

Riparian Encroachment Synthesis

Proposal Identification TRRP-2018-021



2004



2005



2019

John Bair,

Senior Riparian Ecologist,

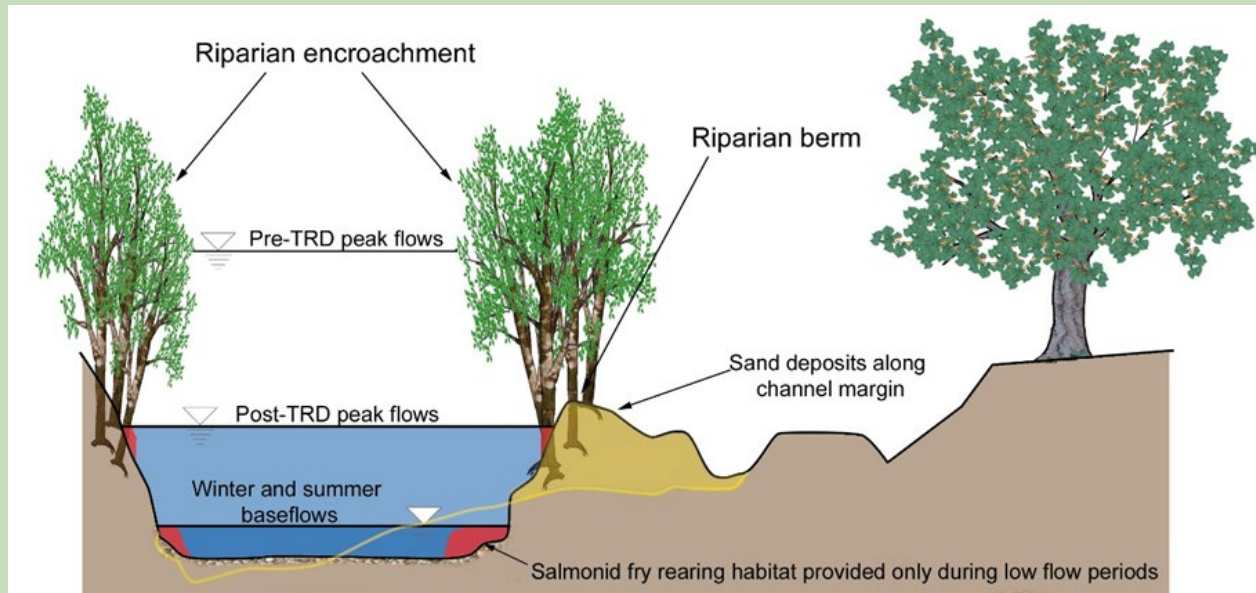
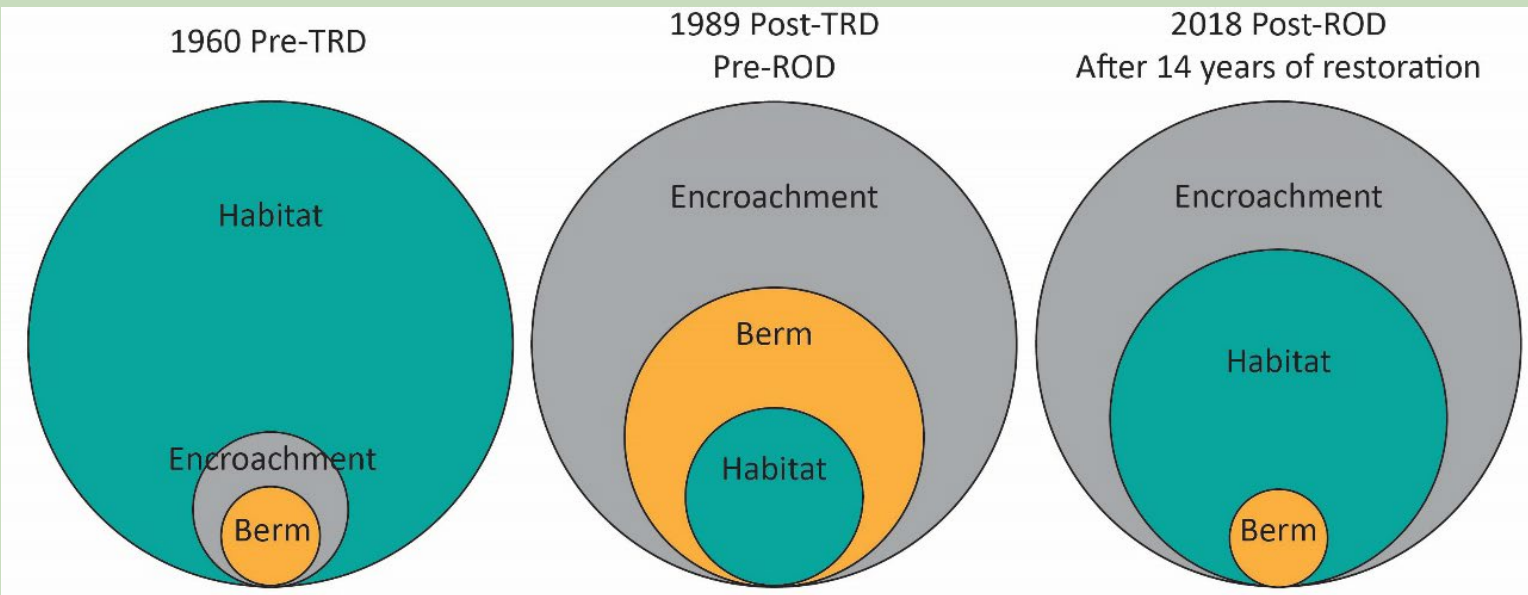
McBain Associates 980 7th St, Arcata, CA, 95521

(707) 273-1046 john@mc bainassociates.com

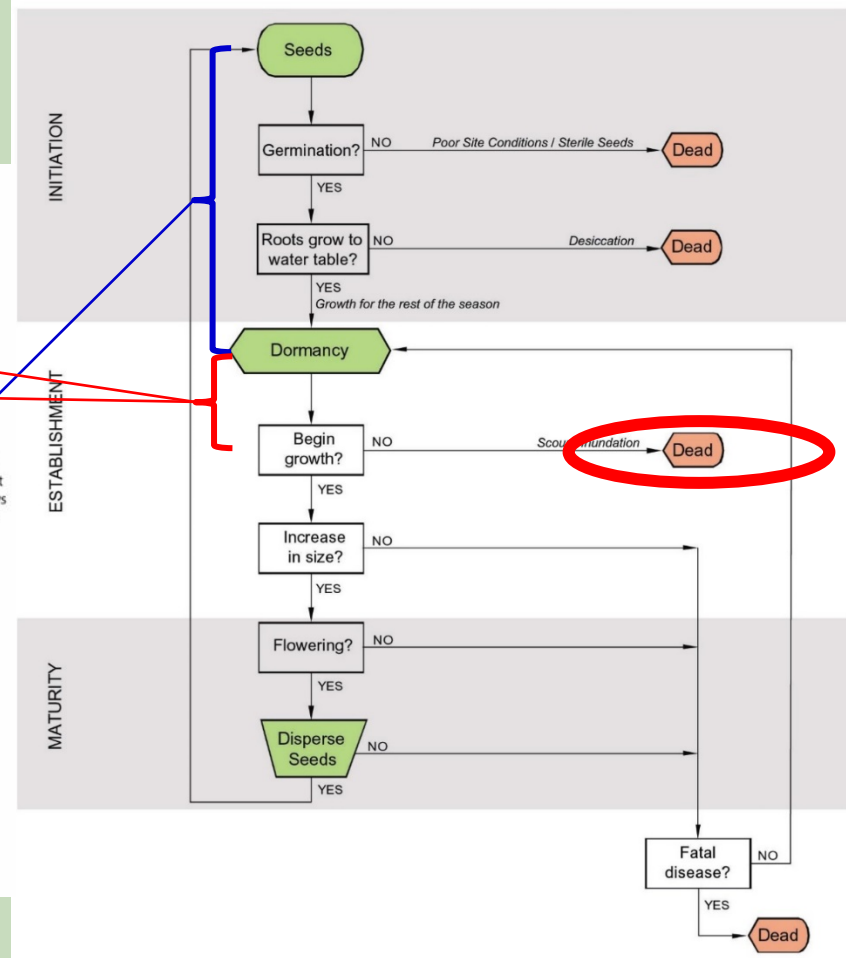
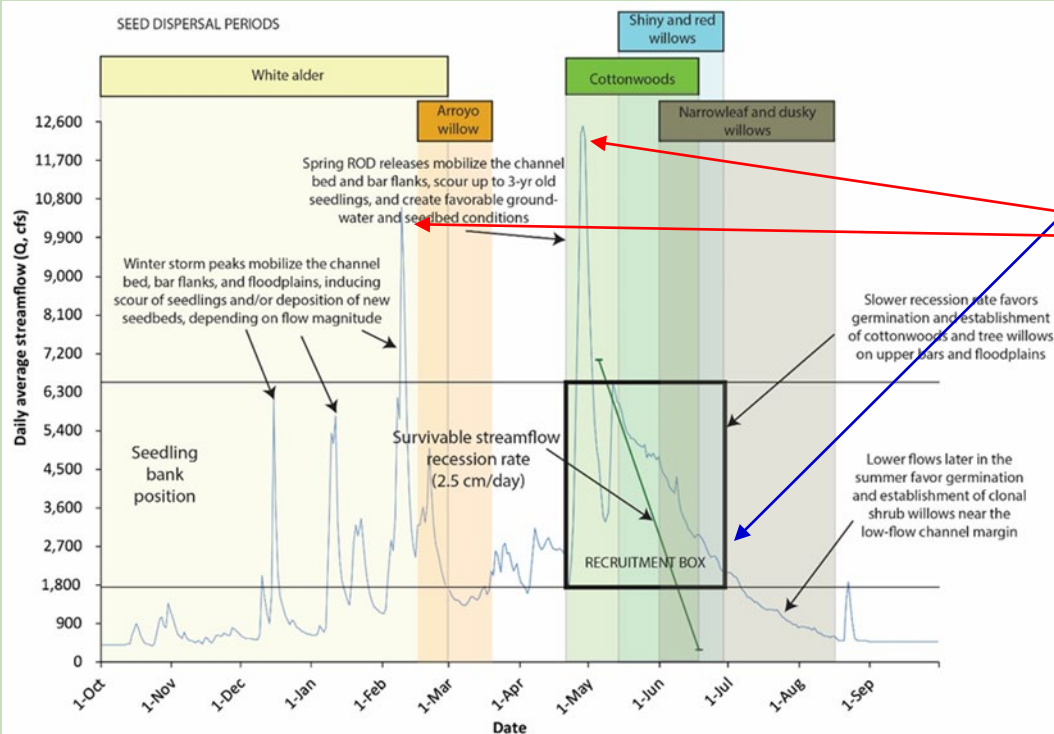
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Conceptual model of the changing relationship between juvenile salmonid habitat, sediment berms, and riparian encroachment



Conceptual plant life history



Window of Opportunity

INITIATION AND ESTABLISHMENT PROCESS

Early Seedling Plant Box Recruitment Model

Species: Cottonwood and Willows

Time of Seed

Dispersal: Spring / Summer

Fall Seedling Plant Rafting Recruitment Model

Species: Alder, Ash, Sycamore, Valley Oak

Time of Seed

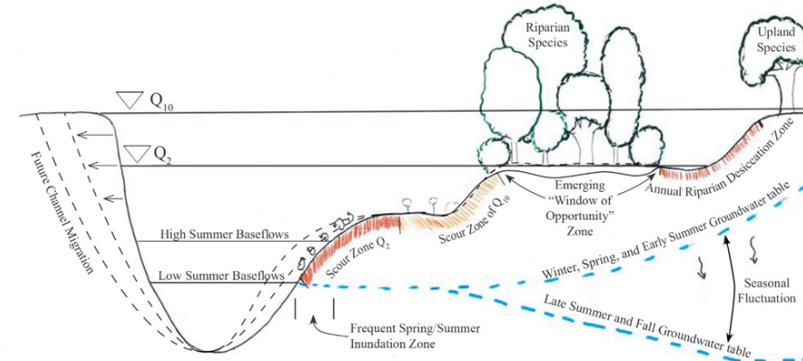
Dispersal: Fall (seeds) / Winter (cones/catkins)

MORTALITY PROCESS

Scour	Desiccation	Inundation
Process: Winter storms, snowmelt peaks mobilizing and/or scouring bed surface	Rapid decline of receding limb of snowmelt hydrograph, low summer baseflows after germination	Prolonged receding limb of snowmelt hydrograph, high summer baseflows during seed dispersal / rafting period

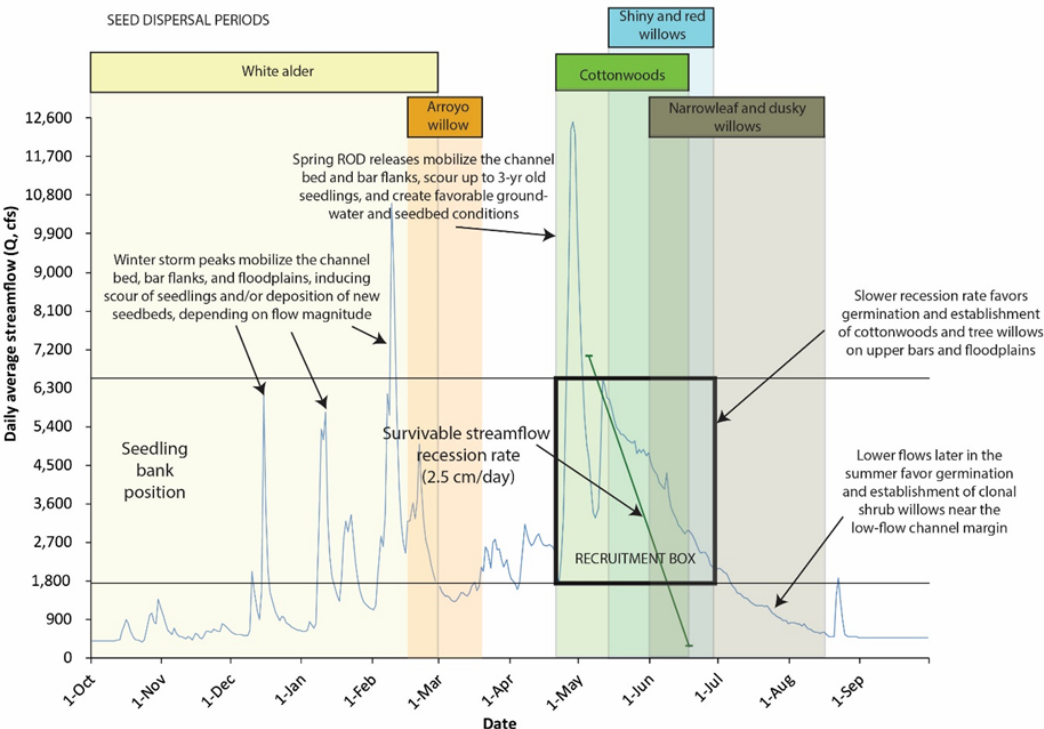


Frequent Scour Induced Mortality → “Window of Opportunity” Resulting in Longer Term Riparian Establishment ← Annual Desiccation Induced Mortality

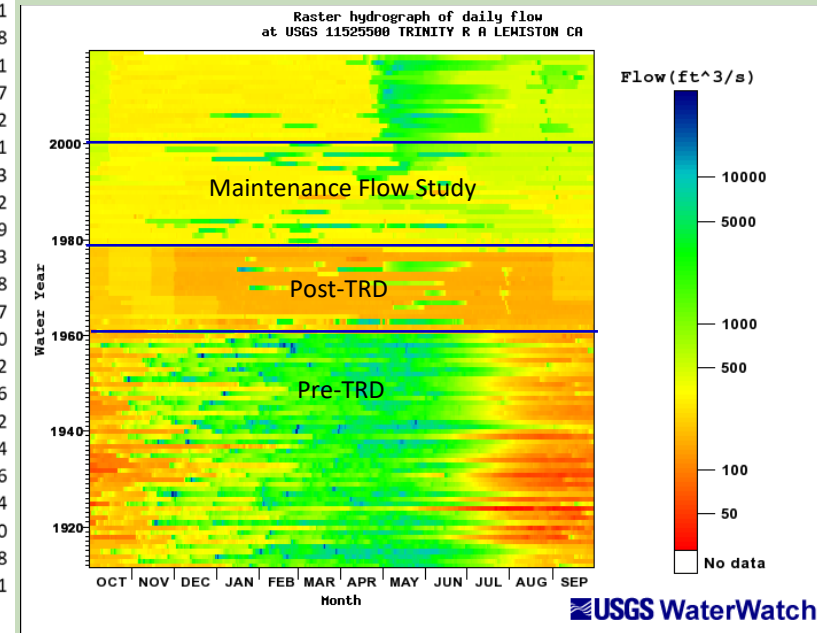
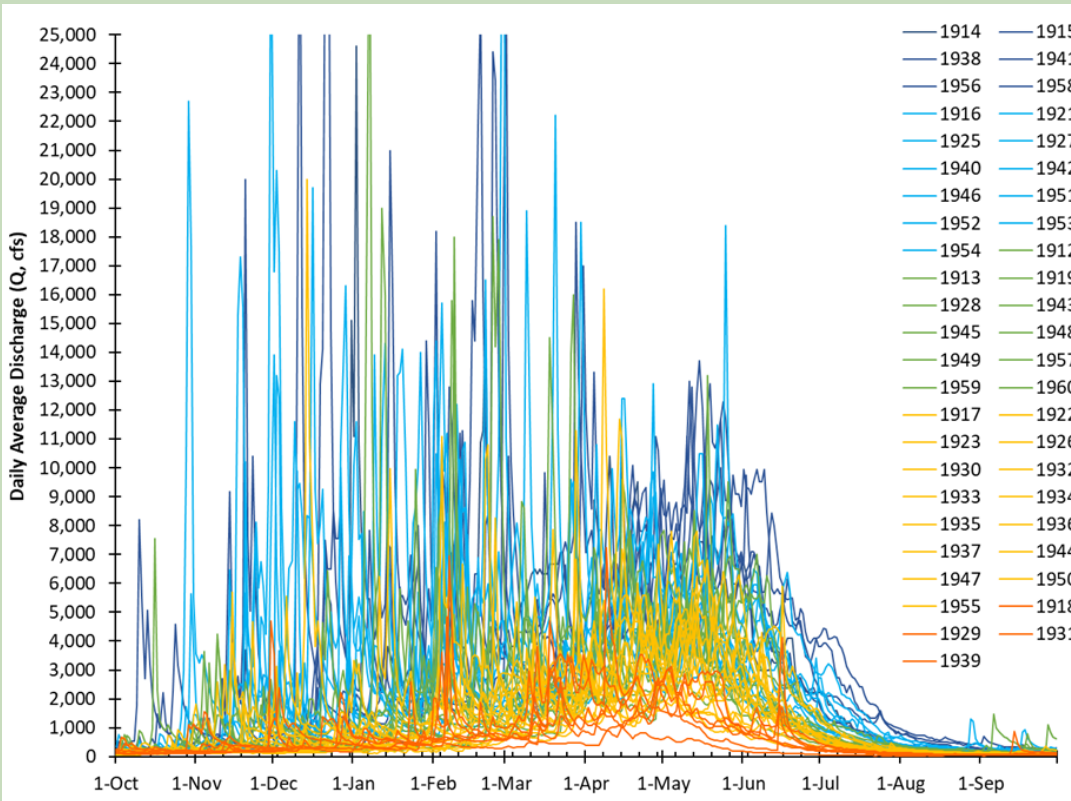


- The 2 year flood (Q_2) removes seedlings
- The 10 year flood (Q_{10}) removes small trees / shrubs, maintaining channel width

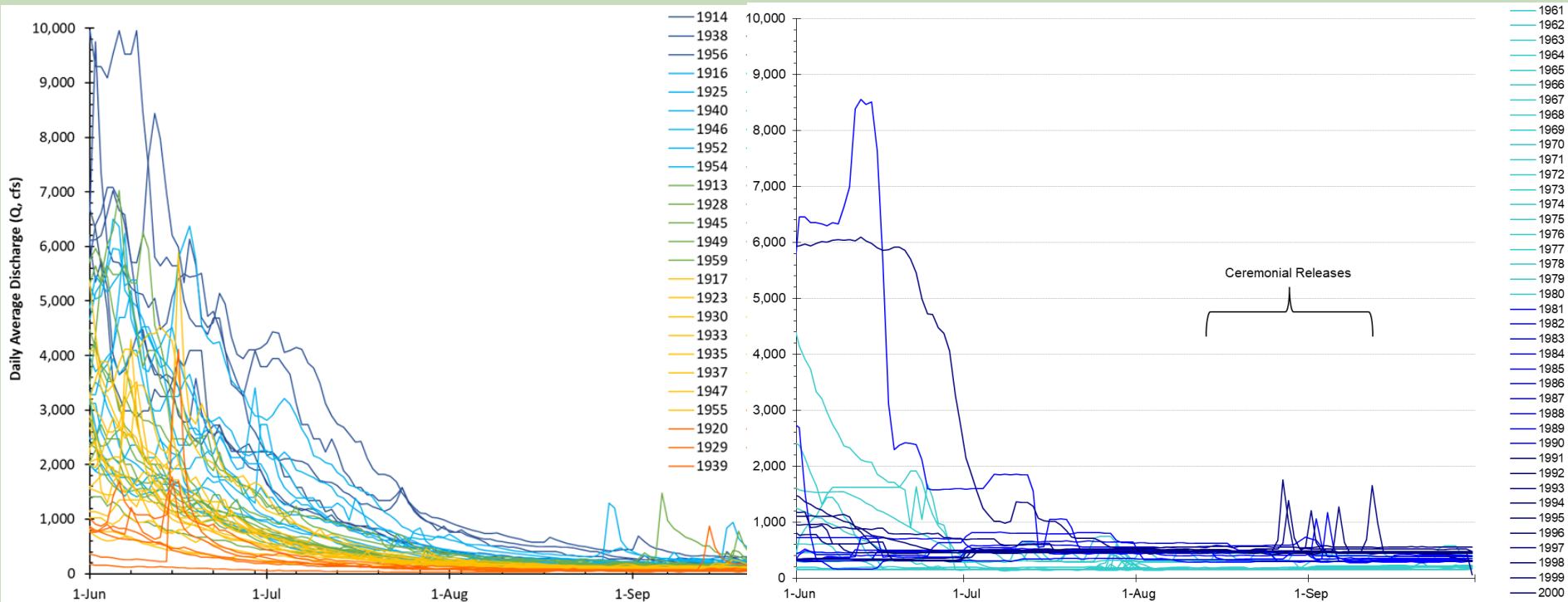
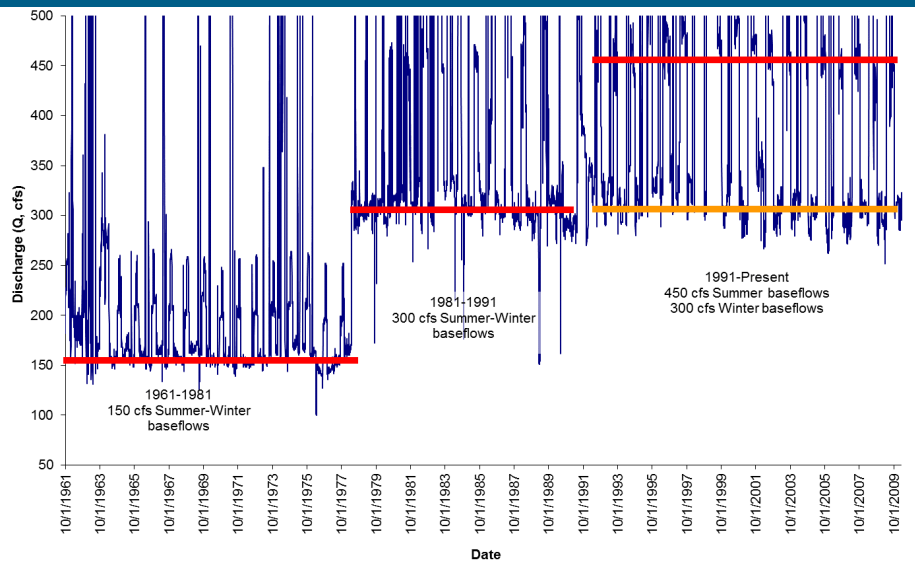
SEED DISPERSAL PERIODS



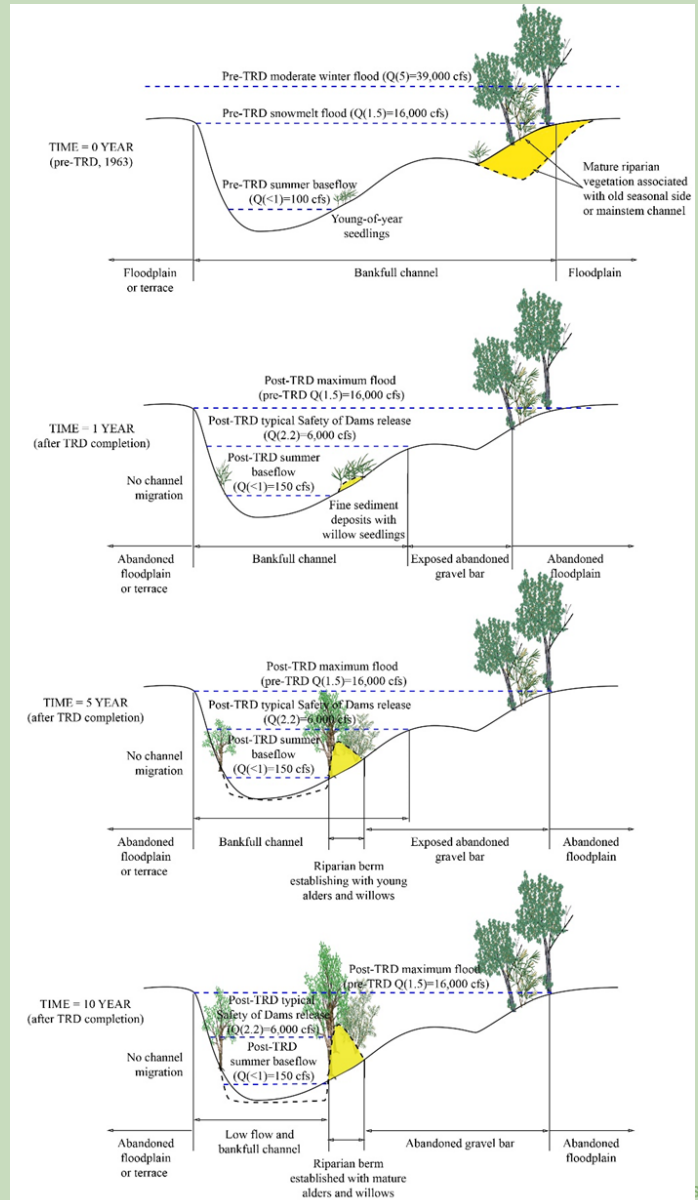
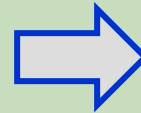
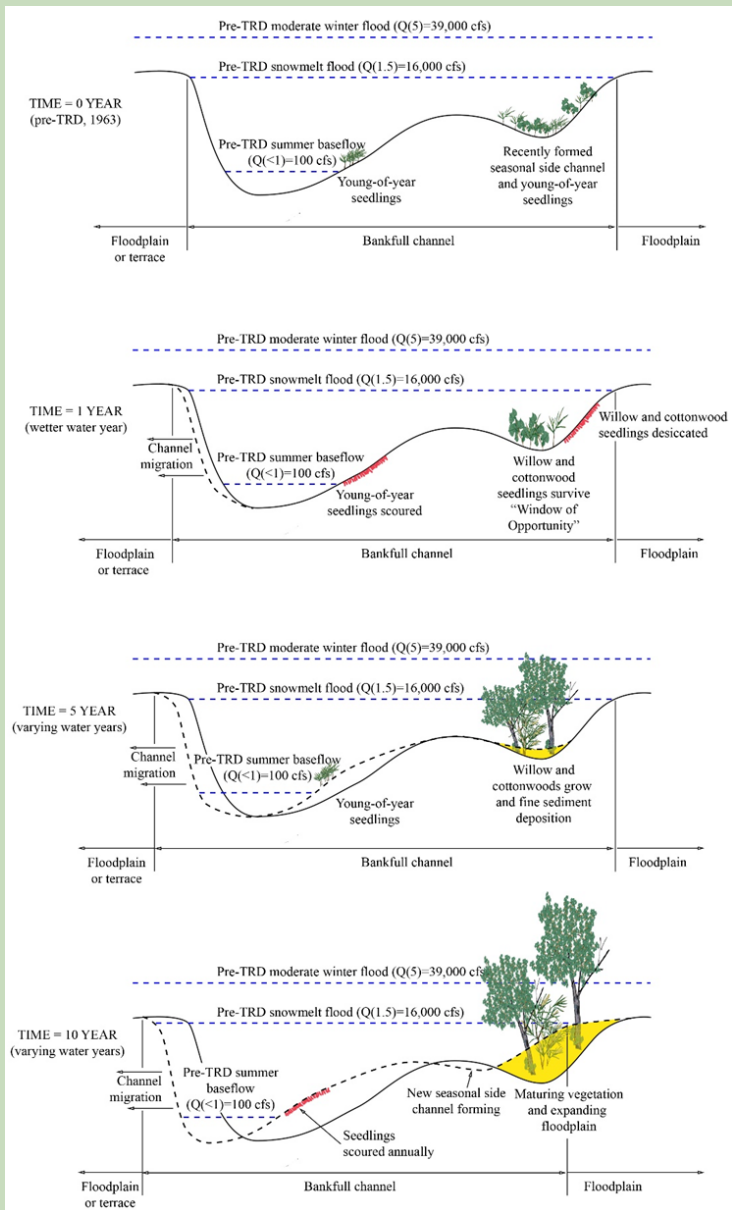
Trinity River at Lewiston Hydrographs



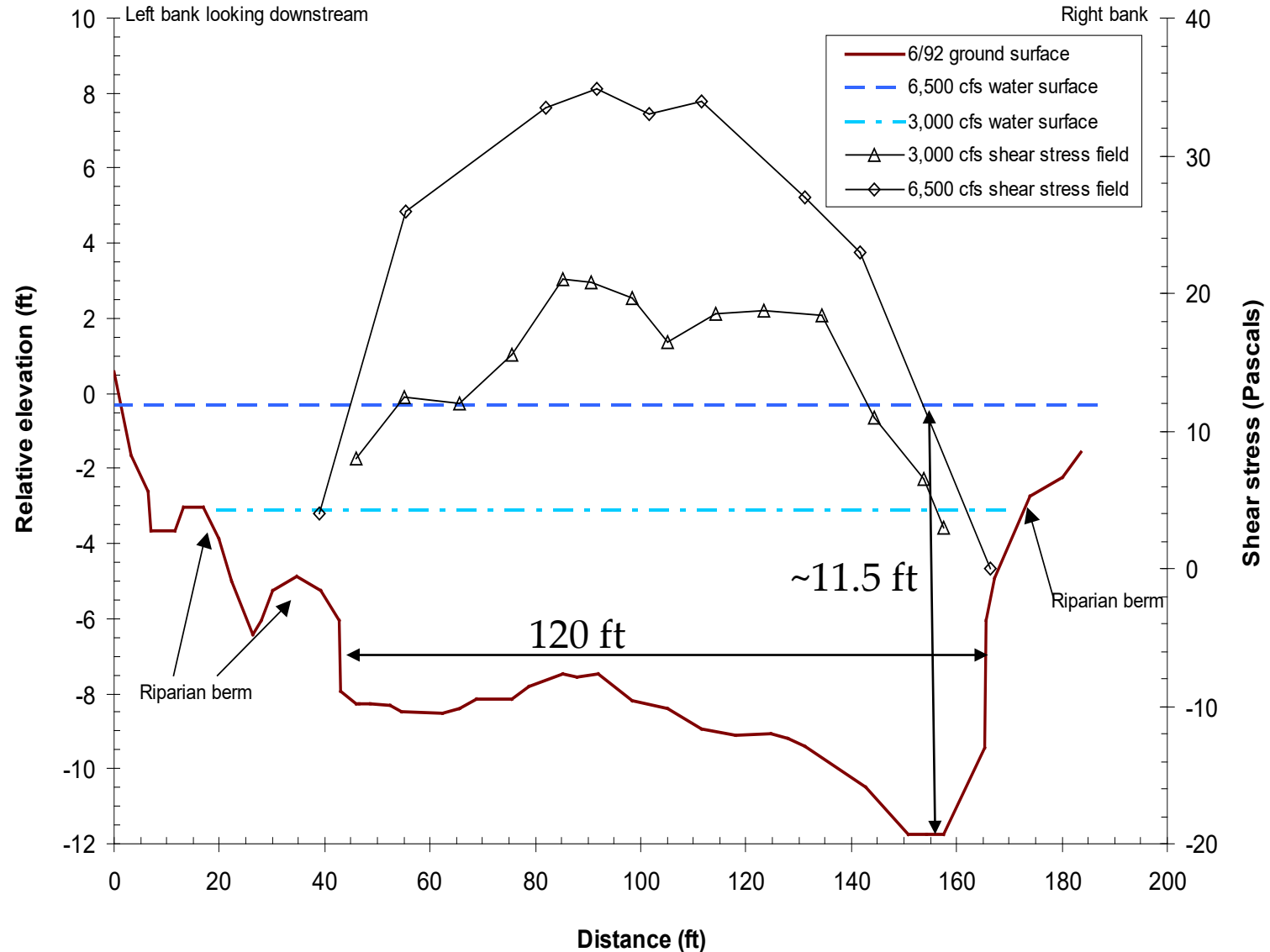
Daily average summer baseflows at Lewiston



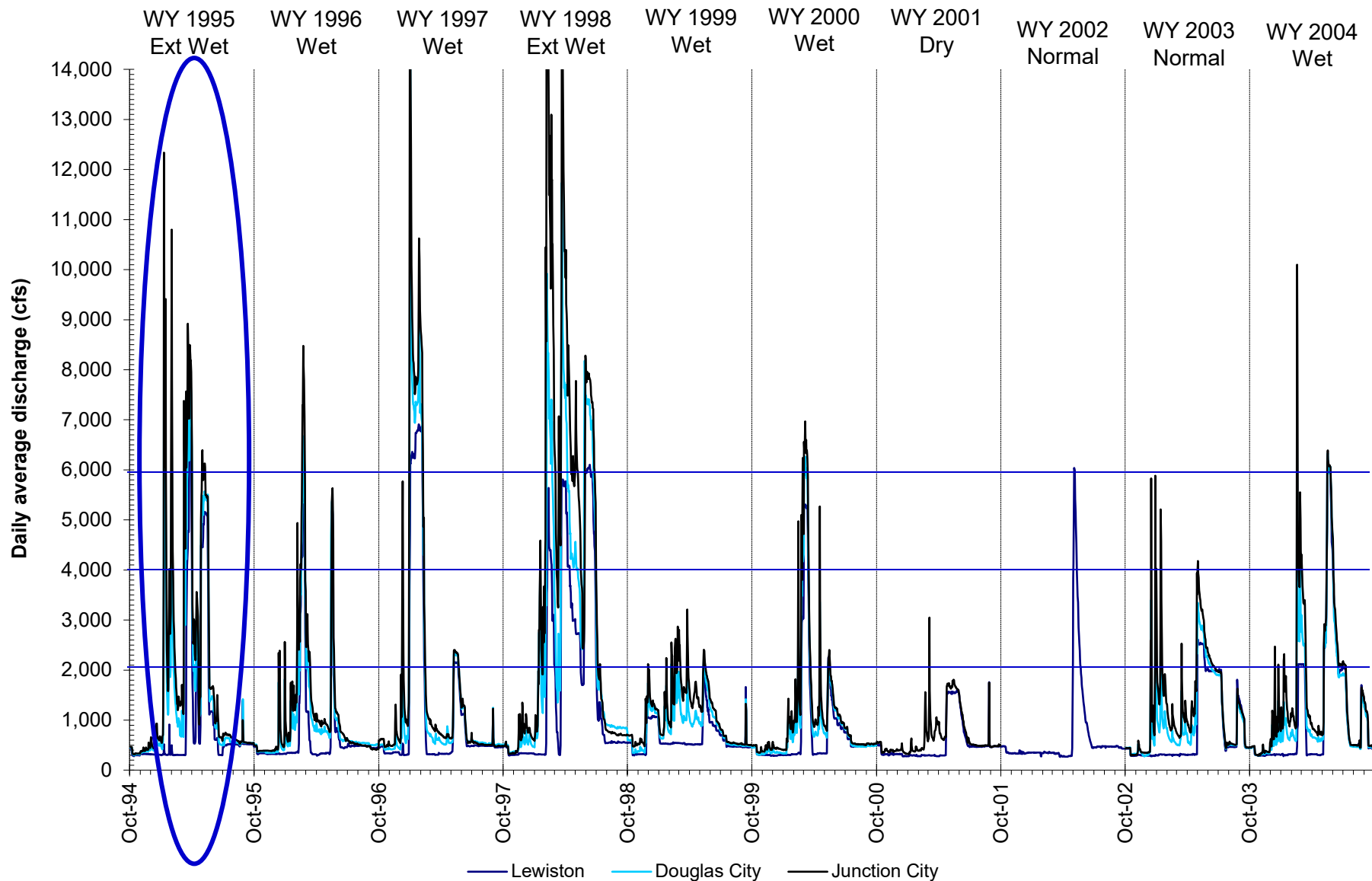
Conceptual model (not to scale) of vegetation dynamics before and after TRD dams and diversions



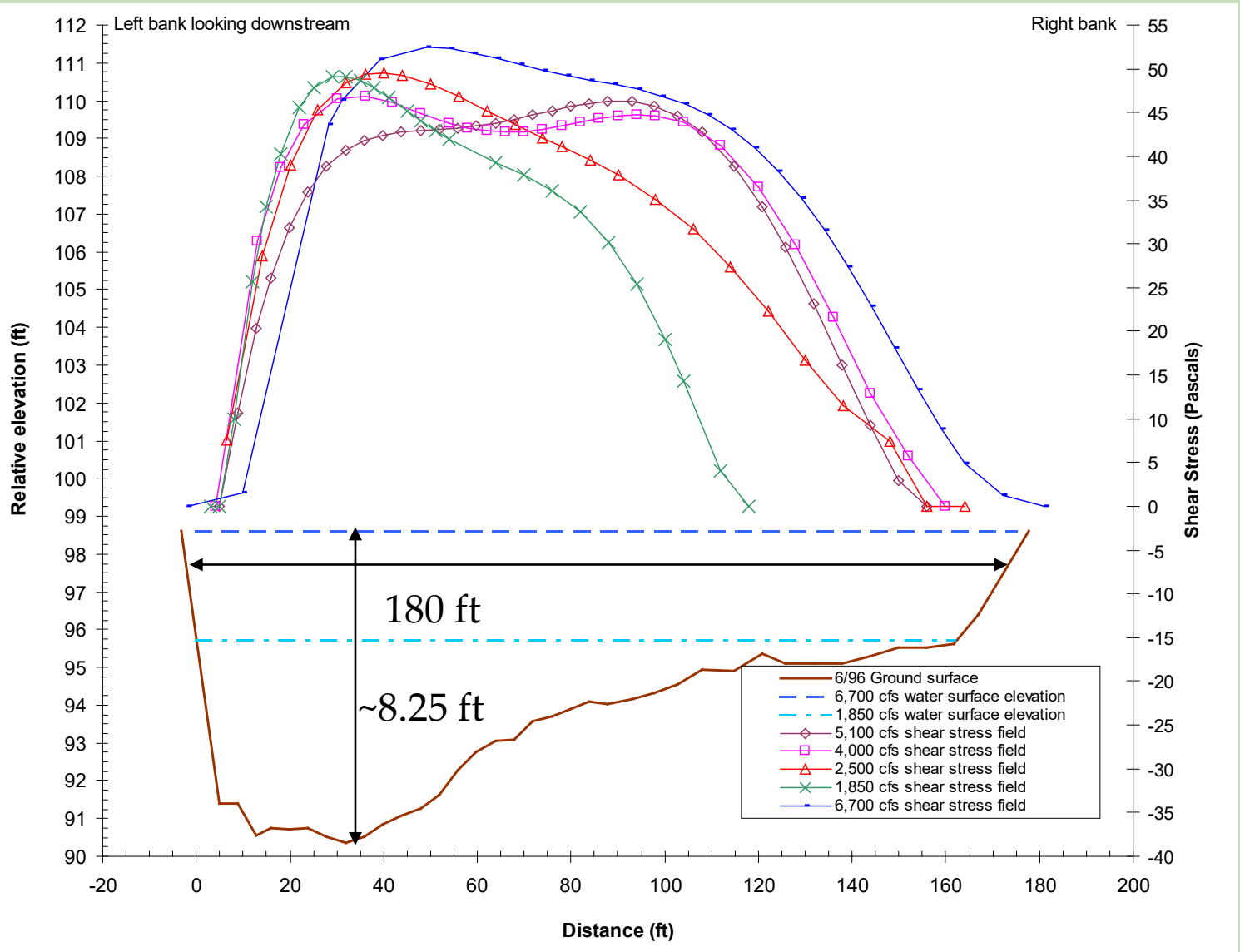
Poker Bar shear stress fields for $Q=2,700 \text{ ft}^3/\text{s}$ and $6,400 \text{ ft}^3/\text{s}$



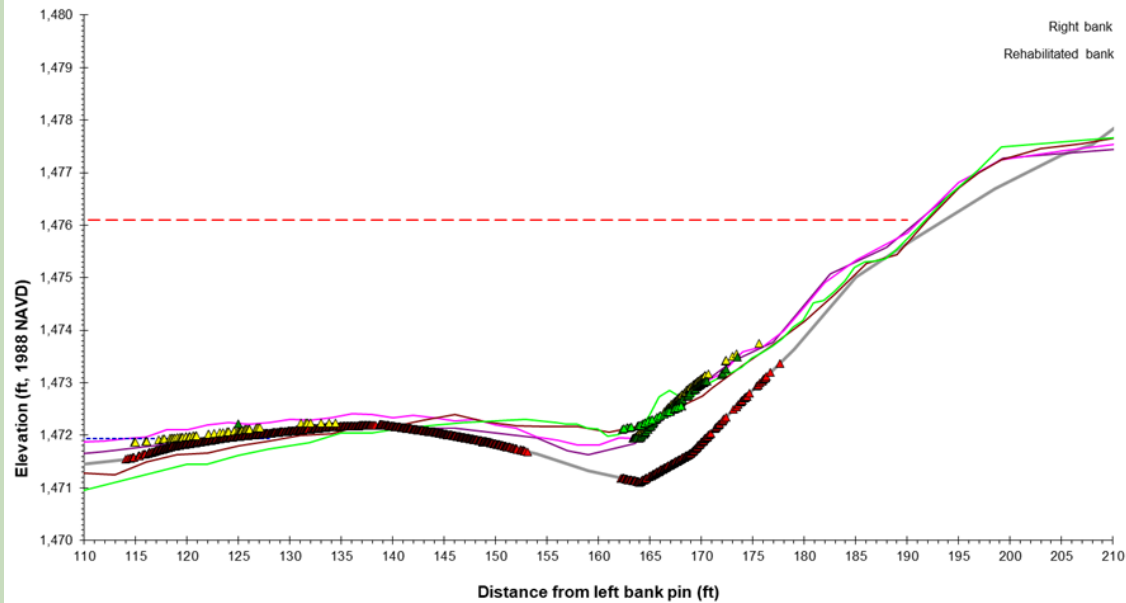
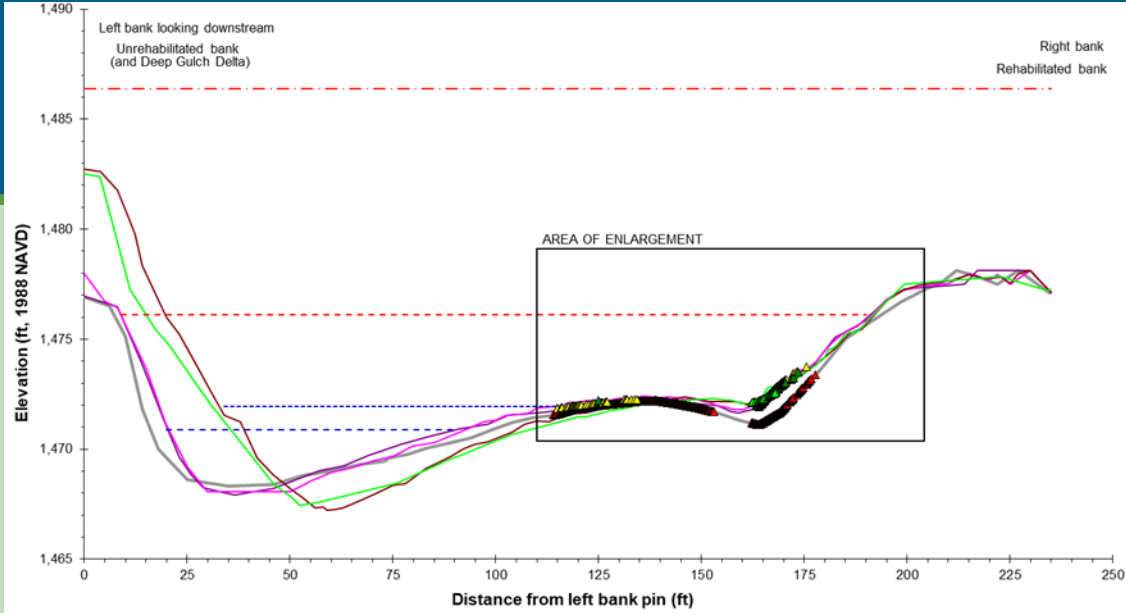
WY 1995 to WY 2004 hydrographs and water year sequencing (n= 10 yrs)



Steiner Flat shear stress fields for $Q=1,850 \text{ ft}^3/\text{s}$ to $6,700 \text{ ft}^3/\text{s}$

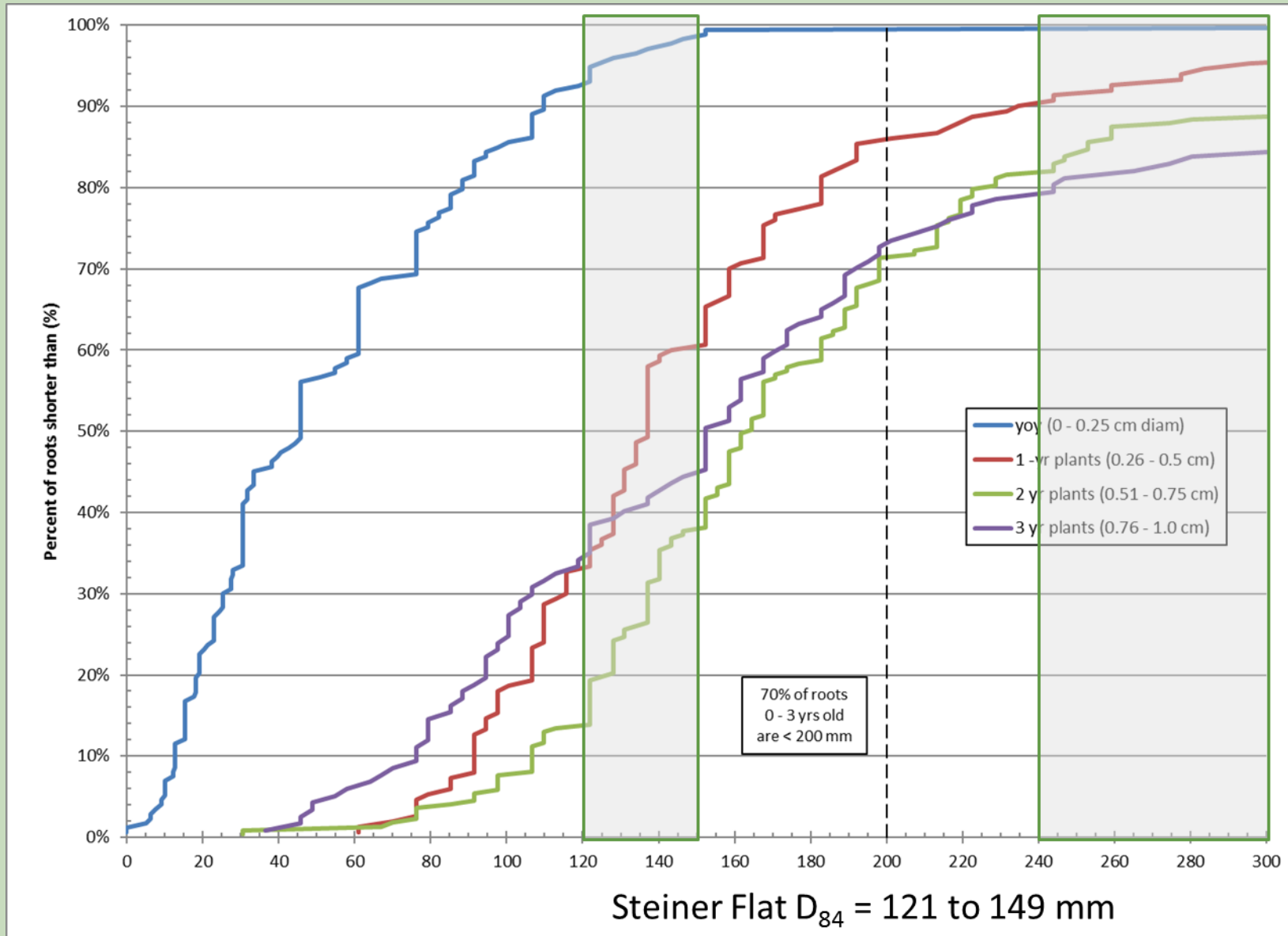


WY1995 Cohort Establishment 1995-1997

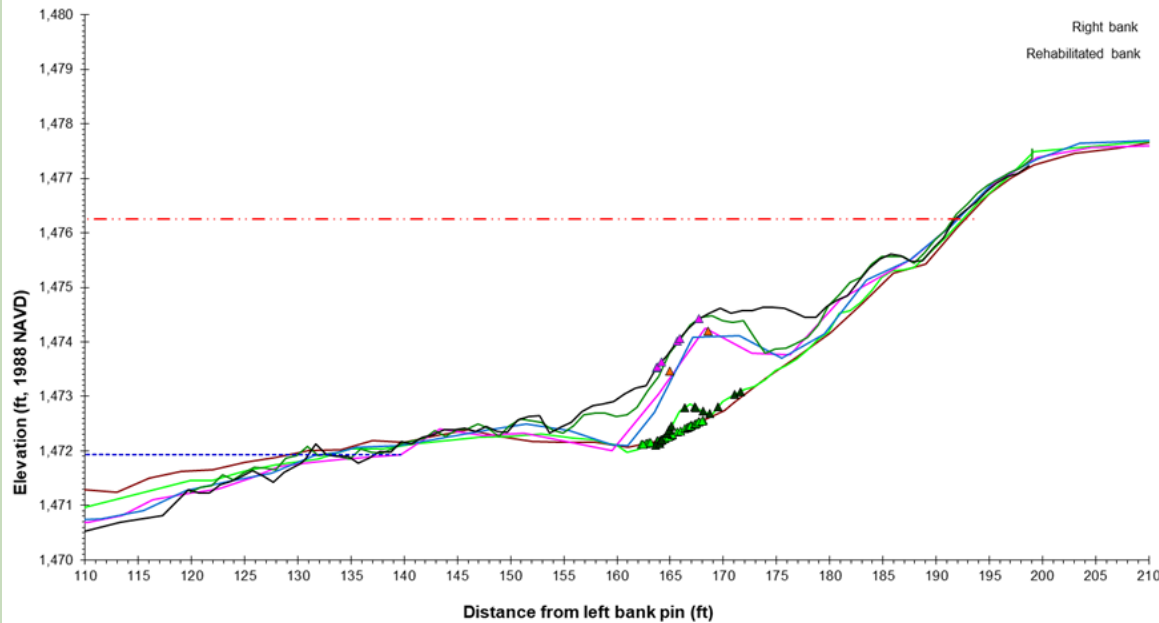
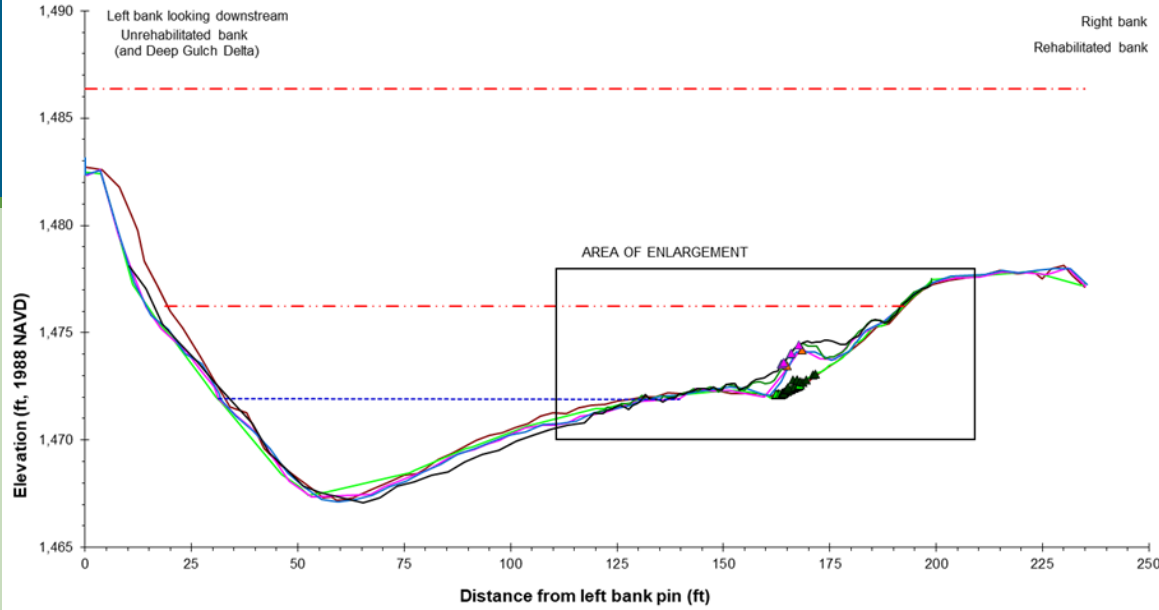


- 7/13/95 Ground Surface
- 7/18/96 Ground Surface
- 8/31/98 Ground Surface
- - - 10/24/96 Water Surface (Q=388 cfs at Junction City)
- - - 10/29/97 Water Surface (Q=337 cfs at Junction City)
- ▲ Salix exigua 1995 cohort survivor of water year 1996, spring
- ▲ Salix exigua 1995 cohort survivor of water year 1997, summer
- 5/10/96 Ground Surface
- 3/18/97 Ground Surface
- - - 1/1/97 Water Surface (Q = 30,000 cfs at Junction City)†
- - - 5/18/96 Water Surface (Q=5,630 cfs at Junction City)
- ▲ Salix exigua 1995 cohort seedling of water year 1995, summer
- ▲ Salix exigua 1995 cohort survivor of water year 1996, summer

Cumulative rooting depths associated with each age class (n=790)



WY1995 Cohort Establishment 1998-2002



- 3/18/97 Ground Surface
- 10/25/00 Ground Surface
- 4/24/02 Ground Surface
- - - 1/1/97 Water Surface (Q = 30,000 cfs at Junction City)†
- - - 5/5/02 Water Surface (Q=5,419 cfs at Junction City)
- ▲ Salix exigua 1995 cohort survivor of water year 1998, summer
- ▲ Salix exigua 1995 cohort survivor of water year 2002, summer
- 8/31/98 Ground Surface
- 7/31/01 Ground Surface
- 7/25/02 Ground Surface
- - - 10/25/00 Water Surface (Q=355 cfs at Junction City)
- ▲ Salix exigua 1995 cohort survivor of water year 1997, summer
- ▲ Salix exigua 1995 cohort survivor of water year 2001, summer

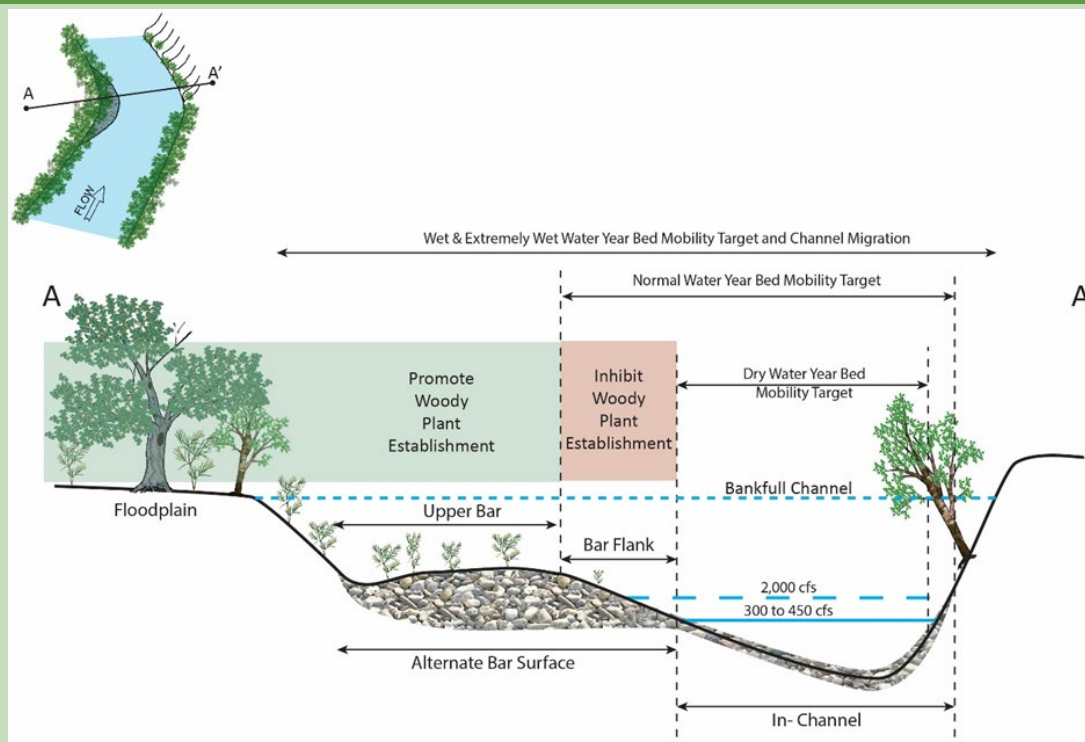
Summary of water year classes, peak streamflows and associated cohort survival and mortality during the 1993–2004 period

Water Year	Water Year Class Based on April 1 Inflow Forecast	ROD Assigned Magnitude (cfs)	Actual Maximum Daily Average Lewiston Release (cfs)	Instantaneous Maximum Lewiston Streamflow (cfs)	Closest Magnitude ROD WY Class Equivalent	Associated Scour Threshold	Cohorts Scoured	Surviving Cohorts
1993	WET	8,500	3,070	3,270	DRY	No scour mortality	None	1992 cohort
1994	CRIT DRY	1,500	1,610	1,630	CRIT DRY	No scour mortality	None	1992, 1993 cohort
1995	EXT WET	11,000	6,890	7,060	NORMAL	1-year-old and YOY	1994 cohort	1992, 1993 cohort
1996	WET	8,500	6,290	6,390	NORMAL	1-year-old and YOY	1995 cohort	1992, 1993 cohort
1997	WET	8,500	6,910	6,970	NORMAL	1-year-old and YOY	1996 cohort	1992, 1993 cohort
1998	EXT WET	11,000	5,990	6,190	NORMAL	1-year-old and YOY	1997 cohort	1992, 1993 cohort
1999	WET	8,500	1,980	2,000	CRIT DRY	No scour mortality	None	1992, 1993 and 1998 cohort
2000	WET	8,500	5,310	5,430	NORMAL	1-year-old and YOY	1999 cohort	1992, 1993 and 1998 cohort
2001	DRY	4,500	1,678	2,140	CRIT DRY	No scour mortality	None	1992, 1993, 1998, and 2000 cohort
2002	NORMAL	6,000	6,040	6,570	NORMAL	1-year-old and YOY	2001 cohort	1993, 1998, and 2000 cohort
2003	NORMAL	6,000	2,610	2,780	CRIT DRY	No scour mortality	None	1993, 1998, 2000 and 2002 cohort
2004	WET	8,500	6,200	6,350	NORMAL	1-year-old and YOY	2003 cohort	1993, 1998, 2000 and 2002 cohort

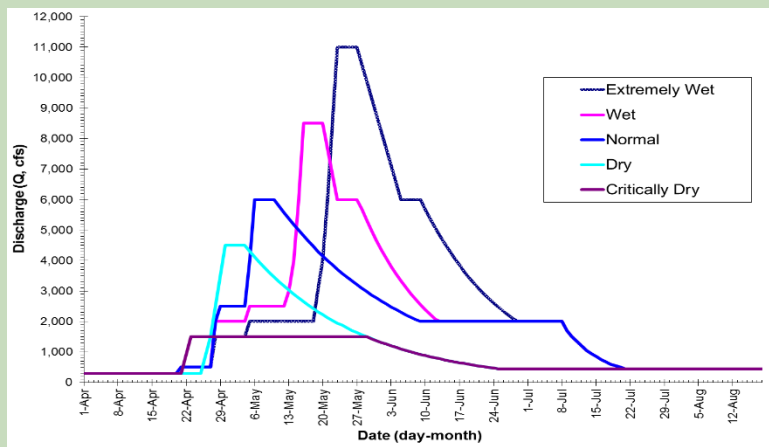
Key points from synthesis of early studies

- Woody plant demographic studies conducted at pilot bank rehabilitation sites in the 1990s found that over 90% of willow seedlings occurred on coarse to fine sands (i.e., more than 15% of the particle size distribution was smaller than 2 mm (Bair 2001b).
- Reducing the fine sediment supply could provide a way to reduce initiation and establishment of willows near the low flow channel margin.
- Younger establishing plants with root lengths approximately the depth of the channel bed surface layer (i.e., depth of D84) were especially prone to mortality when the channel bed was mobilized.
- Marked rock studies combined with woody plant and topographic changes indicated that a flow of 6,000 cfs began to mobilize exposed point bar surfaces,
- When bar surfaces mobilized, 60–90% of 1-year-old and younger plants were removed (M&T 1997, Bair 1998, Bair 2003).
- Measured scour depths and topographic changes indicated that flows above 8,500 cfs measured downstream at Junction City caused subsurface scour, but that that flows between 11,000 cfs and 14,000 cfs were required to cause scour and redeposition beyond 300 mm (or approximately the depth of two D84's).
- Roughly 70% of 3-year-old plants have roots that are less than 204 mm
- Geomorphic data collected during the 1995–2000 period indicates that there is a lateral limit of scour where the shear stress tapers off and the channel bed is not mobilized.

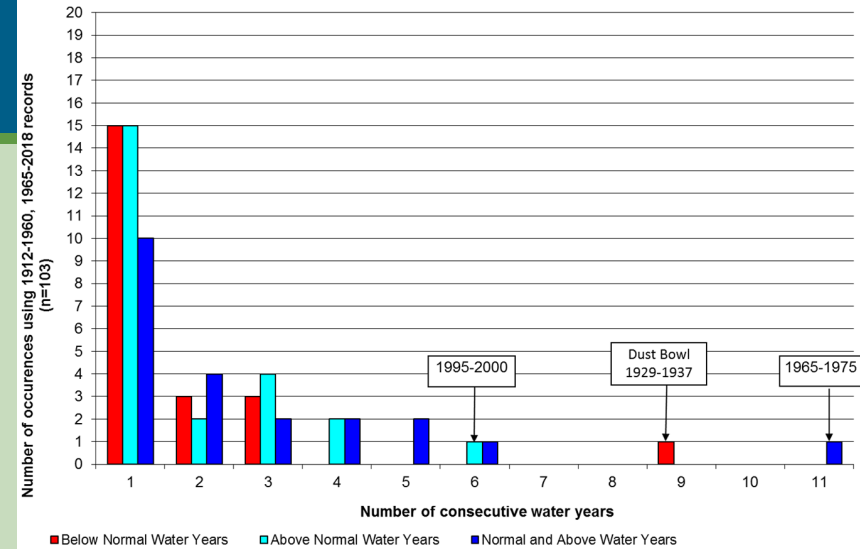
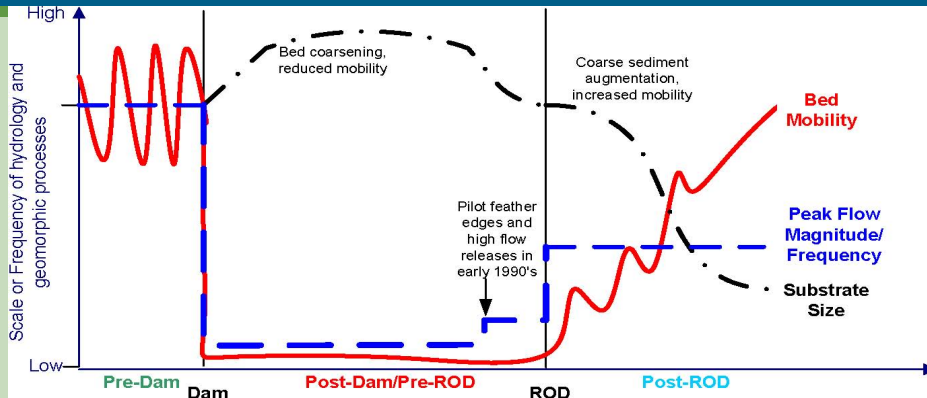
TRFES Riparian Rehabilitation Strategy



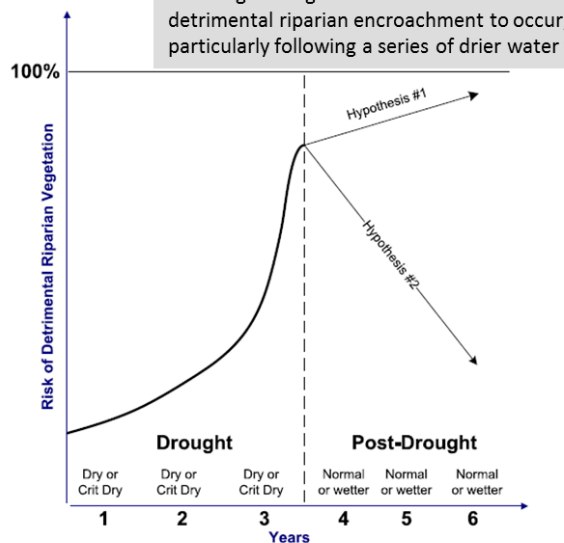
Objective	Critically Dry	Dry	Normal	Wet	Extremely Wet
	($Q_{peak} = 1,500$ cfs)	($Q_{peak} = 4,500$ cfs)	($Q_{peak} = 6,000$ cfs)	($Q_{peak} = 8,000$ cfs)	($Q_{peak} = 11,000$ cfs)
Bar Flank Bed Mobility	(None)	Mobilize the surface of in-channel alluvial features (e.g., spawning gravel deposits).	Mobilize D_{84} particles on general channel bed surface and along flanks of alternate bar surfaces.	Mobilize D_{84} particles on alternate bar surfaces.	Mobilize D_{84} particles on flanks of alternate bar surfaces.
Bar Flank Bed Scour	(None)	(None)	Channel bed scour and redeposition of gravels.	Channel bed scour greater than $1 \times D_{84}$ depth and redeposition of gravels.	Channel bed scour greater than $2 \times D_{84}$ depth and redeposition of gravels on face of alternate bars.
Bar Flank Riparian Seeding Scour	Discourage germination of riparian plants on lower bar surfaces for the early portion of the seed release period.	Discourage germination of riparian plants on bar flank for the early portion of the seed release period.	Woody riparian vegetation mortality up to 1-yr old along bar flank of alternate bar surfaces.	Woody riparian vegetation mortality up to 2-yr old along bar flank of alternate bar surfaces.	Woody riparian vegetation mortality along low water edge of alternate bar surfaces; scour up to 3-yr old woody riparian vegetation along channel margins and scour younger plants higher on bar flanks.
Upper Bar and Floodplain Riparian Establishment	(None)	(None)	Woody riparian regeneration on upper bar surfaces.	Woody riparian regeneration on upper alternate bar surfaces and floodplains.	Woody riparian regeneration on upper alternate bar surfaces and floodplains.
Large Wood Storage	(None)	(None)	(None)	Increase riparian vegetation and future large wood recruitment.	Increase riparian vegetation and future large wood recruitment.
Promote Riparian Germination Lower in the Channel via Lower Summer Baseflows	Not adopted due to water quality (i.e., temperature) criteria	Not adopted due to water quality (i.e., temperature) criteria	Not adopted due to water quality (i.e., temperature) criteria	Not adopted due to water quality (i.e., temperature) criteria	Not adopted due to water quality (i.e., temperature) criteria



Competing detrimental encroachment hypotheses

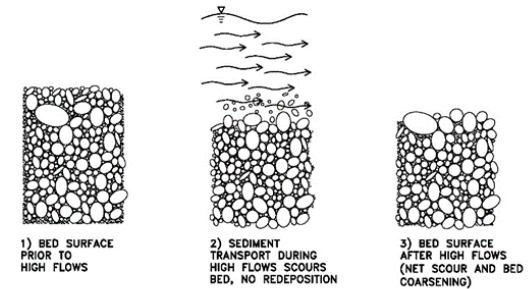


The TRRP flow and sediment regimes are considerably smaller than pre-dam conditions, resulting in a high level of risk for future detrimental riparian encroachment to occur, particularly following a series of drier water years.

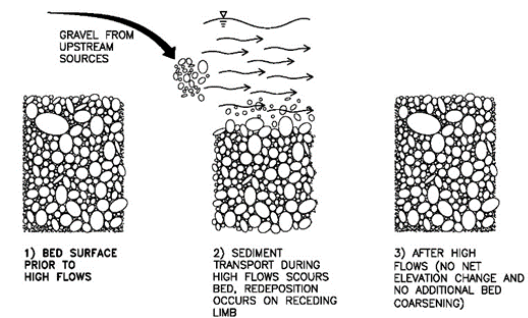


The TRRP flow and sediment regimes are considerably larger than the post-dam conditions that led to detrimental riparian encroachment. The combination of the ROD (variable) flow regime and the prescribed annual gravel augmentations reduces the risk of future detrimental riparian encroachment.

A) Without Coarse Sediment Supply



B) With Coarse Sediment Supply

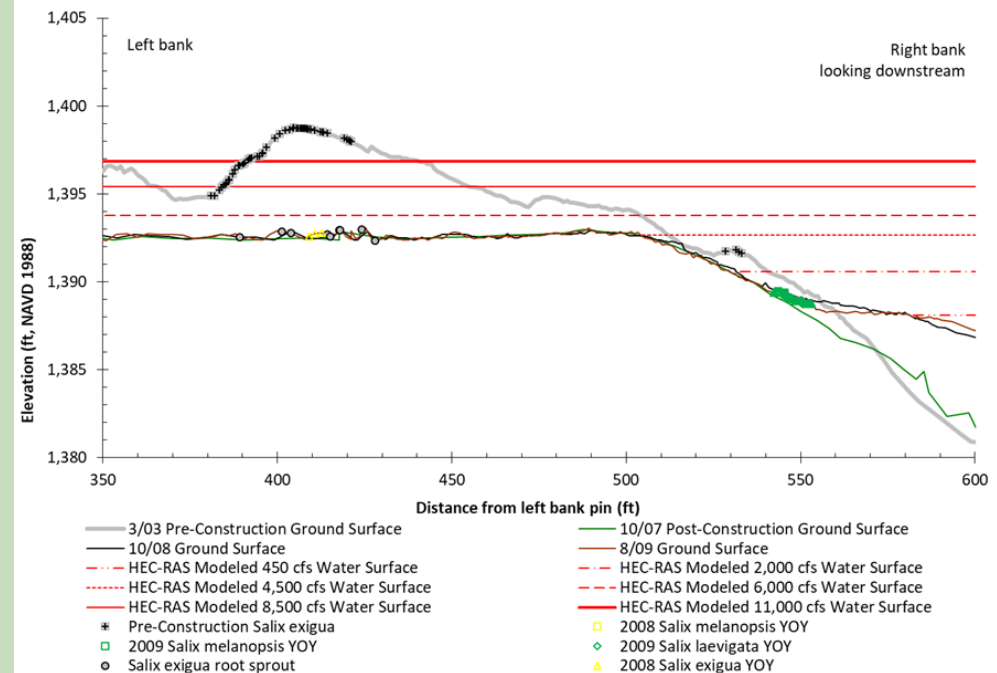
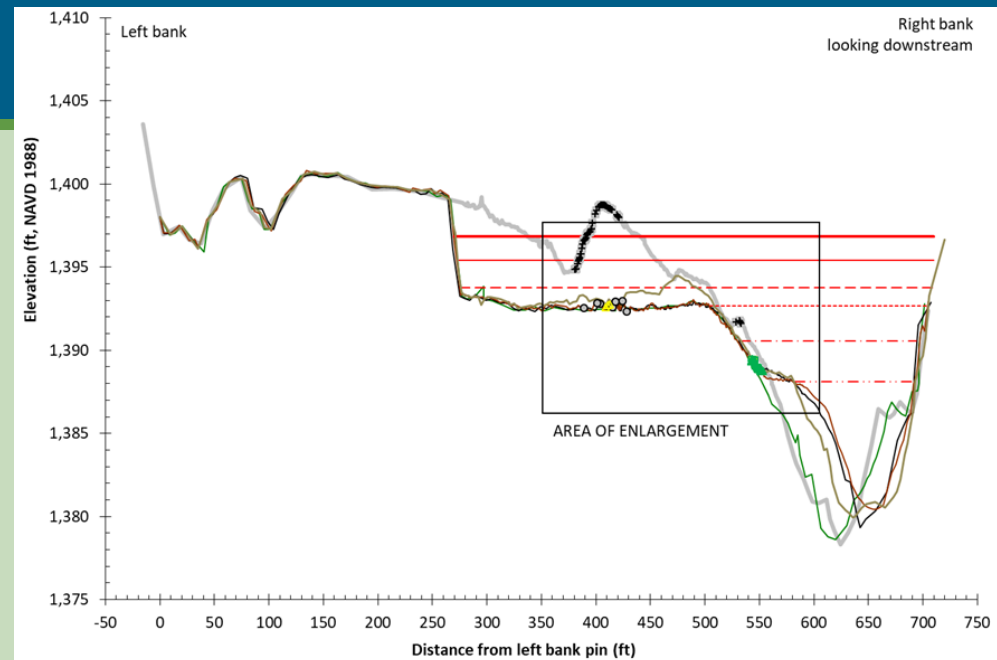


2005 - 2009 Period

Site	Year Constructed	First Cohort that Could Colonize the Surface
Hocker Flat	2005	2006 cohort
Lewiston Hatchery Coarse Sediment Augmentation	2006	2007 cohort
Lower Conner Creek	2006	2007 cohort
Elkhorn	2006	2007 cohort
Pear Tree Gulch	2006	2007 cohort
Valdor Gulch	2006	2007 cohort
Indian Creek	2007	2008 cohort
Dark Gulch/Bucktail	2008	2009 cohort
Lewiston 4 (Sven Olbertson, Deadwood Creek, Cableway, and Hoadley Gulch)	2008	2009 cohort
Sawmill	2009	2010 cohort

Water Year	Instantaneous Maximum Lewiston Streamflow (cfs)	Cohorts Scoured	Surviving Cohorts	Persisting Cohorts
2005	7,640	2004 cohort	None	1993, 1998, 2000 and 2002 cohort
2006	10,400	2003, 2004, and 2005 cohorts	None	1993, 1998, 2000 and 2002 cohort
2007	4,810	None	2006 cohort	1993, 1998, 2000, 2002 and 2006 cohort
2008	6,890	2007 cohort	2006 cohort	1993, 1998, 2000, 2002 and 2006 cohort
2009	4,630	None	2006 and 2008 cohort	1993, 1998, 2000, 2002, 2006 and 2008 cohort

Valdor Gulch



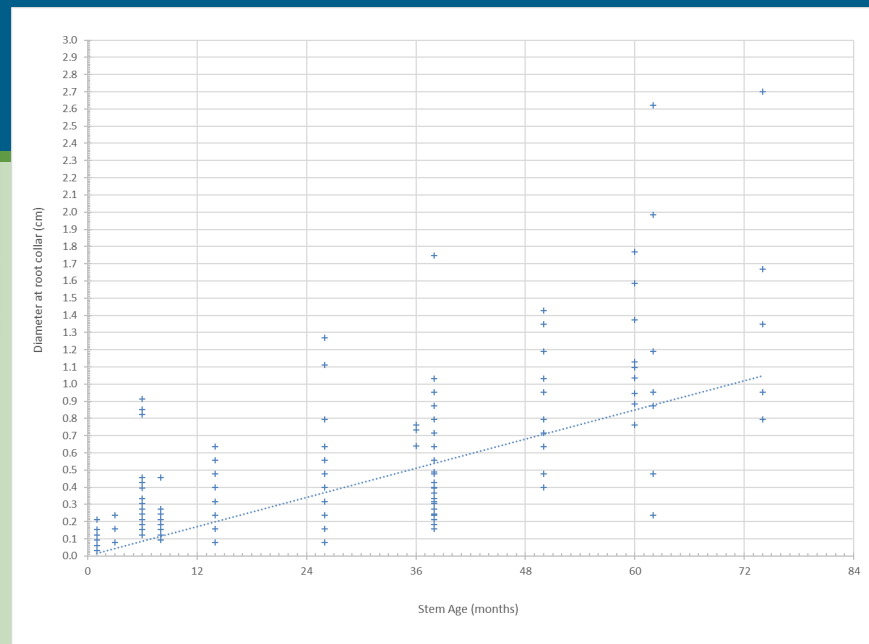
2010-2012 Period

GRTS Panel	Water Year										
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	...
1	X	X			X	X				X	
2		X	X			X	X				
3			X				X	X			
4			X	X				X	X		
5				X	X				X	X	
....											...

Site	Year Constructed	First Cohort that Could Colonize the Surface
Lowden Ranch	2010	2011 cohort
Reading Creek	2010	2011 cohort
Trinity House Gulch	2010	2011 cohort
Wheel Gulch	2011	2012 cohort
Lower Steiner Flat	2012	2013 cohort
Upper Junction City	2012	2013 cohort

Plant Size (DRC, cm)	Plant Age	Plant Density Encroachment Threshold (plants/ft ²)	Plant Density Encroachment Threshold (plants/m ²)
0–0.25	Young-of-Year (YOY)	16	172
0.26–0.50	1-year		
0.51–0.75	2-year	0.65	7
0.76–1.0	3-year	0.15	2
> 1.0	> 3-year	0.11	1

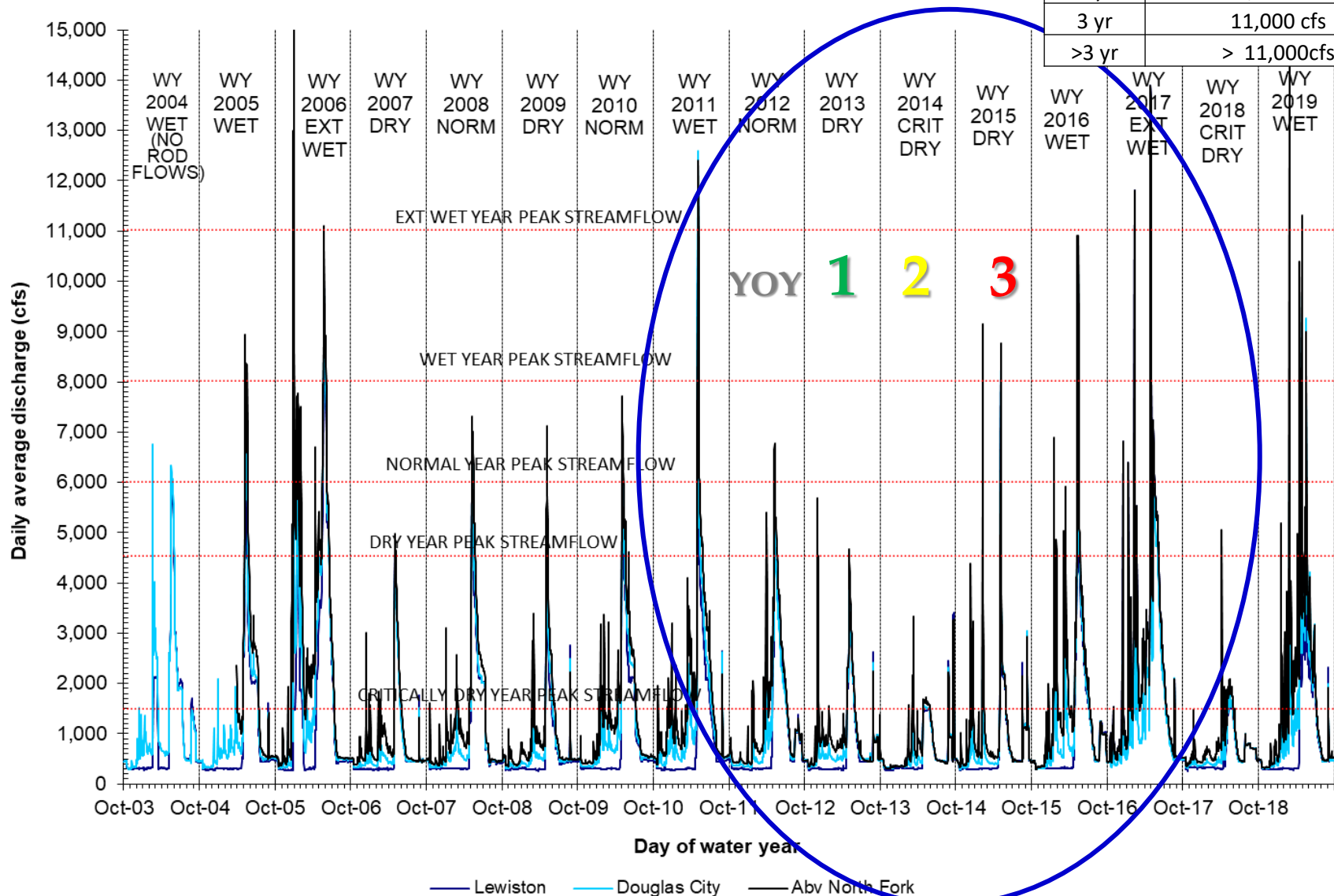
Water Year	Instantaneous Maximum Lewiston Streamflow (cfs)	Cohorts Scoured	Surviving Cohorts	Persisting Cohorts
2010	7,480	2009 cohort	2006 and 2008 cohort	1993, 1998, 2000, 2002, 2006 and 2008 cohort
2011	12,300	2008, 2009, and 2010 cohorts	2006 cohort	1993, 1998, 2000, 2002 and 2006 cohort
2012	6,180	2011 cohort	2006 cohort	1993, 1998, 2000, 2002 and 2006 cohort



Size Class (cm)	Dominant Plant Age	Q to Remove	WY Type to Remove	Risk Code	Risk Description
0.0–0.25	Young-of-Year	6,000 cfs	Normal and wetter	Green	Moderate risk, these hardwoods should be watched to evaluate if they get to the 2-yr old stage; no modification of the hydrograph needed
0.26–0.50	1-year-old	6,000 cfs	Normal and wetter	Green	Moderate risk, these hardwoods should be watched to evaluate if they get to the 2-yr old stage; no modification of the hydrograph needed
0.51–0.75	2-year-old	8,500 cfs	Wet and wetter	Yellow	High risk, 8,500 cfs suggested for that year; may recommend subtle adjustments to hydrograph release for that given water year
0.76–1.0	3-year-old	11,000 cfs	Extremely Wet	Red	Extreme Risk, 11,000 cfs suggested that year; may need to modify hydrograph release for that given water year
1.01–1.50	4-year-old	Unlikely to remove with flows alone	N/A	Grey	Beyond what ROD streamflows are expected to remove
1.51–2.0	5-year-old	Unlikely to remove with flows alone	N/A	Grey	Beyond what ROD streamflows are expected to remove

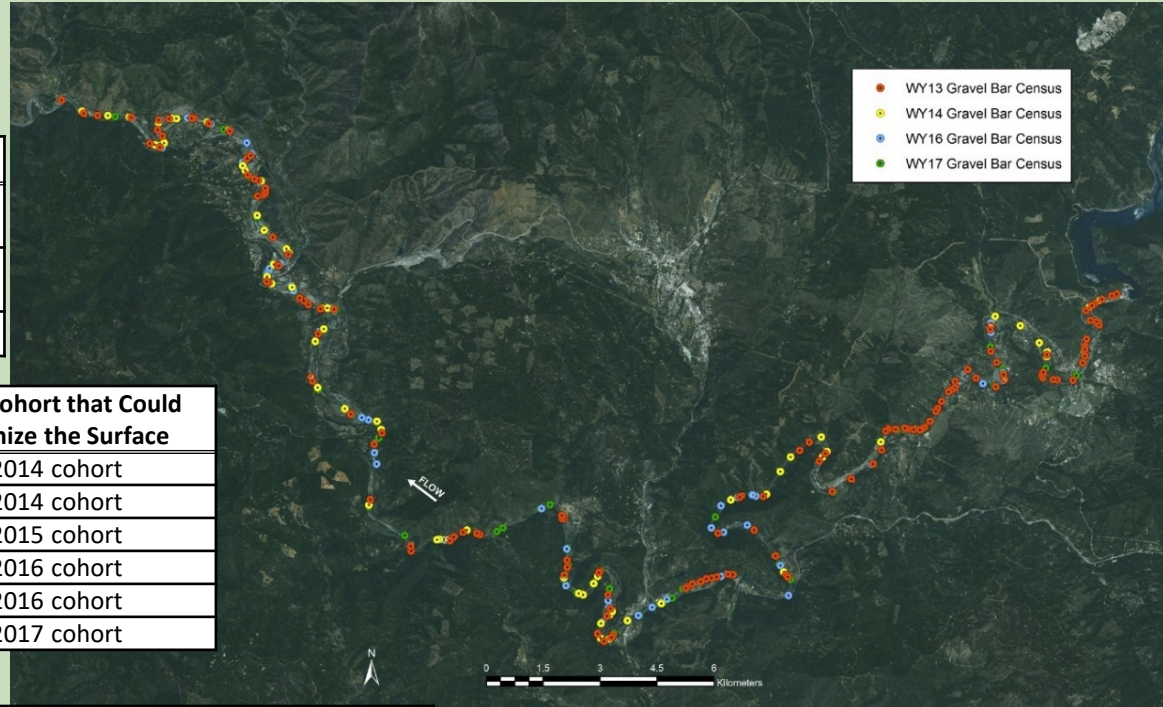
WY 2004 to WY 2019 hydrographs and water year sequencing (n= 16 yrs)

Cohort	Discharge that kills cohort
YOY	6,000 cfs
1 yr	6,000 cfs
2 yr	8,500 cfs
3 yr	11,000 cfs
>3 yr	> 11,000cfs



?

2013-2017 Period



Type of Bar	2012	2013	2015	2016
Bars totally inundated at less than 2,000 cfs	69	125	126	103
Bars totally inundated at more than 2,000 cfs	69	68	68	88
Total	138	193	194	191

Site	Constructed	First Cohort that Could Colonize the Surface
Douglas City 2013	2013	2014 cohort
Lorenz Gulch	2013	2014 cohort
Lower Junction City	2014	2015 cohort
Douglas City 2015	2015	2016 cohort
Limekiln Gulch	2015	2016 cohort
Bucktail	2016	2017 cohort

Water Year	Instantaneous Maximum Lewiston Streamflow (cfs)	Cohorts Scoured	Surviving Cohorts	Persisting Cohorts
2013	4,590	None	2006 and 2012 cohort	1993, 1998, 2000, 2002, 2006 and 2012 cohort
2014	3,460*	None	2006, 2012, and 2013 cohort	1993, 1998, 2000, 2002, 2006, 2012, and 2013 cohort
2015	8,830	2013 and 2014 cohorts	2006 and 2012 cohort	1993, 1998, 2000, 2002, 2006 and 2012 cohort
2016	? 9,600	2012 and 2015 cohorts	2006 cohort	1993, 1998, 2000, 2002, and 2006 cohort

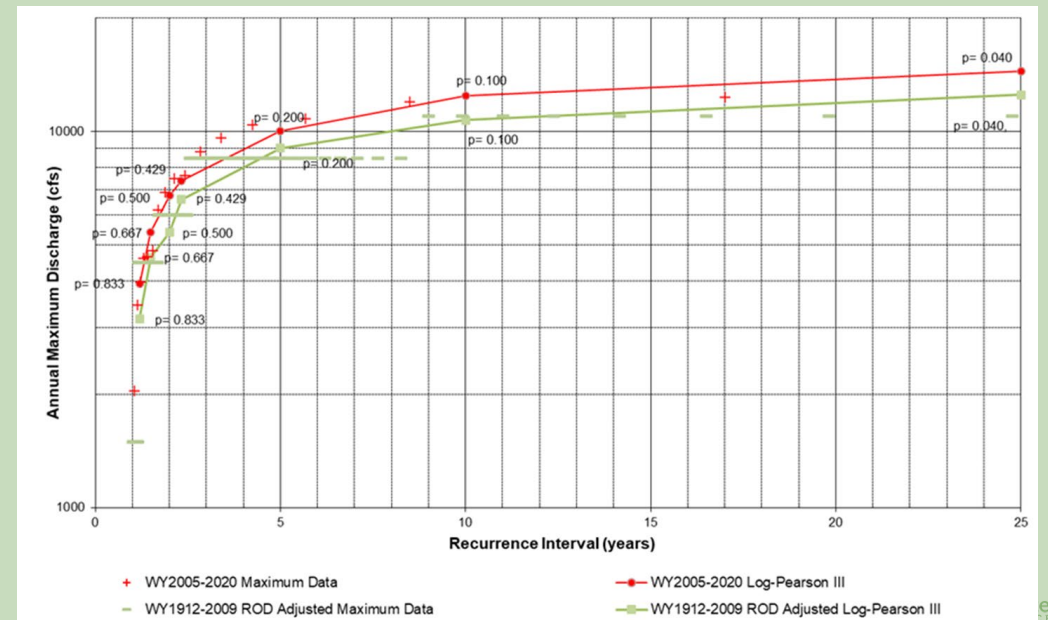
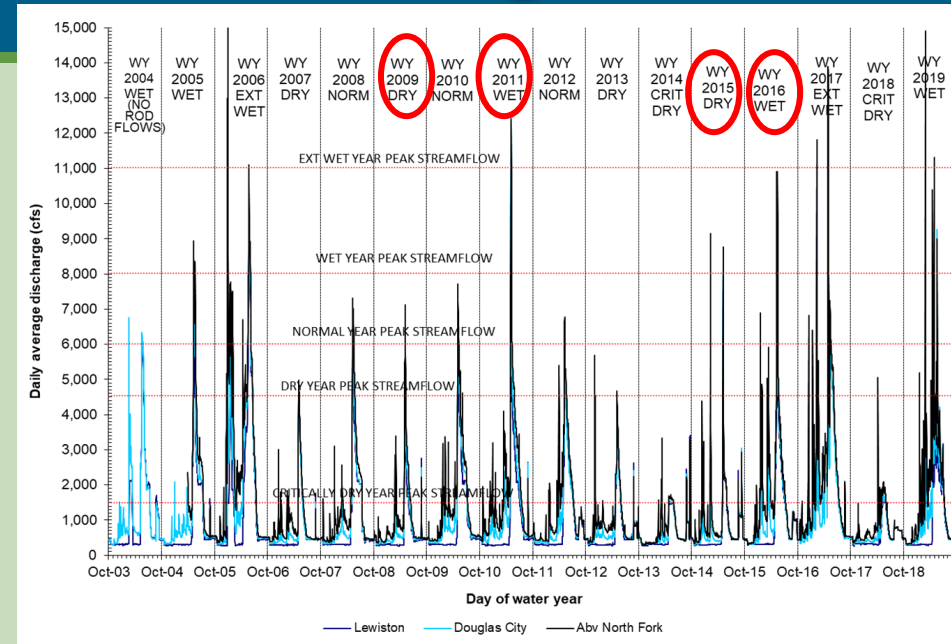
*The peak discharge of 2014 was not associated with spring ROD flows, rather it occurred on September 22, 2013, and was associated with Lower Klamath River water temperature and fish health flows.

Reflections on the TRFE Restoration Strategy and Implications to Riparian Encroachment

- The TRFE oversimplified the academic, social, bureaucratic, and temporal obstacles to developing a smaller-scale alluvial river.
- The physical changes embodied in the TRFE were to be large, obvious, and occur in a short time (i.e., years).
- Considering partial gravel augmentation combined with restoration streamflows, it is apparent that without mechanical restoration, the envisioned changes are minor and may take decades, if they occur at all.
- The TRFE strategy relied on a simple meander wavelength to serve as a template for the future channel condition. While seeming simple in its form 30 years later, the basis of Chinook Salmon population recovery was centered on juvenile habitat recovery which was, and still is, founded on the future channel pattern
- Encroachment in an anabranching channel could lead to reductions in channel width and increases in depth over time, leading to the reduction in channel number. The quantity of aquatic habitat would be reduced; however, the diversity and quality could be potentially maintained.
- Encroachment along a single-thread channel could lead to reduction in width and increases in depth, with reduction in quantity, quality, and diversity of habitats. Without sufficient flows or sediment supply, the channel may become moribund.
- Managing encroachment should be a high priority regardless of the channel type.

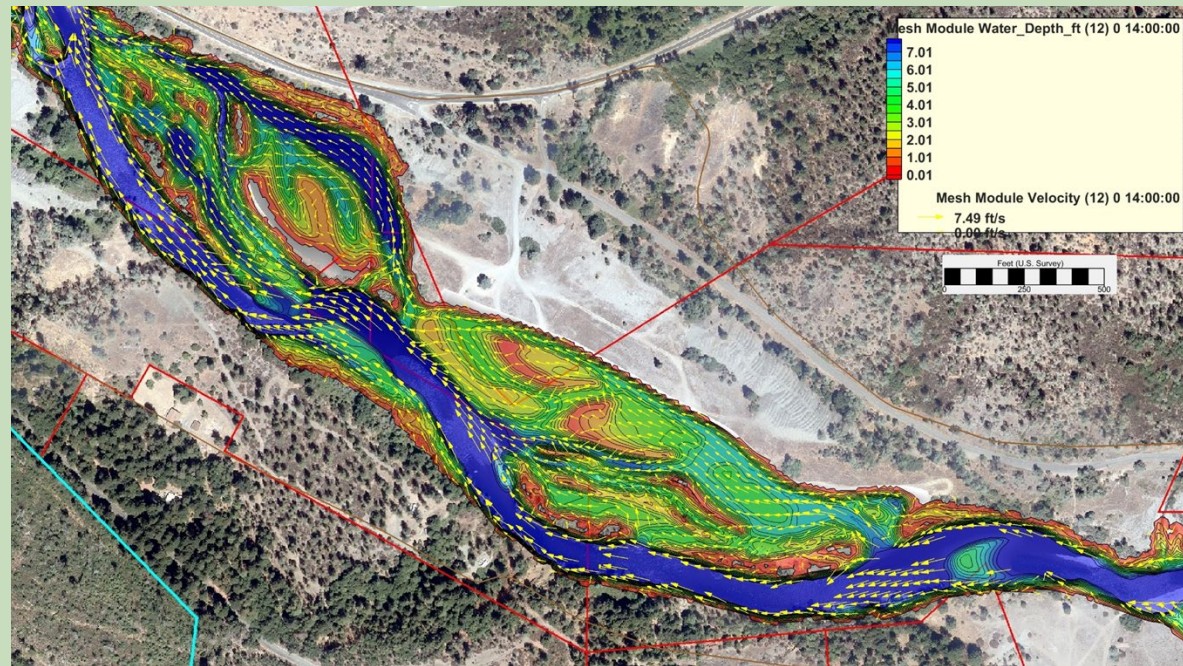
Reflections on Streamflow Management

- The TRRP management objectives evolved to reach the maximum allowable peak streamflow release as frequently as possible in Normal and wetter years.
- The purpose for increasing the frequency of maximum flood peaks has been to maximize the amount of geomorphic work and sediment transport, under the assumption that increasing the rate of physical change would restore the river more rapidly.



Reflections on Channel Rehabilitation Design

- Vegetation structure and patterns adjacent to the channel may vary with channel form, and areas of multi-aged, species-rich riparian vegetation are a valuable ecosystem component of straight, meandering, or anabranching channel forms.
- Lowering ground surfaces next to wetted channels will decrease the distance that establishing plant roots need to grow to access shallow groundwater, thereby increasing the overall amount of riparian hardwood initiation at rehabilitated sites. One trade off that each design team will need to consider is the increase in width next to the wetted channel and the reduced ability of the channel to convey sediment (i.e., scour seedlings to prevent encroachment).



Reflections on Fine Sediment Management

- In the 1960s and 70s, the fine sediment supply from tributaries was orders of magnitudes greater than it is today (GMA 2001).
- Fine sediment is a key ingredient to making sediment berms; however, the lack of berm formation is more likely a reflection of reduced fine sediment supply, and woody plant encroachment can still be detrimental in the absence of a berm.
- Future management actions may need to be directed to recovering burned watersheds to reduce erosion and fine sediment supply.
- Fine sediment supply, transport, and storage should continue to be managed in an AEAM context with respect to floodplain evolution, encroachment risk, and berm formation.

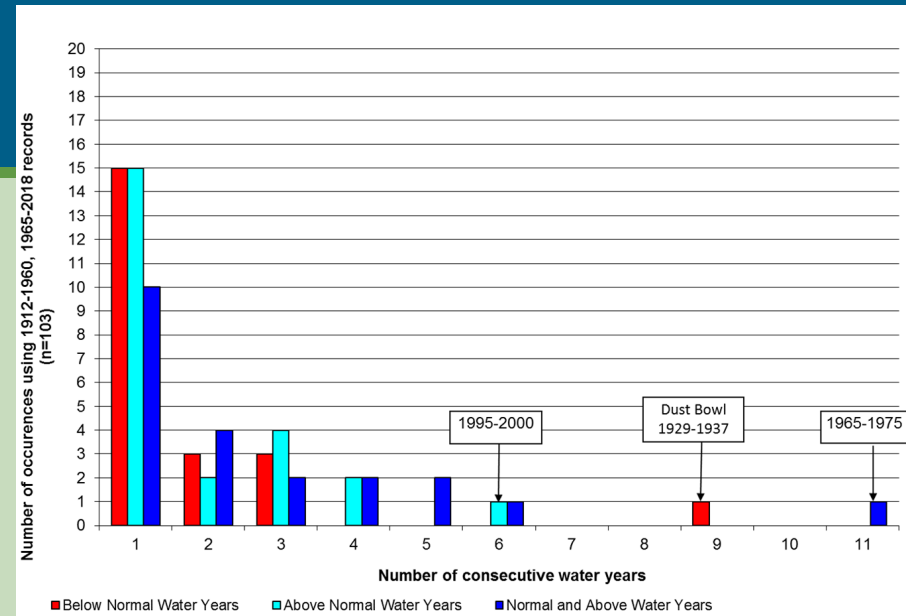
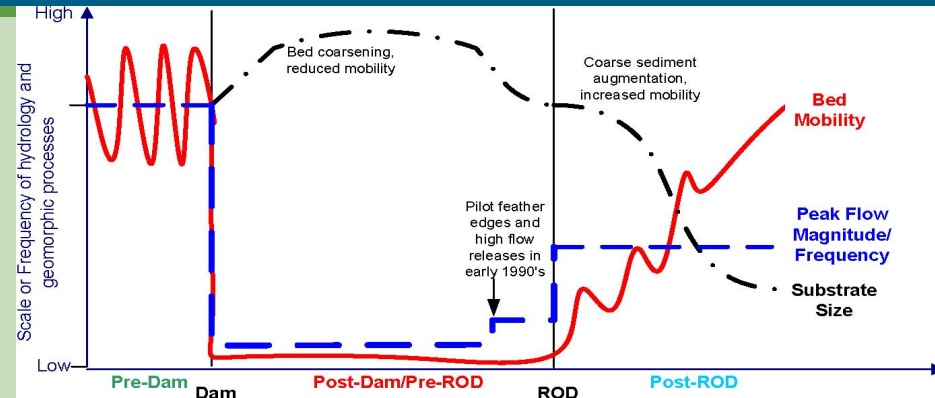
Reflections on Coarse Sediment Management

- There has been an increase in local coarse sediment storage due to increased streamflow magnitude and frequency in locations where coarse sediment augmentation has occurred and at tributary deltas (Gaeuman and Stewart 2017).
- Repeated surface and subsurface particle size sampling conducted in 2001, 2009, 2014, and 2018 do not show a clear trend of particle sizes becoming smaller with time either in the surface or subsurface layers between years (GMA Hydrology 2020).

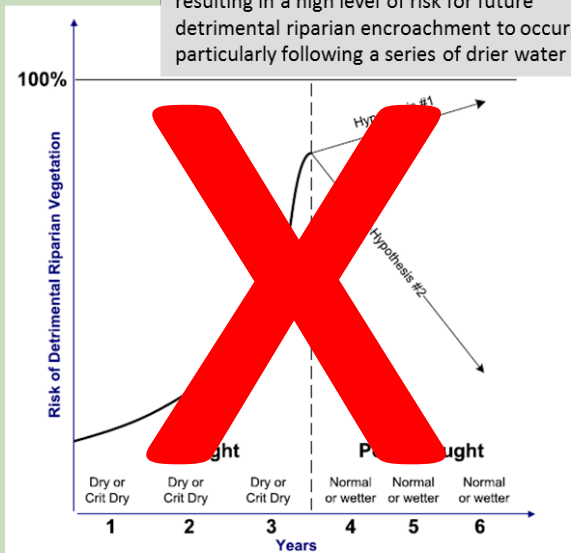
Management Strategies Not Specifically Included in the ROD

- It is possible that with continued large wood addition and large wood structure construction, bank failure and local scour dynamics around wood pieces and wood jams could encourage further bank erosion and inhibit local woody plant encroachment. Large wood supply, storage, and transport will be an important part of maintaining future channel morphology, whether it is a single-threaded or anabranching channel.
- Incorporating diurnal fluctuations into spring ROD releases could be used to encourage bank failure. During the diurnal peak, the soil pores fill with water and during the diurnal low, the pores drain. If daily streamflow fluctuations of 1 to 2 ft were possible at the peak release and then gradually decreased the diurnal fluctuation could create rapid drops in the substrate pore pressure to the extent that the bank may fail (Micheli and Kirchner 2002a, b)
- With sufficient inundation, woody plants will die. There are no monitoring data to quantify the effect of inundation mortality directly; however, it could be a potentially effective mortality agent if streamflow duration and magnitude were managed to target the long-term inundation of mature alder trees, or YOY seedlings in years when ROD releases are insufficient to scour them (i.e., flows below 6,000 cfs).
- With rapidly receding flows and/or no rainfall, coarse substrates may dry quickly and plants that establish where there once was available soil moisture may desiccate and die. Desiccation mortality accounted for about 5% of the YOY seedlings at the upper elevation limits of establishing seedlings and not at lower elevations. Desiccation mortality was not observed in older seedlings or established or mature woody riparian plants.

Evaluation of detrimental encroachment hypotheses



The TRRP flow and sediment regimes are considerably smaller than pre-dam conditions, resulting in a high level of risk for future detrimental riparian encroachment to occur, particularly following a series of drier water years.



The TRRP flow and sediment regimes are considerably larger than the post-dam conditions that led to detrimental riparian encroachment. The combination of the ROD (variable) flow regime and the prescribed annual gravel augmentations reduces the risk of future detrimental riparian encroachment.

Water Year	Water Year Class Based on April 1 Inflow Forecast	TRFE Minimum Recommendation (U.S. Tons)	Actual Total Augmentation (U.S. Tons)	Difference (U.S. Tons)
2000	WET	13,700	2,781	-10,919
2001	DRY	206	0	-206
2002	NORMAL	2,466	0	-2,466
2003	NORMAL	13,700	2,740	-10,960
2004	WET	13,700	0	-13,700
2005	WET	13,700	0	-13,700
2006	EXT WET	42,470	2,302	-40,168
2007	DRY	206	6,138	5,932
2008	NORMAL	2,466	17,002	14,536
2009	DRY	206	11,179	10,974
2010	NORMAL	2,466	22,454	19,988
2011	WET	13,700	7,288	-6,412
2012	NORMAL	2,466	0	-2,466
2013	DRY	206	2,329	2,124
2014	CRIT DRY	0	0	0
2015	DRY	206	3,781	3,576
2016	WET	13,700	4,932	-11,398
2017	EXT WET	42,470	7,672	-34,798
2018	CRIT DRY	0	0	0
2019	WET	13,700	4,795	-8,905
2020	CRIT DRY	0	0	0

Revised Hypotheses

- *H01: The 6,000, 8,500, and 11,000 cfs flood events occurring at the frequency of Normal and wetter years cannot inhibit near channel woody seedling establishment and the formation of a dense band of vegetation after a period of three consecutive dry years.*
- *HA1: The 6,000, 8,500, and 11,000 cfs flood events occurring more frequently than Normal and wetter years and during periods of consecutive dry years can inhibit near channel woody seedling establishment and disrupt the formation of a dense band of vegetation even after a three-year dry period.*

Recommendations

- Review, Revise, and Adopt a Reach-based Prediction of Achievable Channel Pattern
- Develop and Adopt a Revised Vegetation Encroachment Hypothesis
- Evaluate Current Berm Condition
- Evaluate and Revise the Conceptual Model for Coarse Sediment Augmentation and Update the Coarse Sediment Management Plan
- Repeat the Exposed Gravel Bar Census in Normal and Wetter Years
- Annually Estimate Detrimental Encroachment Risk to Inform Annual Flow Release Planning
- Evaluate Variable Summer Baseflows and Conduct Flow Experiment