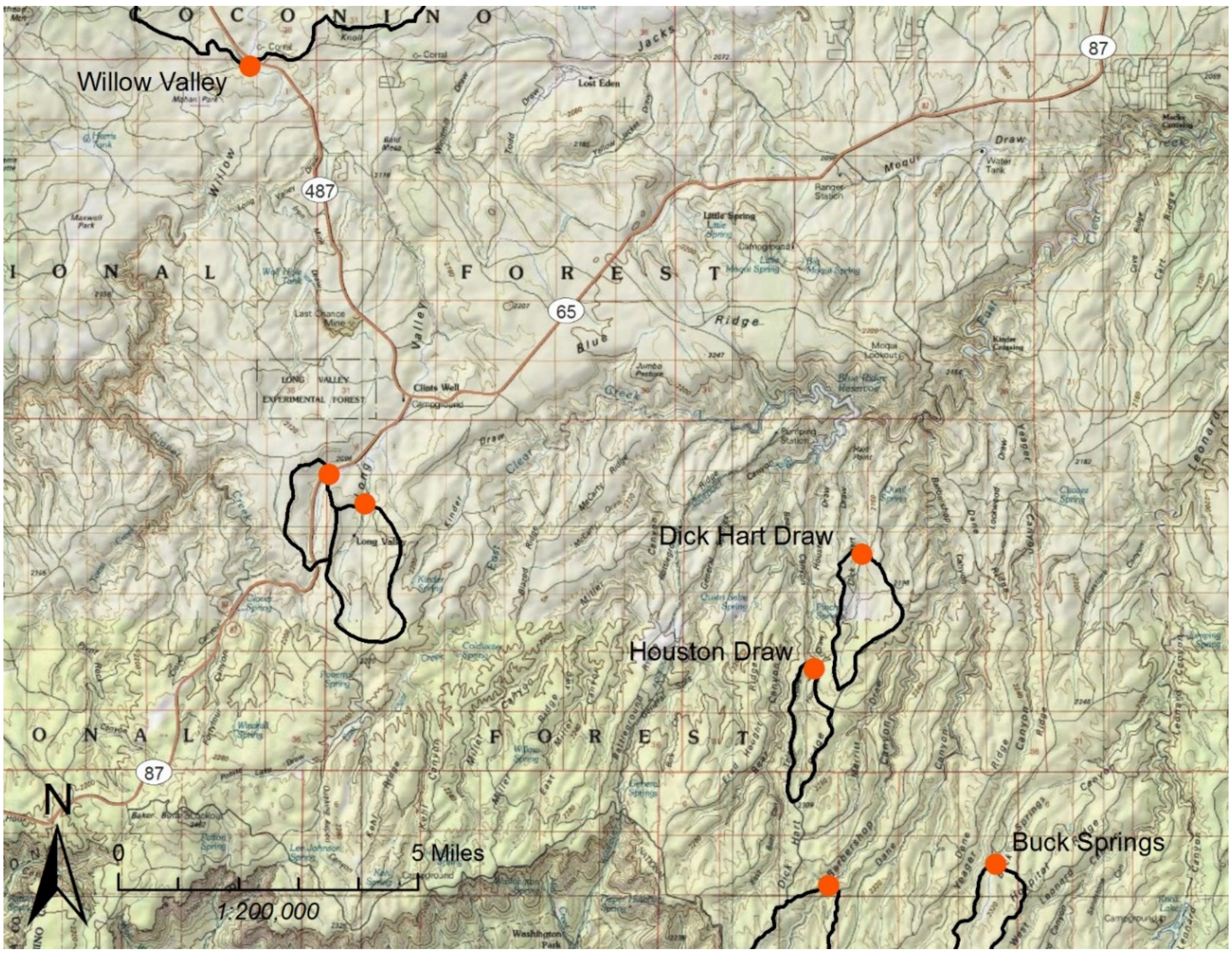

Figure 1: Impaired streams visited on 9/20/2016, in the Mogollon Rim Ranger District of the Coconino National Forest. The black polygons are the watershed boundaries. This map extent is south, southeast of Flagstaff.

CURRENT CONDITIONS

Buck Springs

The Buck Springs channel and riparian zone (Figure 2) is a wet meadow system that has incised in a number of locations, with prior restoration activities to counteract this incision consisting of rock and wood structures, and exclusion fencing. The watershed extent is 1.18 mi^2, with average annual precipitation varying from 33 to 36 inches (PRISM; Daly et al. 2008). The exclusion fencing clearly shows the impact of Elk grazing and browsing activities on the meadow (Figure 3). This watershed has been classified as "functioning at risk" in the watershed condition framework (Potyondy 2011).

Figure 2: Buck Springs wet meadow (circa 11/2010).

Figure 3: Exclusion fence vegetative condition contrast at Buck Springs, with the area on the right grazed by elk.

Existing rock structures to arrest headcutting include zuni bowls, within primary flow channels, and rock-mulch rundowns from side channels (Zeedyk and Clothier 2009). These structures function as rehabilitation features, to stop headcut propagation for a period, but do not restore the function of the lost wet meadow reaches. In general, these rock structures appeared to be performing well, though some maintenance activities will be periodically required. Wood structures for reducing headcut propagation were also observed (Figure 4), though appear to be ineffective as designed and constructed.

A stair-stepped longitudinal profile is apparent along the channel, with a gradually-varied slope a bit less than the valley slope for an extent, then a rapid transition to the lower grade with a steep slope at an active or arrested headcut, followed by once again a gradually-varied lower-gradient slope. The slope transitions are points of instabilities within the wet meadows, especially during large floods. Just downstream of these headcuts, the current riparian zone is much narrower than pre-disturbance conditions (Figure 4), as the channel evolves from Channel Evolution Model stages 2 and 3, to 4 and 5 (Figure 5).

The vegetation condition within the exclusion fence is recovering well, especially compared to reaches outside the fence that are heavily impacted by elk. Willow plantings were also observed to be growing within the wet meadow, though are currently minimal in extent. The fencing, combined with a lack of livestock grazing, makes it clear that elk grazing and browsing is a fundamental impact to this meadow.

Figure 4: Active headcut within the Buck Springs channel, with channel evolution occurring downstream.

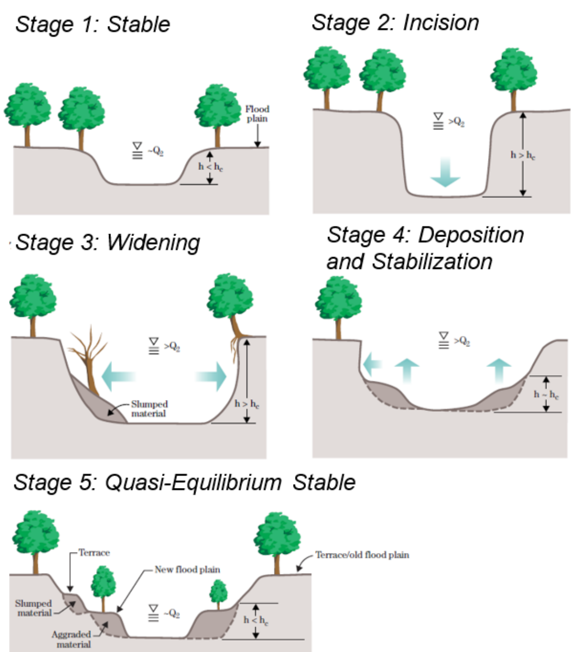

Figure 5: Channel Evolution Model, with channel cross sections illustrating the 5 channel stages (modified from NRCS 2007).

Houston Draw

The inspected reaches of concern in Houston Draw are relatively steep and incised, within a confined valley (downstream reach), and lower gradient within a meadow (upstream reach). The watershed at the downstream limit of the reaches of concern has a watershed area of 0.96 mi^2, with average annual precipitation varying from 27 to 31 inches (PRISM; Daly et al. 2008). This watershed has been classified as "functioning at risk" in the watershed condition framework (Potyondy 2011).

The downstream reach is relatively steep, with a slope that appears to be steep enough (>~3%) to be associated with transitional to step-pool bedform morphology (Montgomery and Buffington 1997), although the channel is not sediment-supply limited and has intermittent flow. A number of headcuts exist within this reach (Figure 6, Figure 7), though some armoring of headcut steps by large clasts and wood (Figure 7) may be providing a degree of stabilization in places. Generally, the channel within this reach appears to be lacking armoring and such flow resistance elements as large wood, and boulders and cobbles; this may be a fundamental reason for the propagation of instability, though the original instability may have been induced by historic livestock grazing.

Figure 6: Lower reach of Houston Draw, with multiple headcut sequences observed.

Figure 7: Lower reach of Houston Draw, with clast and wood-armored headcut.

The upstream reach is also showing instability, with headcutting (Figure 8), and a relatively widely-developed channel and floodplain at a lower grade (Figure 9). This evolving channel appears to be in a Channel Evolution Model stages 2 & 3 (Figure 5) near the headcut, and stages 4 & 5 further downstream. Upstream of the headcut only a small channel is present within this small headwater watershed.

This upper meadow reach is being heavily utilized by elk, which is contributing to the instability. Recognizing this, part of the upper reach has been excluded with an 8-foot fence. Interestingly, while the portion of the upper reach that is not excluded is being heavily utilized by elk (within a relatively wide valley), the lower and confined reach is not.

Figure 8: Headcut within the upper meadow reach of Houston Draw.

Figure 9: Evolved channel at lower grade, upper meadow reach of Houston Draw.

A portion of the meadow reach has had a channel rehabilitation project implemented. The term rehabilitation is explicitly used since this reach has had a channelized cross-section form constructed (Figure 10) rather than a channel and associated floodplain. This channel was constructed with sinuous planform geometry, but will have excess unit stream power and shear stress during high flows due to the disconnected floodplain, potentially leading to incision.

Figure 10: Channel of rehabilitated reach in upper meadow portion of upper Houston Draw.

Dick Hart Draw

Dick Hart Draw is a dry meadow channel that is deeply incising in a fine and deep soil substrate. A number of 4 to 6 ft high berms were historically placed across the channel (Figure 11). This was presumably done to control incision, though the rational for this is unclear since a stabilization mechanism could not be hypothesized. In any case, incised channels have been eroded through the berms and underlying substrate and this drainage is likely a substantial source of fine sediment to Barbershop Canyon, which is a tributary to East Clear Creek. Headcuts of up to about 12 feet deep are currently present (Figure 12). East Clear Creek is habitat for the Little Colorado spinedace (*Lepidomeda vittata*), a threatened species under the Endangered Species Act.

Figure 11: Dick Hart Draw, with eroded berms.

Figure 12: Deep headcut in Dick Hart Draw.

The watershed extent is 1.48 mi^2, with average annual precipitation varying from 23 to 27 inches (PRISM; Daly et al. 2008). This watershed has been classified as "functioning at risk" in the watershed condition framework (Potyondy 2011).

Willow Valley

A remnant patch of narrow-leaf cottonwoods was inspected in Willow Valley. This watershed encompasses 57.7 mi^2, with average annual precipitation varying from 20 to 28 inches (PRISM; Daly et al. 2008). This watershed has been classified as "functioning at risk" in the watershed condition framework (Potyondy 2011). The stream is intermittent at this location.

This reach of the valley has small exclusion fences to promote cottonwood recruitment (Figure 13), though considering where new growth is occurring, the best conditions for recruitment appear to be outside of the exclusion fences at a lower grade, along the margins of what appears to be an incised channel (Figure 14). This reach is grazed by cattle.

Figure 13: Small exclusion fence along the intermittent stream channel in Willow Valley.

Figure 14: Cottonwood recruitment along the incised channel margin of Willow Valley.

CONDITION SUMMARY

There is a general pattern of disturbance and channel evolution of the inspected stream reaches, with the greatest influence likely due to historic grazing practices as well as current elk grazing and browsing. The disturbance of the riparian vegetation has resulted in channel bank and valley bottom instability, from the lack of root density and depth for providing mechanical resistance to erosive flow. Local incision leads to deepening and widening of channels and floodplain disconnections, with increased unit stream power ($\omega = \gamma QS/w$, through decreased widths, *w*), and increased shear stress ($\tau = \gamma hS$, through increased depths, h). [Q = discharge, S = slope, γ = water specific weight] Stream power and shear stress are directly proportional to sediment transport conveyance capacity, hence are fundamental principles for describing driving forces for instability. Low amounts of flow resistance also increase the erosion and incision potential of the stream reach. Lower roughness (Manning's *n*) and consequent flow resistance leads to higher velocities ($V = \frac{R^{2/3}S^{1/2}}{n}$), and higher forces due to momentum transfer to the channel banks along meander bends ($F = \rho Q \Delta V$). [R = hydraulic radius, ρ = water density] Woody vegetation, large in-channel wood, bedforms, and sinuosity are the primary sources of flow resistance in these channel types.

The lack of soil binding by roots, as well as lack of bed armoring and increased velocities, provide for the reduced resisting forces for erosion. In some situations this can lead to a positive feedback loop of ever increasing instability that can persist even if the initial disturbance mechanisms are removed. In other situations, removal of the initial disturbance mechanism, through such actions as riparian exclusion (temporary or permanent) can lead to stabilization of the channel at a lower grade, as Channel Evolution Model stages 4 and 5 (Figure 5).

Restoration of channel and floodplain connectivity in sometimes also needed to provide for longterm stabilization, to best satisfy project goals and objectives. This is done through earth movement, grade control, revegetation efforts, and provision of bank structures or large wood, to reduce the driving forces for instability (shear stress, stream power, velocity) and channel bed armoring and floodplain vegetation for increasing resisting mechanisms. Such restoration also needs to provide for a gradually-varied longitudinal profile (as opposed to the abrupt transition of a longitudinal profile at a headcut), as well as appropriate planform and sinuosity. Hence, appropriate channel dimension, planform pattern, and longitudinal profile is provided, alongside appropriate vegetation, to allow for long term channel and floodplain stability that is in dynamic equilibrium with typical watershed flow and sediment yield.

OPTIONS and RECOMENDATIONS

Restoration and rehabilitation options and recommendations are provided for each of the four visited streams. Restoration is the reestablishment of the structure and function of ecosystems to an approximation of pre-disturbance conditions while rehabilitation establishes conditions to support natural processes for making the land useful for human purposes (NRCS 2007). Generally, using Natural Channel Design terminology the options fall into two categories: rehabilitation at the current (incised) grade is defined as a priority 2 "restoration," while raising the grade of the channel to the abandoned floodplain level is defined as a priority 1 restoration.

Buck Springs

The existing rock structures installed to arrest headcutting, include zuni bowls and rock-mulch rundowns, appear to be functioning well, especially within the elk exclusion. These structures will need periodic inspection and potential maintenance in perpetuity, due to the rapid drop in longitudinal profile at the stabilized headcuts being likely locations of future incision, especially during large flood events. Additionally, they maintain the current lower grade and impaired conditions (compared to pre-disturbance conditions) with narrowed riparian hydrologic and vegetative conditions. Furthermore, some of the wood structures are not effectively arresting the headcut migration, and other headcuts are present within this reach, requiring additional rehabilitation structures in the near term to prevent additional degradation of the wet meadow.

An alternative approach is to utilize a meadow restoration, with reestablishment of a gradually-varied longitudinal profile through earth movement from local (valley side and terrace) borrow areas. Combined with grade control structures (log-type recommended), revegetation efforts, and possibly introduction of large wood and heterogeneously-sized alluvial rock material (gravel and cobble sized; for increased flow resistance and bed armoring), a fully-restored meadow could be developed. Success potential is high for this headwater drainage due to the small watershed and relatively-low stream power. This approach would require at least a temporary exclusion fence, to allow the vegetation to be established. This sort of restoration could likely provide conditions that do not require as much inspection and long-term maintenance, and would likely be more resilient to destabilization during large floods.

If sufficient funding is available, I recommend the priority 1 restoration approach for the portions of the Buck Springs channel where more extensive headcutting has occurred. I would be available to consult on the design for such features as the log grade-control structures if it is decided to utilize a priority 1 restoration approach to addressing the impaired conditions. If a priority 2 approach it utilized, the continued use of existing methods should suffice, though with the caveats presented above.

Houston Draw

Similar to Buck Springs, either priority 1 or priority 2 approaches could be utilized to restore or rehabilitate the reaches of this channel, with both approaches having advantages and disadvantages. Both approaches could be utilized in different portions of the reaches, with priority 1 restoration recommended where there is more substantial disturbance, such as in the lower portion of the upstream reach's meadow.

With the lower reach having a higher gradient that appears to be transitional to a slope where channels typically have step-pool bedforms, providing heterogeneously-sized alluvial rock material for armoring (gravel and cobble size) may be effective for stabilizing the bed grade. One of the existing headcuts has already formed what appears to be an armored step (Figure 7); providing the rock material will allow more of this development over time when high flows occur to sort the material. For channels greater than 2 to 3%, this armoring rock material (gravels, cobbles, small boulders) can be placed as needed to suppress erosion and allowed to sort, while in lesser gradient channels it is recommended to place heterogeneous-sized cobbles and gravel mix in riffle/crossing zones as defined by the channel planform (Figure 15). Additionally, the inclusion of large wood would also be beneficial for providing stabilization. Wood with attached root wads and lengths at least 1.5 to 2 times the channel width will be most stable.

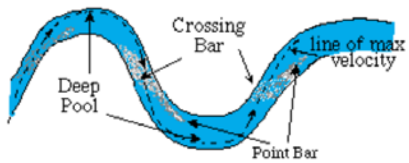

Figure 15: Typical stream channel planform, with riffle/crossing locations (courtesy Paul Maslin, California State University, Chico).

The upstream rehabilitated reach, within the exclusion zone, was constructed with a channelized cross section that disconnects the channel from its floodplain. This reach will need to be periodically inspected for stability, especially after greater than typical annual snowmelt runoff and large floods.

Dick Hart Draw

Dick Hart draw is in a poor state that is very possibly providing substantial sediment to East Clear Creek, habitat for the Little Colorado spinedace. This is a threatened species under the Endangered Species Act. The dry conditions of this intermittent stream will make restoration challenging, with a priority 1 restoration being most effective though very expensive, with large amounts of earth movement.

It is recommended that the downstream drainages are inspected (or potentially studied through research) to understand if the liberated sediment from continued deep headcutting in Dick Hart Draw negatively impacts the endangered spinedace.

Willow Valley

Willow Valley's channel appears to be incised in vicinity of the remnant cottonwood populations. It is likely not reasonable to restore this channel to previous grade within this limited reach due to the large watershed imposing high stream power during floods, as well as the need for providing a gradually varied longitudinal profile. This would require restoration over a much longer extent than the remnant cottonwoods reach. Because of this, I recommend that exclusion fences be installed to protect the current areas of the channel edge (Figure 14) and terrace that currently have cottonwood growth.

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