

A scenic landscape of a river estuary. The foreground shows a calm body of water reflecting the sky and surrounding landscape. A large log with some green vegetation is partially submerged in the water. The middle ground features a grassy bank with some trees. In the background, there are rolling hills and mountains under a blue sky with light clouds.

Salmon River Estuary

Over 40 years of learning

Kami Ellingson
Watershed Program Manager
Siuslaw National Forest

Photo Credit—Barbara Ellis-Sugai



1987

2012

1978

2014

2009

Reference Marsh

1996

2010-11



The nuts and bolts...

- Protections
- Partnership
- Persistence
- Patience



Protections

Cascade Head Experimental Forest

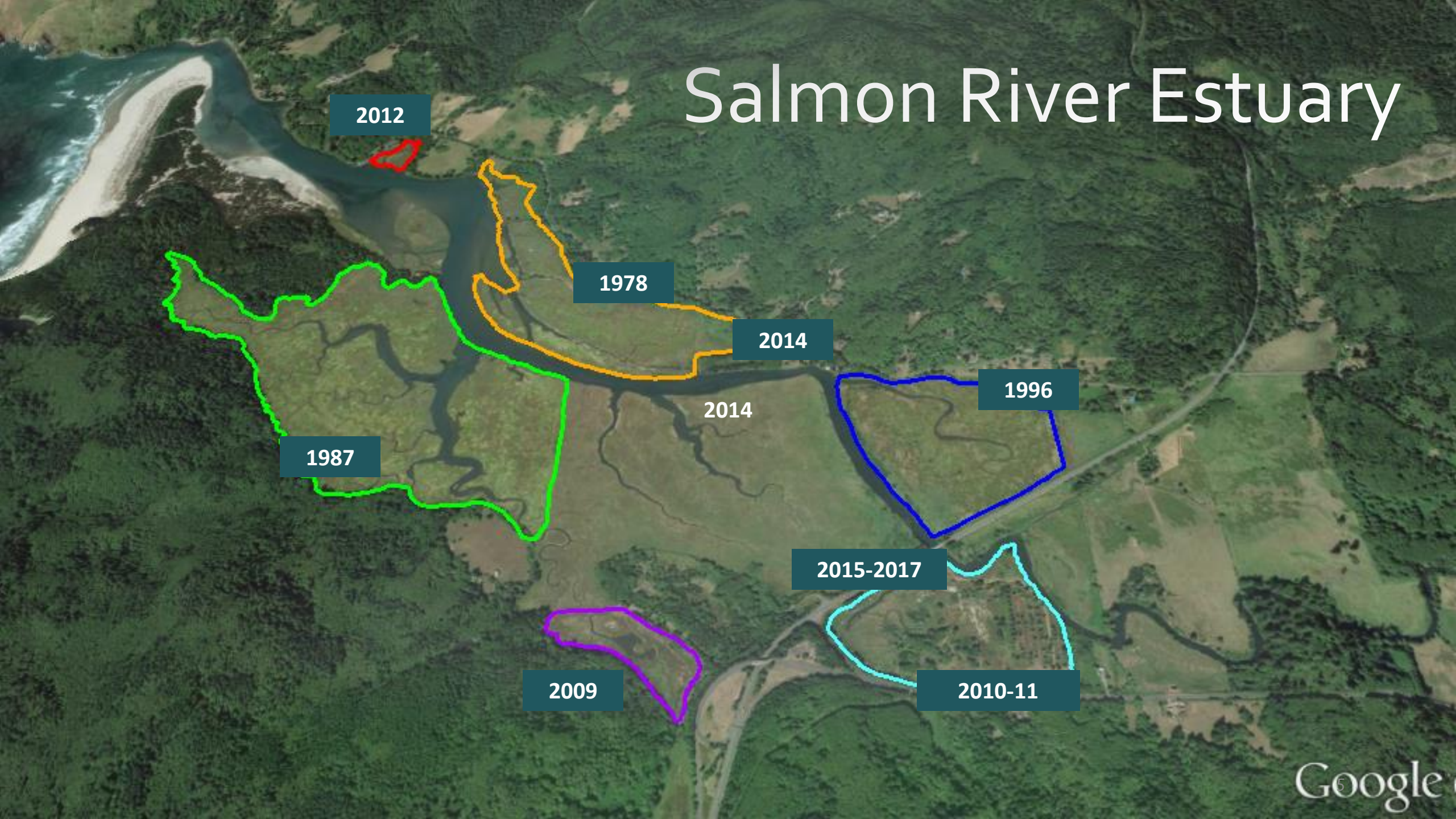
TNC Cascade Head Preserve

Cascade Head Scenic-Research Area

UNESCO Biosphere Reserve

Marine Reserve

Salmon River Estuary



2012

1978

2014

1996

1987

2014

2015-2017

2009

2010-11

1978



1975 Photo

1978

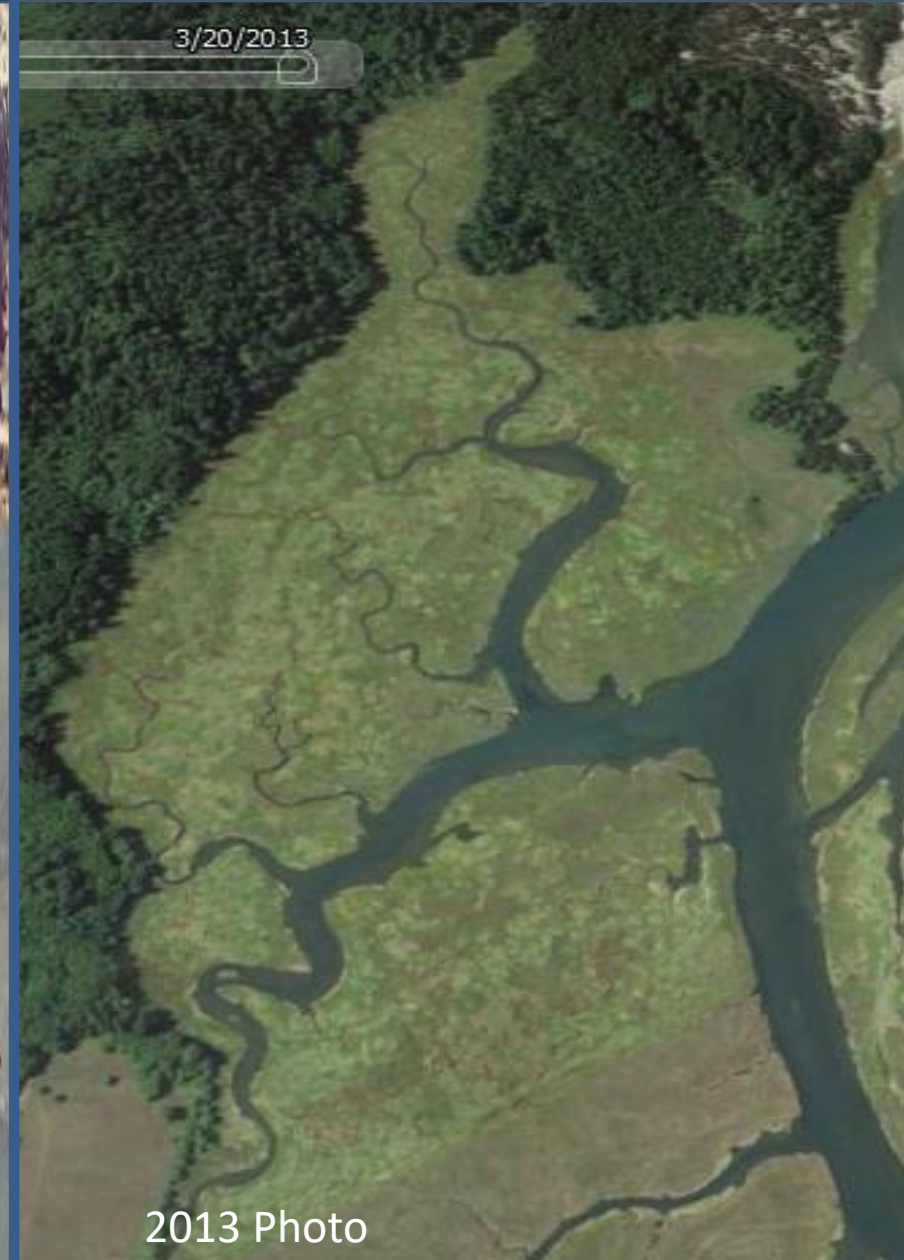


2013 Photo

1987



1987



1996



1975 Photo

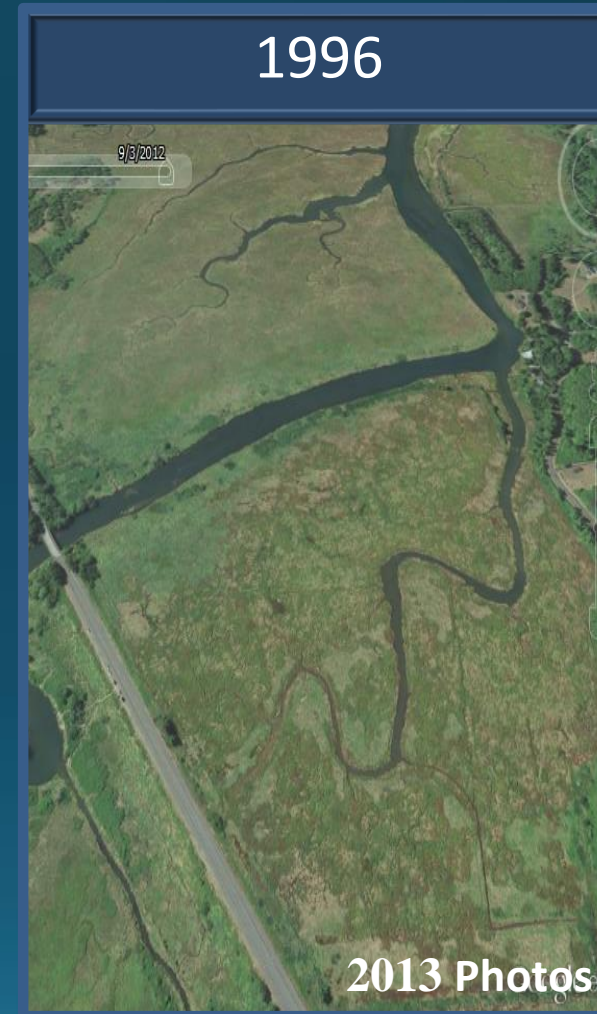
1996



2013 Photo

Google ea

2013- Years Later



Project results:
339 acres restored

2008-2009 Restoration



Pre-Development



Post-Development

2008-2009 Restoration



Project Components

- Removed infrastructure & tidegates
- Installed AOP culvert-Rowdy Creek
- Rebuilt multiple tidal channels
- Native planting & maintenance

Project Results

- 44 acres restored
- Pre & post wetland delineation
- As-built survey &
- 10 years of monitoring

December 17, 2010



2010-2011 Restoration

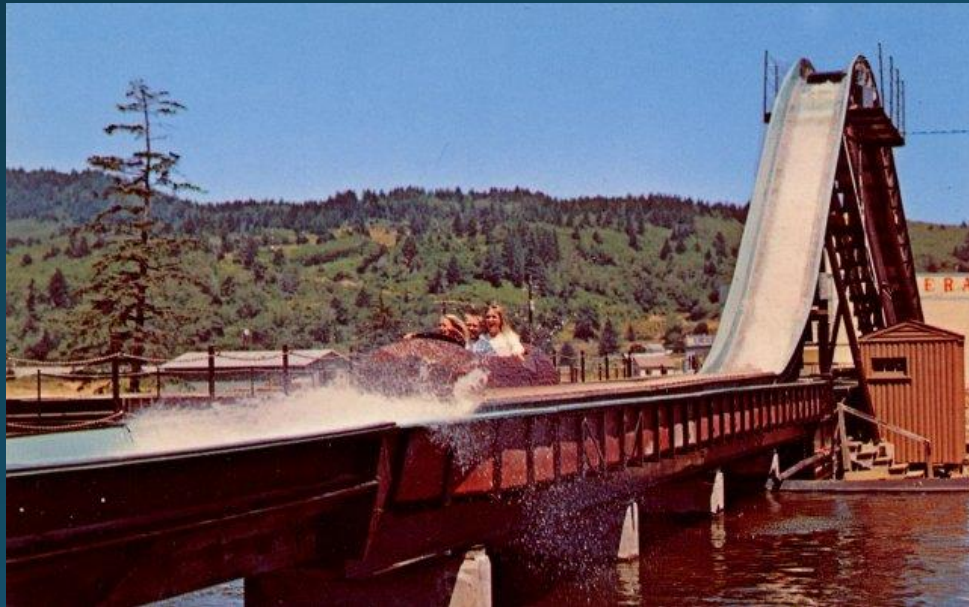
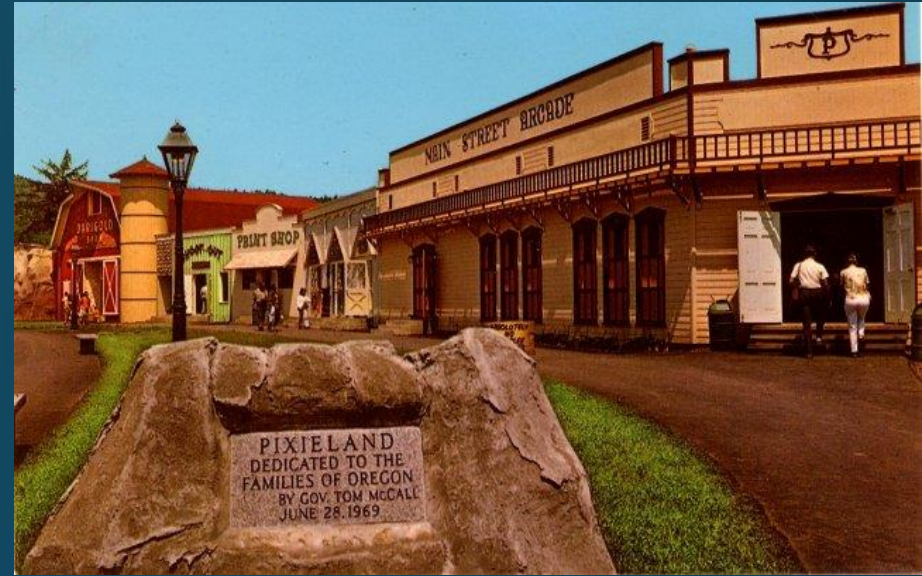


Pre-Development



Post-Development

Pixieland Amusement Park 1969-1974



2010-2011 Restoration



1975 Photo



2012 Photo

Project Components

- Removed infrastructure
- Filled artificial ponds-establish marsh
- Rebuilt multiple tidal channels
- Native planting & maintenance

Project Results

- 52 acres tidal marsh restored
- Miles of new sinuous tidal channels forming
- 5 beaver dams, extensive wetland network
- Baseline data & 10 years of monitoring

January 19, 2012



December 6, 2015



December 7, 2015





1987

2012

1978

2014

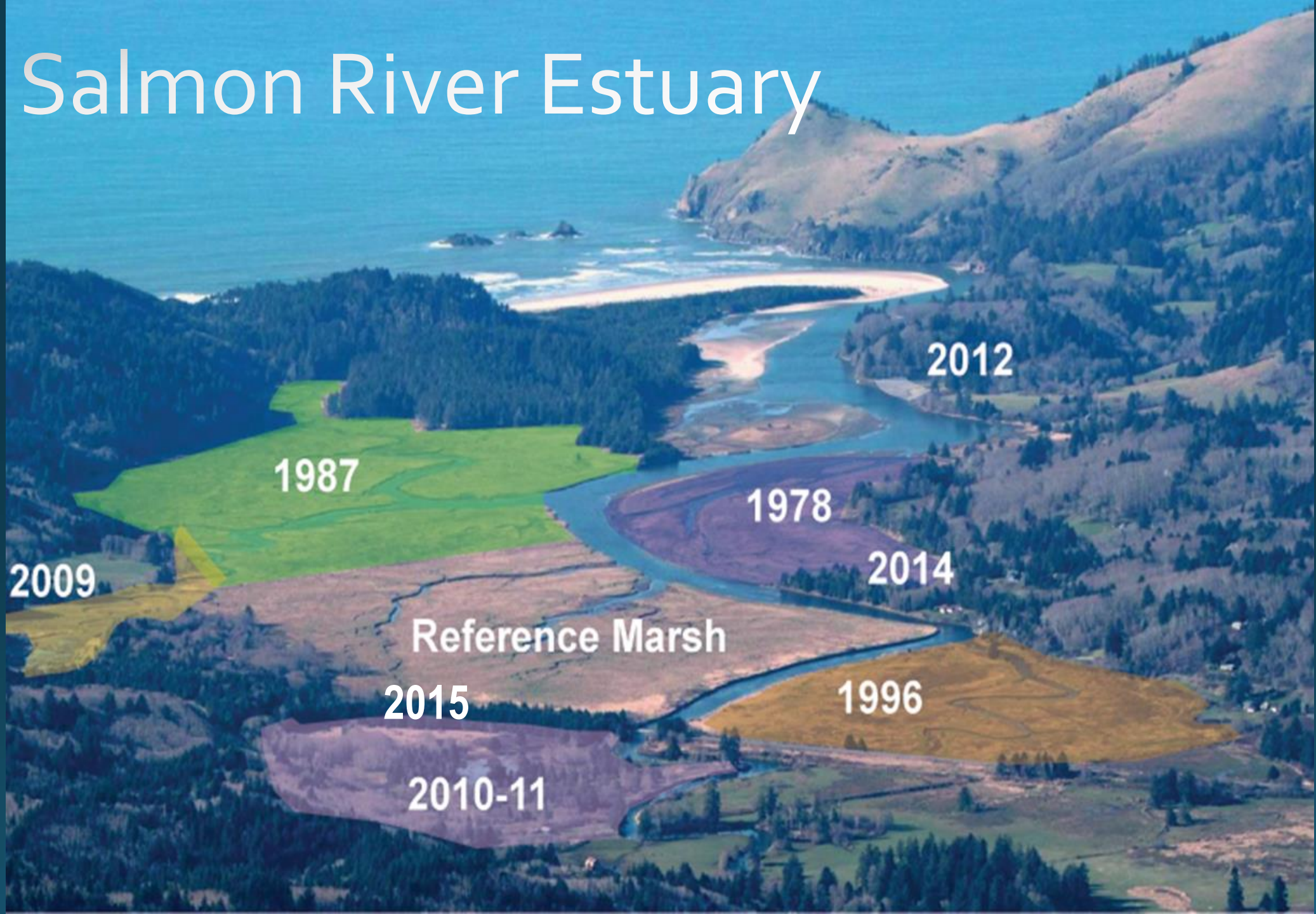
2009

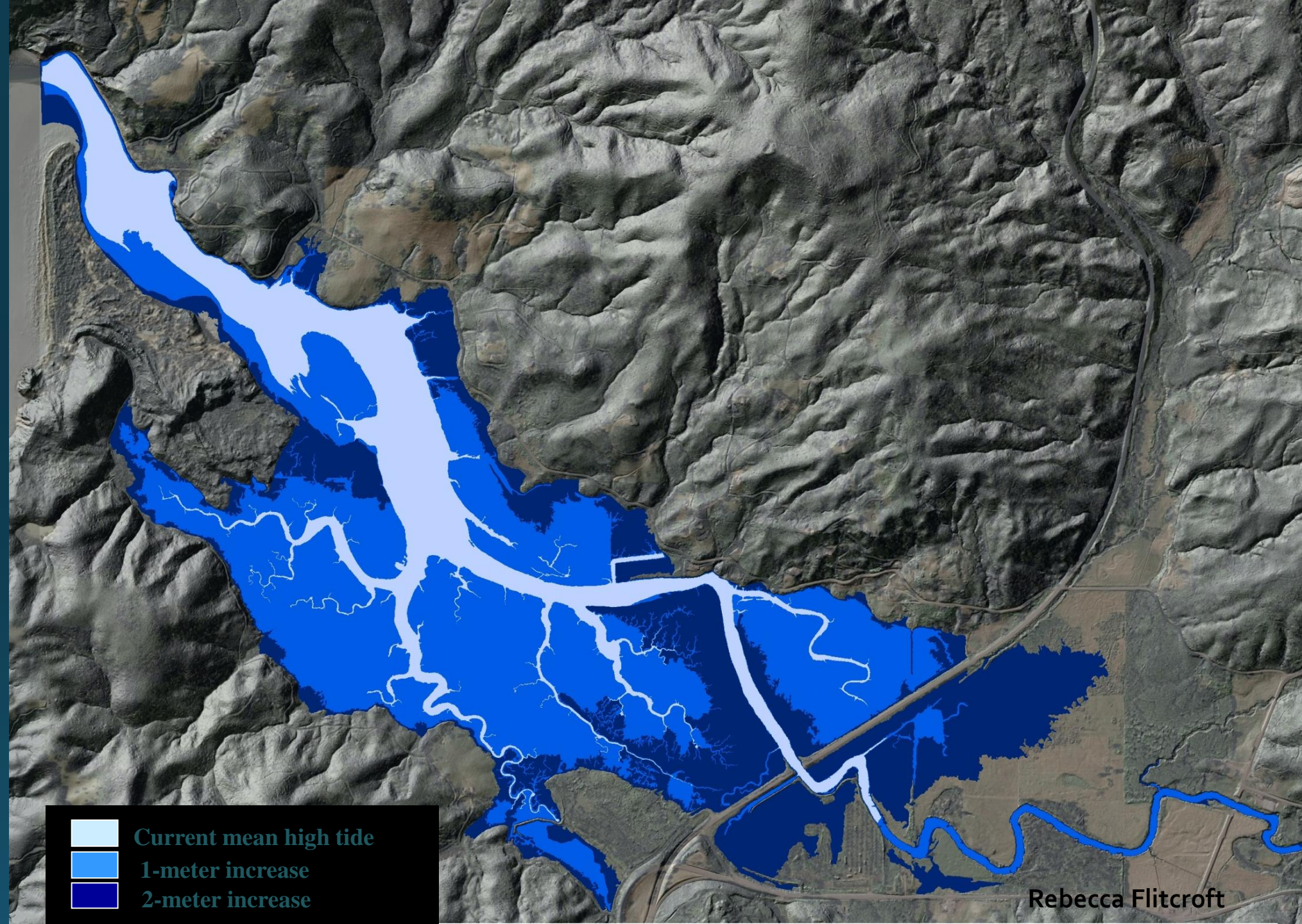
Reference Marsh




1996

2010-11

Salmon River Estuary





-  Current mean high tide
-  1-meter increase
-  2-meter increase

Rebecca Flitcroft

Flood Mitigation



2012

1987

1978

2009

2014

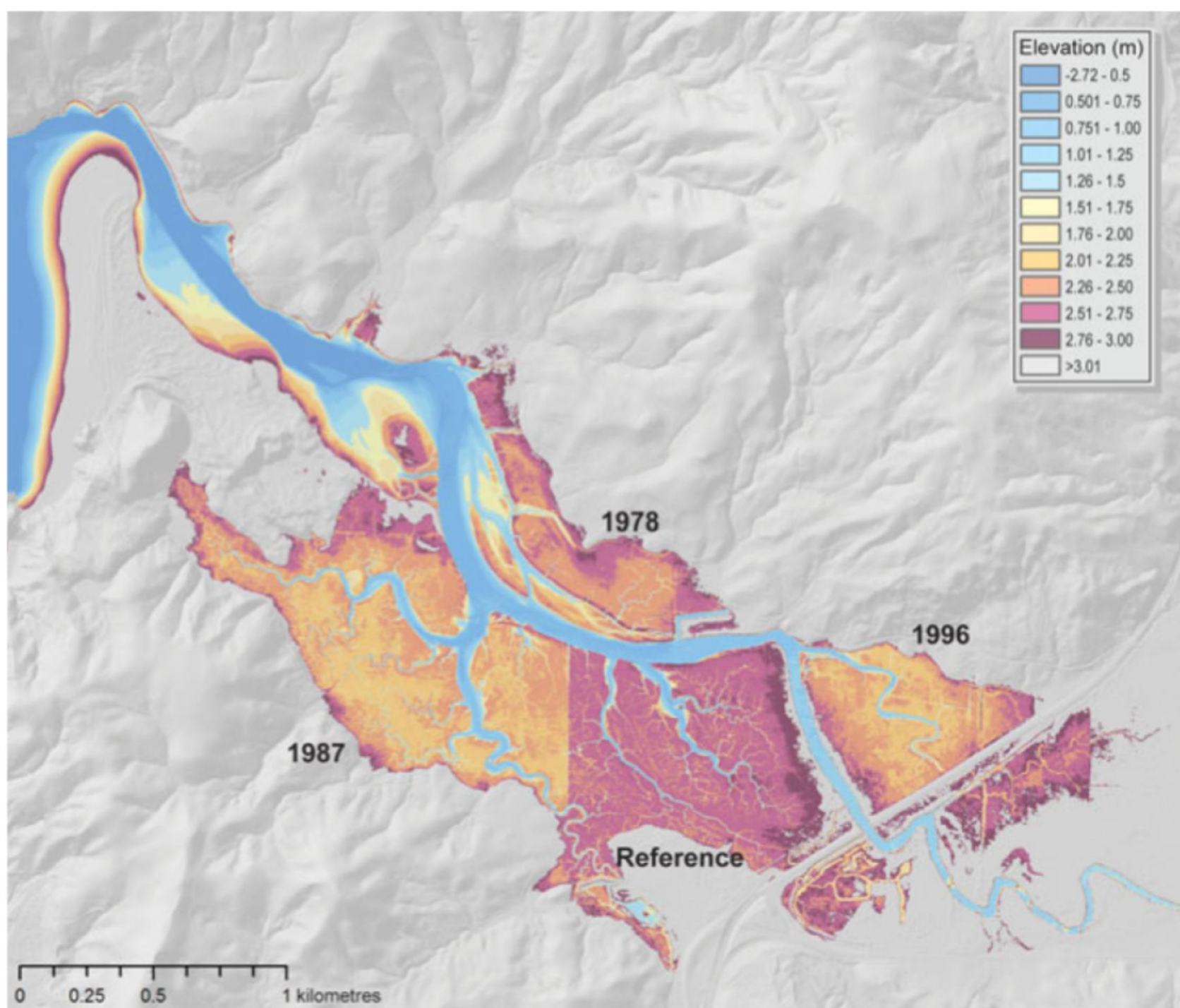
2010-2011

1996

Head
of Tide

Fish
Hatchery

Residences





2009

1987

1978

2012

1996

2010-11

Reference

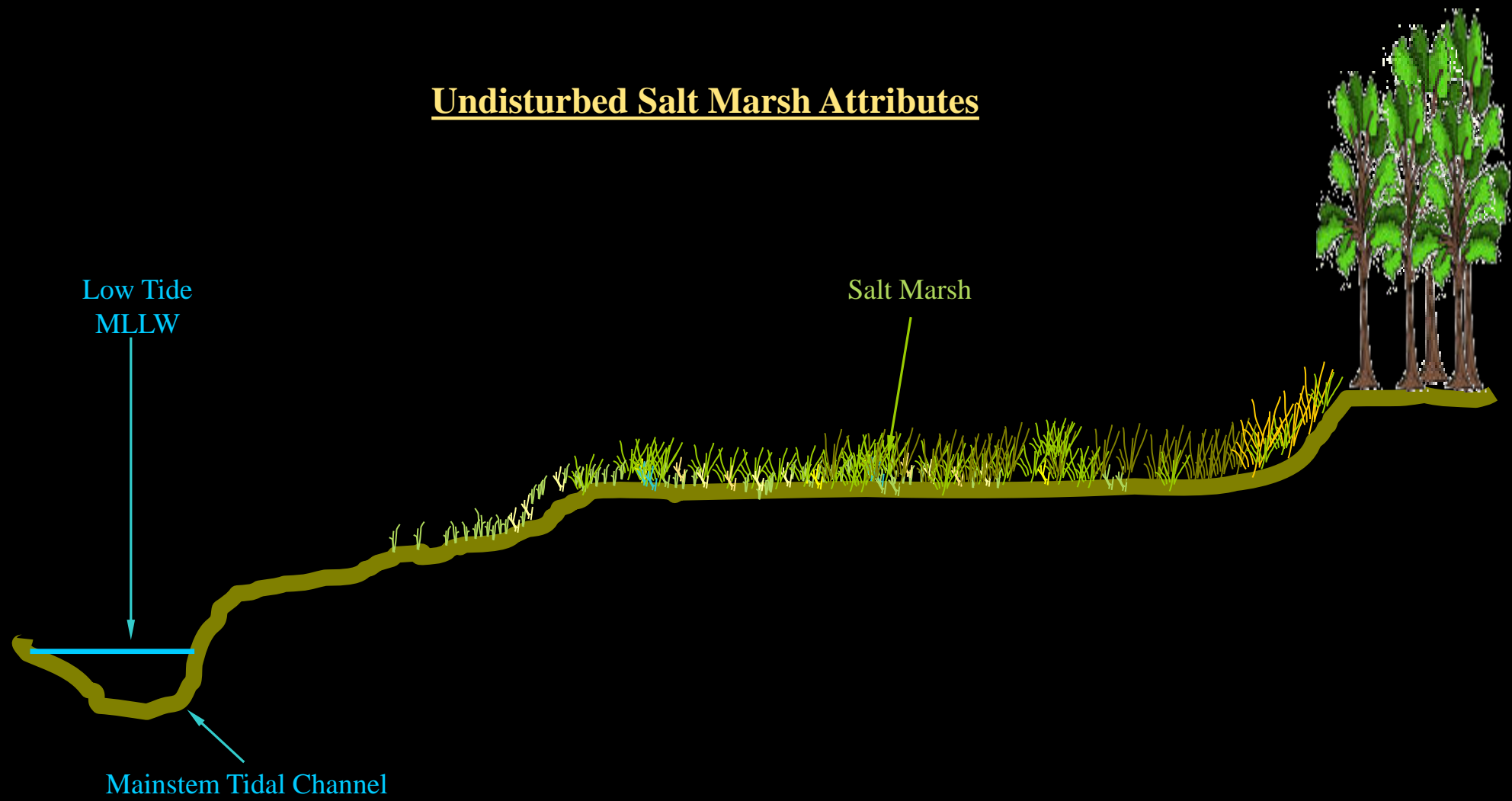
Energy-rich aquatic flies



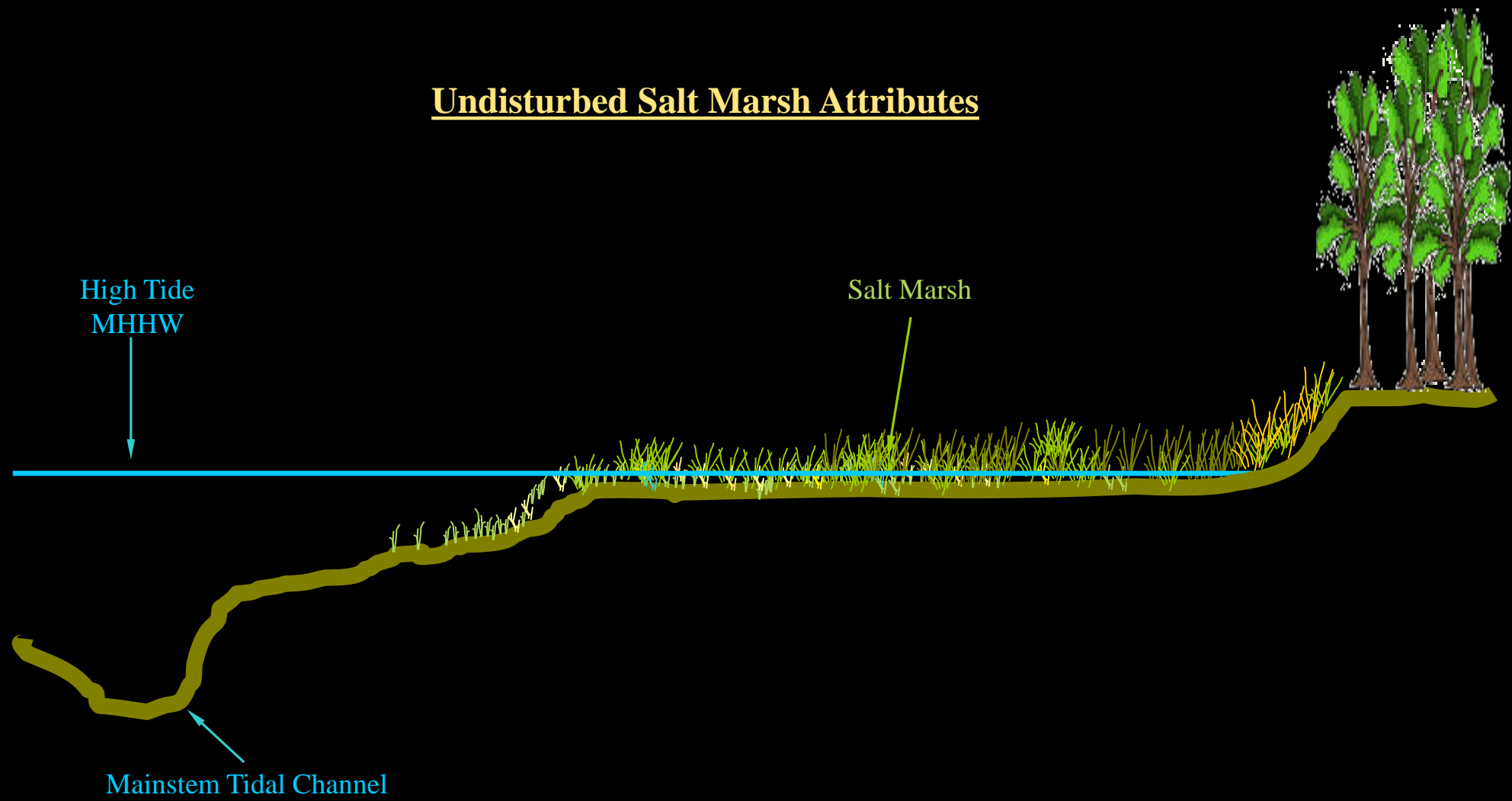
Faster growth

Year Restored	Years Diked
1978	10
1987	19
1996	28
2009	41
2010-11	42
2012	60

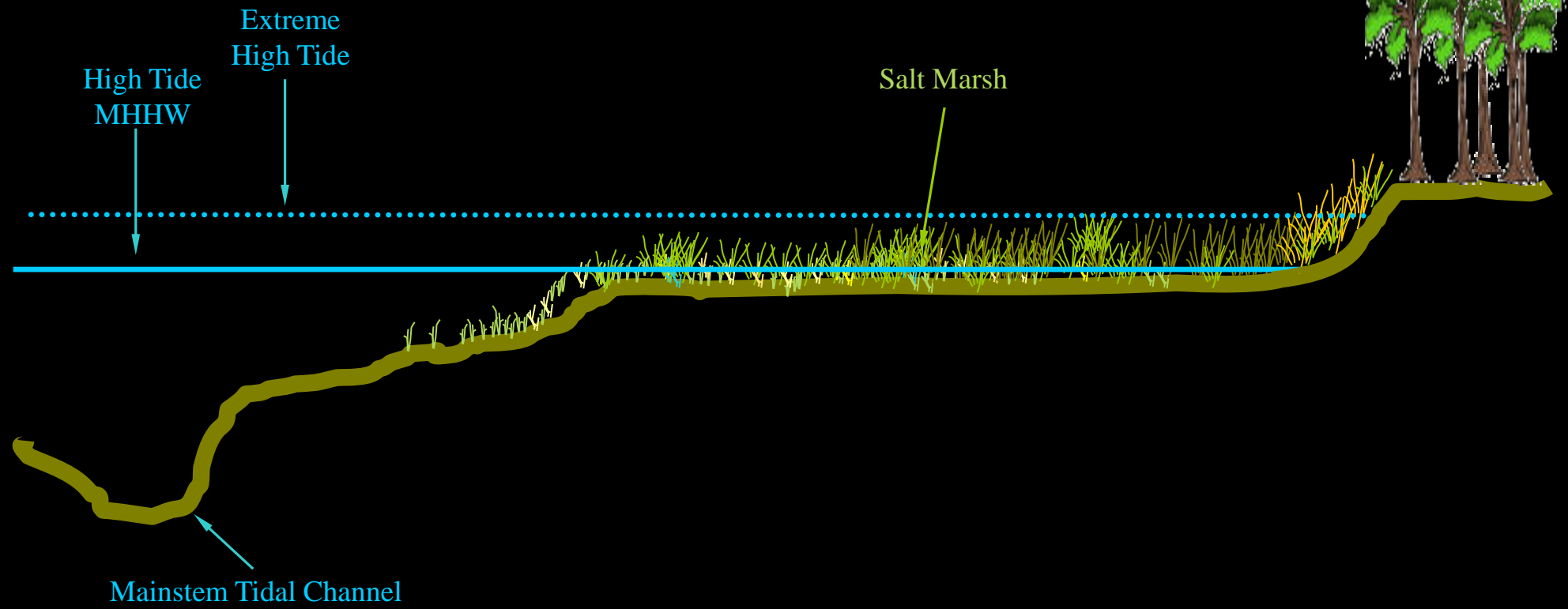
Undisturbed Salt Marsh Attributes



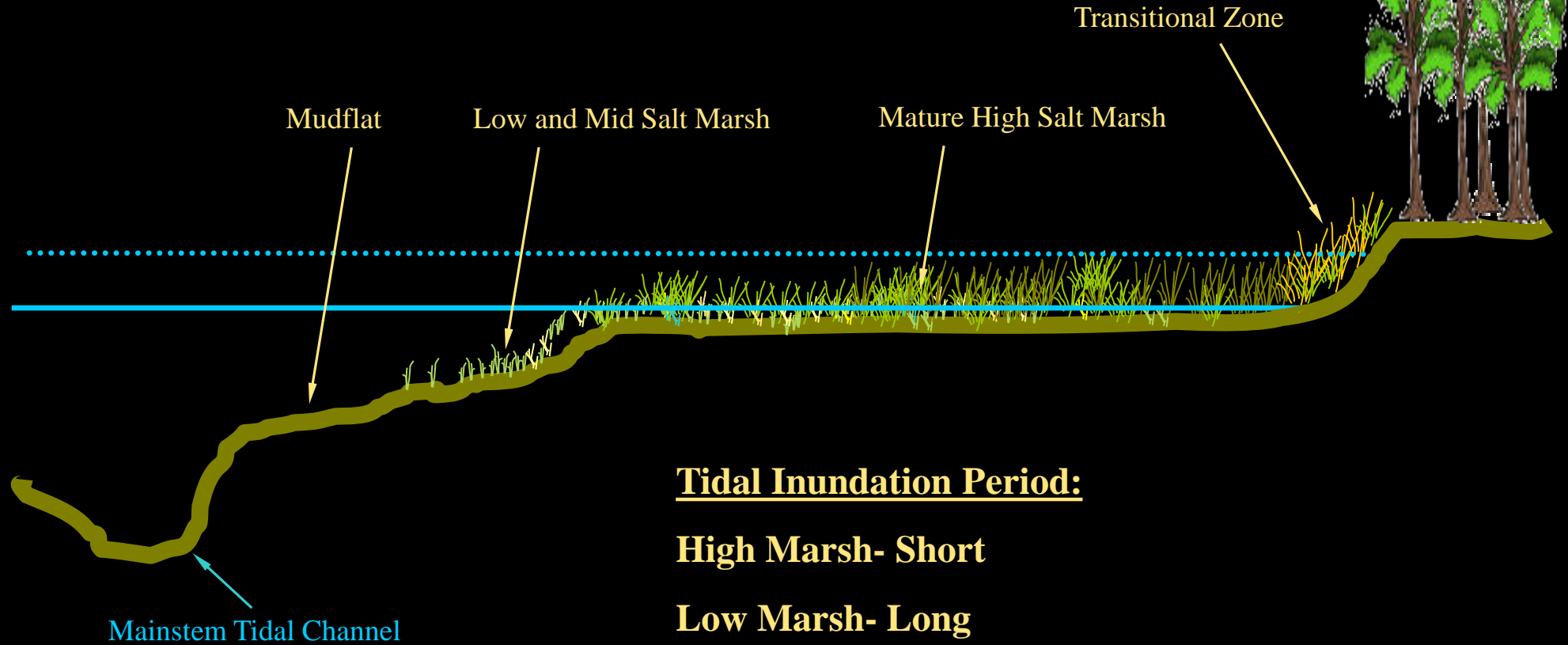
Undisturbed Salt Marsh Attributes



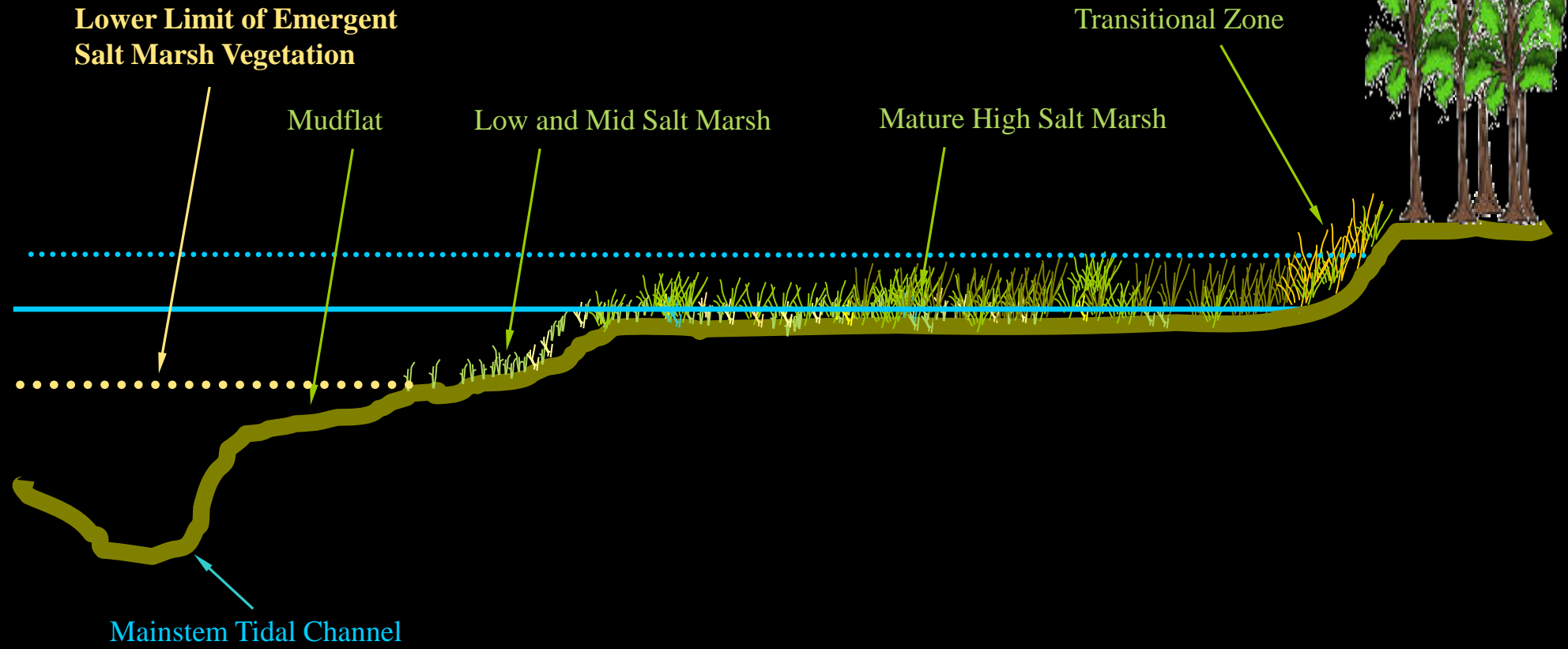
Undisturbed Salt Marsh Attributes



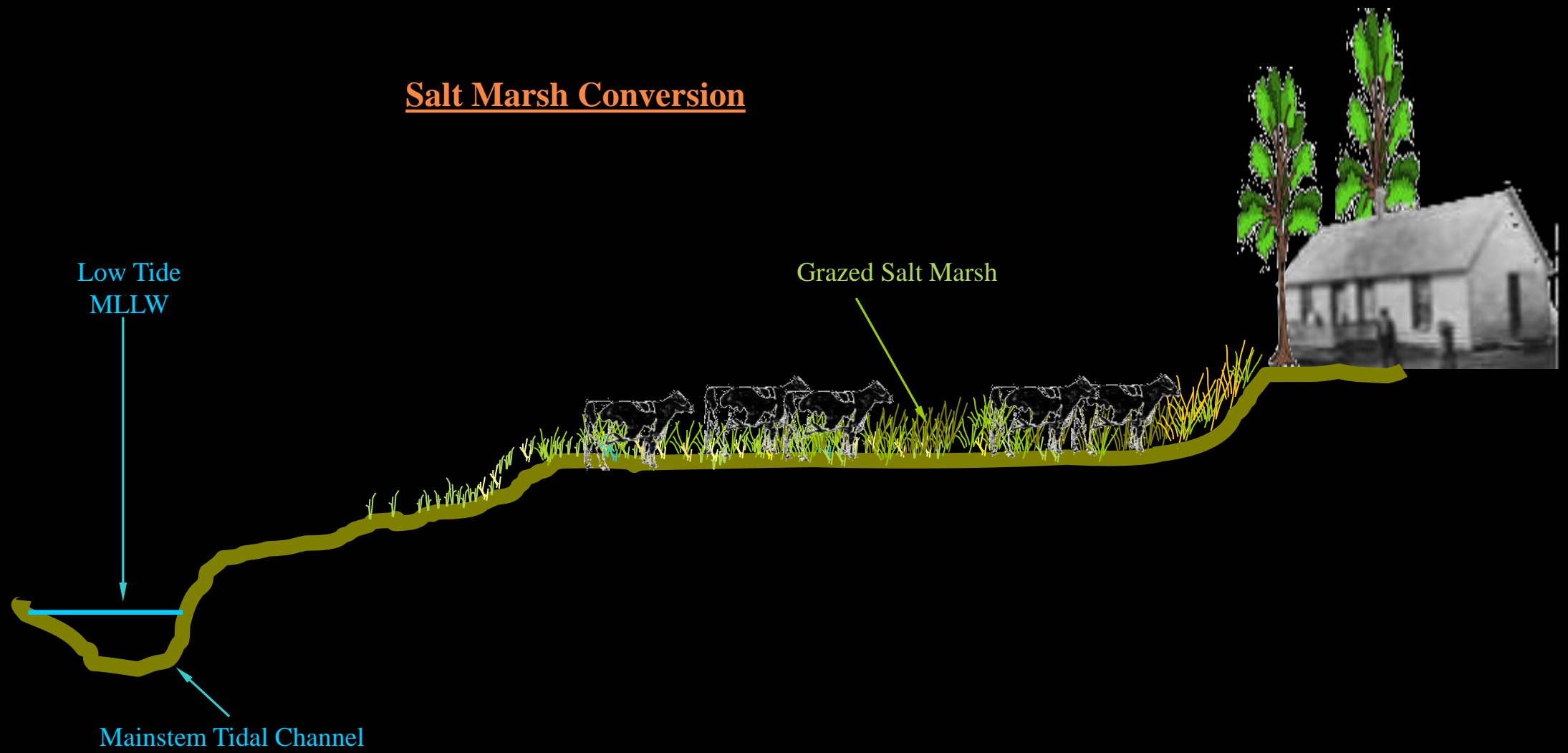
Undisturbed Salt Marsh Zonation



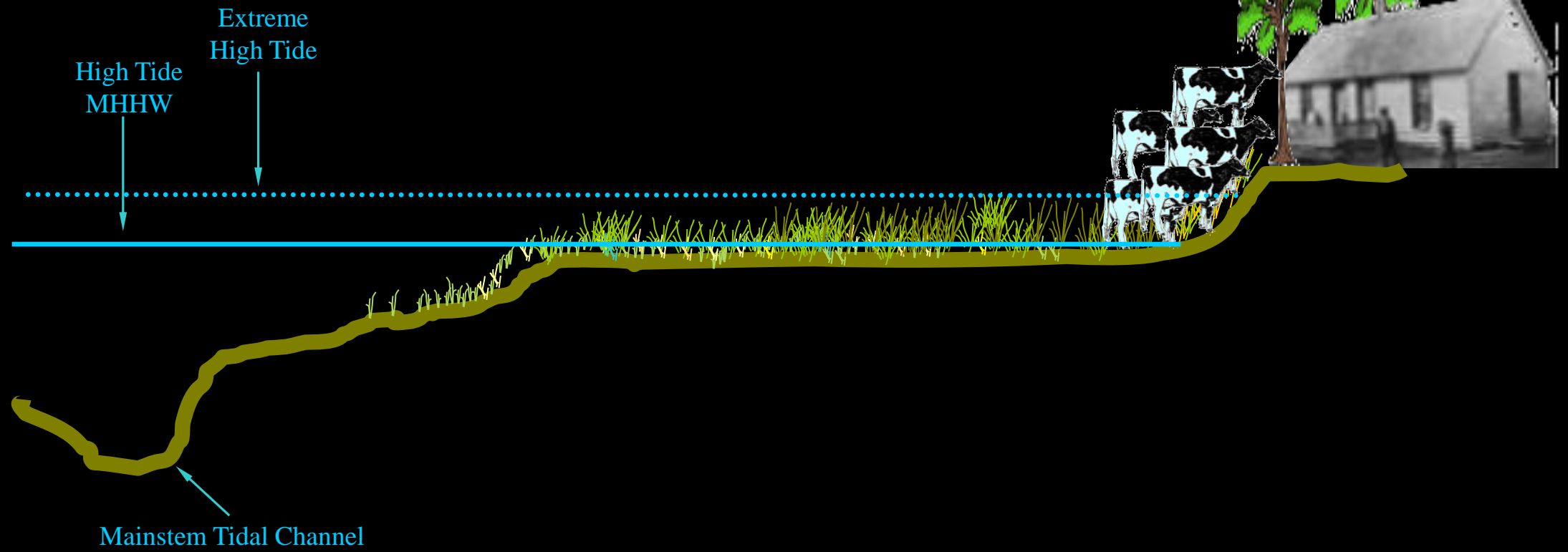
Undisturbed Salt Marsh Zonation



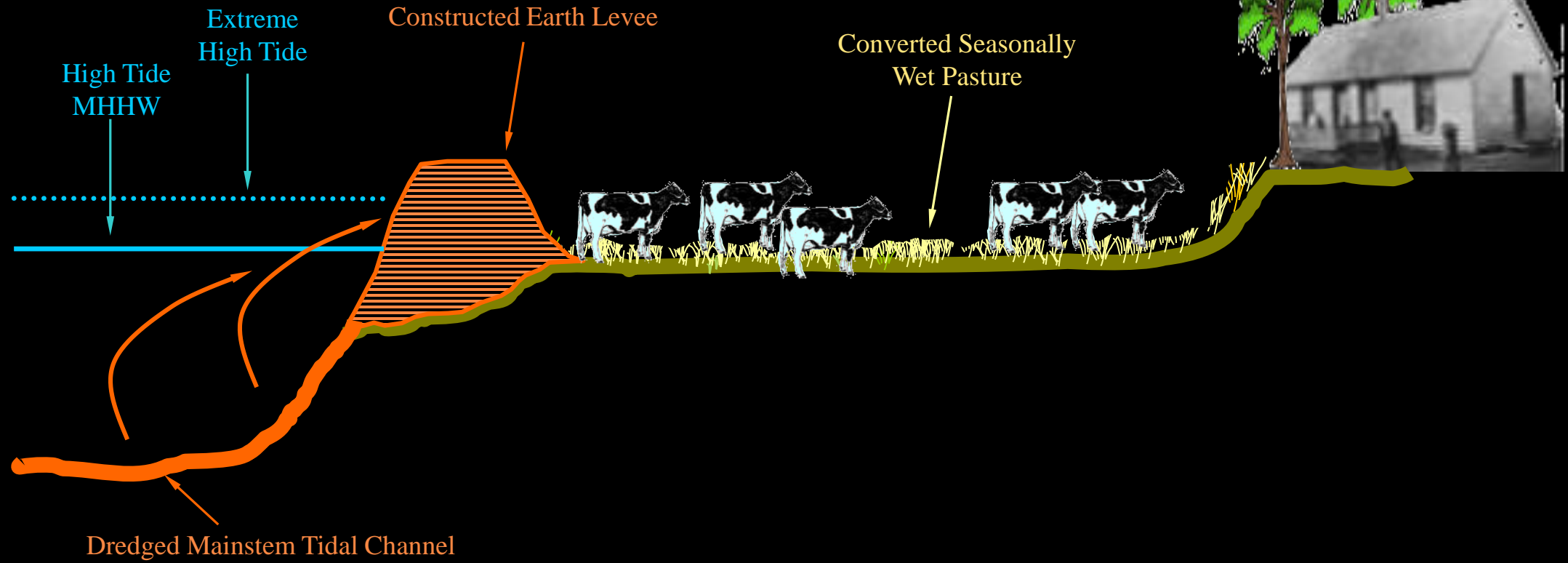
Salt Marsh Conversion



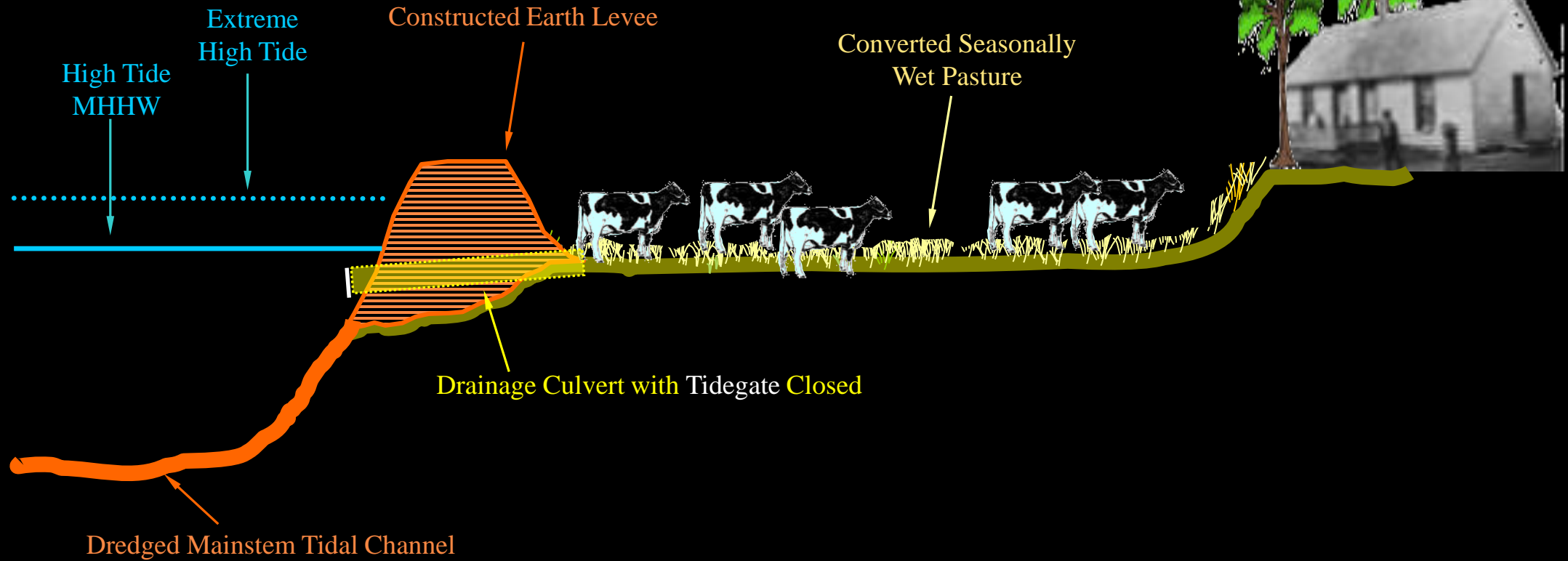
Salt Marsh Conversion



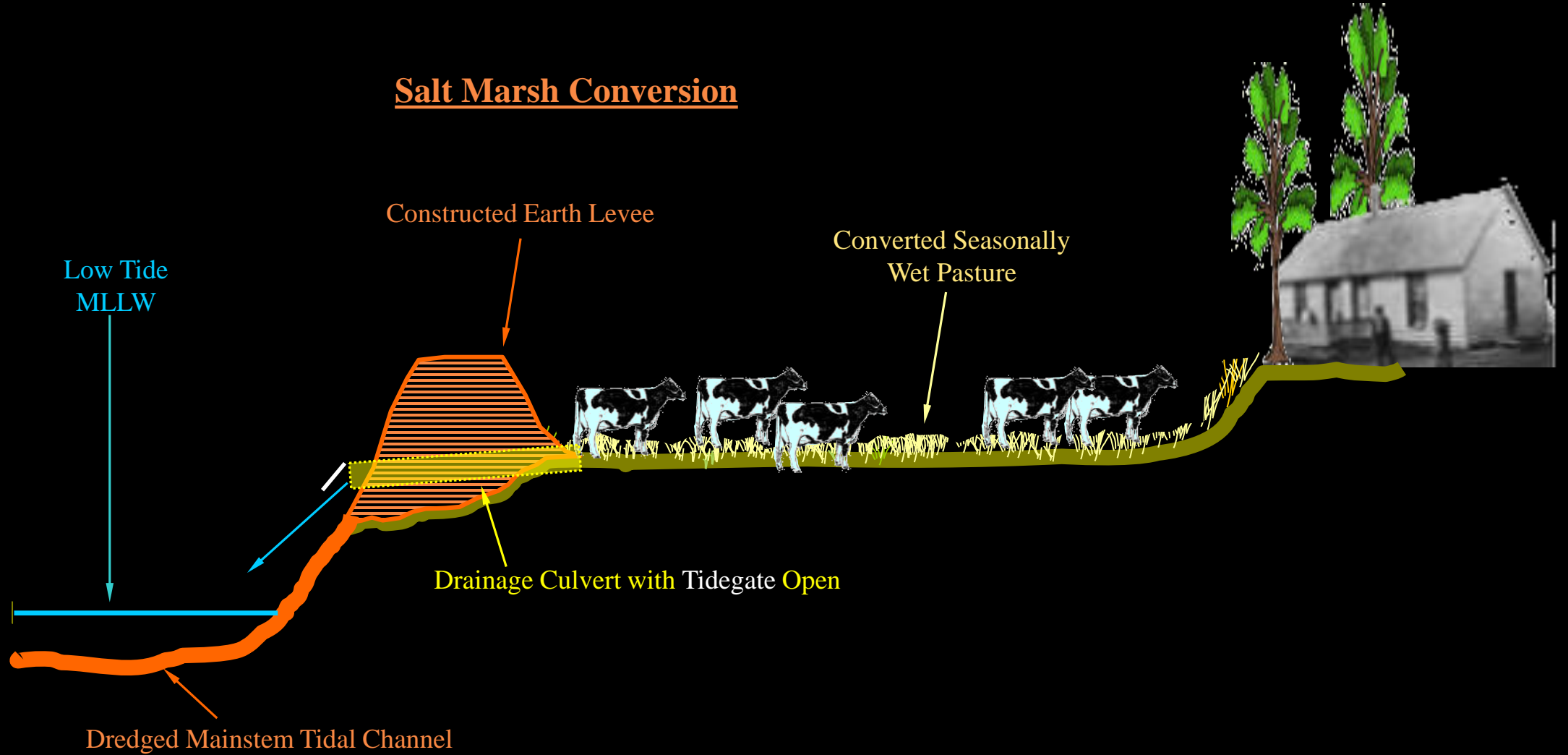
Salt Marsh Conversion



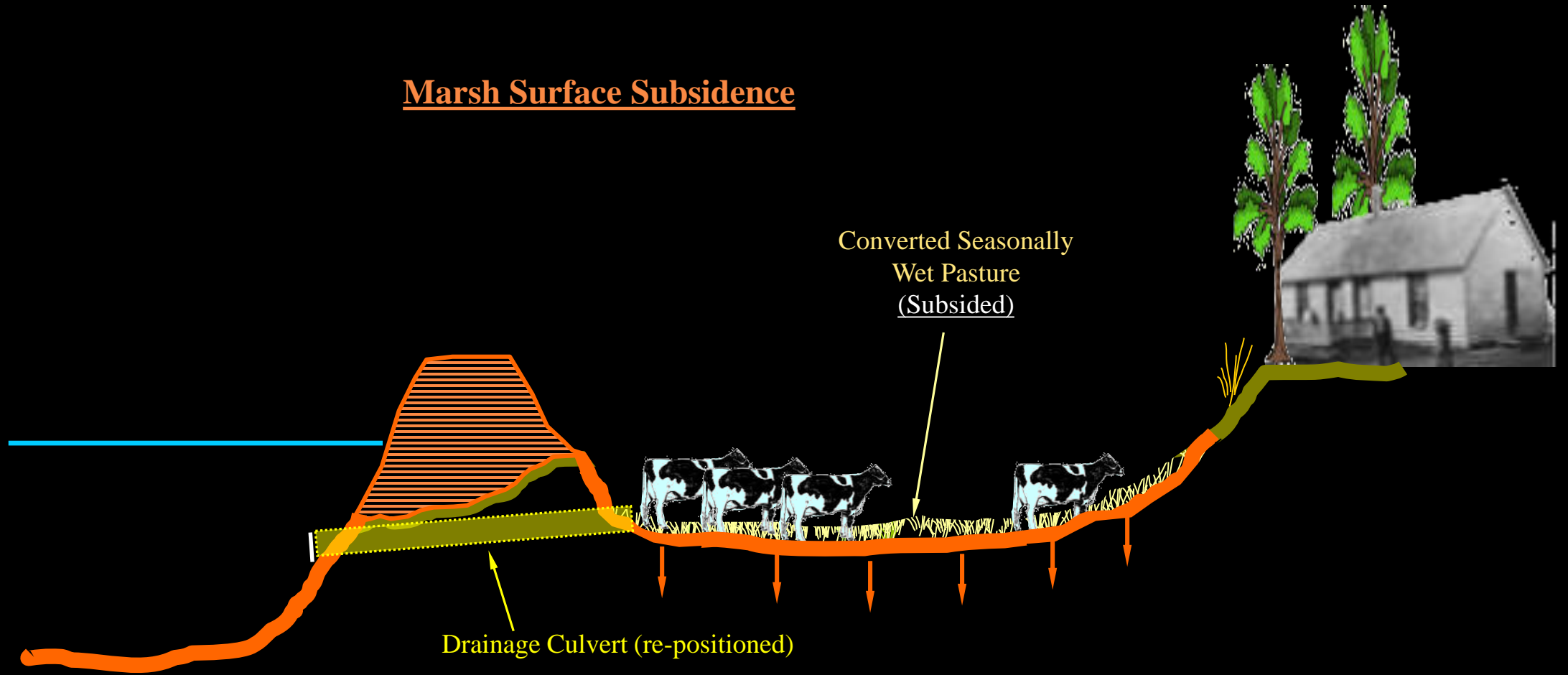
Salt Marsh Conversion



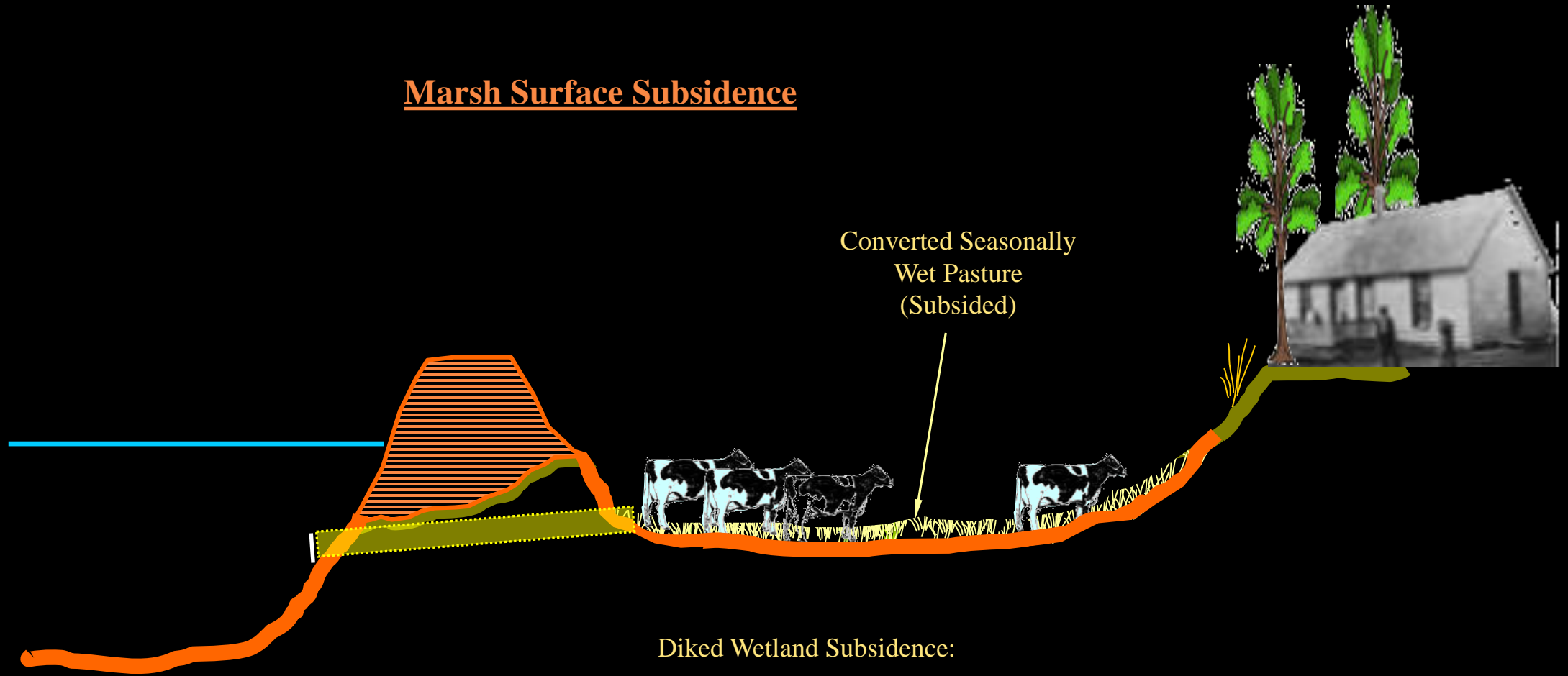
Salt Marsh Conversion



Marsh Surface Subsidence



Marsh Surface Subsidence



Converted Seasonally
Wet Pasture
(Subsided)

Diked Wetland Subsidence:

1. Decomposition of organic peat in soil horizon
2. Loss of sediment inputs from tidal flooding
3. Physical compaction (i.e. grazing animals, farm equipment)
4. Soil shrinking from drying of soils



2009

1987

1978

2012

1996

2010-11

Reference

Energy-rich aquatic flies

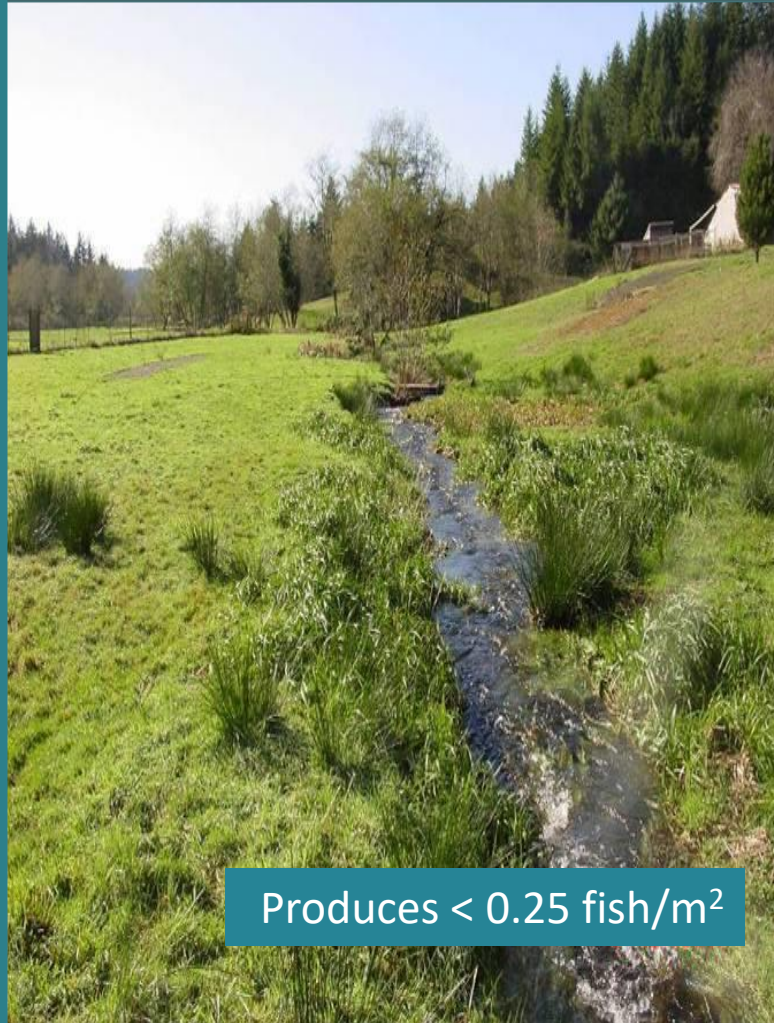


Faster growth

Year Restored	Years Diked
1978	10
1987	19
1996	28
2009	41
2010-11	42
2012	60

Habitat Benefits of Restoring Hydrology

Simplified Habitat



Produces < 0.25 fish/m²

Complex Habitat



Produces $1.5 - 3.5$ fish/m²

A fish story...

- Young salmon occupy and benefit from restored marsh habitats, even soon after dikes are removed (residency, feeding, growth)
- Life History variation CAN recover: Chinook and Coho Life History's responded to habitat removal (diking) and habitat gain (restoration)
- Restored estuarine Life History's contribute to adult returns—up to 75% of Chinook and ~30% of Coho spawners are tied to the restored Salmon River marshes
- Bottom-up restoration can be effective on it's own

Fisheries Research Credit—Kim Jones & Dan Bottom

What we know about our past

Willamette River Historic Channels, North of Corvallis, Oregon



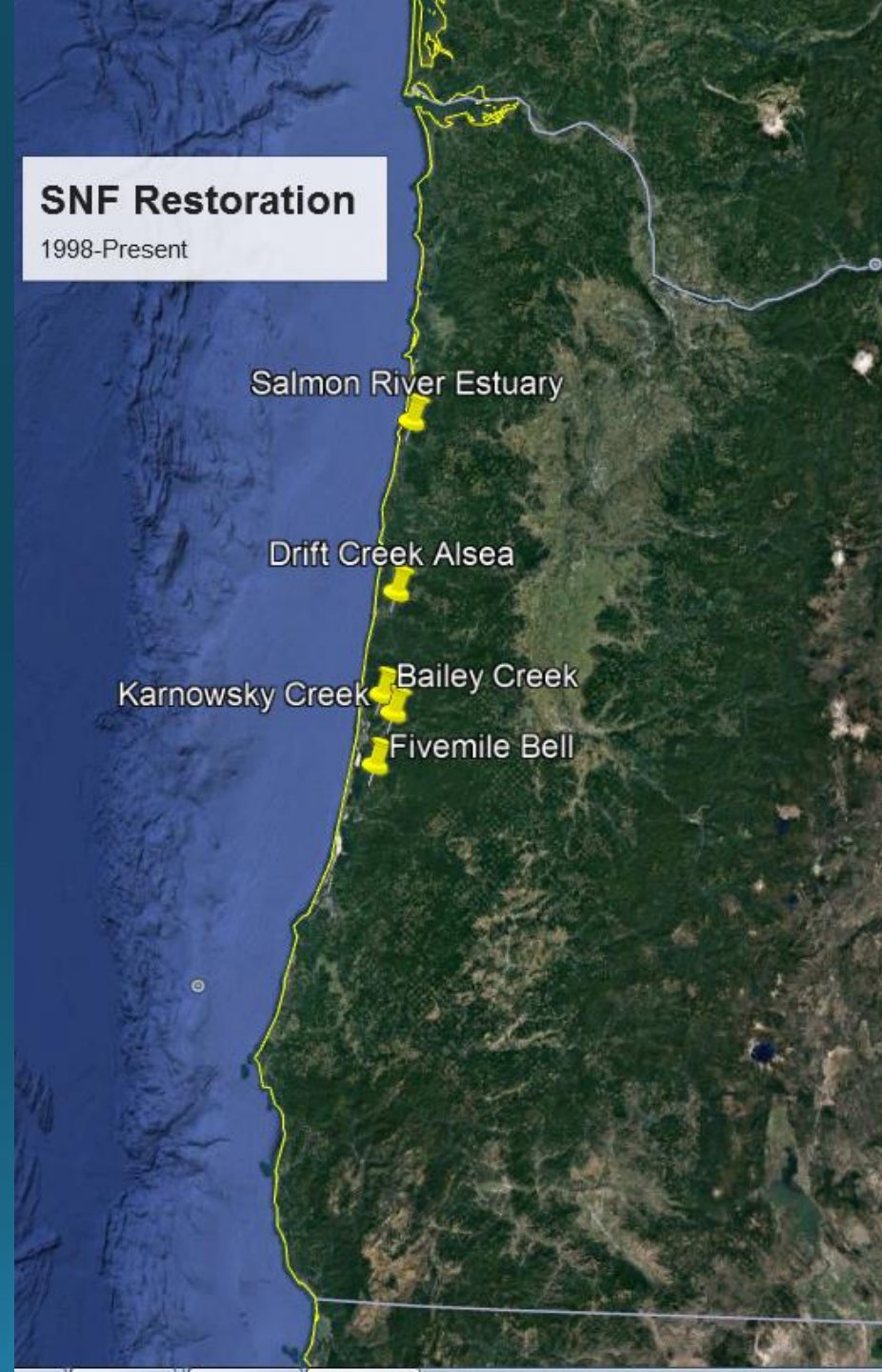
A photograph of a river flowing through a forest. The water is clear and greenish-brown. The banks are lined with trees showing vibrant autumn colors in shades of red, orange, and yellow. Several large, weathered logs are scattered along the riverbank, some partially submerged. The scene is captured from a low angle, looking down the river.

Restoring Processes

And learning along the way

Siuslaw National Forest Aquatic Restoration

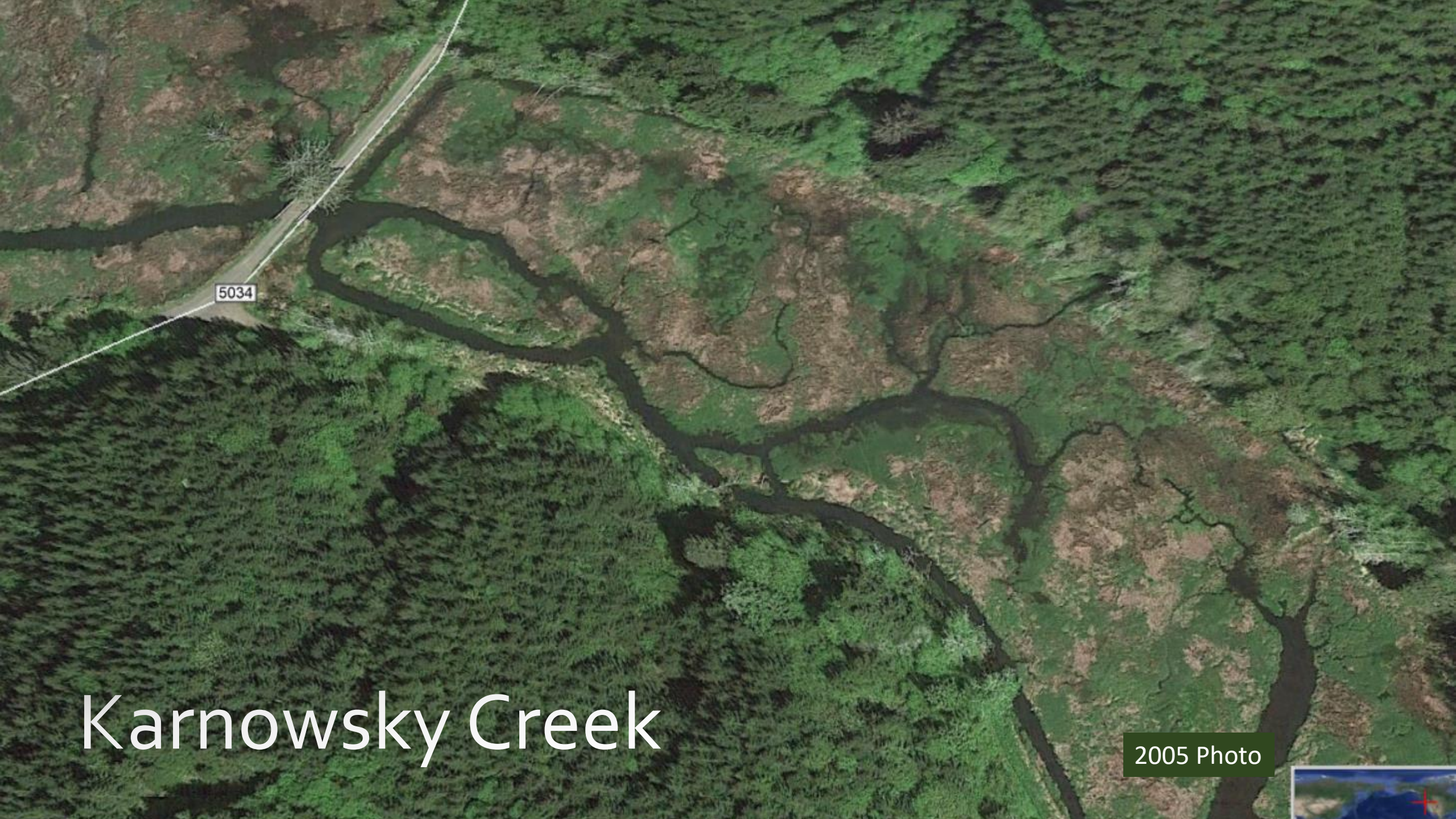
- 1999 Bailey Creek- Enchanted Valley
- 2003 Karnowsky Creek
- 2006 Drift Creek-Alesea
- 2007-2017 Salmon River Estuary
- 2012-present Fivemile & Bell Creeks





Bailey Creek-Enchanted Valley

2004 Photo



Karnowsky Creek

2005 Photo



Drift Creek—Alosea River



2007 Photo

11/2017

Fivemile & Bell Creeks



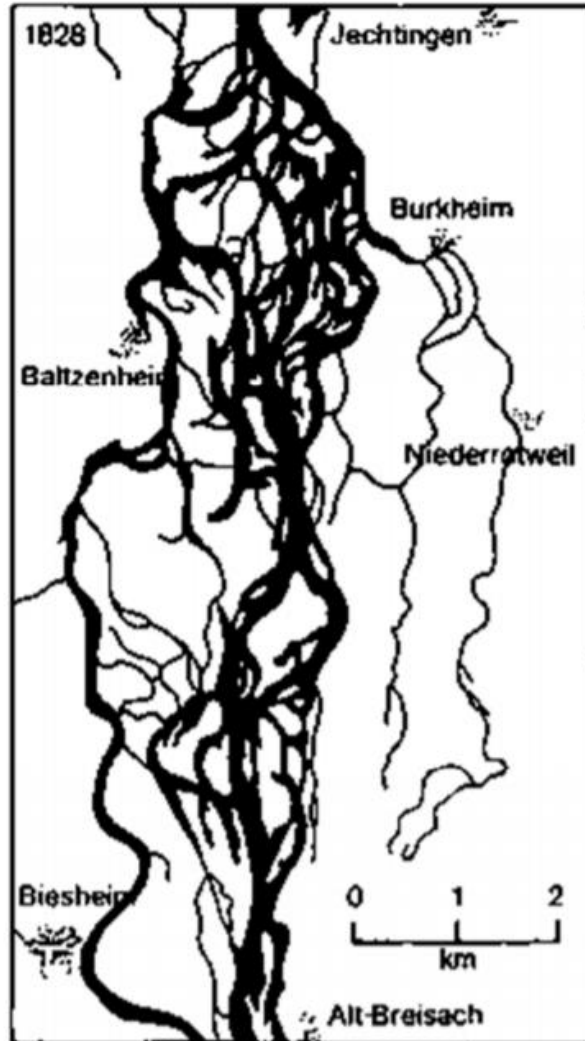
2016 Photo

Google Earth

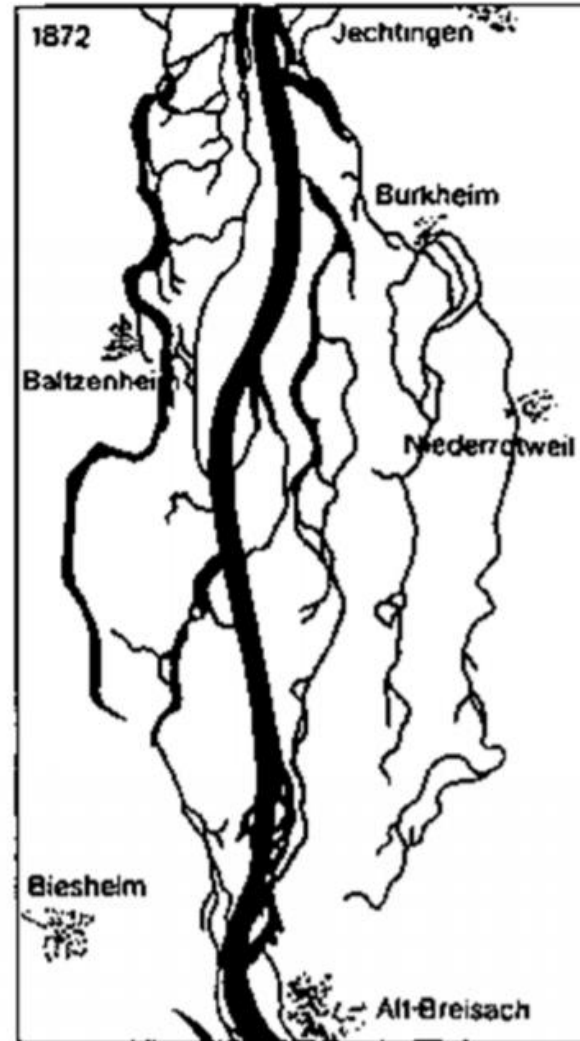
And can we agree?

- 17th to the early 20th centuries European settlement (development & trapping)
- Pre-European settlement condition (shallow & anabranching)
- Seminal geomorphic studies were based on channel and floodplain morphologies that were products of prior anthropogenic disturbance
 - Leopold and Maddock 1953
 - Wolman 1955
 - Wolman and Leopold 1957

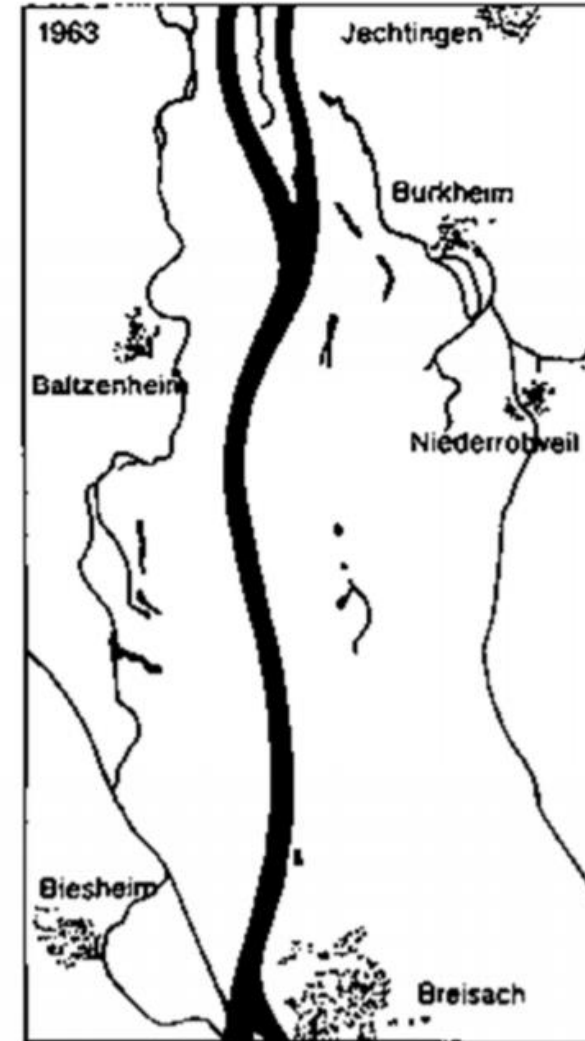
Example from Europe - Upper River Rhine at Breisach Germany



Anastomosed
1828 – Prior to
river training

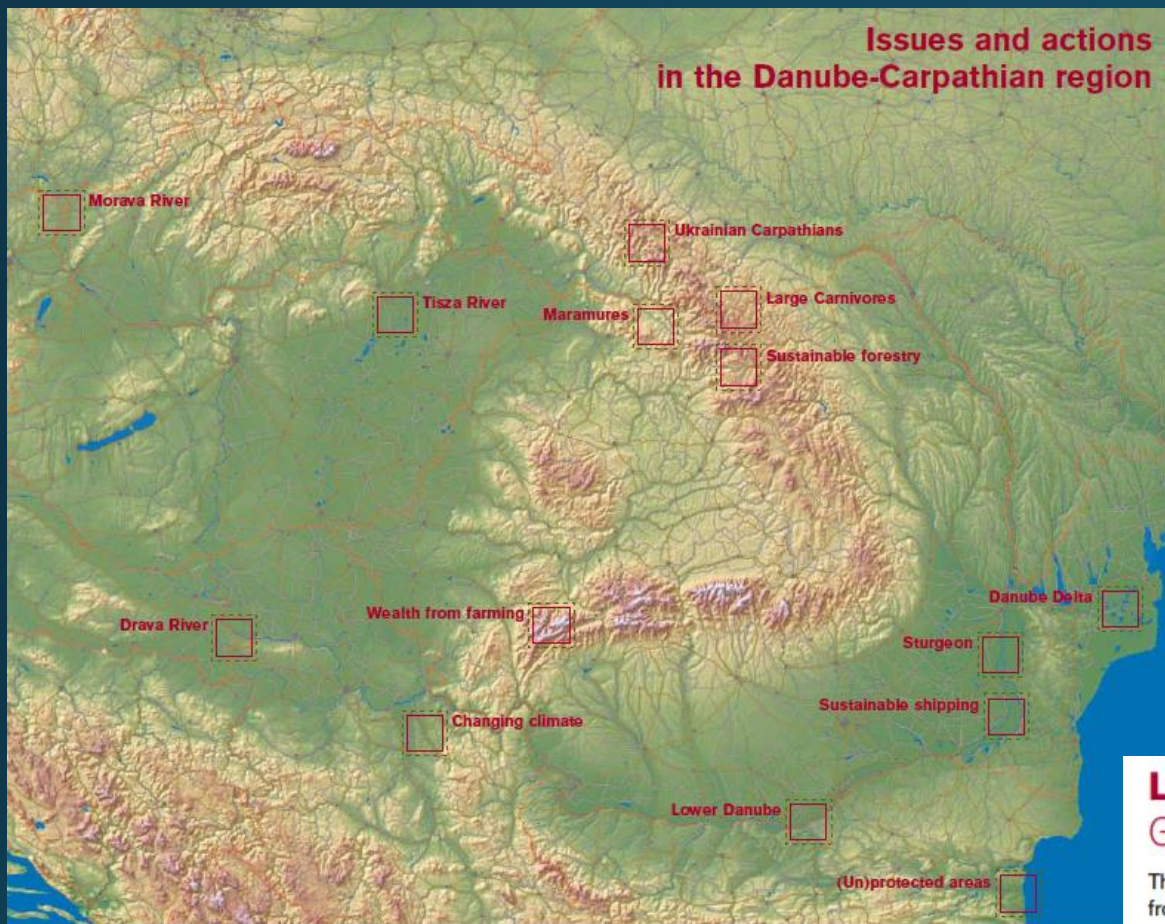


Anabranching
1872 – after re-alignment
by Johann Gottfried Tulla



Meandering
1963 – fully canalised
single-thread

Issues and actions in the Danube-Carpathian region



Global jewels *worth preserving*

The **Danube River** basin is the most international river basin in the world, draining 19 countries on its 2800 km journey from the Black Forest in Germany to the Black Sea. From the largely untamed middle and lower stretches of the river to the spectacular Danube Delta at its mouth, the Danube is home to some of the richest wetland areas in Europe and the world.

“Let the River Breathe”

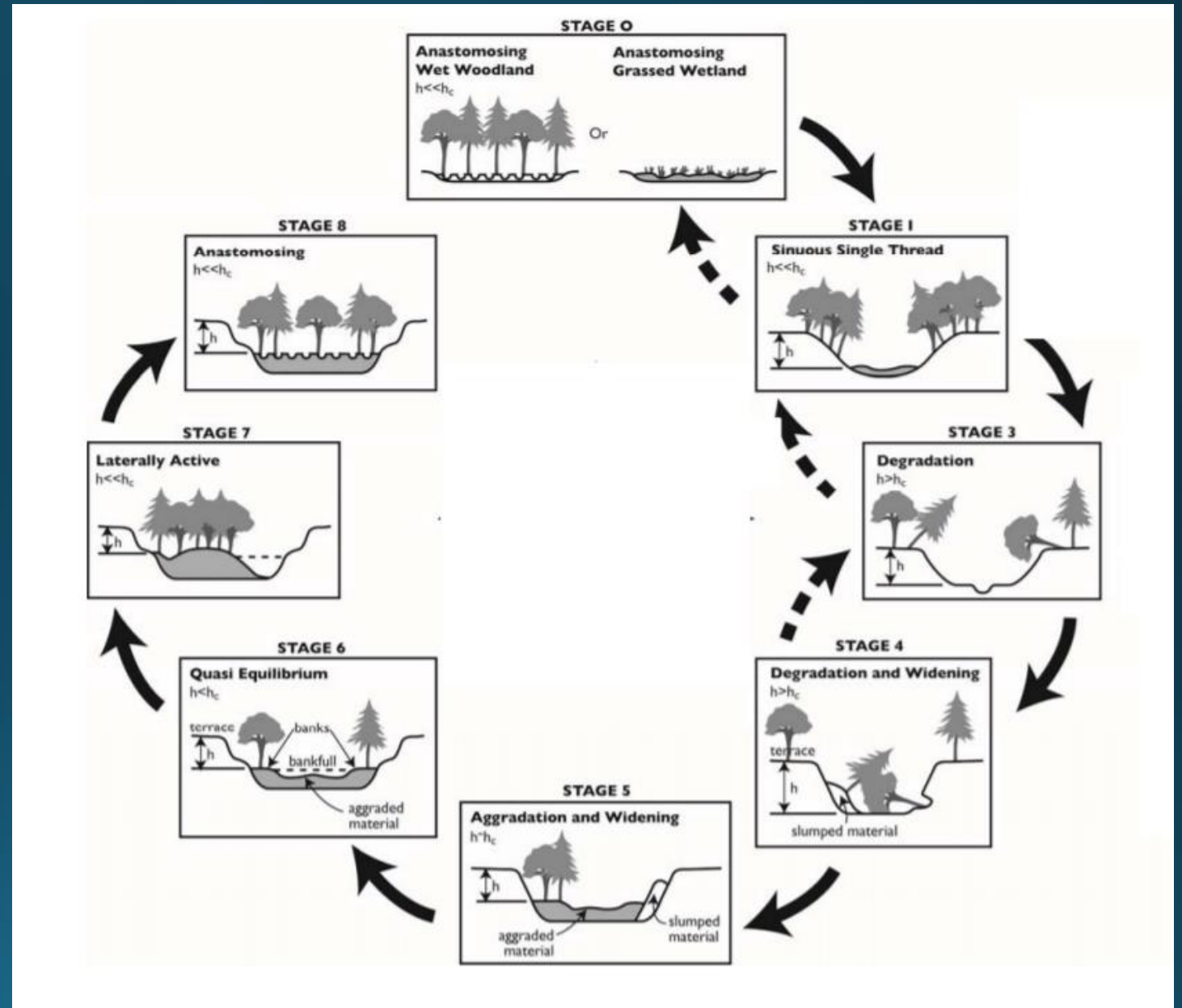
Lower Danube Green Corridor

The last 1,000 km of the Danube contain the river basin's greatest treasures, from the spectacular Danube Delta to the Danube islands that are home to pygmy cormorants and other wildlife. The Lower Danube Green Corridor agreement signed by the governments of Romania, Bulgaria, Moldova and Ukraine and facilitated by WWF represents the most ambitious wetland protection and restoration project in Europe. Nearly 1 million ha are now under some form of protection, and a good start has been made toward achieving the 224,000 ha of wetlands that are to be restored under the agreement.

Lower Danube. | photo © WWF-DCP



The Evolution of Restoration in Low Gradient Depositional Streams



Changes to surface water



Fixed point photos taken from metal posts show how the site has changed dramatically between 2011 and 2016.



Beavers are widely referred to as ecosystem engineers. They modify river systems and surrounding riparian areas to create habitats which they can exploit and which benefit many other species. Beavers are also termed keystone species, having a disproportionately large impact upon aquatic ecosystems, relative to their abundance. The most significant hydrological impact of beavers, results from their dam building activity and the consequent impoundment of large volumes of water in ponds. Dam and pond features alter hydrology, both locally and downstream. Dams hold water, push water sideways and release water slowly, re-wetting surrounding areas and creating complex wetland environments.

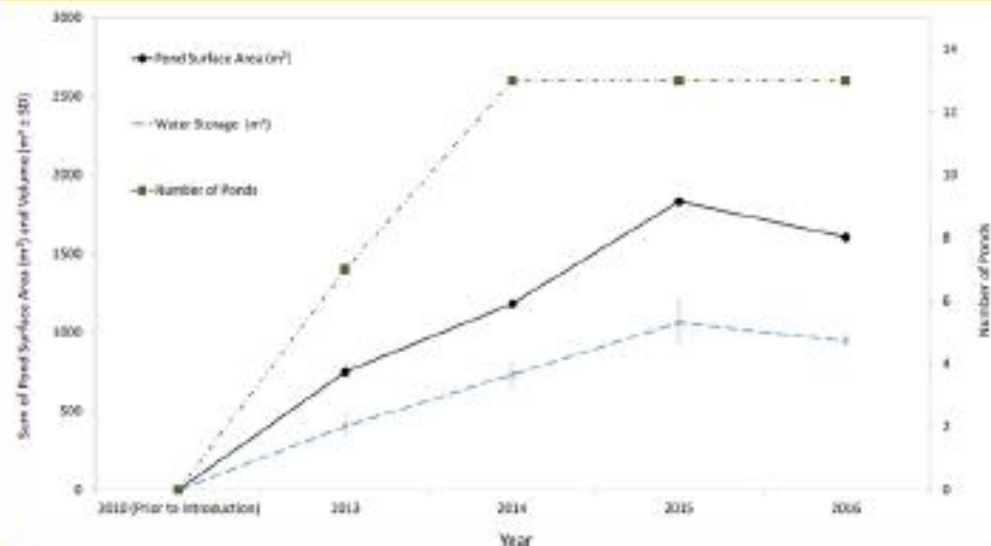
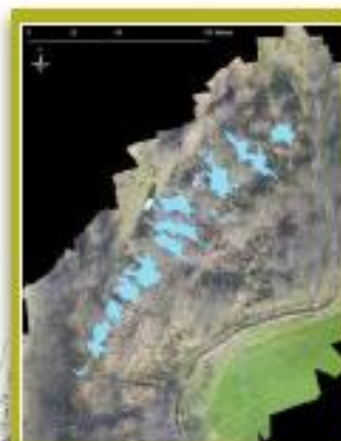


Figure 1. Changes in pond size since 2011

Impacts on water storage

As shown in figure 1, between 2011 and 2016, 13 ponds were created. The surface area of ponded water rose from 90 m² to a maximum of 1800 m², with the largest pond holding 220,000 litres of water.

Water storage is constantly changing with the inflow and outflow of water, but also as dams are maintained and enlarged by the beavers. Even though the number of ponds has stabilised since 2014, the volume of water stored has continued to rise.



Unmanned Aerial Vehicles (UAVs) were used to create high resolution maps of the site, and identify standing water.



How could beavers influence stream flows and flood risk?

Beaver dams slow the flow of water. In storms more water is stored; in droughts more water is released. The potential for beavers to reduce flooding and maintain baseflows downstream is significant and will be explored further.

Experimental design

The amount of water entering, being stored within, and leaving the site has been monitored via a network of instrumented weirs and dipwells. The potential for beavers to reduce flooding and maintain baseflows downstream is significant and will be explored further. By continuously measuring flow upstream and downstream of the beaver-created wetland, it is possible to quantify the impacts of beavers on the hydrology. Recording rainfall, water table levels and pond depths allows a detailed water 'budget' to be constructed. Understanding the mechanisms of water storage to explain the hydrological responses is a key part of the research.

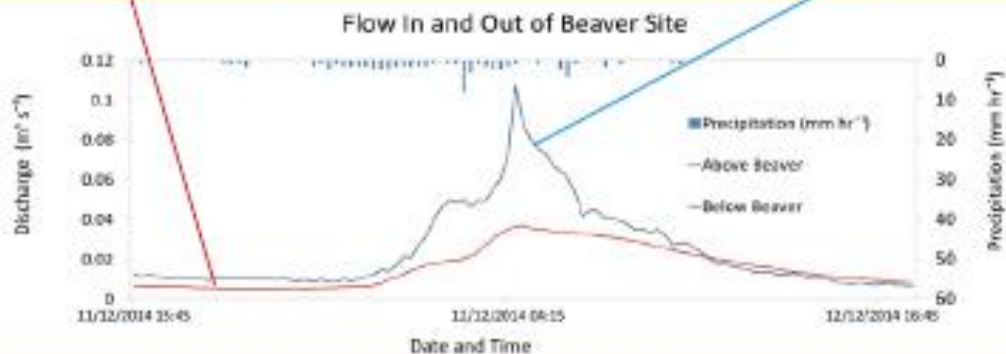


Figure 2. Water flows entering and leaving beaver enclosure during high rainfall.

Impacts on flooding

This research provides strong evidence for the role that beavers might play in reducing flooding downstream, even during prolonged wet periods. As Figure 2 shows, flow into the site (blue line) increases more rapidly in response to rainfall, peaking at a higher flow rate, and falling more rapidly than flow out of the site (red line), as water is quickly moved through the intensively-farmed landscape. The flow leaving the site is attenuated (squashed), rising less rapidly, peaking at a lower rate and falling very slowly after rainfall ceases. This flood attenuation effect is controlled by the storage of water in each beaver pond and the enhanced 'hydraulic roughness' of the landscape, together which slows the flow of the water.



These research findings are all from the enclosed beaver site where the impacts of a series of beaver ponds along 183 m of watercourse have been studied in detail. These findings have been subject to peer review and published in the journal *Science of the Total Environment* (Puttock et al, 2017).

www.sciencedirect.com/science/article/pii/S0048969716323099 (open access)



This profound impact persists even during the wettest times of the year as the leaky dams constantly drain, freeing-up storage capacity in each pond. For example, during storm Frank in December 2015, 29 mm of rain fell on the site; peak flow leaving the site was 3 times lower than into the site and the water took 30 min to travel through the site (a distance of 183 m). Holding water back and desynchronising peak flows from minor watercourses into major rivers is a key principle in flood alleviation and something that beaver dams and increased channel complexity are likely to contribute to.

Impacts on river baseflow during drought

As beaver dams are leaky, stored water drains from the site for a long time after rainfall has stopped. Figure 2 highlights this 'baseflow maintenance' where flow from the site (red line) is greater than flow into the site (blue line) after the storm event. This reversal of hydrological behaviour also relates to the leakiness of the dams, which provide a constant supply of water downstream, even as in summer 2016, when a month long drought left the incoming channel and the top two ponds completely dry, whilst baseflow leaving the site continued. Low flows cause serious environmental problems as oxygen levels are depleted and any pollutants are concentrated.

Key Facts

- Since their introduction into the enclosed site, the beavers have constructed 10 dams holding up to 1 million litres of additional water within ponds on the site.
- The area influenced is 1.8 ha equating to 56 litres of surface water storage per m² of land. During storm events, on average, peak flows were 20% lower leaving the site than entering.
- The lag time between peak flow into the site and peak flow leaving the site was, on average, 1 hour over a distance of 183m.
- Even in saturated conditions and for the largest mentioned flood event since the winter of 2012, the flood peaks are still reduced due to the hydraulic roughness of the dams and felled trees and the leaky nature of the dams.
- The water storage and gentle release effect resulted in significant and constant baseflow from the site, even when periods of drought eliminated flows into the site.

The scientists

Richard Draker is Professor of Earth Surface Processes at the University of Exeter. His interdisciplinary approach to research brings together understanding of hydrology, ecology, geomorphology and soil science to pioneer the emerging field of landscape restoration science. His research group address issues of direct relevance to society including natural flood management, diffuse pollution from agriculture and soil degradation across a wide range of ecosystems in temperate and drylands globally.

More information on Richard's research can be found at:

www.geography.exeter.ac.uk/etbf/index.php?web_id=Richard_Draker

R.Draker@exeter.ac.uk

UNIVERSITY OF
EXETER



Impacts on water quality?



© Alan Puttock, University of Exeter

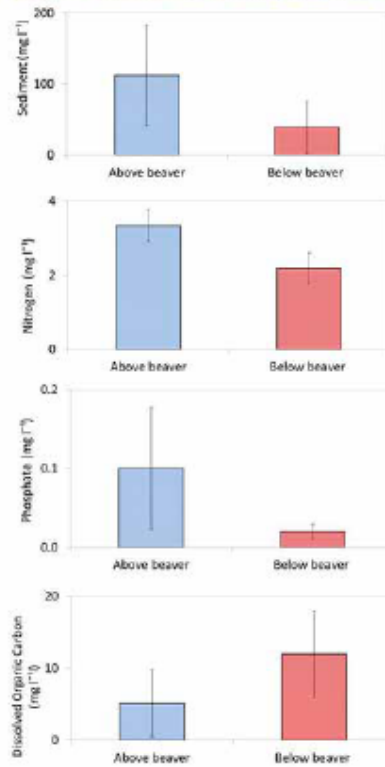


Figure 3. Results of sampling the watercourse above and below the beaver enclosure.

As well as affecting the storage and flow of water, impoundment behind dams can affect the quality of water leaving beaver-engineered sites and the amount of diffuse pollutants being transported downstream. By slowing and filtering the water, beaver dams cause sediment and nutrients to be deposited in ponds. In this case, the source of the material is the intensively managed farmland upstream, which provides elevated levels of not only sediment (from soil erosion), but also nitrogen and phosphorus, from manures, slurries and fertilisers that are added to the land. By the time the water has flowed through the sequence of beaver dams, a high proportion of these diffuse pollutants have been removed from the water, settling out in the ponds.

Impacts on sediment

During storm events, each litre of surface water leaving the beaver-modified site has 3x less sediment than the water entering the site. On average 112 mg l⁻¹ of sediment enters the site, but under 40 mg l⁻¹ of sediment leaves the site.

Nitrogen

During storm events, each litre of surface water leaving the beaver-modified site has 0.7x less nitrogen. On average each litre of water draining from agricultural land and entering the channel contains 3.35 mg of total oxidised nitrogen, but only 2.19 mg when it leaves the site.

Phosphorus

During storm events, each litre of surface water leaving the beaver-modified site has 5x less phosphate than the water entering the site from agricultural land upstream. On average each litre of water draining from agricultural land and entering the channel contains 0.10 mg of phosphate, but only 0.02 mg when it leaves the site.

Carbon

Dissolved organic carbon concentrations were significantly lower entering the site, compared to those leaving the site (5.11 mg l⁻¹ versus 11.87 mg l⁻¹). This difference reflects the fact that intensively managed grasslands are depleted of soil organic carbon. In contrast, fully functioning wetlands are carbon rich environments, which both store and release more carbon to water than their agricultural counterparts.

Experimental design

Each instrumented weir above and below the site was also equipped with an automated water sampler. These 'pump samplers' allowed researchers to collect one litre of water every time water depth changed by 2 cm, during storm events. Sampling storms is important as this is when the water has most energy and most erosion and diffuse pollution occurs, leading to losses of soil and nutrients from land to water. Collected samples were analysed in University of Exeter laboratories for suspended sediment, nitrogen, phosphate, and dissolved organic carbon.

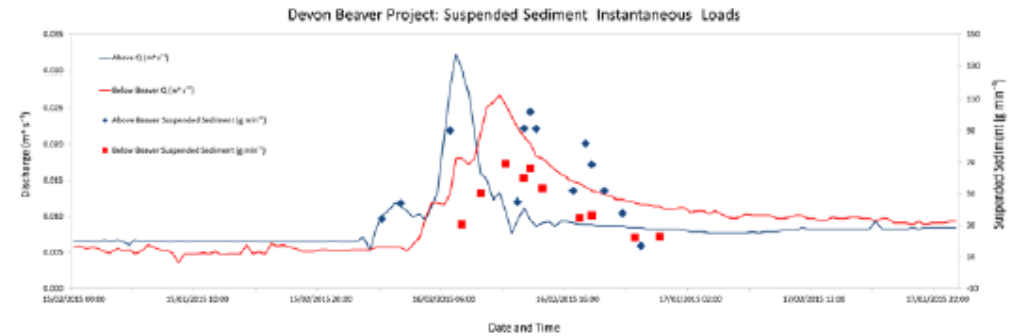


Figure 4. Suspended sediment recorded upstream and downstream of the beaver enclosure during high flows.

Mitigating diffuse pollution from agriculture

Loss of sediment and nutrients from our farmed landscapes can cause problems with land becoming depleted of nutrients and requiring greater fertiliser use and can also cause downstream water quality problems such as eutrophication. For sediment, nitrogen and phosphate, variables which contribute directly to poor ecological status and water quality downstream, the presence of beavers at the Enclosed Beaver Project has led to significant improvement in water quality.

Key Facts

- During the 11 storm events monitored, 1.6 t of sediment was lost from the 20 ha of grassland upstream of the beaver site but only 0.4 t of sediment left the bottom of the site during these same 11 storms. The beaver activity therefore led to a fourfold decrease in sediment yields downstream.
- During monitored storm events there was also a twofold decrease in nitrogen yields and a fourfold decrease in phosphate yields downstream.
- However there was an almost two fold increase in dissolved organic carbon loads downstream leading to some discolouration of water.



One of the more unusual challenges of working within a beaver enclosure is that water trickling through v-notch weirs triggers this instinctive behaviour by the beavers.

The scientists

Dr Alan Puttock is an associate research fellow working with Professor Richard Brazier at the University of Exeter. Alan's research specialises in understanding the relationship between land use or vegetation change and the quality and quantity of water leaving our landscapes. Alan has been working on the Enclosed Beaver Project since 2014 and is a member of the River Otter Beaver Trial Science and Evidence Forum.

More information on Alan's research can be found at:

www.geography.exeter.ac.uk/staff/index.php?web_id=A_Puttock

A.K.Puttock@Exeter.ac.uk

UNIVERSITY OF
EXETER



Prior to European colonization beaver populations were estimated to number 60–400 million in North America (Naiman, Johnston, & Kelley, 1988). Beaver were intensively trapped for their pelts through the 1800s and eradicated from developed areas where they were often considered a nuisance. Beaver populations became isolated, and their numbers were dramatically reduced in urban and rural areas, with only about 10% of historical populations remaining (Wilson & Reeder, 2005).

Example 1: Upper Mississippi and Missouri River Basins (Hey and Phillip 1995).

Researchers estimate that beaver ponds covered 51,100,000 acres in 1600 compared to 511,000 acres in 1990. They estimated wetlands at 44,700,000 acres in 1780 versus 18,900,000 acres in 1980. This reduction in ponds (surface water stored) and wetlands (groundwater stored) has resulted in a huge loss of flood control, and system stability during droughts and years with high precipitation.

Example 2: Elk Island National Park in east-central Alberta, Canada

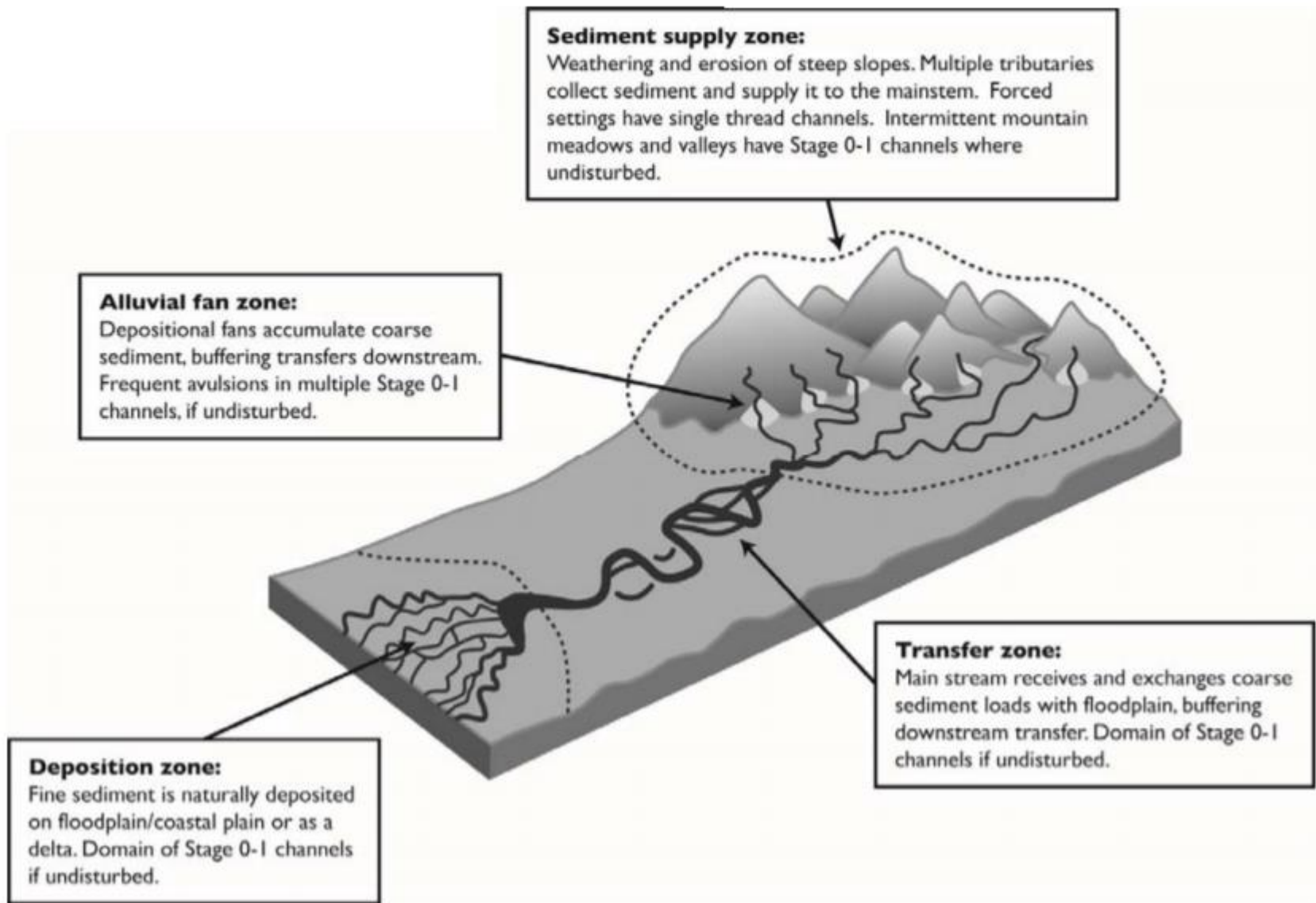
(Hood and Bayley 2008).

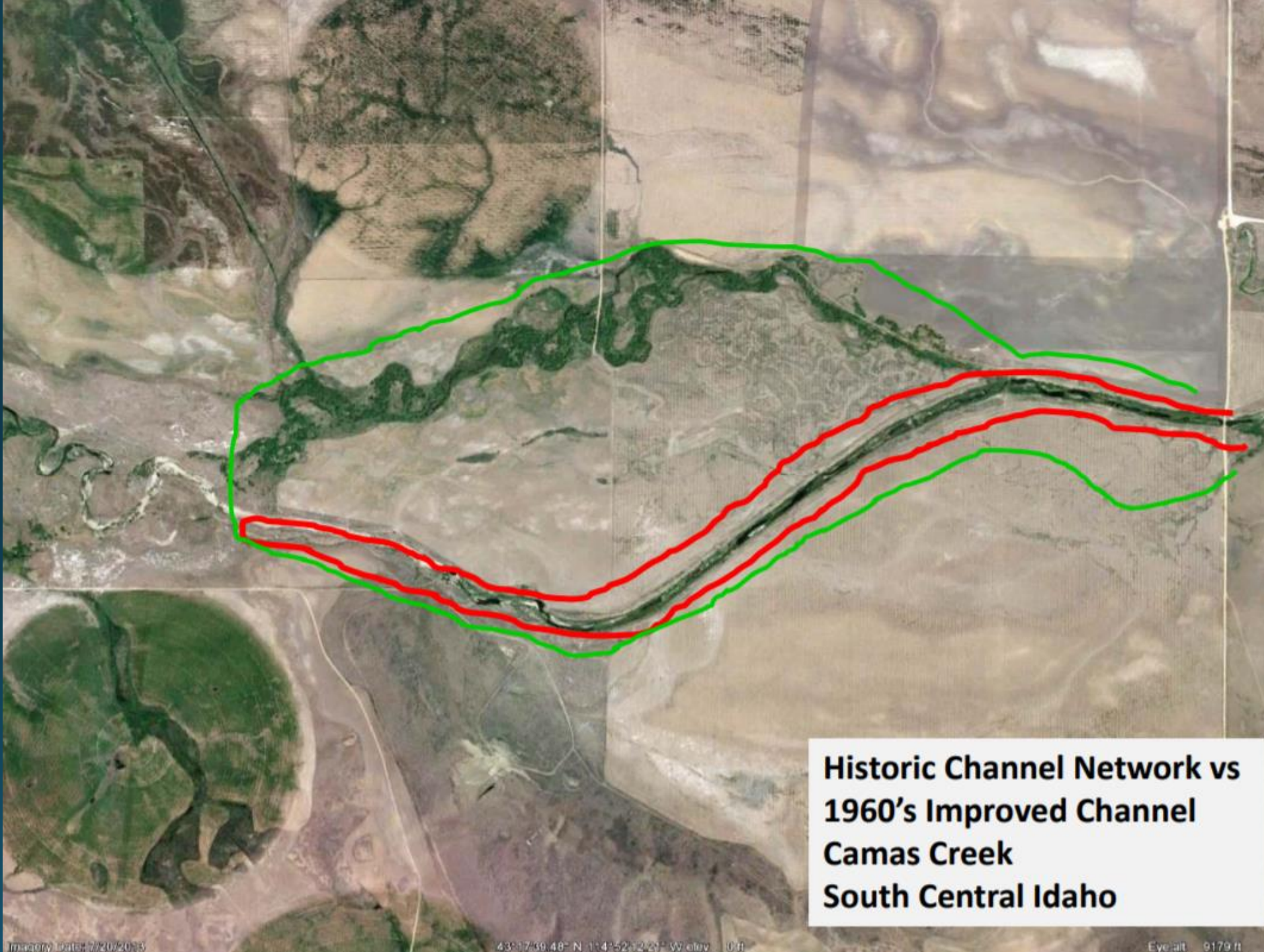
Documenting changes in the amount of open water during dry and wet years between 1948 and 2002 due to the presence, or absence, of beavers. The beaver dam building and maintenance made the area much less sensitive to drought and helped decrease downstream flood peaks by increasing the river's rapid access to its floodplain during high flows.

Example 3: Crane Creek, Oregon (Schaffer 1941).

Prior to 1924 beavers were present in Crane Creek and the meadows had stirrup-high native grasses. The grasses were sub-irrigated by beaver ponds. In 1924 the beavers were trapped out. In 1925 the channel began to incise and by 1935 the channel had deepened 25 feet. In 1936 beavers were reintroduced, and by 1938 the water table had risen and the hay meadow production had improved. 1939 was a drought year, yet water was abundant on the ranch with beaver ponds, while absent downstream on the ranch without beaver ponds.

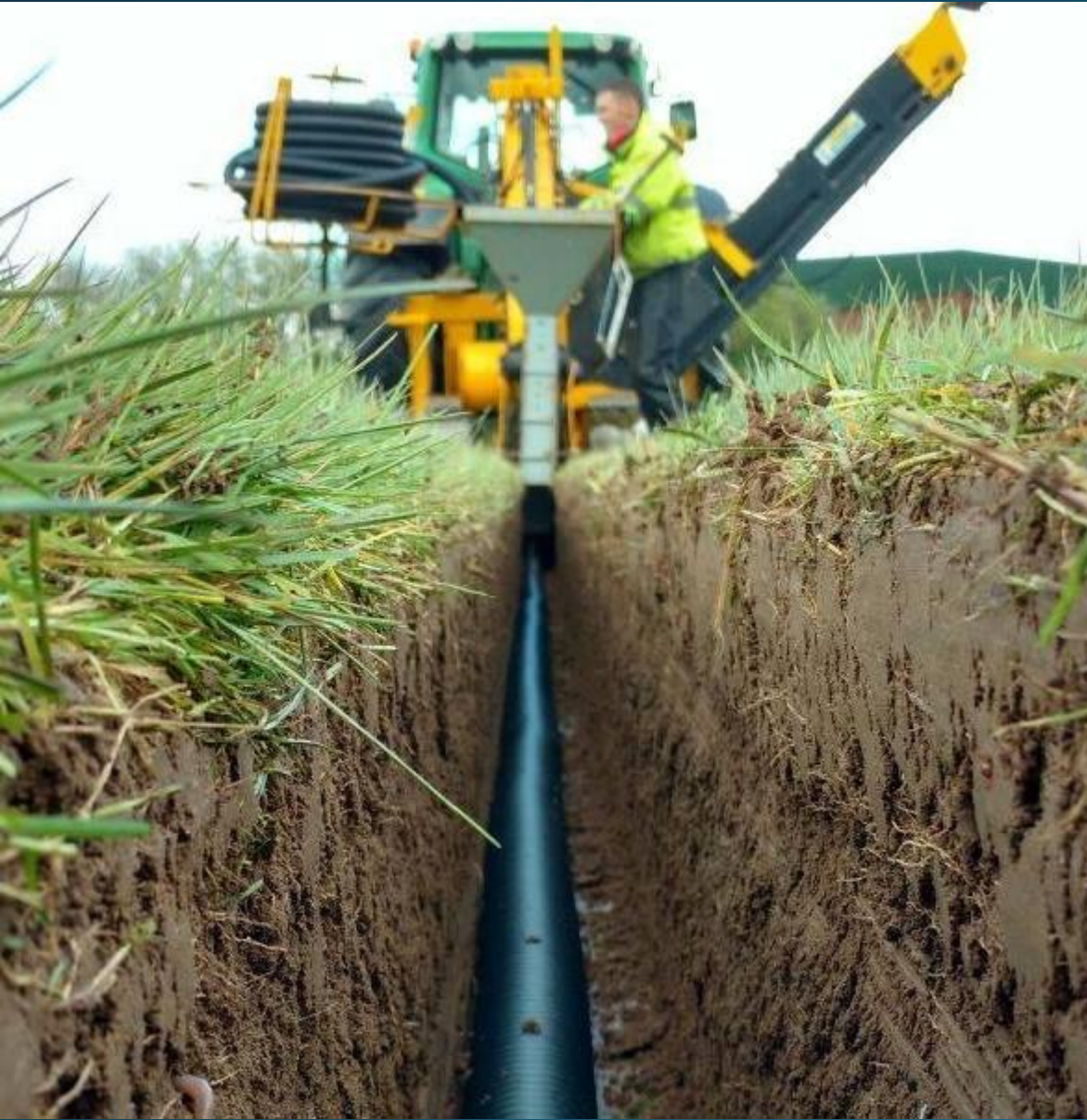
For 100's of years we have actively converted depositional stream reaches into transport stream reaches.





**Historic Channel Network vs
1960's Improved Channel
Camas Creek
South Central Idaho**

Cluer, 2018



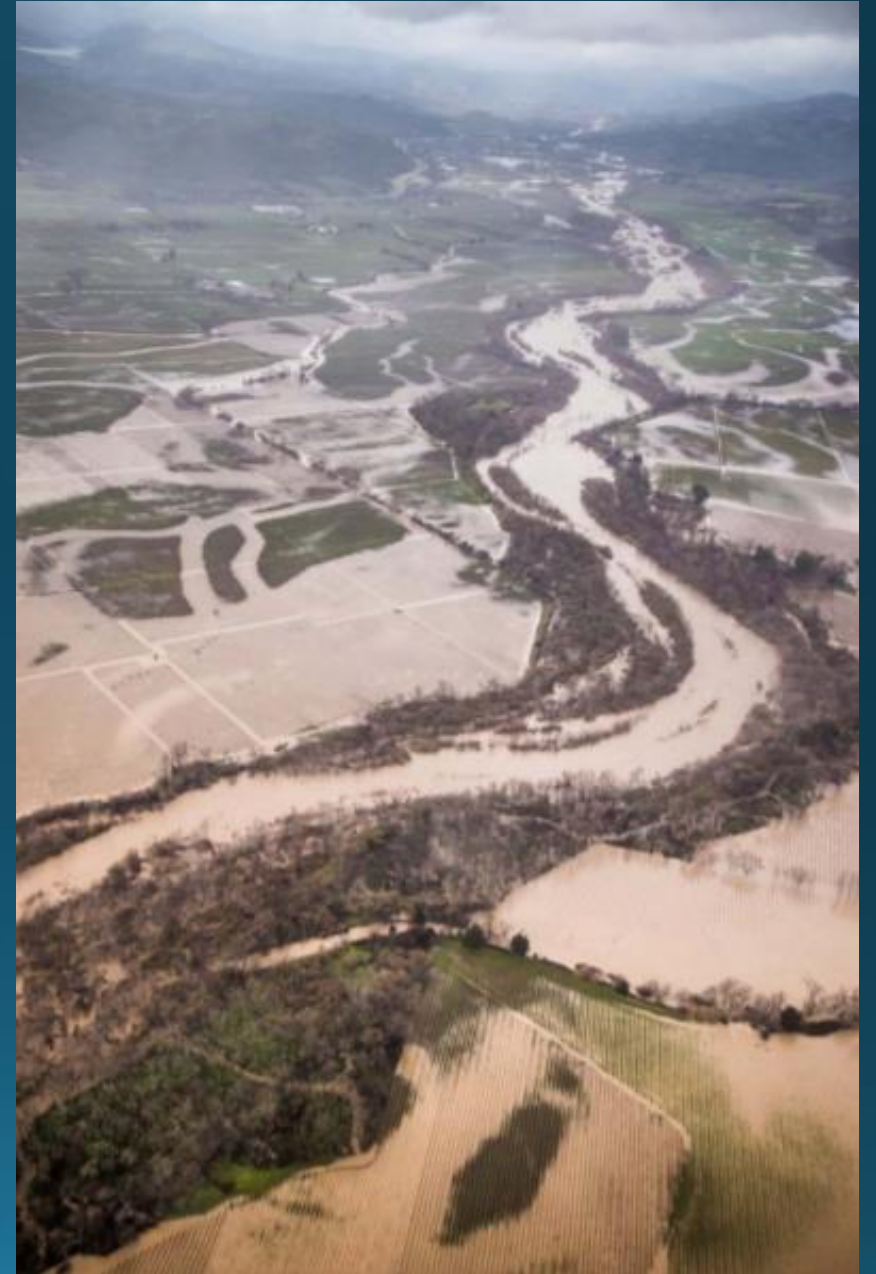
It is now generally accepted that river engineering and management that works with rather than against natural processes is more likely to attain and sustain the multi-functional goals (e.g. land drainage, flood risk management, fisheries conservation, biodiversity, and recreation) demanded by local stakeholders and society more widely.

Wohl et al., 2005; Thorne et al., 2010

Cluer et al., 2013

Room to React

- Maximal flood attenuation
- Maximal GW recharge
- Maximal sediment pulse attenuation
- Resilient to entire range of watershed processes and pulses



Recharge & Connection

- No deep drainage channel
- Stream flow and groundwater connection
- High interaction between flow, sediment, and vegetation
- Small channels easily moderated by vegetation



Restored Hydrology

Working with Natural Processes

Hogervorst, 2019





Photo Credit—Duncan Berry

© duncan berry



Hogervorst, 2019

Willamette River Historic Channels, North of Corvallis, Oregon



A landscape photograph showing a winding waterway through a wetland area. The water is calm and reflects the clear blue sky. The banks are covered in tall, golden-brown grasses. In the background, there are rolling hills with sparse vegetation and a line of evergreen trees. The overall scene is peaceful and natural.

Future Resilience

Changing Conditions

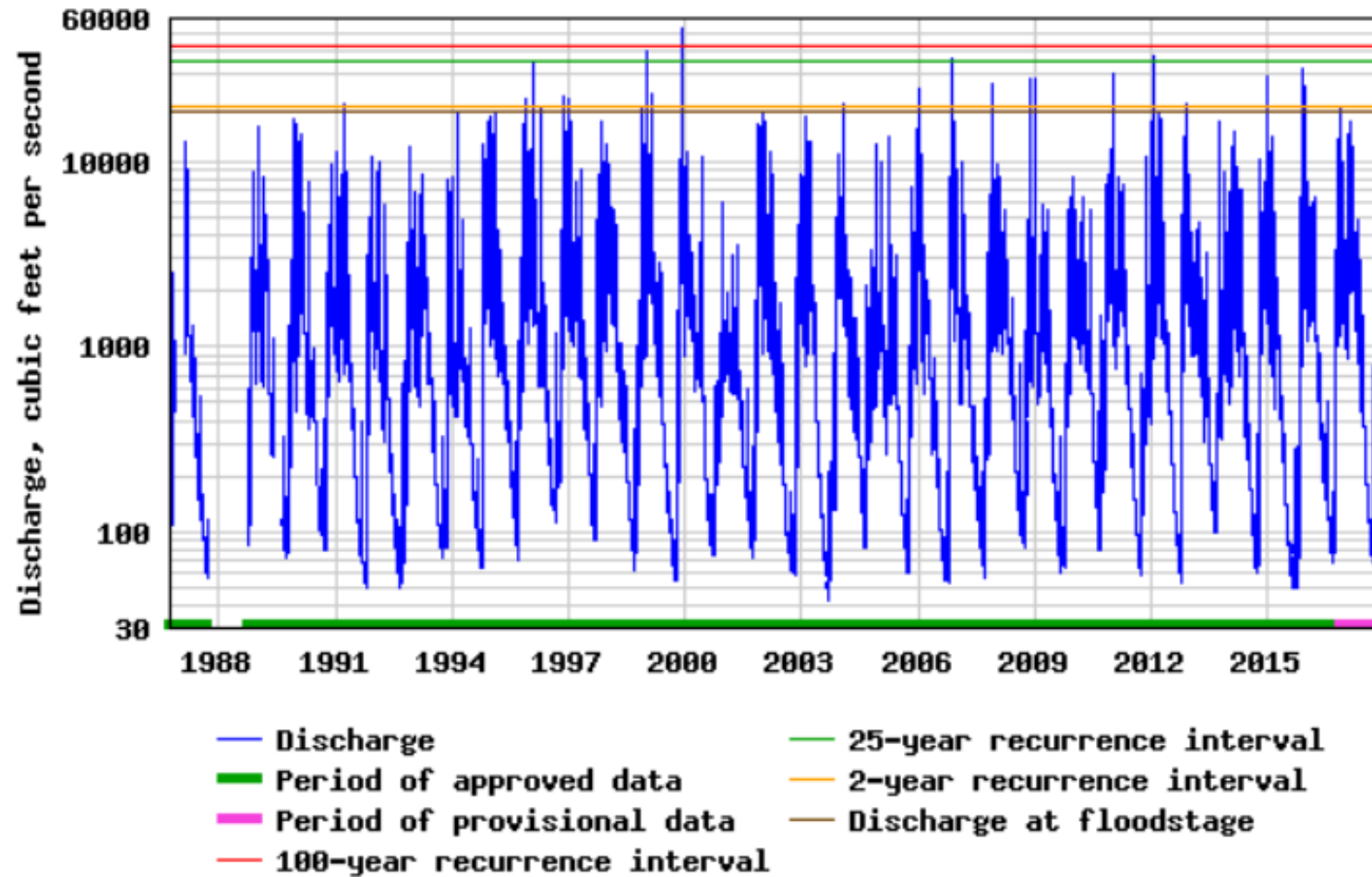


- Floods
 - Frequency
 - Intensity
- Droughts
 - Frequency
 - Duration
- Fog ?

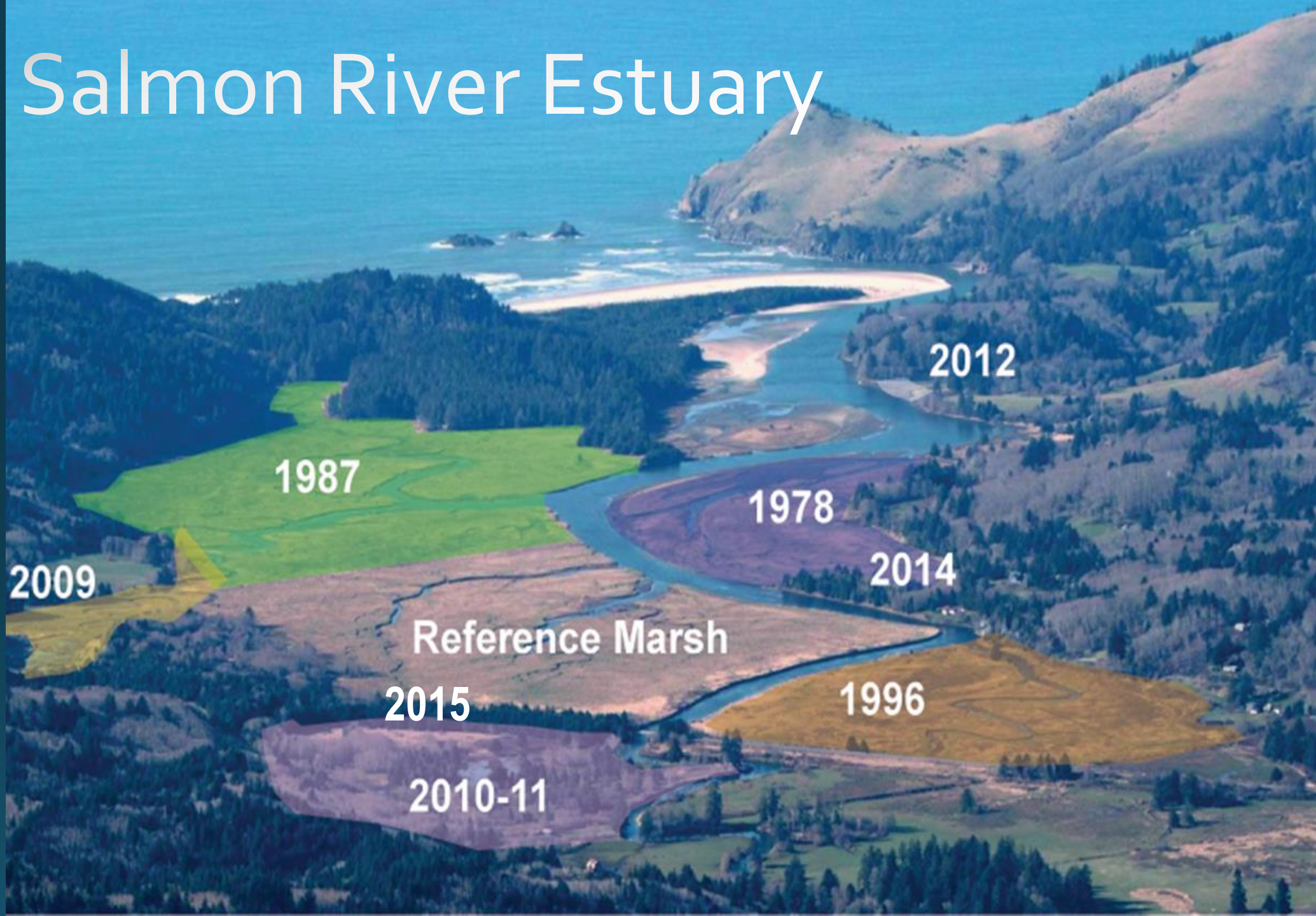
Discharge, cubic feet per second

Most recent instantaneous value: 1280 11-06-2017 15:30 PST

USGS 14305500 SILETZ RIVER AT SILETZ, OR



Salmon River Estuary



Current Conditions	"Fish-Friendlier" Tide Gate	Dike Breach	Dike Removal + Set Back Levee
--------------------	-----------------------------	-------------	-------------------------------

Sediment Accretion	Sediment Accretion	Sediment Accretion	Sediment Accretion
--------------------	--------------------	--------------------	--------------------

Tidal Regime	Tidal Regime	Tidal Regime	Tidal Regime
--------------	--------------	--------------	--------------

Subsidence	Subsidence	Subsidence	Subsidence
------------	------------	------------	------------

Unintended Consequences	Unintended Consequences	Unintended Consequences <ul style="list-style-type: none"> • Size of breach ? • Erosion ? • Sediment accretion ? 	Unintended Consequences <ul style="list-style-type: none"> • Subsidence behind the setback dike • Holding water=wetter longer
-------------------------	-------------------------	---	---