The Lower Columbia River As a System: An Oceanographic Point of View

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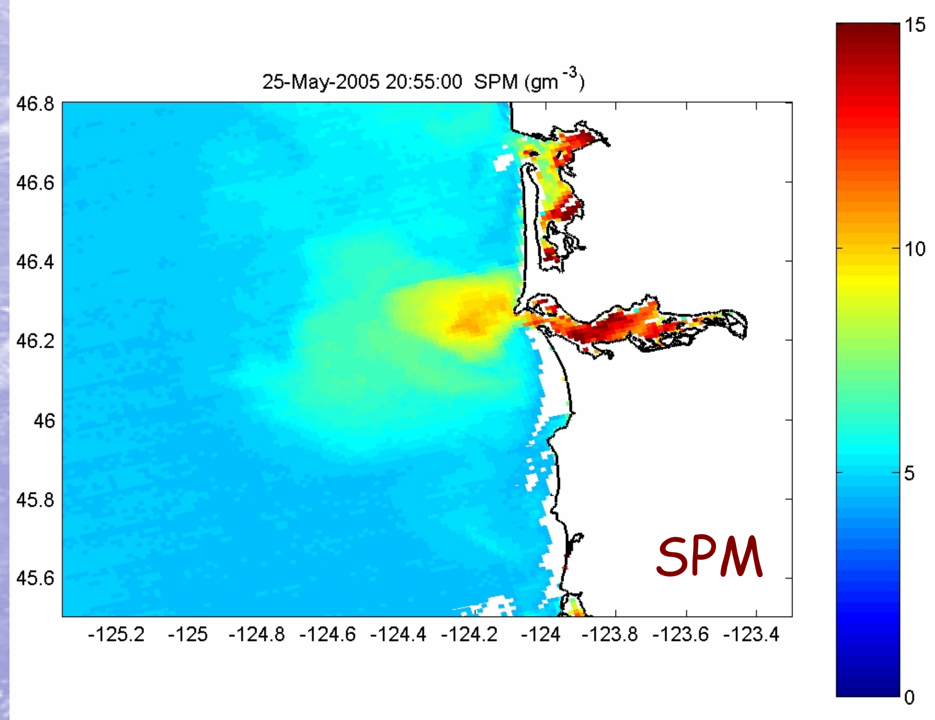
Ocean color image of SPM in estuary and plume, Jiayi Pan, PSU



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What is the LCR or CR Estuary? –

- A river-estuary is defined by –
  - Salinity intrusion (~10-60 km in CR)
  - Tides (245 km, to Bonneville Dam)
  - Coastal mixing zone (the entire CR plume)
  - Adjacent wetlands and floodplain (including historical)

- The main components are:
  - The tidal-fluvial zone (Bonneville to limit of salinity intrusion)
  - The estuary proper (salinity limit to the bar)
  - The coastal plume, which interacts with the upwelling ecosystem

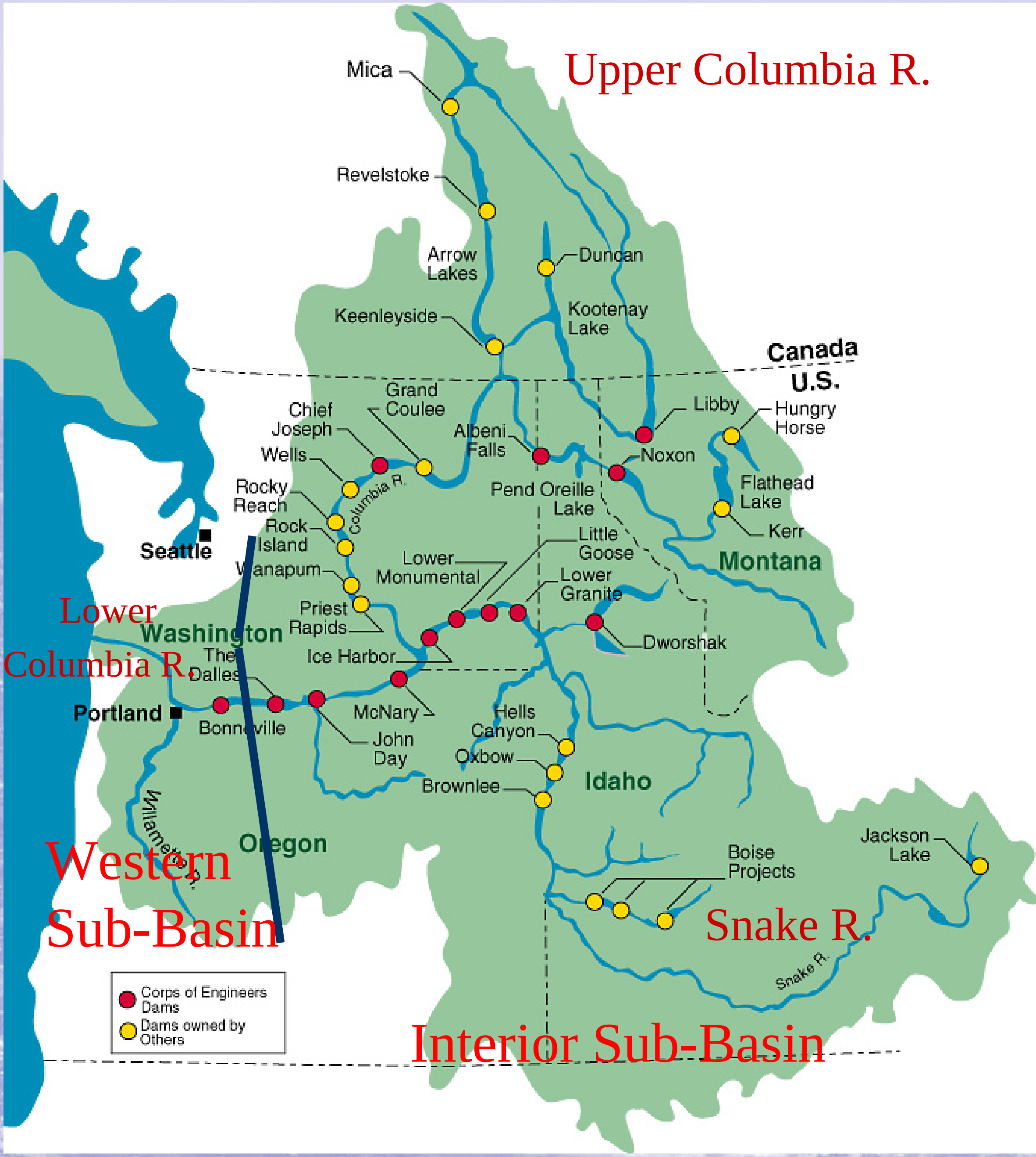
- Have to think about interactions of system with the "boundary conditions" (tides, coastal circulation, weather, quantity and quality of river inflow)

- Study components and processes, then put the pieces together

- Today, I will look at some important changes in processes and inputs

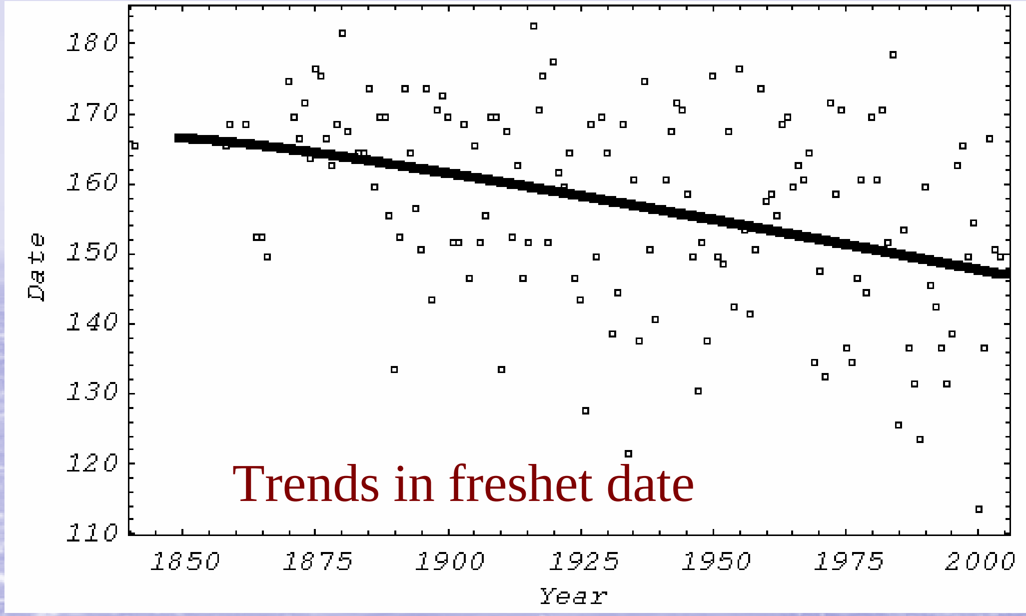
CR Basin Facts –

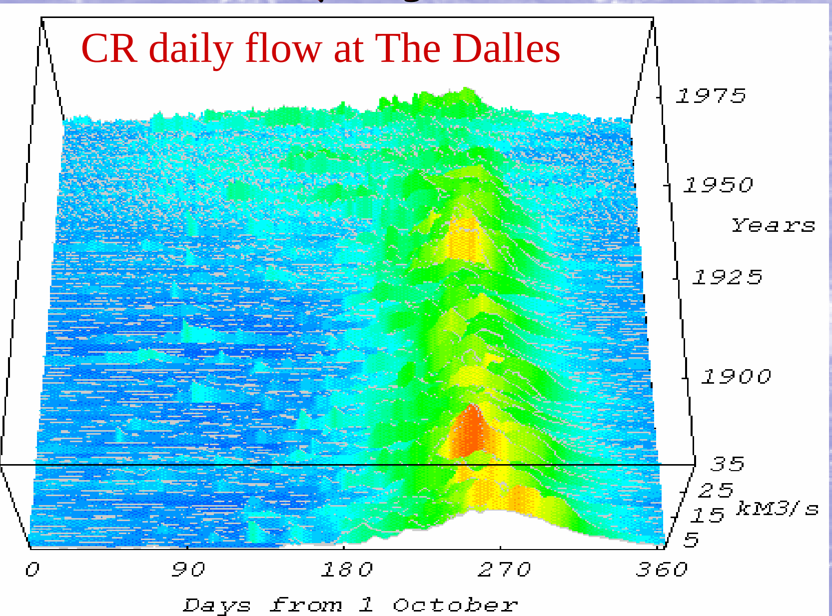
- CR basin: 650,000 km² in 7 states and two provinces
- Has one of the world's most developed hydropower systems
- Average river flow: 7,300 m^3s^{-1} (cubic km in ~12 days)
- Peak flows in spring down to <60% of natural levels due to dams and irrigation
- Sediment transport down to 20-40% of historic levels

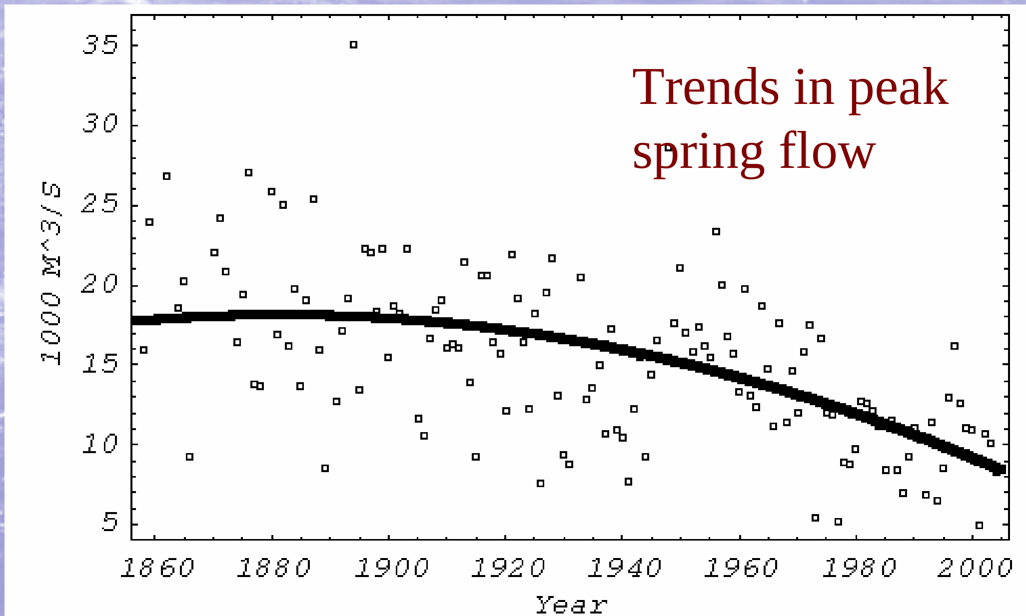


The CR: Human Intervention and Climate Change –

- Spring flows are getting earlier
- Rate of temperature rise in west is predicted to accelerate
- Early snow melt, regulation and irrigation all reduce spring flows
- Human effects are bigger than climate change
- Climate change will probably:
  - Limit management options
  - Sharpen conflicts but also create new synergies

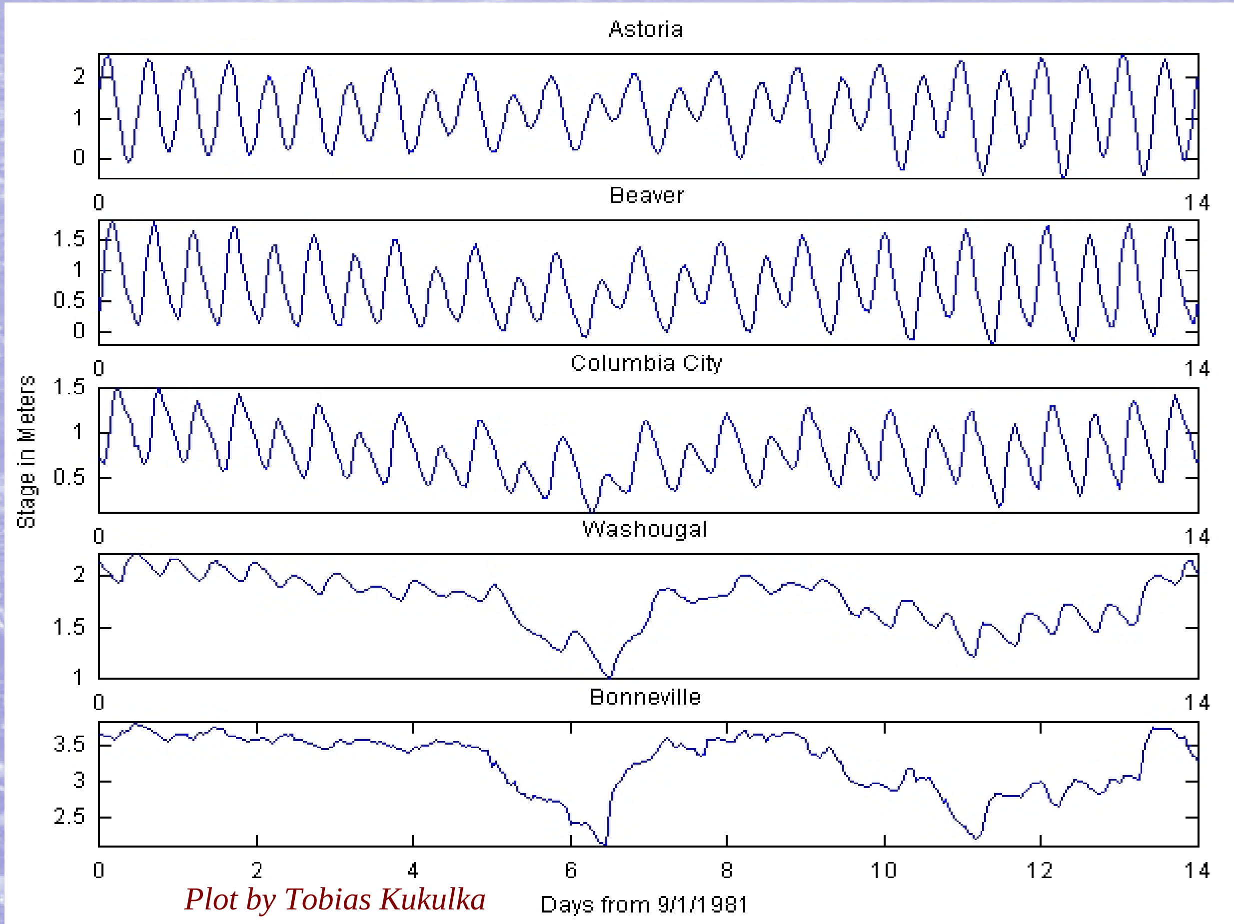






The Tidal River, from Tongue Pt to Bonneville Dam, Vital for Salmoninds –

CR tides, from the ocean (top) to Bonneville (bottom)

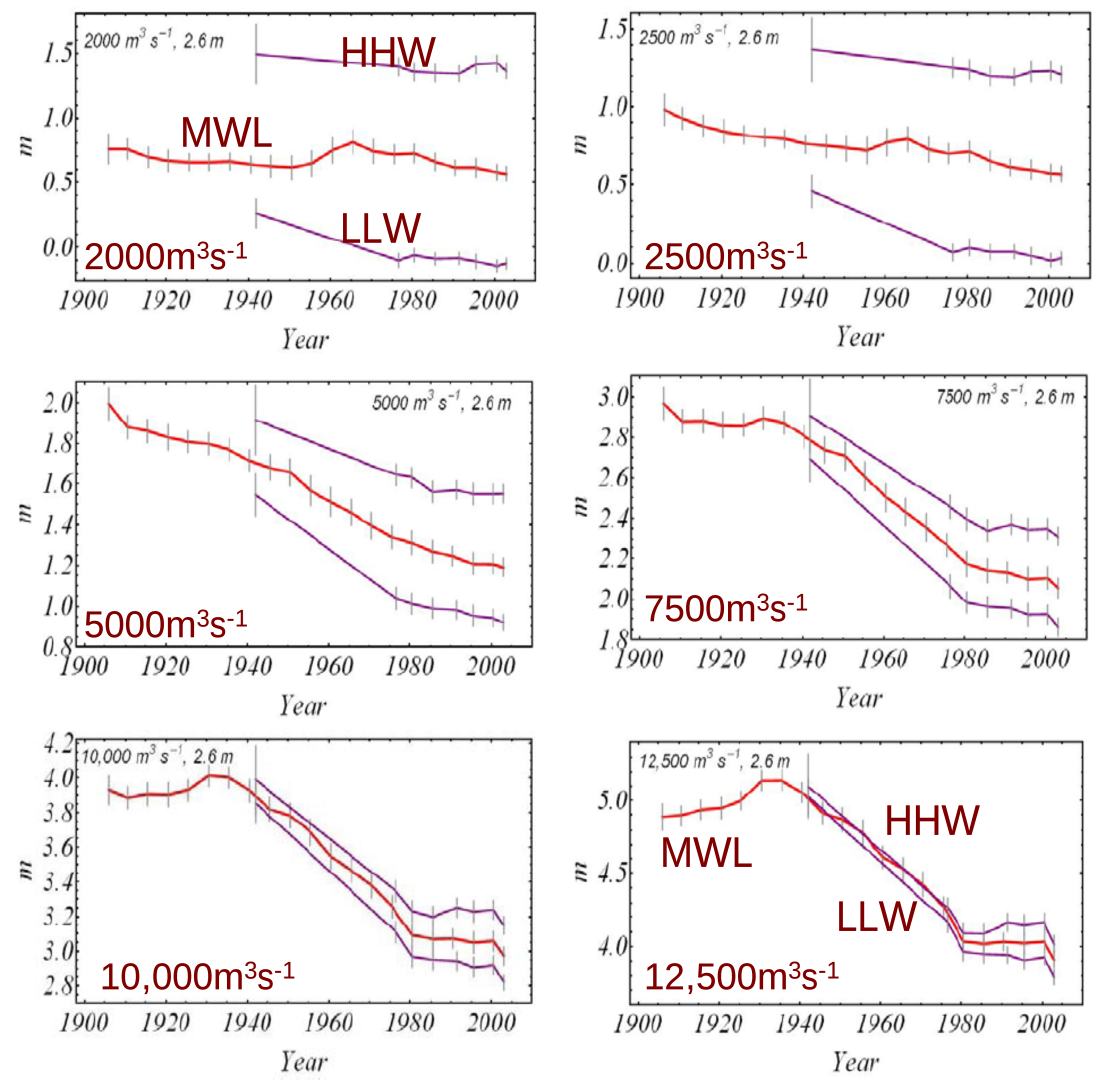


Plot by Tobias Kukulka

Water Levels are Dropping in the Tidal River –

- Lower values of LLW in fall threaten navigation, down by 0.3-0.5m
- Lower high of HHW in the spring inundate less SWHA
  - Down by 1-1.5m
  - Adds to impacts of reduced flows
- Causes:
  - Dams capture sediment
  - Sand mining and dredging remove sediment
  - Channel is more efficient
  - Bigger tides in river
- MWL = mean water level
- LLW = lower low water
- HHW = higher high water

Changes in LLW, MWL and HHW at Vancouver, 1902-2008 for Six Different Flow Levels

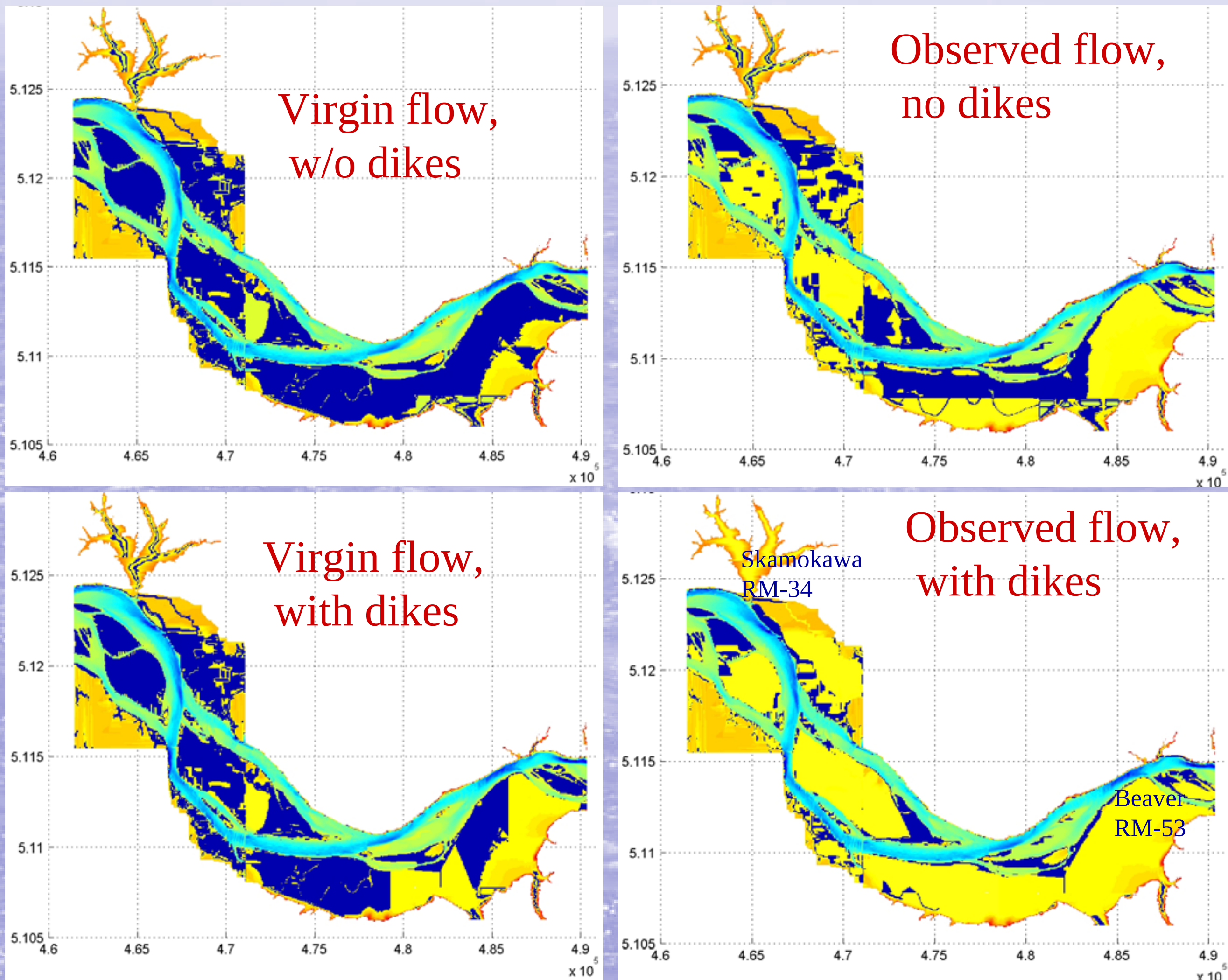


Changes in Shallow-Water Habitat Area (SWHA) 1974-1998 –

- Area AND duration of SWHA decreased
- Virgin flow provides much more SWHA for a longer period
- Dikes account for more loss of habitat than loss of flow
- Easier to restore SWHA above Beaver than below, because dikes (not flow regulation) dominate loss of SWHA
- SWHA: low-velocity waters <2m deep, with salinity =0

1974 Inundation

Dark blue = floodplain SWHA
Yellow = dry area

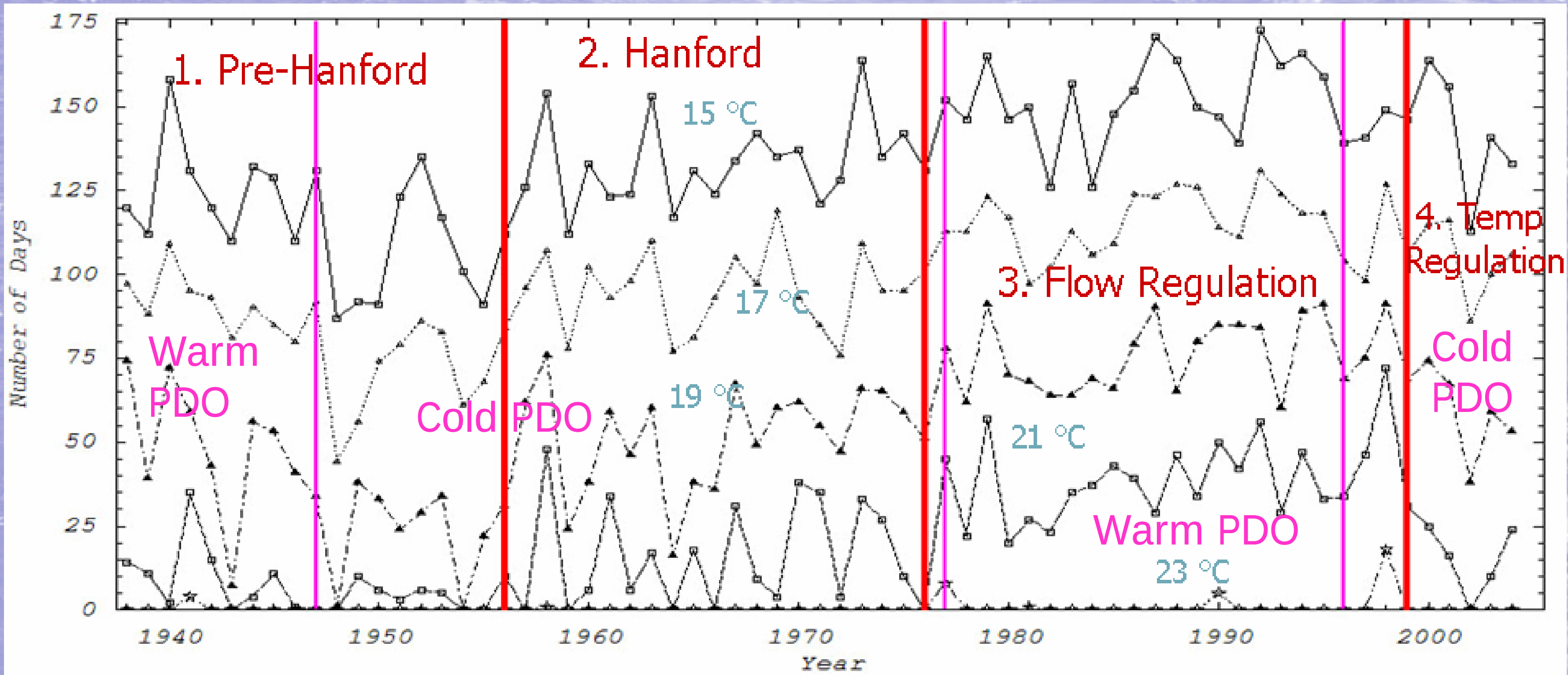


Plot by Tobias Kukulka

Changes in CR Water Temperature –

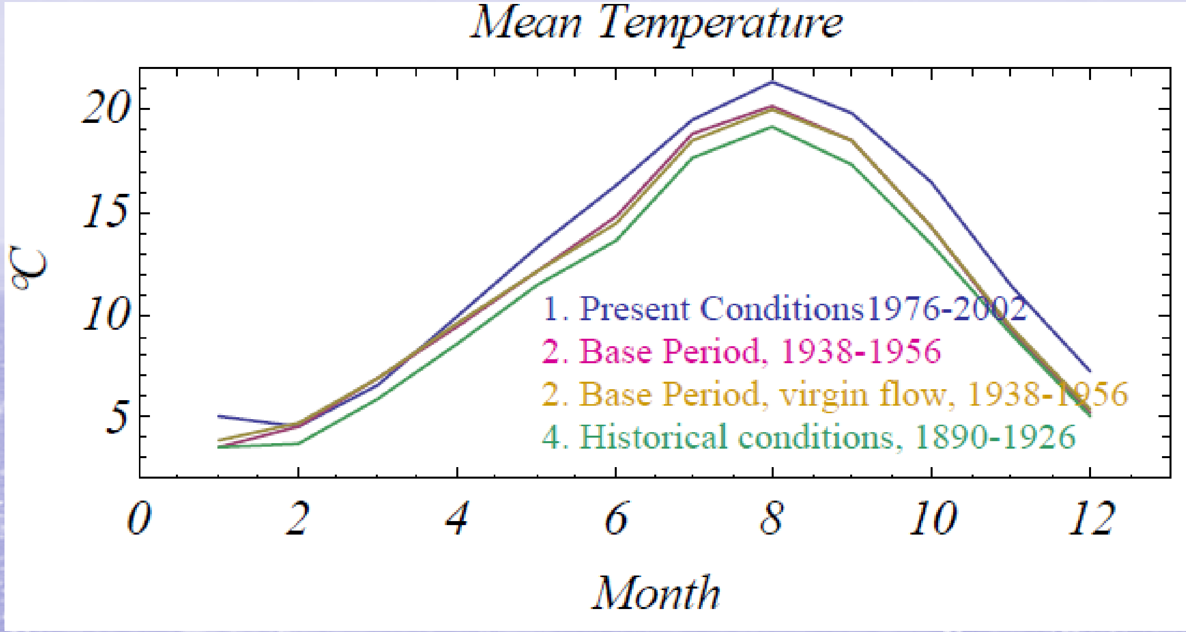
- Water temps were high due to Hanford weapons factories ~1956-1976
- Continued to increase due to reservoirs after 1976
- Improved reservoir management has caused some improvement since 1997

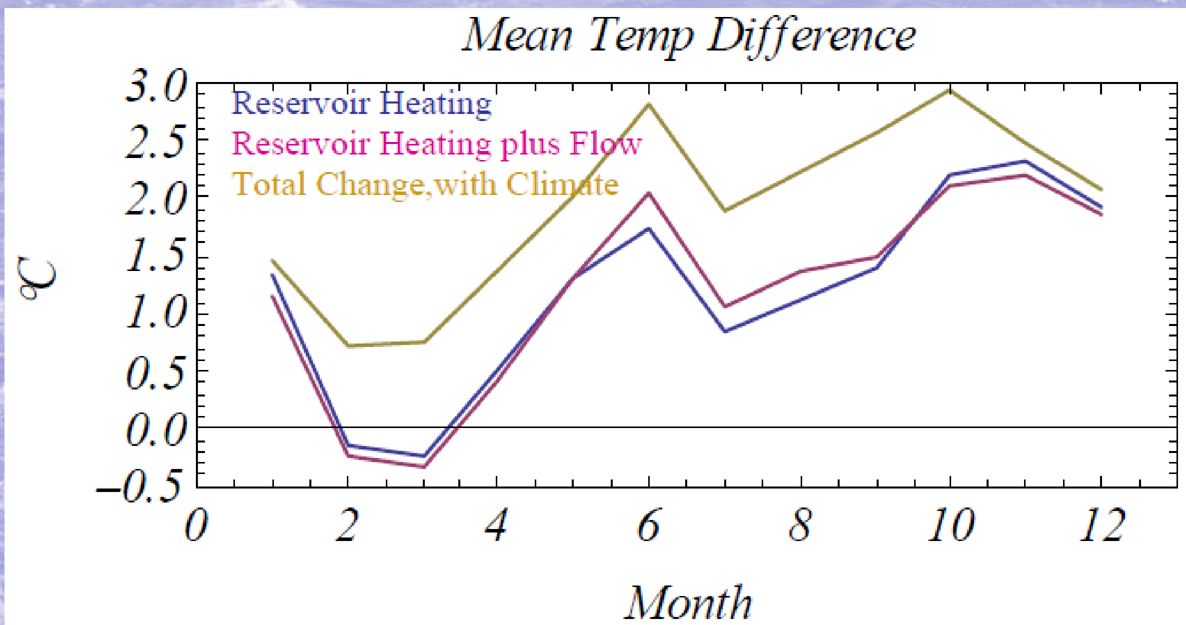
Changes in Number of Days Water Temperature exceeds Critical Levels at Bonneville Dam



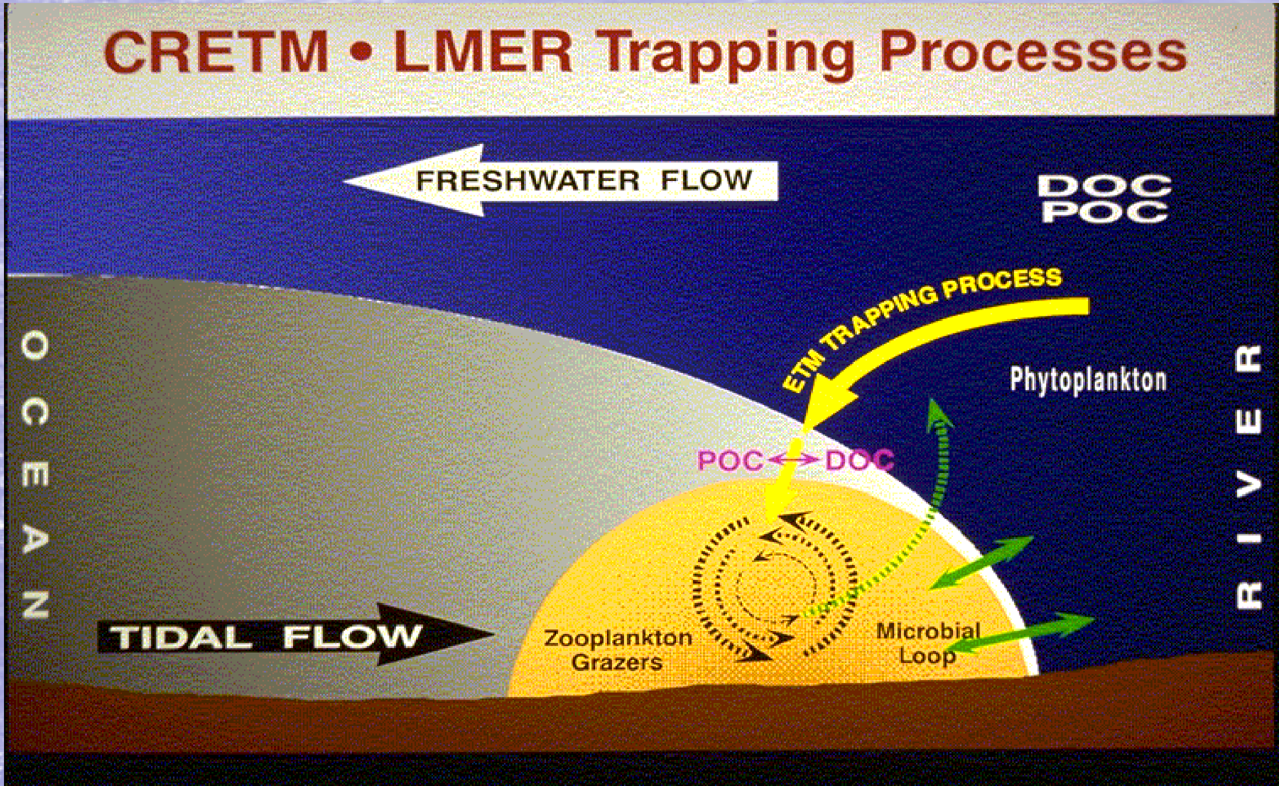
Why is CR Water Temperature Changing? –

- This analysis is based on statistical modeling of Bonneville Dam scroll-case temperature
- Reservoir heating has caused >50% of warming
- Climate change is also important
- Changing flows have a small effect





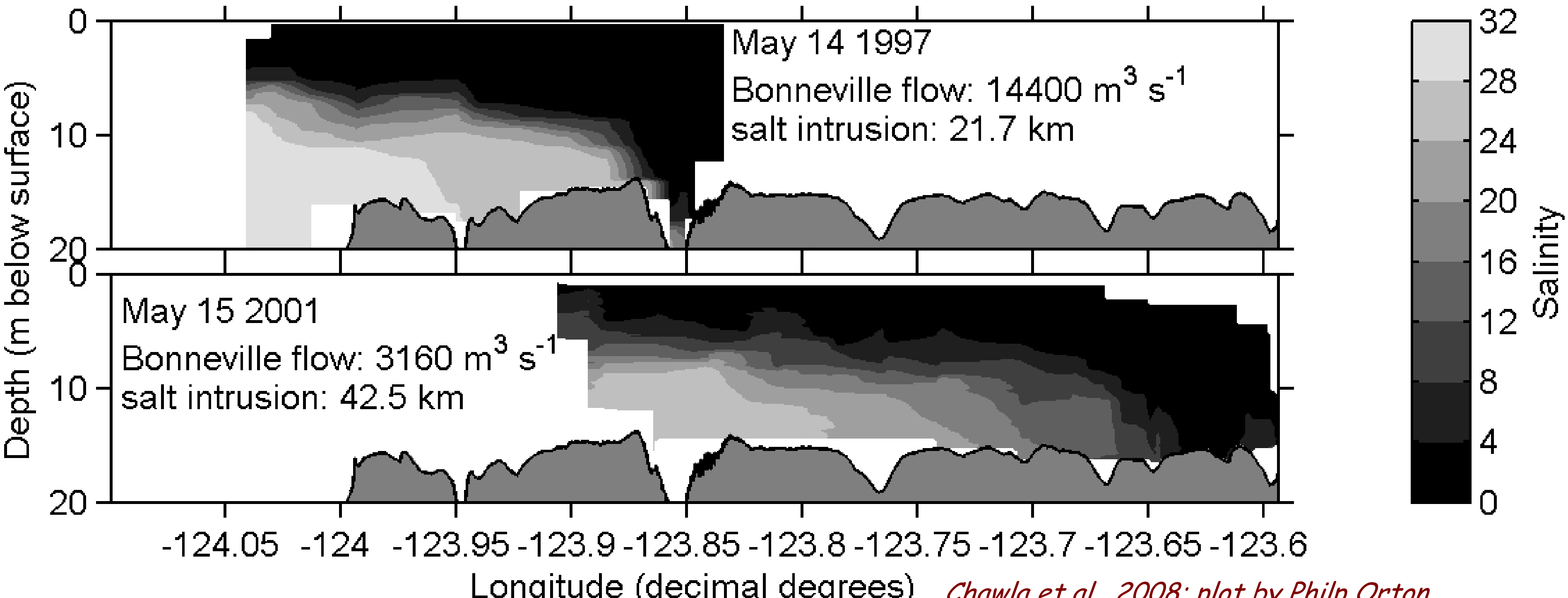
The Estuary Filters what is Carried from the River to the Ocean –



Schematic of CR estuarine turbidity maximum, by Si Simenstad

Estuarine Salinity Intrusion –

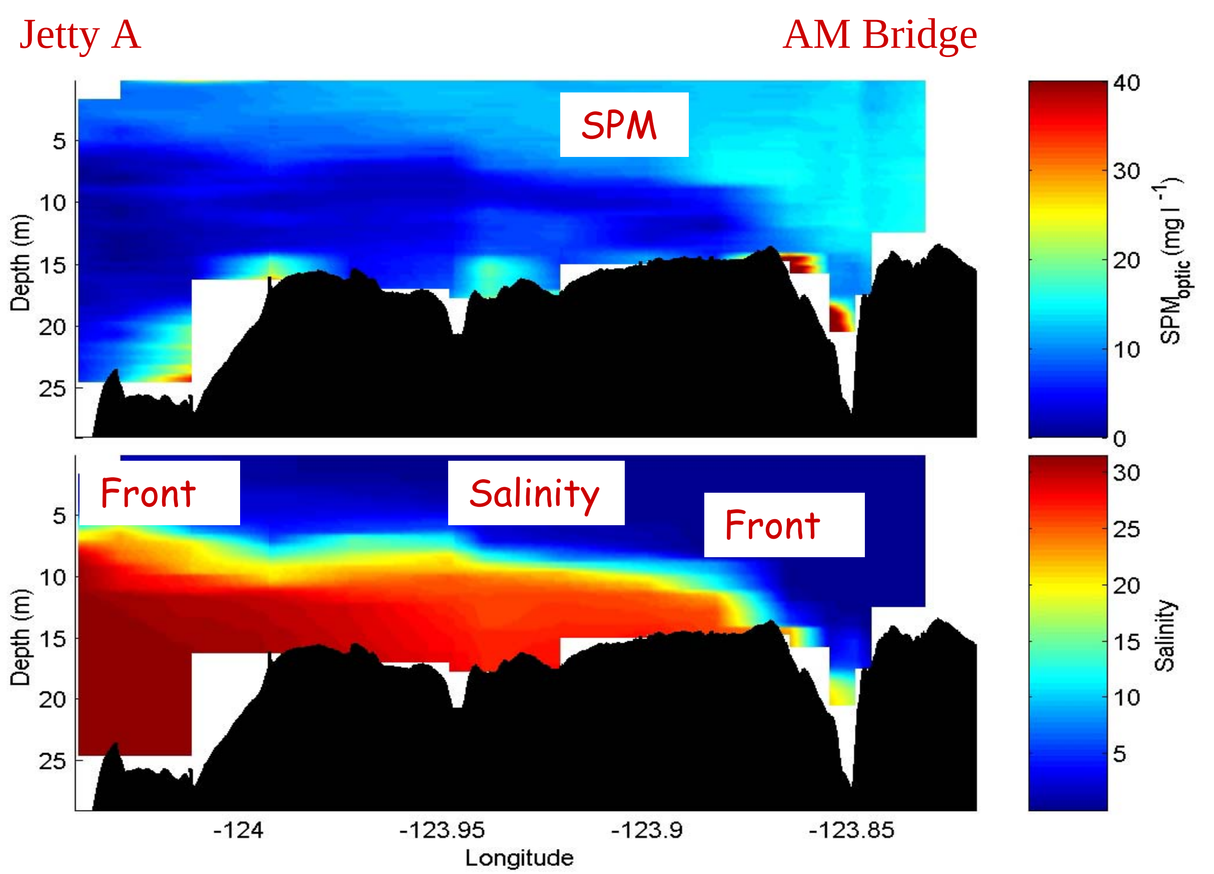
- Varies with ~1/square root of flow Q_R
- Spring tides cause more mixing and less salinity intrusion at depth, but higher salinities at the surface
- Upwelling/downwelling and winds affect salinity intrusion subtly
- Esturine Turbidity Max (ETM) is the heart of the estuary ecosystem, occurs near salinity intrusion limit
- Reduced flow+ deeper channels = more salinity intrusion and less low-salinity habitat



Chawla et al., 2008; plot by Philp Orton

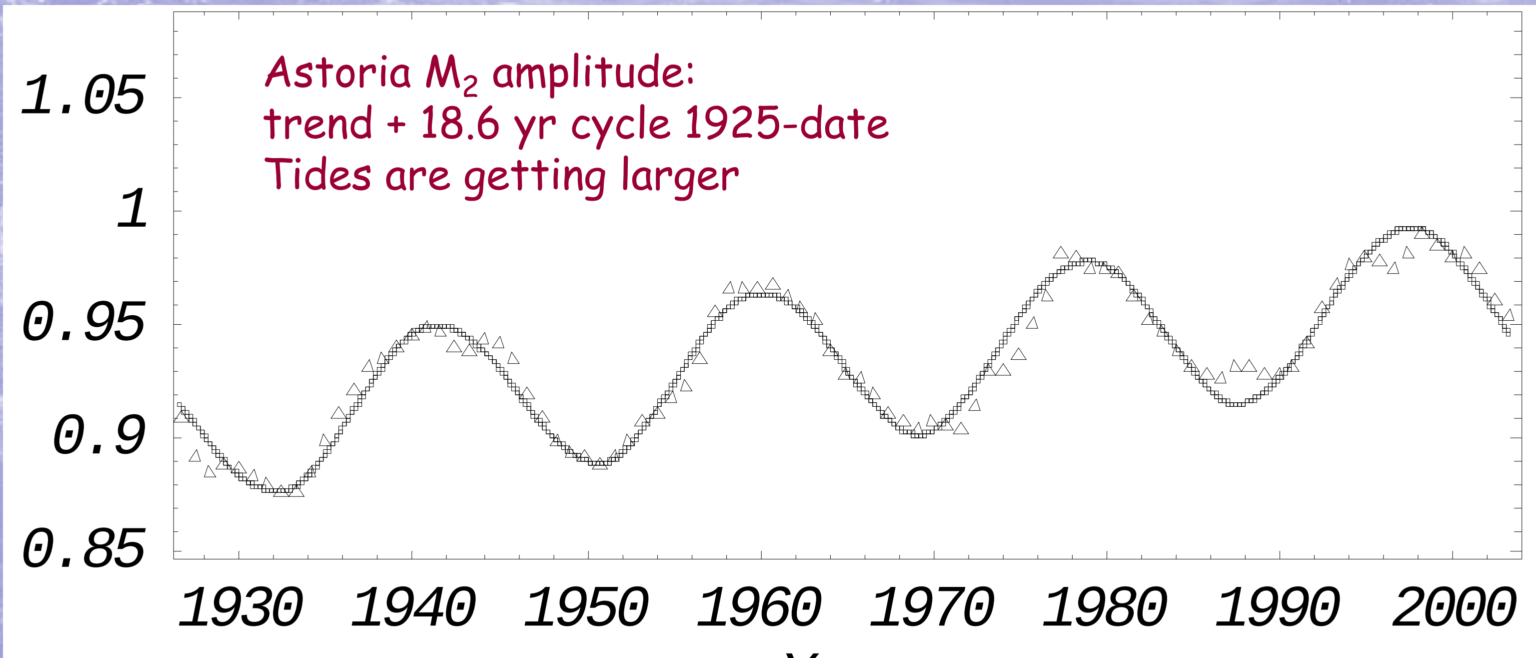
Estuarine Anatomy and Sediment Trapping –

- The estuary is defined by density fronts on both ends:
  - Plume lift-off fronts at bar
  - Upstream limits of salinity intrusion
  - ETM can occur both places; landward ETM is the important one
- Sand is only exported when fronts are compressed together during high flows (zero-length estuary)
- Estuary traps fines (SPM) for weeks to months in the ETM
- Reduced spring flows have reduced sand supply to and export from estuary
- Long-term changes in sediment budget is a big problem

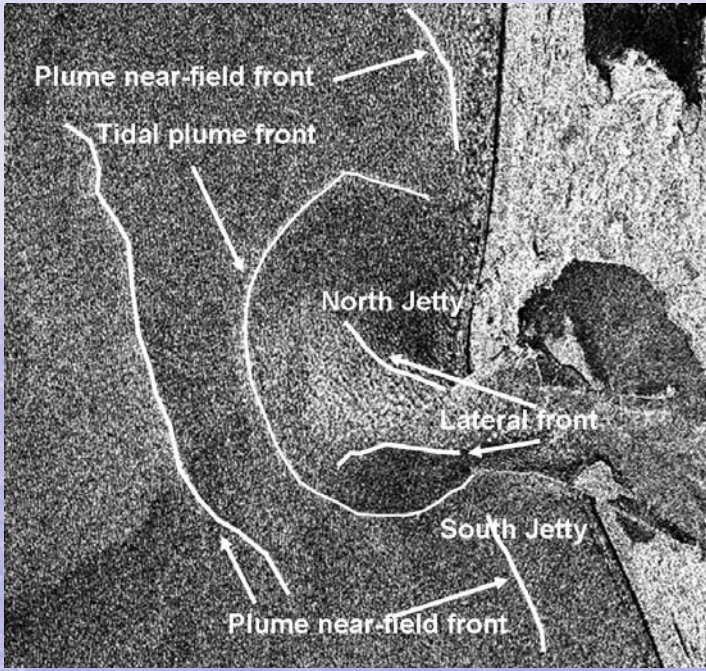


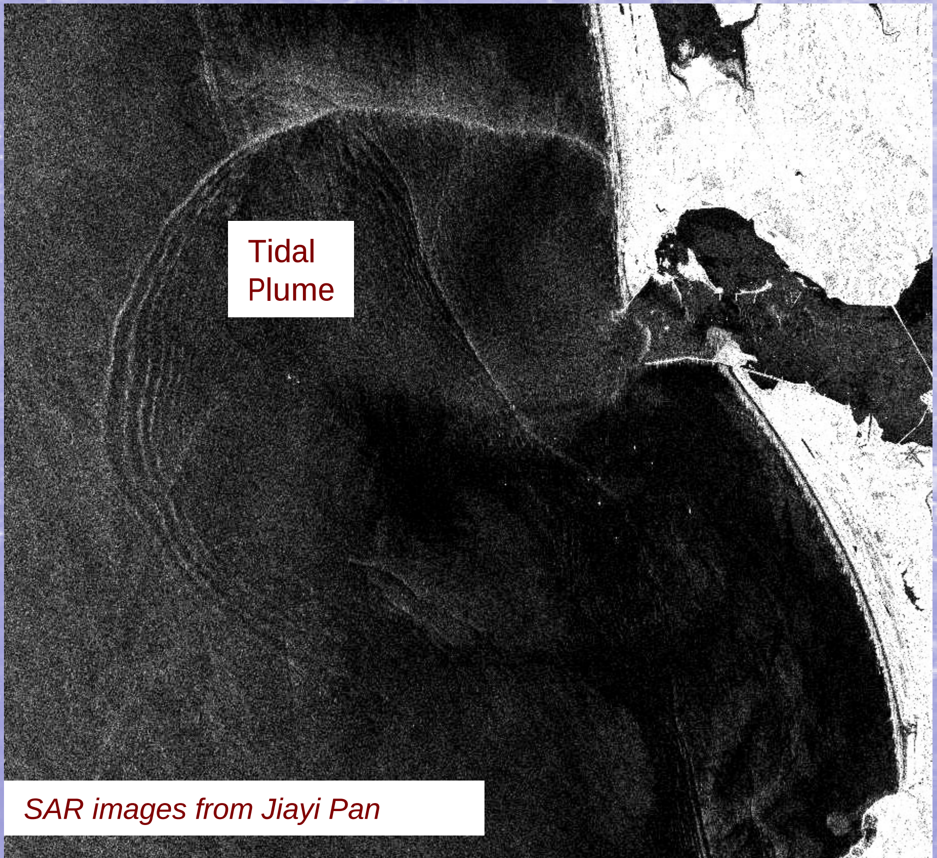
Estuarine Tides –

- Tidal range is increasing in Astoria (and upriver) due to:
  - Increased ocean tides along coast – all over NE Pacific Ocean
  - Reduced friction in river (better alignment, deeper channels, lower flows)
  - Increased bottom depths at entrance and (probably) upriver
- Astoria range is increasing at ~1 ft (30+ cm) per 100 years
- Bigger tides change the location and character of SWHA
- M2 is the largest component of the twice-daily tide



The CR Plume and Regional Context; the Plume is Vital to the Coastal Ecosystem and Salmonids in ways that are Poorly Understood –

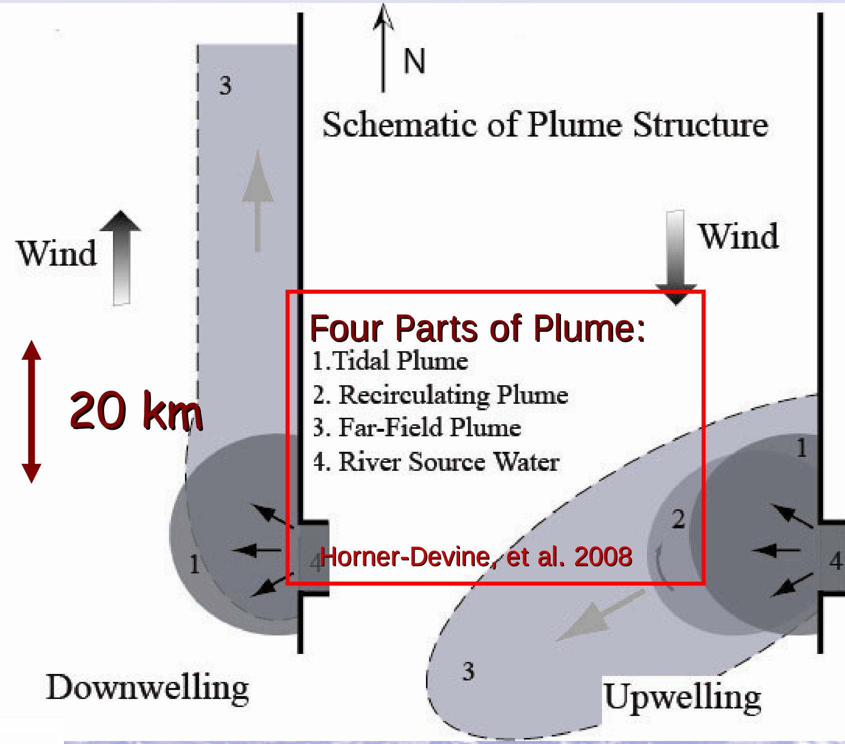


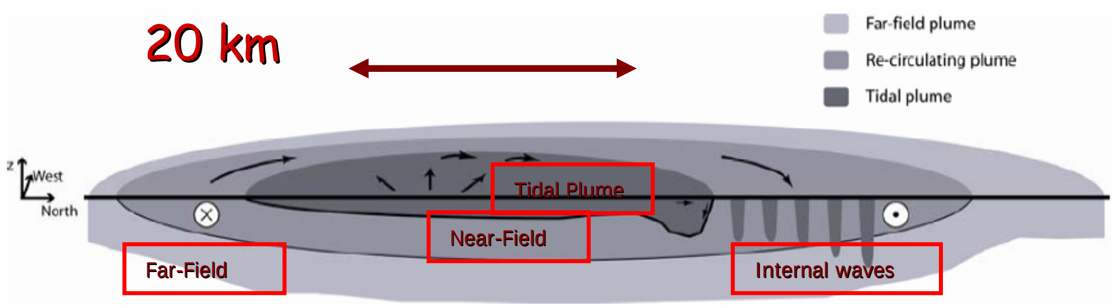


SAR images from Jiayi Pan

Plume Anatomy –

- Plume lift-off (4) occurs at the bar
- Strong fronts and internal waves come from "tidal plume" (1), the initial expansion of outflow for first 6-12 hrs
  - Seabirds and juvenile salmonids(?) feed at front; juveniles are preyed upon
- Near-field (2) is a rotating bulge with 2-4 days water
- Far-field (3) has the rest of the recent plume discharge
- Plume components (1), (2) & (4) are also effectively part of the estuary
- Plume position and motion is affected by the winds, tides and river flow





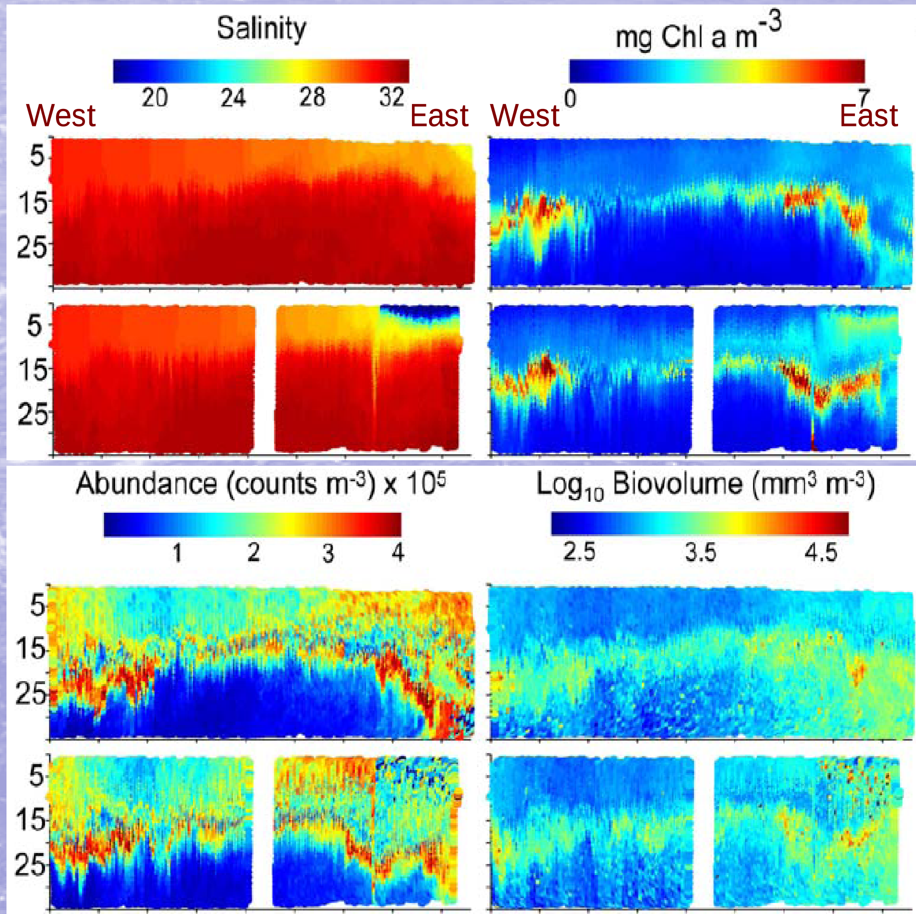
The Plume layer cake

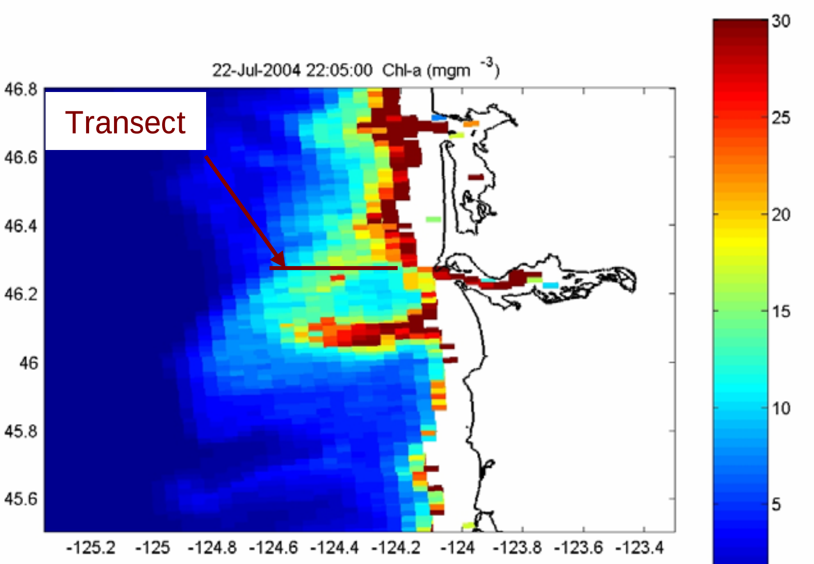
Horner-Devine, et al. 2009

Biological Thin Layers –

- What do thin layers do:
  - Concentrate Chl and zooplankton at the base of the plume
  - Biological rates may be much higher than estimates based on bulk concentration – make sampling and modeling plume biology hard!
  - Form around margins of tidal plume, as material sinks to plume base
  - Move around rapidly with plume
  - Role for salmon unclear
- Thin layers may help account for high biological productivity of plume

From Peterson & Peterson, submitted

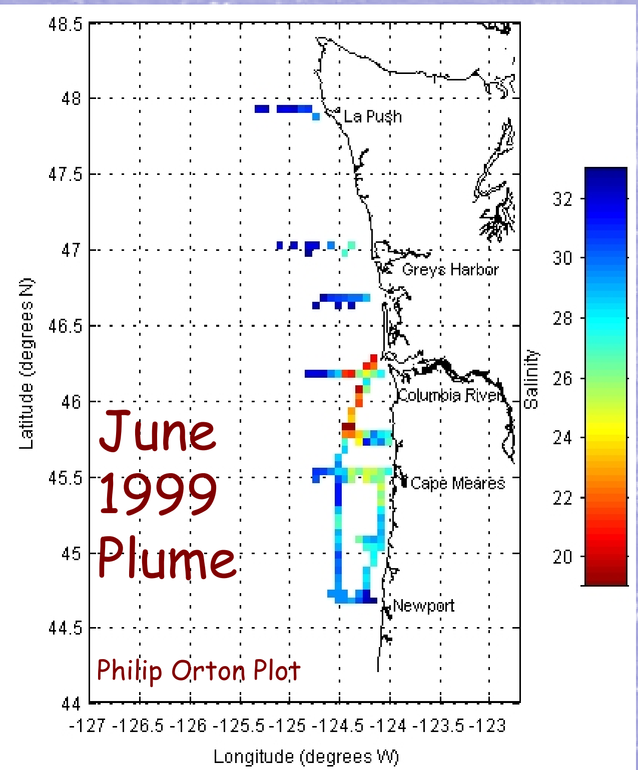


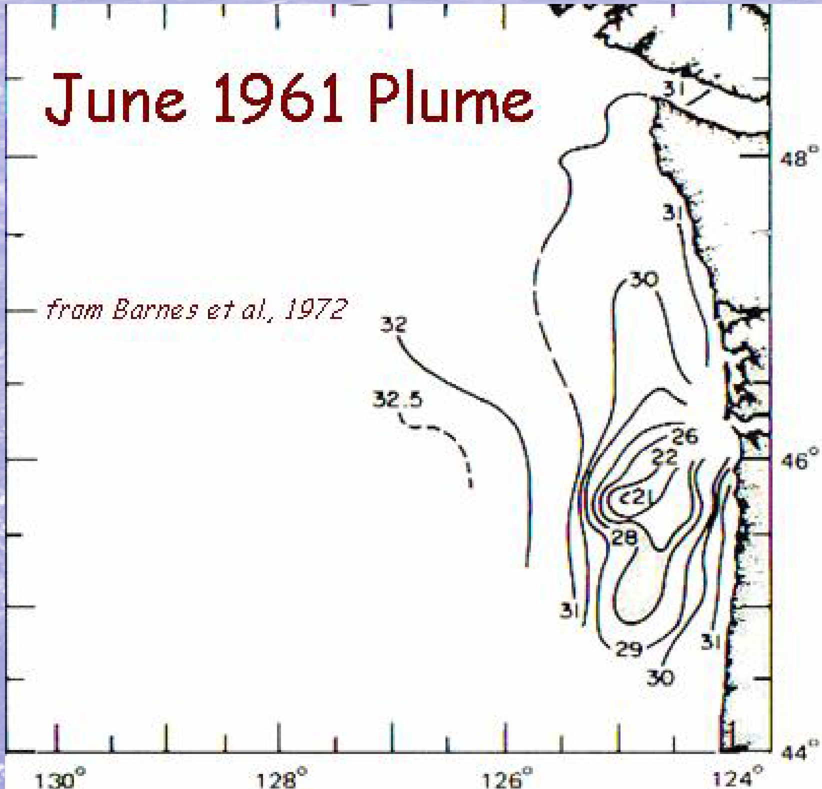


MODIS image, Jiayi Pan

CR Plume Changes, 1961 vs. 1999 –

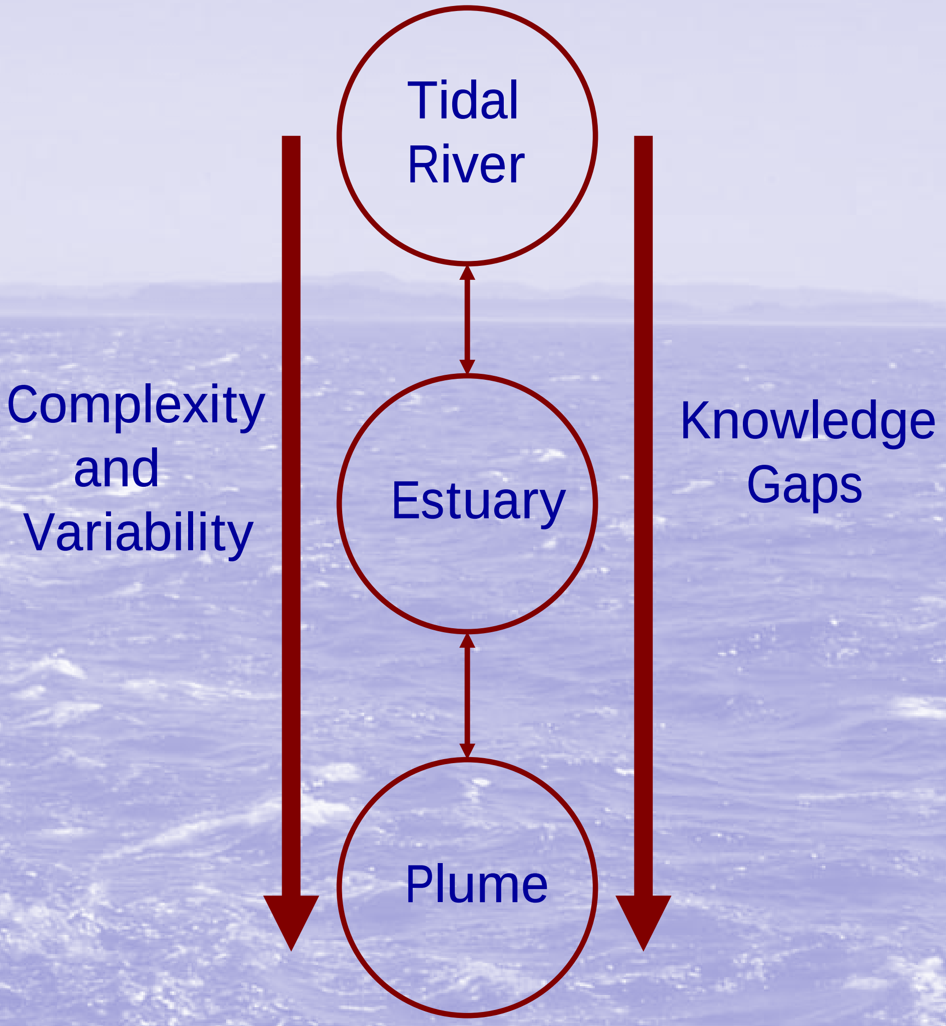
- Plume is vital to coastal production
- CR spring flow is down >40% due to flow regulation, irrigation
- 1999 plume volume was only ~65% of that in 1961, even though the natural flows were very similar
- We know that plume habitat area has been reduced, but we don't know about habitat quality, or if lost plume habitat is limiting





Conceptual Summary –

- *All three components are vital to juvenile salmonids*
- Each presents distinct logistic and intellectual challenges
- *We need to understand processes AND put the pieces together*



Summary –

- The estuary includes the tidal river, estuary proper, and the plume
- These components affect one another, with influences going both directions:
  - Landward (tides, upwelling/downwelling effects, sediment from ocean), and
  - Seaward (flow, plume internal waves, sediment)
- Tides are getting larger in the tidal river and habitat has been much reduced
- Increased flow and larger tides reduce salinity intrusion to estuary
- The plume interacts strongly with upwelling ecosystem and augments coastal production
- All components are important to salmonids, but details are complex and unclear

I do not know much about gods; but I think that the river
is a strong brown god – sullen, untamed and intractable,
Patient to some degree, at first recognised as a frontier;
Useful, untrustworth, as a conveyor of commerce;
Then only a problem confronting the builder of bridges.
The problem once solved, the brown god is almost forgetten
by the dwellers in cities—ever, however, implacable,
Keeping his seasons and rages, destroyer, reminder
Of what men choose to forget.

T. S. Eliot – Four Quartets